



WPT2 – Establishing the ADRISEISMIC methodology for the reduction of seismic vulnerability

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Description of the deliverable (3-5 lines)	The deliverable describes the cataloguing activities carried out to map						
	the intervention techniques currently used in the PP Countries. In						
	addition to the intervention techniques, it was primarily decided to						
	investigate the construction techniques of the building heritage of						
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Definitions & Acronyms

Acronym Full name

CA Consortium Agreement

PP Project Partner
LP Lead Partner

WPT Technical Work Package





Executive summary

Deliverable T2.1.2 aims to investigate the current approach to the theme of interventions on the existing historical heritage, consisting of isolated buildings and building aggregates. The topic is treated with a broad perspective, which ranges from the investigation of the current construction techniques characterizing this heritage, up to the techniques currently used for seismic improvement interventions.

The focus is oriented on the building types that characterize the historic centres of the countries in the Mediterranean basin, with densely built urban areas, and which use traditional construction materials, such as stone, clay, and wood, together with modern ones, such as iron and reinforced concrete.

These materials have been combined and assembled over time to create typical construction schemes, whose common matrices can still be recognized today by a careful examination of local construction practices.

The first part of the activities of the ADRISEISMIC project within the work package T2 was therefore concentrated on the analysis of the construction characteristics of the current heritage, since the main vulnerabilities that can emerge during an earthquake are due these characteristics.

This process was carried out jointly by all the Project Partners, who contributed to the drafting of a detailed and rich database for the classification of the current construction characteristics of the built heritage. The classification was developed on the basis of relevant contents for the characterization, which could show different dynamics from country to country, such as the period of use of these techniques, the diffusion on a national scale, any dimensional variations.

Furthermore, each technique was combined with the critical issues that can be detected on the entire building following an earthquake, so that this basis can be useful in identifying recurrent damage mechanisms.

A functional and innovative step was the combination of these techniques in the so-called structural types: in fact, the combination of the various solutions of vertical, horizontal elements, foundations and roofs is not accidental, but linked to a building process starting in a specific moment, where those techniques are the most common, and eventually undergo subsequent transformations.

This classification in terms of structural types showed that not only the individual construction solutions are convergent, but also the structural types. This allows us to confirm that, for the built heritage of the countries involved in the ADRISEISMIC project, it is possible to proceed in a uniform way both from the assessment and intervention point of view.

The next phase was an attempt to understand the current intervention techniques for seismic improvement in order to determine similarities and differences between the current approaches practiced in different countries. Significant differences in the intervention techniques in different countries are likely due to local regulatory standards and also to different experiences that characterized individual countries during recent seismic events.

In fact, most partner countries have been affected by recent earthquakes, which have certainly left heavy marks on the heritage, but also provided an opportunity for experiencing the phenomena and applying the methods of intervention. In some cases, an earthquake hit the same region multiple times within a relatively short time period, which made it possible to evaluate the effectiveness of the interventions implemented during the first earthquake.

The proposed joint classification of intervention techniques made it possible to highlight both the typical approach of each country and the guidelines to be followed for the selection of most compatible techniques in terms of effectiveness, ease of construction and cost for each country.

The comparison led to a considerable cultural enrichment, allowing to outline the current approach to the seismic issue regarding the existing heritage.





1. Introduction

Historical-monumental constructions represent an important cultural and economic heritage, which is in constant danger due to its vulnerabilities, as a consequence of the high seismicity of various parts of the European territory, and particularly the Mediterranean basin.

Many recent seismic events have shown the fragility of the historic building to seismic actions. The main causes of the various damages and collapses are found, on the one hand, in the characteristics of the seismic motion and, on the other, in the vulnerability factors highlighted by these construction types.

Furthermore, the historic centres are characterized by very varied construction types, ranging from the monumental building dating back to several centuries ago, to ancient buildings, which constitute the population nucleus with residences and small businesses, up to more recent masonry or reinforced concrete buildings, sometimes reworked over time with interventions with no criteria.

To understand the real seismic behaviour of historic buildings and decide where to act to increase the safety level with respect to seismic action, it is necessary to reliably assess their seismic vulnerability. Such a broad panorama needs to be investigated both from the point of view of construction methods and, above all, on the methods of seismic intervention that have occurred over the years, in order to select the most suitable to improve the level of safety.

1.1. Description and objectives of the WPT2

WPT2, in general, aims at developing the ADRISEISMIC methodology to reduce seismic vulnerability through diagnostic investigations and the identification of the most suitable seismic retrofitting techniques, currently adopted in the involved Countries, with the purpose to define and share a common standard of advanced methods and approaches.

The project activities focus on the identification of effective expeditious procedures for the assessment of seismic vulnerability in the regions involved in ADRISEISMIC and, consequently, on different types of seismic improvement techniques for reducing the vulnerability of existing buildings and aggregates of buildings. All PPs cooperate in the collection of practices and techniques with reference to the typical ones of their specific area. The collected data are then analysed, compared, and selected into a set of shared analysis and intervention methodologies to be applied in the ADRION programme area.

The WPT2 provides also for direct activities for the validation of the ADRISEISMIC methodology, through the organization of 6 Study Visits, and the simulation on 3 Pilot Action (to be performed by LP, PP3 and PP8) to test innovative methods for expeditious evaluations of the seismic vulnerability, integrated with instrumental diagnostics to improve the knowledge about the construction characteristics.

The overall aim is to demonstrate the applicability of effective, quick and low-cost methods to evaluate the vulnerability of existing buildings and aggregates of buildings and the related retrofitting interventions. The last step of the process is to provide effective tools for the monitoring of the results.

1.2. Objectives and structure of the deliverable T2.1.2

The aim of the Deliverable T2.1.2 is the cataloguing of the main retrofitting and reinforcement techniques available at the state-of-art for each PP.

From the first stages of the project development, it was decided to set the starting point on the analysis of the typical construction techniques. In fact, it is not possible to identify the most proper procedures for reducing seismic vulnerability, if the typical construction techniques of the existing built heritage in the historic centres of the PPs are not first studied and analysed in depth. The construction characteristics are a crucial part in the





selection of strengthening interventions. Moreover, operating on a masonry building is completely different from operating on a reinforced concrete building, and the intervention solutions must be evaluated on the basis of the current state.

Therefore, the analysis topics of the Activity T2.1 were immediately divided into 3 macro-areas: i) typical and representative case studies of the local building characteristics in the Regions involved, which are presented in this Deliverable T2.1.2; ii) most appropriate analysis methods for the evaluation of the seismic behaviour of existing buildings and aggregates of buildings, which are presented in the Deliverable T2.1.1; iii) most used and new techniques of intervention, which are presented in this Deliverable T2.1.2.

All the data regarding these 3 macro-areas had been collected and systematized, in order to define the local reference framework for the possible techniques, to be linked with specific structural issues generating vulnerability.

The ADRISEISMIC project specifically focuses on the buildings and aggregates of buildings in the main historic centres, therefore the construction techniques and intervention techniques that have been studied are focused on these contexts.

The cataloguing of construction and intervention techniques was developed by UNIBO as Leader Partner (LP) of WPT2 and subsequently submitted to the PPs for the validation of the data regarding their territory.

In particular, a series of general spreadsheets (xls) were structured and, where necessary, the LP entered data about its own region (i.e., Italy). Upon completion of the work, the files were sent to the PPs and they were asked to fill in the data about their territorial context, as the LP did for the Italian area. The spreadsheets are provided in the attachments.

Once the PPs had completed and sent back the files to the LP, the comparison phase of the results began, which allowed highlighting similarities and differences between the various Regional contexts, as will be illustrated below.

This data collection, about the definition of the state of the art of the PP Regions, will become the basis for subsequent decisions regarding the most suitable intervention techniques in relation to the characteristics of the local construction heritage.

2. The built heritage of the historic centres and its seismic vulnerability

In different historical periods, earthquakes have always represented one of the main causes of damage and loss of cultural heritage, both for monumental buildings and for the urban fabric. The damage observed in various countries due to recent earthquakes shows that there is an urgent need for better understanding the seismic behaviour of existing structures and, consequently, for greater reliability of assessment methods and, subsequently, intervention techniques.

The current built heritage represents the testimony of centuries of transformations, for a progressive adaptation to housing needs, according to mostly spontaneous growth models. These construction stratifications give it a historical and testimonial value that assumes, in general, cultural relevance.

The historical urban fabric must therefore be protected as an "extended cultural asset", since it is the representation of the stratified culture of a community, a place of historical memories and self-recognition for the population. Regarding the problem of seismic vulnerability, the evolutionary process that involved urban centres requires a specific and purposely dedicated approach, useful to consider the complexity of this built contexts and based on the awareness of the presence of different construction and structural typologies.





This issue particularly involves the European territory, characterized by compact and dense historical fabrics. Generally, we can recognize how most of the European historic centres are made up of a widespread fabric of traditional masonry buildings, sometimes isolated but in most cases arranged in aggregates of buildings. Among them, over the centuries, a variable percentage of more recent constructions, with reinforced concrete structures, have grown. It is therefore a set of building parcels, placed side by side, according to a mostly spontaneous aggregative rule.

The observation of situations, following seismic events, has repeatedly shown how their vulnerability, i.e. the propensity to damage with consequent reduction of functionality, cannot simply be seen as the sum of the vulnerabilities of individual buildings, since there is a close correlation between structural units mutually interconnected. Therefore, these are heterogeneous systems, whose seismic vulnerability is complicated to assess. The obvious difficulties in identifying a unique path leading to the safety assessment, as well as the possible planning of interventions, derives from the articulation complexity of the urban fabric (Mochi, Predari, 2016).

The widespread damage that the building aggregates show during seismic events descends precisely from the combination of numerous factors, including the interaction between contiguous building units belonging to the same aggregate, which determines specific types of damage. This interaction therefore constitutes the nodal point for the prediction of the structural behaviour of the system. Thus, in order to carry out a careful analysis of the buildings and foresee the possible damage scenarios, the preliminary knowledge of the transformation processes in historical buildings, the typological and construction characteristics and the structural organization are a fundamental prerequisite for a reliable assessment of its seismic vulnerability.

The survey of historic centres, already carried out in numerous contexts, has provided an interesting cataloguing of the building types and of the typical transformations they suffered. Each type, but also each transformation, can lead to specific damage due to the loss of continuity or bad connections.

The mechanical behaviour of each building type is summarized in abacuses of the expected damages (Giuffrè, 1996), which shows their reliability and repetitiveness over time. In Italy, this approach has been studied in depth since the 1990s, in research activities on the seismic vulnerability of the historic centres of Ortigia (Giuffrè, 1993), Matera (Giuffrè, 1997), Città di Castello (Giovannetti, 1998) and Palermo (Giuffrè, 1999).

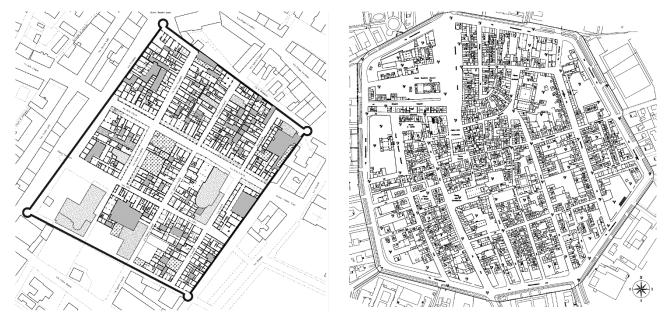


Figure 1 – Example of the typical urban fabric of an Italian historic centre, Medicina and Mirandola (BO, Italy)





2.1. Characteristics and vulnerabilities of the historic masonry buildings

The definition of "masonry building" is very generic: contains a large set of constructions from different periods, which can have very different construction characteristics and, consequently, very different seismic behaviour. Some specific elements in the conception and in the structural organization of masonry buildings represent the discriminating factor for the more or less efficient seismic performance of the building, or for its vulnerability.

In fact, there is a fairly close correlation between the period of construction and the structural behaviour, and this is almost independent of the other construction characteristics and of the state of conservation, which count as improving or worsening conditions of the original behavioural condition (Calderoni et al., 2011). In particular, the fundamental contribution for an efficient seismic behaviour is given by the level of connection between the different masonry walls and between the walls themselves and the floors.

Masonry buildings with a good structural behaviour ought to perform a box-like structural system, made up of vertical and horizontal structural elements (respectively walls, floors and roofs). The vertical loads are distributed from the floors, which act as elements subject to bending stresses, to the load-bearing walls, which are compressed elements; from these, the vertical loads are transferred to the foundation system. For a good box-like behaviour, the walls should be connected by rigid constraints to the floors, so that they are able to distribute the seismic actions between the walls according to their stiffness. This configuration allows to limit deformations on the masonry structure during an earthquake and, therefore, to prevent extensive damage and collapses.

Experimental tests and observations of the damage modes of real structures shows that walls are less resistant to actions that are perpendicular to their mid-plane (out of plane actions) than to actions parallel to their plane (in-plane actions). In the first case, the stiffness of the wall is, in fact, much lower than in the other. Satisfactory seismic behaviour is achieved when out-of-plane collapse is prevented and the in-plane strength and deformation capacity of the walls can be fully exploited.

Old masonry structures rarely meet the conditions to ensure box-like action: the floors and roof are rarely well connected to the walls. Moreover, floors have low stiffness in their plane, the connections between the walls are quite often lacking, while the large openings and openings near the corners lead to a further weakening of the box-like action. This happens because historic masonry buildings are organized according to the practice of assembling individual structural elements mutually connected through isostatic constraints.

Consequently, the behaviour of these kind of constructions under earthquake must be evaluated carefully considering the interaction level between the constituent structural elements. In the absence of appropriate connections between orthogonal walls and at the horizontal elements level, the response to the seismic action occurs for individual parts, depending from their mass; the walls behave independently of each other and develop out-of-plane collapse mechanisms, transforming the overall response of the building into the sum of the local responses of the individual elements.

On the other hand, if there is a sufficient connection between the vertical bearing structures and a floor system discreditable as infinitely rigid, the distribution of seismic actions occurs according to the stiffness of the walls. In this case, it is more likely that the masonry will break due to the achievement of the ultimate resistance in their plan; in addition, they collaborate with each other and the actions are distributed following the non-linear evolution of the structure. Thanks to the connection between vertical and horizontal elements, a box-like system is thus generated.

The seismic vulnerability of masonry buildings depends on various parameters, some depending on the distribution layout of the building, others related to the characteristics of the building elements. In the first category, we find: irregularities in the plan layout, discontinuity of the walls in the elevation, alteration of the





original structural scheme during the life of the building, inadequate interventions following previous seismic events. In the second one, we find: poor construction walls quality, or poor quality of materials in general, inadequate connections between vertical elements or between vertical and horizontal elements, lack of adequate stiffening of the horizontal bearing elements, etc. It is also necessary to consider previous unrepaired damage, lack of maintenance, degradation of materials, etc... that further aggravate the effects of a seismic event.

All these conditions limit the box-like action of the existing buildings.



Brick masonry consisting of several layers



Very inconsistent stone walls



Raising of a stone masonry building with concrete blocks, probably for the renovation of the roof







Poor connection between roof and walls



Timber deformable floor



Lacking of connections between the walls



Openings near the corners

Table 1 – Examples of damage to masonry buildings due to construction deficiencies





2.2. Characteristics and vulnerabilities of the existing reinforced concrete buildings

Reinforced concrete (RC) buildings appeared in Europe in the late 19th century, but began to spread systematically in the early 20th century. They were built according to the first standards concerning structural design (French, German and Italian) which were based on the elastic analysis of the structure and on the permissible stress design. It is interesting to highlight how in some contexts, such as in Italy, the RC construction, at least for civil dwellings, was the technological and architectural evolution of masonry construction: the new material had even more than 10 times greater compressive strength than masonry, and this allowed a significant reduction in the wall size. For example, a header masonry wall 3 m long could be replaced by a 30 x 30 cm RC element.

This possibility was exploited, above all, for the internal masonry walls, in order to achieve a more rational distribution of the rooms, thus obtaining the mixed building type, with external masonry walls and internal RC pillars.

The need to reduce the extension of the external walls was not as important from a distribution point of view, also for their indispensable closing and protecting function. In any case, the technological evolution and construction simplicity brought to the construction of complete RC structures.

So, after the mixed buildings (with the external walls entirely in masonry), the frame structure was also used for the perimeter (Pagano, 1990). The transformation was gradual: initially pillars and beams were cast directly into the walls, that were still made of load-bearing masonry; subsequently there was the frame with well embedded rigid masonry infill.

In varying periods, depending on the country, the need to quickly rebuild or expand cities led to an intensive development of RC constructions, with the simultaneous abandonment of masonry buildings. In fact, the RC technology allowed the construction of taller buildings (up to 20 for the tallest ones) in relatively short times. Thus, the mixed buildings gradually disappeared, giving way to the complete RC structures.

In general, the vulnerability factors of RC existing buildings can be referred to deficiencies relating to: the structural design, executive defects and materials degradation (Cosenza et al. 2008, Manfredi et al. 2007). The main flaw for RC existing buildings belonging to the first half of the Twentieth century is the absence, or lack, of a structural system designed to withstand the horizontal actions deriving by an earthquake. In fact, these constructions were built in Regions that were classified as low seismic, if not as non-seismic, according to the regulations of the time. Therefore, they were designed mainly for vertical loads (Landolfo et al, 2013).

In these cases, the main bearing structure is made up of unidirectional frames and orthogonal beams respecting the floors. The connecting beams in the transverse direction are generally absent or are made using wide beams.

These structures have a high transverse deformability, as well as a low resistance to horizontal loads. When the vertical loads are high, the result of these effects can cause global instability, and the consequent collapse of the entire construction. In the absence of adequate lateral stiffness and due to the high deformability of the structural system, seismic actions can also be particularly severe when the foundations lie on poor consistency soils, such as alluvial deposits.

Another vulnerability factor is the presence of irregularities in the plan layout, which leads to a not negligible eccentricity due to the distance between the centre of gravity and the centre of rigidity. This determines the coexistence of translational and rotational modes, increasing the strain and deformation in the resistant elements.

Furthermore, for plants with a high dimensional difference in the two main orthogonal directions, both floor resistance problems and higher stresses may occur if compared to buildings with compact shapes. In the case





of very elongated layouts just in one direction, in fact, the floors are particularly stressed in their plane due to the transfer of inertial actions on high spans.

Other vulnerability causes may be due to the wrong conception of the floors; for buildings in seismic areas, they must withstand the vertical loads and must also distribute the horizontal actions among the various resistant elements. The structural deficiencies of floors in existing RC buildings are: inadequate resistance and capacity to withstand shear actions; inadequate strength and capacity to withstand bending stresses; extreme flexibility and deformability. In particular, these flaws are due to the absence, or inadequacy, of collaborating slabs (e.g. in the use of prefabricated elements). Further vulnerability factors are constituted by the presence of large openings and local planimetric irregularities, which can generate high concentrations of stresses. Similarly, also the presence of large gaps in the floor plan have a similar impact on the structure.

Moving on to the elevation development, the term "soft story" refers to a type of damage mechanism that is generally activated at the first level, with the breaking at the head and foot of the pillars, causing the rigid translation of the overlying structure. This is a typical structural deficiency for many existing RC buildings. In the past, in fact, it was common to design resistant elements along the height of the building and the perimeter, such as reinforced concrete walls, but using vertical structures of reduced dimensions in the first level in order to leave open spans, for example for the presence of garages.

The soft story mechanism can also occur when there are frames with high strength and stiffness infill (e.g. with solid masonry) at all levels except for the first level, or when rigid masonry is present only in some parts for the level height.

In these cases, there is a strong irregularity in the distribution of stiffness and resistance in elevation: on the first level, they are much lower than on the upper floors. This condition leads to the collapse mechanism, characterized by the translation of the building onto the base pillars.

The soft story mechanism therefore requires considerable local involvement of the pillars and high rotational ductility. Such strains are rarely verified for elements combining compressive and bending stress, especially when designed without specific anti-seismic criteria, as happens for existing buildings. Consequently, the fragile breakage by shear and bending of the pillar can occur, up to total collapse.

In the case of RC existing buildings, it is common to observe also an incorrect or inadequate realization of the construction details. In particular: insufficient and incorrect anchoring of the reinforcements, scarce and discontinuous stirrups in beams and pillars, absence of adequate confinement of the concrete, discontinuity in the casting steps, insufficient dimensions joints with consequent hammering effect, very wide beams and eccentric nodes with respect to the pillars.

In many existing buildings, designed for vertical loads, the transverse reinforcement of the beams (i.e. stirrups and bent bars) was calculated to absorb the shear actions produced by the design actions and not according to the maximum bending capacity, as for modern criteria of "capacity design". For this reason, the beams can collapse due to shear stresses before the formation of a plastic flexural hinge.

Likewise, pillars were designed for the vertical actions and not to have a resistance greater than the flexural capacity of the beams, as the current verification criteria require. For this reason, the plasticization of the pillar is frequently triggered, with a consequent plan mechanism.

The beam-pillar joint represents a further particularly vulnerable area of the RC framed structures, because, if not well designed, it can become critical node of the structure during an earthquake. In fact, due to the particular bending moments distribution that occurs in the pillars immediately above and below it and also for the presence of bending moments in the beams that concur there, joints are subject to shear, horizontal and vertical actions. Such actions can also be greater than the corresponding actions on the converging elements. This condition often causes a brittle fracture and the release of all the rods afferent to the node at the same time, with catastrophic consequences for the structure.



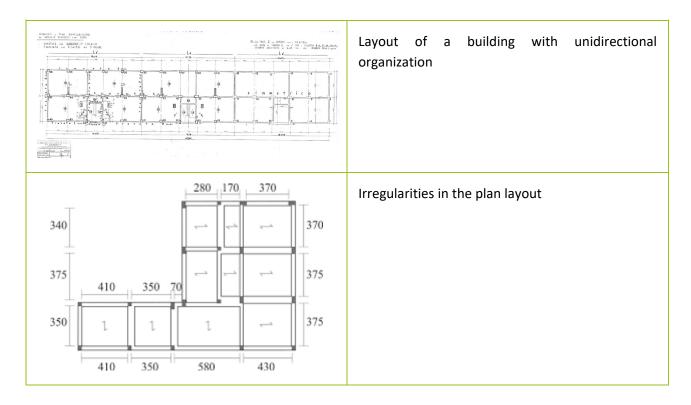


Furthermore, again due to the bending moments distribution, the longitudinal reinforcements in the joint beams can have compression stresses on one side and tensile stresses on the opposite side. This scheme leads to strong tangential tensions between the bars and the surrounding concrete, which can result in a loss of the adhesion and, therefore, of the resistance.

Likewise, the connection at the base of the building can be a vulnerability factor. The lack of an adequate connection with the foundation system can lead to relative movements at the base of the structure with serious consequences for the elevation structure.

Other elements influence the structural performance, both seismic and static. For example, the material degradation can constitute a further seismic vulnerability factor. There are several causes that can lead to the deterioration of the reinforced concrete properties and that can compromise the correspondence between what was designed and the actual behaviour. These include the carbonation of concrete and the corrosion of the reinforcements. The first is triggered when carbon dioxide spreads into the pores of the cement mass, with the consequent reduction of calcium hydroxide, which causes a lowering of the ph in the cement paste, creating the conditions for oxidation of the reinforcing steel. The corrosion of the reinforcements causes both a decrease in their resistant section and a progressive increase in their volume. In addition, it can also lead to the expulsion of the concrete cover and to a reduction in the adhesion between steel and concrete, up to the loss of anchoring.

Finally, a further critical factor can be identified in the context conditions, which can damage the building even if this is well conceived during a seismic event, such as e.g. the presence of an embankment near the building, or for the presence of too close artifacts and buildings, with consequent hammering problems.





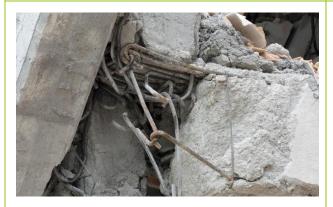




Floor with a non-reinforced slab



Soft story behaviour



Incorrect design of the beam-column joint



Material degradation



Presence of a high-rise RC building in a building aggregate

Table 2 – Examples of damage to RC buildings due to construction deficiencies





3. Cataloguing of the construction techniques

The development of the spreadsheets concerning the cataloguing of the construction characteristics of the existing buildings in the historical centres, started from the understanding of the relevant characteristics for the analysis.

In particular, all the properties of the construction elements were extrapolated, neglecting in this phase the planimetric and elevation differences, which cannot be standardized.

Therefore, from the in-depth study of the available thematic references and from direct experiences, the construction systems have been identified, and each of these has been divided into its constituent elements. The most common building types of buildings and aggregates of buildings in historic centres have been identified as:

- load-bearing masonry construction systems
- reinforced concrete (RC) construction systems

Each of these has been split between vertical elements (walls or pillars), horizontal elements (floors and roofs), and foundation system.

Finally, a specific spreadsheet contains the "main structural types", which collects the prevailing construction types of buildings on the specific context. This organization will allow preparing a scheme in a second phase, so that a classification of construction types can be quickly created. These data intend to propose a typological and structural classification of existing masonry and of reinforced concrete buildings, aimed at the approximate definition of the "overall vulnerability" parameter, referring to large portions of the urban fabric. Specific elements, regarding the conception and structural organization of the building, which are closely linked to the construction period and the corresponding construction techniques, can become the way for defining an expeditious vulnerability level.

In each spreadsheet, all the characteristics useful for the subsequent identification of the seismic vulnerabilities have been filed. As already said, for masonry buildings they are: poor construction quality for walls or poor quality of materials, inadequate connections between vertical elements or between vertical and horizontal elements, lack of stiffening action of the horizontal bearing elements, etc.

Also for reinforced concrete buildings, the spreadsheet has been set up to file all those visible characteristics that could have a connection with a specific type of damage in the event of an earthquake: poor construction quality, inadequate construction details, triggering factors for the soft story mechanism, floor without a reinforced slab, etc.

The database was compiled on the basis of the situation in the LP country, i.e. Italy. The partners were asked to check the correspondence of the data and update those characteristics for their country, adding information on local construction techniques that had not already been registered.

The data that have been inserted in specific tables of the spreadsheets are described here; in the following chapters, the results obtained by each PP will be presented.

3.1. Masonry and RC buildings

The spreadsheets want to help in identifying all the vulnerability characteristics of existing building elements, starting from the vertical structures. In masonry buildings, the construction type, the masonry quality and its state of conservation play a fundamental role in determining the capacity of a building to withstand seismic actions. The masonry resistance to the various actions, in fact, is not regulated just by the mechanical properties of the constituent materials: a masonry able to resist and transfer vertical and horizontal forces without being damaged must also present a monolithic behaviour (Borri, 2019).





Since there is a great variety of construction types for historical masonry, and as each of them has different effects on the structural response of the structure, the starting point for a study on this context should be based on the systematic survey of the different geometries and techniques, including the thickness (e.g. number of layers and type of connection between them).

This systematic investigation on the morphology of masonry walls on the Italian territory started in the early Nineties, conducted by L. Binda (Binda, 2000b), which was followed by other experiences on the mechanical behaviour of masonry typologies based on visual inspections, surveys and typological classifications (Giuffrè, 1993; Giuffrè, 1997; Borri, 1995; Giovanetti, 1998; Giuffrè, 1999).

Significant parameters to classify good quality masonry include: stones or bricks placed in horizontal courses, not aligned vertical mortar joints, use of almost square and large stones, limited volume of mortar compared to the volume of bricks or stones (usually < 13 mm), transversely connected wall layers, sufficient mechanical properties of mortar and bricks (or stones). The structural performance of the masonry can be estimated taking into account these parameters and the following factors (Binda, 2000a): i) its geometry; ii) the characteristics of its texture; iii) the physical, chemical and mechanical characteristics of the components (brick, stone, mortar); iv) the characteristics of the masonry as a composite material.

One of the most negative cases is when masonry do not develop monolithic behaviour in its thickness (or rubble masonry), as often happens in stone walls, that are composed of several layers not correctly connected to each other. This type of masonry is often present in historical structures, and its non-monolithic behaviour becomes a determining parameter for the structural capacity of the system, as it is extremely vulnerable, especially against out-of-plane actions induced by earthquakes.

For buildings with vertical RC structures, the individuation of the relevant characteristics for the seismic vulnerability is much more complex, because many of the critical issues are no longer visible once the building is completed. If the executive structural design is not available, it is very difficult to have an exhaustive identification of the bearing elements. However, some parameters can be detected; among these: the size of beams and pillars (which can affect the activation of fragile shear mechanisms), and the construction quality of the infill (which affect the soft floor mechanism).

Slabs and roofs are, in general, the structural elements that must guarantee stiffness in the horizontal plane, distributing the horizontal actions due to the earthquake among the vertical elements. If these have a low stiffness (as often happens for timber floors, but also for those in steel and reinforced concrete), the correct transfer of stresses is denied. By recognizing the typology of historical floors, it is therefore possible to hypothesize their typical behaviour, as rigid or deformable floor.

Finally, as already highlighted, the foundations are a relevant element in the structural response of the building. They constitute the constraint at the base of the building and transfer actions to the soil. These generally are the most difficult construction element to identify, as they are not visible except through inspections. However, knowing the type of soil, the type of elevation structure and local building customs, it is possible to hypothesize about their constitution.

Vertical structure – Masonry types (Table A)

The spreadsheet contains a series of data relating to all the construction solutions that may exist as vertical elements of a load-bearing masonry structure; they are:

- identification CODE: which allows the quick identification of each construction solution
- DESCRIPTION: brief description of the appearance and features of the masonry type
- EXAMPLES: explanatory image of the masonry type
- CONSTITUENT MATERIAL: it describes the materials that characterize that technical solution
- INSTALLATION OF THE ELEMENTS: it describes the methods of laying the walls





- TRANSVERSAL SECTION: it describes how the cross section of the masonry is composed
- CONNECTIONS: it describes the level of internal connection of the walls in the weak points, in particular in the corners
- THICKNESS: it describes the minimum and maximum thickness which is substantially recurrent for the masonry type
- PERIOD OF CONSTRUCTION: it describes the prevalent period of diffusion
- MAIN GEOGRAPHICAL LOCATION: it describes the geographical areas of greatest diffusion on the national territory
- STRUCTURAL CHARACTERISTICS: it describes the characteristics of static and dynamic behaviour

Vertical Structures - Reinforced concrete solutions (Table B)

The sheet contains a series of data relating to all the construction solutions that may exist as vertical elements of a reinforced concrete structure; they are:

- identification CODE: which allows the quick identification of each construction solution
- DESCRIPTION: brief description of the appearance and features of the RC solution
- EXAMPLES: explanatory image of the RC solution
- CONSTITUENT MATERIAL: it describes the materials that characterize that technical solution
- INFILL ELEMENTS: it describes the materials that make up the infill
- STATIC BEHAVIOR: it describes the static structural scheme
- CONNECTIONS: it describes the level of internal connection of the reinforcements
- DIMENSIONS: it describes the dimensions which are substantially recurrent for the RC elements
- PERIOD OF CONSTRUCTION: it describes the prevalent period of diffusion
- MAIN GEOGRAPHICAL LOCATION: it describes the geographical areas of greatest diffusion on the national territory
- STRUCTURAL CHARACTERISTICS: it describes the characteristics of static and dynamic behaviour

Horizontal elements – Floors and roofs (Table C)

The sheet contains a series of data relating to all the construction solutions that may exist as horizontal elements both in load-bearing masonry structures and in reinforced concrete structures; they are:

- identification CODE: which allows the quick identification of each construction solution
- DESCRIPTION: brief description of the appearance and features of that technical solution
- EXAMPLES: explanatory image of that technical solution
- CONSTITUENT MATERIAL: it describes the materials that characterize that technical solution
- STATIC BEHAVIOR: it describes the static structural scheme
- CONNECTIONS: it describes the level of internal connection with the vertical elements
- MAXIMUM SPAN: it describes the maximum span which is substantially recurrent for the construction elements
- PERIOD OF CONSTRUCTION: it describes the prevalent period of diffusion
- MAIN GEOGRAPHICAL LOCATION: it describes the geographical areas of greatest diffusion on the national territory
- STRUCTURAL CHARACTERISTICS: it describes the characteristics of static and dynamic behaviour





Foundation system (Table D)

About foundations, in historic buildings, the criterion of choice when deciding the type of foundation was simply based on the identification of good, medium, bad and compressible or incompressible soil.

Today, a first criterion for approaching the knowledge of the type of foundation of existing historic buildings, without necessarily proceeding with invasive investigations, is to know the characteristics of the soil at the construction site, which is likely to correspond to a specific execution method.

The sheet contains a series of data relating to all the construction solutions that may exist as foundation system both in load-bearing masonry structures and in reinforced concrete structures; they are:

- identification CODE: which allows the quick identification of each construction solution
- DESCRIPTION: brief description of the appearance and features of that technical solution
- EXAMPLES: explanatory image of that technical solution
- CONSTITUENT MATERIAL: it describes the materials that characterize that technical solution
- TYPE OF SOIL: composition of the soil where the foundation is set
- COMPATIBILITY WITH THE ELEVATION STRUCTURE: it describes the generally combined type of vertical structure
- TYPE OF SOIL ACCORDING TO LOCAL CLASSIFICATION: summary indication of the soil type based on the national classification
- DEPTH: it describes the depth which is substantially recurrent for the foundation system
- PERIOD OF CONSTRUCTION: it describes the prevalent period of diffusion
- MAIN GEOGRAPHICAL LOCATION: it describes the geographical areas of greatest diffusion on the national territory

Main structural types

This sheet contains the identification of some recurring structural types for the contexts under analysis, which derive from the systematic combination of the previously listed construction techniques.

For each of these, the following are indicated:

- DEFINITION: brief description of the typical characteristics of that structural type
- PERIOD OF CONSTRUCTION: it describes the prevalent period of diffusion
- COMPONENTS:
 - VERTICAL STRUCTURES: it describes which solutions are used for vertical structures, both in masonry and in reinforced concrete.
 - HORIZONTAL STRUCTURES: it describes which solutions are used for horizontal structures, such as floors and roofs.





4. Results of the cataloguing in PPs' Regions

As already highlighted, in the first draft, the spreadsheets were set up and compiled on the local experience of the LP Country, that is Italy. The files were then sent to the PPs in May 2020, which were asked to fill in them for their Region and send them back by the end of June 2020. The PPs were also asked to add the same information for local construction techniques that were not already entered.

The result of the data collection performed by each PP is presented here.

4.1. Italy – PP1 (UNIBO) and PP2 (IIPLE)

Italy is a country with high seismicity, which is distributed throughout the country with different severity levels. The most recent regulations, starting from 2003, have acknowledged the presence of a widespread seismic hazard even on areas that the previous classifications declared free from a probability of major seismic events. This circumstance has accentuated the presence on the Italian territory of recent buildings that, although built in accordance with the local standards, do not meet the actual requirements for seismic areas.

Some of the factors that make the Italian urban fabric in city centres extremely vulnerable are: a centuries-old building heritage, the absence of seismic criteria in its design as they were not required until the early years of this century and architectural interventions without adequate structural checks.

Very different building types, from the monumental buildings, dating back to several centuries ago, to historical buildings, characterize Italian centres. Despite being very ancient, they are still the vital core of the populations, as they host residences and small businesses. These buildings coexist with more recent masonry or reinforced concrete constructions.

Over the entire national territory, construction techniques have differentiated over the centuries, due to local cultures and conditioning, which have significantly affected the masonry characteristics and quality, causing substantial differences in terms of seismic response.

Referring to the 2001 census, out of a total of 27.291.993 houses (corresponding to 11.226.595 buildings), more than 60% was built before 1971. The distribution is fairly homogeneous throughout the country, with a peak higher than the 80% in Liguria, followed by Piedmont and Tuscany and a minimum of around 50% in Sardinia. In the 2011 census, the total of buildings surveyed amount to 14.515.795, of which 14.452.680 are isolated and 63.115 are aggregates of buildings. The data shows that 53.7 % of the houses are over 40 years old-i.e. built before 1970-and another 31% dates back to the period 1971-1991.

This simple data provides a clear indication of the old age of the Italian residential heritage and of the lack of adequacy to modern anti-seismic design requirements.

As for the building type, the 2001 census highlights that the Italian heritage is made up of 6.903.982 masonry buildings (61.50%), 2.768.205 reinforced concrete buildings (24.66%) and 1.554.408 with other features. In general, 80% of Italian municipalities have a percentage of masonry buildings higher than 50% and in particular, 44% of municipalities fall into the highest category (75% -100%).



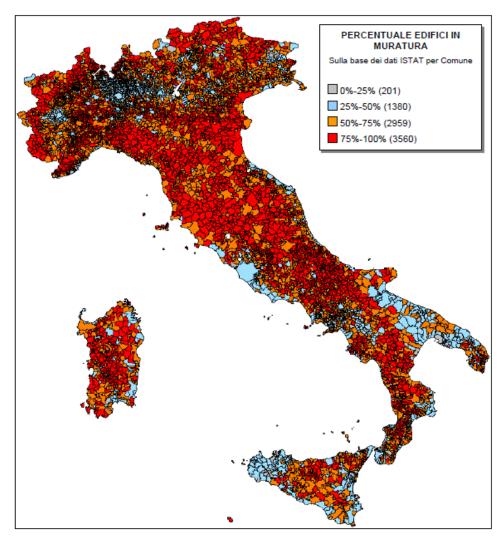


Figure 2 – Percentage of masonry buildings by municipality (Zuccaro, 2002)

The consultation of the "National typological characterization model" (Zuccaro, 2002) had a great importance. for studying the characteristics of the Italian heritage. This analyses in detail the construction characteristics of 34 sample cities and 57 smaller towns, considered significant for individual local aspects. They are also sufficiently distributed throughout the Italian territory to be considered representative in a national classification framework.

The analysis of building materials on the national territory shows an extreme variety from centre to centre (Zuccaro, 2002); even at short distances, there are often significant differences in the used materials, as this choice is strongly conditioned by the geological characteristics of the site as well as by economic and political aspects.

The analysis about dissemination and use of the building materials was based on in-depth bibliographic studies through some important texts written on this subject (Rodolico, 1965; Salmoiraghi, 1892; Penta, 1935).

Vertical structure – Masonry types (Table A)

For masonry constructions, in the study of Zuccaro (Zuccaro, 2002) eight main types of materials are identified:

• limestone is found mainly in the internal Apennine areas, as well as in most of Sicily and in Puglia. In northern Tuscany it is mainly metamorphosed limestone (marble);





- tuff is typical of volcanic areas, i.e. in the Neapolitan area (yellow tuff) and in the centres of the volcanic region near Lake Bolsena, whose inhabitants have always used lava and tuffaceous rocks; the calcareous tuff is found mainly in Southern regions (Puglia, Sicily);
- travertine is typical of some Central Italy areas, where the massive presence of this stone interrupts the continuity of brick use, typical of the Adriatic area;
- sandstone is strongly present in Tuscany;
- granite is found mainly in the Calabrian area, along the Silan Apennines;
- brick strongly characterizes the Adriatic coast and is also found in many Northern centres, especially to the right of the Po river; this is due to the strong presence of alluvial deposits that have always powered the brick industry.

A close connection combines local materials with the construction techniques practice and with specific geometries for wall structures. The analysis of the possible uses of natural and "artificial" stone materials, in terms of the allowed geometry in the wall faces, shows that for some materials the possibilities are very wide. For example, limestone can be in the form of rough stone, but also in pebbles, depending on its sedimentary origin. In the second case, it is layered in planes no greater than 10-12 cm thick and is used in rough-hewn slab-like walls (Umbria), while in the first case, however, it is present in much more massive layers, from a few tens of centimetres to a few meters, and is extracted as rough stone for irregular masonry (Abruzzo, part of Lazio and Campania, etc.).

For other types of stones, the possibilities are more limited, as is the case, for tuff or bricks, which naturally allow for regular masonry.

		Materials									
Possibility of Using Stone Materials		Limest one	Tuff Arenai c Limest one	Volc anic Tuff	Volc anic Elem ents	Sands tone	Trave rtine	Gra nit e	Br ic ks		
T y p e s O f M a s o n r	r r	A 1	Rough Stone	x			x	x		x	
	е gg u — а r	A 2	Rounded Stone or River Pebbles	x						x	
	H e	B 1	Plate Elements	x				x			
	w e d	B 2	Pseudo Regular Elements	×	×	×	x	x		×	
	R e g	C 1	Squared Natural Stone	x	x	×		x	x		
	u — а г	C 2	Artificial Stone								х

Table 3 – Analysis of the relationships between masonry materials and geometry (reworked by Zuccaro, 2002).





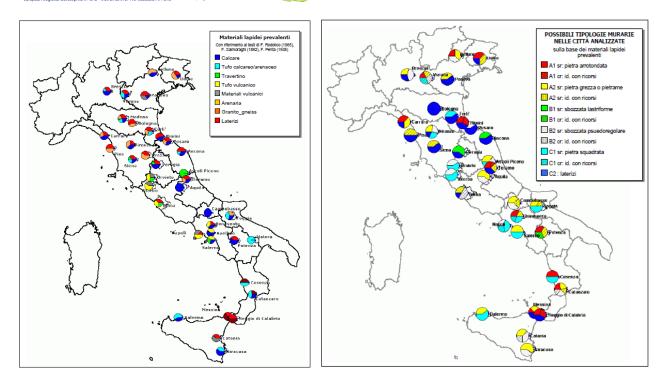


Figure 3 – On the left, percentage of masonry materials in some Italian cities that had been analysed; on the right, possible walls types in some Italian cities subjected to analysis (Zuccaro, 2002)

The study continued on the examination of the construction techniques for masonry buildings (for vertical and horizontal structures). The data collected by Zuccaro (Zuccaro, 2002) highlight, as expected, a general impoverishment of the construction techniques when moving away from the large centres.

It should be emphasized that, although the materials are often linked to the available resources of the context, the construction techniques, in relation to different factors, have many similarities, regardless of distance. Some large centres, such as Naples, Catania, Syracuse and Florence, are examples of a relevant building practice not only locally, but also to an entire area. In particular, by virtue of the political and economic dominance that has characterized it over several centuries, the city of Florence has exported its building culture over a large zone, from Tuscany to Umbria up to the Marche Region.

On the basis of the conducted analyses, Zuccaro developed a first reference map, which proposes the possible masonry types that were found in the studied centres; this map, certainly not exhaustive, summarizes the results of the precise investigations carried out on the individual centres.

For this map, the walls have been classified according to the scheme proposed in the Manual for compiling the AeDES factsheet, 1st Level Damage Detection Factsheet, Emergency Response and Usability for Ordinary Buildings in Post-Seismic Emergency. This is obviously a general classification which consequently leaves out particular situations, which also characterize the Italian construction landscape. This cataloguing, a first level one, is based on the geometry and texture of the stone elements that make up the wall surface; it distinguishes the vertical elements into three large families:

- IRREGULAR MASONRY, consisting of elements with irregular shape, which can be river pebbles, small and medium-sized, smooth or with rounded edges (coming from floods or streams and rivers) but also elements of different sizes with sharp edges, generally in limestone or lava stone;
- ROUGH-HEWN MASONRY, consisting of summarily worked elements, not perfectly squared, which appear in a pseudo-regular shape or with a stone slab structure;





• REGULAR MASONRY, made up with perfectly squared elements, as allowed by the tuff and certain stones, as well as by bricks.

Zuccaro's study highlighted a certain frequency of regular masonry, especially in coastal areas. This depends both to the presence of brick walls, characteristics of the Adriatic area, and to the presence of stone materials suitable for providing well-squared stone, as occurs in the Neapolitan area, in Puglia and in the volcanic regions.

Walls characterized by irregular rounded stones are connected to the presence of rivers. Those made in rough stone are present throughout the Country, although in some Regions, such as Tuscany, they are improved through the use of bricks or levelling courses, designed to regularize the masonry.

Even in Calabria, there are irregular walls: they are often made with large pebbles coming from the disintegration of the Silan Apennines rocks, subsequently smoothed by the rivers. South-eastern Sicily offers irregular wall types, even though they are made with rock splinters. In that region, there are also some regular types, present in Palermo and in cities with the same type of tuffaceous stone (such as Trapani and Agrigento), which is well suited for regular cutting.

In summary, Zuccaro notes that the analysed areas can be divided as follows:

- regular brick masonry: areas rich in clays for the brick industry, Adriatic coast, cities at the right of the Po river;
- regular tuff masonry: Naples, Campania, Palermo, Agrigento, Trapani, Viterbo, Orvieto, Foggia, Matera, Bari, Melfi;
- regular sandstone masonry: Florence, Arezzo, Tuscany in general;
- sandstone, limestone, or lava stone hewn masonry in: Tuscany, Umbria, Molise, upper Calabria, Abruzzo, Etna area;
- limestone or lava stone irregular masonry: as above;
- rounded irregular masonry: Calabria-Peloritan, regions characterized by the presence of rivers, in general areas with the presence of watercourses.

The same macro-categories were used as the basis for setting the spreadsheets for the classification of vertical masonry structures in ADRISEISMIC. In addition, notions on the static and seismic behaviour of the structures have been combined with them. Thirteen different types of masonry have been classified; in particular:

• IRREGULAR MASONRY:

A. 1.



Rubble stone masonry (pebbles, erratic and irregular stones), not well organized and without connection between the two wall surfaces.

The constituent materials are limestone pebbles and small irregular stone, together with lime mortar; usually this masonry type has a messy texture and random pose, with two juxtaposed or slightly connected layers. Connections are weakly effective in corners, with poor grip. These characteristics generate a high vulnerability for against out of plane actions, with the risk of detachment due to instability of the single, badly connected or unconnected, wall surfaces under vertical loads. It presents also poor resistance against







in-plane actions, due to both the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements themselves. In Italy, it generally has a thickness between 40 and 70 cm and it spread between the Medieval period up to about 1950, mainly in mountain areas and in Central and Southern Italy.

A.2.



Rubble masonry with regular sized stones, well organized but without connection between the two external surfaces, with the presence of edges, bundles and / or courses in square stone or solid bricks.

The constituent materials are limestone stones of regular medium size, slightly roughed, bounded with lime mortar. Usually, this masonry type has irregular horizontal courses with stone wedges and absence of strips, with two juxtaposed or slightly connected layers to an incoherent infill core. Connections are weakly effective in corners and are made of blocks of bigger dimensions. These characteristics generate a high vulnerability for out of plane actions, with the risk of detachment due to instability of the single, badly connected or unconnected, wall surfaces under vertical loads. It presents also poor resistance against in-plane actions, due to both the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements themselves. In Italy, it generally has a thickness between 40 and 70 cm and it spread between the Medieval period up to about 1950, mainly in mountain areas and in Central and Southern Italy.

A.3.



Rubble masonry with bricks, well organized, but without connection between the two external surfaces, with the presence of edges, bundles and / or courses in square stone or solid bricks.

The constituent materials are stones of regular medium size, slightly roughed in the infill core and bricks surfaces, bounded with lime mortar. Usually, this masonry type has regular horizontal courses on the surfaces with stone wedges and absence of strips, with two juxtaposed or slightly connected layers to an incoherent infill core. Connections are weakly effective in corners and can be made of stone blocks of bigger dimensions. These characteristics generate a high vulnerability for out of plane actions, with the risk of detachment due to instability of the single, badly connected or unconnected, wall surfaces under vertical loads. It presents also poor resistance against in-plane actions, due to both the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements themselves. In Italy, it generally has a thickness between 40 and 60 cm and it spread between the Medieval





period up to about 1950, mainly in lowland areas and in Northern Italy.

A.4.



Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces and the internal core

The constituent materials are bricks and lime mortar. Usually, this masonry type has regular horizontal courses, with more juxtaposed or slightly connected layers made with bricks. Connections are weakly effective in corners and are made by bricks. These characteristics generate a high vulnerability for out of plane actions, with the risk of detachment due to instability of the single, badly connected or unconnected, wall surfaces under vertical loads. It presents also poor resistance against in-plane actions, due to both the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements themselves. In Italy, it generally has a thickness between 42 and 56 cm and it spread between the Medieval period up to about 1950, mainly in lowland areas and in Northern Italy.

ROUGH-HEWN MASONRY:

A. 5.



Cut stone with effective bonding

The constituent materials are slightly roughed stones of regular medium size with lime mortar. Usually, this masonry type has horizontal courses -both regular and irregular- with stone wedges and absence of strips, with two well or poorly connected juxtaposed layers. Connections are effective in corners with stone blocks of bigger dimensions. These characteristics generate a level of medium vulnerability for out of plane actions, and medium resistance for inplane actions. In Italy, it generally has a thickness between 30 and 50 cm and it spread between 1500 about up to about 1950, mainly in mountain areas and in Central and Southern Italy.

A. 6.



Masonry in rammed earth blocks

The constituent materials are rammed earth blocks and clay. Usually, this masonry type has regular or irregular horizontal courses with a well-organized thickness. Connections are effective in corners, due to the same type of rammed earth blocks. These characteristics generate a high vulnerability for out of plane actions, as typically the wall is not correctly constrained to rigid or semi-rigid floors. It has also a poor resistance against in-plane actions, due to the low resistance of the materials. In Italy, it generally has a thickness between 14 and 56 cm



and it spread between the Medieval period up to about 1800, mainly in Central Italy.

REGULAR MASONRY:

A. 7.

ADRION



Tuff masonry

The constituent materials are tuff stones of regular size with lime mortar. Usually, this masonry type has regular horizontal courses with stone wedges and absence of strips, with a well-organized thickness. Connections are effective in corners. These characteristics generate a level of medium vulnerability for out of plane actions, and medium resistance against in-plane actions. In Italy, it generally has a thickness between 30 and 50 cm and it spread between 1500 about up to about 1950, mainly in Central and Southern Italy.

A.8.



Dressed rectangular (ashlar) stone masonry

The constituent materials are medium-sized squared limestone with lime mortar. Usually, this masonry type has regular horizontal courses with stone wedges and absence of strips, with two juxtaposed and well-connected layers. Connections are effective in corners, due to stone blocks of bigger dimensions. These characteristics generate a level of medium vulnerability for out of plane actions, and medium resistance against in-plane actions. In Italy, it generally has a thickness between 30 and 40 cm and it spread between 1700 about up to about 1950, mainly in mountain areas and in Central and Southern Italy.

A.9.



Solid brick masonry with lime mortar

The constituent materials are bricks and lime mortar. Usually, this masonry type has regular horizontal courses, with a well-organized thickness in continuity with the external surfaces. Connections are effective in corners and are made by bricks. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semirigid floors, capable of redistributing seismic actions to the walls, with a monolithic behaviour. It presents a medium or high resistance against in-plane actions, thanks to the resistance of the materials (in particular the mortar) and / or to the friction that can be developed between the elements. In Italy, it generally has a thickness between 14 and 56 cm and it spread between 1700 about up to about 1950, mainly in lowland areas and in Northern Italy.





A.10.



Solid brick masonry with cement mortar

The constituent materials are bricks elements and cement mortar. Usually, this masonry type has regular horizontal courses, with a well-organized thickness in continuity with the external surfaces. Connections are effective in corners and are made by bricks. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behaviour. It presents a medium or high resistance against in-plane actions, thanks to the resistance of the materials (in particular the mortar) and / or to the friction that can be developed between the elements. In Italy, it generally has a thickness between 13 and 40 cm and it spread starting from 1850. Nowadays is still used for construction in bearing masonry, on the whole Italian territory.

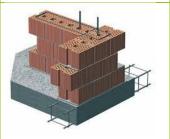
A.11.



Masonry in clay or concrete blocks with cement mortar

The constituent materials are brick or cement blocks and cement mortar. Usually, this masonry type has regular horizontal courses, in a single-layer. Connections are effective in corners and are also made by the same elements. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behaviour. It presents a medium or high resistance against in-plane actions, thanks to the resistance of the materials (in particular the mortar) and / or to the friction that can be developed between the elements. In Italy, it generally has a thickness between 25 and 45 cm and it spread starting from 1980. Nowadays is still used for construction in bearing masonry, on the whole Italian territory.

A.12.



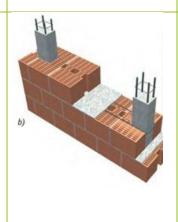
Reinforced masonry with distribution reinforcement

The constituent materials are brick blocks and cement mortar, with steel reinforcements. Usually, this masonry type has regular horizontal courses, with reinforcement horizontally distributed in the mortar joints and vertically in the block holes; composed of a single-layer. Connections are effective in corners with brick blocks or small RC pillars. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behaviour. It presents a high resistance against in-plane actions, thanks to the resistance of the materials. In Italy, it generally has a thickness between 25 and 45 cm and it spread starting from 1980. Nowadays is still used for construction in bearing masonry, on the whole Italian territory.









Confined masonry with concentrated reinforcement

The constituent materials are brick blocks and cement mortar, with steel reinforcements. Usually, this masonry type has regular horizontal courses, with reinforcement horizontally distributed in the mortar joints and vertically in specific small pillars, composed of a single-layer. Connections are effective in corners with small RC pillars. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behaviour. It presents a high resistance against in-plane actions, thanks to the resistance of the materials. In Italy, it generally has a thickness between 25 and 45 cm and it spread starting from 1980. Nowadays is still used for construction in bearing masonry, on the whole Italian territory.

Vertical Structures - Reinforced concrete types (Table B)

Buildings with reinforced concrete structures began to spread throughout the Italian territory from the early 1900s, and more widely immediately after the First World War. Nowadays, they are widespread throughout the Country, even in small town, for both public and private buildings.

The first seismic regulations, for part of the Italian territory, date back to 1913, but only in 2003 the national territory was entirely classified as a seismic zone. In addition, first seismic valid regulations throughout the national territory came definitively into force in 2009. This entails the high probability that existing RC buildings are today subjected to a seismic action greater than that foreseen in the design phase, or even not foreseen in the design phase.

The construction type that was adopted for RC buildings, before the introduction of the seismic regulations, reflects a design concept aimed only considering vertical loads. In this way, the resistant sections for the pillars were substantially related to the axial loads, possibly combined with low bending stresses resulting from node strains. This design attitude involved the construction of framed structures, characterized by pillars with section typically smaller than beams. This is contrary to the hierarchical resistances order, which is the modern design philosophy in seismic areas.

The critical issues that most affect the seismic response of the Italian RC architectural heritage are:

- inadequate arrangement of the non-structural elements in relation to the structure geometry (presence of a "soft story behaviour");
- presence of one direction frames;
- presence of "strong" beams and "weak" columns;
- presence of squat columns;
- inadequate construction details, lack of stirrups in columns and nodes, insufficient anchorage lengths and insufficient overlapping of the reinforcements;
- insufficient quality of materials, first of all of the concrete;
- possibility of out-of-plane mechanism for the infill panels;





- low resistance of the foundation system, often due to poor connection between the foundation beams themselves;
- absence of adequate seismic joints;
- absence of rigid plan;
- wrong arrangement of the reinforcement and insufficient percentage of steel;

It has already been extensively studied how the typical approach that was reserved in Italy to reinforced concrete construction, over the last century, has substantially followed the building dynamics, adapting to pre-existing conditions.

Therefore, it is possible to individuate a first period characterized by the jointed use of the innovative frame structures and traditional masonry systems, with the reinforced concrete load-bearing elements hidden by the external surfaces: the frame system allowed a freedom in the organization of the internal spaces never experienced before, but the proper character of the masonry construction was externally still preserved.

In this way, over time, the load-bearing vertical structure has undergone limited transformations from the structural point of view. Reinforced concrete pillars have gradually seen their aesthetic importance changed, without however enduring dimensional or distance variations. What varied were the materials used for the infill walls, passing from solid masonry to hollow brick or cement blocks.

Regarding the use of reinforced concrete walls, until a few decades ago, these remained confined to stairwells and van elevators, since, as seen, there was no design need for resistance to seismic actions. They were therefore used only where they facilitated construction operations.

The construction techniques for RC existing buildings within the contexts affected by the ADRISEISMIC project, listed below, reflect these previous considerations.

B. 1.



Frame structures with reinforced concrete beams and columns, with infill walls constructed using solid bricks

The structural constituent material is concrete, with variable composition depending on the construction period, and metal reinforcements. Infill elements are realized with solid brick masonry. The static behaviour can be assumed as a frame made of vertical isolated elements and beams; solid brick masonry contributes to the overall strength and stiffness.

The quality of the connections between the structural elements depends on the conformation of the reinforcements in the joints.

These characteristics generate a high vulnerability if nodes are not conceived as perfect joints and if there is a lack of steel reinforcements. High vulnerability is also caused by a lack of stirrups in pillars.

Pillars normally have a size between 30 and 50 cm. This construction system spread between 1910 and 1950, mainly in urban contexts of large cities.









Frame structures with reinforced concrete beams and pillars, with infill walls made with hollow blocks

The structural constituent material is concrete, with variable composition depending on the construction period, and metal reinforcements. Infill elements are realized with hollow bricks. The static behaviour is schematized with a frame, made of vertical isolated elements and beams; hollow brick masonry cannot contribute to the overall strength.

The quality of the connections between the structural elements depends on the conformation of the reinforcements in the joints.

These characteristics generate a high vulnerability if nodes are not conceived as perfect joints and if there is a lack of steel reinforcements. High vulnerability is also caused by a lack of stirrups in pillars.

Pillars normally have a size between 30 and 50 cm. This construction system spread since 1950, mainly in urban contexts of large cities and it is similarly used today.

B.3.



Reinforced concrete wall structures

The structural constituent material is concrete, with variable composition depending on the construction period, and iron reinforcements. Infill elements are absent.

The static behaviour is schematized with vertical continuous elements. The connections are usually effective due to the continuity of the material. These characteristics generate a low vulnerability; medium if the joints are not conceived as perfect joints and if there is a lack of reinforcements.

In Italy, the RC walls usually have a thickness between 15 and 25 cm. This construction system spread since 1950, mainly in urban contexts of large cities and it is still used today.

B.4.

Unreinforced concrete wall structures

The structural constituent material is concrete without metal reinforcements. Infill elements are absent. This typology is a very rare solution, externally the elements look like RC walls, but internally are without rebars.

The static behaviour is schematized with vertical continuous elements working only for compression.

The connections are ineffective due to the absence of reinforcements. These characteristics generate a high seismic vulnerability.

In Italy, the unreinforced walls usually had a thickness between 30 and 60 cm. This construction system spread between 1910 and 1930, mainly in urban contexts of large cities.





B.5.



Prefabricated reinforced concrete structures

The structural constituent materials are high strength concrete and metal reinforcements. The infill is made of solid bricks masonry or hollow bricks masonry. The static behaviour is schematized with vertical isolated elements and beams with simple support constraint. The low connections between pillars and beams are ineffective for horizontal actions. This characteristic generates a high seismic vulnerability.

Pillars normally have a size between 30 and 60 cm. This construction system spread since 1950, mainly in industrial areas and it is still used today.

Horizontal elements – Floors and roofs (Table C)

The aforementioned study by Zuccaro (Zuccaro, 2002) is taken as a reference also for the horizontal structures. For the floor types, as for the masonry, it is found an impoverishment in the used techniques and materials in small centres, compared to those observed in larger settlements. Timber floors, for example, often have non-squared main beams, arranged at a very large distances and not well connected to the walls. Even the vaults often lack the necessary precautions or are made with poor materials.

The reason for this divergence is generally found in the different economic evolutions of centres, which have always played a fundamental role in the growth of a city and its housing structures. In fact, even in small settlements, which have enjoyed a certain economic and political favour, it is possible to observe a widespread quality of the structures. In large cities, typically, it is easy to find a general impoverishment of techniques and materials between stately buildings and ordinary ones. The study also highlighted a prevalence of wooden floors and vaulted structures in the smaller towns.

The categories studied by Zuccaro are:

- TIMBER FLOORS: one of the most common solutions for houses in Central Italy, characterized by the use of few large main beams, at a distance between 2.60 and 3.50 meters, with a rather sparse second level of joists. This type of system responded to a relative scarcity of timber. In Northern Italy, and especially in Veneto, where wood was particularly abundant, the floors were more often made with a single layer of main squared beams placed at dense and regular distances.
 - A common floor for many cities in Central Italy, in particular in Tuscany, Marche and Umbria, is the one made with brick tiles. There may be several levels of beams, with the function of creating intermediate supports in the middle and consequently to limit bending deformations. Beams and joists were inserted into the walls to a depth varying between two thirds and the entire thickness of the wall, but there were no particular measures aimed at making the floor solid with the masonry.

In the Naples province, the most frequent type of timber floor is the one consisting of non-squared chestnut beams (often debarked trunks of 20 - 30 cm) with a span of about 5 meters, arranged alternately at distances between 70 and 100 cm. Above them, usually there are semi-cylindrical elements, with a diameter between 8 and 10 cm. To complete the floor, lime and lapillus conglomerate were used, with also waste materials derived from the tuff processing. There were no particular measures aimed at ensuring the connection between the floor and masonry.





In the double warping floor, chestnut wood was the most used essence, both in the Roman and Neapolitan area. Other woods, such as fir, were not typical of these areas and can be found in Northern Italy.

- IRON FLOORS: the iron floors were used starting from the Nineteenth century and do not show major differences from place to place. The variety concerns only the types of materials used to complete the floor itself.
 - In Naples, and in its province, for example, the iron beams were associated with tuff splits and more rarely vertically arranged solid bricks. In Catania, this system was made using both with brick vaults, both, more frequently, with pumice and plaster. This type of floor is also widespread in Calabria and in the surroundings of Messina.
 - One of the most widely used iron floors, not linked to particular local conditions, is undoubtedly the iron floor and hollow brick tiles. It is a rather standardized typology that was frequently used, like reinforced concrete floors, in renovations, to replace the original vaulted or timber structures.
- VAULTED STRUCTURES: are undoubtedly the most complex types of horizontal elements, although they can be classified into a few recurrent types, especially referring to minor buildings -excluding architectural types of churches and monuments. This construction system can be divided into simple and composite vaults, in relation to the continuity or subdivision of the intrados surface.
 - Among the simple ones, there are: the barrel vault, the dome and the sail vault.
 - Among the composite ones: the pavilion vaults and the cross vaults are both obtained from the intersection of two-barrel vaults. A pavilion vault with a flat central intrados is called "a schifo".

Regarding the construction methods, the differences are essentially due to the different type of used material, since the vault is the natural continuation of the wall structure. In the Roman area, the use of tuffaceous elements as regular blocks is widespread, although often the economy of work favoured the use of irregularly shaped elements. In Naples too, tuff is the most used stone for the construction of vaults. This material can easily be found in the vaulted structures of other Italian centres, especially thanks to its lightness. Other elements are light, as volcanic materials, such as pumice, and these have been used for concrete vaults in Naples, in the Etna area, and in the Sicily islands. Examples of concrete structures are also found in the Roman area, where the concrete is made up of irregular pieces of tuff. Lightness characteristics are also offered by the brick vaults, found in numerous Italian centres: in Rome or in many cities in the North, as well as on the Adriatic coast and in the Tuscan-Umbrian area. Here in particular, we find the type characterized by bricks placed in a flat layer, bound by gypsum mortar. The structure allows a considerable saving of material, but requests to stiffen it, with larger bricks arches at the intrados and with a rubble filling at the extrados. This vaulted typology could also include vertical arrangement of bricks, to constitute a more robust and heavier system.

Economic reasons determine a higher or lower level of quality, both for the types of materials used and for the execution of the structure itself. In any case, the choice in the use of vaults are never attributable to a single factor. For example, this system is adopted in coastal areas for the wood scarcity.

The same macro-categories were used as the basis for setting the spreadsheets about the classification of horizontal structures in ADRISEISMIC. The types of floors using reinforced concrete have been added, which are widely used since the early Twentieth century. For each type of system, notions on the static and seismic behaviour have been considered.

In conclusion, 11 different types of horizontal structures were identified in the study; in particular:





• TIMBER FLOORS:

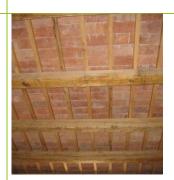
C. 1.



Single or double timber floors (beams and joists) with simple wooden planks

The constituent materials are timber beams and joists with wooden planks. The levelling layer is made of loose mixed filling. This floor type has a deformable static behaviour. Beams and joists are usually found in a simple support constraint on the walls. These characteristics generate a very flexible floor, usually not correctly connected to the walls, which does not constitute an effective constraint against the triggering of out-of-plane mechanisms. In Italy, it generally covers a maximum span of 6 m. It spread between the Medieval period and it is still used today in the whole national territory, both urban and rural areas.

C.2.



Single or double timber floors (beams and joists) with brick tiles

The constituent materials are timber beams and joists, with brick tiles and lime, or plaster based mortar. The levelling layer is made of loose mixed filling. This floor type has a deformable static behaviour. Beams and joists are usually found in a simple support constraint on the walls. These characteristics generate a very flexible floor, usually not correctly connected to the walls, which does not constitute an effective constraint against the triggering of out-of-plane mechanisms. In Italy, it generally covers a maximum span of 6 m. It spread between the Medieval period and it is still used today in the Northern Italy, both urban and rural areas.

• IRON FLOORS:

C. 3.



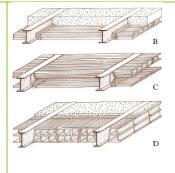
Floors with metal beams and vaults

The constituent materials are iron beams with arched arranged brick tiles, with lime, or plaster based mortar. The levelling layer is made of loose mixed filling. This floor type has a deformable static behaviour. Beams and joists are usually found in a simple support constraint on the walls. These characteristics generate a very flexible floor, usually not correctly connected to the walls, which does not constitute an effective constraint against the triggering of out-of-plane mechanisms. In Italy, it generally covers a maximum span of 9 m. It spread between about 1850 up to 1940 in the whole national territory, both urban and rural areas.





C.4.



Floors with metal beams and hollow bricks

The constituent materials are iron beams with hollow bricks and lime, or cement mortar. The levelling layer is made of loose mixed filling. This floor type has a deformable static behaviour. Beams and joists are usually found in a simple support constraint on the walls. These characteristics generate a very flexible floor, usually not correctly connected to the walls, which does not constitute an effective constraint against the triggering of out-of-plane mechanisms. In Italy, it generally covers a maximum span of 9 m. It spread between about 1850 up to 1940 in the whole national territory, both urban and rural areas.

VAULTED STRUCTURES:

C. 5.



Brick vaults

The constituent materials are bricks arranged in an arched pattern, with different thickness and curvature. This floor type has a deformable static behaviour. The vaulted structures are grafted onto the supporting walls, and can generate thrusts on the supporting walls. In Italy, it generally covers a maximum span of 5 m. It spread between the Medieval period up to 1800 mainly in urban areas in Northern Italy.

C.6.



Stone vaults

The constituent materials are flat stones arranged in an arched pattern, with different thickness and curvature. This floor type has a deformable static behaviour. The vaulted structures are grafted onto the supporting walls, and can generate thrusts on the supporting walls. In Italy, it generally covers a maximum span of 5 m. It spread between the Medieval period up to 1800 mainly in urban areas in Central and Southern Italy.

REINFORCED CONCRETE FLOORS:

C. 7.

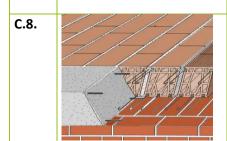


Cast-in-situ reinforced concrete slab

The constituent material is reinforced concrete for the whole thickness of the floor. This floor type has a rigid behaviour. The slab is built in continuity with the vertical reinforced concrete structure or with a semi-joint constraint on masonry walls. Its behaviour can be considered rigid in its plan, with a heavy weight. In Italy, it generally covers a maximum span from 4 m for a simple slab, up to 10 m with RC ribs. It spread between 1900 - 1930 mainly in urban areas in the whole Italian territory.



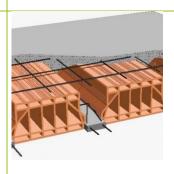




Hollow clay block floor without reinforced concrete slab

The constituent materials are reinforced concrete ribs with hollow bricks. This floor type has a deformable static behaviour. The slab is built in continuity with the vertical reinforced concrete structure or with a semi-joint constraint on masonry walls. Its behaviour cannot be considered rigid in its plan, with a medium weight. In Italy, it generally covers a maximum span of 6 m. It spread between 1900 - 1950 mainly in urban areas in the whole Italian territory.





Hollow clay block floor with reinforced concrete slab

The constituent materials are reinforced concrete ribs with hollow bricks and upper reinforced concrete slab. This floor type has a rigid behaviour. The slab is built in continuity with the vertical reinforced concrete structure or with a semi-joint constraint on masonry walls. Its behaviour can be considered rigid in its plan, with a medium weight. In Italy, it generally covers a maximum span of 6 m. It spread between 1910 and it is still used today mainly in urban areas in the whole Italian territory.

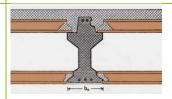
C.10.



Prefabricated reinforced concrete floor

The constituent material is reinforced concrete for the whole thickness of the floor. This floor type has a rigid behaviour. The floor is not in continuity with the reinforced concrete structure, the connection with the supporting structure is a simple support constraint. Its behaviour can be considered rigid in its plan, but it can be not well connected with the supporting system; it has a high weight. In Italy, it generally covers a maximum span of 12 m. It spread between 1950 and it is still used today in industrial areas.

C.11.



Hollow brick floor with prefabricated joists

The constituent materials are prefabricated reinforced concrete joists with hollow bricks. The upper reinforced concrete slab can be present or not. This floor type has a deformable static behaviour. The structural part of the floor is not in continuity with the vertical structure, the connection is a simple support constraint. Its behaviour cannot be considered rigid in its plan, for the probable absence of a reinforced concrete slab, and joists are not well connected with the supporting system; it has a medium weight. In Italy, it generally covers a maximum span of 8 m. It spread between 1930 and 1950 mainly in urban areas in the whole Italian territory.





Foundation system (Table D)

In the foundations design of historic buildings, knowing the laying soil (which was generally simply classified as good-medium-bad or compressible-incompressible) was the prior element for choosing the most appropriate type of foundation.

Nowadays, a first criterion for making reasonable assumptions about the foundation type of existing historical buildings, without necessarily carrying out invasive investigations, is identifying the soil characteristics in the building site, which most likely corresponds to a specific execution method.

For rocky soils, the laying surface can consist of terraces, with parallel horizontal planes, engraved into the rock. For sufficiently compact clayey soils, the laying surface can be a levelling, or a wooden trellis placed on inert elements at the bottom of the excavation. For compressible and yielding soils, there may be wooden poles, in addition to the trellis. In the presence of poor quality and compressible soils, foundations may have been realized using fixed wooden poles, with the laying surface arranged at the top.

In presence of concentrated vertical loads, the foundations of historic buildings could include isolated plinths for low stress values, or unloading arches for high stress values, with or without wooden poles into the more consistent soil.

The foundations above illustrated, represent only a part of the wide range of types found in existing buildings, whose survey however is always complex, since they are not visible works.

In general, we can reduce them to five different types:

- continuous foundations;
- foundations with inverted arches;
- pier foundations;
- wooden piles;
- concrete slabs.

The so-called continuous foundations (brick and stone footing) are the simplest and most widespread model, as were widely used in buildings with load-bearing masonry walls. They are simple enlargements of the masonry, using the same materials as the elevated structure (usually terracotta bricks, squared stone blocks, river pebbles or stones). These foundations are normally superficial, with a depth of 50-70 cm and, very rarely, deeper than one meter.

Often the basement enlargement is even absent, especially when the masonry is set on a rocky ground.

Continuous foundations are still widely used in newly constructed load-bearing walls buildings, with the masonry footing replaced by reinforced concrete beams.

The foundations with inverted arches, and the pier foundations, were instead used on more difficult situations. Typically, they are found in presence of underperforming soils and of heavy buildings or with underground floors. The first system, conceptually identical to the inverted beams, consisted on the construction of a series of inverted arches, with the convexity facing upwards, which connected robust stone or brick pillars.

The pier foundations are similar, but the arches are of the normal type, with the convexity facing downwards. The wooden poles foundations were built by arranging poles in the ground. They were made up of barked and sharpened larch or oak trunks, up to 7.5 meters long, in the number of 6-9 for each square meter.

Subsequently, all the poles were cut on the top at the same height and connected by sturdy wooden boards. The walls were set on these planks with a base consisting of ashlars and, in a second time, by courses of bricks. For particularly heavy structures plain concrete slabs (i.e. unreinforced) were used.





The foundations of more recent buildings, which mainly use reinforced concrete, add up to these traditional types:

- continuous foundations with a reinforced concrete base;
- plinth foundations;
- inverted beam foundations;
- slab foundations;
- pile foundations.

Continuous foundations are used in recent load-bearing masonry buildings, while other types of foundations are more common in structural frame systems.

Plinths foundation are normally used in compact soils, characterized by good-excellent bearing capacity (at least $1.5 \div 2$ daN / cm²), which minimize the generation of differentiated settlements. They consist of RC parallelepipeds or pyramidal blocks with steel rods and stirrups. They can both be cast on site or prefabricated. On the other hand, if the soil has a lower bearing capacity or can be subject to important differential settlement, the foundation with inverted beams is adopted. It is a series of reinforced concrete beams with a thickness normally between 40 and 80 cm, width between 50 and 200 cm. They are so called because their reinforcement and static behaviour are exactly reversed compared to the common elevated beams.

They are built according to a perpendicular grid, arranged both longitudinally and transversally, which firmly connect the base of the various vertical load-bearing elements and repeats the organization of the elevation floors. They are generally cast on site.

The slab foundations are RC monolithic platforms, with variable thickness depending on the soil characteristics and the loads to be supported. They are mainly used for heavy buildings on soils with very low bearing capacity. Finally, the modern piling foundations are formed by prefabricated steel or concrete piles that are driven into the soil with a specific machinery, or by drilled concrete piles. However, these are extremely rare foundations for ordinary buildings, they are used in case of very underperforming soils and, also, for the construction of tall buildings, such as towers and skyscrapers, and for large infrastructures, such as dams, viaducts or for the containment of the ground in the presence of slopes.

As regards the foundation types, the prevailing categories, illustrated before, have been used for the study areas of the ADRISEISMIC project. They are identified according to the type of elevation structure and the characterizing type of soil.

• CONTINUOUS FOUNDATIONS:

D. 1.



Stepped foundation, engraved in the rock

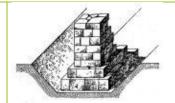
The constituent material is the shaped rocky terrain, where the elevation structures of the walls rest. It is generally used for rock-based soils, such as type A (rock outcrops or very rigid soils) and type B (soft rocks, coarse-grained or very consistent thick-grained soils) according to local standards. It is generally used for masonry structures, both in stone and bricks. Its depth is about $1-1.5\,\mathrm{m}$.

This construction system spread since the Medieval period, mainly in mountainous areas in the whole national territory.









Regular stone masonry foundation

The laying surface is prepared by levelling the soil, or by placing wooden trellis filled in with inert material at the bottom of the excavation. The foundation is made with regular stone blocks.

It is generally used for sufficiently compact clay soils (incompressible soil), such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is generally used for masonry structures, predominantly in stone. Its depth is about 1 - 1,5 m, a greater depth can be used for particular buildings.

This construction system spread since the Medieval period in areas where stone is mainly used as a building material for elevation structures.

D.3.



Irregular stone masonry foundation

This foundation is made by rubble stone masonry (pebbles, erratic and irregular stones) and the laying surface is prepared by levelling the soil. It is generally used for clay soils, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is generally used for masonry structures, both in stone and bricks. Its depth is about 1 - 1,5 m.

This construction system spread between the Medieval period up to 1800, in areas where bricks are mainly used as building material for the elevation structures and resistant stones are lacking.

D.4.



Stone rubble foundation with concrete binder

This foundation is made by rubble stone masonry (pebbles, erratic and irregular stones) and lean concrete as binder. The laying surface is prepared by levelling the soil.

It is generally used for clay soils, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is generally used for brick masonry structures. Its depth is about 1 m.

This construction system spread between the Medieval period up to 1800, in areas where bricks are mainly used as building material for the elevation structures and resistant stones are lacking.





D.5.



Brick masonry foundations

This foundation typology consists of bricks organized in a regular way, with slightly larger width than the thickness of the upper walls. It is generally used for clay soils, such as type C (deposits of medium-

thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is generally used for masonry structures, both in stone and bricks. Its depth is about 0.3 - 0.6 m. This construction system spread between the Medieval period up to

This construction system spread between the Medieval period up to 1900, in areas where bricks are mainly used as a building material for the elevation structures.

D.6.



Continuous reinforced concrete foundations (strip footings)

The constituent material is reinforced concrete for the whole foundation structure.

It consists of reinforced concrete strip footing under the masonry elevation structure. It can be used, in relation to the vertical loads, with any type of soil. Generally, it is widespread for medium-compressible terrain, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil, typically, is about $1-1,5\,\mathrm{m}$.

This construction system spread since 1920 in the whole Italian territory and it is still used today.

• PILE FOUNDATIONS:

D. 7.



Wooden piles

The foundation consists of wooden piles driven into the ground to increase its compactness. It is generally used for compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is generally used for brick masonry structures. The piles depth is about 3-5 m under the ground level. This construction system spread between the Medieval period up to 1800, mainly in lowland areas on the whole national territory.





D.8.



Reinforced concrete piles

They consist of prefabricated steel or concrete piles that are driven into the soil with a specific machinery, or drilled concrete piles.

They are generally used for compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. They are generally used for RC structures, with a depth normally up to 10 m under the ground level.

This construction system spread since 1970 in the whole national territory and is still used today for very heavy buildings.

• RECENT RC FOUNDATION:

D. 9.



Inverted beams foundation

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a grid of inverted RC beams under the RC frame structure. It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible soil, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil, typically, is about $1-1.5\,$ m.

This technique spread since 1910 in the whole Italian territory and it is still used today.

D. 10.



Isolated footing

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a grid of isolated plinths under the RC frame structure. It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible soil, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil, typically, is about 1,5-2 m.



D. 11.



D T2.1.2 – REPORT ON THE STATE OF THE ART IN ADRISEISMIC PARTNER COUNTRIES REGARDING TECHNIQUES OF INTERVENTIONS FOR REDUCING SEISMIC VULNERABILITY

This technique spread since 1910 in the whole Italian territory and it is still used today.

Slab foundation

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a monolithic RC platform and it is generally used with compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is used both for masonry and RC elevation structures. Its depth is related to the consistency of the soil, typically, is about 1 m.

It spread since 1910 in the whole Italian territory and it is still used today.

Main structural types

The last part of the spreadsheets, relating to the classification of the main structural types, will assume great relevance in relation to the subsequent developments of the project activities. It attempts to group the analysed construction techniques that can most frequently be found in the built heritage of the Country, referring to specific building types.

This approach will allow, in the next phase, to better target the seismic vulnerability assessment actions.

For the Italian masonry heritage, a simple but effective classification of load-bearing masonry buildings was proposed by Pagano (Pagano, 1969) and revived by Boscolo Bielo (Boscolo Bielo, 2012). These categories have very different mechanical and resistance behaviours:

- ENTIRE MASONRY BUILDINGS WITH VAULTS: they are historic construction types, with the structural organization (foundations, vertical elements, horizontal elements) composed of stone or brick elements, having different shapes and connections. Roofs are generally made up of wooden trusses, while horizontal elements work mainly for arch and / or vault principle. Generally, the openings are characterized by an upper arch or jack arch element. The construction concept, together with the changes and deteriorations suffered over the years, lead to a poor tensile strength and a behaviour for separate elements, comporting the possibility of local breakages following seismic events.
- BUILDINGS WITH VERTICAL MASONRY ELEMENTS AND HORIZONTAL ELEMENTS CONSISTING OF FLOORS WITH WOOD OR IRON ISOSTATIC BEAMS: they are historic construction types, with a onedirection load distribution for the floors and beams, generally, resting on the main walls. The assessment of the seismic behaviour of these structures must consider some variables, including: the different materials for the elevation and horizontal elements, the insertion of the beams in the loadbearing walls and their capacity to transfer the horizontal actions to the vertical elements, the stiffness of the floor, the presence of any openings in the load-bearing walls that can reduce their resistant capacity.





• BUILDINGS WITH VERTICAL MASONRY ELEMENTS AND FLOORS CONNECTED BY A RC PERIMETER BEAM: they are the most common type for recent masonry buildings. In this system, beams are a key structural element, in fact, if realized continuously on the floor perimeter, they have a hooping effect. Moreover, they can also guarantee: a greater connection between horizontal and vertical elements, a general distribution of any localized loads and a decrease in the inflection of the wall. The hollow brick floors have the function of creating a rigid connection that distributes the horizontal actions due to the earthquake on the vertical elements.

A recent classification for masonry and RC building structures was recently also proposed by Calderoni, Cordasco, Sandoli (Calderoni, Cordasco, Sandoli, 2016). This typological classification is based on the seismic behaviour detected on site or predictable through theoretical considerations. This study can be usefully adopted for large-scale vulnerability assessments, while for the single building valuation can only provide preliminary indications, useful as a basis for assessing its seismic capacity.

- ANCIENT BUILDINGS: they present not sufficiently reliable connections between the various components, which can cause the separation of the masonry in individual wall elements with the risk of their overturning during an earthquake. Detailed numerical analyses carried out by many authors (eg Degli Abbati et. al., 2015; Calderoni et al., 2016) have shown that this type of buildings has a very low seismic capacity.
- IMPROVED ANCIENT BUILDINGS: these are buildings subjected (in more or less recent periods) to improving interventions, consisting mainly in the inclusion of diffuse effective connections (ancient or modern type), which guarantee a box-like behaviour of the construction, with the substantial elimination of the possible activation of out-of-plane mechanisms. This leads to a significant increase in the seismic performance of the building, which is strictly related to the more efficient behaviour of the walls in their plane.
- MODERN BUILDINGS: this type groups masonry buildings of the Twentieth century in compliance with the rules for seismic areas. It is characterized by an excellent box-like behaviour, ensured by the effective connections between the vertical walls and the floors. The seismic vulnerability is therefore very low, as it is related to the resistance of the walls against in-plane actions. It is also favoured by a significant rigidity in the horizontal plane of the floor. In general, the seismic analyses carried out on buildings of this type have shown significant accelerations response before collapse.

According to this classification, two other categories, the SEMI-MODERN BUILDINGS and the MODERN NON-STANDARD BUILDINGS, constitute variations of the previous types. They are connected to the emanation of a seismic norm of 1937, which was not valid for the whole national territory.

For RC buildings, the main categories are identified starting from the Italian law on the R.D. 11/16/1939 n.2229:

- BUILDINGS BUILT BEFORE 1939: this first type groups buildings with a structure designed for vertical loads only, consisting of perimeter and internal frames essentially arranged in one direction. The beams are commonly emerging, while the infill panels are always of the heavy type (solid masonry), well embedded in the frames. This characteristic implies a considerable stiffness in the building.
- BUILDINGS REALIZED BETWEEN 1939 AND 1970: from a structural point of view, this type of buildings is designed to support only vertical loads. Therefore, its approach is very similar to the previous one. However, the demand for more architectural flexibility leads to a greater use of thick beams in the internal frames. Furthermore, the improvement of the mechanical characteristics of concrete allowed





an increase in the number of floors, rather than the reduction of the cross sections of the pillars. Therefore, these buildings are generally more deformable than the previous ones. From the mid-1960s, the use of light perimeter walls became common; they were made of hollow bricks with an interposed air chamber.

- BUILDINGS REALIZED BETWEEN 1971 AND THE ENTRY INTO FORCE OF THE SEISMIC RULES: the year 1971 represents a turning point, as Law 1086 of 5/11/1971 was issued. This law reorganizes reinforced concrete and steel constructions from a technical-administrative point of view. In particular, it established that all structural projects had to be deposited at the Offices of the Civil Engineers. On one side, the buildings themselves are not very dissimilar from those prior to 1971, as they were designed to essentially support vertical loads only. However, the use of thick beams is more widespread, the infills are of a light type and irregularities increase, both in plan and in elevation. Relevant differences can be found in the adopted materials, affecting the building's seismic capacity. In particular, the steel bars used are exclusively those with improved adhesion, also characterized by greater tensile strength than in the past. In addition, the concrete usually has better mechanical characteristics.
- BUILDINGS REALIZED AFTER THE ENTRY INTO FORCE OF THE SEISMIC RULES: for this type, the seismic
 capacity can actually be considered corresponding to the level of seismic acceleration used in the
 design. All these constructions have been designed using the old generation standards, where the
 horizontal actions were conventionally evaluated with coefficients applied to the masses, depending
 on the seismic zone in force at the time of construction.

The classification of the main structural type, above presented, is taken as a starting point for the ADRISEISMIC project:

MASONRY BUILDINGS:

Definition	Buildings with vertical structures made entirely in masonry (using
	bricks or stone depending on the local area) and with vaulted or flat
	floors (with wooden or iron beams), not effectively connected to the
	walls and without widespread tie rods.
Period of construction	Before entry into force of the specific anti-seismic technical standards
	for each area.
Vertical structures	In the Apennine areas or in areas characterized by the presence of
	hard rocks: irregular or semi-regular stone masonry, with lime mortar
	(A.1, A.2, A.3 types).
	In the Apennine areas or those characterized by the presence of soft
	rocks (tuff, sandstone): masonry of predominantly regular soft stone
	with lime mortar or sometimes pozzolanic (A.5, A.7, A.8 types).
	In the lowland areas, characterized by the presence of clay (north-
	central Italy): regular masonry in solid bricks and lime mortar (A.4, A.6,
	A.9 types).
	The foundations are continuous or placed on wooden piles (D.1, D.2)
	D.3, D.4, D.5, D.7 types).





	Horizontal structures	Vaults of any type double or simple surveture (C.E. C.6 types)
	Horizontal structures	Vaults of any type, double or simple curvature (C.5, C.6 types). Floors with wooden beams, without stiffening in the horizontal plane, and without specific connections with the walls (C.1, C.2 types). Floors with iron beams, without stiffening in the horizontal plane, and without specific connections with the walls (C.3, C.4 types).
2	ANCIENT MASONRY BUILD	INGS WITH ANTI-SEISMIC PROTECTION
	Definition	Buildings with vertical structures made entirely in masonry (using bricks or stone depending on the local area) and with vaulted or flat floors (with wooden or iron beams) not effectively connected to the walls but with widespread tie rods.
	Period of construction	Before entry into force of the specific anti-seismic technical standards for each area, which have been reinforced with tie rods as a result of failures or seismic events of the past
	Vertical structures	In the Apennine areas or areas characterized by the presence of hard rocks: irregular or semi-regular stone masonry, with lime mortar (A.1, A.2, A.3 types).
		In the Apennine areas or those characterized by the presence of soft rocks (tuff, sandstone): masonry of predominantly regular soft stone, with lime mortar or sometimes pozzolanic (A.5, A.7, A.8 types). In the lowland areas, characterized by the presence of clay (north-central Italy): regular masonry in solid bricks and lime mortar (A.4, A.6, A.9 types).
		The foundations are continuous or placed on wooden piles (D.1, D.2, D.3, D.4, D.5, D.7 types).
	Horizontal structures	Vaults of any type, double or simple curvature (C.5, C.6 types). Floors with wooden beams, without stiffening in the horizontal plane, and without specific connections with the walls (C.1, C.2 types). Floors with iron beams, without stiffening in the horizontal plane, and without specific connections with the walls (C.3, C.4 types).
	Tie rods	Round or squared iron elements (steel if more recent), anchored at the ends with different shaped anchor-plate, depending on the time of the reinforcement intervention. Wooden or iron beams are appropriately anchored to the walls, with different types of devices.
3	PRE-MODERN MASONRY B	UILDINGS
	Definition	Buildings with vertical masonry walls and flat floors not effectively connected to the walls and without tie beams at any floor
	Period of construction	After 1915
	Vertical structures	In the Apennine areas, or characterized by the presence of hard rocks: irregular or semi-regular listed stone masonry, with lime and cement mortar or cement mortar (A.1, A.2, A.3 types).
	I	





		5 5 1 6 5
		In areas characterized by the presence of soft rocks (tuff, sandstones):
		masonry of predominantly regular soft stone, with lime and cement
		mortar or cement mortar (A.5, A.7, A.8 types).
		In the lowland areas characterized by the presence of clay (north-
		central Italy): regular masonry in solid bricks and lime and cement
		mortar or cement mortar (A.4, A.6, A.9 types).
		Everywhere (generally in recent constructions): regular masonry of
		brick or concrete blocks, with lime and cement mortar or cement
		mortar (A.10, A.11, A.12, A.13 types).
		The foundations are continuous or placed on wooden piles (D.1, D.2,
		D.3, D.4, D.5, D.6, D.7 types).
	Horizontal structures	Hollow bricks floors, usually semi-prefabricated and without upper
		reinforced slab, with the ribs simply resting on the walls without tie
		beams (C.7, C.8, C.9 types).
		Floors with steel beams and brick tiles or hollow bricks, devoid of an
		upper reinforced slab. The steel beams simply resting on the walls
		without tie beams (C.3, C.4 types).
4	MODERN MASONRY BUIL	
	Definition	Buildings with vertical masonry walls interrupted by floors with
		reinforced concrete tie beam on each level
	Period of construction	After 1930
	Vertical structures	In the Apennine areas or areas characterized by the presence of hard
		rocks: irregular or semi-regular stone masonry, with lime mortar (A.1,
		A.2, A.3 types).
		In the Apennine areas or those characterized by the presence of soft
		rocks (tuff, sandstone): masonry of predominantly regular soft stone,
		with lime mortar or sometimes pozzolanic (A.5, A.7, A.8 types).
		In the lowland areas, characterized by the presence of clay (north-
		central Italy): regular masonry in solid bricks and lime mortar (A.4, A.6,
		A.9 types).
		The foundations are continuous in RC or are made of a RC slab (D.b.
		The foundations are continuous in RC or are made of a RC slab (D.6, D.11 types).
	Horizontal structures	D.11 types).
	Horizontal structures	D.11 types). Hollow bricks floors, cast on site or semi-prefabricated, with or
	Horizontal structures	D.11 types). Hollow bricks floors, cast on site or semi-prefabricated, with or without upper reinforced slab (C.7, C.8, C.9 types).
	Horizontal structures	D.11 types). Hollow bricks floors, cast on site or semi-prefabricated, with or without upper reinforced slab (C.7, C.8, C.9 types). Floors made with steel beams and brick tiles or hollow bricks, with the
	Horizontal structures	D.11 types). Hollow bricks floors, cast on site or semi-prefabricated, with or without upper reinforced slab (C.7, C.8, C.9 types).





• RC BUILDINGS:

5	PRE-CODE REINFORCED C	ONCRETE BUILDINGS
	Definition	RC structure designed to support vertical loads only, with perimeter and internal frames in one direction with emerging beams, rarely thick-beams. The infill walls are made with heavy elements (solid masonry).
	Period of construction	1910 - 1950
Vertical structures		The pillars dimensions depend on vertical loads, ranging from a minimum of 25x25 cm (even 20x20 in older buildings) to a maximum variable according to the number of floors (B.1, B.4 type). The foundations are direct isolated plinths or piles, if there are foundation beams, are in one direction only (D.9, D.10 type).
	Horizontal structures	The beams have dimensions dependent only on vertical loads and are equal for all floors.
		The floors are cast on site, or semi-prefabricated, without an upper reinforced slab (C.7, C.8, C.9 types).
6	RECENT REINFORCED CON	
	Definition	RC structure designed to support vertical loads only, with perimeter frames made of emerging beams and internal frames oriented in one direction with beams in the thickness of the floor. The infill walls can be heavy (almost always up to the mid-60s) or light type (generally with double layer from 1970 onwards).
	Period of construction	1950 - 2000
	Vertical structures	The pillars dimensions depend on vertical loads, ranging from a minimum of 25x25 cm (even 20x20 in older buildings) to a maximum variable according to the number of floors (B.2 type). The foundations are direct isolated plinths or piles; if there are foundation beams, they are in one direction only (D.8, D.9, D.10, D.11 type).
	Horizontal structures	The beams have dimensions dependent only on vertical loads and are equal for all floors, both for emerging beams and beams in the thickness of the floor. The floors are cast on site, or semi-prefabricated, without an upper reinforced slab until the 1960's (C.7, C.8, C.9 types).
7	MODERN REINFORCED CO	DNCRETE BUILDINGS
	Definition	Buildings designed according to seismic standards, with frames in both directions (with emerging beams and / or beams in the thickness of the floor, especially inside), always closed by light infills
	Period of construction	2000 - today





Vertical structures	Pillars are larger than in older types of buildings, up to the top floor,
	and generally rectangular. Presence of RC walls (B.2, B.3,B.5 type).
	Foundations with direct plinths or placed on piles connected in both
	directions, alternatively, foundation beams in the two directions or
	direct continuous foundation (D.8, D.9, D.10, D.11 type).
Horizontal structures	Emerging beams in the perimeter frames, larger than in older types of
	buildings and variable on the various floors. Those made in the
	thickness of the floor are often very wide.
	Hollow bricks floors cast on site, or semi-prefabricated, always with
	reinforced upper slab (C.7, C.8, C.9 types).

4.2. Croatia – PP3 (Grad Kaštela)

Located in southern Europe, Croatia belongs to the area of high seismic activity of the Mediterranean-trans-Asian. It is therefore among the European countries most subject to earthquakes. The regions most affected by seismic risk include the coastal and the north-western portions of the country.

These earthquake-prone regions cover about 30% of Croatia's land area and are characterized both by a relatively dense population and by the presence of large urban centres. The urban areas of Zagreb, Split, Dubrovnik and Rijeka have around 60% of the country's whole population and a particular social-economic importance.

Croatia is cyclically affected by strong earthquakes. In particular, the devastating earthquakes occurred in the 1960s and 1970s led the federal government to adopt a new generation of specific codes for the construction, targeted to seismically active regions. In addition, significant financial resources were invested in research for seismic risk reduction, such as: seismic hazard studies, seismic vulnerability analysis, and improvement of seismic design and construction practices.

Despite a long history of earthquake engineering research and development (the beginning can be dated back to the second half of the 19th century), the seismic assessment, both of exposure and damage to buildings, is a fairly new concept in Croatia (Pavic´, Hadzima-Nyarko, Bulajic´, Jurkovic´, 2020).

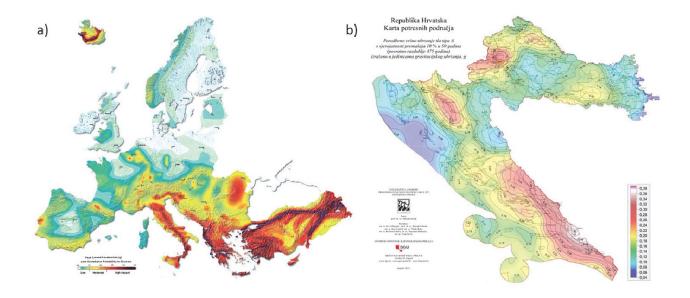


Figure 4 – Expected peak ground acceleration (PGA) on bedrock with probability of exceedance of 10 % in 50 years (return period of 1 in 475 years) for: a) Europe, and b) Croatia (Novak, Atalic, Uroš, Prevolnik, Nastev 2019)





The historical context of the Country, including the derivation of a significant part of it from the former Yugoslavia, must be considered to fully understand the characteristics of the Croatian built heritage. Buildings were designed according to precise concepts and codes that unite several European countries. As a result, many of them are still a large part of the current building stock of the Country. It is estimated that around one third of all residential units in Croatia were built before the introduction of earthquake regulations (Novak, Atalic, Uroš, Prevolnik, Nastev 2019).

Masonry buildings are quite common and make up a large percentage of the existing built heritage, but during the Twentieth century a reversal trend has occurred: reinforced concrete became the preferred material for buildings.

The creation of a viable seismic risk model at an urban or regional scale, in Croatia, has not been yet produced. At present, building information that could be used in standard seismic risk assessment studies is very limited. The last census conducted in 2011 provided certain data (such as the date of construction, occupancy category, number of dwellings, and number of people per dwelling). However, other useful information for a more comprehensive description of the building, e.g., construction material, structural type, number of storeys, etc., are not available.

The ongoing Horizon 2020 SERA project focuses on the improvement of the existing exposure models in Europe. In the scope of this project, the exposure model of Croatia, consisting of information on residential and commercial, has been updated. In addition, four main residential buildings typologies have been identified: CR - reinforced concrete dual wall-frame (estimated about ~ 1 % of the total building count), CR - reinforced concrete infilled frame systems (~23 %), MUR - unreinforced masonry wall systems (~ 45 %) and MCF - confined masonry wall systems (~31 %).

Furthermore, some individual initiatives for detailed exposure models have already started. Adriseismic project could find useful information, about the current Croatian situation in these activities.

Preliminary steps towards a standard building inventory database for the City of Zagreb are implemented since 2013, undertaken within the disaster risk assessments and earthquake risk reduction studies, conducted in collaboration between the Faculty of Civil Engineering and the Office for Emergency Management of Zagreb. As a first step, residential units were categorized using the information from the 2011 census. The division was conducted by eras of construction; each building was associated with the reference standard of the period. Further efforts were subsequently undertaken in collaboration with the Faculty of Architecture; the aim was to divide the city territory into areas characterized by similar building types (e.g., monolithic RC structures, prefabricated RC structures, masonry buildings with RC floors, masonry buildings with timber floors, etc.) and similar period of construction.

Summarizing the phases of introduction of the national seismic legislation, we can highlight how there was no standard valid before 1945. Between 1946 and 1964, a "Temporary Technical Code for building loads" was introduced, but the first seismic standard dates back to 1965, "Ordinance on Temporary Technical Regulations for Construction in Seismic Areas", which remained in force until 1981. The following year (1982) the "Ordinance on Technical Standards for Construction of Buildings in Seismic Areas" was issued, and it was valid until the beginning of the transition period towards the entry into force of the Eurocode 8, definitively acquired in 2013.

The results of the Zagreb mapping, already mentioned, showed that 38% of the analysed heritage was built in the absence of an anti-seismic design standard (i.e. before 1964). Constructions were mostly masonry buildings with wooden floors and without confining elements; RC floors were introduced since 1920. Other common factor of these buildings are: aging of materials, suffered events through history (earthquakes, fires, etc.), insufficient initial resistance, exceeded design service life of 50 years, poor maintenance, particularly





endangered cultural heritage, poor lateral resistance, poor construction quality, poor structural details, questionable design.

The 53% of the heritage was instead built with temporary seismic standards or first-generation seismic standards (in the period 1965 - 1998). These are masonry buildings with horizontal and vertical confining elements, and RC residential buildings. Their main vulnerabilities have been recognized in: design for low seismic loads, poor quality of materials, poor details, illegal construction, buildings adaptations, improper upgrading and reconstruction.

Certainly, the results of this survey on the city of Zagreb cannot be taken as a basis for the study of the whole territory, but we can certainly acquire the regulatory variations, and recognize some trends. First of all, most residential buildings were built before the introduction of the seismic codes. In particular, those built before 1964 were not explicitly designed to sustain earthquake. In subsequent years, depending on the location of the structure, design seismic loads were several times lower than those prescribed by current standards. In 2013, Eurocode 8 was officially introduced; it is assumed that the newly built structures, from that moment, will satisfy seismic demands related to different limit states. But the number of buildings respecting the Eurocode 8 is very limited at the moment.

Another interesting dating of the built heritage in Croatia is available in a study of the 2018 (Kalman Šipoš, Hadzima-Nyarko, 2018). The authors highlight how the construction age parameter for buildings allows to capture the conditions of design standards as well as the requirements of the building codes. The classification was made by six groups, according to associated seismic regulation and type of construction. The results show that the most of the buildings were built in 1945-1980 (30% between 1946 and 1970, and 23% between 1971 and 1980).

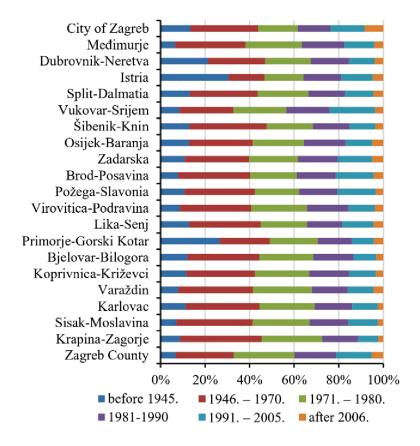


Figure 5 – Distribution of buildings by age in Croatia (Kalman Šipoš, Hadzima-Nyarko, 2018)





More recent and detailed information on the characteristics of the national building stock can be obtained in a 2020 study (Pavic', Hadzima-Nyarko, Bulajic', Jurkovic', 2020).

Seven characteristic historical periods are listed. The classification is made considering, for each time frame, the construction materials and techniques:

- The period prior to 1940: characterized by buildings made with traditional techniques and materials, such as unreinforced masonry buildings. Their wall thickness was usually 25 or 38 or 51 cm for bricks and 30–50 cm for stones. Floor structures were generally made with wood beams, or, at the end of this period, with concrete elements (ribbed concrete floors).
- Construction period from 1941 until 1970: in addition to traditional techniques and materials, new ones started to be used, such as reinforced concrete that permitted the realization of structures thinner and lightweight characterized by large glazed frames (single glazed).
- Construction period from 1971 until 1980: reinforced concrete structures became thinner and lighter. Walls were made with minimum structural thicknesses of 16 and 18 cm.
- Construction period from 1981 until 1987: all available materials at the time on the market were used for construction.
- Construction period from 1988 until 2005: masonry, RC structures, steel, and laminated wooden structures.
- Construction period from 2006 until 2009: the load-bearing structure of the buildings was mostly reinforced concrete.
- Construction period from 2010 until today: all contemporary materials and construction techniques are used.

A study of the 2011 census, extended to the whole national territory (Croatian Bureau of Statistics, 2013; (Pavić, Hadzima-Nyarko, Bulajić, 2020), led to a more precise dating of the existing heritage. In particular, compared to the total number of dwellings, those built before 1964 are approximately 42%, and those built between 1965 and 1998 are approximately 47%.

The characteristics of building structures in the region, as well as the construction practices, may change over time, but some of the most important stay the same for each period, due to the similarity of the materials, construction techniques, and quality of construction. E.g., until 1920, masonry buildings had wooden floor structures. These constructions, built in most cases between 1860 and 1920, are currently part of the old town centres in Croatia and are not designed to deal with severe horizontal ground motions (e.g., earthquakes). The first semi-prefabricated RC floors were introduced after 1930, monolithic RC floors after 1964. Only after the earthquake in Skopje in 1963, masonry buildings were built systematically with horizontal tie-beams and with vertical tie-columns, in order to obtain confined masonry.

Load-bearing systems in reinforced concrete structures (RC frames and RC shear walls) were built with respect to the provisions of the seismic regulations introduced in 1964 (i.e., after the 1963 Skopje earthquake) and in 1981 (i.e., after the 1979 Montenegro earthquake).





Age Distribution	before 1948	1948–1964	1964–1981	1981–2005	2005–2012	2010–Today
Seismic regulation (design standards)	-	-	1st earthquake design regulation ¹	Regulation 1981 [18]	Pre-standards	Eurocode 8 [22]
The common type of construction	Stone and brick masonry buildings with wooden floors	Brick masonry with reinforced concrete floors	Masonry with RC floors (houses), confined masonry (residential buildings), and pre-code RC frames	Reinforced concrete buildings, confined masonry buildings		

1—after the 1963 Skopje earthquake.

Figure 6 – Classification of dwellings by age of construction, common type and seismic code in Croatia (Pavić, Hadzima-Nyarko, Bulajić, 2020)

If we assume that the buildings belonging to the historical centres, which are the study areas of the ADRISEISMIC project, were built generally by the mid-twentieth century (and possibly have been subsequently modified), we find strong correspondences with the structural types already identified in the Italian territory. The tabulated data in terms of construction techniques for Italy have thus been updated for the Croatian territory; to facilitate the reading of the contents, only the changes that have been made are highlighted in the following tables.

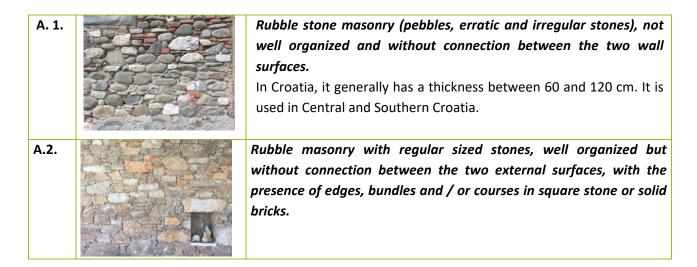
Vertical structure – Masonry types (Table A)

Comparing the results of the repertoire with the data mapped for the Italian territory, we note that there are only a few differences regarding masonry construction techniques. Basically, the types are all present on the Croatian territory as well, with the exception of tuff walls, probably due to the lack of tuff itself. The predominantly used stone is limestone.

We note that, for all historic walls, the thicknesses are generally greater, up to 120 cm. The irregular stone walls are mainly present in the Central-Southern area of the Country, while cut stones and bricks are mostly used in Continental Croatia.

We also note that solid brick masonry began to be used later, at the beginning of the 20th century, and there is no difference from modern masonry techniques (masonry in brick or cement blocks with cement mortar, Reinforced masonry with distributed or concentrated reinforcement).

IRREGULAR MASONRY:







In Croatia, it generally has a thickness between 40 and 120 cm. It spread between 1500 up to about 1950 in Central and Southern Croatia.

A.3.



Rubble masonry with bricks, well organized but without connection between the two external surfaces realized with bricks, with the presence of edges, bundles and / or courses in square stone or solid bricks.

In Croatia, it generally has a thickness between 40 and 120 cm. It is used in Continental Croatia.

A.4.



Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces realized with bricks and the internal core

In Croatia, it generally has a thickness between 30 and 120 cm. It spread between 1500 up to about 1950 in Continental Croatia.

ROUGH-HEWN MASONRY:

A. 5.



Cut stone with good bonding

In Croatia, it generally has a thickness between 40 and 100 cm. It is used in Continental Croatia.

A. 6.



Masonry in rammed earth blocks

In Croatia, it generally has a thickness between 14 and 60 cm. It spread between 1400 up to about 1950 in Continental Croatia.

REGULAR MASONRY:

A. 7.



Tuff masonry

This type of construction technique is not common in Croatia.





European Regional	Development Fund - Instrument for Pre-Accession II Fund	INTERVENTIONS FOR REDUCING SEISMIC VULNERABILITY
A.8.		Dressed rectangular (ashlar) stone masonry In Croatia, it generally has a thickness between 30 and 70 cm. It is used in Southern Croatia.
A.9.		Solid brick masonry with lime mortar In Croatia, it generally has a thickness between 12.5 and 70 cm. It spread between 1800 up to about 1950 in Continental Croatia.
A.10.		Solid brick masonry with cement mortar In Croatia, it generally has a thickness between 12.5 and 60 cm. It spread between 1900 up to about 1950 in the whole Croatian territory.
A.11.		Masonry in clay or concrete blocks with cement mortar No changes, all the data correspond.
A.12.		Reinforced masonry with distributed reinforcement In Croatia, it generally has a thickness between 16 and 45 cm. It is used Recent construction in the whole Croatian territory.
A.13.	b)	Confined masonry with concentrated reinforcement In Croatia, it generally has a thickness between 16 and 45 cm. It is used Recent construction in the whole Croatian territory.





Vertical Structures - Reinforced concrete types (Table B)

RC constructions spread early in Croatia. First examples date back at 1850 and it is particularly relevant to highlight how both the use of reinforced concrete walls and the use of prefabricated structures predates the Italian one by about 10 - 20 years. On a construction level, only the adoption of light infill panels with hollow brick masonry spread with a few years of delay.

B. 1.	Frame structures with reinforced concrete beams and columns, with infill walls constructed using solid bricks It spread between 1850 and 1950, mainly in urban contexts of large cities in Continental Croatia.
B.2.	Frame structures with reinforced concrete beams and pillars, with infill walls made with hollow blocks It spread between 1950 and 1960, mainly in the whole national territory and it is still used today.
B.3.	Reinforced concrete wall structures In Croatia, the thickness of the RC walls varies between 15 and 30 cm. It spread since 1930 in urban contexts of large cities, and it is still used today in the whole national territory.
B.4.	Unreinforced concrete wall structures No changes, all the data correspond.
B.5.	Prefabricated reinforced concrete structures It spread since 1940 and 1950, mainly in industrial areas and it is still used today.

Horizontal elements – Floors and roofs (Table C)

As for floors and roofs, compared to the Italian data, there is a perfect match for the floors with timber structure and planks, both as regards the maximum span and the period of construction. In addition, geographical data seem to indicate that this is the most used historical solution in Croatia.

The timber floor with brick tiles is used generally where the use of brick is widespread, i.e., where it has been adopted also for the walls, thanks to the presence of clay (Continental Croatia). The same goes for brick vaults. Alike, stone vaults are present where there are stone walls, i.e., in Southern Croatia.





The steel floors, both with vaults and with hollow bricks, are an uncommon solution.

RC floors cover bigger spans than those found for Italy, moreover, they began to be widely used about 20 years later.

• TIMBER FLOORS:

C. 1.



Single or double timber floors (beams and joists) with simple wooden planks

No changes, all the data correspond.

C.2.



Single or double timber floors (beams and joists) with brick tiles
It spread since 1500 and 1950, mainly in Continental Croatia and it is still used today.

IRON FLOORS:

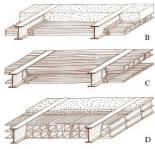
C. 3.



Floors with metal beams and vaults

It spread between 18500 and 1940 mainly in urban areas, but it is not a very common technique.

C.4.



Floors with metal beams and hollow bricks

It spread between 1850 and 1940, mainly in urban areas, but it is not a very common technique.





• VAULTED STRUCTURES:



Brick vaults

It spread between the Medieval period and 1900, mainly in Continental Croatia.

C.6.



Stone vaults

It spread between the Medieval period and 1950, mainly in Southern Croatia.

REINFORCED CONCRETE FLOORS:

C. 7.



Cast-in-situ reinforced concrete slab

In Croatia, it generally covers a maximum span up to 7 m for a simple slab and up to 12 m with RC ribs. It spread since 1930 mainly in urban areas and it is still used today.

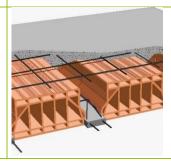
C.8.



Hollow clay block floor without reinforced concrete slab

It spread between 1930 and 1950, mainly in urban areas.

C.9.



Hollow clay block floor with reinforced concrete slab

In Croatia, it generally covers a maximum span up to 7 m. It spread since 1930 mainly in the whole national territory, both in urban and rural areas.





C.10.		Prefabricated reinforced concrete floor No changes, all the data correspond.
C.11.		Hollow brick floor with prefabricated joists It spread in urban areas in the whole Croatian territory.

Foundation system (Table D)

The solutions relating to the foundation structures find a perfect correspondence with those already listed, as happened with the elevation structures.

• CONTINUOUS FOUNDATIONS:

D. 1.	Stepped foundation, engraved in the rock No changes, all the data correspond.
D.2.	Regular stone masonry foundation No changes, all the data correspond.
D.3.	
D.3.	Irregular stone masonry foundation No changes, all the data correspond.
D.4.	Stone rubble foundation with concrete binder No changes, all the data correspond.





D.5.



Brick masonry foundations

No changes, all the data correspond.

D.6.



Continuous reinforced concrete foundations (strip footing)No changes, all the data correspond.

• PILE FOUNDATIONS:

D. 7.



Wooden piles

No changes, all the data correspond.

D.8.



Reinforced concrete piles

No changes, all the data correspond.

RECENT RC FOUNDATION:

D. 9.



Inverted beams foundation

No changes, all the data correspond.





D. 10.	Isolated footing No changes, all the data correspond.
D. 11.	Slab foundation No changes, all the data correspond.
D. 11.	

Main structural types

The previously cited bibliographic sources have already allowed understanding how, in general, the main structural types, listed in the case of the Italian territory, find an excellent correspondence with the Croatian ones. Further confirmations come from the consultation of other written and photographic documentation suggested by our PP (Živković, 2015).

MASONRY BUILDINGS:

1	ANCIENT MASONRY BUILDINGS
	It is widely used. This type of structure prevails in the city cores and represents a valuable
	architectural heritage of southern Croatia
2	ANCIENT MASONRY BUILDINGS WITH ANTI-SEISMIC PROTECTION
	It is present in Croatian territory.
3	PRE-MODERN MASONRY BUILDINGS
	It is present in Croatian territory.
4	MODERN MASONRY BUILDINGS
	It is present in Croatian territory.







RC BUILDINGS:

5	PRE-CODE REINFORCED CONCRETE BUILDINGS
	It is present in Croatian territory.
6	RECENT REINFORCED CONCRETE BUILDINGS
	It is widely used in Croatia.
7	MODERN REINFORCED CONCRETE BUILDINGS
	It is widely used in Croatia.

4.3. Albania – PP4 (Gjirokaster)

Albania is a Balkan country with high rate of seismicity and earthquake risk reduction is an important socioeconomic concern. The Country is situated in the Alpine-Mediterranean seismic belt and accommodates part of the deformation due to collision of the Adriatic microplate with the Eurasian plate.

The seismicity is characterized by an intensive micro-activity: many small earthquakes, rare medium-sized earthquakes, and very seldom, strong earthquakes. The Country has repeatedly been the site of historical earthquakes with considerable losses, even from moderate size events. This is commonly attributed to the poor quality of the construction in rural areas (Muço, 2012).

Albania has a deep and long history, spanning thousands of years and the occupation of several ancient world empires, such as Illyrian, Byzantine and Ottoman. The result is the many influences of which the local architecture is rich.

The Country has an important heritage but has suffered considerably from a long period of isolation (1950–1990), during which concerns for the slowdown of economic development and the increase of poverty among the community overshadowed heritage-related matters. More recently, there have been many positive achievements in raising awareness about the role of cultural heritage preservation, restoration, and rehabilitation (Dollani, 2016).

Traditional and historic masonry buildings constitute the majority of the current building stock in Albania, like in many other countries. These existing constructions were designed to resist only to vertical loads until the seismic code became in force in 1989.



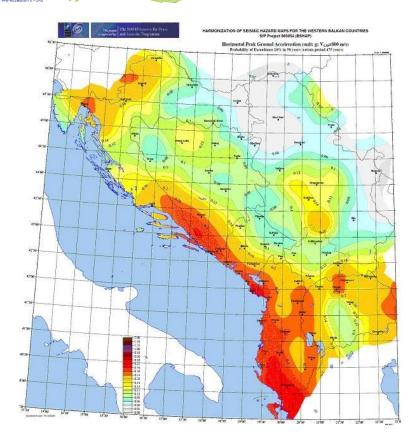


Figure 7 – Seismic hazard map for PGA on uniform firm rock site conditions at 10% probability of exceedance in 50 years (Causevic, 2019)

The city of Gjirokastra, a small city in southern Albania, has strong peculiarities compared to the national territory. The old town of Gjirokastra was included in the World Heritage List in 2005, as a rare example of a well-preserved Ottoman town. It has maintained its residential vernacular architecture, enabling the present generations to understand the diversity of urban societies in the Balkans and ways of life, which today almost disappeared. It is known as "the Stone City" and its most distinctive feature is the silvery-colored limestone, which gives the city its character.

Over the last thousand years it has been invaded by Ottoman Turks, Italians and Germans. This mixture of different cultures led to the development of the architecture that has been preserved to these days.

The town itself was built by big landowners. Its castle, Citadel, is one of the biggest in the Balkans, originated in the 13th century. With the decline of the Byzantine Empire, it became the residence of the very powerful Zenebeshi feudal clan.

Gjirokastra has some typical dwellings, a sort of tower-house, called Turkish Kule dating back to the 18th century. Some more recent and more elaborate ones are from of the 19th century.

The historic town of Gjirokastra is legally protected by the Decree on the Museum City (1961, 2007), the Law on Cultural Heritage (2003) and its status as a World Heritage Site (2005). While the Decree and the World Heritage status protect the whole area of the historic town, the Law on Cultural Heritage places, in addition, more than 600 individual buildings under protection as cultural monuments of 1st or 2nd category.

Precisely the monumental historical interest of the 1960s gave the city great importance during the communist regime, and thanks to it, many of the development plans that plagued many of the other Albanian cities were spared in its city centre. However, its designation as a Museum City did not mean the maintenance of the buildings of the old city. Despite the strict legal protection, in fact, many constructions are at great risk of neglect or subject to interventions that do not respect the integrity of the building (Dipasquale, 2020).





The city of Gjirokastra is both exposed to various natural hazards (such as earthquakes, landslides, fires and flooding) due to its geographical location, and to human induced risks. Among the latter, the abandonment of the site from the inhabitants, certainly contribute to the general degradation over time and to increase potential fire risks. This process began with the fall of the regime and the economy in 1992, when the municipal offices and merchants moved to the 'new towns' in the valley, followed by many skilled builders and craftsmen. During 1997 anti-government violence and fires destroyed much of the bazaar, houses and much documentation on historic buildings. Since then, many dwellings have been abandoned and are now owned by many heirs who do not reside in town.

From the early 2000s, "Gjirokastra Conservation and Development Organization" and "Cultural Heritage without Borders" work for the conservation and development of cultural heritage in the city, aiming to save degradating heritage and to rebuild interest and capacities.

The urban structure is strongly influenced by the orography of the Drino valley and its slopes, where the city was founded. Local stone is the material that characterizes the paving of streets, the walls and the roof coverings. Wood also is very common: timber was used for the masonry reinforcement elements, for the structures of the floors and for the roofs and the uppermost walls. The uppermost floors are characterized by timber structure (called *çatma*), a wooden lath and plaster, a row of windows and terraces are typical of Ottoman residential houses.

In December 2018, as part of the activities of the project "3D Past - Living & virtual visiting European World Heritage", funded by the European Program Creative Europe, Italian and Albanian students took part in a workshop in Gjirokastra, to understand the tangible and intangible components of the vernacular heritage of the city (Dipasquale, 2020).

The published data, relating to these activities, provide a knowledge base for construction solutions used in Gjirokastra. The urban density is relatively low and characterized by the presence of tower-houses and of building aggregates. The uniformity of construction materials (particularly, local stone), of the volumetric layouts and of the arrangement of public paths, create a cohesive, recognizable and unique historic centre. Some urban interventions, dated back to the socialist dictatorship, transformed some larger public spaces within the historical fabric, expanding the section of some streets, taking advantage of some changes in elevation and replacing a few historic buildings.

The buildings were indirectly connected to the streets through a gradual system of filters, consisting of courtyards, gardens and private or semi-public spaces. Traditional road paving is made with two different type of local stones, depending on the variety of solutions to overcome the problem of different slopes.

As reported by the results of the survey carried out for the project "3D Past - Living & virtual visiting European World Heritage", in all the observed buildings, bearing walls were made of local limestone hewn blocks. The larger stones were placed on the external profiles, while the internal interstices were filled with smaller stones and pebbles. Stone blocks large enough to occupy all, or almost all, the thickness of the wall, were used to connect the different surfaces together.

Elements were walled with lime and sand mortar. The mortar was generally more abundant in the external faces, while in the central core is almost absent. Horizontal timber ties, generally squared and made of oak or chestnut, were placed every 80-120 cm within the load bearing masonry. They were arranged along the wall direction, on both sides, and connected by transverse wooden pieces and a diagonal tie element was used at the corners. Typically, elements placed on the external side of the wall were protected by a stone course.

This system allowed to connect the different surfaces of the masonry and to create horizontal planes to lay the successive layers of stone blocks.





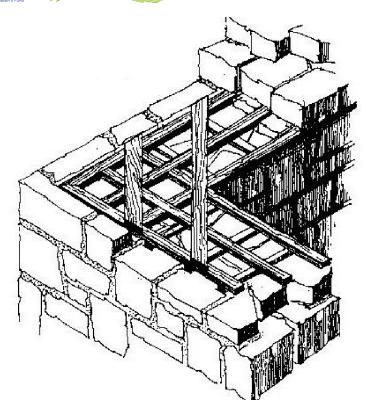


Figure 8 – Timber ties used to connect the different masonry layers (Merxhani, 2012)

Çatma is the building technique used for the walls of the upper floors, characterized by wide windows and reduced thickness. It consists of a structure of vertical posts and horizontal battens, where wooden boards were nailed. The filling of this frame was made of waste material and stones.

The first layer of covering was composed of a 2 cm thick straw-earth plaster. After the drying and the subsequent cracking of the plaster, a second 5 cm straightening coat of lime and wool, with a small amount of sand, was applied.

Barrel vaults were used to cover large spaces, such as entrances or tanks. They consist of an extremely fine and accurately dressed layer of stone blocks with joints, which were always walled with lime mortar.

When vaults were not made of exposed stone, but they were covered with a first layer of earthen mortar, then with another layer of lime and sand covering plaster.

The supporting structure of the roof was made of wooden beams, sometimes creating a rather complex hyperstatic three-dimensional configuration, where all elements cooperate to support the heavy stone covering (Merxhani, Pompejano, 2015). A system of ceiling joists, with size $14 \div 18 \times 15 \div 20$ cm, was connected to the edge beams through riveted joints. On the edge beams also the principal rafters who supported the ridge beam rested. Ridge beam and principal rafters were also supported by vertical posts (called *baballëk*), supported by the horizontal beams (Merxhani, Pompejano, 2015). The principal rafters can also be borne by radial timber elements, working as struts, that converges in the horizontal edge beams resting on a central wall or are placed at 90 degrees on the ceiling joists. The common rafters, placed at a narrow distance, have a cross section of $5 \div 12 \times 5 \div 12$ cm.





Wooden boards were fixed on them, at a distance of 5-8 cm from each other, on which the stone slabs are placed, without connections with mortar or metal hooks. The grey slate stone slabs of the roof were approximately 1.5 cm thick and can vary in size. The larger ones are generally used in the lower part of the roof, which had to be the most stable. Smaller elements are arranged in the upper part so as not to overload the structure and to reduce the thrust towards the lower layers. The eaves protrude for 50-60 cm and are supported by the rafters (called *testek*). These rafters are in turn supported by timber elements, connected to the wall at the height of the lower floor.

Brick is a material used in Gjirokastra only recently, probably imported from Western Europe. It is adopted for the construction of floors, combined with iron profiles.

Vertical structure – Masonry types (Table A)

Comparing the results of the repertoire with the data mapped for the Italian territory, we note only some similarities, due to two main reasons. First of all, the analysed territory relates only to the city of Gjirokastra; therefore, is very small if compared to the national surface. Since this is a restricted area, and protected from International codes, the construction characteristics are very homogeneous on its territory.

As already highlighted, most of the walls are made almost exclusively of stone, with the particularity of having the lime-based mortar only on the external surfaces and not in the core. This masonry system can be assimilated to dry stone walls, therefore with a high vulnerability due to the poor mutual connection between the elements.

In order to characterize these specific solutions, Albanian PP provided precise data.

• IRREGULAR MASONRY:

A. 1.



Dry tuff masonry (assimilated to rubble stone masonry not well organized and without connection between the two wall surfaces for its behaviour).

The constituent materials are tuff stones of irregular size (10 - 15 cm) arranged without mortar, simply disposed in layers of stone with non-uniform placement. This solution may present different composition in the thickness of the wall, varying between 20 and 40 cm.

It was mainly used for surrounding walls and it is documented between 1200 and 1800. It is used in the south-east, south-west and south of Albania.





• REGULAR MASONRY:

A. 7.





Wet tuff masonry (assimilated of tuff masonry for its behaviour)

The constituent material is tuff stones of regular size (10 - 15 cm) walled with clay mortar, placed on horizontal layers. This solution may present different composition in the thickness of the wall, varying between 30 and 40 cm for surrounding walls, and between 80 - 120 cm for outer walls.

It is documented between 1200 and 1800 for surrounding walls, and between 1300 - 1850 cm for outer walls. It is used in the south-east, south-west and south of Albania.

Vertical Structures - Reinforced concrete types (Table B)

No solution, for vertical RC structures, is documented for the city of Gjirojastra.

Horizontal elements – Floors and roofs (Table C)

The most used type of floor is the timber one, with simple and double arrangement, with wooden planking. This typology can cover considerable spans, up to 11 m.

TIMBER FLOORS:

C. 1.



Single or double timber floors (beams and joists) with simple wooden planks

The most common wood is pine.

No changes on constituent materials, static behaviour, connections and structural characteristics.

In Gjirokastra, it generally covers a maximum span up to 11 m. It spread between 1300 and 1850.

A similar solution is:

Double timber floors (beams and joists)

It consists of timber beams and joists, with the use of plunks above the double wooden beam structure. This typology is mainly found in the tower-like constructions.







It generally covers a maximum span of 4 m. It spread between 1300 and 1800 in Northern Albania and it is present also in some parts of Southern Albania too, such as Gjirokastra.

IRON FLOORS:

Iron floors are not common in Gjirokastra.

• VAULTED STRUCTURES:

Vaulted structures are not common in Gjirokastra.

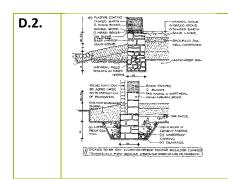
• REINFORCED CONCRETE FLOORS:

RC floors are not common in Gjirokastra.

Foundation system (Table D)

The foundations are made exclusively of stone masonry, following the material continuity with the construction solutions of the elevation.

• CONTINUOUS FOUNDATIONS:



Regular stone masonry foundation

Natural stone is the constituent material, together with mortar. Under the foundation, there ought to be a layer of lean concrete (min. 5 cm) or tamped sand.

Construction should start on firm, uniform strong subsoil. The minimum depth is 40 cm.

This foundation type was used between 1450 and 1800 in Northern and Southern Albania, such as in Gjirokastra.

Main structural types

The buildings belonging to the historical centre of Gjirokastra are exclusively masonry structures; therefore, RC construction types have not been classified.





MASONRY BUILDINGS:

1	ANCIENT MASONRY BUILDINGS It is widely used, this type of structure prevails in the city cores and represents a valuable
	architectural heritage of southern Albania.
2	ANCIENT MASONRY BUILDINGS WITH ANTI-SEISMIC PROTECTION
	It is present in Albanian territory.

4.4. Serbia – PP5 (RDA Backa)

Serbia is located in a region of moderate seismic activity, however its territory is close to regions of high seismic hazard which triggered major earthquakes in recent history, e.g. the 1979 Montenegro earthquake (ML 6.9) the 1977 Vrancea, Romania earthquake (M 7.2), and most recently the 2020 Petrinja, Croatia earthquake (M 6.4). In the last 100 years more than 10 earthquakes with magnitude 5.0 or higher occurred in Serbia. The most significant earthquake in the 20th century occurred in 1922, had magnitude 6.0 and epicenter near Lazarevac (approximately 60 km aerial distance from the capital Belgrade). More recently, the 2010 Kraljevo earthquake (M 5.4) caused 2 fatalities and more than \$100 million in damages, based on the World Bank's (WB) country risk profile for Serbia (WB 2017). Several other earthquakes affected rural areas of Serbia, such as the 1927 Rudnik earthquake (M 5.9), the 1980 Kopaonik earthquake (M 5.8), and the 1998 Mionica earthquake (M 5.5). The country risk profile reports that an infrequent but intense earthquake event (a 250-year return period) could result in nearly \$1 billion of capital losses in Serbia (about 3 % of the country's GDP in 2015 – estimated at \$36.4 billion).

Majority of heritage buildings in Serbia were constructed before any seismic design codes were in place. However, in line with the unified approach for all partner countries, the following 3 general periods can be distinguished based on the level/advancement of seismic design code provisions: 1) no-code period (1948-1963), when structures were designed for lateral loads according to the Provisional Technical Regulations (PTP) for Loading of Structures", Part 2, which were issued in 1948 but did not contain specific provisions related to seismic detailing of RC structures; 2) low-code period (1964 – 1981) characterized by the first comprehensive seismic design regulations, and 3) moderate-code period (1982 - present), which is characterized by application of a modern seismic code. The first comprehensive seismic design code in the SFRY (Serbia was a part of the SFRY from 1944-1991) was published in 1964 (Provisional Technical Regulations for Construction in Seismic Regions", Official Gazette of SFRY No. 39/64) and was prompted by the 1963 Skopje earthquake. Next version of the code (Provisional Regulations for Construction of Buildings in Seismic Regions", Official Gazette of SFRY No. 31/81) was issued in 1981 and it was the governing design code in Serbia until 2020. The level of advancement of the 1981 code was similar to other international codes at the time (Fajfar, 2018). Based on the "Regulations for Building Structures", Official Gazette of Republic of Serbia No. 89/2019, which were issued in 2019, the application of Eurocodes is mandatory for design, construction, and maintenance of building structures in Serbia. As a result, Eurocode 8 is to be used for seismic design and assessment/retrofit of buildings in Serbia. Current seismic hazard maps for Serbia are presented in Figure 9 (Seismological Survey of Serbia, 2018). It can be seen from Figure 9 a) that the maximum expected intensity according to the MCS scale is VIII, and that less than 50% of the Serbian territory falls in seismic zone VIII. The map in Figure 9 b)



shows that the maximum Peak Ground Acceleration (PGA) for design level earthquake with 10% probability of exceedance (475 years return period) is 0.25 g (Southern Serbia) and 0.2g (Central Serbia), while structures in other parts of Serbia need to designed for lower PGA values. Previous seismic hazard maps for Serbia were issued in 1950 (that map was incorporated in the 1964 seismic code), 1982, and 1990.

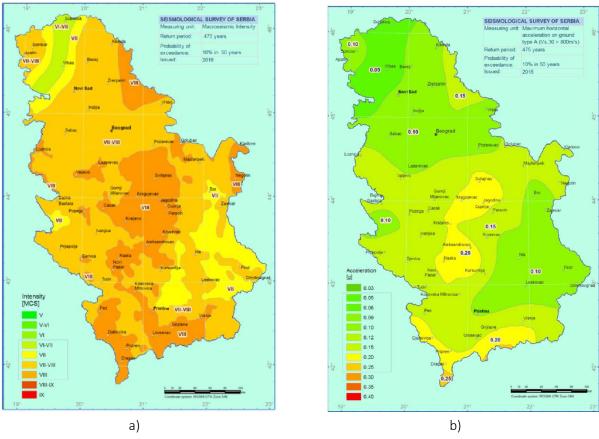


Figure 9 - Current seismic hazard maps for Serbia: a) seismic intensity maps (based on the MCS scale) and b) seismic hazard map based on the Peak Ground Acceleration (PGA) for design earthquake with 10% probability of exceedance in 50 years (475 year return period earthquake) (Seismological Survey of Serbia, 2018)

A design standard related to repair, strengthening and reconstruction of buildings affected by earthquakes was published in SFRY in 1985 (Official Gazette of SFRY No. 52/85), but it did not address seismic strengthening (retrofitting) of existing buildings for mitigating risk effects of future earthquakes.

Construction practice and architectural planning of Serbia's built heritage in different historic periods were influenced by the political, economic, and social context characteristic for specific period. The relevant historic periods are: i) the Ottoman Empire (from 1459 until 1815); ii) transition period during the Principality of Serbia (1816-1918); iii) the Kingdom of Yugoslavia (1919-1940); iv) World War II (1941-1945); v) post-war recovery, no seismic code (1946-1963); vi) construction boom, low seismic code (1964-1980); vii) reduced investments and construction activities, moderate seismic code (1981-1991), and viii) post-SFRY period (1992-present) characterized by reduced investments and lower level of regulation related to building construction compared to previous periods. During this period many existing buildings have been renovated; vertical extensions constructed atop the existing buildings in many cases significantly increase their seismic vulnerability.

Serbia and other Western Balkan countries were a part of the Ottoman Empire from the 15th to 19th century. Construction practice during that period was significantly influenced by the Turkish rulers. Massive earthen loadbearing wall structures and traditional buildings featuring a Turkish-style wooden frame with earthen or





brick masonry infill were widely used for construction of public and residential buildings. These were low-rise buildings (usually single-storeyed buildings in rural areas and up to 3-storey high in urban areas).

Within a century, from the Second Serbian Uprising in 1815 until the beginning of World War I (WWI) in 1914, the Principality of Serbia evolved from an authoritative to a democratic society. The transition period was characterized by the development of local facilities for manufacturing of building materials and artisan workshops which produced architectural and decorative elements. Several important public buildings, including hospitals, educational and cultural institutions were constructed during that period. In 1896 the first Building Act for the Town of Belgrade was issued and it spelled out provisions related to local design and construction practices. The Act limited the use of wooden structures with earthen infill in the city and prescribed the standard dimensions for clay bricks, which became the prevalent building material (Radivojević, Đukanović, and Roter-Blagojević, 2016).

During the period from 1918 to 1941, that is, beginning of the World War II (WWII), Serbia, Croatia, and Slovenia were a part of the Kingdom of Yugoslavia. During that period brick masonry was prevalent wall construction practice. Ribbed reinforced concrete floors were used for the construction of residential and public buildings, but wooden floors were also used for construction of single-family buildings. Jack arch system ("pruski svod") was also used. Sloped roofs were common, with wooden structure and clay tile covering. In urban areas adjacent buildings were joined in building blocks (buildings in the row), while individual buildings were prevalent in rural areas. During the WWII Serbia and other Western Balkan countries suffered a severe destruction. Many buildings were destroyed in bombing raids. It is expected that, if any, construction activities were undertaken only for military purposes.

After the WWII Serbia was a part of the Socialist Federal Republic of Yugoslavia (SFRY) from 1945 to 1991. The initial period (1945-1963) was characterized by rebuilding and recovery after the war devastation. There was a significant need for mass housing construction to accommodate the population needs. Majority of urban buildings from that period are medium-rise unreinforced masonry structures. Most buildings in larger cities were 4-6 storeys high, while low-rise buildings (up to 3-storey high) were prevalent in smaller towns and rural areas. Unreinforced masonry was the prevalent construction practice, and solid clay bricks were used in combination with cement, lime, sand mortar. The thickness of exterior walls was typically 38 cm. Reinforced concrete floor slabs were used in multi-storey buildings (mostly ribbed slabs). Large-scale use of reinforced concrete construction started in the 1950s, including the first applications of prefabricated concrete construction systems for housing construction (first application of the IMS system in 1957).

Period from 1964-1980 was characterized by a construction boom. Reinforced concrete technology was widely used both for prefabricated and cast-in-situ construction. Several proprietary prefabricated concrete systems were used for housing construction in urban areas. Cast-in-situ reinforced concrete buildings were mostly in the form of frames with masonry infills, however structural (shear) walls were provided in taller buildings. Buildings in urban areas were larger in size and were usually 4-7 storeys high, except for free-standing high-rise buildings (towers) which were usually taller than 10 storeys. Loadbearing masonry continued to be a prevalent form of construction for low-rise buildings. Masonry walls were reinforced with horizontal and vertical reinforced concrete elements (confined masonry). During that period solid clay bricks were slowly replaced by hollow (multi-perforated) masonry blocks (this transition started in the 1960s).

Construction practices in the period after 1981 are similar to the previous period, but the scale of construction activities was much smaller due to reduced investments. It should be noted that prefabricated concrete technologies were no longer practiced after the breakdown of SFRY in 1991. Due to the economic challenges and civil war in the 1990s there was a limited construction activity, both in the public and private sector. From 2000-present the scale of construction activities has somewhat increased compared to the previous period (1991-2000).





Since many existing heritage buildings in Serbian urban centres date back to the 19th century it is important to explain construction techniques characteristic for that period. Radivojević, Đukanović, and Roter-Blagojević (2016) presented an overview of construction practices in Serbia during that period, as illustrated in Figure 10. At the beginning of 19th century infilled timber frames were widely practiced in Serbia and other countries/regions within the Ottoman Empire. *Bondruk* is popular name for a Turkish-style timber frame system with an infill made of clay bricks (*ćerpič*) or thatch covered by mud plaster. Another type of timber-framed system (*čatmara*) had walls of woven brushwood infilled with mud. This traditional construction practice existed in Serbia for about 400 years and it was adopted by all sections of the society, ranging from poor peasants to wealthy merchants in Belgrade and other urban areas. *Bondruk* construction practice was affordable since timber was widely available at that time. The type of infill depended on the needs and financial constraints – ranging from low-cost materials (thatch and mud) to more expensive materials like clay bricks. Figure 11 shows examples of timber-framed construction in Serbia.

		per	riod of a	pplication	on [years]						L SI			
struc	tural elements of buildings	1800	1810	1820	1830	1840	1850	1860	1870	1880	0681	1896 Law	1900	1910	1920
	timber-framed (bondruk) structure														
vertical	combination of timber- framed structure and brick						E						I		
ver	brick masonry structure														
_	cast-iron columns													Ш	
	wooden beams														
le	brick vault											П			
horizontal	Prussian vault														
	iron traverses														
	reinforced concrete														= =

Figure 10 – Evolution of construction technologies for vertical and horizontal components of buildings in Serbia in the 19th and early 20th century (Radivojević, Đukanović, and Roter-Blagojević, 2016).





a) b)

Figure 11 – Examples of common building techniques in the 19th century Serbia: a) timber-frame infilled masonry in a residential building, Belgrade, and b) Cultural Monument Protection Institute, Belgrade (photo credit: S. Brzev)





As Serbians were fighting for the independence from the Ottoman rulers, an initiative to break away from the oriental traditions and adopt culture and traditions of Central Europe in all spheres of life, including architecture and construction practices, emerged during the so-called "transition period" (1830-1850). During that period, traditional timber-framed construction was still used, but brick masonry infills became thicker and more robust over time. Local artisans were used to timber construction practice and required training before they were able to build massive brick masonry walls which were characteristic for European buildings. A complete transition to brick masonry construction took place in second half of the 19th century. It was reported that a few brick manufacturing facilities were established around the 1880s (Đukanović, 2015).

European-style masonry buildings became prominent in the centre of Belgrade after 1870s, and they reflected the principles of architectural planning and design, as well as construction practices characteristic for Central Europe. Walls were constructed using clay bricks and lime mortar. Many buildings had a basement and floor slab in the form of jack arch system ("pruski svod"), while wooden floors were used at upper part of the building. These buildings had timber roofs and clay tile roofing. Unlike other European countries in the region, use of stone masonry in Serbia was limited to construction of monumental buildings, such as churches and town halls (Živaljević-Luxor, 2017).

The first reported application of reinforced concrete technology in Serbia was featured in the National Museum in Belgrade, which was originally constructed as the National Treasury in 1903 (Figure 12 a and b). Vertical structural elements are massive unreinforced masonry walls, but the floor system consisted of 10 cm thick reinforced concrete slab segments spanning between the iron beams (Stojanović, 2019). The building is one of landmark heritage structures in Belgrade and is located at the Republic Square in the historic centre of the city. Hotel "Moskva" (Moscow), constructed from 1905-1907, features the first major structural application of reinforced concrete in Serbia. It was constructed approximately 50 years after the invention of reinforced concrete technology in France. This five-storey building was one of the tallest buildings in the city at the time of construction (see Figure 12 c and d). It was originally called "Rossiya Palace" and the investor was a Russian insurance company "Russia". It represents one of the important examples of the Secession architectural style in Europe. It was designed by one of the top Serbian architects at the time, Jovan Ilkić, with the involvement of Russian architects and engineers. The details of construction are available in a city museum (Lopušina and Lopušina, 2008; Wikipedia). A massive concrete slab (2.2 m thick) was constructed at the foundation level, due to unfavorable soil conditions and underground water at the construction site. Reinforced concrete was used for the superstructure, both for the floor and wall construction (German system "Luitpold&Schnaider"). Brick masonry was also used for wall construction in this building.





a) b)









c) d)

Figure 12 – Early applications of reinforced concrete technology in Serbia: a) National Museum, Belgrade (around 1910); b) National Museum, Belgrade (2020); c) Hotel "Moskva", Belgrade (around 1920), and d) Hotel "Moskva", Belgrade (2020) (Source: Wikipedia.org)

According to the 2011 Census of Serbia (SORS, 2011), low-rise single family buildings, mostly located in rural and suburban areas, constitute major fraction of the residential building stock (Jovanović-Popović et al. 2013). A comprehensive overview of construction features of Serbian residential buildings is an outcome of the research project TABULA which was conducted at the Faculty of Architecture, University of Belgrade (Jovanović-Popović et al. 2013). The aim was to create an unprecedented, comprehensive classification of single- and multi-family residential buildings. The buildings were classified into 39 types based on the construction period (before 1919; 1919 -1945; 1946 - 1960; 1961 - 1970; 1971 – 1980; 1981 - 1990; 1991 - 2011) and the architectural form, i.e. free-standing single family houses, houses in a row, free-standing multifamily housing, lamela (housing block), multi-family housing in a row, and high-rise buildings (towers), see Figure 13.

In Serbia, most of the residential construction took place from 1945 (end of the World War II) until 1990, when over 70% of all existing dwellings had been built (Jovanović-Popović et al. 2013; Novikova, 2015). Between 1971 and 1990, there was an upswing in the construction sector in terms of both single-family houses and apartment blocks built using industrialised technology. It is estimated that around 41% of all dwellings were constructed during that period. Only 15 % of all dwellings were constructed before 1945. Note that in some regions of Serbia, for example Vojvodina, buildings of pre-1945 vintage constitute more significant fraction of the residential building stock compared to other regions (about 24 %). A breakdown of the residential building stock in Serbia based on the construction period is presented in Figure 14.

Public buildings, including those used for service sector purposes, constitutes a small fraction of the overall building stock in Serbia: only 17% of the total floor area of the building stock (estimated at 197 mM²). ENTRANZE project included nine European countries and provided an overview of the building stock and the corresponding energy demands in the participating countries, including Serbia (Mariottini, 2014). A breakdown of the service sector facilities based on the built-up floor area is presented in Figure 15. It can be seen that educational institutions account for 32% of the overall floor area for service sector facilities in Serbia; this is followed by wholesale and retail trade facilities (21%) and offices (18%).





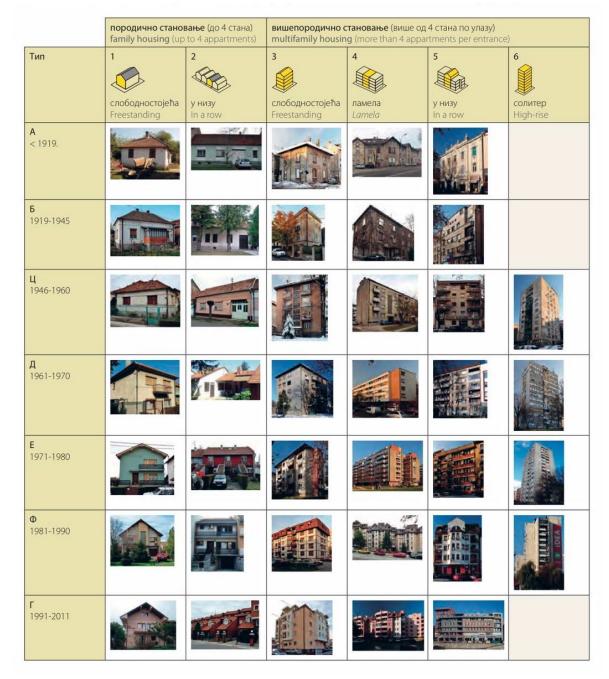


Figure 13 – Serbian residential building classification according to the TABULA project (Jovanović-Popović et al. 2013)

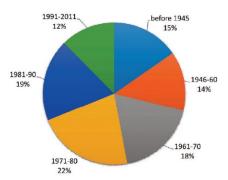


Figure 14 – Classification of the dwellings in Serbia based on the construction period using the 2011 Census of Serbia data (Novikova, 2015)





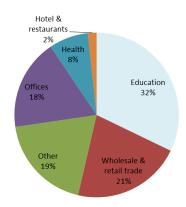


Figure 15 - Classification of service sectors in Serbia by built-up floor area (Mariottini, 2014)

The most common form of residential construction in Serbia is a free-standing single-family house, which accounts for almost 95% of the residential building stock. Houses in a row are common in some regions, e.g. Vojvodina. Masonry is the prevalent construction technology for residential buildings in Serbia. Until the 1960s solid clay bricks were the most common masonry unit in Serbia but were later on replaced by hollow clay blocks. Typical older unreinforced brick masonry walls had 38 cm thickness, while a smaller wall thickness is characteristic for modern masonry buildings constructed with hollow clay blocks (25 cm for exterior walls and 19 cm for interior walls). It should be noted that in some regions of Serbia, such as Vojvodina, many older existing buildings (about 31% of the overall building stock) were constructed using rammed earth or adobe (unburnt clay bricks).

The territory of Serbia can be divided into 6 geographic regions: Western Serbia, Central Serbia, Southeast Serbia, East Serbia, Vojvodina, and Belgrade. It is important to acknowledge that natural aspects of the regions, e.g. climate, topography, and demography, have significantly influenced the construction practice in Serbia, at least until the beginning of the period of mass housing construction after the WWII. Since then, unification of construction technologies and of applied materials has been omnipresent. An overview of regional characteristics of building construction in Serbia was presented by Jovanović-Popović et al. (2014).

Specific details of construction techniques characteristic for Serbia are presented in the following tables. Refer to the tabulated information presented for Italy in the specific section for a detailed description of vertical and horizontal structural elements and foundations.

Vertical structure – Masonry types (Table A)

Comparing the results of the repertoire with the mapped data for the Italian territory, project partner from Serbia noted specific differences regarding the masonry construction techniques, which are summarized in the following tables. There are no differences between Italian and Serbian construction practices related to constituent materials, installation of the elements, cross-section, connections, thickness, structural characteristics, period of construction.

Construction materials and techniques found in Serbian heritage buildings are summarized in Figure 10. Clay brick masonry is prevalent in majority of heritage buildings and also general construction practice in Serbia. Stone masonry is not common in Serbia and is limited to heritage structures with a monumental character. There is no relevant difference between Italy and Serbia in terms of modern masonry construction techniques (masonry in brick or concrete blocks with cement mortar; confined masonry).





• IRREGULAR MASONRY:

A. 1.		Rubble stone masonry (pebbles, erratic and irregular stones), not well organized and without connection between the two wall surfaces. This type of construction is not common in Serbia, and its application is limited to monumental heritage structures such as churches, fortresses and monasteries.
A.2.		Rubble masonry with regular sized stones, well organized but without connection between the two external surfaces, with the presence of edges, bundles and / or courses in square stone or solid bricks. This type of construction is not common in Serbia, and its application is limited to monumental heritage structures such as churches, fortresses and monasteries.
A.3.		Rubble masonry with bricks, well organized but without connection between the two external surfaces realized with bricks, with the presence of edges, bundles and / or courses in square stone or solid bricks. This type of construction is not common in Serbia, and its application is limited to monumental heritage structures such as churches, fortresses and monasteries.
A.4.	The same of the sa	Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces realized with bricks and the internal core This type of construction is not present in Serbia.

• ROUGH-HEWN MASONRY:

A. 5.	帝国王的 图	Cut stone with good bonding
		This type of construction is not common in Serbia, and its
		application is limited to monumental heritage structures such as
		churches, fortresses and monasteries.





A. 6.



Photo: Preradović

Rammed earth construction

This type of construction was practiced in Serbia from the medieval period until about 1920 (end of World War I). The houses constructed using rammed earth technology are known in Serbia as "nabijače" (Preradović 2016).

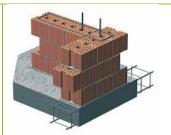
• REGULAR MASONRY:

A. 7.	位于14°30	Tuff masonry
		This type of construction is not present in Serbia because tuff
		stone is not locally available.
A.8.		Dressed rectangular (ashlar) stone masonry
		This type of construction was practiced in Serbia from 1800s until 1930s for buildings of special importance.
A.9.		Solid brick masonry with lime mortar
		This type of construction was practiced In Serbia between 1880 until about 1930, mainly in the urban centres.
A.10.		Solid brick masonry with cement mortar
		The use of cement mortar in brick masonry construction in Serbia started in the 1930s, initially in the urban centres, and it is still used today.
A.11.		Masonry in clay or concrete blocks with cement mortar
,		The use of this construction practice started in Serbia in the 1960s
		and it is still used today. Note that multi-perforated clay blocks are more common in Serbia than concrete blocks. In Serbia there
		is a practice of filling both bed and head mortar joints.





A.12.



Reinforced masonry with distributed reinforcement

This construction is not practiced in Serbia.

A.13.



Confined masonry with concentrated reinforcement

This construction technology has been practiced in Serbia since the first seismic design code was issued in 1964, and it is known as "masonry with horizontal and vertical confining elements", but it is globally known as "confined masonry".

Photo: Svetlana Brzev

A.14.



Photo: Svetlana Brzev

Timber-framed masonry

Existing timber-framed structures with masonry infills (adobe or clay bricks) can be found throughout Serbia. These infilled frames act like wall structures when subjected to earthquake shaking. This traditional construction technology was introduced by the Ottoman rulers in the 15th century and it was practiced in Serbia until the 20th century.

Vertical Structures - Reinforced concrete types (Table B)

Reinforced concrete construction technology was first used in Serbia in the beginning of the 20th century. There are no differences between Italian and Serbian construction practice in terms of constituent materials, infill elements, structural behaviour, connections, dimensions, structural characteristics.

B. 1.



Frame structures with reinforced concrete beams and columns, with infill walls constructed using solid bricks

This type of construction was practiced in the 1950s and 1960s, mainly in Serbian urban centres.

B.2.



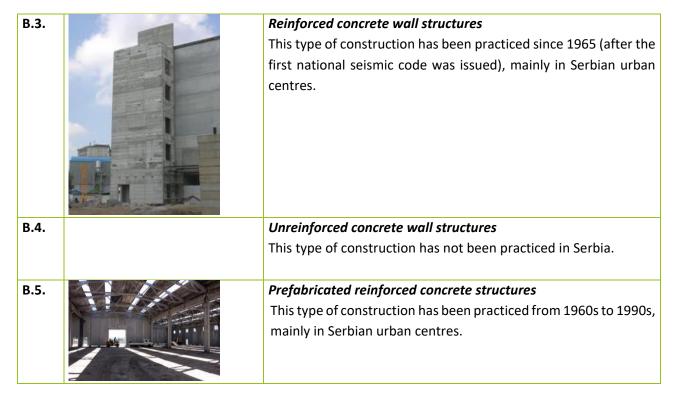
Photo: S. Brzev

Frame structures with reinforced concrete beams and columns, with infill walls constructed using hollow blocks

This type of construction has been practiced since the 1960s, mainly in Serbian urban centres.







Horizontal elements – Floors and roofs (Table C)

Most heritage buildings in Serbia from the 19th century have timber floors (similar to Italian practice). However, floor systems such as brick vaults supported by iron beams were also common at the time, particularly at the ground floor level (since most buildings had basements). Refer to Figure 10 for an overview of historical evolution of floor systems in Serbia during this period.

The first application of reinforced concrete floor slab system in Serbia was reported in 1903. Ribbed reinforced concrete slabs were widely used from 1920s until 1960s. Semi-prefabricated composite masonry and concrete floors have been used in Serbia since 1960s. There are no differences in construction practices for floors and roofs between Serbia and Italy in terms of the constituent materials, structural behaviour, connections, maximum span, and structural characteristics.

Roofs in older existing buildings in Serbia are usually sloped due to heavy rainfall. Roof structure is wooden, with clay tile roofing (Jovanović-Popović, Milica et al., 2014).

TIMBER FLOORS:



Single or double timber floors (beams and joists) with simple wooden planks

This type of construction had been practiced in Serbia from the medieval period until 1945 (end of the WWII), both in rural and urban areas. In the 19th and the beginning of 20th century floors consisted of timber beams (typically cross-section 16x24 cm) at 80 cm spacing, which supported 2.4 cm wooden planks overlaid by flooring and 2 cm sand layer between the planks and the flooring. A 5 cm cane ceiling was attached to the floor structure.





C.2.



Single or double timber floors (beams and joists) with brick tiles This type of construction has not been practiced in Serbia.

• IRON FLOORS:

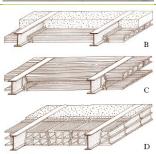
C. 3.



Floors with iron beams and brick vaults

This type of construction was practiced in Serbia from 1870 until 1945 (end of the WWII), mostly in urban areas. It is known under the name "Pruski svod".

C.4.



Floors with iron beams and hollow masonry blocks with concrete topping

This type of construction was practiced in Serbia from 1870 until 1945 (end of the WWII), mostly in urban areas.

• VAULTED STRUCTURES:

C. 5.



Brick vaults

This type of construction is not common in Serbia and its application was limited to heritage structures e.g. monasteries. It had been practiced from medieval period until the 20th century.

C.6.



Stone vaults

This type of construction is not common in Serbia, and its application is limited to monumental heritage structures such as fortresses and monasteries.





• REINFORCED CONCRETE FLOORS:

C. 7.





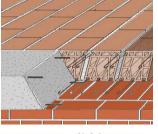
b) Photo: S. Brzev

Cast-in-situ reinforced concrete slab

Construction of solid reinforced concrete slabs has been practiced in Serbia since the 1900s, mostly in urban areas.

Construction of reinforced concrete slabs with closely spaced joists, that is, one-way joist system or "sitnorebrasta tavanica" (in Serbian), has been practiced in Serbia since the 1920s (Figure b).

C.8.



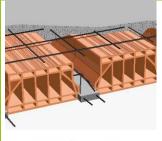
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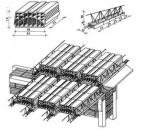
Source: Bogdanović and Vasov (2016)

Hollow clay block floor without reinforced concrete slab

This is a semi-prefabricated floor system which was practiced in Serbia in the 1960s and 1970s and it is known as TM3 system.

C.9.





Source: Krunić and Krunić (2008)

Hollow clay block floor with reinforced concrete slab

This semi-prefabricated floor system has been practiced in Serbia since the 1970s and it is still in use. It has been referred to as LMT (Light prefabricated floor).





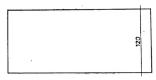
C.10.



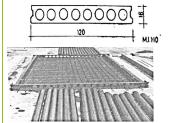


Source: Abramov, 1971

a)



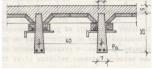




Source: Stan 2, Army Press, SFRY, 1970

b)

C.11.



Source: Bogdanović and Vasov

(2016)

Prefabricated reinforced concrete floor

This type of construction has been practiced in Serbia since the 1960s, mostly in urban areas. Solid floor panels were used in prefabricated buildings (e.g. large panel buildings), see Figure a). Hollow core planks were used in reinforced concrete or masonry buildings which have been cast-in-situ (Figure b).

Semi-prefabricated ribbed reinforced concrete floor

This floor system consists of prefabricated reinforced concrete joists and a 50 mm thick cast-in-situ concrete slab. It was practiced in Serbia from 1920 until 1945 under the name "Herbst" system and from 1945-1965 as "Avramenko" system.

Foundation system (Table D)

Foundation construction practice in Serbia is similar to Italy and other neighbouring countries. There are no differences in terms of the constituent materials, type of soil, compatibility with the elevation, type of soil according to local classification, depth, and the period of construction.





CONTINUOUS FOUNDATIONS:

D. 1.		Stepped foundations, engraved in the rock
		This is not a common foundation construction practice in Serbia.
D.2.	bee 1	Regular stone masonry foundation
		This type of foundation was used for the construction of heritage buildings in Serbia.
D.3.		Irregular stone masonry foundation
		This type of foundation was used for the construction of heritage buildings in Serbia.
D.4.		Stone rubble foundation with concrete binder This type of foundation was used for the construction of heritage buildings in Serbia.
D.5.		Brick masonry foundation This type of foundation has been used for the construction of heritage buildings in Serbia.
D.6.		Continuous reinforced concrete foundation (strip footings)
		This type of foundation has been used in Serbia since the beginning of the 20 th century.





• PILE FOUNDATIONS:

D. 7.



Wooden piles

This type of foundation was used in Serbia in the second half of the 19^{th} century. Initially, cast-in-situ unreinforced concrete piles were used, but the application of prefabricated concrete piles has started in the 20^{th} century.

D.8.



Reinforced concrete piles

This type of foundation has been used in Serbia since the 1950s.

• RECENT RC FOUNDATIONS:

D. 9.



Inverted beam foundation

This type of foundation has been used in Serbia since the 1950s.

D. 10.



Isolated footing

This type of foundation has been used in Serbia since the 1950s.

D. 11.



Slab foundation

This type of foundation has been used in Serbia since the 1950s.





Main structural types

An overview of construction practices presented earlier in this section is useful for understanding of the main building typologies in Serbia. These typologies are similar to Italian practice discussed in the specific section, but there are differences, especially related to ancient buildings. Reinforced concrete typologies in Serbia seem to correspond well to Italian practice, both in terms of structural features and initial applications.

MASONRY BUILDINGS:

1

2

ANCIENT MASONRY BUILDINGS

These masonry buildings were constructed before 1900, including earthen and brick masonry construction.

ANCIENT MASONRY BUILDINGS WITH ANTI-SEISMIC PROTECTION

These structures are generally not common in Serbia, however traditional timber-framed system infilled with brick masonry (bondruk) can be considered as an example of an ancient construction technology with anti-seismic features. The system was practiced during the Ottoman rule in Serbia (15th to 19th century).

3 PRE-MODERN MASONRY BUILDINGS

Buildings of this type were constructed in Serbia from 1900 until 1964. These buildings have unreinforced masonry walls. Timber and iron floors were used before 1920, while a wide application of reinforced concrete floor systems (e.g. ribbed slabs) started in 1920s. Floor-to-wall connections are not adequate per modern standards; for example, the floors are simply supported by the walls without an effective connection, and reinforced concrete tie-beams are absent. The walls were constructed using solid clay bricks in lime mortar (before 1920) and cement-lime mortar after this period. Due to relatively high precipitation these buildings have sloped timber roofs.

4 MODERN MASONRY BUILDINGS

Buildings of this type were constructed in Serbia after 1964, after the first seismic design code was issued in the SFRY. These buildings have masonry walls and rigid floors, either cast-in-situ reinforced concrete slabs or semi-prefabricated masonry and concrete floors. The walls are reinforced with horizontal and vertical reinforced concrete elements (confined masonry). The walls were constructed using hollow clay blocks in cement mortar. These buildings have sloped timber roofs.

RC BUILDINGS:

5

PRE-CODE REINFORCED CONCRETE BUILDINGS

These reinforced concrete buildings were constructed before the seismic-code was introduced (1920 – 1964). Structural elements were designed for gravity loading, without seismic design and detailing provisions.





6 RECENT REINFORCED CONCRETE BUILDINGS

These buildings were constructed according to the first seismic code which was issued in 1964 (1965 – 1980). Reinforced concrete frames with masonry infills and dual frame-wall structures are most common, but structural (shear) wall system was also used. Prefabricated concrete systems were also used for urban residential construction during that period.

7 MODERN REINFORCED CONCRETE BUILDINGS

These buildings were constructed according to the second seismic code which was issued in 1981 (1981 – present). The prevalent structural systems are dual frame-wall system and structural (shear) wall system. Application of prefabricated concrete systems for residential construction discontinued during this period.

A few examples of building typologies characteristic for Serbia are presented in the following figures.



Ancient masonry buildings: Princess Ljubica's Residence, Belgrade (1830)



Pre-modern masonry buildings: Ilija M. Kolarac Endowment building, Belgrade (1932)

Figure 16 – Examples of masonry building typologies from Serbia



Ancient reinforced concrete buildings: Ethnographic Museum, Belgrade (1935)



Recent reinforced concrete buildings: Faculty of Philosophy, University of Belgrade (1977)

Figure 17 - Examples of reinforced concrete building typologies from Serbia





4.5. Slovenia – PP6 (ZAG)

Slovenia has a great exposure to seismic events, more than most European countries. Earthquakes of intensity VII and VIII, referred on the European macro-seismic scale (EMS) with a 475-years return period, are expected, respectively, in 41% and 57% of the territory of the entire Slovenia. The most severe earthquakes are expected in the areas around the city of Ljubljana, which have also the highest population density of the country, in the Soča River valley and in the region around the city of Brežice.

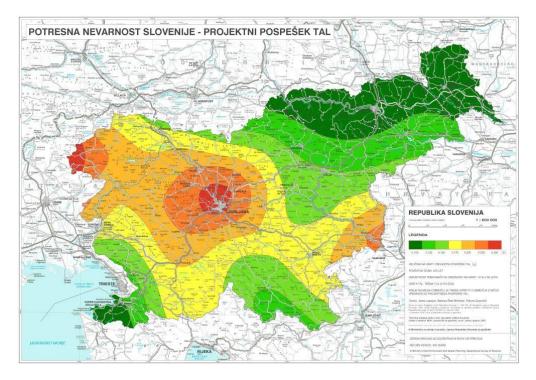


Figure 18 – Design ground acceleration (seismic hazard) map of Slovenia (Lapajne, 2001) and Intensity seismic hazard map of Slovenia (Šket-Motnikar, Zupančič, 2011)

A huge part of building heritage in Slovenia was built in the period before 1895, when the most intense earthquake hit Ljubljana region. Till then building practice was based upon the experience, but from then on first seismic code was prepared to prescribe measures for adequate seismic safety. It was an ordinance for earthquake resistant construction of buildings, a very prescriptive-type code based mainly upon the observation, how a structure suffers damage during earthquake. From that first, most prescriptive type of seismic code the vital professional knowledge has been incorporated into the following codes. Not really earlier than the destroying earthquakes hit Friuli and Montenegro in 1976 and 1979 the design-engineers became more aware of destructive potential of earthquakes. Noticeably higher seismic resistance level of building stock was enabled by the application of last national code from 1981, which was replaced by Eurocode 8 in early 2008 (Lutman, 2010).

This environmental situation meets the Slovenian richness in building heritage. There are thirty thousand listed properties, concentrated especially in towns and villages, due to the predominantly wooded and alpine landscape. Half of these properties are secular architectural objects: 25% are religious buildings, 15% are protected areas such as historic cities or villages and 10% percent are archaeological sites.

From a legislative perspective, in Slovenia, the development of earthquake building codes has been gradual (Kilar, 2009). Typically, they were usually extended and made stricter after every strong earthquake. The first





regulation that included earthquake loading, as a separate loading case, was the *Temporary technical code* (Privremeni tehnički propisi – PTP), which was issued in the Federative Republic of Yugoslavia in 1948. According to this code, Yugoslavia was divided into three earthquake zones:

- Zone a) of smaller damage,
- Zone b) of bigger damage and
- Zone c) of possible catastrophic destruction.

Maximum earthquake force, for Zone (c), amounted to 3% of the dead load and half of the live load. These values are up to five to ten times smaller than the forces used in modern standards. In this period, the quality of the buildings was not very high, also due to the political situation.

After the catastrophic earthquake in Skopje in 1963, a new earthquake building code was introduced in 1964. This regulation significantly increased seismic forces for all types of constructions, prescribing distribution of horizontal forces along the building height and including influence of soil quality on their determination. During the same year, a new seismic hazard map of Slovenia was issued, which presented a more accurate division of earthquake prone areas. Moreover, requirements for masonry buildings, included in these regions, were completely changed. For the first time, vertical reinforced concrete confinement elements at the corners and at the junctions of masonry walls were prescribed.

The new code also regulated RC buildings, prescribing reinforcement details, such as: shape and distance between stirrups, overlapping of reinforcing bars and anchorage. Nevertheless, these construction details were much less stringent than those in current codes. In general, earthquake resistance of buildings built in this period was higher than for older ones.

Regarding the types of material, in Slovenia, stone masonry, brick masonry, reinforced concrete structures, combined structures (load-bearing walls and vertical reinforced concrete elements) and metal structures were used. About traditional construction materials, limestone and slate, are locally available, which are replaced by clay brick in some parts of the country (Tomaževič, 2007). Stone masonry walls are made of rubble or riverbed stone. Usually, they were built in two outer layers composed of irregularly sized bigger stones, with an inner infill of smaller pieces of stone, in poor mud mortar with a little lime. In the city centres and towns, walls are made of relatively compact mix of stone, brick, and mortar; with no distinct separation between each individual layers. Regularly cut or partly cut stone is rarely used, as also connecting stones.

Typically, in the cities and towns, stone-masonry houses are three to four stories high, whereas their height is limited to two stories in rural areas. The structural layout is usually adequate: the distribution of walls is uniform in both orthogonal directions, and, because of their thickness, rooms are relatively small. The wall/floor area ratio is large, in many cases exceeding 10 % in one direction (Lutman, 2002).

Floor structures and lintels are traditionally wooden, without any wall ties provided to connect the walls. Brick vaults sometimes replace wooden floors. Roof structures are wooden and are covered with ceramic tiles, sometimes laid in mortar. As a rule, the buildings are built without any foundation, and foundation walls are of poorer quality than walls present above the ground level.

About their response to earthquakes, the analysis of seismic damage indicated that there are two main vulnerabilities: i) inadequate structural integrity, lack of connection between load-bearing walls at floor levels, which results into out-of-plane vibration, separation, and collapse; ii) inadequate structural resistance, which results into typical diagonal shear cracking and disintegration of walls, causing partial or total collapse of buildings.

In some cases, also irregular structural layout is the reason for partial and/or total collapse. Whereas in the other cases, an inadequate foundation system and/or foundation soil causes partial settlements, sinking, sliding, tilting, and/or overturning of buildings (Tomaževič, 2007).





Rubble-stone masonry houses are still found throughout Slovenia. This housing type is special because of its history. It represents a typical, older residential building in the northwestern part of Slovenia. After their destruction during World War I, these houses were rebuilt, mostly with the recycled stone material (from the buildings that were demolished). Many houses of this type were subsequently damaged during the last two earthquakes in Slovenia (1976 Friuli and 1998 Bovec). In order to preserve the country's architectural heritage, about 66% of these houses were strengthened after the earthquakes (Lutman, 2002a).

Information about recent constructions can be obtained by the study from Kilar (Kilar, 2009) where, by statistical analysis, the realizations between 1895 and 1981 were classified by age, material and number of storeys. Below, some useful information is recalled to give a general description of Slovenian building types. In the Country, the majority of the population, especially in cities, lives in multi-residential buildings. These dwellings are mainly multi-storey apartment blocks and skyscrapers. They were built in the previous century, especially after the end of World War II, when the erection of such structures became more popular (Kilar, 2009).

The results of the census of the population, households and apartments, performed by Statistical Bureau of Republic of Slovenia in 2002, show that there were 18,005 multi-residential buildings in the country, representing only 3.9% of all dwellings. However, these buildings counted within them 242.011 apartments, which was almost one third of all in Slovenia. In the previous census (1981) there were 14,744 multi-residential buildings with 185.994 apartments.

On the base of the building periods, which were characterized by important historical events and major developments in earthquake building codes, a judgment about current condition and earthquake resistance of the construction stock of the country can be given.

The previously mentioned 2002 census classified multi-residential buildings as: apartment blocks, skyscrapers and older municipal multi-storey buildings, which were constructed one next to another and do not look like modern ones. So they are considered as buildings aggregates.

Most of the analysed constructions are made of a combination of reinforced concrete elements and shear resistant masonry walls. RC is mostly used for floors, staircases and beams; while shear walls are mostly made of masonry units or prefabricated concrete panels. In older buildings, floors are composed by wooden beams, while walls by masonry without any concrete confinement elements.

Concrete became more used for erecting walls after World War II. Instead, wood, as structural material, has been mainly used for roofing. Wooden multi-residential buildings were only exceptions in the considered time period. Similarly, the use of steel frame structures for multi-residential buildings had not been popular until the last decade.

Most Slovenian multi-residential buildings have an elevated ground floor where the main entrance is followed by a small entrance hall (windbreak) for letterboxes. This space is usually separated from the main communications routes inside the buildings. Typically, the corridors and staircases are positioned in the centre of the building, while the apartments are arranged on the perimeter.

Three types of multi-residential buildings are the most common in Slovenia: multi-storey houses, skyscrapers and apartment blocks. Each type has its own characteristics; nevertheless, the multi-storey house and apartment block seem to be structurally very similar to each other. A typical skyscraper has a rectangular or even square floor plan shape and ranges, in height, from 10 to 12 storeys. Instead, apartment blocks are usually elongated in one direction and include more than one communication shaft. They usually have a ground floor and three or four upper storeys, because for all buildings higher than four storeys elevators were mandatory. In some cases, apartment blocks have vertical communications in the centre, while in others, they are positioned closer to the side, with one wall attached to the perimeter of the building.





Storey height in older buildings is about 3 m, respecting the standards valid at that time, which required a minimal height of 2.8 m. For newer buildings it is lower: nowadays the required height amounts to 2.5 m, but in practice it is usually exceeded. We can conclude that the total height for older multi-residential buildings, with a ground floor and four storeys, is about 15 or 16 m. That of an average older skyscraper with twelve storeys is up to 36 m.

Unreinforced brick masonry apartment building structural type was commonly used for residential buildings in all Slovenian towns (Lutman, 2002b). It constitutes up to 30% of the entire housing stock in Slovenia. Majority of buildings of this type were built in the period between 1920 and 1965. Buildings of this type are generally medium-rise, usually 4 to 6 stories high. The walls are of unreinforced brick masonry construction laid in lime/cement mortar. In some cases, wall density in the longitudinal direction is significantly smaller as compared to the transverse direction. In the pre-1950 construction, there are mainly wooden floor structures without RC tie-beams. In the post-1950s construction, there are concrete floors with RC bond-beams provided in the structural walls. Roof structures are either made of wood (pitched roofs) or reinforced concrete (flat roofs). Since this construction was widely practiced prior to the seismic code development (the first national seismic code was issued in 1964), many buildings of this type exceed the allowable number of stories permitted by the current seismic code (maximum 2 or 3 stories for unreinforced masonry construction).

Reinforced concrete shear-wall building structural type has been practiced in urban areas, mostly in bigger cities in Slovenia since 1965. The average fraction is estimated to 5% of entire housing stock in Slovenia (Lutman, 2010). Following the limitation for the number of floors in seismic regions, according to first national seismic code (1964), many large residential areas in bigger cities in Slovenia have been built using RC shearwall structures. The RC shear-walls are constructed along the complete height of building, which is from 5 to 12 storeys above ground, besides one or two basement floors. In layout, the walls used to be oriented predominantly in one direction, but in last 15 years, they are distributed mostly uniform in both orthogonal directions. In some cases, the lintels are coupling the walls. Seismic performance is expected to be good. Buildings have reinforced concrete strip footings or mat foundations. Reinforced concrete walls are typically distributed in both orthogonal directions. The thickness of the walls varies from 15 cm to 30 cm. Floor structures are reinforced concrete plates of thicknesses of 12 to 20 cm. The roof structure is a reinforced concrete plate in case of flat roof and a wooden roof in case of pitched roof. The wall density varies from 1.5 to 4.0 % in each direction. The wall density in transversal direction is typically higher than in longitudinal direction. Individual segments of longitudinal facades between two adjacent transverse walls are either open, or have a longitudinal bearing wall without openings. In the first case there are windows or balcony doors of size at least 3.0 m². In transverse facades, which are load-bearing walls, there are windows of size up to 2.0 m². Their surface represents about 10% of the surface of transverse facade wall. Interior doors in the inner wall are of size up to 2.5 m², representing approximately 10% of the surface of interior walls.

Before the 1895, the seismic resistance was mainly achieved by practical experience, for example: reducing the height of the building, increasing the wall thicknesses in lower storeys, lowering the mass centre of the building, etc.

The quantity of multi-residential buildings from this period amounts to 6.5% of all multi-residential buildings in Slovenia. They are made of masonry (41.1%), combined materials (20.6%), stone (17.9%) and concrete (16.8%). Most apartments (70.2%) are in one to three-storeys buildings, while 14.6% are in taller buildings, with five or more storeys.

From 1895 to 1945, especially before World War I and between the World Wars, buildings were designed according to Austrian and old Yugoslavian codes, which prescribed: different thickness of the masonry walls according to different storeys, the width of walls between windows, procedures for fabrication of floors, firewalls and massive floor plates. The only horizontal load considered was wind. Most buildings built in those





years were solid, relatively regular in plan and in elevation with prescribed details and carefully selected materials. RC had begun to be used during this period to construct the first taller buildings and skyscrapers, which react to seismic loading completely different from rigid masonry buildings of previous centuries.

The most well-known example in Slovenia is the Ljubljana skyscraper from 1933.

Referring to this period, multi-residential buildings amount to 9.2% of all multi-residential buildings in Slovenia. They are mostly made of masonry (67.9%) and combined materials (18.0%). While most of apartments (76.9%) are in one- to three-storey buildings and 8.6% of them are in buildings with five or more storeys.

From 1946 to 1963, constructions were made according to the first Yugoslavian codes for imposed building loads (PTP – Privremeni tehnički propisi, 1948).

In this period, multi-residential buildings amount to 22.6% of all multi-residential buildings in Slovenia. They are mostly made of masonry (62.9%), concrete (21.5%) and combined materials (13.8%). Most of the apartments (45.6%) are in one to three-storeys buildings, while 29.1% of them are in buildings with five or more storeys.

Between 1964 and 1981, after the catastrophic earthquake in Skopje of 1963 and the new earthquake building code introduced in 1964, multi-residential buildings amount to 40.6% of all multi-residential buildings in Slovenia. The majority of them are built of concrete (73.7%), much less of masonry (16.7%) and of combined materials (8.2%). In this period approximately one third of apartments (31.6%) were built in four storey multi-residential buildings, while more than half of them (53.9%) are in buildings with five or more storeys.

Before 1895:

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	0.50	35.41	2.83	1.73	0.63
Concrete		0.48	4.82	4.75	6.77
Combination of different materials	0.46	17.41	2.00	0.50	0.22
Wood		0.25			
Stone	0.56	16.60	0.75		
Other	0.01	0.06	0.02		

1895 - 1945:

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	1.40	55.16	6.71	4.17	0.51
Concrete		2.20	2.08	1.61	1.35
Combination of different materials	0.63	14.85	1.69	0.84	0.06
Wood	0.06	0.14			
Stone	0.05	3.89			
Other		0.12			

1945 - 1963:

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry Concrete	0.62 0.01	33.97 4.46	14.47 5.78	11.53 6.87	2.17 4.41
Combination of different materials Wood	0.06 0.03	6.27 0.18	3.83	2.81	0.82
Stone Other	0.03	0.38 0.28	0.02 0.45	0.47	





1963 - 1981:

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry Concrete Combination of different materials Wood Stone Other	0.09	5.50 5.90 2.01 0.03 0.11	6.16 21.80 3.23	3.80 21.41 2.49 0.05	1.17 24.56 0.43

Figure 19 – Division of the area of multi-residential buildings built in the analysed periods, according to the prevailing structural material and number of storeys (Kilar, 2009)

Vertical structure – Masonry types (Table A)

Comparing the results of the repertoire with the mapped data for the Italian territory, we note that there are only a few differences as regards the masonry construction techniques. Basically, the types are all also present on the Slovenian territory, with the exception of the tuff walls and rubble masonry with bricks probably due to the specific construction tradition in the Country.

We note that, for all historic walls, the thicknesses are generally greater, up to 100 cm, than this in Italy. The irregular stone walls are present in the whole national territory, while rammed earth blocks and solid bricks are mostly used in the eastern part of the Country.

There is no difference for modern masonry techniques, as for masonry in brick or cement blocks with cement mortar, while reinforced masonry is not very common.

IRREGULAR MASONRY:



Rubble stone masonry (pebbles, erratic and irregular stones), not well organized and without connection between the two wall surfaces.

In Slovenia, it generally has a thickness between 40 and 100 cm. It spread between 1000 and 1900 and it is used throughout the national territory.

A.2.



Rubble masonry with regular sized stones, well organized but without connection between the two external surfaces, with the presence of edges, bundles and / or courses in square stone or solid bricks.

In Slovenia, it generally has a thickness between 40 and 100 cm. It spread between 1000 and 1900 and it is used throughout the national territory.





A.3.



Rubble masonry with bricks, well organized but without connection between the two external surfaces realized with bricks, with the presence of edges, bundles and / or courses in square stone or solid bricks.

This type of construction technique is not common in Slovenia.

A.4.



Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces realized with bricks and the internal core

This type of construction technique is not common in Slovenia.

ROUGH-HEWN MASONRY:

A. 5.



Cut stone with good bonding

In Slovenia, it generally has a thickness between 40 and 100 cm. It spread between 1500 and 1900 and it is used throughout the national territory.

A. 6.



Masonry in rammed earth blocks

In Slovenia, it generally has a thickness between 20 and 30 cm. It spread between 1800 and 1950, mainly on the east part of the Country.

REGULAR MASONRY:

A. 7.



Tuff masonry

This type of construction technique is very rare in Slovenia.

A.8.



Dressed rectangular (ashlar) stone masonry

In Slovenia, it generally has a thickness between 30 and 60 cm. It spread between 1500 and 1900, mainly on the Mediterranean coast. This type of construction technique is very rare in Slovenia.

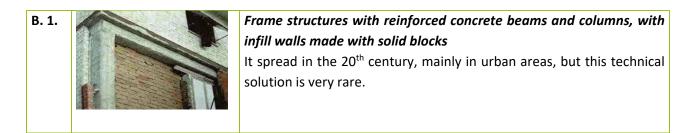




A.9.		Solid brick masonry with lime mortar
A.3.		In Slovenia, it generally has a thickness between 40 and 120 cm. It spread between 1500 and 1900, mainly on the east part of the
		Country.
A.10.	med and market and the second	Solid brick masonry with cement mortar
		In Slovenia, it generally has a thickness between 12.5 and 45 cm. It is used throughout the national territory.
A.11.		Masonry in clay or concrete blocks with cement mortar
		In Slovenia, it generally has a thickness between 19 and 29 cm. It spread since 1970 throughout the national territory and it is still used today.
A.12.		Confined masonry with distributed reinforcement
		This type of construction technique is very rare in Slovenia. It is present in some buildings, constructed in the past.
A.13.	River and the second	Reinforced masonry with concentrated reinforcement
		The constituent materials are brick blocks and cement mortar for
	H-1111	masonry and concrete and steel reinforcement for vertical RC
	THE S	confinement elements. There is no reinforcement in the masonry. In
	1	Slovenia, the walls are generally of a thickness between 19 and 29 cm
		and it has been practiced from 1982. It is still used.

Vertical Structures - Reinforced concrete types (Table B)

Moment frame RC structures, both with solid bricks and hollow bricks as infill, are rarely used in Slovenia. Since the last century, RC structures were mainly used with RC walls.









Frame structures with reinforced concrete beams and pillars, with infill walls made with hollow bricks

It spread in the 20th century, mainly in urban areas, but this technical solution is very rare.

B.3.



Reinforced concrete wall structures

In Slovenia, it spread in the 20th century and it is still used today. It is common for structures all around the country.

B.4.

Unreinforced concrete wall structures

In Slovenia, it had been used for some buildings in the late 50s and early 60s.

B.5.



Prefabricated reinforced concrete structures

No changes, all the data correspond.

Horizontal elements – Floors and roofs (Table C)

As for floors and roofs, compared to the Italian data, there is a perfect match for the floors with timber structure and planks, both as regards the maximum span and the period of construction. In Slovenia, this is the most used historical solution too.

The timber floor with brick tiles, instead, it is not used. About vaults, the brick ones are very common and widespread, while the stone ones are rare. Regarding the iron floors, only the solution with vaults is used, while hollow bricks are not used together with iron profiles.

For the RC floors, we note a substantial correspondence with the Italian condition for all the data.





• TIMBER FLOORS:

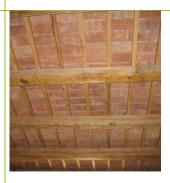
C. 1.



Single or double timber floors (beams and joists) with simple wooden planks

No changes, all the data correspond.

C.2.



Single or double timber floors (beams and joists) with brick tiles This type of construction technique is not present in Slovenia.

IRON FLOORS:

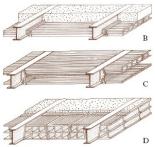
C. 3.



Floors with metal beams and vaults

It spread between 1850 and 1960 throughout the national territory, both urban and rural.

C.4.



Floors with metal beams and hollow bricks

This type of construction technique is not present in Slovenia.

• VAULTED STRUCTURES:

C. 5.



Brick vaults

It is present throughout the national territory, both urban and rural.





C.6.



Stone vaults

It is present throughout the national territory, both urban and rural, but is very rare.

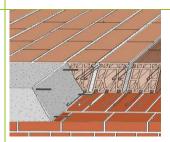
• REINFORCED CONCRETE FLOORS:

C. 7.

Cast-in-situ reinforced concrete slab

In Slovenia, it is used since 1900, mainly in urban areas and it is still used today.

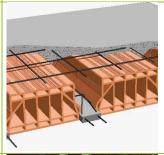
C.8.



Hollow clay block floor without reinforced concrete slab

In Slovenia, this type of floor structure was used in 50-ties and 60-ties of the 20th century.

C.9.



Hollow clay block floor with reinforced concrete slab

It is used mainly urban area in the whole Slovenia. This type of floor structure was used in 50-ties and 60-ties of the 20th century.

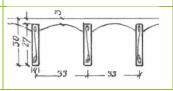
C.10.



Prefabricated reinforced concrete floor

No changes, all the data correspond.

C.11.



Floor with prefabricated joists with RC slab

Timber planks are usually attached to the beams from below. This type of floor structure was used in 50-ties of the 20th century.





Foundation system (Table D)

Regarding the foundation systems, the most used for historic masonry buildings was the irregular stone block foundation with a depth up to 120 cm. In recent centuries, between 1800 and 1900, the pebbles and lean concrete solution began to be used, especially in combination with elevation structures in brick masonry. As already pointed out by the bibliographical information, the foundation system was often neglected and realized up to limited depths. In addition, the collected data confirm that it was made with lower quality materials than these used in elevation.

• CONTINUOUS FOUNDATIONS:

D. 1.	2	Stepped foundation, engraved in the rock
		No changes, all the data correspond.
D.2.	E. /	Regular stone masonry foundation
		No changes, all the data correspond.
D.3.		Irregular stone masonry foundation
		In Slovenia, its depth varies between 70 and 120 cm. It spread between
		the Medieval period up to 1900, throughout national territory, both
		urban and rural.
D.4.		Stone rubble foundation with concrete binder
		In Slovenia, it spread between 1800 and 1900, in areas where bricks
		are mainly used as a building material for elevation structures and resistant stones are lacking, such as the eastern part of Slovenia.
D.5.		Brick masonry foundations
		In Slovenia, its depth varies between 70 and 130 cm. It was used in
		areas where bricks are mainly used as a building material for elevation
		structures and resistant stones are lacking, such as the eastern part of Slovenia.
		Siovenia.





D.6.



Continuous reinforced concrete foundations (strip footings) In Slovenia, it is still used throughout the national territory.

PILE FOUNDATIONS:

D. 7.



Wooden piles

In Slovenia, it spread between the Medieval period up to 1900, in areas with clay terrain, such as coastal towns and the capital Ljubljana.

D.8.



Reinforced concrete piles

The typology consists of prefabricated steel, or concrete piles, which are driven into the soil with a specific machinery, or consists of drilled concrete piles.

Generally, it is used for compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. Piles depth can reach 10 m under the ground level, are used mainly for RC structures.

They spread since 1970 in the whole national territory and are still used today for very heavy buildings.

• RECENT RC FOUNDATION:

D. 9.



Inverted beams foundation

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a grid of inverted RC beams under the RC frame structure. It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible terrain, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local





standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil, typically, is about $1-1,5\,$ m.

This technique spread in the whole territory and it is still used today.

D. 10.



Isolated footing

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a grid of isolated plinths under the RC frame structure. It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible terrain, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil, typically, is about 1,5 – 2 m.

This technique spread in the whole territory and it is still used today.

D. 11.



Slab foundation

The constituent material is reinforced concrete for the whole foundation structure.

This construction system consists of a monolithic RC platform and it is generally used with compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is used both for masonry and RC elevation structures. Its depth is related to the consistency of the soil,typically, is about 1 m.

It spread in the whole territory and it is still used today.

Main structural types

The previously mentioned bibliographic sources have allowed to understand how, in general, the main structural types listed in the case of the Italian territory find a good correspondence with the Slovenian ones, especially for modern masonry and RC buildings.

MASONRY BUILDINGS:

1 ANCIENT MASONRY BUILDINGS

Stone-masonry buildings, which were constructed before 1850 and brick-masonry buildings, constructed before 1895.







2 ANCIENT MASONRY BUILDINGS WITH ANTI-SEISMIC PROTECTION Buildings, built after Ljubljana 1895 earthquake were constructed respecting the code that was prepared to prescribe measures for adequate seismic safety. It was an ordinance for earthquake resistant construction of buildings. 3 PRE-MODERN MASONRY BUILDINGS

Many types of this structural type are present in Slovenia.

This type is from the period between 1920 and 1964, before the adaption of first seismic code in

The load bearing structure consists of brick masonry walls (solid bricks in lime mortar with a little cement or without cement) and floor structures, which may be of timber joists or different types of RC structure. Their typical drawbacks are poor connections between walls and floor structures.

4 **MODERN MASONRY BUILDINGS**

Many types of this structural type are present in Slovenia.

This type is being practiced since 1982 till now. The load bearing structure consists of brick masonry walls (hollow bricks in lime and cement mortar) and RC slabs as floor structures. Structural walls are confined with reinforced concrete tie-beams and tie-columns.

RC BUILDINGS:

	5	PRE-CODE REINFORCED CONCRETE BUILDINGS
		It is not present in Slovenia.
	6	RECENT REINFORCED CONCRETE BUILDINGS
		It is present in Slovenia RC frame structures prevail in case of public buildings, while RC wall
		structures prevail in case of residential buildings. Floor structures are RC slabs.
	_	
	7	MODERN REINFORCED CONCRETE BUILDINGS
		It is present in Slovenia. RC frame structures prevail in case of public buildings, while RC wall
		structures prevail in case of residential buildings. Floor structures are RC slabs.
L		

4.6. Greece – PP7 (UoC) and PP8 (ROC)

Greece is the most seismically active region in Europe and also rank high (sixth position) on a global scale (Tsapanos and Burton, 1991). The seismicity of Greece has been evaluated mainly during the 20th century, though descriptions of the earthquake occurrences have been reported since the middle of 19th century.





Anyway, chronicles and similar studies have been reported since the dawn of Greek civilization, dates back to 500 BC. They mostly focused on shake-ability and on damages caused in popular areas (Tsapanos, 2008).

The basic lithospheric process in the Aegean Sea is the subduction of the African plate under the Eurasian plate south of Crete which forms the Hellenic arc and trench.

The first Greek seismic code date back to 1959 and it was supplemented in 1985. In 1995 a new generation law was approved, then amended in 2000 to include the European pre-Standard – ENV provisions (predecessor of *Eurocode*), and was finalized with the name EAK (*Greek Seismic Code*).

In 2012, the provisions of *Eurocode* (EC-8) were enforced in conjunction with the occasionally more stringent EAK.

Greek culture is undoubtedly one of the oldest in Europe, this makes the study of local construction techniques extremely complex, given the very long chronological evolution and the vastness of the territory, with also very different climatic conditions from region to region.

Not considering the monumental construction, where huge structures were made of stones, the local building material was the most used in housing construction, easy to find and work with. Stone, bricks, wood, straw, marble, ceramics, lime, glass, reeds, sand, clay are the materials found mostly in Greece and, in general, in Mediterranean architecture.

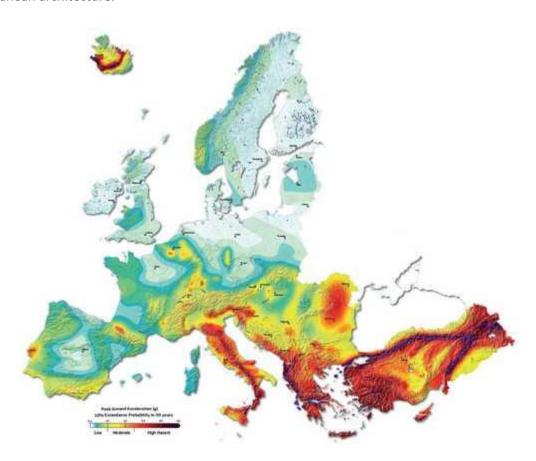


Figure 20 – Seismic intensity in Greece, compared with that of other European countries

Much of the traditional architecture, in both rural and urban areas, was built with raw earth, because clay-rich soils are abundant and cheap. Furthermore, in this Country, the use of timber elements has been adopted as a technique for improving the seismic response of structures since nearly 5000 years.

This technique played a central role in the organization of building technology since the ancient Greek civilizations: it was used in combination with other natural materials such as wood (more or less worked), straw, sugar cane and lime. A key factor that shaped traditional construction methods on the use of earth was



the contacts of the Greeks with other neighbouring civilizations. Namely those of North Africa, the Middle East and Asia Minor where, as is known, raw earth was extensively used.

Excavations and archaeological research have shown that earth has been used as the main building material since the Minoan era (2600-1100 BC). Evidence of the use of adobe bricks and other earthen building materials can be found in palaces such as Zakros, Malia and Knossos. During the classical period, the use of adobe bricks involved not only dwellings, but also important public buildings, such as temples and fortifications in Athens, Mantineia, Eretria, Elefsina. The use of earth in Greek architecture continued mainly in rural buildings in the following historical periods: Hellenistic, Roman, Byzantine and Ottoman.

Adobe bricks are the most common construction technique. They are air-dried bricks and formed in wooden molds, made of a mixture of loam, mud, sand, and water, with binding additives such as straw. Adobe is a solid structural element and is used for masonry. Typically, these bricks are bonded with mud and mortar, rarely with plastered with mud. They are simple to make and therefore suitable also for unskilled bricklayers. Their dimensions depending on the geographical area, from a minimum of $35 \times 28 \times 7.5$ cm to a maximum of $52 \times 52 \times 8.5$ cm. In Crete, the dimensions are around $50 \times 35 \times 10$ cm.

In lowland areas, where stone is scarce, such as the plain of Thessaly or the plain of Mantine in the Peloponnese, purely adobe brick structures with stone foundations can be found.

In semi-mountainous areas, the percentage of stone masonry increases and the use of adobe is usually limited to the upper floors or, even, to small parts of the supporting structure. Often, the adobe brick structure is reinforced with horizontal wooden beams that run for the width of the walls, ensuring they are more effectively connected to each other. Usually this perimeter is repeated every 1m high (called *xylodesis*). Often, these buildings are covered with pitched tiled roofs.

This wooden masonry, consisting of ring-shaped wooden beams arranged at a regular distance for the entire height and in pairs for the thickness of the walls, improves the seismic performance of the building by providing horizontal sliding planes, dissipating energy and improving the In-Plane and Out-Of-Plane masonry strength by confining parts of the walls. In addition, this technique improves the connection between transverse walls and helps to bind the wall layers together avoiding disintegration.

So, the earth was used either as a primary material in load-bearing walls or as a filling material in non-load-bearing structures. The combination of wooden structure and adobe (or earth with straw) is often encountered in traditional Greek settlements. This technique is the so-called "tsatmas" (method of construction of wattle and daub), a system of walls with a wooden structure filled with adobe or mud (Mousourakis, 2020).





Figure 21 – Veroia: Timber-framed traditional house; construction details of the exterior wall (Mousourakis, 2020)

Lighter walls were made with the *bagdati* technique, which is common in Greek traditional architecture. These have a wooden supporting structure and are covered with a latticework of vertical studs and horizontal





wattles, woven together like a basket. A mixture of earth and straw is then spread over a lattice, forced into the cracks and smoothed to fill any space. The final surface can be left as a rustic finish or plastered with earth for a smoother result. The thickness of the wall can vary from 0.15 to 0.20 cm, so this makes it the ideal solution for dividing interior spaces. Sometimes, the seismic resistance of the building is increased by the use of diagonal rods, properly connected with the other construction elements.

Due to their lightness, these walls are often built on the upper floors and can protrude from the profile of the ground floor.

However, the applications of the earth for secondary elements are also important, such as in floors, in roofs with special clay and compressed clay (commonly found in the Greek island as Crete and other Aegean islands), in the application of connective mortars in stone masonry and earth reinforced with straw, algae and goat wool. Geographical distribution of earthen buildings is scattered across lowland and mainly in rural, semi-urban and urban areas of mainland Greece, although much has been lost in the past years. In these areas, there are simple single storey ground floor buildings as well as impressive two and three storey buildings of various uses such as residential, auxiliary, industrial, shops. Traditional adobe brick buildings, adapted to new standards, were systematically implemented at least until the middle of the last century.

Together with earthen techniques, Greek builders used stone and rubble masonry to construct everyday structures, such as houses, sheds, and workshops. Rubble masonry was composed by small blocks of limestone roughly chipped from quarries. The smooth and round surface of such stones did not allow significant bond and interlocking to be developed and structural walls disintegrated easily.

Walls were built by stacking these stone and filling the space between them with mud. Earth mortar was mainly used in the masonry buildings, introducing further vulnerability. Such mortar is characterized by low cohesive properties, low compressive strength and sensitivity to water content. This method was used where stone was more common than clay.

An interesting repertoire of Greek construction techniques has been analysed for the island of Lesvos (Vlachakis, 2020). The general characteristics of this study can also be applied to larger parts of the territory. Indeed, the analysed historical building stock consists mainly of stone masonry constructions and, less frequently, of brick masonry constructions. Most part of them were built during the second half of the 19th century and at the beginning of the 20th century, as a reconstruction process.

The residential buildings, in most cases, follow a rectangular plan layout of about 4×10 m; the height is up to 3 stories. The majority of the roofing and flooring systems are made of timber, while the internal spaces are separated by internal walls, poorly connected to the masonry façades. Timber-reinforced masonry buildings were also identified, composing a small yet particular structural typology.

In general, materials of poor quality were used in the masonry construction, resulting in remarkably low seismic performance.

Unreinforced Masonry buildings were constructed typically with two and three-leaf walls with an overall thickness varying between 0.4 and 0.7 m. However, the lack of transversal interlocking stones (through stones, bond stones, tie stones) that could connect the external layers, usually resulted in detachment and masonry delamination.

The corners of the buildings were generally constructed with quoin-stones. Well-shaped and made with more than a single stone in the course, quoins, in most cases help the connection of transverse walls, preventing local or global failures.





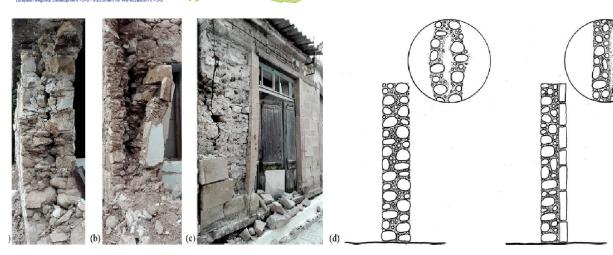


Figure 22 - Typical multi-leaves wall sections with lack of transversal interlocking stones (Vlachakis, 2020)

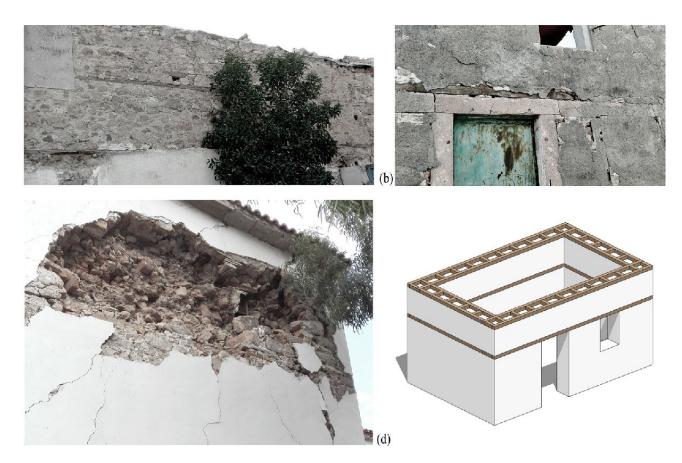


Figure 23 – Intact timber-laced masonry walls and typical multi-leaves wall sections with lack of transversal interlocking stones (Vlachakis, 2020)







Figure 24 – Localized out-of-plane collapse of external unreinforced leaf and schematic sketch of timber-frame masonry (Vlachakis, 2020)

Another interesting repertoire of Greek construction techniques has been analysed for the island of Lefkada (Karababa, 2011). In the island, stone masonry constructions constitute 30% of the island's building stock in terms of number of buildings.

Load-bearing stone masonry structures have walls with a thickness varying from 60 cm to 1m and height up to 3m. Limestone mortar is commonly used in the construction of walls, consisting generally of two loosely interlocked wythes. The internal skin is made of rubble stones of various sizes and forms, and it is often arranged irregularly, while the external skin is constructed with hewn stones. The space in between is filled with smaller stones, bricks and in some cases broken tiles.

The type of mortar used to connect the masonry units varies according to the period of construction. In older buildings, it was made of pozzolanic material known for its excellent bonding properties and its superior strength. Later, lime mortars mixed with straw and in cases mud mortars were also used. In more recent buildings, cement mortars are the most common.

Floors made of timber beams are covered with wooden planks and, usually, supported on timber sole beams resting on the perimeter stone masonry. Most structures have pitched roofs with 25° - 30° slopes. The roofs are, in general, made of king-post timber trusses with detailed mortising, so as to allow sufficient interlocking of the members. The main rafters are covered with timber planks, on top of which clay tiles are nailed or tied. Almost 50% of all the existing masonry buildings were constructed before 1919, while 40% were constructed in the period 1919 - 1960. 6.5% of them were constructed between 1961 and 1980. In more recent times stone masonry buildings has almost ceased (1.5% were built in the 1981–1995 period and 2% in the 1996–





2000 period). The construction of stone masonry buildings is based mostly on empirical knowledge and local building tradition and not on the European construction codes applicable to such structures.

Timber frames (post and beam type) buildings are made with locally supplied timber from the island's oak, cypress, pine, fir, and olive tree reserves. These buildings constitute 4% of the island's present-day building stock in terms of number.

Floors are made of timber joists covered on top with wooden planks, the joists rest on top of a perimeter sole beam, which sits on top of the timber columns (vertical load-bearing system). Column heads are used to distribute effectively the load from the joists to the columns. Above them rests another beam, that run around the perimeter of the building and, upon it, the vertical load-bearing frame of the second storey is erected.

The roofs are made of timber trusses similar to those of the stone masonry buildings.

Over a third of these structures were constructed between 1946 and 1960 (approx. 37%), while approximately 10% were constructed before 1919. An increased use of this solution followed the April 22, 1948 Lefkada's earthquake, given its observed good performance in the earthquakes of November 17, 1914, March 13, 1938 and April 22, 1948. The proportion of timber frames buildings constructed after 1960 is approximately a third of the total stock.

Another category of building present in this region is the dual load-bearing stone masonry and timber frame structures. It is a system comprising of load-bearing stone masonry and a set of load-carrying timber columns on the ground floor, working together. The first and any subsequent storeys, is constructed with timber frames.

Floors are made of timber joists covered with wooden planks. Roofs are composed of timber trusses.

Dual systems constitute 10% of the island's present-day building stock in terms of number of buildings. The majority of them (approx. 65%) were constructed between 1946 and 1959, with nearly a quarter constructed before 1945. A further 10% was constructed between 1960 and 1984, while less than 2% was constructed after 1984.

It is also present the mixed system, comprising of load-bearing stone and (or) brick masonry walls, confined by reinforced concrete vertical and horizontal elements. They are not designed to behave as moment-resisting frames. Reinforced concrete ring beams are often used at mid-height and on top of the masonry walls, enhancing the bonding of the units, tying the walls together, and improving their out-of-plane stiffness. In older structures, ring-beams were usually not anchored to the reinforced concrete column elements.

Floors are cast in-situ reinforced concrete slabs, although, in some cases, timber joist and sheathing boards are also used. The roofs are made of timber trusses similar to the previous ones.

The most of the mixed buildings were constructed between 1960 and 1985, while approximately 14% were constructed after 1985. This typology constitutes 10% of the island's present-day building stock in terms of number of buildings.

The last construction typology examined is existing reinforced concrete frame buildings. They have a cast insitu reinforced concrete beam and column arrangement, with hollow clay brick infill. Depending on their construction period, they may include shear walls in the form of wide-columns, since became compulsory in Greece after the revision of the seismic code in 1984. Floors are usually cast in-situ reinforced concrete slabs, 30cm in thickness. Typically, they have reinforced concrete flat slabs or low-pitch roofs (15°–20°) constructed with timber frames and covered in tiles.

RC buildings constitute approximately 43% of the island's building stock and a larger proportion in terms of total built floor area.

The introduction of the first seismic code in 1959 and its subsequent revisions signify turning points, which have been shown to result in structures of better quality, and hence better seismic performance.





Another interesting study collects a cataloguing of the damages following some recent earthquakes (Pomonis, 2014). It consists in a database with the most reliable and detailed damage surveys, carried-out in Greece following four small to moderate magnitude earthquakes that affected parts of the Peloponnese peninsula and the Island of Lefkas, during the period 1986 to 2003.

Here, it is possible to detect the percentage of damaged buildings for the different technologies in the different territories.

- Kalamata (1986): 41% of the buildings were RC frames with unreinforced clay brick infill walls, constructed mostly in the period 1959-1985. These were buildings of 1 to 7 levels, 22.8% of them had a soft-storey at ground floor level (characterized by opening for car parking or other use, as shops or other commercial use).
 - 44% of the buildings were old load-bearing masonry (mostly were rubble or hewn stone or mixed rubble and hewn stone masonry, but, in some case, there were also adobe buildings). In terms of height 98.8% of these were of one or two storeys. In addition, 15% of the them were of mixed structural type or with mixed masonry materials.
- Pyrgos (1993): 66% of the existing buildings were single-storey and 46.5% were old load-bearing masonry structures. More than half of the constructions in Pyrgos (52.2%) were of RC frames with unreinforced clay brick infill panels. Many of the load-bearing masonry buildings are quite old (20.6% of the existing building stock was built before 1946).
- Aegion (1995): 53% of the existing buildings were single-storey and just 6.3% had three to seven floors. 41.6% of the total number were load-bearing masonry structures with the proportion of adobe buildings being quite significant (26.2%). More than half of the buildings in Aegion (57.7%) was from RC frames with unreinforced clay brick infill panels. Many of the load-bearing masonry buildings were quite old (26.6% of the existing building stock was built before 1946). In addition, there were around 800 RC buildings that were constructed following the 1984 Greek earthquake code revision, making this one of the first events to test the performance of these structures under significantly strong ground motion. The event in Pyrgos town two years earlier was less severe.
- Lefkas Island (2003): in Lefkas town, 57% of the buildings are RC, 6% stone masonry, 9% mixed structure (RC and masonry) and 28% are either wooden or buildings of masonry with timber frame elements. RC buildings on Lefkas Island are up to 4-storeyed and in 2003 formed about 43% of the building stock, specifically 5% of them have been built before the 1959 earthquake code and 46% built in the period 1959-1984. There are very few RC buildings with soft-storey (around 0.5% of the RC stock) as this practice is avoided in this region and very few 4-storeyed structures.

The data allow us to detect a substantial uniformity in the construction techniques in the investigated territories. The percentage of RC existing buildings is comparable to that of buildings with a masonry structure. The vulnerability analysis showed also that stone masonry buildings, in Greece, being more than 50 years old are quite vulnerable and in need of strengthening measures. Greek RC frame structures constructed before 1985 are also shown to be more vulnerable than their more recent counterparts.

In Greece, 65% of the RC building stock was built before 1985. The problem of RC buildings with soft-storeys is another concern as these buildings are quite common (approximately 25% of them have this feature) and have been shown to be more vulnerable than those with regular ground floors, especially when built before 1985.





Vertical structure – Masonry types (Table A)

If we compare the results of the repertoire with the mapped data for the Italian territory, we note that there are only a few differences as regards the masonry construction techniques. Basically, the types are all also present on the Greek territory, with the exception of the tuff walls, probably due to the lack of this material. We note that, for all historic walls, the thicknesses are generally similar. There is no difference for modern masonry techniques.

As already highlighted thanks to the bibliographic search, timber reinforced masonry structures are very common and widespread for historic constructions.

• IRREGULAR MASONRY:

_		-	-	52



Rubble stone masonry (pebbles, erratic and irregular stones), not well organized and without connection between the two wall surfaces.

In Greece, it spread up to about 1950 and it is used mainly in rural areas, in the whole Greek territory.

A.2.



Rubble masonry with regular sized stones, well organized but without connection between the two external surfaces, with the presence of edges, bundles and / or courses in square stone or solid bricks.

In Greece, it spread up to about 1950 and it is used in the whole Greek territory.

A.3.



Rubble masonry with bricks, well organized but without connection between the two external surfaces realized with bricks, with the presence of edges, bundles and / or courses in square stone or solid bricks.

In Greece, it spread up to about 1950 and it is used in the whole Greek territory.

A.4.



Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces realized with bricks and the internal core

In Greece, it spread up to about 1950 and it is used in lowland areas, in the whole Greek territory.





• ROUGH-HEWN MASONRY:

A. 5. Cut stone with good bonding In Greece, it spread up to about 1950 and it is used in the whole Greek territory. Masonry in rammed earth blocks In Greece, it spread up to about 1950 and it is used in the whole Greek territory.

REGULAR MASONRY:

A. 7.	- 1	Tuff masonry				
		This type of construction technique is not present in Greece.				
A.8.		Dressed rectangular (ashlar) stone masonry				
		In Greece, it generally has a thickness between 30 and 50 cm; it				
		spread up to 1950 mainly in historical urban areas, in the whole Greek territory.				
A.9.		Solid brick masonry with lime mortar				
		In Greece, it is mainly used in lowland areas, in the whole Greek territory.				
A.10.		Solid brick masonry with cement mortar				
		In Greece, it spread since 1900 in the whole national territory and it is still used today.				







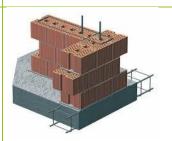




Masonry in clay or concrete blocks with cement mortar

In Greece, it spread since 1980 in the whole national territory and it is still used today.

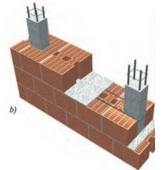
A.12.



Confined masonry with distributed reinforcement

In Greece, it is used in the whole national territory.

A.13.



Reinforced masonry with concentrated reinforcement

In Greece, it spread since 1950 in the whole national territory and it is still used today.

A.14



Timber reinforced masonry

The constituent materials are timber elements, slightly roughed limestone stones of regular medium size, lime or clay mortar; usually this masonry type has horizontally distributed timber laces or complete timber frames with diagonal braces, regular or irregular horizontal courses with stone wedges. It presents two juxtaposed layers, connected by the timber reinforcement.

Connections are effective in corners with blocks of bigger dimensions, or with timber elements. These characteristics generate a low vulnerability for out-of-plane actions, if the wall is correctly constrained at the top and at the bottom to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior. It presents a medium or high resistance for in-plane actions, thanks to the resistance of the materials (in particular the mortar) and / or the friction that can develop between the elements.

In Greece, it generally has a thickness between 40 and 60 cm; it spread up to about 1950 in the whole Greek territory.





Vertical Structures - Reinforced concrete types (Table B)

As for the RC construction, we note substantially a perfect match with the Italian techniques.

B. 1.	Frame structures with reinforced concrete beams and columns, with infill walls constructed using solid bricks The PPs highlight the problem of soft-storey behaviour for this type of structures: probable high vulnerability in presence of pilotis or squat pillars induced by the infills
B.2.	Frame structures with reinforced concrete beams and pillars, with infill walls made with hollow bricks The PPs highlight the problem of soft-storey behaviour for this type of structures: probable high vulnerability in presence of pilotis or squat pillars induced by the infills
B.3.	Reinforced concrete wall structures No changes, all the data correspond.
B.4.	Unreinforced concrete wall structures
	No changes, all the data correspond.
B.5.	Prefabricated reinforced concrete structures The PPs highlight the problem of possible vulnerability by extended corrosion.

Horizontal elements - Floors and roofs (Table C)

As for floors and roofs, we note a perfect match for the floors with timber structure and planks, both as regards the maximum span and the period of construction. Also in Greece, this is the most used historical solution for floors.

Also the timber floor with brick tiles is used, especially on the islands. About vaults, both the brick ones and the stone ones are present. Regarding the steel floors, both the solutions are used.

For the RC floors, we note a substantial correspondence with the Italian condition for all the data, even if the hollow brick floor without reinforced concrete slab are not present.





• TIMBER FLOORS:

C. 1.



Single or double timber floors (beams and joists) with simple wooden planks

It is still used today in the whole national territory.

C.2.



Single or double timber floors (beams and joists) with brick tiles
It is still used today in the whole national territory, mainly on the islands.

IRON FLOORS:

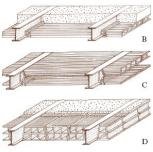
C. 3.



Floors with metal beams and vaults

It is used in the whole national territory, mainly in urban areas.

C.4.



Floors with metal beams and hollow bricks

It is used in the whole national territory, mainly in urban areas.





• VAULTED STRUCTURES:



Brick vaults

In Greece, it spread up to 1950 mainly in lowland areas, in the whole national territory.

C.6.



Stone vaults

In Greece, it spread up to 1950 in the whole national territory.

• REINFORCED CONCRETE FLOORS:

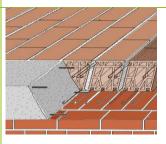
C. 7.



Cast-in-situ reinforced concrete slab

In Greece, it spread since 1910 mainly in the whole national territory and it is still used today.

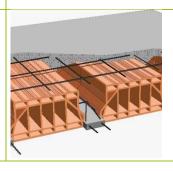
C.8.



Hollow clay block floor without reinforced concrete slab

This type of construction technique is not used in Greece.

C.9.



Hollow clay block floor with reinforced concrete slab

It is used in the whole Greek territory.





C.10.		Prefabricated reinforced concrete floor No changes, all the data correspond.
C.11.		Hollow brick floor with prefabricated joists No changes, all the data correspond

Foundation system (Table D)

Regarding foundation system, there is a perfect match with the scheduled data.

• CONTINUOUS FOUNDATIONS:

D. 1.	Stepped foundation, engraved in the rock No changes, all the data correspond.
D.2.	Regular stone masonry foundation No changes, all the data correspond.
D.3.	Irregular stone masonry foundation No changes, all the data correspond.
D.4.	Stone rubble foundation with concrete binder No changes, all the data correspond.









Brick masonry foundations

No changes, all the data correspond.

D.6.



Continuous reinforced concrete foundations (strip footings)
No changes, all the data correspond.

• PILE FOUNDATIONS:

D. 7.



Wooden piles

No changes, all the data correspond.

D.8.



Reinforced concrete piles

They consist of prefabricated steel or concrete piles that are driven into the soil with a specific machinery (steel piles), or cast in place in a drilled hole to form a RC pile.

They are generally used for compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. Also for areas with very high water table, and soil of poor geotechnical properties. They are generally used for RC structures, as well as for mansonsry building foundation reinforcement. Their depth can reach 10 m or more under the ground level.

They spread since 1970 in areas in the whole national territory and are still used today for very heavy buildings and also for building foundations on weak soils





RECENT RC FOUNDATION:

D. 9.



Inverted beams foundation

The constituent material is reinforced concrete for the whole foundation structure.

It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil; generally, $1-1,5\,\mathrm{m}$.

It spread since 1910 in the whole Italian territory and it is still used today.

D. 10.



Isolated footing

The constituent material is reinforced concrete for the whole foundation structure.

It consists of a grid of isolated plinths under the RC frame structure. It can be used with any type of soil, in relation to the vertical loads. Generally, it is used for medium-compressible, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils) according to local standards. It is used both for stone and brick masonry structures. Its depth is related to the consistency of the soil; generally, 1,5-2 m.

It spread since 1910 in the whole Italian territory and it is still used today. $\label{eq:today}$

D. 11.



Slab foundation

The constituent material is reinforced concrete for the whole foundation structure.

It consists of a monolithic RC platform and it is generally it is used with compressible clay soils, having poor quality, such as type C (deposits of medium-thick coarse-grained or medium-fine or fine-grained soils) and type D (deposits of coarse-grained soils that are not very thick or thin-grained) according to local standards. It is used both for masonry and RC elevation structures. Its depth is related to the consistency of the soil; generally about 1 m.

It spread since 1910 in the whole Italian territory and it is still used today.







Main structural types

The previously cited bibliographic sources have already allowed understanding how, in general, the main structural types listed in the case of the Italian territory find a good correspondence with the Greek ones.

MASONRY BUILDINGS:

1	ANCIENT MASONRY BUILDINGS
	It is present in the Greek territory.
2	ANCIENT MASONRY BUILDINGS WITH ANTI-SEISMIC PROTECTION
	It is present in the Greek territory.
3	PRE-MODERN MASONRY BUILDINGS
	It is present in the Greek territory.
_	
4	MODERN MASONRY BUILDINGS
	It is present in the Greek territory.

• RC BUILDINGS:

5	PRE-CODE REINFORCED CONCRETE BUILDINGS				
	It is present in the Greek territory.				
6	RECENT REINFORCED CONCRETE BUILDINGS				
	It is present in the Greek territory.				
7	MODERN REINFORCED CONCRETE BUILDINGS				
	It is present in the Greek territory.				





5. Intervention criteria on existing buildings

Evaluating the influence of any intervention on an existing building, local or global, means, first of all, predicting how the building will modify its response to static and seismic stresses. This means to understand the mechanical characteristics of the structure and the geometry of the building, which are fundamental for the response of the system.

The study of the construction must focus on some relevant elements, as the materials' mechanical properties, the geometry, the construction details, the crack and deformation pattern of the building. The knowledge of these basic elements should clarify which are the principal vulnerabilities of the structure. Thus, it is possible to choose the best intervention to obtain an improvement in structural behaviour. Before proceeding with the design of any seismic improvement intervention, it is necessary to evaluate the quality of the materials. The ability of the structural elements to resist predictable static and dynamic actions is closely linked to the characteristics of the materials that constitute them and their degree of conservation. If they cannot develop sufficient capacity, any analytical assessment of seismic improvement interventions will be ineffective.

The choice of the type, technique, extent and urgency of the intervention depends on the results of the previous assessment phase, aiming primarily to counter the development of local mechanisms and / or fragile mechanisms and, consequently, to improve the overall construction behaviour.

In general, the aspects to consider are: repairing any present damage, reducing deficiencies due to clear errors in the design or execution phase; reducing the conditions that determine strong irregularity of the buildings, in terms of mass, strength and/or stiffness (also linked to the presence of non-structural elements); reducing the masses; reducing the excessive deformability of the horizontal structures; improving the connections of the non-structural elements; improving the foundation system, where necessary.

The choice of the type of intervention and the consequent design depends on several factors, including:

- the nature and conformation of the building. To achieve the safety requirements of buildings with historical-monumental nature or with artistic value, the intervention must be based on maximum conservation, trying to minimize the impact as much as possible;
- reduction of interference. In the case of interventions on strategic or relevant buildings (schools, hospitals, etc.), it will be necessary to minimize interference with the activities carried out within, while preserving the users' safety even in the preliminary cognitive phases;
- temporal contingency. The safety of existing buildings may become necessary following the
 occurrence of emergencies (such as in the immediate post-seismic event, in the presence of a swarm,
 in case of a progressive damage to the building due to changes conditions of use, lack of maintenance,
 etc.). Different measures must be implemented depending on the context where the intervention is
 carried out, including installing any provisional works;
- performance to be achieved. Among the numerous available techniques for the designer, it is essential
 to consider not only the speed of intervention in terms of both application and design, but also, and
 above all, the structural performance to be achieved.

5.1. Intervention criteria on masonry buildings

The interventions on masonry structures must aim at reducing the vulnerability in existing buildings. They must be evaluated for the capacity: to improve the connections between floors and walls (or between roof and walls





and between walls that converge in edges), to reduce and eliminate the non-contrasted thrusts of roofs, arches and vaults, to strengthen the walls around the openings.

These factors make it possible to determine whether the building is capable of developing an overall seismic behaviour. In fact, if the walls are not connected to each other, they probable tend to behave independently; vice versa, a good connection gives the structure a box-like behaviour.

This behaviour is favourite by the presence of rigid floors, capable of redistributing the horizontal stresses to the vertical structures in proportion to their resistance.

It is certainly useful to draw a graphic representation of the deformations and cracks that emerge from the analysis of the wall surfaces and construction details if this is present. The crack pattern allows to have an overview of the general state of conservation of the building and to identify the different damage mechanisms and the causes that generated them.

To obtain the best efficiency, interventions must be graduated and articulated according to actual needs. They must be correlated to the damage mechanisms that produced them or that can produce them (stresses in the plane and outside the masonry plane, presence or absence of connections, increase in the thrusts of the horizontal structures, hammering effects, subsidence of the foundations, etc.), so as to identify the most suitable interventions to reduce the specific vulnerability. All materials used must be durable and compatible with the original ones.

We can classify interventions based on of their function:

1. <u>WALLS STRENGTHENING</u>: masonry reinforcement interventions, aimed at restoring deteriorated or damaged masonry and improving their mechanical properties. Generally, they are not sufficient to improve the overall structural integrity of the building. For the success of the intervention, it is necessary that the used materials have physical-chemical and mechanical characteristics similar to those of the original masonry. The intervention must aim at recovering a substantially uniform resistance and the continuity in the wall stiffness, also making the appropriate clamping, if missing. The insertion of concrete elements is allowed only where the ratio between the effectiveness obtained and the impact caused is lower than other types of possible interventions, such as damaged and particularly stressed architraves.

The most commonly types are:

- a. Local dismantling and reconstruction: it is aimed at restoring both masonry continuity along the crack lines and severely deteriorated masonry portions, when they show good quality, a certain regularity, and limited damage. This intervention can also be used for closing niches, flues and for reducing voids. It is recommended to use materials similar to the original ones in shape, size, stiffness, and strength, paying attention to make an effective connection between the new elements and the existing masonry. An adequate clamping in the plan of the wall and, possibly, even transversely, is mandatory in order to achieve maximum homogeneity and monolithicity of the repaired wall.
- b. *Injection of binder mixtures*: it is used to improve the mechanical characteristics of the masonry in the presence of widespread cracks and of internal voids; good mechanical characteristics of the material are required. When intervening with injections of binder mixtures, it is not possible to perform effective clamping between the wall panels. Moreover, it is ineffective if used on masonry types that by their nature are poorly injectable (scarce presence of voids and / or voids not connected to each other). Particular attention should be paid to the choice of the inlet pressure of the mixture, to avoid the occurrence of transverse expansion. The mixture to be injected must be chosen carefully, taking into account the





chemical, physical and mechanical compatibility with the original type of masonry. For example, the use of cement-based mortars can cause damage to the masonry, in particular on the surfaces, due to the production of salts: the emergence of soluble salts from the mortar causes efflorescence on the masonry surface, particularly harmful in the presence of coating plasters.

- c. Joints repointing: if carried out in depth and on both faces, it can improve the mechanical characteristics of the masonry, in particular in the case of masonry of not high thickness. If, on the other hand, it is carried out on masonry of greater thickness and / or with facing not properly connected to each other, or incoherent, this intervention may not be sufficient to guarantee a significant resistance increase.
- d. *Intramural tying*: when the wall has scarcely connected faces, the insertion of artificial tying elements made of reinforced conglomerate inside the coring holes, can create an effective connection between the wall surfaces, avoiding the triggering of compression instability phenomena. Furthermore, this intervention gives the wall a monolithic behaviour due to actions orthogonal to its plane. In the case of degraded facings, it is advisable to carry out a preventive consolidation with the injections of mortar or joints repointing. This is an invasive intervention, as it is irreversible and to be applied in an extensive form, but that preserves the original behaviour of the historical masonry.
- e. *Jacketing*: the masonry jacketing with RC plaster is an invasive intervention and not consistent with the principles of conservation. It is effective only if it is carried out on both faces and if transverse connecting bars are installed. This technique should be considered only in single masonry walls, heavily burdened by vertical loads or damaged by seismic events. In these cases, an alternative can still be represented by a demolition and reconstruction of the wall portion. From a seismic point of view, it should be considered that the high shear stiffness of the reinforced wall panels profoundly alters the typical seismic response of a load-bearing masonry construction. Generally, this has negative effects, thus the reinforcement intervention must be accurately calibrated to limit the eccentricities between the centre of gravity of the masses and the stiffness. Jacketing with fibre-reinforced fabrics or sheets is also an invasive intervention, whose effectiveness must be adequately proven, both locally and globally. This technique can represent a valid solution for localized interventions, for example flexural reinforcements, reinforcement of architraves, or aimed at absorbing the thrust of elements of the roof, arches and vaults.
- 2. <u>INTERVENTIONS AIMED AT REDUCING THE LACK OF CONNECTIONS:</u> these interventions are aimed at ensuring that the construction has a satisfactory overall behaviour through the creation of a good connection system between the structural elements. The realization of these interventions is an essential prerequisite for the application of global seismic analysis methods, which are based on the resistance of the walls in their own plane, assuming their stability with regard to seismic actions outside it. If the structural elements are not sufficiently connected to each other, the response of the building cannot be global, therefore the results of this kind of analysis would be completely unreliable. The connection between the structural elements can be improved through the use of the following interventions:
 - a. *Tied rods*: they are one of the most used intervention for masonry structures. They constitute a reinforcement system widely tested and applied in all types of wall structures, even in very old ones. The system consists in the reinforcement of the masonry building through tie rods capable of restoring a box-like behaviour of the structure. These connections are therefore





effective for: masonry walls placed in contiguity, opposing masonry walls, masonry walls subjected to the action of thrusts such as not mutually contrasted vaults. Generally, single or paired tie rods are arranged in the two main directions of the building, at the level of the floors and in correspondence with the load-bearing walls; anchor plates are used as fixing system. From an executive point of view, the operations are: drilling of the walls and/or floors; masonry breakthrough for insertion of the anchor plates; possible improvement of the mechanical characteristics of the anchoring areas; insertion of tie rods; tensioning of the tie rods; closure of the anchoring area.

- b. Reinforced perforations: they are appropriate in the case of unconnected elements, such as corner areas, or to clamp orthogonal masonry and to consolidate damaged parts. This technique is limited to cases where other solutions are not feasible, due to the invasiveness of these elements and the dubious effectiveness. From an executive point of view, the phases are: drilling of the masonry for the installation of the reinforcements (inclined holes); cleaning of the holes in order to ensure perfect adhesion between masonry and binder mixture; positioning of the reinforcements (with anchors to avoid any slipping off); performing injections.
- c. External hoops: the hoops can be made both using metal elements and composite materials. The use of FRP bands (acronym of fibre reinforced polymer) is currently spreading. This type of material has high mechanical strength characteristics, allowing very low thicknesses, with minimal intervention invasiveness. The external hoops can create an effective connection between orthogonal walls; it is more effective for buildings of small dimensions, where the straight sections of the hoop are not too extended, or when anchors are made in correspondence with the masonry edges (areas of intersection between facade masonry and orthogonal panels). It is necessary to avoid the onset of stress concentrations at the edges of the walls, by adopting appropriate distribution elements.
- d. *Tie beams at the masonry top*: they are indicated for tying the walls in case of lack of connections and to improve interaction with the roof. The execution of tie beams at intermediate levels, performed in the thickness of the wall (especially if made of stone), should be avoided, given the negative effects that the breach openings produce in the distribution of stresses. From an executive point of view, the intervention phases are: shoring of the floor or the roof; in the case of insertion at floor level, a break in the existing wall; execution of the tie beam and connection with existing structures.

The tie beams can be made of:

- i. reinforced masonry: they must be made of full-thickness masonry, with a metal or composite material reinforcement inside. The connection between the tie beam and the underlying masonry can generally be guaranteed by adherence, meshing and friction. The use of reinforced perforations arranged with an inclined course must be avoided as much as possible, as it strongly weakens the affected portions of masonry.
- ii. **steel**: the metal tie beams represent a good technical solution thanks to their lightness and the limited invasiveness during the installation. They can be carried out in two different ways: through a reticular structure placed at the top of the wall at the roof level and connected to the vertical masonry through reinforced perforations, otherwise through the installation of plates or profiles on the two faces of the load-bearing masonry, connected together with passing bars. In the presence of poor-quality masonry, the intervention must be accompanied by a work of reinforcement





- on the wall. The metal tie beams lend themselves particularly well to be used as a connecting element between the wooden elements of the roof and the walls, also contributing to the elimination of any thrusts.
- iii. **reinforced concrete**: for the right application of this solution, it is necessary to limit the height of the beams. This avoids overloads and excessive stiffening of the wall structure. Indeed, in the event of seismic actions, there is the risk of high tangential stresses between the tie beam and the masonry, with consequent sliding and disintegration of the latter.
- e. Interventions aimed at ensuring the connection of floors and roofs to the walls: the connection between the horizontal structures and the walls is necessary to prevent the beams pulling out, with consequent collapse of the floors, caused by horizontal actions. An effective connection between these elements is also necessary for a correct distribution of the floor forces to the various partitions. Moreover, the walls are retained, reducing the risk of out-of-plane overturning. In the case of intermediate floors, the heads of the wooden beams can be anchored to the masonry through metal or other material (resistant to traction elements). The insertion of RC tie beams in the thickness of the masonry at the intermediate levels produces negative consequences on the structural functioning of the wall and is therefore to be avoided. In the case of very flexibly and deformable walls, due to a high distance between the orthogonal spine walls, it may be useful to insert steel tie beams. These elements are made with plates or section bars, disposed on the two surfaces of the wall, and they are connected to each other by passing bars. In the case of perimeter walls, the possibility of making the tie beams with only one section bar inside, anchored to the external wall face through widespread passive anchors, can be evaluated, so as not to affect the external image of the building.
- 3. INTERVENTIONS ON ARCHED OR VAULTED STRUCTURES AND INTERVENTIONS AIMED AT REDUCING THRUSTS: in addition to the interventions that will be described, to reduce or eliminate the thrusts, it is possible to intervene by decreasing the permanent loads by acting on the extrados using light fillings, or small brick walls (frenelli), etc. In this case, however, it is necessary to take into account that this intervention will alter the original pressure curve; moreover, a lower permanent load makes the vault more sensitive to variations in accidental loads. In the presence of lesions in the arches or vaulted structures, a repair aimed at reconstituting the contact between the parts must be provided. Interventions can be carried out by simple injections of mortar or, in special cases, by inserting wedges. In areas subject to crushing, it may be necessary to resort to masonry replacement. Particular attention must be paid in the event that there are evident and significant loss of shape of the arch or vault: with this type of instability, the rehabilitation is often problematic, so it could be necessary to resort to the insertion of sub-arches or other integrative structures.
 - a. Interventions on arched or vaulted structures: they are carried out with the use of the traditional tie rod technique, which compensate for the thrusts on the supporting walls and prevent mutual distancing. Since this is an intervention on an existing construction, the tie rods have to be installed with an adequate pre-stress, in order to absorb part of the thrusts, without reaching excessive values which could lead to localized damage of the anchoring masonry.
 - b. Buttresses or thick walls: they are used to absorb the thrusts of vaults and arches. However, this type of intervention necessarily gives rise to a considerable visual impact, whose opportunity must be evaluated case by case in relation to various factors. The effectiveness





of these insertions is subject to the creation of a correct clamping with the existing wall structure, to be carried out through localized connections in stone or brick elements, and to the creation of an adequate foundation structure.

- 4. REDUCTION OF THE EXCESSIVE DEFORMABILITY OF THE FLOORS: the floors must be effectively connected to the walls thanks to a sufficient support and, when necessary, through connection elements that prevent them from slipping off in the event of horizontal actions. This condition avoids the collapse of the floor itself and allow them to participate in the overall seismic response, thus guaranteeing a box-like behaviour. The role of floors is to transfer the horizontal actions to the walls and constitute an additional constraint for the walls stressed by actions orthogonal to their plane. For these reasons, when the floors deformability is excessive, it is useful to operate a limited stiffening that is inevitably associated with an increase in the elements' resistance. Only in special cases, it is necessary to significantly stiffen the floors in their own plane to distribute the seismic action between the different walls: without this intervention the forces are concentrated on the most loaded elements, anticipating their breakage, and, in the case of planimetric irregularities, on the perimeter elements, with accentuation of the torsional effects.
 - a. Construction of a second planking on the existing one: a limited stiffening of the floors, in the case of wooden elements, can be achieved by working on their extrados. One possibility is to fix a second plank on the existing one, arranged with an orthogonal or inclined orientation, paying particular attention to the connections with the side walls.
 - b. Reinforcements with metal strips, or of composite materials with a crossed pattern: alternatively, or in addition, to the second planking, it is possible to use reinforcements in metal strips, or in composite materials, fixed to the planking with a crossed pattern. A similar benefit can be achieved through bracing made with metal tie rods.
 - c. Reinforcement with collaborating slab in light concrete: a stiffening of the floor can also be obtained by adding a collaborating concrete slab (possibly lightened in order not to overload the wall box). In the event that the wooden elements are not adequately connected to the walls, it may be necessary to connect the slab to the perimeter walls using point connection elements. In the case of wooden beam floors and terracotta tiles, the extrados stiffening interventions can be adopted with a thin reinforced slab in lightened concrete, suitably connected to the perimeter walls and to the wood beams.
- 5. INTERVENTION ON ROOFS: they must be evaluated according to the type of material. It is generally advisable to maintain wooden roofs, as it is a light system, maintaining low masses in the highest part of the building, while ensuring elastic characteristics similar to those of the underlying wall structure. In general, the connections between the upper part of the masonry and the roof frameworks and planks should be improved as much as possible. In addition to the traditional methods: the punctual connection of the wooden elements with metal anchor plates, which prevents their translation on the wall structure, it is possible to create wooden or metal tie beams, suitably connected both to the walls and to the wooden roof, so as to guarantee the connection of the elements to each other and to the vertical masonry. In general, huge RC tie beams should be avoided, due to the different stiffness they introduce in the system and the overload they cause on the wall structures.

When the roof has a framework generating thrusts, as in the case of inclined struts, it is necessary to provide for the introduction of elements that compensate for the thrust. In the case of truss roofing, the presence of a good connection of the nodes to the vertical walls must be checked, as it is necessary





to avoid their sliding and detachment in the case of horizontal actions. In case of lack of connection, it can be improved by plates and bars in steel or in other materials (for example fibre-reinforced).

- 6. <u>CHANGE IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS</u>: this intervention involves the insertion of new walls, in order to limit the problems arising from planimetric or altimetric irregularities and to increase the resistance to seismic action; these interventions must be adequately verified. The creation of new openings is possibly to be avoided; if necessary, alignment between openings in vertical direction must be maintained. Furthermore, a closed box frame must be realized, with stiffness and resistance to restore the pre-existing condition as much as possible.
- 7. <u>PILLARS AND COLUMNS</u>: they are generally intended to bear vertical loads with small eccentricities, thus the interventions must be configured to restore the initial resistance to normal stresses, if lost, with hoops and tessellations. In some cases, the hooping can be performed with bands of fibre-reinforced material. It may also be necessary to eliminate, or in any case contain, the horizontal thrusts exerted by arches and vaults with the insertion of tie rods or, if appropriate, the construction or strengthening of buttresses or masonry ribs.
- 8. <u>FOUNDATION INTERVENTIONS</u>: for ordinary type of civil construction the inadequacy of foundations is rarely the only, or the main, cause of the damage observed after an earthquake (different is the case of rural buildings, where foundations are often strongly undersized or practically absent). It is therefore possible to omit the interventions on the foundation structures, as well as the relative checks, if the following conditions are verified: there are no significant failures attributable to subsidence in the foundation, the interventions on the elevated structure do not involve substantial alterations to the static layout of the building, the same interventions do not involve significant changes in the stresses transmitted to the foundations and the phenomena of overall building overturning due to seismic actions are excluded. The interventions must, in any case, aim primarily at maintaining the pre-existing distribution of contact pressures. They must also guarantee values as low as possible for the absolute and differential expected settlements, which must, in any case, be compatible with the characteristics of the construction. Therefore, interventions distributed over large areas should be favoured, avoiding as much as possible the use of localized deep foundations. Due to the considerable risks that arise from inducing movements in the subsoil that are not easily predictable, the use of injection treatments in the soil should in general be excluded.
 - a. Foundation enlargement: in the case of undersized foundations (related to high values of the acting load and / or the presence of particularly poor foundation soil), an intervention to widen the foundations can be evaluated. The enlargement is achieved by inserting beams, or reinforced stalls, below the existing foundation structures. Particular attention must be paid to create an effective connection between the old and the new foundation to obtain an overall system sufficiently rigid to limit possible differential settlements. RC beams, steel crosspieces of adequate stiffness or post-tensioned bars must be adopted to guarantee the transmission of forces due to friction and similar devices. This type of intervention also has the beneficial effect of creating an effective horizontal connection between the walls at the foundation level.
 - b. *Poles and micropiles*: they are used if a deep foundation must be realized. It must generally be extended to the entire building, evaluating the overall behaviour of the foundation system. It is necessary to introduce an adequate connection between the piles and the existing elements, consisting, for example, of reinforced beams. Another solution to ensure an effective connection is to use piles that are drilled through the masonry, with a drilling length





sufficient to transfer the loads by adhesion. In this case, it will be necessary to verify the strength of the existing structure in the changed support conditions.

5.2. Intervention criteria on RC buildings

The assessment of the high seismic vulnerability of the existing building stock at the international level is increasingly important, as repeatedly demonstrated by the huge socio-economic consequences of seismic events. In recent decades there has been a significant increase in studies aimed at develop structurally effective reinforcement solutions and, at the same time, easy to apply, economically convenient, potentially reversible and respectful of the preservation of the cultural heritage.

Even in the case of buildings with RC structures, the repetitiveness of some collapse mechanisms requires interventions targeted to eliminate the original design deficiencies (or "non-design" in the case of older buildings) that compromise any accurate structural analysis. Some examples are: the weaknesses of the external beam-pillar nodes in the RC frames, the fragility and poor connection of the infill walls compared to the RC framework.

By choosing the strengthening interventions, an overall qualitative analysis of the characteristics of the building (structural and non-structural parts) cannot be ignored. This preventive analysis allows to set up a repair and strengthening project aimed at eliminating, or drastically reducing, the weaknesses and shortcomings that may compromise the correct overall behaviour of the structure. Therefore, the conceptual definition of the interventions must be followed by the choice of the most suitable technology. This choice can derive from both economic and construction aspects, concerning the geometric characteristics of the elements and the interaction with other building elements.

In general, consolidation interventions can be grouped into two major categories:

- Local reinforcement interventions
- Interventions on global behaviour

For the first category, the aim is to increase the strength and ductility of some elements (preferably in a systematic way) to modify the behaviour of the structure minimally. This typology includes strengthening nodes, RC jacketing, steel jacketing, CAM method, and reinforcements with FRP.

For the second category, the works intervene by modifying the response of the structure, acting on the vibration period and on the stresses distribution in order to reduce the project demand on the existing elements. This type of intervention includes the insertion of structural walls, the insertion of steel bracing (including dissipative), and the use of seismic isolators (FEMA 547, 2006).

As for the techniques and materials available, they can range from more traditional solutions to more advanced technologies and materials. Among the traditional solutions there are: jacketing, the reinforcement or addition of new infill panels, the insertion of shear walls, and the use of dissipative bracing. More recent techniques are, for examples, base insulation, the use of composite fabrics (carbon or glass fibers, Fiber Reinforced Polymers) for the reinforcement of single elements and of connections between them, the adoption of apparently counterintuitive approaches such as the selective weakening of structural elements or connections to modify the fragile behaviour to a ductile mechanism.

The strengthening interventions on nodes and structural elements must reduce, as much as possible, the triggering of fragile mechanisms (e.g., failure of the beam-column joints due to actions transmitted directly by the shafts converging in the node itself; failure of the lower node-pillar connection; shear failure at the ends of the beams; shear failure of short pillars). The interventions must also increase the ductility of the pillars ends, where strong demands for ductility are normally concentrated.





The damaging effects or the ineffective collaboration of infill and partition walls are essentially determined by their scarce or absent connection with the structural frame, particularly along the upper edge and the lateral edges, due to their typical executive methods: they are realized after the completion of the structure. The creation of effective connections between these panels and the structural frame achieves the threefold objective of preventing their ruinous collapse outside the floor, improving their collaboration with the reinforced concrete structure and limiting or eliminating adverse local effects.

For more complex conditions, the global approach is preferred. The interventions must take into account: the reinforcement of all or part of the structural elements, the addition of new resistant elements (such as RC walls, steel braces etc.), the elimination of any weak floor and the introduction of an additional structural system capable of fully resisting the seismic action.

We can classify as follow interventions based on of their function:

1. REDUCTION OF THE RISK FRAGILE MECHANISMS + INCREASE IN THE DUCTILITY OF THE PILLARS ENDS: the aim of this intervention is to improve the beam-column resistance hierarchy, trying to protect the joints from fragile shear breaks, thus aiming at the development of a plastic hinge in the beams. In particular, the intervention tries to avert the failure of the lower node-column connection, the failure caused by shear at the ends of the beams and the failure caused by shear of short pillars. Interventions may result in increased shear resistance in beams and pillars (at their edges) and confinement of the ends of columns, where the maximum ductility demands in buckling are concentrated. In this manner, the resistant capacity of the nodes and of the upper portion of the pillars is increased and able to resist the shear action exerted by the infill.

Composite materials require an external reinforcement made with metal or carbon fabrics or, in the case of steel jacketing, with a plate on the node and metal section bars placed in the corners of the pillars. When the CAM system is used, external reinforcement is provided to connect the L-shaped press-bends that confine the pillars above and below the node.

The increase in shear resistance in the ends of the beams allows preventing a possible fragile mechanism that could be activated if the resistance of the concrete is relatively low and / or the shear reinforcements are lacking. The reinforcement can be realized, for composite materials, with a U-shaped bandage with unidirectional carbon fabric or, for steel jacketing, with the arrangement of metal plates. In the case of CAM system, the wrapping of the beam is applied with high-strength steel strips contrasted on L-shaped press-bends on the intrados and on plates or plates drawn on the extrados.

2. <u>BENDING REINFORCEMENT:</u> Due to inadequacy design, it is frequent that the earthquake causes damage to the beams near the centre line, for the combined effect of the vertical loads and the seismic action particularly of its vertical component. In this case, it is necessary to adopt bending and / or shear strengthening interventions on the beam to improve its bearing capacity. These interventions, however, must avoid increasing the resistant moment of the beam at the joint attachment in order to not favour fragile collapse mechanisms in weak columns and strong beams).





Short	tcoming	Reinforcement Technique					
Туре	Shortcoming	Addition of New Elements	Improvement of Existing Elements	Improving the Connection Between Elements	Reducing Demand	Removal of Elements	
Configuration	Weak Plane Mechanism	Adding Resistance or Stiffness to The Plane to Balance the Others					
	Recessed Corners in Plan. Torsional Behaviour	-Adding Floor Surfaces to Minimise the Effects of Recesses. -Adding Walls And/Or Frames		Addition of Tie- Rods, Floor Connections, Floor Bracing			
	Weak or Torsion-Causing Tamping	- Reinforced Concrete Walls -Masonry Walls -Steel or Braced Frames	-Disconnect Infills -Replace Infills with Resistant Walls from the Structure			Removal of Infill	
Load Path	Inadequate Connections	Adding or Reinforcing Beam Grids					

Table 4 – Global reinforcement techniques (reworked from FEMA 47)

Shorto	oming	Reinforcement Technique					
Туре	Shortcoming	Addition of New Elements	Improvement of Existing Elements	Improving the Connection Between Elements	Reducing Demand	Removal of Elements	
Global Resistance	Insufficient Number of Elements or Presence of Weak Elements	-Concrete walls -Masonry walls -Braced steel frames -Bending resistant elements (reinforced concrete or steel)	increasing the dimensions of beams and columns		-Removing floors (or loads) at upper levels - Additional dampers - Seismic isolators		
Global Stiffness	Insufficient Number of Elements or Elements with Inadequate Rigidity	-Concrete walls -Masonry walls -Braced steel frames -Bending resistant elements (reinforced concrete or steel)	-Increase beam and column dimensionsReinforce columns with FRP Casing of reinforced concrete or steel columns - Improving the deformation capacity of elements		Additional dampers	Elimination of elements generating short columns	

Table 5 – Global reinforcement techniques (reworked from FEMA 47)





- 3. INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE: these types of interventions can be used on beams, on pillars and also on structural nodes. Even if local, these interventions nonetheless have a non-negligible influence on global behaviour. In particular, the RC jacketing, being based on the increase in the size of the sections, modifies both the position of the centre of gravity (with the relative ellipse of the stiffnesses) and the vibrating modes. In a marginal way, this effect is also present for steel jacketing and the CAM method, while with the use of FRPs the greatest contribution is the increase in deformation capacity. This type of intervention must be applied, as far as possible, regularly and uniformly. Interventions on limited areas of the building must be appropriately evaluated so as not to achieve significant variations in the distribution of stiffness, resistance and masses.
 - a. *RC jacketing*: the pillars and pillar-beam nodes jacketing is an effective intervention obtained through the reinforcement of the original section with a RC jacket.
 - b. This technique has already been applied for some time and is supported by clear regulatory references. With the appropriate attention to detail, a series of benefits are obtained, such as the increase in stiffness, the increase in resistance to normal stress, bending, shear and in ductility. It contributes to achieve seismic adaptation easily.
 - c. Steel jacketing: the reinforcement of RC pillars using metal angles and plates is widely used to improve the resistant and deformation capacity of existing buildings, especially when these are lacking in seismic details or are in critical conditions even concerning vertical loads. Several authors (Braga et al. 2006, Montuori and Piluso 2009, Nagaprasad et al. 2009) have carried out theoretical-experimental studies on the capacity of the angles section bars connected directly in the intersections with the beams and floors. Often, in such conditions, the technique is difficult to perform, as it requires the creation of a perfect connection between the elements. It is sometimes preferred to carry out interventions where the corner parts are not in direct contact at the ends, coupling them to the columns with compensated shrinkage cement mortars, to improve adhesion between the surfaces.
- 4. <u>REDUCTION OF DISPLACEMENTS</u>: a global intervention approach consists of adding newly built structural elements to make them absorb most of the seismic action, thus stiffening the structure. Commonly this type of new structural elements are dissipative walls (if a significant contribution of resistance is needed) or steel braces.
 - a. Use of cast-in-situ partitions or post-tensioned prefabricated walls: a drift control strategy of an existing RC frame building, with vulnerabilities in terms of both design and construction details, can be achieved by inserting traditional shear walls or external partitions. These elements are cast in place to allow the formation of plastic hinges at the connection with the foundation. Other techniques are the adoption of new-concept low-damaging systems, with non-adherent post-tensioning and external and replaceable heat sinks. The post-tensioning, through cables, strands or bars anchored to the foundation, guarantees capacity for overturning moment and increase shear resistance at the base. It is kept non-adherent to protect against yielding and therefore premature failure and guarantee (remaining in the elastic range) centring capacity. The post-tensioning techniques can use various materials, both traditional (harmonic steel for RC pretension, in the form of stranded bars, etc.) and new types, such as cables or carbon post-tension strips (FRP), with high resistance and without corrosion problems.
 - b. Addition of non-dissipative bracing systems: the insertion of steel bracing, for the seismic improvement of existing buildings, represents an effective solution for structures that do not meet the performance requirements of the current standards. These techniques are normally





associated with the introduction, within the structural grid, of a system of diagonal steel bracing. In this case, the main effect is the increase in stiffness of the structure with a consequent significant reduction of displacements, which corresponds to an increase in the response in accelerations and, therefore, in the forces of inertia.

- 5. <u>SEISMIC ENERGY DISSIPATION</u>: the so-called passive systems modify the stiffness and / or capacity characteristics of the structure, obtaining a more favourable dynamic response to the actions of the earthquake. The devices are sized to work best during the maximum intensity phase of the project earthquake, maintaining constant behaviour throughout the life of the building. The base seismic isolation and energy dissipation systems fall within the passive control.
 - a. Addition of dissipative bracing systems: This technique, in fact, drastically reduces both the deformability of the system (thanks to the stiffness of the bracing) and the size of the forces involved (thanks to the dissipative capacity of the devices inserted in the bracing). This entails a clear improvement in the behaviour of the entire structural organism and of all the non-structural elements contained therein (infill walls, architectural elements, plant components, etc.). In general, these interventions require a more demanding design and more in-depth analysis than traditional intervention techniques. Therefore, this approach has to be preferred if a substantial improvement has to be achieved.
 - b. *Base isolation*: The isolation at the base reduces the seismic energy entering the existing structure; these devices also provide a significant dissipation, which determines a further reduction of stresses and displacements. Indeed, at the same time, it allows a reduction in the input energy and an increase in its dissipation. This technique was born towards the beginning of the 1980s as a highly innovative technique in the anti-seismic engineering sector, aimed at obtaining structural performances significantly higher than those achievable in buildings designed according to ordinary anti-seismic criteria. During the 1980s and early 1990s, there was a significant development in theoretical studies and practical applications in building, essentially new construction. In the context of existing structures, the use of seismic isolators is much more complex and is applicable according to the structural configuration, as it is necessary to identify the level where to place the seismic isolation, compatibly with the functions assigned to the affected building area.

6. Cataloguing of the intervention techniques

The development of the spreadsheets on the cataloguing of intervention techniques on existing buildings in historical centres started with the understanding of the main materials used for the interventions.

For interventions on existing buildings, it is possible to use both traditional materials, such as cement, mortar, reinforced concrete or steel, and innovative materials, such as special mortars, fibre-reinforced polymers (FRP), special metals (high-strength steels, stainless steel etc.) and some particular devices borrowed from advanced seismic protection systems and based on passive control technologies.

The solution to be adopted can be identified by evaluating the materials that can be used for the intervention and the original materials of the existing structures, analysing the possible combinations between them. The choice of the most suitable combination is the main objective of the structural consolidation activity.

In the cataloguing, five different materials were identified for interventions on masonry buildings, and three on RC buildings. Two of these are applied only to masonry constructions as they are properly used in pre-





modern intervention techniques, i.e., wood and brick. The other three (steel, RC and fibres) can be applied to both masonry or RC buildings.

		New Composite Materials				
		Steel	Concrete	Masonry	Wood	FRP
	Steel	++				+
Damaged	Concrete	++	+			+
Structures	Masonry	++	+	+	+	+
	Wood	++			+	+

Figure 25 - Combination matrix between original material and intervention material

From an initial analysis of the possible consolidation systems, it emerges that:

- Interventions based on cement and cement conglomerates are very widespread, especially for seismic
 upgrading interventions. These materials are usually injected and / or used to create RC construction
 elements, but their compatibility with masonry is questionable; moreover, these interventions are not
 reversible.
- Interventions based on polymers or composite materials are quite recent and, at least for the moment, there are not enough available elements to judge their duration over time; their reversibility is partial.
- Interventions based on steel structures have been frequently and successfully adopted both in the case of monumental constructions and in the case of normal masonry or RC buildings.
- The use of special devices is still scarce, but suggests a more massive spread in the future.

From a structural point of view, the analysis of several concrete examples worldwide shows that, with an adequate steel structure, it is possible to satisfy the complex needs that can emerge during the consolidation process. In addition, in the case of buildings of architectural value, steel makes it possible to follow the severe limitations imposed restoration principles.

Steel solutions can effectively carry out interventions static safety, local reinforcement, improvement, or seismic adaptation of existing masonry or RC buildings. The steel solutions, favoured by the high strength/weight ratio of the material and the ease of transportation, minimize the operations to be carried out in construction site and consequently facilitate the implementation.

It is necessary to highlight the problems related to the intrinsic differences between the new elements, or metal system, and the existing construction, having different material properties, execution tolerances, stiffness, etc. For this reason, the intervention design must be accurately sized. Thanks to the relative ease of installation and versatility, the steel systems can be used for the safety of buildings in different conditions, including the emergency ones or post-seismic emergency.

Regarding the material, in addition to the excellent characteristics in terms of resistance and ductility, the steel offers excellent durability performance even in contexts at high atmospheric corrosivity or in saline environments, if adequately protected from corrosion by protective treatments.

The wide range of available steel products for designers (rolled sections, hollow sections, round and square bars, welded composite sections, sheets, panels, etc.) lends itself to almost all interventions, offering a considerable number of solutions.





The use of metal carpentry for consolidation and structural interventions has the following characteristics:

- the prefabrication allows to weld the main elements in the factory. They are measured according to the operational and transport needs on-site, where they can be assembled using bolts;
- reversibility is typical of steel structures, where bolts are used not only for temporary joints, but also for final constructions;
- lightness of the structural elements, this is made possible by the high weight / strength ratio: it allows to simplify the transport and installation, minimizing the collateral effects due to the increase in load on existing structures;
- small size of the structural elements is natural consequence of the high structural efficiency of steel: this feature allows to simplify the replacement and / or integration of existing works with reinforcing elements;
- speed construction, a feature that is always desirable, but especially when the intervention is extremely urgent to prevent further deterioration and / or to ensure immediate protection;
- availability of a large variety of steel products to satisfy all construction and design needs, with a high level of flexibility.

FRP materials have been used for several years in naval, aeronautical and military sectors, where they are exploited for their unparalleled specific resistance (intended as mechanical tensile strength per unit of weight). The significant reduction in costs, in particular of carbon fibres, due to the great optimization of production processes, has allowed the introduction of FRP also in the building construction sector.

The use of composite materials has recently found increasing interest in the development of new types of fibres and matrices, as well as for applications based on the use of innovative technologies, that are alternatives to traditional systems.

Composite materials have proved to be very effective for structural consolidations in exceptional situations, such as extremely urgent interventions for the safety and temporary conservation of structures damaged by seismic events. Another area of application is the reinforcement of buildings of historical and artistic significance, where the requirements of "reversibility", "transparency" and "selectivity" of the intervention must be privileged.

FRP systems are made of composite materials, consisting of high mechanical strength fibres and polymeric resins, specially formulated for static and seismic strengthening of any type of structures.

The term FRP is the acronym of Fibre Reinforced Polymer, or "fibre-reinforced polymeric material". FRPs belong to the vast family of "structural composites" and are made up of reinforcing fibres immersed in a polymeric matrix. In fibre-reinforced composites, the fibres play the role of load-bearing elements both in terms of resistance and stiffness, while the matrix serves to protect them from external agents and to distribute the efforts. The fibres can be arranged in all directions, according to the design data, this allows to optimize the mechanical properties of the composite as needed. The peculiar characteristic of structural composites is to provide better mechanical performances or, at least, more "complete" than those provided by the single component phases. In polymeric matrix composites, the matrix is generally based on epoxy resins that mixed with an appropriate reagent, polymerize to become a glassy solid material.

The reinforcements consist of:

- Carbon fibres: they are distinguished in high strength and high elastic modulus fibres and high strength and very high elastic modulus fibres.
- Glass fibres: they are type E glass and glass type A.R. alkali resistant.
- Basalt fibres: they have intermediate properties compared to carbon and glass fibres, as they have comparable mechanical resistance to carbon fibres and similar modulus of elasticity to glass fibres.





Metallic fibres: they have very high mechanical resistance.

Fibre-reinforced polymeric matrix materials are composite materials, heterogeneous and anisotropic, which show a linear elastic behaviour up to collapse.

Structural composites are used in the form of distinct fabrics in:

- uniaxial, with the fibres all oriented in the direction of the length and held together by a light weft of non-structural type;
- biaxial, consisting of an orthogonal weft-warp weaving usually balanced (same percentage of fibres in both directions);
- quadriaxial, with fibres oriented in different directions.

Fabrics are distributed in the dry state and in rolls, to be used for impregnation with the "wet system" or on site with the "dry system".

Together with the fabrics, there are also rigid elements already impregnated with the resin, obtained through an industrial process of extrusion under traction (the pultrusion). They are used in the form of sheets and bars, are glued to the structure to be reinforced using epoxy resins of thixotropic consistency.

The main parameter that defines the characteristics of a FRP reinforcement is not the tensile strength, which is always enormously higher than the working rates of FRP reinforcements, but the elastic modulus. The higher the elastic modulus, the greater the stiffening contribution the fibres can provide.

The use of FRPs in the construction sector essentially concerns the restoration of degraded or damaged structures and their static and seismic rehabilitation.

Thanks to their lightness, FRP materials can be applied without the aid of special equipment and machinery by a limited number of workers, in a very short time and, often, without interrupting the operation of the structure.

The applications are very wide; they can be used for:

- static and seismic restoration of damaged or degraded structures, where it is essential to integrate the resistant section to traction and shear stresses;
- confinement of compressed or combined compressive and bending stress elements (pillars, bridge
 piers, chimneys) to improve their bearing capacity or ductility, whereas a simultaneous integration of
 the longitudinal reinforcements is required;
- reinforcement of bent elements, by external plating of the areas subjected to traction;
- seismic improvement of structures without increasing the seismic masses;
- plating of beam-pillar joints, for adaptation in the seismic field;
- reinforcement of load-bearing elements in buildings whose structural system is modified due to new architectural or use requirements;
- repair of structures damaged by fire;
- seismic upgrading of RC industrial buildings.

Other fibre-based systems are FRG systems, composite materials which, unlike traditional FRPs, allows the polymer matrix to be replaced using an inorganic binder with pozzolanic reactivity capable of ensuring an excellent chemical-physical and elastic-mechanical compatibility with masonry supports (stone, brick and tuff). They are applicable to the restoration and static and seismic rehabilitation of all types of concrete and masonry structures.

The term FRG is the acronym for "Fibre Reinforced Grout", i.e., "fibre-reinforced inorganic material". They consist of reinforcing fibres immersed in an inorganic matrix. These materials offer a series of advantages even in the presence of a historical-monumental building heritage, such as: high mechanical performance, low architectural impact, high durability, ease of application, and reversibility of the interventions. Moreover, they do not have any problem of corrosion of the applied reinforcements, unlike what happens for the steel plates





used in the restoration interventions carried out with the beton plaqué technique. Using these techniques there is no increase in the building masses.

Their application allows to compensate the lack of tensile and shear resistance of masonry structures and to give greater ductility to the overall behaviour of the structures. They consist of a square mesh in fiberglass or basalt, laid using a two-component, highly ductile, premixed cement mortar.

Inorganic matrix composites can be used as:

- structural reinforcement of wall surfaces, to be applied externally and / or internally;
- reinforcements to evenly distribute the stresses induced by seismic events on both RC and masonry elements;
- reinforcement for the correct connection of load-bearing walls to RC framed structures.

6.1. Intervention techniques on masonry buildings

The spreadsheets are intended to help identify and classify the most common intervention techniques used on existing masonry structures. The interventions found in the specific references, for existing masonry buildings, have been identified and for each of them the function and vulnerabilities that they are able to counter are indicated. Furthermore, it is indicated if the interventions are recommended or not on the basis of specific prescriptions at national level.

Five different materials have been catalogued in relation to the possible intervention techniques (STEEL, MASONRY, FIBERS, RC and WOOD).

In the tables relating to each partner, the cells whose contents have been modified have been highlighted in green. In bold, there are additions and clarifications provided by the PPs.

In the spreadsheets, the catalogued indications are:

- **FUNCTION**: the specific functions of the intervention were chosen between the following:
- REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;
- REDUCTION OF UN-CONTRASTED THRUSTS OF ARCHES AND VAULTS;
- REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS;
- IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS;
- IMPROVEMENT OF WALL RESISTANCE;
- STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS;
- INTERVENTIONS ON ROOFS;
- IMPROVEMENT IN THE FOUNDATION STRUCTURES;
- REALIZATION OF SEISMIC JOINTS;
- ADVANCED ANTI-SEISMIC TECHNIQUES;
- PILLARS AND COLUMNS;
- INTERVENTIONS ON THE STAIRS
- RECOMMENDED OR NOT RECOMMENDED: it is a judgment based on the following criteria:
- RESPECT FOR THE STRUCTURAL AUTHENTICITY;
- MINIMAL INTERVENTION;
- COMPATIBILITY;
- DURABILITY;
- NON-INTRUSIVENESS (NON-INVASIVITY);
- REMOVABILITY;





- **DIFFUSION (LOW, MEDIUM, HIGH),** indicates how widespread the practice is in the case of interventions on the existing heritage in the area of study.
- TECHNICAL COMPLEXITY (LOW, MEDIUM, HIGH), indicates the complexity of the intervention technique
- COST (LOW, MEDIUM, HIGH), indicates the cost of the intervention technique, if compared to the analogues one that have the same function
- EASILY APPLICABLE (YES, NO), indicates whether the intervention technique is easily applicable or not in relation to any architectural, urban or plant constraints

6.2. Intervention techniques on RC buildings

The spreadsheets are intended to help identify and classify the most common intervention techniques used on existing RC structures. The interventions found in the specific references, for existing RC buildings, have been identified and for each of them the function and vulnerabilities that they are able to counter are indicated. Furthermore, it is identified if the interventions are recommended or not on the basis of specific prescriptions at national level.

Three different materials have been catalogued in relation to the possible intervention techniques (STEEL, FIBERS and RC).

In the tables relating to each partner, the cells whose contents have been modified have been highlighted in green. In bold, there are additions and clarifications provided by the PPs.

In the spreadsheets, the catalogued indications are:

- **FUNCTION**: the specific functions of the intervention were chosen between the following:
- REDUCTION OF THE RISK OF FRAGILE MECHANISMS;
- INCREASE IN THE DUCTILITY OF THE PILLAR ENDS;
- INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE;
- SEISMIC ENERGY DISSIPATION;
- REDUCTION OF MOVEMENTS;
- BENDING REINFORCEMENT
- **RECOMMENDED OR NOT RECOMMENDED**: it is a judgment based on the following criteria:
- RESPECT FOR THE STRUCTURAL AUTHENTICITY;
- COMPATIBILITY;
- DURABILITY;
- REMOVABILITY;
- **DIFFUSION (LOW, MEDIUM, HIGH)** indicates how widespread the practice is in the case of interventions on the existing heritage in the area of study.
- TECHNICAL COMPLEXITY (LOW, MEDIUM, HIGH) indicates the complexity of the intervention technique
- COST (LOW, MEDIUM, HIGH), indicates the cost of the intervention technique, if compared to the analogues one that have the same function
- EASILY APPLICABLE (YES, NO), indicates whether the intervention technique is easily applicable or not in relation to any architectural, urban or plant constraints





7. Results of the cataloguing in PPs' Regions

As already highlighted, in the first draft, the spreadsheets were set up and compiled on the local experience of the LP Country, that is Italy. The files were sent in May 2020 to the PPs, which were asked to complete them for their Region and return them by the end of June 2020. The PPs were also asked to add the same information for local intervention techniques that were not already entered.

The result of the data collection performed by each PP is presented here.

7.1. Italy – PP1 (UNIBO) and PP2 (IIPLE)

In accordance with the Italian Cultural Heritage Code, buildings over 70 years old and that are part of the urban fabric of historic centres are considered of cultural interest by the "Guidelines for the assessment and reduction of seismic risk of the cultural heritage" aligned with the "Technical standards for construction". In recent decades, the safeguarding of cultural heritage from seismic risk (including, as mentioned, the urban fabric of historic centers) is felt, first of all, as a theme of prevention, scarcely implemented during the end of the 20th century, if not in singular cases. The preservation of cultural heritage depends on the nature of the projects implemented, since a poor-quality intervention is worse than no intervention (Ministero per i Beni e le Attività Culturali, 2006).

The current national approach, in terms of seismic improvement, is based on the knowledge of the building, thus require the elaboration of a project that, while giving appropriate safety guarantees, is respectful of the context where it is applied.

From the 1970s to the present, a new sensitivity has developed to address structural and seismic safety issues. The main objective is the preservation not only of the asset but also of the ascertained structural functioning; if this does not present deficiencies that could lead to its loss.

This new sensitivity substantially denies the previous approach that characterized the interventions on the buildings up to the end of the 90s, when the most common practice was to intervene on existing masonry buildings with diffuse use of reinforced concrete. This trend followed the enthusiasm that had permeated the country's building boom based on the massive use of reinforced concrete for new structures, reaching the peak in the 1960s and 1970s. Then, a few years later, the use of concrete also raged the building rehabilitation.

The regulations on seismic risk of the 1980s (Ministero dei Lavori Pubblici, 1981) recommended, for example:

- replacement of deteriorated timber floors with hollow-brick floors;
- strengthening of structural vaults in stone or brick by an extradosal RC slab;
- construction of heavy RC tie beams, both at the top and at the floor, generally obtained in breach in the thickness of the load-bearing walls.

In recent years, also wall strengthening solutions with cement mortar and the insertion of RC structural elements have been proposed and applied. However, these interventions were discouraged by the first seismic legislation of 2008, valid for the whole national territory, as they are considered invasive, non-reversible, problematic in their execution, not respectful of the original structural concept and techniques; furthermore, they increase significantly the building stiffness.

These interventions have shown all their limits on some recent earthquakes, when the buildings consolidated in this way have suffered devastating damage.

One of the main problems has been recognized in a practice, common until the end of the 90s, for seismic improvement of masonry buildings, i.e., the construction of RC tie beams at the roof level. The widespread use of this structural element was mainly linked to its ease of execution (Borri and De Maria, 2004).

Recent earthquakes (2009, 2012, 2016) have tested the seismic repair and improvement interventions carried out a few decades earlier on buildings damaged by previous earthquakes (Valnerina 1979, Umbria-Marche 1997, just to name a few examples referring to the current seismic crater of Central Italy, hit by the devastating earthquake of 2016). A test that was often heavily negative. This forced a serious reflection on the correct execution technique. Seismically adequate buildings, according to the traditional guidelines of the 70s and 80s on the seismic recovery of existing buildings, which suggested the replacement of wooden roofs and floors with heavy RC slabs, have recorded many partial collapses; many of them were due to the presence of very rigid RC tie beams, both at the top and between the floors.

These collapses happened because, when the RC tie beams are made on poor quality masonry, the difference in stiffness between the two elements determines a not uniform load transmission. This phenomenon affects only some areas, depriving large portions of the walls of the stabilizing compression action and thus leaving them free to overturn in the presence of horizontal actions. Basically, the excessive stiffness of the RC tie beam transformed it into a beam on two supports, transmitting most of the weight of the roof only on the end wall supports and, consequently, leaving unloaded the central part of the underlying wall. Furthermore, it was highlighted how rigid roofs, under the dynamic action due to the earthquake, tend to oscillate, unloading the walls which tend to overturn (Cangi, 2012). Recent experiences have shown how the use of "heavy" consolidation techniques can lead to unbalance conditions within historic building structures that worsen the overall static performance.

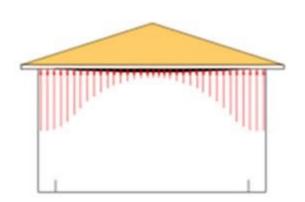




Figure 26 - Representation of the "beam effect" of the RC tie beam on masonry walls

Interventions should be as limited as possible, targeting specific parts of the building. In any case, the alteration of the original distribution of rigidities and masses of the building has to be avoided, taking into account the effects of interventions in the general framework. The choice of intervention techniques must be assessed on a case-by-case basis, giving preference to those that are less invasive and more compatible with the conservation criteria, also considering the safety and durability requirements. Interventions capable of transforming the building in a non-permanent way should be privileged. They must also be assessed on the basis of its cost, relating it to the extent of the benefit it produces and the actual need.

The intervention strategy can belong to one of the following general categories or combinations of them:

• reinforcement of the resistant elements, to selectively increase their characteristics, as resistance, stiffness, ductility or a combination of them (always paying close attention to the modifications induced to the structural scheme);





- insertion of new elements, compatible with existing ones, in order to eliminate the local vulnerability
 of some parts of the construction and improve the overall functioning in terms of resistance or
 ductility;
- introduction of passive protection through the use of dissipative bracing structures and / or base isolation;
- reduction of masses (with due precautions);
- limitation, or change, of the intended use of the building.

For application on existing masonry buildings, the not recommended interventions are:

- on vertical structures: reinforced concrete plaster with electro-welded steel mesh on the vertical walls;
 execution of reinforced perforations with steel bars anchored with cement-based injections;
 consolidation of the walls with cement mortar.
- on horizontal structures: consolidation of vaulted structures with reinforced concrete slabs and electro-welded mesh; execution of rigid slabs on the floors of irregular building aggregates.
- in roofing interventions: execution of thick reinforced concrete tie beams.

The RC tie beams, however, today are not prohibited, they are allowed also on listed historic buildings under certain conditions: "in general, thick reinforced concrete edge beams should be avoided because of the different stiffness they introduce into the system and the impact they produce. They can only be used when they do not alter the static situation of the masonry and their effectiveness is clearly demonstrated".

As for the inter-floor edge beams, the national directives advise against their execution in breach for the entire wall perimeter: "the insertion of RC edge beams in the thickness of the masonry at the intermediate levels produces negative consequences on the structural functioning of the walls, in addition to being an intervention not compatible with the conservation criteria" (DPCM, 2011).

However, the RC tie beams at the roof level are still valid in some building contexts as long as it is made with the appropriate precautions. It is important to limit their stiffness by using lightened or low strength concrete, and to improve the bonds to the underlying wall by inserting vertical bars. The inter-floor perimeter tie beam, when necessary for the consolidation of existing floors, should be limited to the punctual anchorage of the slab, for example, with the "dovetail technique" or with direct grouting of metal bars, avoiding any invasive breach in the load-bearing masonry.

Over time, next to the common RC technique, new and alternative construction solutions have been developed to overcome their excessive rigidity. Today it is recommended to perform top tie beams with different materials and techniques, for example in reinforced masonry, in lamellar masonry (by reinforcing the mortar joints with composite materials), or in steel (with perimeter anchoring of metal section bars). All these are valid solutions if checked with the historical-building context. In all cases, great attention must be paid to the quality of the wall texture and the vertical anchoring bars are inserted.

In RC structures, the globally ductile behavior of newly designed buildings is generally not found in existing ones. Indeed, they highlighted recurrent shortcomings during recent seismic events, essentially because of the used design criteria. They do not present particular anti-seismic measures and the methods of construction and execution lack attention to construction details and mechanical characteristics of materials.

For reasons related to the Italian seismic zoning, buildings with a RC frame structure were designed to withstand only vertical loads, substantially up to the 1970s. This led to structures with "strong beams - weak pillars", with sometimes disastrous consequences, as various seismic events have shown.

To design and perform effective reinforcement interventions on a building, it is important to correctly identify its structural deficiencies. Conceptually, verifications are conducted by comparing the seismic demand, that





is, the effects on the system due to the earthquake (forces and displacements), with the seismic capacity of the structure. Thus, it is possible to establish whether or not the system is able to cope with the seismic event. The capacity of a building is independent of seismic demand, but is based on its resistance and deformation reserves, which are derived from the organization, characteristics, and proportions of each individual component. Instead, performance demand is established by the regulations in terms of force requests (proportional to accelerations) and displacement (i.e., acceleration and spectral displacement).

To reinforce a structure, it is therefore possible to act in two different ways:

- Increase the capacity: it can be obtained by increasing the value of the maximum acceleration endured, i.e., improving the resistance or the ductility of the system.
- Reduce the demand: it can be achieved by reducing the incoming energy or increasing the dissipation of the structure.

The more traditional interventions belong to the first group, such as: the introduction of RC walls that improve the stiffness and strength of the structure; the increase of the sections and the protection of the reinforcement; the introduction of bracing diagonals, etc. These measures are the most commonly used, because they are simpler to implement. The trend is to apply the criteria of the protected buildings (reversibility, compatibility and non-invasiveness) also in the case of RC historical buildings, favoring the use of steel or fiber interventions on them, limiting the further application of reinforced concrete to recent buildings.

The interventions that reduce demand are, for example, the insulation at the base and the adoption of devices designed to dissipate the energy of the earthquake. These measures are less used on the national territory, and often limited to particular categories of structures, such as highly crowded buildings (schools, public buildings, etc.) or classified as strategic (hospitals, emergency centers, etc.), which must reach the maximum level of seismic adaptation in order to reduce the impact of the event in terms of users' involvement.

Masonry buildings – Steel solutions (Table A)

The seismic improvement techniques using steel are currently very widespread in Italy, especially for historic buildings, as they are reversible, minimally invasive and easy to build. Many of these have a low cost; others, more complex, have a higher cost.

They can be applied to various parts of the structure and are able to solve most of the problems that existing masonry buildings can present: they create the connection between floor and walls, avoiding the overturning of the facades; they provide stiffening to the floors, reducing their deformations; they reinforce the vertical elements or permit the creation of new openings for doors or windows through hoops.





Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDED	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.	THE STATE OF THE S	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 2	Paired tie-rods on both sides of the wall or paired plates on the two sides of the wall connected together with steel bars and external anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 3	Tie-rods in the thickness of the wall, made with metal bars or steel cables passing through a hole injected with nonshrink mortars	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	YES	HIGH	LOW	LOW	NO





A. 4	Floor connections made with coupled steel profiles on two sides of the wall and connected to each other, between one room and the other and to the outside with steel	2 (25886 170-00-12 that one NCH in prefero 000 mis con from 000 mis con fr	Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 5	rebars, ribbed metal plates, and bolts. Crossed steel		Reduction of	YES	LOW	LOW	LOW	YES
	bands in the thickness of the floor	Concrete or I suggestion and Concrete or I su	the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs					
A. 6	Tie-rods for arches and vaults made with steel bars, with the possibility of tensioning them		Reduction of un-contrasted thrust of arches and vaults;	YES	HIGH	LOW	LOW	YES
A. 7	Tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 8	Stitching, through reinforced perforations made with steel bars	b Distriction of the second of	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	NO	LOW	MEDIUM	MEDIUM	YES





A. 9	Connection of	2794	Reduction of	YES	MEDIUM	MEDIUM	MEDIUM	YES
	floor slabs and roofs to walls (connection of purlins or ridge beams with the walls of the	SOUTH A HTCHAIN A HTCHAIN A HTCHAIN AND HTCHAIN BACTICALAEL SCATCIA DI SCATCIA DI SCOTTORA DI SCOT	the deficiencies of the connections; intervention on roofs					
	tympanum)	OLEGAMENTO AUE MURATURE						
A. 10	Steel plates connecting the wooden plank to the walls	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability of the floors; intervention on roofs	YES	LOW	LOW	LOW	YES
A. 11	Application of steel anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 12	Replacement of floor and roof slabs with iron floor and brick planks or wooden boards		Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs	YES	MEDIUM	MEDIUM	MEDIUM	YES





A. 13	Stiffening of floors with metal strips	Productivation Inchesian	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES
A. 14	Adding beams of the same type as existing ones (steel beams)		Reduction of high deformability of the floors; intervention on stairs; intervention on roofs	YES	LOW	MEDIUM	MEDIUM	NO
A. 15	Steel box frame connected to masonry walls to create new openings		Improvement in the distribution of resistant vertical elements; strengthening of wall portions around the openings	YES	HIGH	MEDIUM	MEDIUM	YES
A. 16	Reinforcement intervention on arches with steel elements		Improvement in the distribution of resistant vertical elements; strengthening of wall portions around the openings	YES	LOW	HIGH	MEDIUM	NO
A. 17	Reinforced repointing, combining the traditional repointing with the inclusion, within the bed joints, of reinforcing bars.		Improvement of resistance in walls	YES	LOW	HIGH	HIGH	NO





A. 18	Confinement of pillars and columns through the application of steel hoops reinforcements	Improvement in the distribution of resistant vertical elements; pillars and columns	YES	HIGH	MEDIUM	LOW	YES
A. 19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados	Strengthening of wall portions around the openings	YES	LOW	HIGH	MEDIUM	NO
A. 20	Substitution of existing architraves and jack arches with steel profiles	Strengthening of wall portions around the openings	YES	HIGH	LOW	LOW	YES
A. 21	Bracing of the roofing structures with steel cables or bars	Intervention on roofs	YES	LOW	LOW	LOW	YES
A. 22	Advanced anti- seismic techniques (base isolation systems, dissipative bracing systems)	Advanced anti- seismic techniques	NO	LOW	HIGH	HIGH	NO

Masonry buildings - Masonry solutions (Table B)

Current seismic improvement techniques employing masonry recall the concepts and principles of the construction of historic buildings thus fall under the so-called "pre-modern techniques".

Brick material, rather than stone, is widely used in vertical structures. Particularly to reinforce walls, to compensate for any gaps, to rebuild weak parts, to insert buttresses or to thicken excessively slender walls.





The use of this material is instead scarce for horizontal structures, considering its nature; the only rather widespread use of bricks in floors is for the stiffening of vaults through the so-called *frenelli*.

The masonry reinforcement techniques with injections of mortars, or resins, inside special cavities and the restyling of the joints, for the replacement of deteriorated mortar, are also very widespread.

Reinforced masonry tie beams are becoming more popular in recent years and they are a very advantageous option: they have a stiffness comparable to that stone or brick masonry one, but thanks to the reinforcement, they resist very well to traction, bending and cutting. Moreover, they are reliable in the medium and long term and, if built perfectly, they are fully compatible with the materials of traditional building.

В	Interventions us	ing masonry solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	HIGH	LOW	YES
B. 2	Buttress on masonry walls		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults	YES	LOW	LOW	LOW	NO
B. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called "scuci-cuci" = "unstitch-stitch")		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	HIGH	LOW	LOW	YES





B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	YES	LOW	LOW	MEDIUM	YES
B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	MEDIUM	MEDIUM	YES
B. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	HIGH	MEDIUM	YES
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders	gen joints reported growing growing and selection and sealed growing g	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	LOW	YES
B. 8	Localized grout injections of mortars or resins		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	MEDIUM	YES





В.	9	Structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	MEDIUM	YES
В.	10	Substitution of existing architraves and jack arches with reinforced brick masonry		Strengthening of the wall portions around the openings	YES	HIGH	LOW	LOW	YES
В.	11	Execution of masonry foundation below the existing one	Murdura portania Fondazione esistente Estindontazioni in rurelura di muttori tissaria con malta consentida	Improvement in foundation structures	YES	LOW	HIGH	HIGH	NO
В.	12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	NO	LOW	HIGH	MEDIUM	NO
В.	13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors	YES	HIGH	MEDIUM	LOW	YES

Masonry buildings – Fibres solutions (Table C)

The reinforcement of masonry walls is one of the most important and widespread interventions among those aimed at improving the building performance, because the walls are stressed both vertically, by the static actions, and horizontally, by the seismic action, potentially triggering kinematics in and out of their plane. To perform the structural reinforcement of the wall panels, as written, several types of intervention are available. As for fibres, it is possible to use bandages with FRP systems (carbon fibre fabrics combined with resins) or fibre-reinforced systems with a low thickness inorganic matrix can be used. They derive from the





combination of nets, or strips, of various nature (fiberglass, basalt or steel) incorporated in inorganic matrices, lime or cementitious mortars, to be applied with a maximum thickness of 15 mm.

These solutions are spreading in the last 10 years as they are highly recommended by the local Superintendencies, since they are considered to be minimally invasive and removable. The main advantage, however, remains their lightness.

There are still few manufacturers of these materials, so the costs are higher than those of techniques that allow the same improvements with traditional materials. In addition, it must also be remembered that their application requires very skilled workers.

С	Interventions us	ing fibres solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
C. 1	Application of composite materials strips (reinforced fibres)		Reduction of the deficiencies of the connections; intervention on roofs; pillars and columns	YES	MEDIUM	MEDIUM	MEDIUM	YES
C. 2	Tie beams in brick and FRP		Reduction of the deficiencies of the connections; intervention on roofs;	YES	LOW	MEDIUM	MEDIUM	YES
C. 3	Stitching, through reinforced perforations made with fiberglass or carbon fibre bars	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	YES	MEDIUM	MEDIUM	MEDIUM	YES





C. 4	Stiffening of floors		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
	with FRP fibers		the					
			deficiencies of					
			the					
		Solaio rinforzato con FRP	connections;					
			reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs;					
			intervention on					
			stairs					
C. 5	Intrados or		Reduction of	YES	HIGH	MEDIUM	MEDIUM	YES
	extrados		un-contrasted					
	application of		thrust of					
	composite		arches and					
	materials strips to		vaults;					
	vaults (reinforced	1631	intervention on					
	fibres)		stairs					
		ATTENDA !						
C. 6	Jacketing, through		Improvement	YES	MEDIUM	MEDIUM	MEDIUM	YES
	a reinforced		in the					
	plaster with fibres		distribution of					
	mesh		resistant					
			vertical					
			elements;					
			improvement					
			of resistance in					
			walls; pillars					
			and columns					
C. 7	Strengthening of		Strengthening	YES	LOW	LOW	MEDIUM	YES
	architraves and		of the wall					
	jack arches by		portions					
	applying carbon		around the					
	fibre strips or		openings					
	meshes to the							
	intrados							

Masonry buildings – RC solutions (Table D)

The interventions using concrete have been the mostly used in the national territory due to their easy realization, as materials are easy to find and because specialized workers are not required. However, the reinforced concrete used for interventions on existing masonry buildings has shown a very damaging effect in recent earthquakes, due to the poor compatibility between concrete and masonry from the point of view of structural behaviour.

As already highlighted, on several occasions, where reinforced concrete tie beams have been adopted together with hollow brick roofs, collapses have occurred outside the plane of the upper parts of the walls. This mechanism is caused by the substantial increase in stiffness, which generates a greater seismic force, and increases in the difference in stiffness between the roof and the wall.





D	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams	ADMIA IN CLS ARRAYA	Reduction of the deficiencies of the connections; intervention on roofs	NO	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Res. 99 2000 Solder in CLs. Singerior Solder in Cls. Solder in CLs. Singerior Solder in Cls. Solder i	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs	NO	MEDIUM	MEDIUM	LOW	YES
D. 3	Replacement of floor and roof slabs with reinforced concrete slab		Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs	NO	LOW	MEDIUM	MEDIUM	YES
D. 4	Stiffening of floors with a reinforced concrete slab		Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs	NO	HIGH	LOW	MEDIUM	YES





D. 5	Reinforced concrete box frame connected to masonry walls to create new openings	Improvement in the distribution of resistant vertical elements; strengthening of the wall portions around the openings	NO	HIGH	MEDIUM	LOW	YES
D. 6	Realization of new structural elements (reinforced concrete walls or pillars)	Improvement in the distribution of resistant vertical elements; pillars and columns	NO	LOW	HIGH	HIGH	YES
D. 7	Reinforcement intervention on arches with reinforced concrete elements	Improvement in the distribution of resistant vertical elements; strengthening of the wall portions around the openings	NO	LOW	HIGH	MEDIUM	YES
D. 8	Jacketing, through a reinforced plaster with welded steel mesh	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	NO	HIGH	MEDIUM	MEDIUM	YES
D. 9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)	Improvement of resistance in walls	YES	MEDIUM	MEDIUM	LOW	YES
D. 10	Intramural tying, through the application of punctual	Improvement of resistance in walls	YES	MEDIUM	HIGH	MEDIUM	YES





	confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	deser year left miner deser year left miner deser legt hemme						
D. 11	Substitution of existing architraves and jack arches with a reinforced concrete beam		Strengthening of the wall portions around the openings	NO	HIGH	LOW	LOW	YES
D. 12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		Improvement in the foundation structures	YES	HIGH	MEDIUM	MEDIUM	YES/ NO
D. 13	Execution of a reinforced concrete foundation below the existing one		Improvement in the foundation structures	YES	MEDIUM	HIGH	HIGH	NO
D. 14	Execution of foundation by micro-piles		Improvement in the foundation structures	YES	MEDIUM	MEDIUM	MEDIUM	NO

Masonry buildings – Wood solutions (Table E)

Current seismic improvement techniques employing wood recall the concepts and principles of the construction of historic buildings, thus fall under the so-called "pre-modern techniques".

The use of wood to reinforce horizontal structures is frequent, considering its mechanical characteristics.





In particular, the replacement, or insertion, of a double wooden planking at the floor or roof level, with the aim of stiffening the horizontal plane, is very common. This technique does not increase excessively the weight of the floors, as happens with the insertion of RC slabs.

The wooden roof tie beams were a technique widely used in the past, today often abandoned due to poor durability. However, it is a very compatible solution with the horizontal structure and with the walls, as long as it is suitably protected.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHINICAL COMPLEXITY	COST	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	Non-states saltwards Southern States and August States St	Reduction of the high deformability of the floors; intervention on roofs	YES	MEDIUM	LOW	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES
E. 3	Replacing the roof plank with a double wooden plank		Reduction of the high deformability of the floors; intervention on roofs	YES	HIGH	LOW	MEDIUM	YES
E. 4	Timber tie beam		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	LOW	YES

RC buildings – Steel solutions (Table F)

The use of steel reinforcements on RC existing structures is one of the classic methods of intervention; e.g., one of the most classical is the employment of steel jacketing and beams plating to compensate for the missing longitudinal reinforcement. The CAM system, patented at the end of the 90s, instead, is part of the innovative consolidation techniques using steel, and allows to create a diffused stirrup distribution, added afterwards in place. This technique allows to avoid fragile shear failure mechanisms of beams, pillars and nodes. Thus,





through a careful design, it is possible to hierarchize the behaviour of the building allowing the maximum exploitation of its ductile capacities. This system was born for the consolidation of masonry buildings, but its use on RC structures distinguishes it from other techniques for its easy and quick application.

F	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
F. 1	Steel jacketing for column and beam strengthening, through welding or bolting with a steel section, where the gap between the concrete and steel is filled with grout		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	LOW	MEDIUM	YES
F. 2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive		Bending reinforcement		LOW	LOW	LOW	YES
F. 3	Addition of bracing systems		Reduction of displacements; reduction of the risk of fragile mechanisms		LOW	MEDIUM	MEDIUM	YES
F. 4	Addition of dissipative bracing systems		Seismic energy dissipation; reduction of the risk of fragile mechanisms		LOW	HIGH	HIGH	NO





F. 5	Dissipative external systems	Reduction of displacements; reduction of the risk of fragile mechanisms	LOW	HIGH	HIGH	NO
F. 6	Bandaging of reinforced concrete walls and pillars with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts"), which uses a highperformance metal tape closed on itself through joining elements; this creates circles under tension which induce an active three-dimensional confinement.	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	YES
F. 7	Bandaging of reinforced concrete nodes with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts")	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	NO
F. 8	Advanced anti- seismic techniques, as base isolation systems	Advanced antiseismic techniques	LOW	HIGH	HIGH	NO





RC buildings – Fibres solutions (Table G)

These solutions are spreading in the last 10 years as they are very light and thin, and therefore they do not vary the structural weight. Considering the recent diffusion, the costs are higher than the other techniques in steel and RC, due to the fact that the manufacturers of these materials are still few. Furthermore, their application requires very competent workers.

Interventions with fibres are used today in all component parts of the structural system: pillars (which are generally entirely wrapped), beams and floors (for bending reinforcement), nodes (for shear reinforcements) and infill walls (to avoid detachment from the structures and consequent overturning).

G	Interventions us	ing fibres solutions						
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMIMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>cost</i>	EASILY APPLICABLE
G. 1	FRP or fibres jacketing for column and beam strengthening, through the application of external fabric wraps around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	MEDIUM	YES
G. 2	FRP or fibres jacketing for column and beam strengthening, through the application of external strips around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	MEDIUM	YES
G. 3	Reinforcement of the floor joists with carbon fibres		Bending reinforcement		HIGH	MEDIUM	MEDIUM	YES





G. 4	Bending and shear reinforcement of beams with carbon fibres	Bending reinforcement	HIGH	MEDIUM	MEDIUM	YES
G. 5	Anti-overturning system for infill walls	Reduction of the risk of fragile mechanisms	HIGH	MEDIUM	MEDIUM	YES

RC buildings – RC solutions (Table H)

The use of RC has become very popular over the years. Similarly to steel, the key factors for their success have been their compatibility with the existing structure, the easy availability of materials and the lack of need for skilled workers. However, it should be considered that these techniques cause an increase in structural weight and that RC reinforcements often require a real widening of the foundation to transmit their new load to the ground. The other materials, steel and fibres, do not substantially add structural weight and significant additional thicknesses.

Н	Interventions us	Interventions using RC solutions						
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
H. 1	Reinforced concrete jacketing for column and beam strengthening, through the addition of an external layer of reinforced concrete		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	LOW	MEDIUM	NO





H. 2	Stiffening of floors with a reinforced concrete slab	Increase in the stiffness and strength of the structure	HIGH	LOW	LOW	YES
Н. 3	Realization of new structural elements (reinforced concrete walls or pillars)	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms	LOW	MEDIUM	MEDIUM	NO
H. 4	Replacement of structural elements	Increase in the stiffness and strength of the structure	LOW	HIGH	MEDIUM	NO
Н. 5	Replacement of non-structural elements	Reduction of the risk of fragile mechanisms	MEDIUM	LOW	LOW	YES
Н. 6	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Improvement in foundation structure	HIGH	MEDIUM	MEDIUM	NO
Н. 7	Execution of foundation by micro-poles	Improvement in foundation structure	MEDIUM	MEDIUM	MEDIUM	NO





7.2. Croatia – PP3 (Grad Kaštela)

According to the results of a systematic research, Croatia's national building stock consists of approximately 800.000 residential and 125.000 non-residential buildings (Stepinac, Kisicek, Reni'c, Hafner and Bedon, 2020). More than 75% of the building stock is older than 30 years, thus requiring, at least, some renovation or modification of primary structural components. In addition, more than 40% of the building stock is older than 50 years, meaning that the service life is fully expired. In the Croatian building sector, finally, it is recognized that up to 40% of the expenses are dedicated to the rehabilitation, modification and demolition of existing structures.

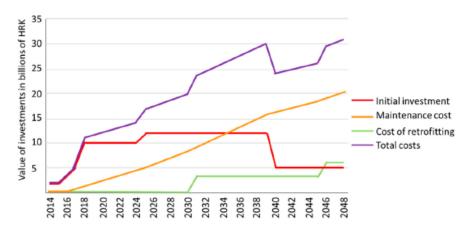


Figure 27 – Investment (values in HRK) for the renovation of Croatian national building stock (Stepinac, Kisicek, Reni´c, Hafner and Bedon, 2020)

The main characteristic of Croatian buildings constructed in the period before the 1970s is the use of traditional construction techniques and materials, such as masonry and timber. The structures were mostly brickworks, 30-60 cm thick, with mostly wooden floor, resulting in a statically satisfactory configuration. In the 1960s, reinforced concrete (in combination with timber and steel) started to progressively replace traditional constructional materials. In fact, most of the residential structures are still built as a combination of concrete, masonry and timber load-bearing components.

In the Croatian framework, it is recognized that the majority of residential buildings older than 50 years consists of masonry structures without appropriate bonding elements to connect floors and walls.

As in all other Countries, the seismic resistance of existing buildings is the criterion used to decide if rehabilitation or strengthening is necessary. The choice of intervention must consider the significance of the building, the quality of the construction material and its general condition; moreover, it is necessary to take into account the feasibility of the operation and the availability of the appropriate technology and qualified labour.

The provisions for ordinary buildings apply to historic buildings only if the application does not compromise their historical or artistic value. Conservation requirements must meet the following criteria:

- efficiency which must be proven by quality and quantity,
- **consistency** with the original structure and materials from chemical, mechanical, technological and architectural standpoint,
- durability which must be ensured by the use of materials and techniques that are durability
 comparable to those built in the building. If an occasional replacement is foreseen, the shorter
 duration is acceptable,
- reversibility of the procedure the applied technique can be removed in future improvements.





The size, the type of the procedure and the technique to be applied to the building depends on its inner characteristics, as: seismic resistance, significance and function performed. The process of reconstruction and/or strengthening should follow the principles of selectivity and consistency both in the selection of priorities and in the respect of historical values, using scientifically based interventions.

Methods for strengthening and/or restoration of historic masonry structures can be grouped as (Hadzima-Nyarko, Ademovic, Pavic, Sipos, 2018):

- those that renew and/or strengthen the walls in order to increase the resistance of the existing ones (glueing, injection, shot concrete, prestressing, wrapping, complete replacement of elements)
- those that increase the resistance of the entire structure (addition of new walls in the weak direction, shrinkage-connection of walls, ties, clamps)
- those that act on the spatial stiffness of the entire structure, i.e., it prevents the movement perpendicular to the plane (interconnection of the walls, interconnection of the walls and floors-tie beams, reinforced concrete frames, prestressed steel frames).

The renovation and/or strengthening of the cultural heritage buildings can be carried out using traditional and/or modern techniques, or, by a combining of them. There is a large choice of the type of existing interventions (both classical and innovative), as well as opinions about what would be more suitable for use. The strengthening of masonry surface is most often performed with ferro-cement, reinforced plaster and guniting or shotcrete.

Ferro-cement is characterized by high elasticity and resistance to crack occurrence, indeed, its tension resistance is equal to the carrying capacity of the reinforcement itself. In the case of compression load, the carrying capacity of this system depends on the ratio of reinforcement and mortar in the cross-section and on the cross-section orientation. The mesh helps to limit the movements of wall elements after cracking and increases the capacity of non-elastic deformations in-plane of the wall. Static cyclic experiments on the walls reinforced by this technique showed significant lateral in-plane resistance of the masonry. This technique is intended to decrease slenderness of the masonry, which improves the out-of-plane stability of the masonry. Reinforced plaster increases the ductility and shear resistance of masonry, reduces stresses and ensures better control of cracking. Mechanically, the most resistant mortars are cement-based, reinforced with nets or fibres. The improvement in the strength of the masonry depends on the thickness of the cement layer, the amount of reinforcement, the means for its binding to the wall and the degree of damage to the walls. Compatibility with original materials increases the durability of the intervention and guaranties a more efficient response of the strengthened wall to the seismic actions.

Guniting (jet concrete)-shotcrete significantly contributes to the improvement of dissipation of seismic energy due to the successive extension and relaxing of reinforcement and lateral resistance of masonry. The thickness of the concrete layer can be adapted to the seismic requirement, i.e., the required lateral resistance. This strengthening technique affects the physical properties of masonry, substantially limiting the vapour permeability, which should especially be considered in the old damp buildings.

Injection is generally effective as a strengthening technique, as it increases the initial stiffness and the masonry strength. Indeed, by filling the cavities and cracks, masonry restores its integrity, equalizes its stiffness, and increases bending and shear strength. Walls strengthened by injection has significant lateral deformability and better ability to dissipate seismic energy.

Injection efficiency in terms of improving the mechanical properties of masonry depends on physical and chemical compatibility of the mixture with the existing elements.

A cementitious injection mixture is suitable to fill larger voids and cracks, while for relatively small cracks (less than 2 mm wide) more efficient injection is with epoxy resins.





External strengthening with steel plates and/or bars/pipes provides relative stiffness to the structure and ensures seismic cooperation between the elements. Particularly, masonry's lateral resistance increases at the ends, due to the resistance of the perpendicular wall. Instead, vertical and diagonal support improves the lateral plane resistance and significantly reduces bucking. In the case of an earthquake, on such a supported and reinforced structure, cracks are expected, but the system of masonry and steel reinforcement, will remain effective and sufficiently rigid. The metallic components ensure a satisfactory mechanism of energy dissipation and good control of lateral displacement.

The confined masonry is performed with the aim to increase the deformability and to improve the bending and shear strength in-plane of the wall. The efficiency of the confined masonry on the existing wall depends, largely, on the relative stiffness between the existing walls and the frames, the material properties are less significant. The contribution of the confinement can be neglected, prior to cracking of the wall, but the lateral deformability is improved. In addition to preventing the disturbance of the whole masonry wall and improving ductility, this technique also increases the ability of seismic energy dissipation, but its effect is limited when it comes to improving the total resistance of the building (Hadzima-Nyarko, Ademovic, Pavic, Sipos, 2018).

Another intervention is the prestressing: it improves the final behaviour of the walls in-plane and out-of-the plane. Moreover, it ensures a significant increase in strength and ductility of the walls and an even distribution of loads and cracks. Prestressing has three positive effects: a) decreases the eccentricity of the resulting horizontal force in the cross-section; b) ensures a ductile behaviour of the reinforced element to bending stresses due to the presence of reinforcement in the tensile zone, allowing longitudinal forces of high eccentricity in complex, stone-reinforced, cross section; c) increases the resistance of the wall to the effects of horizontal forces.

Vertical prestressing was applied as a successful strengthening technique of cultural heritage, especially for Croatian belfries damaged during the earthquakes in Dubrovnik.

Traditional strengthening techniques often do not provide the structure with sufficient resistance to the maximum expected earthquake action and may cause changes in the original constructive shape that is not acceptable from the cultural standpoint. Strengthening with these techniques can often be complex, resulting in disruption of use, higher financial costs and, in some cases, these kinds of strengthening procedures are even unmanageable.

Recently, therefore, techniques that meet criteria such as minimal intervention, compatibility, durability, reversibility or substitutability have been increasingly appreciated (Hadzima-Nyarko, Ademovic, Pavic, Sipos, 2018).

Among modern techniques, to strengthen the historic heritage buildings, there are different types of composite polymers and devices of specific use and function. Interest in modern fibre-based techniques has grown very recently, and in particular following the earthquake that affected the Zagreb area in March 2020 (Kišiček, Stepinac, Renić, Hafner, Lulić, 2020).

Fibre reinforced polymers (FRP) are composites of at least two layers of fine continuous fibres and a polymeric substrate that connects them (epoxy resin, polyester, vinylester). Most commonly used fibres are: carbon fibre reinforced plastic (CFRP), aramid-fibre reinforced polymer (AFRP), glass-fibre reinforced polymer (GFRP), and natural fibres of cellulose and agave. Composite fibres take over the load, while the substrate ensures the load distribution between them, protecting the material against adverse environmental and mechanical damage. In addition to the mechanical characteristics, the composite efficiency is directly influenced by the matrix system, interlayer area and fiber orientation.

Depending on the external conditions, composite polymers may be thin, in the form of strips, lamellas, sheets and nets, or rods and strips of square or round cross-section.





The main characteristics of composite polymers are easy handling and transport, good material fatigue properties, high tensile strength in the direction of fibres, suitability for processing, extraordinary corrosion resistance, good behaviour under dynamic load, small specific weight, non-conductivity of electric current and good ratio stiffness-weight ratio compared to conventional materials.

An increase of overall masonry capacity is realized by placing vertical, horizontal and diagonal fibre-reinforced polymers on an existing masonry wall and by glueing and/or anchoring.

Devices based on smart materials (shape memory alloys) are devices that have the ability to recover from large deformations during the loading/ unloading cycle. They are developed as a substitute for the conventional rigid, horizontal connections of structural elements (masonry wall-floor/roof) with the aim of reducing the risk of out-of-plane walls collapse. The wired (nickel, titanium) flexible connection controls the displacements and limits the forces to the design value by changing the crystal structure according to heating/cooling or physical stress. As an effective means of improving the dynamic response of the structure, this technique is used to protect the historic cultural heritage buildings.

Numerical analyses and experimental results have shown that devices based on smart materials reduce the effects of ground acceleration and prevent in-plane collapse of the masonry. Shape memory alloys are sensitive to temperature changes.

Modern strengthening techniques with composite polymers, due to small or no additional weight, increased tensile and shear strength of the masonry and rapid, and non-invasive, applications have become the primary technique for masonry buildings of cultural heritage. The passive control devices affect the parameters of the dynamic response of the structure (attenuation, frequency or mass arrangement) with the aim to reduce the seismic demand. The use of these modern interventions is unavoidable in strengthening and preserving the buildings of historic cultural heritage (Hadzima-Nyarko, Ademovic, Pavic, Sipos, 2018).

The literature contents regarding technical specifications and practical application in strengthening projects on masonry buildings confirm that all the techniques that have been classified are known and used, with recent interest and application on those based on fibres.

An interesting starting point for our activity comes from the studies conducted by Croatian researchers to identify the best decision support model for the selection of the technology for seismic strengthening of masonry buildings (Sigmund, Radujkovic, Lazarevic, 2016).

According to this research, numerous criteria can be found in the literature reviews, based on the reinforcement techniques selected by the authors. Tomaževič (Tomaževič, 2009) suggests selecting the intervention based on the type of structure and its effects on the building. For each solution adopted must be considered, in addition to the structural flaw that can be solved, all the possible negative mechanical effects or the possible ineffectiveness of the intervention. A similar approach is present in Canadian guidelines (IRC and NRCC, 1995), European Norms and according to Kolbitsch (Kolbitsch, 1989). Additionally, according to Tomaževič (Tomaževič, 2009) and Kolbitsch (Kolbitsch, 1989), the historical value of the building plays an important role in the selection.

The importance of intervention costs cannot be left out. Canadian guidelines (IRC and NRCC, 1995) present a number of intervention technologies that are supposed to be cost-effective for all existing constructions, though authors of Canadian guidelines do not consider the usability of specific intervention on historic buildings.

Further on, Public Works and Government Services Canada (PWGSC) has oriented its research towards the identification of existing interventions and the development of new cost effective techniques. Also other authors have shown their interests in cost-effectiveness of seismic strengthening of buildings as Bostenaru (Bostenaru, Gehbauer, 2004) or FEMA (FEMA, 1994).





Material interactions are also to be considered, according to NIKER research program results (POLIMI, 2010). Another important criterion, according to Bothara (Bothara, Brzev, 2011), Corradi (Corradi, Borri, Vignoli, 2002), NRCC (IRC and NRCC, 1995) and many others, is also the behaviour compatibility between the building specifics and the chosen intervention.

Finally, a set of decision support criteria have been identified and selected:

- Recognition of the problem solved by the intervention which building weaknesses can be improved by the specific strengthening technique
- Consideration about the technology contribution to resistance increase
- Identification of the elements needed for the intervention to be effective, if any what additional improvements need to be done for the intervention to be effective
- Identification of the contraindications for a certain intervention, when should the technique not be used
- Consideration about the invasiveness of the technique how much of the original structure should be
 preserved if a certain technique is used, e.g., the introduction of vertical confinement is extremely
 invasive since each corner or wall end must be partially dismantled
- Applicability of the technique in built heritage if materials and techniques could have been used in the history
- Knowledge of technique material and behaviour compatibility
- Determination of cost.

During the review and identification of the important criteria for strengthening selection, the researchers also listed possible intervention techniques and create a database by combining these two subjects. Thus, within the database, a description of each important criterion was filled for each strengthening technology. Since the main aim of this work was not the discovery of new strengthening techniques, but the collection of existing ones, the main contribution was on three areas:

- technology contribution to resistance increase
- technology processes research
- technique execution costs.

In the first area, load-bearing structures was divided into two part: horizontal and vertical elements.

Regarding vertical bearing system, each intervention contributes to increase the seismic resistance of them. These contributions vary on the original bearing structure and the strengthening technology applied; therefore, the researchers stated that these cannot be generalized.

The strengthening of the horizontal bearing structure, on the other hand, can be generalized. These techniques can be divided into two groups: interventions that ensure in-plane rigidity of the element (slab) and those that do not. The latter can automatically be excluded from the decision support model.

Those strengthening techniques that can contribute to the in-plane rigidity of the slab are left in the model and can be taken into account without any special need to recheck their contribution, as long as limit states of their usefulness are known. These simplifications were made on the basis of the EuroCode calculation indications: in the EC6 and EC8, to assess the resistance capability of an existing building, floors (slabs) are thought of as having enough in-plane stiffness to ensure equal peak horizontal movement of walls. These indications set by EC can only be valid if slab constructions are rigid enough to ensure shear transference proportional to the wall stiffness.

Since historic buildings, built in the period 1860s - 1920s, were mainly characterized by wooden floors, which could not ensure in-plane stiffness, interventions to eliminate this weakness should be considered first when strengthening these old buildings.





The analysis of each strengthening technique, based on the execution processes and interaction with the existing building, was carried out to identify indicators and contraindications for their use. Usage contraindications were identified through indications to use a strengthening on one building type based on strengthening intervention and original structure mechanical compatibility, or new and old material chemical compatibility, or strengthening technique and its wanted and unwanted effects on the strengthened building, or even research results from the legislative chapter of this paper.

Research resulted in five simple questions used for contraindication identification and data collection:

- Does the need for partial or complete removal of building finishing works exist? If yes, which ones?
- Is the strengthening technology compatible to building materials? mechanical, chemical, executional compatibility
- Are there any special needs for the strengthening technique?
- Are the materials compatible with historical construction techniques? If not, is the intervention removable?
- What are the basic material needs for strengthening execution?

The research also aimed to allow the identification of execution feasibility and to provide a quick overview of the strengthening costs. To test the shortened cost comparison procedures, strengthening costs including all necessary works were evaluated for 3 different example buildings. For each one the costs were assessed for 5 strengthening techniques for floor structures and 5 strengthening techniques for walls, giving in total 25 strengthening combinations. Hereafter, those 75 combinations (25x3 buildings) were ranked from lowest to highest price. The research was conducted in several attempts to setup the simple as possible, but accurate cost comparison basis.

After many attempts, tests showed an interesting result: no matter how the building was to be strengthened, only the construction strengthening costs would never accumulate over 10-15 % of construction costs for a new building of a similar size.

Although the economic part is important in the strengthening works, based on the presented research results, it was concluded that:

- intervention feasibility, or the right price ratios, cannot be assumed based only on intervention works
 costs. This is due to the fact that they do not increase proportionally with complete intervention costs
 as when preparation and repair costs are included.
- To assess costs and feasibility of the intervention, it is necessary to include all works and cost estimations that cannot be shortened effectively
- strengthening works costs are extremely low comparing to complete intervention costs (never above 10÷15 % of construction costs for a new buildings) and therefore all strengthening works should be done at the same time as other retrofitting works (e.g. energy efficiency works, or general renovations works...).

The strengthening selection support model was intended to be simple and accurate, therefore complicated data analysis cannot be acceptable. The aim was to provide a direct decision support tool when selecting a strengthening technique for the desired building type.

To define the strengthening technique selection method, it had to be broken into work processes. These were acquired through experience in design and through regulative framework requirements. Hereby, for the strengthening technique selection process were defined:

- building typology identification
- building screening (on-site and building documentation)
- heritage protection status identification.



These three simple questions help to identify the possible interventions from the strengthening technique decision support list. This data collection enables the selection making engineer (the user) to simply identify buildings' weak points and create the "list of buildings' weak points". This process is the next existing element of the model:

• weak points identification

By knowing the building typology and all existing limits of the project (e.g., cultural heritage, accessibility of the building, etc.) the user can simply eliminate not usable strengthening techniques. For the others, intervention cost should be evaluated. This creates the next step of the model, consisting of two dependant processes:

- technology selection
- intervention cost evaluation.

This strengthening selection process, as is created, guides the user to select only those techniques that are suitable for the specific building type and the identified weak point of the building. The repeated cost evaluation process ensures that all possible strengthening combinations are assessed. Finally, suggestions on strengthening can be made on a simple cost ranking.

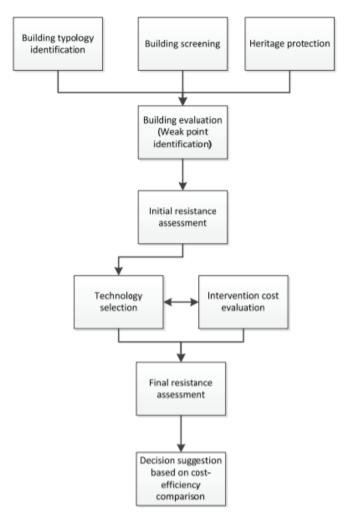


Figure 28 – Strengthening selection process – final process definition (Sigmund, Radujkovic, Lazarevic, 2016)





Masonry buildings – Steel solutions (Table A)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.	Herenstein Transmission of the Parketter	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 2	Paired tie-rods on both sides of the wall or paired plates on the two sides of the wall connected together with steel bars and external anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 3	Tie-rods in the thickness of the wall, made with metal bars or steel cables passing through a hole injected with nonshrink mortars	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement	YES	HIGH	LOW	LOW	NO





			of resistance in walls					
A. 4	Floor connection made with couple steel profiles on two sides of the wall and connected to each other, between one room and the other and to the outside with steel rebars, ribbed metal plates, and bolts.	2 plastes 170:00x12 mis conclines 0200 Tabulone M24 in previore 0200 mis conclines 0200 Concline	Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 5		Connect of a 1 singenoring sort of the second of the secon	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs	YES	LOW	LOW	LOW	YES
A. 6	Tie-rods for arche and vaults made with steel bars, with the possibili of tensioning the	y B	Reduction of un-contrasted thrust of arches and vaults;	YES	HIGH	LOW	LOW	YES
A. 7	Tie beams made with steel profile anchored with vertical reinforce perforations to the masonry wall		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 8	Stitching, throug reinforced perforations mad with steel bars		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	NO	LOW	MEDIUM	MEDIUM	YES





A. 9	Connection of floor slabs and roofs to walls (connection of purlins or ridge beams with the walls of the tympanum)	MARTICOLARE SATURA DI COLLEGAMENTO ANTICOLARE SATURA DI COLLEGAMENTO SATURA DI COLLEGAMENTO SATURA DI COLLEGAMENTO COLLEGAMENTO ALLE MUZATURE	Reduction of the deficiencies of the connections; intervention on roofs	YES	MEDIUM	MEDIUM	MEDIUM	YES
A. 10	Steel plates connecting the wooden plank to the walls	a a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability of the floors; intervention on roofs	YES	LOW	LOW	LOW	YES
A. 11	Application of steel anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 12	Replacement of floor and roof slabs with iron floor and brick planks or wooden boards		Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs	YES	MEDIUM	MEDIUM	MEDIUM	YES





Α.	13	Stiffening of floors		Reduction of	YES	LOW	MEDIUM	LOW	YES
		with metal strips	Profits Metallico Inchindero.	the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs					
A.	14	Adding beams of the same type as existing ones (steel beams)		Reduction of high deformability of the floors; intervention on stairs; intervention on roofs	YES	LOW	MEDIUM	MEDIUM	NO
A.	15	Steel box frame connected to masonry walls to create new openings		Improvement in the distribution of resistant vertical elements; strengthening of wall portions around the openings	YES	HIGH	MEDIUM	MEDIUM	YES
Α.	16	Reinforcement intervention on arches with steel elements		Improvement in the distribution of resistant vertical elements; strengthening of wall portions around the openings	YES	LOW	HIGH	MEDIUM	NO
A.	17	Reinforced repointing, combining the traditional repointing with the inclusion, within the bed joints, of reinforcing bars.		Improvement of resistance in walls	YES	LOW	HIGH	HIGH	NO





A. 18	Confinement of pillars and columns through the application of steel hoops reinforcements	Improvement in the distribution of resistant vertical elements; pillars and columns	YES	HIGH	MEDIUM	LOW	YES
A. 19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados	Strengthening of wall portions around the openings	YES	LOW	HIGH	MEDIUM	NO
A. 20	Substitution of existing architraves and jack arches with steel profiles	Strengthening of wall portions around the openings	YES	HIGH	LOW	LOW	YES
A. 21	Bracing of the roofing structures with steel cables or bars	Intervention on roofs	YES	LOW	LOW	LOW	YES
A. 22	Advanced anti- seismic techniques (base isolation systems, dissipative bracing systems)	Advanced anti- seismic techniques	NO	LOW	HIGH	HIGH	NO

Masonry buildings - Masonry solutions (Table B)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

Only the realization of structural joints presents differences; this is considered a recommended and easy to apply practice.





В	Interventions us	ing masonry solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	HIGH	LOW	YES
B. 2	Buttress on masonry walls		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults	YES	LOW	LOW	LOW	NO
В. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called "scuci-cuci" = "unstitch-stitch")		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	HIGH	LOW	LOW	YES
B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	YES	LOW	LOW	MEDIUM	YES





B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	MEDIUM	MEDIUM	YES
B. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	HIGH	MEDIUM	YES
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders	Serial selection and reads of growth provided and provided and provided pro	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	LOW	YES
B. 8	Localized grout injections of mortars or resins		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	MEDIUM	YES
В. 9	Structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	MEDIUM	YES





В.	10	Substitution of existing architraves and jack arches with reinforced brick masonry		Strengthening of the wall portions around the openings	YES	HIGH	LOW	LOW	YES
В.	11	Execution of masonry foundation below the existing one	Muratura portante Fondazione elistente Estimondustrione in suretura de mutice i lissassi con malta contentida	Improvement in foundation structures	YES	LOW	HIGH	HIGH	NO
В.	12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	YES	LOW	HIGH	MEDIUM	YES
B.	13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors	YES	HIGH	MEDIUM	LOW	YES

Masonry buildings – Fibres solutions (Table C)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

С	Interventions using fibres solutions							
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
C. 1	Application of composite materials strips (reinforced fibers)		Reduction of the deficiencies of the connections; intervention on roofs; pillars and columns	YES	MEDIUM	MEDIUM	MEDIUM	YES





C. 2	Tie beams in brick		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
G. 2	and FRP		the deficiencies of the connections; intervention on roofs;	, 25	2011			, 23
C. 3	Stitching, through reinforced perforations made with fiberglass or carbon fibre bars		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	YES	MEDIUM	MEDIUM	MEDIUM	YES
C. 4	Stiffening of floors with FRP fibers	Silves riskratio can FRP	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs	YES	LOW	MEDIUM	MEDIUM	YES
C. 5	Intrados or extrados application of composite materials strips to vaults (reinforced fibres)		Reduction of un-contrasted thrust of arches and vaults; intervention on stairs	YES	HIGH	MEDIUM	MEDIUM	YES
C. 6	Jacketing, through a reinforced plaster with fibres mesh		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	MEDIUM	MEDIUM	MEDIUM	YES





C. 7	Strengthening of	Strengthening	YES	LOW	LOW	MEDIUM	YES
	architraves and	of the wall					
	jack arches by	portions					
	applying carbon	around the					
	fibre strips or	openings					
	meshes to the						
	intrados						

Masonry buildings – RC solutions (Table D)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

D	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>cost</i>	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams	ADDIA N CLS ARMATA AG CORESTE LATERZE STATE & B/25	Reduction of the deficiencies of the connections; intervention on roofs	NO	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Lames packs As a 02 2020 Sales in CLS departs As	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs	NO	MEDIUM	MEDIUM	LOW	YES





D.	3	Replacement of		Reduction of	NO	LOW	MEDIUM	MEDIUM	YES
		floor and roof slabs		the					
		with reinforced	A CONTRACTOR OF THE PARTY OF TH	deficiencies of					
		concrete slab		the					
				connections;					
				reduction of					
				the high					
				deformability					
				of the floors;					
				intervention on					
				roofs					
D.	4	Stiffening of floors		Reduction of	NO	HIGH	LOW	MEDIUM	YES
		with a reinforced	1	the					
		concrete slab		deficiencies of					
				the					
				connections;					
				reduction of					
				the high					
				deformability					
				of the floors;					
				intervention on					
				roofs;					
				intervention on					
D.	_	Reinforced		the stairs	NO	HIGH	MEDIUM	LOW	YES
D.	5	concrete box		Improvement in the	NO	пібп	INEDION	LOW	153
		frame connected	THE PARTY OF THE P	distribution of					
		to masonry walls		resistant					
		to create new	· 图111 · 图1	vertical					
		openings	THE STATE OF THE S	elements;					
		openings	September 1	strengthening					
				of the wall					
				portions					
				around the					
				openings					
D.	6	Realization of new		Improvement	NO	LOW	HIGH	HIGH	YES
		structural		in the					
		elements	7 200	distribution of					
		(reinforced		resistant					
		concrete walls or		vertical					
		pillars)	44 WWW.	elements;					
				pillars and					
				columns					
D.	7	Reinforcement		Improvement	NO	LOW	HIGH	MEDIUM	YES
		intervention on		in the					
		arches with	TIN	distribution of					
		reinforced		resistant					
		concrete elements		vertical					
				elements;					
				strengthening					
			WALL STORY	of the wall					
				portions					
				around the					
				openings					





D. 8	Jacketing, through		Improvement	NO	HIGH	MEDIUM	MEDIUM	YES
	a reinforced plaster with welded steel mesh		in the distribution of resistant vertical elements; improvement of resistance in walls					
D. 9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)		Improvement of resistance in walls	YES	MEDIUM	MEDIUM	LOW	YES
D. 10	Intramural tying, through the application of punctual confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	Annu yen kil solar Annu yen kil solar Annu yen kil solar	Improvement of resistance in walls	YES	MEDIUM	HIGH	MEDIUM	YES
D. 11			Strengthening of the wall portions around the openings	NO	HIGH	LOW	LOW	YES
D. 12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		Improvement in the foundation structures	YES	HIGH	MEDIUM	MEDIUM	YES/ NO





D. 13	Execution of a		Improvement	YES	MEDIUM	HIGH	HIGH	NO
	reinforced		in the					
	concrete		foundation					
	foundation below		structures					
	the existing one							
D. 14	Execution of		Improvement	YES	MEDIUM	MEDIUM	MEDIUM	NO
	foundation by	11 1 1000	in the					
	micro-piles		foundation					
			structures					
							_	

Masonry buildings – Wood solutions (Table E)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	Nicha diffee sittlerida American del relación del considerado	Reduction of the high deformability of the floors; intervention on roofs	YES	MEDIUM	LOW	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES
E. 3	Replacing the roof plank with a double wooden plank		Reduction of the high deformability of the floors; intervention on roofs	YES	HIGH	LOW	MEDIUM	YES





E. 4	Timber tie beam		Reduction of	YES	LOW	LOW	LOW	YES
			the					
		The state of the s	deficiencies of					
			the					
			connections;					
		::	intervention on					
			roofs					

RC buildings – Steel solutions (Table F)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

F	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
F. 1	Steel jacketing for column and beam strengthening, through welding or bolting with a steel section, where the gap between the concrete and steel is filled with grout		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	LOW	MEDIUM	YES
F. 2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive		Bending reinforcement		LOW	LOW	LOW	YES
F. 3	Addition of bracing systems		Reduction of displacements; reduction of the risk of fragile mechanisms		LOW	MEDIUM	MEDIUM	YES





F. 4	Addition of dissipative bracing systems	Seismic energy dissipation; reduction of the risk of fragile mechanisms	LOW	HIGH	HIGH	NO
F. 5	Dissipative external systems	Reduction of displacements; reduction of the risk of fragile mechanisms	LOW	HIGH	HIGH	NO
F. 6	Bandaging of reinforced concrete walls and pillars with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts"), which uses a highperformance metal tape closed on itself through joining elements; this creates circles under tension which induce an active three-dimensional confinement.	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	YES
F. 7	Bandaging of reinforced concrete nodes with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts")	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	NO





F. 8	Advanced anti-		Advanced	LOW	HIGH	HIGH	NO
	seismic	1001	antiseismic				
	techniques, as	The state of the s	techniques				
	base isolation						
	systems	sales de Selve					

RC buildings – Fibres solutions (Table G)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

G	Interventions us	ing fibres solutions						
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>cost</i>	EASILY APPLICABLE
G. 1	FRP or fibres jacketing for column and beam strengthening, through the application of external fabric wraps around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	MEDIUM	YES
G. 2	FRP or fibres jacketing for column and beam strengthening, through the application of external strips around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	MEDIUM	YES
G. 3	Reinforcement of the floor joists with carbon fibers		Bending reinforcement		HIGH	MEDIUM	MEDIUM	YES





G. 4	Bending and shear reinforcement of beams with carbon fibres	Bending reinforcement	HIGH	MEDIUM	MEDIUM	YES
G. 5	Anti-overturning system for infill walls	Reduction of the risk of fragile mechanisms	HIGH	MEDIUM	MEDIUM	YES

RC buildings – RC solutions (Table H)

There is no difference with the data already catalogued; all contents the terms of recommendation, diffusion, technical complexity, cost and ease in applicability correspond.

Н	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>COST</i>	EASILY APPLICABLE
H. 1	Reinforced concrete jacketing for column and beam strengthening, through the addition of an external layer of reinforced concrete		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	LOW	MEDIUM	NO





H. 2	Stiffening of floors with a reinforced concrete slab	Increase in the stiffness and strength of the structure	HIGH	LOW	LOW	YES
Н. 3	Realization of new structural elements (reinforced concrete walls or pillars)	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms	LOW	MEDIUM	MEDIUM	NO
H. 4	Replacement of structural elements	Increase in the stiffness and strength of the structure	LOW	HIGH	MEDIUM	NO
Н. 5	Replacement of non-structural elements	Reduction of the risk of fragile mechanisms	MEDIUM	LOW	LOW	YES
Н. 6	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Improvement in foundation structure	HIGH	MEDIUM	MEDIUM	NO
Н. 7	Execution of foundation by micro-poles	Improvement in foundation structure	MEDIUM	MEDIUM	MEDIUM	NO





7.3. Albania – PP4 (Gjirokaster)

Albania is a country with high seismic risk, for this reason it is very important the design and seismic evaluation of buildings. From the economic point of view, there are two possible options: repair or demolition. The choice depends on the actual condition of the structure and, consequently, on the cost of each option. In the new and old Albanian design codes, there is no specified procedure about the assessment of the seismic performance of the existing buildings (Guri, Vesho, Marku, 2020). This situation becomes even more serious when considering the degradation of some constructions over the years and the theme of the structural interventions (Guri, Lluka, Luca, 2015).

Protection of cultural heritage has become an emerging problem in recent years. It rises as a necessity when considering the elimination of structural shortcomings, uncertainties arising from unusual load conditions, poor design or construction practices. These deficiencies may be caused by overloading, natural disasters, foundation settlement, deterioration of materials, etc. Moreover, there could be other reasons for the structures to be strengthened, as: to eliminate structural problems or distresses; to correct design or construction errors; to resist exceptional or accidental loadings; to increase tensile, shear, flexural or compressive strength of structural members (Mustafarai, 2013).

All interventions should be carefully planned and performed. They must assure structural compatibility with the original structure, keeping its original conformation as much as possible. Modified or new structural elements should not vary the architectural appearance and aesthetics of the building. In general, assessment of seismic vulnerability of historic masonry constructions is a very challenging task due to several uncertainties regarding mechanical properties and geometrical characteristics of the structure. Each masonry building is unique. Hence, it should be treated with special care (Mustafarai, 2013). A correct structural analysis of the building requires a deep knowledge of its history, evolution, geometry, structural details, material properties, cracking pattern and masonry construction techniques. An accurate structural investigation can be developed by combining in-situ and laboratory test results. Generally, obtaining all the needed information to properly define the numerical model is very difficult, or even impossible. For this reason, simplified and iterative procedures of assessment are often required.

The studies carried out by Albanian researchers provided an insight into the current approach to seismic improvement of existing masonry buildings (Mustafaraj, Yardim, 2017).

In particular, the following techniques are known and used:

- Traditional Retrofitting Techniques: i) filling cracks and voids by grouting; ii) stitching of large cracks and weak areas with metallic or brick elements; iii) external or internal post-tensioning with steel ties; iv) shotcrete jacketing; v) ferrocement and vi) centre core vii) confining using RC tie columns (Kalali & Kabir, 2012; Triantafillou, 1998).
- Surface Treatment: it is a technique that covers the exterior face of masonry by affecting the architectural appearance of the structure. It consists on constructing a steel, or polymeric, mesh, coated by high strength mortar, around the exterior of the building. This system confines the masonry after cracking and increases the ultimate load resistance. The surface treatment improves the out-of-plane resistance and reduces any "arching action". However, application of this technique seriously affects the architectural properties and the lack of "transpiration" of the wall may accelerate the degradation.
- Ferrocement jacketing: this technique is applied by embedding closely spaced meshes of fine rods with reinforcement ratio of 3-8% in high strength (15-30 MPa) cement-mortar layer of 10-50 mm thickness. It causes considerable increase in stiffness. Strengthening of pre-damaged walls can restore its original capacity. Ferrocement can control crack formation as it has high flexural and shear strength, it has





been subject of many studies for both unreinforced masonry (Mustafaraj & Yardim, 2016a, 2016b) as well as concrete structures (Rosenthal, 1986; Razvi & Saatcioglu, 1989). Some of the advantages of ferrocement such as considerably low price and ability to be completed with unskilled workers, make it an ideal solution for low-cost housing (Mustafaraj, Yardim, 2017).

- Reinforced Plaster: this technique is achieved by applying a thin layer of cement plaster over high strength steel reinforcement (diagonal bars or horizontal mesh). It was observed that in diagonal tension tests and static cyclic test, the in-plane resistance was increase by 1.25-3 times (Jabarov et al., 1980).
- Grout and epoxy injection: it is applied by injecting grout into pre-drilled holes on the wall. The main purpose is to restore the original integrity and to fill the voids and cracks that are present in the wall. Injection is a sustainable technique and may also be able to restore the initial strength of masonry. However, the success of this system depends on the mechanical properties of the grout mix, they are compatible with the physical and chemical properties of the masonry that is to be retrofitted.

According to these studies, traditional strengthening techniques offer a suitable method to improve the structural behaviour of masonry buildings, but there are some limitations, such as: the time required to be applied, the reduction of available space, the impact on aesthetics etc. Furthermore, the additional weight of the reinforcing techniques may also increase the earthquake induced inertial forces and may require strengthening of the foundations as well.

Development of new materials and techniques came as a necessity to overcome the limitations of traditional methods. The reinforced polymers are an efficient alternative, as they improve the behaviour of masonry elements under monotonic, seismic and explosive loads. Additionally, since the added mass and stiffness are negligible, the dynamic properties of the reinforced structure will not be altered. Some of the most used techniques are:

- TRM (Textile reinforced mortar): it combines the essential properties of both conventional and modern materials by using textile grids externally, embedded in mortars. The grid is made of long fibre roving (made of carbon, glass or aramid) arranged in two orthogonal directions. Instead of polymer resins, cement or lime-based mortars are used. The composite action of TRM is achieved through the mechanical interlock of the grid structure and the mortar, it increases shear strength, stiffness and ductility.
- **Fibre Reinforced Mortar (FRM):** it is a reinforcing technique that consists of microfibers made of steel, glass, synthetic fibres (acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene) and natural fibres (straw, coconut, bamboo, etc.) embedded in mortar. Polypropylene fibres are chemically inert fibres that bond mechanically with the mortar through contact area.
- Fibre Reinforce Polymer (FRP) reinforcement: A fibre reinforced polymer (FRP) system consists of two main materials: resin and fibres. These composites can be made of carbon (CFRP), glass (GFRP) (Mustafaraj, Yardim, 2018) or aramid (AFRP), fibres bonded together in an inorganic polymeric matrix (such as putty fillers, saturants and adhesives like epoxy, polyester or vinylester) that offer many advantages such as high strength and stiffness in the direction of the fibres, immunity to corrosion, low weight, availability in various forms as laminates, fabrics and tendons of unlimited lengths, exceptional durability in many environments and cost-effectiveness. The FRP characteristics are defined by: type of fibre volume, the orientation, the thickness and type of resin used. One of the most important characteristics of FRP composites is that when a structural member is reinforced with this material, stresses are transferred from substrate to the FRP through shear and epoxy interface. Among other advantages, some of the most useful properties of FRP materials are: i) easy implementation; ii)





requirement of minor preparation works, iii) well-preservation of the material integrity of the masonry wall.

On the other hand, some of the disadvantages of FRP are: the difficulty of removal, the resins are highly flammable and emit toxic vapours when burnt (additional fire protection measures must be taken when implementing such a system); exposure to ultraviolet light makes the resin slowly brittle; the long-term reliability of FRPs is largely unproven and FRPs are impermeable to moisture transport. For a successful application, surface preparation is required, as unfilled cracks or unsmoothed irregularities can cause premature debonding.

In Albania, it is actually believed that, in many cases, FRP retrofitting techniques may be inappropriate for heritage or historic buildings due to the lack of compliance with conservation principles resulting from excessive invasiveness and non-removability. It may be advisable to use a technique composed of traditional materials such as wood or ceramics bonded to the wall surface and anchored with mechanical devices (Roca & Araiza, 2010).

Retrofitting of masonry walls with FRP is a promising technique as it was observed that it improves the in-plane lateral resistance by 1.1-3 times and the out-of-plane resistance by more than 7 times.

Masonry buildings - Steel solutions (Table A)

The steel techniques currently used in the Gjirokaster area are only the insertion of tie rods, anchor plates, and tie rods in the thickness of the wall.

Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES





A. 2	Paired tie-rods on		Reduction of		This techni	que is not doc	umented	
	both sides of the		the					
	wall or paired	<i>\\\\\\</i>	deficiencies of					
	plates on the two		the					
	sides of the wall		connections;					
	connected		reduction of					
	together with steel		un-contrasted					
	bars and external		thrust of					
	anchor plates	(///)	arches and					
		V77.771	vaults;					
			intervention on					
			roofs		ı		ı	
A. 3	Tie-rods in the		Reduction of	YES	HIGH	LOW	LOW	NO
	thickness of the		the					
	wall, made with	公共会计划	deficiencies of					
	metal bars or steel	公司	the					
	cables passing		connections;					
	through a hole		reduction of					
	injected with non-		un-contrasted					
	shrink mortars		thrust of					
			arches and					
			vaults;					
			improvement of resistance in					
			walls					
			walls					
A. 4	Floor connections		Reduction of		This techni	que is not doc	cumented	-
	made with coupled		the					
	steel profiles on	2 plastre 170/50x12 1 bullone M24 in prefero 6/26	deficiencies of					
	two sides of the	man con stro sizes Controvento 224	the					
	wall and		connections;					
	connected to each	2 pisatre di rinforzo, sp. 25 mm pisatra di collegamento, sp. 25 mm	intervention on					
	other, between	1 buttone M24 in prefero Ø26 Controvento	roofs					
	one room and the	024						
	other and to the	2 piastre di rinforzo, sp. 25 mm UPN 240 2 bame @14 in apposito protoco (@16 mm) salla munitura; n. collegamenti						
	outside with steel	come da planimetria						
	rebars, ribbed							
	metal plates, and bolts.							
A. 5	Crossed steel		Reduction of		This techni	que is not doc	rumented	
7. 3	bands in the		the		THIS CECHILI	que is not aut	amenteu	
	thickness of the		deficiencies of					
	floor		the					
		Amended and Amended	connections;					
		Controveris de portir UN ed E	reduction of					
			high					
		Rabs E	deformability					
		PANTO UPIN	of the floors;					
			intervention on					
			roofs					





Λ	1			
A. 6	Tie-rods for arches		Reduction of	This technique is not documented
	and vaults made		un-contrasted	
	with steel bars,	В	thrust of	
	with the possibility		arches and	
	of tensioning them		vaults;	
	J		,	
A. 7	Tie beams made		Reduction of	This technique is not documented
	with steel profiles,		the	
	anchored with		deficiencies of	
	vertical reinforced		the	
	perforations to the		connections;	
	masonry wall	22	intervention on	
	,		roofs	
A. 8	Stitching, through		Reduction of	This technique is not documented
<i>7</i> 0	reinforced		the	to to
	perforations made		deficiencies of	
	with steel bars	That b	the	
	with steel pars			
		Mau	connections;	
			reduction of	
			un-contrasted	
			thrust of	
			arches and	
			vaults;	
			improvement	
			of resistance in	
			walls	
A. 9	Connection of floor	20-34	Reduction of	This technique is not documented
	slabs and roofs to		the	
	walls (connection	CARCALA AFROGRAP CARCALA - ON HOUSE	deficiencies of	
	of purlins or ridge	SOURCE DI CONCENTION C	the	
	beams with the	SISTEMA SI ARCCOND SCOREDIO LE _VED.	connections;	
		LY4 TIMEROHD OF LEGOM		
	walls of the	NOTICE OF THE PROPERTY OF THE	intervention on	
1		SCATOLA DI	_	
	tympanum)	SCATOLA DI COLLEGAMENTO AUE MUPATURE	roofs	
		COLLEGAMENTO		
A. 10	tympanum) Steel plates	COLLEGAMENTO	roofs Reduction of	This technique is not documented
A. 10		COLLEGAMENTO		This technique is not documented
A. 10	Steel plates	COLLEGAMENTO	Reduction of	This technique is not documented
A. 10	Steel plates connecting the	COLLEGAMENTO	Reduction of the	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections;	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults;	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability of the floors;	This technique is not documented
A. 10	Steel plates connecting the wooden plank to	COLLEGAMENTO	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability of the floors; intervention on	This technique is not documented





A.	11	Application of steel		Reduction of	YES	HIGH	LOW	LOW	YES
		anchor plates	Once the mode are unputs in the independent of the control of the	the					
			It is the man and the state of	deficiencies of					
			Account of the second of the s	the					
			AN ABOUT COMES P.	connections;					
			Tripi	reduction of					
				un-contrasted					
				thrust of					
				arches and					
				vaults;					
				intervention on					
				roofs					
Α.	12	Replacement of		Reduction of		This technic	que is not doc	umented	
		floor and roof slabs		the					
		with iron floor and		deficiencies of					
		brick planks or	A Park A	the					
		wooden boards	A MOLAND WILL	connections;					
				reduction of					
				high					
				deformability					
				of the floors;					
				intervention on					
				roofs;					
				intervention on					
				stairs					
_	12	C.:				-1 · · · · ·			
Α.	13	Stiffening of floors		Reduction of		This techni	que is not doc	umented	
		with metal strips		the					
				deficiencies of					
			Profile Metallico Inchiodato	the					
				connections;					
				reduction of					
			-	high					
				deformability					
				of the floors;					
				intervention on					
				roofs					
Α.	14	Adding beams of		Reduction of		This technic	que is not doc	umented	
"		the same type as		high			.,		
		existing ones (steel		deformability					
		beams)		of the floors;					
		negilis)		1					
				intervention on					
				stairs;					
				intervention on					
				roofs					
A.	15	Steel box frame		Improvement		This techni	que is not doc	umented	
		connected to		in the					
		masonry walls to		distribution of					
		create new		resistant					
		openings		vertical					
		-	1 1 1 1 1	elements;					
				strengthening					
				of wall					
				portions					
				around the					
				openings					





A.	16	Reinforcement		Improvement	This technique is not documented
		intervention on		in the	
		arches with steel		distribution of	
		elements		resistant	
				vertical	
				elements;	
				strengthening	
				of wall	
				portions	
				around the	
				openings	
A.	17	Reinforced		Improvement	This technique is not documented
		repointing,		of resistance in	
		combining the		walls	
		traditional			
		repointing with the			
		inclusion, within			
		the bed joints, of			
		reinforcing bars.			
A.	18	Confinement of	等的 400	Improvement	This technique is not documented
		pillars and columns		in the	·
		through the		distribution of	
		application of steel		resistant	
		hoops		vertical	
		reinforcements		elements;	
			A CONTRACTOR OF THE PARTY OF TH	pillars and	
				columns	
			The same of the sa	Columns	
A.	10	Charach anima of		Chun u nhh nu iu n	This to show in wat do some outed
A.	19	Strengthening of		Strengthening	This technique is not documented
		architraves and		of wall	
		jack arches by	Margaret William A	portions	
		applying sheets,		around the	
		plates or metal		openings	
		sheets to the			
		intrados			
A.	20	Substitution of		Strengthening	This technique is not documented
		existing architraves	A COLON	of wall	
		and jack arches	to the land on the land	portions	
		with steel profiles		around the	
				openings	
			1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		
_			"		
A.	21	Bracing of the	THE LEGISLAND	Intervention	This technique is not documented
		roofing structures		on roofs	
		with steel cables or			
		bars			
		1	I.	I.	I .





A. 22 Advanced antiseismic techniques (base isolation systems, dissipative bracing systems)



Advanced antiseismic techniques This technique is not documented

Masonry buildings - Masonry solutions (Table B)

These techniques are rarely used, as in the Gjirokastra territory the buildings are made of stone, and not of bricks. So, only the local dismantling and reconstruction is used, when needed, and the replacement of walls with solid bricks or rough or squared stones. Also lime grout injections with mortar mixtures are used, as they are highly compatible with stone walls.

В	Interventions us	ing masonry solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs		This techni	que is not doc	umented	
B. 2	Buttress on masonry walls		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults		This techni	que is not doc	umented	
B. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls		This techni	que is not doc	umented	





	, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,								
	"scuci-cuci" = "unstitch-stitch")								
B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	This technique is not documented					
B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls		This techni	que is not do	cumented		
В. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones	Section (1998)	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	HIGH	MEDIUM	YES	
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders	NUMBERS OF THE STATE OF THE STA	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	LOW	YES	
В. 8	Localized grout injections of mortars or resins		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns		This techni	que is not do	cumented		





	1	l	Ι.	
B. 9	Structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	This technique is not documented
B. 10	Substitution of existing architraves and jack arches with reinforced brick masonry		Strengthening of the wall portions around the openings	This technique is not documented
B. 11	Execution of masonry foundation below the existing one	Norabra portente Fondazione existente Sotiofondazione in murabra con malta censeriois	Improvement in foundation structures	This technique is not documented
B. 12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	This technique is not documented
B. 13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors	This technique is not documented

Masonry buildings – Fibres solutions (Table C)

In Gjirokaster, there are no documented interventions consisting of fibre solutions. In general, the fibre solutions are not widely used in Albania; some cases are documented only in Tirana.





Masonry buildings – RC solutions (Table D)

The interventions using concrete, in the Gjirokaster area, are limited to the insertion of new RC tie beams in the floors and widening of the masonry foundations, as it is well known that RC solutions contradicts the traditional techniques of construction and/or restoration.

D	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHINICAL COMPLEXITY	COST	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams	PLATES 1 SATING 1 SATING	Reduction of the deficiencies of the connections; intervention on roofs	NO	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Lamen groots Span 160/9007 and mm Span 160/9007 and mm Res. 90 2029 Soletts in Cit singgerfor videor (160/56/900) Constitution 160/56/9000 Constitution 160/56/9000 Constitution 160/56/9000 Constitution 160/56/9000 Res. 160 cm N.B. Elbarra disconseppor node muritaria sendores recitat Limited 46 cm	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs		This technic	que is not doc	cumented	
D. 3	Replacement of floor and roof slabs with reinforced concrete slab		Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs		This technic	que is not doc	cumented	





D. 4	Stiffening of floors with a reinforced	1.26	Reduction of the	This technique is not documented
	concrete slab		deficiencies of	
			the	
			connections;	
			reduction of	
			the high	
			deformability	
			of the floors;	
			intervention on	
			roofs;	
			intervention on	
			the stairs	
D. 5	Reinforced		Improvement	This technique is not documented
	concrete box	THE TANK	in the	
	frame connected		distribution of	
	to masonry walls	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	resistant	
	to create new		vertical	
	openings	STATE OF THE PARTY	elements;	
			strengthening	
			of the wall	
			portions	
			around the	
			openings	
D. 6	Realization of new		Improvement	This technique is not documented
	structural		in the	
	elements		distribution of	
	(reinforced		resistant	
	concrete walls or		vertical	
	pillars)		elements; pillars and	
			columns	
D. 7	Reinforcement		Improvement	This technique is not documented
	intervention on		in the	
	arches with	THE STATE OF THE S	distribution of	
	reinforced		resistant	
	concrete elements	A STATE OF	vertical	
			elements;	
			strengthening of the wall	
			portions	
			around the	
			openings	
D. 8	Jacketing, through		Improvement	This technique is not documented
5. 0	a reinforced		in the	This teeningue is not documented
	plaster with		distribution of	
	welded steel mesh		resistant	
	The state of the s		vertical	
			elements;	
			improvement	
			of resistance in	
			walls	
		l .		





D.	9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)		Improvement of resistance in walls		This techni	que is not doc	cumented	
D.	10	Intramural tying, through the application of punctual confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	Georges of solar Georges of s	Improvement of resistance in walls			que is not doc		
D.	11	Substitution of existing architraves and jack arches with a reinforced concrete beam		Strengthening of the wall portions around the openings		This techni	que is not doc	cumented	
D.	12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Manufacture de la companya de la com	Improvement in the foundation structures	YES	HIGH	MEDIUM	MEDIUM	YES/ NO
D.	13	Execution of a reinforced concrete foundation below the existing one		Improvement in the foundation structures		This techni	que is not doc	cumented	





D. 14	Execution of		Improvement	This technique is not documented
	foundation by	11 1 60	in the	
	micro-piles		foundation	
			structures	

Masonry buildings – Wood solutions (Table E)

The techniques using wood find the greatest correspondence, presumably due to the fact that most of the existing floors are made of this material and the need to preserve it leads to intervene on the horizontal elements rather than on the vertical elements.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	ASTORE WALL ASSOCIATE TARGET THE	Reduction of the high deformability of the floors; intervention on roofs	YES	MEDIUM	LOW	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES
E. 3	Replacing the roof plank with a double wooden plank		Reduction of the high deformability of the floors; intervention on roofs		This techni	que is not doc	cumented	





E.	4	Timber tie beam		Reduction of	YES	LOW	LOW	LOW	YES
				the					
				deficiencies of					
				the					
				connections;					
				intervention on					
				roofs					
			NIC.						

RC buildings – Steel solutions (Table F), Fibres solutions (Table G) and RC solutions (Table H)

As noted in the first part of the deliverable, in the area of Gjirokaster there are no buildings with a reinforced concrete structure, so the mapping of these intervention techniques is not relevant.

7.4. Serbia – PP5 (RDA Backa)

Serbia is located in a region of moderate seismic activity and its urban areas were not significantly affected by major damaging earthquakes in the last 50 years, except for the 2010 Kraljevo earthquake (M5.4). Other notable earthquakes during this period, namely the 1980 Kopaonik earthquake (M 5.8) and the 1998 Mionica earthquake (M 5.5) affected mostly rural areas. Due to infrequent earthquake occurence and the financial constraints there is a lack of awareness related to the need for mitigating effects of future earthquakes by strengthening existing infrastructure, especially significant stock of vulnerable unreinforced masonry buildings. As a result, there is a limited experience in Serbia related to the application of seismic strengthening techniques.

Development of expertise related to seismic strengthening of buildings in the region dates back to the 1979 Montenegro earthquake (M 6.9), which occurred when both Montenegro and Serbia were a part of the former Yugoslavia (SFRY). The earthquake caused significant damage of buildings in Montenegro and Croatia, including heritage structures along the Adriatic coast, in cities such as Budva and Kotor in Montenegro and Dubrovnik in Croatia. Engineers and academics from the entire country participated in planning, design, and construction supervision of post-earthquake rehabilitation activities. The earthquake also prompted regional projects which provided an opportunity for collaboration and exchange of experiences related to seismic safety of new and existing buildings, such as the UNIDO-sponsored project "Building Construction Under Seismic Conditions in the Balkan Region". The project resulted in the development of comprehensive technical resources related to seismic strengthening of existing reinforced concrete (RC) and masonry buildings (UNIDO, 1983) and also heritage structures (UNIDO, 1984). Notable research studies and practical applications of seismic strengthening of existing masonry buildings were performed by Tomaževič and his colleagues at ZAG, Slovenia. The findings of these research studies were published internationally (Tomaževič, 1999). A state of knowledge in the region related to this subject was presented by Aničić et al. (1990).

After the 1979 Montenegro earthquake, a new version of the Yugoslav seismic design code was published in 1981 (PTN-S, 1981), and in 1985 for the first time a national code related to repair, rehabilitation and strengthening of existing buildings was issued (PTN-R, 1985). Both codes were valid in Serbia until 2019, when Eurocodes were officially adopted as governing codes for the design of building structures (PGK, 2019). In particular, Eurocode 8 – Part 3 (CEN, 2005) was adopted for seismic assessment and strengthening of buildings





in Serbia (SRPS EN 1998-3/NA:2018, 2018). As of this writing there are no reported applications of Eurocodes related to seismic strengthening of buildings in Serbia, hence the discussion will be focused on the application of previous codes which have been in place for more than 35 years.

The 1985 code (PTN-R, 1985) contained provisions related to masonry and RC structures and the foundations. The main performance objective for rehabilitated or strengthened buildings according to the code was same as for the code for seismic design of new structures (PTN-S, 1981): structural damage is acceptable in case of a major damaging earthquake but the collapse must be avoided. Seismic rehabilitation/strengthening provisions for a specific building depend on its configuration, type and quality of the materials, the extent of damage, as well as the expected seismic performance. Relevant code provisions and examples of applications to masonry and RC buildings in Serbia.

PTN-R code prescribed the following approaches for structural rehabilitation or seismic strengthening of existing masonry structures: a) rehabilitation/strengthening of the existing loadbearing structure, b) reconstruction of existing walls, c) construction of new structural walls to enhance seismic capacity of the existing lateral load-resisting system, and d) strengthening of wall-to-floor connections.

Damaged masonry walls constructed using clay bricks or blocks need to be either replaced (if they have experienced heavy damage) or repaired by injecting cracks using a cement-based grout. In addition to repair, walls could be strengthened using one of the following techniques: a) by applying 3 to 5 cm thick reinforced plaster overlay on one or two sides of the wall, or b) by constructing new RC vertical and horizontal confining elements, or c) by applying post-tensioning in existing walls. The code also specified the minimum amount (ratio) of horizontal and vertical reinforcement for reinforced plaster overlay, and also the requirement related to anchorage of vertical reinforcement into floor/roof structure. The design of seismic strengthening provisions had to be performed either according to the Allowable Stress Design approach or the Ultimate Limit States design approach. Thickness of added overlay had to be considered for seismic analysis purposes.

The code also prescribed strengthening of existing flexible floor structures in masonry buildings by one of the following approaches: a) provision of steel ties on both sides of the walls in buildings with timber floors, or b) installation of horizontal diagonal bracings anchored into existing timber floors, or c) replacement of existing timber floor by a new RC floor and enhancing wall-to-floor connections.

Radonjanin, Lađinović, and Malešev (2011) presented an overview of rehabilitation and strengthening techniques for masonry buildings for possible applications in Serbia. Several unreinforced masonry apartment buildings were damaged in the 2010 Kraljevo, Serbia earthquake (M 5.4) (Ostojić and Stevanović, 2010; Ostojić et al., 2012; Ostojić, Muravljov and Stevanović, 2011; Nikić, 2012). These buildings were constructed after World War II (1945-1963), before the first seismic code in the former Yugoslavia was published (Brzev, Blagojević, and Cvetković, 2021). Masonry walls were typically constructed using solid clay bricks and cement:lime:sand mortar, and their thickness ranged from 25 cm (interior walls) to 38 cm (exterior walls). The floors were ribbed RC slabs, and RC tie-beams (ring beams) were provided at each floor level. In most cases the walls experienced moderate damage in the form of cracks due to in-plane or out-of-plane seismic loads. These buildings were repaired and strengthened according to the PTN-R code. The main focus of seismic strengthening schemes was on a) enhancing the overall structural integrity by installing corner strengthening (RC jacketing) at wall corners, b) by constructing reinforced plaster overlay (4 cm thick) applied on wall surfaces (one-sided or two-sided), or c) by constructing new RC shear walls (usually 10 cm thick) bonded to the existing masonry walls via steel anchors. These techniques are illustrated in Figure 29. A similar building with a vertical extension was strengthened using the same approach before the 2010 earthquake, and it did not experience any damage in the earthquake (Manić and Bulajić, 2013). It should be noted that the seismic design code PTN-S (1981) prescribed seismic evaluation of an existing building in which seismic weight was changed by more than 10% as a result of the renovation or vertical extension. The code prescribed that these buildings had to





comply with the seismic safety requirements for new buildings, which in many cases prompted the need for seismic strengthening.

A few buildings experienced damage due to flexible timber floors/roofs and were subsequently strengthened by constructing horizontal steel trusses attached to the existing floors and walls, see Figure 30 (Ostojić et al., 2012).

Several heritage structures, including churches and monasteries, were also damaged in the same earthquake and have subsequently undergone repair and/or rehabilitation (Krstivojević, N. 2014, 2016; Krstivojević, M., 2014, 2016). A church in the Sirča village near Kraljevo was severely damaged in the 2010 earthquake (Figure 31 a). The walls and vaulted roof structure of the unreinforced masonry structure were severely damaged (Krstivojević, N., 2014). Seismic strengthening of the vaulted roof was performed by constructing a thin RC shell on top of the existing masonry vault. Horizontal steel ties were also installed in altar portion of the church to enhance the overall structural integrity (Figure 31 b).

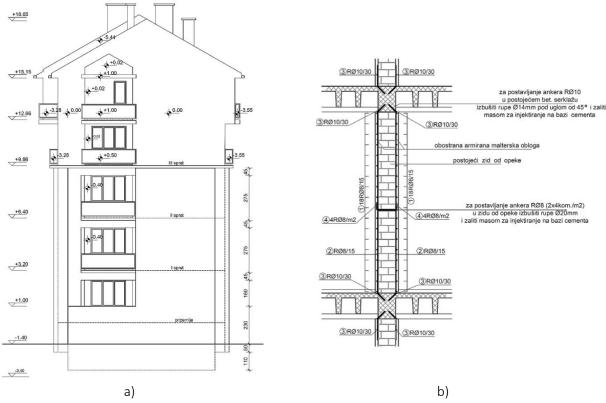


Figure 29 – Seismic rehabilitation of a masonry building damaged in the 2010 Kraljevo earthquake: a) vertical elevation of a gable wall showing corner strengthening at the lower 3 floors, and b) two-sided RC jacketing of interior walls (Ostojić, Muravljov, and Stevanović, 2011).

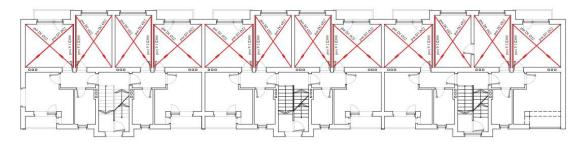
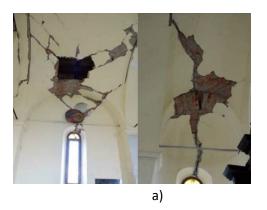


Figure 30 – Horizontal steel truss installed in a masonry building in Kraljevo to increase in-plane stiffness of the existing floor diaphragm (Ostojić et al., 2012).







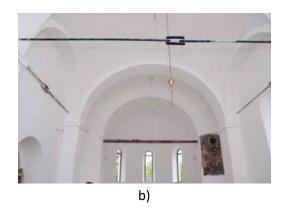
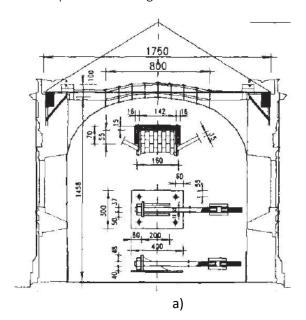


Figure 31 – Post-earthquake rehabilitation of a church in the Sirča village near Kraljevo after the 2010 earthquake:
a) severe damage in the vaulted ceiling and b) horizontal steel ties provided to improve the overall structural integrity (Krstivojević, N., 2014).

Several heritage masonry structures have been rehabilitated to restore their structural integrity. In many cases these buildings deteriorated due to environmental effects and were in a poor condition, as discussed in a case study of a 100-year old RC and masonry building by Radonjanin, Malešev, and Milovanović (2007). Muravljov and Pakvor (1998) described structural rehabilitation strategy for a 150-year old brick masonry church in Belgrade, Serbia. The rehabilitation was prompted by excessive deflections of arches in the church's ceiling. The existing steel ties, installed as a part of a previous rehabilitation project, loosened over time hence new prestressed steel ties (36 mm diameter) were installed as a part of the rehabilitation, which resulted in improved compatibility between existing and new materials. New anchorage blocks for the ties were constructed using recycled brick aggregate. "\pi"-shaped anchorage elements were cast using recycled brick concrete were bonded to the existing arches, see Figure 32 a.

Advanced structural/seismic rehabilitation techniques involving the application of Fibre Reinforced Polymer (FRP) products, especially carbon fibre (CFRP) strips or wraps, have also been used on a few masonry rehabilitation projects in Serbia. An example of strengthening existing brick masonry vaults in a church in Serbia is presented in Figure 32 b.



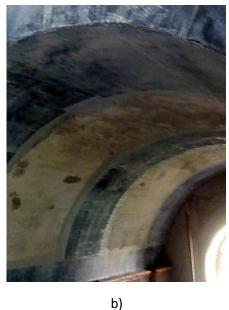


Figure 32 – Rehabilitation of masonry churches in Serbia: a) application of an innovative tie anchorage system in a church in Belgrade (Muravljov and Pakvor, 1998) and b) CFRP strips used to strengthen existing brick masonry vaults in a church (SIKA Srbija d.o.o.).





The requirements for structural rehabilitation and/or strengthening of reinforced concrete (RC) structures in Serbia were also prescribed by the 1985 code (PTN-R, 1985). General approach and specific requirements related to structural elements prescribed by the code are as follows:

- 1. Damaged wall and floor structures are to be rehabilitated i) by applying new RC overlays on both sides of existing structural elements, ii) by repairing cracks using epoxy-based grout, and/or iii) by prestressing or other feasible methods. A new RC overlay must be attached to the existing wall by means of through-wall anchors, and new reinforcement must be anchored into the foundations. Strengthening of the foundations may also be required due to increased capacity of strengthened elements in the superstructure portion.
- 2. Existing RC buildings can be strengthened by constructing new RC shear walls which are connected to the existing structure. The design of new shear walls must take into account flexural and shear effects, foundation rotation, and a reduction of the lateral stiffness caused by cracking.
- 3. When the dimensions of strengthened structural elements exceed the dimensions of original elements by more than 15% it is required to perform structural analysis of the entire structure and take into account the dimensions of strengthened elements. Seismic analysis of a rehabilitated structure must take into account joint action of the existing and new structural elements and their deformation compatibility.
- 4. Seismic evaluation of the existing floor systems must be performed to verify their in-plane stiffness and ability to transfer seismic forces to the strengthened structural elements. When an existing floor structure is unable to transfer seismic forces to vertical elements of lateral load-resisting system, it needs to be strengthened either by replacing the existing floor by a new one, or by constructing a new RC overlay on top of the existing slab.

There are only a few reported case studies featuring field applications of seismic strengthening in RC buildings in Serbia. In most cases the existing RC buildings were deteriorated due to ageing and corrosion and the interventions were focused on restoring structural stability of existing deteriorated structural elements, e.g. floor slabs (Bešević and Prokić, 2012). The rehabilitation was usually performed using conventional techniques. For example, structural rehabilitation of an existing ribbed RC slab was performed by installing external prestressed steel ties anchored into the RC perimeter beams. A case study featuring the strengthening of RC columns in an existing mixed function building in Inđija, Serbia, was reported by Orelj and Radonjanin (2010), see Figure 33. New 10 cm thick RC jackets were constructed to strengthen the columns in the original portion of the building. New steel plates welded to longitudinal reinforcement at a few locations along the column height were provided to ensure adequate confinement. A notable rehabilitation project is related to the Army Headquarters (Generalštab) building in Belgrade, a heritage RC structure constructed in the 1950s, which was severely damaged during the 1999 bombing of Serbia (Nikolić and Delić-Nikolić, 2012).





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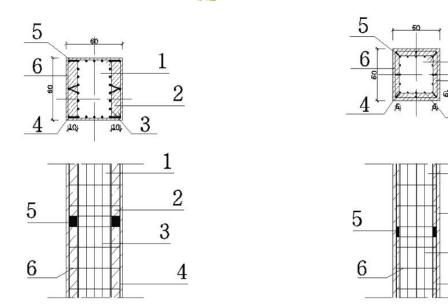


Figure 33 – Examples of RC jacketing schemes for existing RC columns in a building in Inđija, Serbia (Orelj and Radonjanin, 2010).

Zlatkov (2014) reported an application of CFRP for seismic strengthening of RC columns in a building which was a part of the tyre manufacturing plant "Tigar" in Pirot, Serbia. The building was constructed before the first Yugoslav seismic design code was issued, hence the elements of existing RC frame system were not designed and detailed for ductile seismic behaviour. The purpose of strengthening was to increase the capacity and ductility of existing RC columns by means of CFRP wraps (manufactured by SIKA), see Figure 34 a. Another project was related to storage facility in the DIN (Tobacco Factory Niš), Niš, Serbia, where CFRP U-shaped wraps were used to increase shear resistance of the existing floor beams, while CFRP strips were externally bonded to the beams to increase their flexural capacity in the tension zone, see Figure 34 b. A few other case studies featuring application of FRP technology for structural rehabilitation of buildings in Serbia were also reported (Muravljov et al., 2008).

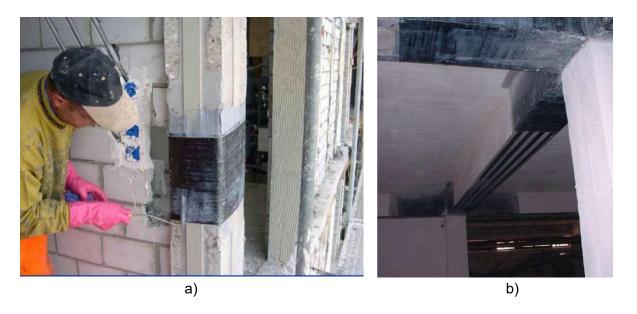


Figure 34 – Applications of CFRP technology for strengthening existing RC structures in Serbia: a) wrapping of an existing non-ductile RC column in the "Tigar" plant, Pirot and b) strengthening of beams with deficient shear and flexural capacity, DIN, Niš (Zlatkov, 2014).





Petraškovich and Savić (2011) reported an application of passive seismic control system (seismic dampers) called DC90 for seismic rehabilitation of a few masonry and RC school buildings affected by the 2010 Kraljevo earthquake. The system was developed in Serbia and it was patented in a few other countries. The dampers are installed in an inclined configuration parallel to the existing masonry walls. The choice of dampers depends on the in-plane rigidity of the masonry walls within the building and their capacity to participate with the dampers in the seismic energy dissipation (Gocevski and Petrašković, 2013). According to Manić and Bulajić (2012) DC90 system was partially installed in several schools in Kraljevo. The dampers were installed mostly at the partition wall locations in the interior of the building and were attached to a few exterior walls in X-shaped configuration along the building height.

Masonry buildings - Steel solutions (Table A)

Some of the seismic strengthening techniques using steel, such as steel ties, are used for rehabilitation of churches and monasteries in Serbia. Horizontal steel braces are used for seismic strengthening of floors.

Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>COST</i>	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 2	Paired tie-rods on both sides of the wall or paired plates on the two sides of the wall connected together with steel bars and external anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults;	YES	LOW	LOW	MEDIUM	YES





			intervention on					
			roofs					
A. 3	Tie-rods in the		Reduction of	YES	LOW	MEDIUM	MEDIUM	NO
	thickness of the		the					
	wall, made with		deficiencies of					
	metal bars or steel		the					
	cables passing		connections;					
	through a hole	a	reduction of					
	injected with non-		un-contrasted					
	shrink mortars.		thrust of					
			arches and					
			vaults;					
		4	improvement					
		4000	of resistance in					
			walls					
	Flanconomica			VEC	10)4/	1014	NAEDILINA	VEC
A. 4	Floor connections		Reduction of	YES	LOW	LOW	MEDIUM	YES
	made with coupled		the					
	steel profiles on	2 plaster 170x90x12	deficiencies of					
	two sides of the	Controvento 8724	the					
	wall and		connections;					
	connected to each	2 piastre di rinforzo, sp. 25 mm piastre di collegamente, sp. 25 mm sp. 25 mm	intervention on					
	other, between	1 bullone M24 in prefero 9/26	roofs					
	one room and the	3 Controvens 924						
	other and to the	2 piastre di rinforzo, sp. 25 mm UPN 249 2 barre 014 lin apposito pretoro (016						
	outside with steel	mm) nella maratura; n. collegamenti come da planimetria						
	rebars, ribbed							
	metal plates, and							
	bolts.							
A. 5	Crossed steel		Reduction of	YES	LOW	LOW	LOW	YES
	bands in the		the					
	thickness of the	Connetted part a collegamento de profit UPN est E. Controvers.	deficiencies of					
	floor		the					
			connections;					
		Pedio E Pedio UTN	reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs					
A. 6	Tie-rods for arches		Reduction of	YES	LOW	LOW	LOW	YES
	and vaults made		un-contrasted					
	with steel bars,	8	thrust of					
	with the possibility	W/A	arches and					
	of tensioning them		vaults;					
			,					
A. 7	Tie beams made		Reduction of		This technic	ue is not use	d in Serhia	
, ,	with steel profiles,		the		s ccciniic	1 13 1101 4361	JC: Dia.	
	anchored with		deficiencies of					
	vertical reinforced		the					
	perforations to the		connections;					
	periorations to tile		connections,					
	masonnywall		intorvention on					
	masonry wall		intervention on roofs					





A. 8	Stitching, through		Reduction of		This technic	jue is not used	d in Serbia.	
/ 0	reinforced		the			1440 15 1100 4500		
	perforations made	T	deficiencies of					
	with steel bars	LYN .	the					
			connections;					
		. 29/	reduction of					
			un-contrasted					
		10000000	thrust of					
			arches and					
			vaults;					
			improvement					
			of resistance in					
			walls					
A. 9	Connection of floor	- <u>A</u>	Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
	slabs and roofs to	COMPLIA AFRICANI CHROLATA - GA PROMIRO	the	. = -				1
	walls (connection	SAMEN AND CONCENSION	deficiencies of					
	of purlins or ridge	SISTEMA DI APPONTO PODERICOLARE PAPITICOLARE	the					
	beams with the	AND THE POLICY A DE SATURATION OF TH	connections;					
	walls of the	PARTICOLARE BICOMPONENTI COLLEGAMENTO	intervention on					
	tympanum)	AUE MURATURE	roofs					
	cypaa,		100.0					
Λ 10	Ctool plotos		Reduction of	YES	LOW	LOW	1014/	YES
A. 10	Steel plates		the	YES	LOW	LOW	LOW	YES
	connecting the		deficiencies of					
	wooden plank to the walls	-3	the					
	tile walls		connections;					
			reduction of					
			un-contrasted					
			thrust of					
		*	arches and					
			vaults;					
			reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs					
A. 11	Application of steel		Reduction of		This technic	lue is not used	l in Serbia	
/ 11	anchor plates		the		This teerinie	1 13 1101 4301	JCI DIG.	
	and places		deficiencies of					
			the					
			connections;					
			reduction of					
			un-contrasted					
			thrust of					
			arches and					
			vaults;					
			intervention on					
			roofs					
	1		,					





A 12	Paula : C	 	Destroit 6		The second		tta C. I.i	
A. 12	Replacement of		Reduction of		This techniq	ue is not used	ı ın Serbia.	
	floor and roof slabs		the					
	with iron floor and	432	deficiencies of					
	brick planks or		the					
	wooden boards		connections;					
			reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs;					
			intervention on					
	Critt i til		stairs	\/FC	1011	1.45DU.11.4	1011	\/FC
A. 13	Stiffening of floors		Reduction of	YES	LOW	MEDIUM	LOW	YES
	with metal strips	evit.	the					
		Profile Metallico Inchiedate	deficiencies of					
			the 					
		4359 v	connections;					
			reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs	\				
A. 14	Adding beams of		Reduction of	YES	LOW	MEDIUM	MEDIUM	NO
	the same type as		high					
	existing ones (steel		deformability					
	beams)		of the floors;					
			intervention on					
			stairs;					
			intervention on					
			roofs					
A. 15	Steel box frame		Improvement	YES	LOW	MEDIUM	MEDIUM	NO
A. 15			1	TES	LOVV	INIEDIOINI	INIEDIOINI	NO
	connected to		in the					
	masonry walls to		distribution of resistant					
	create new							
	openings		vertical					
			elements;					
		LIFE STEEL	strengthening of wall					
			portions around the					
Λ 10	Steel box frame		openings	VEC	LOW	LIICH	MEDILINA	NO
A. 16			Improvement	YES	LOW	HIGH	MEDIUM	NO
	connected to		in the					
	masonry walls to		distribution of					
	create new	-	resistant					
	openings.		vertical					
			elements;					
			strengthening					
			of wall					
			portions					
			around the					
			openings					





A. 17	Reinforced repointing, combining the traditional repointing with the inclusion, within the bed joints, of reinforcing bars.	Improvement of resistance in walls	YES	LOW	HIGH	HIGH	NO	
A. 18	Confinement of pillars and columns through the application of steel hoops reinforcements.	Improvement in the distribution of resistant vertical elements; pillars and columns	This technique is not used in Serbia.					
A. 19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados.	Strengthening of wall portions around the openings		This techniq	ue is not used	d in Serbia.		
A. 20	Substitution of existing architraves and jack arches with steel profiles	Strengthening of wall portions around the openings	YES	LOW	LOW	LOW	YES	
A. 21	Bracing of the roofing structures with steel cables or bars	Intervention on roofs	This technique is not used in Serbia.					
A. 22	Advanced anti- seismic techniques (base isolation systems, dissipative bracing systems)	Advanced anti- seismic techniques	Seismic dampers (system DC90) were applied for seismic retrofitting of a few schools after the 2010 Kraljevo earthquake. The system was developed in Serbia, but its performance has not been extensively tested to be recommended for wider use. There is no evidence of use of other techniques (e.g., base isolation) in the country, but some projects involving base isolation in buildings of special importance are currently under way.					





Masonry buildings - Masonry solutions (Table B)

There is a very limited experience related to application of Solutions B in Serbia. Many of the listed techniques are not used.

В	Interventions us	ing masonry solutions						
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs		This technic	que is not use	d in Serbia	
B. 2	Buttress and slubs on masonry walls		Reduction of the deficiencies of the connections		This technic	que is not use	d in Serbia	
В. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called "scuci-cuci" = "unstitch-stitch")		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls		This techniqu	ue is rarely uso	ed in Serbia	
B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	YES	MEDIUM	LOW	MEDIUM	YES





B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls		This technic	ue is not use	d in Serbia	
B. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	This technique is not used in Serbia				
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders	Series process reported principles and a series and a ser	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	This solution is rarely used in Serbia because of limited stone masonry building stock.				se of
B. 8	Localized grout injections of mortars or resins Grout injections are used for repairing cracks in masonry walls for structural or seismic applications.		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	MEDIUM	LOW	MEDIUM	YES
B. 9	Structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	MEDIUM	YES





	10	Substitution of existing architraves and jack arches with reinforced brick masonry		Strengthening of the wall portions around the openings	This technique is not used in Serbia
В.	11	Execution of masonry foundation below the existing one	Mandaria portante Fondazione esistente Fondazione lei muretura ed mantino intuadi con malta censentias	Improvement in foundation structures	This technique is not used in Serbia
B.	12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	This solution might have been used in Serbia, but there is no reported evidence.
В.	13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors	This technique is not used in Serbia

Masonry buildings – Fibres solutions (Table C)

Fibre Reinforced Polymer (FRP) products are available in Serbia and could be used for many applications, but their application for structural/seismic interventions is very limited as of this writing.

С	Interventions using fibres solutions									
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>COST</i>	EASILY APPLICABLE		
C. 1	Application of composite materials strips (reinforced fibers)		Reduction of the deficiencies of the connections; intervention on roofs; pillars and columns	YES	LOW	MEDIUM	HIGH	YES		





C. 2	Tie beams in brick and FRP		Reduction of the deficiencies of the connections; intervention on roofs;		This techniq	ue is not usec	l in Serbia.	
C. 3	Stitching, through reinforced perforations made with fiberglass or carbon fibre bars		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls		This techniq	ue is not used	l in Serbia.	
C. 4	Stiffening of floors with FRP fibers	Solve riferate cus Free	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs	YES	LOW	MEDIUM	HIGH	YES
C. 5	Intrados or extrados application of composite materials strips to vaults (reinforced fibres)		Reduction of un-contrasted thrust of arches and vaults; intervention on stairs	YES	LOW	MEDIUM	HIGH	YES
C. 6	Jacketing, through a reinforced plaster with fibres mesh		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns		This techniq	ue is not usec	l in Serbia.	





C. 7	Strengthening of	Strengthening	YES	LOW	LOW	HIGH	YES
	architraves and	of the wall					
	jack arches by	portions					
	applying carbon	around the					
	fibre strips or	openings					
	meshes to the						
	intrados						

Masonry buildings – RC solutions (Table D)

The insertion of RC tie beams is a common type of intervention in Serbia, but the buildings are not of heritage value (historic buildings). Then, stiffening of floors with a reinforced concrete slab and the realization of new structural elements (reinforced concrete walls or pillars) are used for structural rehabilitation projects.

Jacketing, through a reinforced plaster and welded steel mesh has been used after the 2010 Kraljevo earthquake. It was applied only to the most heavily damaged buildings.

The most common type of intervention on foundations is the execution of a reinforced concrete foundation below the existing one.

D	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams	AG CONSENS. LATERIZE STATE & B/25	Reduction of the deficiencies of the connections; intervention on roofs	YES	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Res 02 2000 Soleta in Cit a dioprofision e de contra la	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs		This tech	nnique is no	ot used in Serl	bia





D.	3	Replacement of		Reduction of	YES	MEDIU	MEDIUM	MEDIUM		YES
		floor and roof slabs		the		М				
		with reinforced	A SALES - LESS -	deficiencies of						
		concrete slab		the						
				connections;						
				reduction of						
				the high						
				deformability						
				of the floors;						
				intervention on						
				roofs						
D.	4	Stiffening of floors		Reduction of	YES	HIGH	LOW	MEDIUM	YE	ES
		with a reinforced	144	the						
		concrete slab		deficiencies of						
				the						
				connections;						
				reduction of						
				the high						
				deformability						
				of the floors;						
				intervention on						
				roofs;						
				intervention on						
				the stairs						
D.	5	Reinforced		Improvement	NO	LOW	MEDIUM	LOW	ΥE	ES
		concrete box	THE T	in the						
		frame connected		distribution of						
		to masonry walls	· 图 · 1 · 2 · 1	resistant						
		to create new		vertical						
		openings	STATE OF THE PARTY	elements;						
				strengthening						
				of the wall						
				portions						
				around the						
				openings						
D.	6	Realization of new		Improvement	YES	HIGH	HIGH	HIGH	YE	ES
		structural		in the						
		elements	Sa VISS ILL	distribution of						
		(reinforced		resistant						
		concrete walls or	香料 WWW	vertical						
		pillars)		elements;						
				pillars and						
				columns						
D.	7	Reinforcement		Improvement		This tec	hnique is no	ot used in Serb	oia	
		intervention on		in the						
		arches with	TIM	distribution of						
		reinforced		resistant						
		concrete elements		vertical						
				elements;						
				strengthening						
			The state of the s	of the wall						
				portions						
				around the						
L				openings						





D. 8	Jacketing, through a reinforced plaster with welded steel mesh		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	HIGH	MEDIUM	MEDIUM	YES	
D. 9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)		Improvement of resistance in walls		This technique is not used in Serbia				
D. 10	Intramural tying, through the application of punctual confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	George and Continue C	Improvement of resistance in walls		This tech	nnique is no	ot used in Serk	oia	
D. 11	Substitution of existing architraves and jack arches with a reinforced concrete beam		Strengthening of the wall portions around the openings	YES	MEDI UM	LOW	LOW	YES	
D. 12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		Improvement in the foundation structures	YES	HIGH	MEDIUM	MEDIUM	YES	





13	Execution of a		Improvement	YES	HIGH	HIGH	HIGH	NO
	reinforced		in the					
	concrete		foundation					
	foundation below		structures					
	the existing one							
14	Execution of		Improvement	YES	MEDIU	MEDIUM	HIGH	NO
	foundation by	11 1 1000	in the		М			
	micro-piles		foundation					
			structures					
		reinforced concrete foundation below the existing one Execution of foundation by	reinforced concrete foundation below the existing one 14 Execution of foundation by	reinforced concrete foundation below the existing one 14 Execution of foundation by micro-piles In the foundation structures Improvement in the foundation	reinforced concrete foundation below the existing one 14 Execution of foundation by micro-piles In the foundation structures Improvement in the foundation	reinforced concrete foundation below the existing one 14 Execution of foundation by micro-piles In the foundation structures Improvement in the foundation M MEDIU M M M M M M M M M M M M M	reinforced concrete foundation below the existing one 14 Execution of foundation by micro-piles In the foundation structures Improvement in the foundation Improvement in the foundation MEDIUM MEDIUM	reinforced concrete foundation below the existing one Improvement in the foundation by micro-piles in the foundation structures Improvement in the foundation Improvement in the foundation

Masonry buildings – Wood solutions (Table E)

Application of interventions using wood are limited in Serbia.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	Solice referable con diagno forcido	Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES





E. 3	Replacing the roof plank with a double wooden plank	Reduction of the high deformability of the floors; intervention on roofs	YES	HIGH	LOW	MEDIUM	YES
E. 4	Timber tie beam	Reduction of the deficiencies of the connections; intervention on roofs		This solution	n is rarely use	d in Serbia	

RC buildings – Steel solutions (Table F)

Interventions on existing RC structures using steel solutions are recommended in Serbia but practical applications are very limited.

F	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
F. 1	Steel jacketing for column and beam strengthening, through welding or bolting with a steel section, where the gap between the concrete and steel is filled with grout		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		This techniq	ue is not used	l in Serbia.	
F. 2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive		Bending reinforcement		This solutio	n is not used	in Serbia.	





F. 3	Addition of bracing systems	Reduction of displacements; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	MEDIUM	YES
F. 4	Addition of dissipative bracing systems	Seismic energy dissipation; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	HIGH	NO
F. 5	Dissipative external systems	Reduction of displacements; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	HIGH	NO
F. 6	Bandaging of reinforced concrete walls and pillars with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts"), which uses a highperformance metal tape closed on itself through joining elements; this creates circles under tension which induce an active three-dimensional confinement.	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		This techniq	ue is not usec	in Serbia.	





F. 7	Bandaging of reinforced concrete nodes with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts")	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the		This techniq	ue is not usec	l in Serbia.	
F. 8	Advanced anti- seismic techniques, as base isolation systems	ductility of the pillar ends Advanced antiseismic techniques	YES	LOW	HIGH	HIGH	NO

RC buildings – Fibres solutions (Table G)

Applications of technical solutions for structural/seismic interventions involving FRP products are currently limited in Serbia.

G	Interventions us	ing fibres solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
G. 1	FRP or fibres jacketing for column and beam strengthening, through the application of external fabric wraps around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	YES	LOW	MEDIUM	HIGH	YES
G. 2	FRP or fibres jacketing for column and beam strengthening, through the application of external strips around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the	YES	LOW	MEDIUM	HIGH	YES





			ductility of the pillar ends					
G.	3	Reinforcement of the floor joists with carbon fibers	Bending reinforcement	YES	LOW	MEDIUM	HIGH	YES
G.	4	Bending and shear reinforcement of beams with carbon fibres	Bending reinforcement	YES	LOW	MEDIUM	HIGH	YES
G.	5	Anti-overturning system for infill walls	Reduction of the risk of fragile mechanisms		This techniq	ue is not used	d in Serbia.	

RC buildings – RC solutions (Table H)

RC solutions are most commonly used for structural or seismic interventions on RC structures in Serbia.

н	Interventions using RC solutions							
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
H. 1	Reinforced concrete jacketing for column and beam strengthening, through the addition of an external layer of reinforced concrete		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	YES	MEDIUM	LOW	MEDIUM	NO





H. 2	Stiffening of floors with a reinforced concrete slab	Increase in the stiffness and strength of the structure	YES	HIGH	LOW	LOW	YES
Н. 3	Realization of new structural elements (reinforced concrete walls or pillars)	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms	YES	HIGH	MEDIUM	MEDIUM	NO
H. 4	Replacement of structural elements	Increase in the stiffness and strength of the structure	YES	MEDIUM	HIGH	MEDIUM	NO
H. 5	Replacement of non-structural elements	Reduction of the risk of fragile mechanisms	YES	MEDIUM	LOW	LOW	YES
Н. 6	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Improvement in foundation structure	YES	MEDIUM	MEDIUM	MEDIUM	NO
Н. 7	Execution of foundation by micro-poles	Improvement in foundation structure	YES	MEDIUM	MEDIUM	HIGH	NO





7.5. Slovenia – PP6 (ZAG)

As for all partner countries, more information on seismic strengthening interventions was found for existing masonry buildings. In fact, stone masonry is the traditional form of construction in the regions where the stone is locally available. It is still present in old historic centres, both in ordinary buildings and in buildings of cultural and historical significance.

The main vulnerabilities of masonry buildings must be controlled and contained with appropriate designs. Thanks to the studies of Slovenian researchers, we can understand the main interventions in existing stone masonry buildings (Lutman,2004). For example, the shear resistance of structural walls can be improved if they are properly tied and connected to floor and roof structures. In the case of existing buildings, steel, timber, or reinforced concrete ties can be used at floor levels. Vertical ties, made of the same materials as those above, can be inserted at corners and between openings to prevent instability. The timber joists of floor structures must be connected to the walls through steel anchors and plates (Lutman, 2004). Interestingly, Lutman reports that an RC ring beam provided at the roof level is one of the most effective measures to prevent the out-of-plane collapse of gable walls. In fact, she states the dislocation of the roof structure is prevented by anchoring its elements into the ring beam (Lutman, 2004). Therefore, this approach testifies to a different custom and technical conception than what is believed in Italy today.

Increased lateral load resistance can be additionally achieved by constructing new stone walls, in one or both directions, and/or by decreasing the dead load. Indeed, the new walls are much more effective when subjected to less compressive stresses. This measure is recommended in combination with the replacement of existing timber floors with RC slabs, which act as rigid diaphragms. This is another aspect that differentiates the Slovenian approach from the Italian one.

Furthermore, another study on the subject (Uranjek M., Dolinšek B., Gostič S., 2011) explains some of the basic strengthening procedures applied on churches in the Posočje region (in the north-east of Slovenia). As the authors state, although churches are mostly of better quality than ordinary buildings, because of their typical design, strengthening procedures are more complex and demanding. Moreover, churches are usually under cultural heritage protection, thus interventions must be performed without substantial modifications of the basic structural system. Therefore, adequate seismic resistance is more difficult to achieve compared to ordinary buildings. In order to achieve optimal results, strengthening procedures should be carefully planned and implemented, based on the results of the preliminary investigations and static and seismic analyses.

The study presents in practice some of the strengthening procedures implemented as part of the postearthquake renovation in the Posočje region. There are also other techniques, not described in detail, such as sewing of walls with grouted anchors, application of polymer grids or carbon fibre-reinforced polymer wraps.

- Tying walls with steel ties can be applied at the level of individual inter-storey structures. In this way
 the integrity of a structure is improved, the horizontal load is distributed to the walls according to their
 stiffness and the walls are both better protected against excessive rocking and possible failure in the
 out-of-plane direction.
- Reinforced concrete tie-beams can be constructed at floor or roof level and anchored to load-bearing
 walls. This technique improves the structural integrity of a building and ensures a more uniform
 behaviour. Anchoring the roof to the tie-beams avoids possible uncontrolled movements of the roof
 elements and failure of head-walls.
- Injected anchors, applied in the middle of the wall cross-section, can successfully replace steel ties and reinforced tie beams if properly designed and executed. This solution is similar to method used by the old builders: connecting walls with ties, installed in the middle of them, has been prescribed





even after the 1895 earthquake in Ljubljana. Injected anchors can perform either as un-tensioned steel reinforcement or prestressed tendons.

- Repointing can be applied where bed-joints are relatively level, mortar is poor and units are good. The resistance of a wall to vertical and lateral loading can be considerably improved by replacing part of the existing mortar with a better quality one. Although this technique is usually applied on brick masonry, some authors [1] propose the application of the procedure also on stone masonry walls.
- Injection grouting can be used to improve the mechanical properties of two or three-leaf stone masonry walls. Because of inadequate connections between the separate stones, the voids and the poor quality of the mortar used, the load-bearing capacity of such walls, especially for horizontal loading, is not sufficient. With this technique, grout (liquid mixture made of water, binder and additives) is injected into a masonry wall under moderate pressure (2-3 bars). The aim of the intervention is to achieve better bonding between separate stones and leaves after the hardening of the injected material and, consequently, to improve mechanical properties of the masonry. On-site work showed that it is best to carry out injection grouting of all load-bearing walls, over their whole height of the structure. The damage that occurred in the buildings after strengthening and repeated earthquake has shown that grouting only parts of walls is not a good solution.
- Strengthening by applying reinforced cement coating is usually used for strengthening of brick masonry. However, for more vulnerable structures, such as bell towers, it can also be used in combination with steel ties and grout injection. By providing thicker layers concrete technology can be applied.
- Strengthening the foundations is recommended in the case of weak or shallow systems, when it is
 necessary to widen or deepen them. That is achieved by constructing a reinforced concrete tie-beam
 along the outside edge of the foundations. The new tie-rod should be bounded to the existing ones
 by transverse anchors.

Only carefully designed combination of strengthening procedures can provide adequate behaviour of the structure during the impact of an earthquake.

Masonry buildings – Steel solutions (Table A)

The spreadsheet filling for the Slovenian territory confirms the Country's different approach to the issue of interventions on existing buildings. In fact, some of the most used and recommended techniques in Italy, especially for protected buildings, are not suggested in Slovenia, because they are considered not effective. For example, tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall and steel box frame connected to masonry walls, to create new openings.

Others are considered incompatible for protected buildings, while in Italy they are recommended as they are considered to be easily removable; for example, confinement of pillars and columns through the application of steel hoops reinforcements and strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados.

Then, there is a different evaluation for some interventions using steel in terms of diffusion (generally less common than in Italy) and cost (generally a little higher than in Italy).





Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	MEDIUM	LOW	MEDIUM	YES
A. 2	Paired tie-rods on both sides of the wall or paired plates on the two sides of the wall connected together with steel bars and external anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	MEDIUM	LOW	MEDIUM	YES
A. 3	Tie-rods in the thickness of the wall, made with metal bars or steel cables passing through a hole injected with nonshrink mortars. In Slovenia, the system adopted the name Perfo anchors. The biggest problems of the system are that when drilling through the middle of the wall (for later insertion	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	YES	LOW	MEDIUM	MEDIUM	NO





	of a steel rod) the material is sprinkled and it is difficult to drill a hole along the wall evenly in the middle. The drilling also requires cooling with water.							
A. 4	Floor connections made with coupled steel profiles on two sides of the wall and connected to each other, between one room and the other and to the outside with steel rebars, ribbed metal plates, and bolts.	2 joines 15-00-022 and contino DCS 15-bidon 1054 in protion DCS Controversio CCS 2 joines of configuration, sp. 25 inm plants of configuration, sp. 25 inm 2 joines of configuration, sp	Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 5	Crossed steel bands in the thickness of the floor	Control or integers and in the control of integers and integers	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs	YES	LOW	LOW	LOW	YES
A. 6	Tie-rods for arches and vaults made with steel bars, with the possibility of tensioning them	1	Reduction of un-contrasted thrust of arches and vaults;	YES	HIGH	LOW	LOW	YES
A. 7	Tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall The procedure is occasionally used in Slovenia, but there are disadvantages of the technique as there is incompatibility of		Reduction of the deficiencies of the connections; intervention on roofs	NO	LOW	LOW	MEDIUM	YES





	steel and masonry							
	in terms of							
	ductility and							
	elasticity, and							
	consequently this							
	technique is not							
	recommended.							
Λ 0			Reduction of	NO	1014	NAEDILINA	MEDILIM	VEC
A. 8	Stitching, through			NO	LOW	MEDIUM	MEDIUM	YES
	reinforced		the					
	perforations made		deficiencies of					
	with steel bars	Топт в	the					
		NA	connections;					
			reduction of					
		QQ x	un-contrasted					
			thrust of					
		iocolynosoci	arches and					
			vaults;					
		,	improvement					
			of resistance in					
			walls					
A. 9	Connection of floor		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
	slabs and roofs to		the					
	walls (connection	CAROLIA ARROGEN CAROLIASA - G. MOLEGO	deficiencies of					
	of purlins or ridge	SCAPILA DI COURSEMANTO ALIE RIPATTOR	the					
	beams with the	SUSPENA DI AMPANAO SUSPENA DI AMPANAO	connections;					
	walls of the	PAPITICALARE Nº4 TRAPENDI Mº6-L-80mm BARDE FILERATE MIL	intervention on					
	tympanum)	PARTICOLA PE SCATTOLA DI SCATTOLA DI	roofs					
	,,	OUEGAMENTO AUE MURATURE						
A 10	Charl minter	- '	Dadwatian of	YES	LOW	LOW	1014	VEC
A. 10	Steel plates		Reduction of	YES	LOW	LOW	LOW	YES
	connecting the		the					
	wooden plank to	a	deficiencies of					
	the walls		the					
	The wooden floor		connections;					
	beams are directly		reduction of					
	connected to the		un-contrasted					
	walls by means of	\longrightarrow	thrust of					
	steel plates.	V	arches and					
			vaults;					
			reduction of					
			high					
			deformability					
			of the floors;					
			intervention on					
			roofs					
A. 11	Application of steel		Reduction of	YES	HIGH	LOW	LOW	YES
	anchor plates		the					
			deficiencies of					
			the					
			connections;					
			reduction of					
			un-contrasted					
			thrust of					
			arches and					
			vaults;					
and the second s		İ		I	I	l .	I .	i





				intervention on					
				roofs					
Α.	12	Replacement of		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
		floor and roof slabs		the	0	2011		25.0	
		with iron floor and		deficiencies of					
		brick planks or		the					
		wooden boards		connections;					
		The procedure		reduction of					
		should be		high					
		combined with A.1	Mark Control	deformability					
		and A.11		of the floors;					
				intervention on					
				roofs;					
				intervention on					
				stairs					
A.	13	Stiffening of floors		Reduction of	YES	LOW	MEDIUM	LOW	YES
		with metal strips		the					
			Profile Metallico Inchiodato	deficiencies of					
				the					
				connections;					
				reduction of					
				high					
				deformability					
				of the floors;					
				intervention on					
				roofs					
^	1.1	Adding booms of		Reduction of	YES	LOW	MEDIUM	MEDIUM	NO
A.	14	Adding beams of			TES	LOW	INEDION	IVIEDIUIVI	NO
		the same type as		high					
		existing ones (steel		deformability					
		beams)		of the floors;					
				intervention on					
				stairs;					
				intervention on					
				roofs					
A.	15	Steel box frame		Improvement	NO	MEDIUM	MEDIUM	MEDIUM	YES
		connected to		in the					
		masonry walls to		distribution of					
		create new		resistant					
		openings		vertical					
		New openings		elements;					
		weaken the		strengthening					
		structure and steel		of wall					
		frames do not		portions					
		adequately		around the					
		replace the		openings					
		extracted							
		masonry.							
		The procedure is							
		problematic, since							
		the steel frame							
		cannot replace the							
		removed part of							
		the wall in terms							
		of rigidity. The							





	problem is also							
	the connection of							
	the frame with the							
	old structure. The							
	procedure is							
	controversial, but							
	applied also in							
	Slovenia.							
A. 16	Steel box frame		Improvement	NO	LOW	HIGH	MEDIUM	NO
7 20	connected to		in the		2011		25.6	
	masonry walls to		distribution of					
	create new		resistant					
	openings.		vertical					
	The procedure is		elements;					
	problematic, since		i i					
	-		strengthening					
	the steel frame		of wall					
	cannot replace the		portions					
	removed part of		around the					
	the wall in terms		openings					
	of rigidity. The							
	problem is also							
	the connection of							
	the frame with the							
	old structure. The							
	procedure is							
	controversial, but							
	applied also in							
	Slovenia. The							
	efficiency of this							
	type of							
	intervention is							
	low.							
A. 17	Reinforced		Improvement	YES	LOW	HIGH	HIGH	NO
	repointing,		of resistance in					
	combining the		walls					
	traditional							
	repointing with the							
	inclusion, within							
	the bed joints, of							
	reinforcing bars.							
A. 18	Confinement of		Improvement	YES	LOW	MEDIUM	LOW	YES
	pillars and columns		in the				.= .•	•
	through the		distribution of					
	application of steel	多多多	resistant					
	hoops		vertical					
	reinforcements.		elements;					
	In Slovenia, the		pillars and					
		THE PERSON NAMED IN	· ·					
	procedure is rarely used because the		columns					
		S. C.						
	monumental	B I						
I	discipline is very							
I	atuint and		1					
	strict, and							
	generally does not							





A. 19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados. In Slovenia, the procedure is rarely used because the monumental discipline is very strict, and generally does not allow the visible interventions.	Strengthening of wall portions around the openings	YES	LOW	HIGH	MEDIUM	NO
A. 20	Substitution of existing architraves and jack arches with steel profiles	Strengthening of wall portions around the openings	YES	HIGH	LOW	LOW	YES
A. 21	Bracing of the roofing structures with steel cables or bars	Intervention on roofs		This techniqu	ue is not used	in Slovenia	
A. 22	Advanced anti- seismic techniques (base isolation systems, dissipative bracing systems)	Advanced anti- seismic techniques	NO	LOW	HIGH	HIGH	NO

Masonry buildings - Masonry solutions (Table B)

For the masonry solutions, the spreadsheet filled for the Slovenian territory confirms some differences. Also in this case, there is a different evaluation for some interventions in terms of diffusion (generally less common than in Italy) and technical complexity.

On the whole, the techniques using the masonry seem less widespread than in Italy.





В	Interventions us	ing masonry solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs	YES	LOW (reinforced masonry is very rare)	MEDIUM	LOW	YES
B. 2	Buttress on masonry walls		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults		This techniqu	ue is not used	in Slovenia	
В. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called "scuci-cuci" = "unstitch-stitch")		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	MEDIUM	LOW	LOW	YES
B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	YES	MEDIUM	LOW	MEDIUM	YES





B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in	YES	LOW (Very rare, but with connecting steel elements)	LOW	MEDIUM	YES
B. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW (Very rare)	MEDIUM	MEDIUM	YES
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders This is the most widely used intervention technique for stone and mixed walls in Slovenia. The procedure was invented on Building and Civil Engineering Institute (ZRMK) in Slovenia in the 60s.	open justs regioned given by growing g	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	MEDIUM	MEDIUM	YES
B. 8	Localized grout injections of mortars or resins Only if the masonry has been previously systematically injected (B.7)		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	MEDIUM	MEDIUM	YES





B. 9	Structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	YES	MEDIUM	LOW	MEDIUM	YES
B. 10	Substitution of existing architraves and jack arches with reinforced brick masonry In Slovenia, usually with RC architraves.		Strengthening of the wall portions around the openings	YES	HIGH	LOW	LOW	YES
B. 11	Execution of masonry foundation below the existing one	Munistria portante Fondazione esistente Sottofondazione in munistria di matteri orinada den makit consentità	Improvement in foundation structures	This t	echnique is no only wi	ot used in Slov th RC founda		oplied
B. 12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	YES but only for new buildi ngs	LOW	HIGH	MEDIUM	NO
B. 13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors		This techniqu	ue is not used	in Slovenia	

Masonry buildings – Fibres solutions (Table C)

Regarding the interventions using fibres, there is an almost perfect correspondence, except for the strengthening of architraves and jack arches by applying carbon fibre strips or meshes to the intrados, whose effectiveness is considered low. In fact, in Slovenia it has been proven that the epoxy contact between lamellas





and stone/brick surfaces does not resist dynamic loads. Therefore, this procedure is believed not appropriate in terms of seismic strengthening.

This positive result, in terms of comparison, probably derives from the recent study and the recent diffusion of this type of interventions, which have therefore developed and spread almost in the same way in all national contexts.

С	Interventions us	ing fibres solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHINICAL COMPLEXITY	COST	EASILY APPLICABLE
C. 1	Application of composite materials strips (reinforced fibers)		Reduction of the deficiencies of the connections; intervention on roofs; pillars and columns	YES	MEDIUM	MEDIUM	MEDIUM	YES
C. 2	Tie beams in brick and FRP		Reduction of the deficiencies of the connections; intervention on roofs;	YES	LOW	MEDIUM	MEDIUM	YES
C. 3	Stitching, through reinforced perforations made with fiberglass or carbon fibre bars	8 0 0 2	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	YES	MEDIUM	MEDIUM	MEDIUM	YES
C. 4	Stiffening of floors with FRP fibers	Solito cirlorato con Feb	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on	YES	LOW	MEDIUM	MEDIUM	YES





		I	T			l			
				roofs;					
				intervention on stairs					
	_	latar de car			VEC	LUCII	NAEDILINA	A 4 E DULIN 4	VEC
	. 5	Intrados or extrados		Reduction of un-contrasted	YES	HIGH	MEDIUM	MEDIUM	YES
		application of		thrust of					
		composite		arches and vaults;					
		materials strips to vaults (reinforced		intervention on					
		fibres)	WAN!	stairs					
		Horesy		314113					
			ATEN						
	. 6	Jacketing, through		Improvement	YES	MEDIUM	MEDIUM	MEDIUM	YES
	. 0	a reinforced		in the	ILS	IVILDIOIVI	IVILDIOIVI	IVILDICIVI	ILS
		plaster with fibres		distribution of					
		mesh		resistant					
		The intervention		vertical					
		technique with		elements;					
		reinforced plaster	The second of th	improvement					
		made of high-		of resistance in					
		ductile mortar and		walls; pillars					
		glass		and columns					
		reinforcement has							
		been used in							
		Slovenia for about							
		five years, but it is							
		now expanding.							
C	. 7	Strengthening of		Strengthening	NO	LOW	LOW	MEDIUM	YES
		architraves and		of the wall					
		jack arches by		portions					
		applying carbon		around the					
		fibre strips or		openings					
		meshes to the							
		intrados							
		It has been proven							
		that the epoxy contact between							
		lamelas and							
		stone/brick							
		surfaces does not							
		resist dynamic							
		loads. Therefore							
		this procedure is							
		not appropriate in							
		terms of seismic							
			· ·	1		I .		1	

Masonry buildings – RC solutions (Table D)

In this section, we find confirmation of the different approach reserved in Slovenia to the intervention on existing masonry buildings compared to what is currently done in Italy. In fact, we note that the prevailing





techniques are those using reinforced concrete that are strongly opposed in Italy today. Insertion of tie beams and entire RC floors, new structural elements and reinforced plasters are very common in Slovenia.

As already highlighted, this approach also characterized the way of intervening on buildings existing in Italy up to the 1980s, but then subsequent earthquakes showed the harmful effects of these solutions and, in recent years, they have been abandoned, while they continue to be the most common in Slovenia.

This trend does not appear so strong in any of the other partner countries.

D	Interventions us	ing RC solutions						
соре	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams This solution is always combined with a steel rod on the external surface of the wall, anchored to the internal RC beam.	ADMIA IN CLS ARMATA AND AS AS CONSENT. LATERIZE STATE & B/25.	Reduction of the deficiencies of the connections; intervention on roofs	YES	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Lamina process Joo Sofroot = Lamina process Re s. 60 2000) Sofroat in C1s allogarite Ped so 10 2000) Sofroat in C1s allogarite Ped so 10 2000) Sofroat in C1s allogarite Ped so 10 2000) Sofroat in C1s allogarite Ped sofroat in C1s allogarite	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs		This technique	ue is not used	in Slovenia	
D. 3	Replacement of floor and roof slabs with reinforced concrete slab In Slovenia, this is a common type of intervention.		Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	MEDIUM	YES





D. 4	Stiffening of floors with a reinforced concrete slab In Slovenia, this is a common type of intervention.	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on roofs; intervention on the stairs	YES	HIGH	LOW	MEDIUM	YES
D. 5	Reinforced concrete box frame connected to masonry walls to create new openings	Improvement in the distribution of resistant vertical elements; strengthening of the wall portions around the openings	NO	HIGH	MEDIUM	LOW	YES
D. 6	Realization of new structural elements (reinforced concrete walls or pillars) In Slovenia, this procedure is widely used. The new elements have to be appropriately dimensioned and there should be a rigid connection to the old structure.	Improvement in the distribution of resistant vertical elements; pillars and columns	YES	HIGH	HIGH	HIGH	YES
D. 7	Reinforcement intervention on arches with reinforced concrete elements In Slovenia, this procedure is widely used	Improvement in the distribution of resistant vertical elements; strengthening of the wall portions around the openings	YES	HIGH	HIGH	MEDIUM	YES





D. 8	Jacketing, through a reinforced plaster with welded steel mesh In Slovenia, this procedure is widely used		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	HIGH	MEDIUM	MEDIUM	YES
D. 9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)		Improvement of resistance in walls		This techniqu	ue is not used	in Slovenia	
D. 10	Intramural tying, through the application of punctual confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	General years follows Sales and Trackers Sales and Trackers Sales and Trackers Sales and Trackers	Improvement of resistance in walls	YES	MEDIUM	HIGH	MEDIUM	YES
D. 1:			Strengthening of the wall portions around the openings	YES	HIGH	LOW	LOW	YES
D. 12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		Improvement in the foundation structures	YES	HIGH	MEDIUM	MEDIUM	YES/ NO





ow	in the foundation					
ow	foundation					
ow						
	structures					
е						
	Improvement	YES	MEDIUM	MEDIUM	MEDIUM	NO
"	in the					
	foundation					
	structures					
,	ne de la constant de	Improvement in the foundation	Improvement in the foundation	Improvement yES MEDIUM in the foundation	Improvement YES MEDIUM MEDIUM in the foundation	Improvement YES MEDIUM MEDIUM MEDIUM in the foundation

Masonry buildings – Wood solutions (Table E)

For the wood solutions, the spreadsheet filled for the Slovenian territory shows some slight differences. Overall, the interventions using wood seem not much widespread in Slovenia. Other materials find a greater diffusion.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMIMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	<i>COST</i>	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	Organization of biological control of the control o	Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	LOW	YES





E. 3	Replacing the roof plank with a double wooden plank	Reduction of the high deformability of the floors; intervention on roofs	YES	HIGH	LOW	MEDIUM	YES
E. 4	Timber tie beam	Reduction of the deficiencies of the connections; intervention on roofs	No such method has been recognized in Slov The standard procedure for replacing the roo connection of the walls with RC connection which the new roof is carried out.				f is the

RC buildings – Steel solutions (Table F)

Overall, interventions using steel on existing RC structures are recommended in Slovenia. If properly sized, they are also considered effective.

The diffusion is perhaps more limited than in Italy, as more technical complexity is perceived.

The CAM system is not used, as it is an Italian patent that presumably has not been exported to the country.

F	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
F. 1	Steel jacketing for column and beam strengthening, through welding or bolting with a steel section, where the gap between the concrete and steel is filled with grout If the steel elements are appropriately anchored at the bottom and on the top as well as connected to the column, the technique is sufficient.		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	YES	LOW	MEDIUM	MEDIUM	YES





	1	l	T =					
F. 2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive The problem of this type of intervention is the high weight of steel lamels, so they need to be supported with anchors in the installation phase		Bending reinforcement	YES	LOW	LOW	LOW	YES
F. 3	Addition of bracing systems		Reduction of displacements; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	MEDIUM	YES
F. 4	Addition of dissipative bracing systems		Seismic energy dissipation; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	HIGH	NO
F. 5	Dissipative external systems		Reduction of displacements; reduction of the risk of fragile mechanisms	YES	LOW	HIGH	HIGH	NO
F. 6	Bandaging of reinforced concrete walls and pillars with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts"), which uses a highperformance metal		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		This techniqu	ue is not used	in Slovenia	





F. 7	tape closed on itself through joining elements; this creates circles under tension which induce an active threedimensional confinement. Bandaging of	Increase in the		This techniqu	ue is not used	in Slovenia	
	reinforced concrete nodes with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts")	stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends					
F. 8	Advanced anti- seismic techniques, as base isolation systems	Advanced antiseismic techniques	YES	LOW	HIGH	HIGH	NO

RC buildings – Fibres solutions (Table G)

For the solutions with fibres, the spreadsheet filled for the Slovenian territory does not show relevant differences with Italy, as already highlighted in the case of masonry buildings. The motivation is believed to be the same.

G	Interventions using fibres solutions								
соре	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMIMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE	
G. 1	FRP or fibres jacketing for column and beam strengthening, through the application of external fabric wraps around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	YES	HIGH	MEDIUM	MEDIUM	YES	





G. 2	FRP or fibres	T.	Increase in the	VEC	IIICII	NACDILINA	NAEDU INA	VEC
G. 2				YES	HIGH	MEDIUM	MEDIUM	YES
	jacketing for	- Marie and	stiffness and					
	column and beam		strength of the					
	strengthening,		structure;					
	through the	the street of th	reduction of					
	application of		the risk of					
	external strips		fragile					
	around them		mechanisms;					
			increase in the					
		O Lambour Company	ductility of the					
			pillar ends					
G. 3	Reinforcement of		Bending	YES	HIGH	MEDIUM	MEDIUM	YES
	the floor joists		reinforcement					
	with carbon fibers							
G. 4	Bending and shear		Bending	YES	HIGH	MEDIUM	MEDIUM	YES
	reinforcement of		reinforcement		-	_		
	beams with carbon							
	fibres	11						
	1101 03							
G. 5	Anti-overturning		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
	system for infill		the risk of					
	walls		fragile					
			mechanisms					
		X						

RC buildings – RC solutions (Table H)

Again, for RC solutions, the spreadsheet filled for the Slovenian territory does not show relevant differences.

Н	Interventions using RC solutions							
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE





H. 1	Reinforced concrete jacketing for column and beam strengthening, through the addition of an external layer of reinforced concrete	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	YES	HIGH	LOW	MEDIUM	NO
H. 2	Stiffening of floors with a reinforced concrete slab The procedure should be combined with anchoring and the implementation of the horizontal beams.	Increase in the stiffness and strength of the structure	YES	HIGH	LOW	LOW	YES
H. 3	Realization of new structural elements (reinforced concrete walls or pillars)	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms	YES	LOW	MEDIUM	MEDIUM	NO
H. 4	Replacement of structural elements	Increase in the stiffness and strength of the structure	YES	LOW	HIGH	MEDIUM	NO
Н. 5	Replacement of non-structural elements	Reduction of the risk of fragile mechanisms	YES	MEDIUM	LOW	LOW	YES





Н. 6	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Improvement in foundation structure	YES	HIGH	MEDIUM	MEDIUM	NO
Н. 7	Execution of foundation by micro-poles	Improvement in foundation structure	YES	MEDIUM	MEDIUM	MEDIUM	NO

7.6. Greece – PP7 (UoC) and PP8 (ROC)

As in all other partner Countries, in Greece, assessing the seismic performance of historical buildings is an important subject. In case of an earthquake, the risk of casualties and collapses, as well as the potential impact on culture and the economy, would be very relevant. Moreover, for the retrofit of historic buildings, the strengthening methods should not alter the traditional architectural characteristics of the construction.

To conserve such structures, the prevention of extended damage during earthquakes is necessary (Maraveas, 2019a).

The vulnerabilities characterizing Greek masonry buildings are those already highlighted for the other countries: similarly, to most historical structures, the timber floors and roof of the masonry building are assumed to be inadequate to act as diaphragms; the connection between the floor and the walls is poor and walls do not have effective lateral support perpendicular to the applied seismic load. This cause that there is not adequate support to distribute the horizontal forces; as a result, the walls experienced an excessive out-of-plane response.

In Greece, however, there is a further construction technique, which seems to present fewer criticalities: the timber walls. The seismic behaviour of these elements with masonry infills is a complex topic in earthquake engineering. The most important parameter for the seismic response of such structures is the connection between the different materials. Even in cases where the interaction between timber and masonry is limited, overall seismic behaviour improves. The timber carries the horizontal forces induced by the earthquake, while the masonry carries mainly the gravitational loads, dissipating energy through the movement of joints after the cracking of mortar (Maraveas, 2019a).

The most important step in the process of retrofitting a masonry building involves the elucidation of its flaws and, generally, the intervention needed is to restore the lateral stability of the walls.

This can be achieved by following one of these two strategies, or even a combination of them: reducing the seismic demands on the members and the structure as a whole, or increasing the capacity of the members. Bibliography on the subject detect the following techniques as the most used in interventions on existing buildings in Greece (Spyrakos, Touliatos, Patsilivas, Pelekis, Xampesis, Maniatakis, 2005; Maraveas C., Tasiouli K., Miamis K., Fasoulakis Z., 2014; Maraveas, 2019a; Maraveas, 2019b):

• Construct rigid diaphragms at floor level. This method provides an effective way of distributing the horizontal forces induced by the earthquake to all masonry walls, thus decreasing the damaging out-of-





plane response of the walls perpendicular to the seismic action. In this way, the separation of the walls along the vertical joints and excessive cracking should be resolved.

- Repointing. It is the replacement of the existing mortar with mortar of significantly better quality (i.e., cement mortar, according to Greek uses)
- Cement grouting. Filling the voids by injecting cementitious grout may be a suitable solution for retrofitting.
- External bonding of timber members with masonry and improvement of shear connection.
- Construction of RC tie beams to create an overall "box" connection at the top of the masonry walls and connection of the tie beams to the masonry walls with steel bars and dowels to the timber roof.
- Use of pre-stressed tie-bars to connect intersecting walls
- Use of fibre reinforced polymer (FRP) composites to increase the tensile strength of masonry.
- Use of textile-reinforced mortar (TRM) for the external bonding of thick walls. TRM is similar to FRP solutions, using textiles instead of sheets and mortars instead of epoxy resins.
- Shotcreting of the wall in a thickness of 4-8 cm, typically the reinforcement has a diameter of 8/25. The new wall has to be anchored to the existing masonry. This technique can be done only on one side of the wall if the façade has to be kept.

Currently, among the partner countries, only for Greece and Italy exhaustive information has been found for interventions on existing reinforced concrete buildings.

This is probably due to the fact that, in Greece, the RC construction technique is much more widespread than in other partner countries and earthquakes are frequent and often violent. This has led to a high interest in the study and in the application of these intervention techniques.

This consideration is confirmed by a research (Antonopoulos, Anagnostopoulos, 2015). It reports that existing RC buildings with brick infill and open ground stories (pilotis), designed with the Greek codes applicable till 1984, represent the structural type that has suffered most of the damage and collapses during earthquakes in Greece (in the Alcyonides 1981, Kalamata 1986, and Athens 1999 earthquakes) and worldwide (e.g. in the Mexico 1985 and Kocaeli-Izmit 1999 earthquakes). The response of such buildings to earthquake actions is characterized by substantial uncertainty, while their overall behaviour is strongly influenced by the response of their open ground stories.

After understanding the structural deficiencies in existing buildings, several techniques have been and are being developed to upgrade existing structures. These methods are either targeted at upgrading the performance of existing elements such as beams and columns (in terms of strength, stiffness or ductility), or at creating a totally new lateral load resisting system, such as new reinforced concrete walls, steel braces or upgrading the existing infill walls to make them a reliable resisting system. Moreover, in special cases, techniques that involve base isolation or dampers can be used, although their application in common residential structures is rather uncommon and, therefore, will not be examined hereafter (Gkournelos, Bournas, Triantafillou, 2019).

When the upgrading of a structure is proven to be completely uneconomic, a total demolition and reconstruction might be preferred. Of course, a newly built structure will always be more reliable than a retrofitted one, no matter how well-designed and applied is the retrofitting scheme (Gkournelos, Bournas, Triantafillou, 2019).

The followings are the intervention techniques for the seismic retrofitting of existing buildings with a RC structure in Greece, as found in the references (Gkournelos, Bournas, Triantafillou, 2019):





Upgrading of individual elements

of confinement.

The simplest idea is the improvement of individual elements, which are beams, columns and shear walls. These techniques are most effective when the building has already a considerable lateral resistance and phenomena such as brittle failures need to be avoided. It is ineffective when a significant strength upgrade is necessary.

- Reinforced concrete jacketing
 It regards the jacketing of an existing element with an exterior layer of reinforced concrete.
 Through the proper project, almost all the properties of the element can be affected, like its bending, shear and axial strength, its stiffness and even its ductility by the additional confinement that the jacket can provide. It is a simple technique that has been proven to work satisfactorily in the field, as it has been used in many applications over the past years.
- Externally applied steel reinforcement

 The same effects as jacketing can be achieved with steel plates bolted on the outer surfaces of the RC elements. The disadvantage of this method is the corrosion of the externally applied reinforcement, unless special measures are taken.
- Fibre reinforced polymer-based solutions
 Another method to improve the performance of individual elements, is by their upgrading using fibre reinforced polymers. FRP-based solutions can be employed to affect the properties of an element. The most common uses of FRPs in RC structural retrofitting are: increasing bending resistance in RC beams by applying/gluing fibres strips or sheets on the faces of the element to act as external tensile reinforcement; increasing shear resistance in beams and columns by wrapping them with FRP sheets; wrapping RC columns to achieve a greater degree

FRPs are not without disadvantages. Because of their nature, they behave in a linear elastic manner, so it is no possible to achieve fully ductile behaviour when used as tensile reinforcement. In addition, the epoxy resins they contain show significant strength loss when they are subjected to high temperatures, therefore it is necessary to protect them against fire. Furthermore, their application requires skilled and trained technicians and of course their price can be quite high.

However, FRPs allow for a highly reliable strengthening technique, thoroughly tested and implemented in practice, which minimally affects the dimensions of the retrofitted elements and whose application disturbs much less the occupants of the structure. In general, when it comes to shear strengthening or providing additional confinement in columns for ductility reasons, FRPs are probably the most efficient way of achieving these objectives.

- Textile reinforced mortar-based solutions

The last method of upgrading existing RC members is the one using textile reinforced mortar (TRMs in short) to achieve the same effects of the FRP-based solutions. The only two differences between the two techniques are that TRMs use textiles instead of sheets as their load-bearing mechanism and mortars instead of epoxy resins as their binding material. The resulting material has the same behaviour as FRPs but, with the same dimensions, slightly reduced strength and stiffness. However, the cost of TRMs is considerably lower than that of FRPs mainly because of the high cost of the epoxy resins; in addition, TRMs resist high temperatures better because their binding material is an inorganic mortar rather than the organic epoxy resins.





TRMs can be used to improve the shear strength of RC elements and provide confinement in columns just like FRPs. For what concerns seismic retrofitting of RC columns, TRM jackets have the same effectiveness as FRP jackets. There have been many experiments in the past proving it, but the application of TRMs in engineering practice is much less extended than that of FRPs.

- Addition of new lateral load resisting systems
 - The above-mentioned techniques are efficient and economic as long as no extreme strength upgrade is needed. When this is the case, techniques that completely change the lateral load resisting system rather than just upgrading it have to be employed.
 - One efficient way to greatly increase a RC structure's resistance against lateral loads is to select specific bays and infill them with reinforced concrete, thus converting the initial frames to a wall-like configuration. The selection of the bays to be transformed must be done very carefully, taking into account the serviceability restrictions of the building (e.g., obligatory existence of openings) as well as structural engineering ones (e.g., the floor shear centre should not move away from the centre of mass). Obviously, the implementation of this method requires specific measures to be taken at the interface of the frame with the new wall to ensure optimal interaction. However, it has been proven to be very effective and economic when it comes to multi-storey RC buildings, especially those with soft storeys.
 - External steel bracing
 An alternative to the above techn
 - An alternative to the above technique is the insertion of vertical steel bracing in RC bays. Depending on the dimensioning of the bracing system, the seismic resistance of the building can be increased several times. Again, special measures need to be taken in order to ensure the optimal interaction between the new and the old elements so that the transfer of the internal forces can occur in a reliable way. This technique has been successfully used in many cases in the past and has shown satisfactory behaviour.
 - Strengthening of masonry-infilled RC frames with TRM Jackets
 The last retrofitting method is the strengthening of Masonry-Infilled RC Frames with TRM. This method was developed and tested by Koutas et al. (2015 a,b) and Koutas and Bournas 2019. It exploits the existing infill walls that are present in buildings, improving their behaviour by applying layers of TRM on their faces. This creates a lateral load resistance mechanism similar to that of a wall, but at a significantly lower cost. After a set of experiments were completed, it was found that the proposed method can increase the lateral strength, the stiffness, the energy dissipation and the deformation capacity of the retrofitted structure. Moreover, it is very important to note that this technique prevents the falling of debris from the wall when crushing occurs and also contributes to the out of plane stability of the wall although the exact amount of how much is yet to be experimentally tested. Both these features are essential for the security of people.





		Strength	Stiffness	Ductility	Irregularity	Force demand	Deformation demand
se	Concrete jacket	✓	✓	✓		×	✓
sur	Steel jacket	✓		✓			
mea	FRP jacket	✓		✓			
Local measures	Post-tensioning	✓		✓			
Γο	Strength reduction	×					
	New frames, shear walls, braces	✓	✓		✓	*	✓
တ္ဆ	Mass removal				✓	✓	*
sure	Partial demolition				✓	✓	
neas	Isolation				✓	✓	✓
Global measures	Dampers		✓			×	✓
lob	Expansion joints				✓		
	Connect independent sections				✓		

Figure 35 – Effect of local and global retrofit measures on building properties [Tsionis, 2014].

In conclusion, steel or RC jacketing are the most common strengthening techniques that are applied to increase the strength and ductility of RC members. RC jacketing of columns is widely used in seismic rehabilitation of old buildings, since it can increase considerably the strength of columns when weak columns-strong beam situations are detected. However, when there is lack of lateral stiffness in the building, RC jacketing is not very effective, as intervention is required to significantly reduce the displacements. In order to sufficiently increase the lateral stiffness, a comprehensive retrofit measure, including most possibly the addition of shear walls, is required (Bournas, 2018).

Overall, the application of conventional strengthening techniques, such as steel, RC jacketing or RC walls placed around columns require intensive labour and skilful detailing (high cost), considerable amounts of materials (higher embodied CO₂ emissions, more energy in manufacturing), and significantly disturb the inhabitants of the building (or traffic in railways, bridges, roads) during renovation. To overcome the disadvantages of conventional strengthening techniques, researchers have introduced the use of fibre-reinforced polymer (FRP) materials.

FRPs for strengthening of structures are available in the form of: (a) thin unidirectional strips (with a thickness in the order of 1mm), (b) flexible sheets or fabrics, made of high strength fibres in one or at least two directions which are usually impregnated with resin. In FRPs-concrete interventions, it is essential to remember that the tensile stresses in these materials are carried only by the fibres in their respective directions. The use of FRP has gained increasing popularity in the civil engineering community, due to the favourable properties possessed by these materials, namely: extremely high strength to weight ratio, corrosion resistance, ease and speed of application, minimal change in the geometry. FRP jacketing can be used to increase the strength and deformation capacity of RC elements. In particular, it is very effective in containing all failure mechanisms of columns (shear, bar buckling and concrete crushing, short lap-splices), except bending. When the flexural strength (moment capacity) of the columns is lower than that of the adjacent beams, a soft storey mechanism may be triggered.

Effective strengthening of columns in bending (often needed, for instance, to satisfy capacity design requirements, that is, the elimination of weakness in strong-beam/weak-column situations or when existing reinforcing bars have been affected by corrosion) calls for the continuation of longitudinal reinforcement. This



reinforcement should extend beyond the end cross sections, where moments are typically maximum. Therefore, placement of externally bonded FRP jacket is not effective. On the other hand, as explained above, RC jacketing requires intensive labour, increases the dimensions and weight of columns and result in substantial obstruction of occupancy.

To overcome difficulties associated with conventional strengthening techniques and FRP jacketing, recent research efforts have focused on the use of near-surface mounted (NSM) FRP or stainless-steel reinforcement or through a combination of externally bonded (EBR) FRP sheets (or laminates) and anchors for the flexural strengthening of columns. This longitudinal reinforcement is prevented from local buckling, also in highly compressed areas, through the use of confining jackets made of composite materials (i.e. TRM/FRP). Despite their well-established the FRP strengthening technique entails drawbacks: poor behaviour at high temperatures, high costs, inapplicability on wet surfaces or at low temperatures, health and safety issues for manual workers, incompatibility with substrate materials, mainly attributed to the organic resins used to bind and impregnate the fibres.

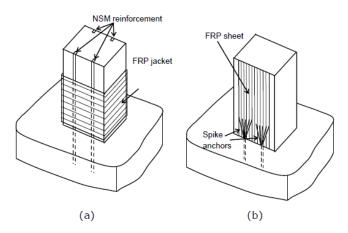


Figure 36 - Flexural strengthening of RC column with: (a) NSM reinforcement combined with composite material jacketing; (b) externally bonded FRP sheets combined with spike anchors (Bournas, 2018).

Masonry buildings – Steel solutions (Table A)

The spreadsheet filled for the Greek territory confirms the Country's different approach to the issue of intervention on existing buildings, as happens for the Slovenian Country. In fact, some of the interventions that are the most used and the most recommended in Italy, especially for protected buildings, are not recommended in Greece (for example: tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall; steel box frame connected to masonry walls to create new openings; reinforcement intervention on arches with steel elements; substitution of existing architraves and jack arches with steel profiles). The reasons are the absence of regulations and specialized staff to apply such reinforcements.

Then, there is a different evaluation for some interventions using steel in terms of technical complexity and cost, but there is not a single upward or downward trend.





Α	Interventions us	ing steel solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
A. 1	Single tie-rods consisting of metal elements (bars, flat bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or bars, traditionally called anchor plates.		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 2	Paired tie-rods on both sides of the wall or paired plates on the two sides of the wall connected together with steel bars and external anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 3	Tie-rods in the thickness of the wall, made with metal bars or steel cables passing through a hole injected with nonshrink mortars	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	NO	MEDIUM	MEDIUM	LOW	NO





A. 4	Floor connections made with coupled steel profiles on two sides of the wall and connected to each other, between one room and the other and to the outside with steel	2 pleases 1700de 12 mile conclusion (25 mile c	Reduction of the deficiencies of the connections; intervention on roofs; reduction of the high deformability	YES	LOW	LOW	MEDIUM	YES
A. 5	rebars, ribbed metal plates, and bolts. Crossed steel		of the floors Reduction of	YES	LOW	MEDIUM	LOW	YES
A. 3	bands in the thickness of the floor	Connected and assegments in south thinking the control of the cont	the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs	13	LOW	WEDIOW	LOW	
A. 6	Tie-rods for arches and vaults made with steel bars, with the possibility of tensioning them		Reduction of un-contrasted thrust of arches and vaults;	YES	HIGH	LOW	LOW	YES
A. 7	Tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall		Reduction of the deficiencies of the connections; intervention on roofs	NO	MEDIUM	MEDIUM	MEDIUM	YES
A. 8	Stitching, through reinforced perforations made with steel bars	b Colored	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	NO	LOW	MEDIUM	LOW	YES





A. 9	Connection of floor slabs and roofs to walls (connection of purlins or ridge beams with the walls of the tympanum)	MARTICOLA DE SCATULA DI COLLEGAMENTO DE CANCENDATO DE CONTROL DE C	Reduction of the deficiencies of the connections; intervention on roofs	YES	MEDIUM	MEDIUM	MEDIUM	YES
A. 10	Steel plates connecting the wooden plank to the walls	a	Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; reduction of high deformability of the floors; intervention on roofs	YES	LOW	LOW	MEDIUM	YES
A. 11	Application of steel anchor plates		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; intervention on roofs	YES	HIGH	LOW	LOW	YES
A. 12	Replacement of floor and roof slabs with iron floor and brick planks or wooden boards		Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs	NO	LOW	MEDIUM	HIGH	YES





				1	I -	_			_
A.	13	Stiffening of floors		Reduction of	YES	LOW	MEDIUM	MEDIUM	YES
		with metal strips		the					
			Profile Metallico Inchiedato	deficiencies of					
				the					
				connections;					
				reduction of					
				high					
				deformability					
				of the floors;					
				intervention on					
				roofs					
^	14	Adding beams of		Reduction of	YES	MEDIUM	LOW	MEDIUM	NO
Λ.	14			high	1123	IVILDIOIVI	LOVV	IVILDIOIVI	NO
		the same type as							
		existing ones (steel		deformability					
		beams)		of the floors;					
				intervention on					
				stairs;					
				intervention on					
				roofs					
A.	15	Steel box frame		Improvement	NO	HIGH	MEDIUM	MEDIUM	NO
		connected to		in the					
		masonry walls to		distribution of					
		create new		resistant					
		openings		vertical					
		- 0-		elements;					
				strengthening					
				of wall					
				portions					
				around the					
_	1.0	Dainfausanant		openings	NO	1014/	NACDILINA	NACDILINA	NO
A.	16	Reinforcement		Improvement	NO	LOW	MEDIUM	MEDIUM	NO
		intervention on		in the					
		arches with steel		distribution of					
		elements		resistant					
				vertical					
				elements;					
				strengthening					
				of wall					
				portions					
				around the					
				openings					
A.	17	Reinforced		Improvement	YES	LOW	MEDIUM	MEDIUM	NO
		repointing,		of resistance in					
		combining the		walls					
		traditional							
		repointing with the							
		inclusion, within							
		the bed joints, of							
		reinforcing bars.							





A. 18	Confinement of pillars and columns through the application of steel hoops reinforcements	Improvement in the distribution of resistant vertical elements; pillars and columns	YES	HIGH	LOW	LOW	YES
A. 19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados	Strengthening of wall portions around the openings	NO	LOW	MEDIUM	LOW	NO
A. 20	Substitution of existing architraves and jack arches with steel profiles	Strengthening of wall portions around the openings	NO	MEDIUM	LOW	LOW	YES
A. 21	Bracing of the roofing structures with steel cables or bars	Intervention on roofs	YES	LOW	MEDIUM	LOW	YES
A. 22	Advanced anti- seismic techniques (base isolation systems, dissipative bracing systems)	Advanced anti- seismic techniques	NO	LOW	HIGH	HIGH	NO

Masonry buildings - Masonry solutions (Table B)

Also for the masonry solutions, the spreadsheet filled for the Greek territory highlights some differences.

Again, there is a different evaluation for some interventions in terms of diffusion, technical complexity and cost, but also in this case there is not a single upward or downward trend.

Overall, the interventions that use the masonry seem less widespread than in Italy and they are felt to be more difficult to apply.





В	Interventions us	ing masonry solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
B. 1	Tie beams in reinforced masonry, with concrete and steel		Reduction of the deficiencies of the connections; intervention on roofs	NO	LOW	MEDIUM	LOW	YES
B. 2	Buttress on masonry walls		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement in the distribution of resistant vertical elements	YES	MEDIUM	LOW	LOW	NO
В. 3	Local dismantling and reconstruction with flat bricks or rough or squared stone with mechanical characteristics similar to the existing one (called "scuci-cuci" = "unstitch-stitch")		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	HIGH	LOW	LOW	YES
B. 4	Realization of new structural elements (masonry walls)		Improvement in the distribution of resistant vertical elements	YES	HIGH	LOW	MEDIUM	NO





B. 5	Thickening of the walls with solid bricks or rough-hewn or squared stone having the same mechanical characteristics as the existing one		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	YES	LOW	LOW	MEDIUM	NO
B. 6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to the existing ones		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls	NO	LOW	MEDIUM	MEDIUM	NO
B. 7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the absence of cement binders	Open parts reported providing growing and selected providing growing and selected parts to several parts and selected parts to several parts and selected parts to several parts and selected parts and sel	Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	MEDIUM	MEDIUM	YES
B. 8	Localized grout injections of mortars or resins		Improvement in the distribution of resistant vertical elements; improvement of resistance in walls; pillars and columns	YES	HIGH	MEDIUM	MEDIUM	YES
В. 9	structural repointing, through the partial but deep removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better mechanical properties and durability)		Improvement of resistance in walls; pillars and columns	YES	HIGH	LOW	LOW	YES





B.	10	Substitution of existing architraves and jack arches with reinforced brick masonry		Strengthening of the wall portions around the openings	NO	LOW	LOW	LOW	NO
В.	11	Execution of masonry foundation below the existing one	Muratura portante Fondazione elistente Bistinicolosizione in ruretura de motitori lisenza Gon malta centrericia	Improvement in foundation structures	YES	LOW	HIGH	HIGH	NO
В.	12	Separation of masonry structures to create seismic joints	70	Realization of seismic joints	NO	LOW	HIGH	LOW	YES
В.	13	Construction of small brick walls (frenelli) for vaults stiffening		Reduction of the high deformability of the floors	YES	MEDIUM	MEDIUM	LOW	YES

Masonry buildings – Fibres solutions (Table C)

As for interventions with fibres, it is evident that in Greece these are almost never recommended for masonry buildings. Probably the reasons are identified in the lesser effectiveness compared to other techniques or in the lack of compatibility with the existing material.

As a result, these are less common than the other techniques.

С	Interventions using fibres solutions								
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE	
C. 1	Application of composite materials strips (reinforced fibers)		Reduction of the deficiencies of the connections; intervention on roofs; pillars and columns	NO	LOW	MEDIUM	MEDIUM	YES	





	I	I	- 1 · · · · · · ·					1/50
C. 2	Tie beams in brick and FRP		Reduction of the deficiencies of the connections; intervention on roofs;	NO	LOW	MEDIUM	MEDIUM	YES
C. 3	Stitching, through reinforced perforations made with fiberglass or carbon fibre bars		Reduction of the deficiencies of the connections; reduction of un-contrasted thrust of arches and vaults; improvement of resistance in walls	NO	LOW	HIGH	MEDIUM	YES
C. 4	Stiffening of floors with FRP fibers	Solve inferrate cut Free	Reduction of the deficiencies of the connections; reduction of high deformability of the floors; intervention on roofs; intervention on stairs; reduction of the high deformability of the floors	NO	LOW	MEDIUM	MEDIUM	YES
C. 5	Intrados or extrados application of composite materials strips to vaults (reinforced fibres)		Reduction of un-contrasted thrust of arches and vaults; intervention on stairs	NO	MEDIUM	MEDIUM	MEDIUM	YES





C.	6	Jacketing, through	Improvement	YES	MEDIUM	MEDIUM	MEDIUM	YES
		a reinforced	in the					
		plaster with fibres	distribution of					
		mesh	resistant					
			vertical					
			elements;					
			improvement					
			of resistance in					
			walls; pillars					
			and columns:					
			intervention of					
			the stairs					
C.	7	Strengthening of	Strengthening	NO	LOW	LOW	LOW	YES
		architraves and	of the wall					
		jack arches by	portions					
		applying carbon	around the					
		fibre strips or	openings					
		meshes to the						
		intrados						

Masonry buildings – RC solutions (Table D)

As for interventions with RC solutions, in Greece these are not recommended for masonry buildings and they are considered difficult to apply. The reasons are identified in the lack of compatibility with the existing material and in the high rate of irreversibility of the intervention. However, these are quite widespread on the territory.

D	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMIMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
D. 1	Reinforced concrete tie beams	ADMIN TO CONTROL LATER 22	Reduction of the deficiencies of the connections; intervention on roofs	NO	HIGH	LOW	LOW	YES
D. 2	Reinforced slab with crossed steel perforation plates	Lames greated Jayo 156/000 ref-8 min Re s. 69 2000 Soleta in CLIs. steggetts evident (16/05/greq) Evident (16/05/gr	Reduction of the deficiencies of the connections; reduction of the high deformability of the floors; intervention on	NO	MEDIUM	HIGH	MEDIUM	NO





			roofs;					
			intervention on					
			the stairs					
D. 3	Replacement of		Reduction of	NO	MEDIUM	MEDIUM	HIGH	NO
	floor and roof slabs		the			-		
	with reinforced	A STATE OF THE PARTY OF THE PAR	deficiencies of					
	concrete slab		the					
			connections;					
			reduction of					
			the high					
			deformability					
			of the floors;					
			intervention on					
	2.155		roofs					
D. 4	Stiffening of floors		Reduction of	NO	MEDIUM	MEDIUM	MEDIUM	NO
	with a reinforced		the					
	concrete slab		deficiencies of the					
			connections;					
			reduction of					
			the high					
			deformability					
			of the floors;					
			intervention on					
			roofs;					
			intervention on					
			the stairs					
D. 5	Reinforced		Improvement	NO	HIGH	MEDIUM	MEDIUM	NO
•								
	concrete box	THE TOTAL PROPERTY OF THE PARTY	in the					
	frame connected		distribution of					
	frame connected to masonry walls		distribution of resistant					
	frame connected to masonry walls to create new		distribution of resistant vertical					
	frame connected to masonry walls		distribution of resistant vertical elements;					
	frame connected to masonry walls to create new		distribution of resistant vertical elements; strengthening					
	frame connected to masonry walls to create new		distribution of resistant vertical elements; strengthening of the wall					
	frame connected to masonry walls to create new		distribution of resistant vertical elements; strengthening of the wall portions					
	frame connected to masonry walls to create new		distribution of resistant vertical elements; strengthening of the wall portions around the					
D. 6	frame connected to masonry walls to create new		distribution of resistant vertical elements; strengthening of the wall portions around the openings	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings		distribution of resistant vertical elements; strengthening of the wall portions around the	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings		distribution of resistant vertical elements; strengthening of the wall portions around the openings	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings Realization of new structural		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements;	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and	NO	LOW	MEDIUM	HIGH	NO
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars)		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns	NO	LOW	MEDIUM	HIGH	NO
D. 6	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns	NO	LOW	MEDIUM	HIGH	NO
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the					
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on arches with		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the distribution of					
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on arches with reinforced		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the distribution of resistant vertical elements; pillars and columns					
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on arches with		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the distribution of resistant vertical elements; pillars and columns					
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on arches with reinforced		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the distribution of resistant vertical elements; pillars and columns					
	frame connected to masonry walls to create new openings Realization of new structural elements (reinforced concrete walls or pillars) Reinforcement intervention on arches with reinforced		distribution of resistant vertical elements; strengthening of the wall portions around the openings Improvement in the distribution of resistant vertical elements; pillars and columns Improvement in the distribution of resistant vertical elements; pillars and columns					





				portions					
				around the openings					
D.	8	Jacketing, through a reinforced plaster with welded steel mesh		Improvement in the distribution of resistant vertical elements; improvement	NO	HIGH	MEDIUM	HIGH	NO
				of resistance in walls					
D.	9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced concrete or steel cylinders (artificial diatons)		Improvement of resistance in walls	YES	MEDIUM	MEDIUM	LOW	YES
D.	10	Intramural tying, through the application of punctual confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar in a confining socket (anti-expulsion tierods)	General States Improvement of resistance in walls	YES	MEDIUM	MEDIUM	LOW	YES	
D.	11	Substitution of existing architraves and jack arches with a reinforced concrete beam		Strengthening of the wall portions around the openings	NO	HIGH	MEDIUM	LOW	NO
D.	12	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		Improvement in the foundation structures	NO	HIGH	MEDIUM	HIGH	YES/ NO





D. 13	Execution of a		Improvement	NO	MEDIUM	HIGH	HIGH	NO
	reinforced		in the					
	concrete		foundation					
	foundation below		structures					
	the existing one							
D. 14	Execution of		Improvement	NO	LOW	HIGH	HIGH	NO
	foundation by	11 1	in the					
	micro-piles		foundation					
			structures					

Masonry buildings – Wood solutions (Table E)

For the wood solutions, the spreadsheet filling for the Greek territory shows many differences.

Overall, the interventions using wood seem not much widespread in Greece, they have a limited technical complexity but, in some cases, they can be expensive.

E	Interventions us	ing wood solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
E. 1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	Injust orders differed to the control of the contro	Reduction of the high deformability of the floors; intervention on roofs	YES	LOW	MEDIUM	MEDIUM	YES
E. 2	Adding beams of the same type as existing ones (wooden beams)		Reduction of the high deformability of the floors; intervention on roofs	YES	MEDIUM	LOW	LOW	YES





E. 3	Replacing the roof		Reduction of	NO	HIGH	MEDIUM	HIGH	NO
	plank with a		the high					
	double wooden		deformability					
	plank		of the floors;					
			intervention on					
		11/2 3 13418	roofs					
		A STATE OF THE STA						
E. 4	Timber tie beam		Reduction of	YES	LOW	LOW	LOW	YES
			the					
			deficiencies of					
			the					
			connections;					
			intervention on					
			roofs					

RC buildings – Steel solutions (Table F)

Regarding the steel solutions on RC existing buildings, the spreadsheet filling for the Greek territory shows some slight differences in the technical complexity and in the easy application.

F	Interventions us	ing steel solutions						
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
F. 1	Steel jacketing for column and beam strengthening, through welding or bolting with a steel section, where the gap between the concrete and steel is filled with grout		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	MEDIUM	YES
F. 2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive		Bending reinforcement		LOW	LOW	LOW	YES





F. 3	Addition of bracing systems	Reduction of displacements; reduction of the risk of fragile mechanisms	MEDIUM	MEDIUM	MEDIUM	NO
F. 4	Addition of dissipative bracing systems	Seismic energy dissipation; reduction of the risk of fragile mechanisms	LOW	HIGH	HIGH	NO
F. 5	Dissipative external systems	Reduction of displacements; reduction of the risk of fragile mechanisms	LOW	HIGH	HIGH	NO
F. 6	Bandaging of reinforced concrete walls and pillars with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts"), which uses a high-performance metal tape closed on itself through joining elements; this creates circles under tension which induce an active threedimensional confinement.	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	YES





F. 7	Bandaging of reinforced concrete nodes with CAM system ("Cuciture Attive dei Manufatti" = "Active Seams of the Artifacts")	Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends	LOW	MEDIUM	MEDIUM	YES
F. 8	Advanced anti- seismic techniques, as base isolation systems	Advanced antiseismic techniques	LOW	HIGH	HIGH	NO

RC buildings – Fibres solutions (Table G)

For the fibres solutions, the spreadsheet filling for the Greek territory does not show some differences, mainly in the technical complexity.

In fact, in Greece the technical complexity is considered low, proof of the fact that these interventions are considered easier to carry out than those in steel and reinforced concrete.

Consequently, their diffusion is quite high.

G	Interventions us	Interventions using fibres solutions							
СОВЕ	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMIMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE	
G. 1	FRP or fibres jacketing for column and beam strengthening, through the application of external fabric wraps around them		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	LOW	MEDIUM	YES	





			1					
G.	2	FRP or fibres		Increase in the	MEDIUM	LOW	MEDIUM	YES
		jacketing for		stiffness and				
		column and beam		strength of the				
		strengthening,		structure;				
		through the	the strength of the strength o	reduction of				
		application of		the risk of				
		external strips		fragile				
		around them		mechanisms;				
			TOTAL STATE OF THE	increase in the				
			See and the second	ductility of the				
				pillar ends				
G.	3	Reinforcement of		Bending	MEDIUM	LOW	MEDIUM	YES
		the floor joists		reinforcement				
		with carbon fibers						
			11/1/2					
			11////					
G.	4	Bending and shear		Bending	HIGH	LOW	MEDIUM	YES
		reinforcement of		reinforcement	-		_	
		beams with carbon						
		fibres	11					
G.	5	Anti-overturning		Reduction of	MEDIUM	MEDIUM	MEDIUM	YES
		system for infill		the risk of				
		walls		fragile				
				mechanisms				
				1				

RC buildings – RC solutions (Table H)

The spreadsheet filling about RC solutions for the Greek territory shows significant differences; in particular, we highlight how the cost of the interventions is higher while the diffusion is lower than in the Italian case, taken as a comparison in this first phase of analysis.

The two variations are presumably linked, since a high cost (perhaps higher than the cost of the other techniques) can correspond to a lower diffusion. Furthermore, already from the phase of the references analysis, it emerged that this type of intervention is considered uncomfortable for the inhabitants, so this could be a further reason for the lower diffusion.





н	Interventions us	ing RC solutions						
CODE	DESCRIPTION	EXAMPLES	FUNCTIONS	RECOMMENDE D	DIFFUSION	TECHNICAL COMPLEXITY	COST	EASILY APPLICABLE
H. 1	Reinforced concrete jacketing for column and beam strengthening, through the addition of an external layer of reinforced concrete		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms; increase in the ductility of the pillar ends		HIGH	MEDIUM	HIGH	NO
H. 2	Stiffening of floors with a reinforced concrete slab		Increase in the stiffness and strength of the structure		MEDIUM	LOW	MEDIUM	YES
Н. 3	Realization of new structural elements (reinforced concrete walls or pillars)		Increase in the stiffness and strength of the structure; reduction of the risk of fragile mechanisms		MEDIUM	MEDIUM	HIGH	NO
H. 4	Replacement of structural elements		Increase in the stiffness and strength of the structure		LOW	HIGH	HIGH	NO





Н. 5	Replacement of non-structural elements	Reduction of the risk of fragile mechanisms	MEDIUM	LOW	LOW	YES
Н. 6	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	Improvement in foundation structure	MEDIUM	MEDIUM	HIGH	YES
Н. 7	Execution of foundation by micropoles	Improvement in foundation structure	MEDIUM	HIGH	HIGH	YES

8. Conclusions

Historic cities are more than just built up areas, but they are part of the complex and dynamic system of the urban cultural heritage, characterized by a continuous interaction between material and immaterial and by the constant evolution of their constituent elements (UNESCO 2013). The urban environment has an evident historic stratification, where geomorphology, topography, hydrology, buildings and open spaces are present (UNESCO 2012).

Managing, protecting and enhancing such a vast heritage is a process that requires addressing the numerous aspects of conservation. Among these, the structural and seismic engineering sector must protect the built heritage by preserving it from possible effects of future seismic events. The definition of procedures for the reduction of seismic risk is an indispensable prerogative to protect the existing buildings, and in recent years it is increasingly evident due to the occurrence of seismic events that have caused devastating effects, both in terms of damages and losses of human lives.

These procedures concern the assessment and reduction of the seismic vulnerability of buildings, that is the predisposition to suffer a specific level of damage following the occurrence of seismic events with expected intensity. Together with the probability that in a certain area, in a given interval, a seismic event of a certain intensity will occur, and the exposure, as the quantity and quality of the different elements in an area exposed to risk, it defines the seismic risk for a given territory.

The issue is particularly complex, especially because the need to ensure adequate safety levels against seismic actions is intertwined with the need to preserve the original urban and building fabric of historic settlements.



The issue is further complicated considering the extent of the built heritage, especially in the European context, which is characterized by an extremely high number of historic centers. An appropriate methodology is based on the concept of urban seismic vulnerability.

The built heritage can be analyzed at different in-depth scales (from structural elements to structural units, buildings and aggregates of buildings up to the entire historic center), strictly related to the level of knowledge obtainable on the structures. In fact, it is inevitable that an increase in the scale of analysis corresponds to a decrease in the detail level of the information, due to the difficulty of obtaining precise data for a large number of buildings, the long times and the necessary burden for the analyzes.

Once the most appropriate evaluation method has been defined (as discussed in Deliverable T2.1.1), the next step is to determine the current condition of the heritage structure under study, its construction characteristics and its state of conservation. The built heritage of the historic centers has a very heterogeneous fabric, and consists of buildings made of different structural materials, which have been transformed over time, demolished and subsequently rebuilt, and expanded horizontally and/or vertically.

The vulnerability of heritage structures is due to great variability in the characteristics of the urban fabric, which must be understood in order to identify most effective interventions. The aim of the seismic strengthening interventions is to mitigate the vulnerabilities, in order to guarantee, on the one hand, the safety of the inhabitants, and on the other hand to preserve the heritage itself.

Since the main objective of the project is to share effective methods of seismic assessment and intervention on the built heritage within the partner countries, as a first step, it was considered essential to proceed with the knowledge of the heritage itself, looking for common traits and differences in the existing buildings.

This first objective was achieved through a careful study, mapping and cataloging of the construction characteristics of the existing buildings, divided into the various structural components (vertical elements, floors, roofs and foundations), in terms of earthquake performance, dimensions, and the age of construction. A comparison of the characteristics of heritage structures in the PPs and the corresponding interventions is presented below. Here is a summary of the data for each country, which are then compared with the help of diagrams and graphs in the final part of this paragraph.

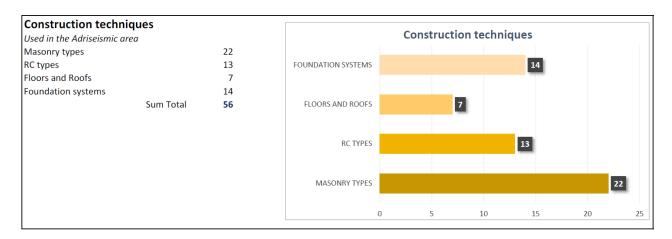


Figure 37 – Summary of the construction techniques for the vertical structures that have been catalogued for the Adrisesmic area.

About **Italy** (PP1 and PP2), the analysis highlighted a clear prevalence of historic load-bearing masonry buildings, equal to 61.50% of the assets compared to 24.66% of reinforced concrete buildings. In general, 80% of Italian municipalities have a percentage of masonry buildings higher than 50% and in particular, 44% of municipalities fall into the highest category (75% -100%).





13 different types of masonry have been identified, each of them with its own prevalent belonging area (limestone in the internal Apennine areas, tuff in volcanic areas, travertine in Central Italy, sandstone in Tuscany, granite in the Calabrian area, brick on the Adriatic coast and in many Northern centres, due to the strong presence of alluvial deposits). In fact, a close connection combines local materials with the construction practice and with specific dimensions of wall structures.

11 different types of horizontal structures were identified; timber floors are the most common solution in Northern and Central Italy, both with wooden plank and with brick tiles. Iron floors were used starting from the Nineteenth century and do not show major differences from place to place; the iron floor with hollow brick tiles is a rather standardized typology that was frequently used also in renovations to replace the original vaulted or timber structures. Stone or brick vaulted structures can be found in numerous Italian centres, in the whole territory. In addition to these types of floors there are, of course, the most recent types of RC floors. 11 different types of foundations have been classified, from the oldest stone types, placed at the base of traditional masonry buildings, without reaching high depths of the ground, to the most modern technologies, also used in consolidation interventions.

Regarding RC buildings, 5 different types of vertical structures have been classified; Italian practice followed the local building dynamics, adapting to pre-existing conditions. At the beginning, the innovative frame structures were used in conjunction with traditional masonry systems and, over time, just the infill walls varied, passing from solid masonry to hollow brick or concrete blocks. Framed structures are the prevalent type, and the use of RC walls is very limited.

The most innovative approach of the classification was to group the construction types linked to the decomposition into elements in a unique structural type, composed of typical combinations of vertical, horizontal elements and foundations. The composition of the load-bearing structure of an existing building is not in fact accidental, but derives from precise specifications linked to the period of construction (as material availability), to the performance requirements and to the construction practice. In this way, it was possible to identify 4 masonry structural types and 3 RC structural types.

Also for **Croatia** (PP3), the analysis of the actual building stock highlights a predominance of unreinforced masonry wall systems (about 45 %), but also a large number of confined masonry wall systems (~31 %), followed by RC infilled frame systems (~23 %) and a very limited number of reinforced concrete dual wall-frame (about 1%).

About the construction techniques, we note that there are only a few differences regarding masonry construction techniques with the Italian case. All the 13 types of masonry are present, even if tuff masonry (A.7) is not common; the predominantly used stone is limestone. For all historic walls, the thicknesses are generally greater, up to 120 cm, against about 70 cm of the Italian territory.

As for floors and roofs, geographical data seem to indicate that timber structure and planks is the most used historical solution also in Croatia, and also timber floor with brick tiles is used, especially where the use of brick is widespread, i.e., where it has been adopted also for the walls (Continental Croatia). The same goes for brick vaults. Alike, stone vaults are present where there are stone walls, i.e., in Southern Croatia.

Iron floors are not a uncommon solution. RC floors began to be widely used about 20 years later compared to Italy.

Vertical RC structures seems to have spread earlier in Croatia than in Italy; the RC types correspond, and they predate the Italian one by about 10-20 years. Only the adoption of light infill panels spread with a few years of delay. As for foundation systems, there are not relevant differences; also for the main structural types, we find an excellent correspondence between Italian and Croatian ones.





Analysing the Albanian case (PP4), we highlight that traditional and historic masonry buildings constitute the majority of the current building stock in **Albania**, like in the other countries. Referring mainly to the territory of Gjirokastra, its name of "the Stone City" makes the typical characteristics of its buildings clear: in the city, local stone is the material characterizing the paving of streets, the walls and the roof coverings. Wood also is very common: timber was used for the masonry reinforcement elements, for the structures of the floors and for the roofs and the uppermost walls.

So, most of the walls are made almost exclusively of stone; only 2 of the 11 masonry types are present, working as a dry stone walls. Also for foundations, they are made exclusively of stone masonry, following the material continuity with the construction solutions of the elevation. The only type of floor is the timber one, with wooden planking. This typology can cover considerable spans, up to 11 m. Iron floors, vaults, and RC floors are not present in Gjirokastra. No solution, for vertical RC structures, is documented for the city of Gjirokastra. Regarding structural types, only the ancient masonry ones are present, as there is no use of RC structures and elements.

In **Serbia** (PP5), solid clay brick masonry is prevalent in majority of heritage buildings and also general construction practice. This happens because most of these buildings are date back to the 19th century, when the bricks became available due to advancement in manufacturing process. Stone masonry is not common in Serbia and is limited to heritage structures with a monumental character. Regarding modern masonry construction techniques (clay bricks or blocks with cement mortar; confined masonry), there is no relevant difference between Serbia and the other countries. Timber-framed construction with masonry infills (adobe or clay bricks) was practiced until the 20th century and existing buildings of this type can be found throughout Serbia.

In terms of the floor types, most heritage buildings in Serbia from the 19th century have timber floors with wooden planks; solutions with brick tiles were not used. Floor systems with brick vaults supported by iron beams were also common, particularly at the ground floor level. Vaults are common in churches and older heritage structures constructed before 20th century. RC floor construction practice started in 1903, especially in the form of ribbed RC slabs used in older buildings before 1960.

Foundation construction practice in Serbia is similar to Italy and other neighbouring countries, with stone and brick foundations used for the construction of heritage buildings and the widespread use of RC foundations since the beginning of the 20th century.

The main structural types are similar to the Italian ones, but there are differences, especially related to ancient buildings. Among these, ancient buildings often had earthen walls and timber frames infilled with brick masonry; the latter can be considered as an example of an ancient construction technology with anti-seismic features. In terms of pre-modern and modern masonry buildings, however, there is more similarity between Serbia and Italy.

RC typologies in Serbia seem to correspond well to Italian practice, both in terms of structural features and initial applications.

In **Slovenia** (PP6), until 1964 there was a prevalence of residential buildings built a masonry structure, with the higher percentage of 62.9% between 1946 and 1963. After this date, RC becomes the main structural material, with a percentage of 73.7% of the new buildings having a RC structure.

Regarding the classification of the construction elements, basically all the types of masonry are present on the Slovenian territory, with the exception of the tuff walls and rubble masonry with bricks probably due to the specific construction tradition in the Country.





For all historic walls, the thicknesses are generally greater than the Italian ones, up to 100 cm. The irregular stone walls are present in the whole national territory, while rammed earth blocks and solid bricks are mostly used in the eastern part of the Country. There is no difference for modern masonry techniques, as for masonry in brick or concrete blocks with cement mortar, while reinforced masonry is not very common.

As for floors and roofs, timber structure and wooden planks is the most used historical solution as in all other countries. The timber floor with brick tiles, instead, it is not used. About vaults, the brick ones are very common and widespread, while the stone ones are rare. Regarding the steel floors, only the solution with vaults is used. For the RC floors, there is a substantial correspondence.

Referring to the foundation systems, the most used for historic masonry buildings was the irregular stone block foundation with a depth up to 120 cm. Between 1800 and 1900, the pebbles and lean concrete solution began to be used, especially in combination with elevation structures in brick masonry.

Moment frame RC structures, both with solid bricks and hollow bricks as infill, are rarely used in Slovenia. Since the last century, RC structures were mainly used with RC walls.

Finally, the main structural types listed in the case of the Italian territory find a good correspondence with the Slovenian ones, especially for modern masonry and RC buildings.

In **Greece** (PP7 and PP8), much of the traditional architecture, in both rural and urban areas, was built with raw earth, and the use of timber elements has been adopted as a technique for improving the seismic response of structures since nearly 5000 years. The combination of wooden structure and adobe (or earth with straw) is typical in traditional Greek settlements. Together with earthen techniques, Greek builders used stone and rubble masonry, which was composed by small blocks of limestone roughly chipped from quarries. If we compare the classified masonry types, we note that there are only a few differences. Basically, the types are all present on the Greek territory, with the exception of the tuff walls, probably due to the lack of this material. Thicknesses are generally similar and there is no difference for modern masonry techniques.

Timber reinforced masonry structures are very common and widespread for historic constructions. As for floors and roofs, timber structure and wooden planks is the most used historic solution for floors. Even timber floor with brick tiles is used, especially on the islands. About vaults, both the brick and the stone ones are present. Regarding the steel floors, both the solutions are used; for the RC floors, we note a substantial correspondence for all the data, even if the hollow brick floor without reinforced concrete slab are not present. All solutions for foundations are confirmed and also for the RC vertical elements, there are not relevant differences. The main structural types listed in the case of the Italian territory find a good correspondence with the Greek ones.

Therefore, concluding this first step of analysis relating to the construction characteristics of the built heritage of the PP countries, we can deduce that, if we assume that the buildings belonging to the historic centres (which are the study areas of the ADRISEISMIC project) were built generally by the mid-twentieth century (and possibly have been subsequently modified), we find strong correspondences among the structural elements and types identified for the PP countries.





Masonry

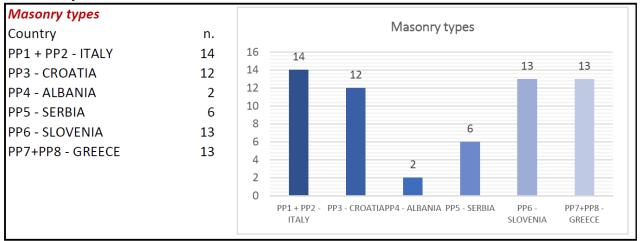


Figure 38 - Comparison between the types of masonry found in the PP.

Floors and roofs

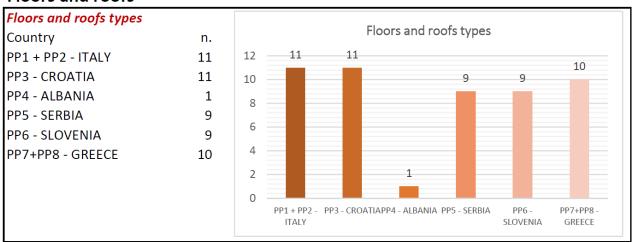


Figure 39 – Comparison between the floors and roofs types found in the PP.

In fact, up to this time, we note a clear prevalence of construction solutions that use load-bearing masonry as a resistant structural material, whether it is stone or brick. The differentiation in the use of one or the other obviously does not depend on the belonging nationality, but derives exclusively from the availability of local materials: in mountainous areas, where it is easy to find stone, solutions that use this material prevail; near streams, in the plains and on islands, where there is a high quantity of clay, the use of brick prevails. The same subdivision concerns the vaults.

Some data relating to the differences in the various countries have been mapped in the following graphs, for the prevailing masonry types; what mainly differentiates the PP are the historical periods of use and the thicknesses of the walls, which have a great importance in a seismic context.

However, the most common material for floors is wood, which was present in the various territories in historical times, it is light and easily workable. It is not surprising, therefore, that this is the most used solution everywhere. Again, in areas where there is an abundant use of brick, it can also be combined with brick tiles. It follows that the most common structural type is ancient masonry one, with only limited local variations, linked to the wall thickness and the floor spans. These may have already been made more efficient in historic





times for their earthquake behaviour, with traditional interventions of restraint and connection, such as metal tie rods

In some countries, however, the structural type with timber frame and earthen infill is also widely used, conceived as effective in earthquake behaviour, due to its high deformability. This must be taken into consideration together with the ancient masonry type in carrying out the definition activities of the ADRISEISMIC methodology.



Figure 40 – Comparison between period of construction and thickness for the main masonry types.





case, it is possible to acquire the same seismic behaviour of such buildings.

The complete outcome of the comparisons can be clearly seen from the comparative tables in the annex. For the modern structural types of masonry buildings, there is a greater variability in the combination of floors with vertical elements; iron beams and brick vaults, reinforced concrete or hollow brick floors are variously diffused in the countries, with slightly different periods, but this does not change the substance. Also in this

For the RC structural types, we substantially found a perfect match, with the exception of the more widespread use of reinforced concrete walls in some countries, and instead of frame structures in others. However, the diffusion of these structural solutions in historic centres is very limited.

The analysis illustrated so far has allowed us to confirm that the construction basis for the seismic assessment and improvement interventions to be proposed is, with good approximation, the same in all countries; therefore, the built heritage can be treated with common traits, while differentiating the solutions according to local specificities. It is therefore possible to define shared common guidelines.

The current approach to the issue of seismic vulnerability in the PP was then investigated, to understand if the current way of acting also has common traits.

On this issue, we must first of all highlight how the current approach to the seismic strengthening on existing buildings is necessarily the result of the local culture, as well as of the previous experiences of seismic events. In some cases, in fact, the know-how derived from previous earthquakes, sometimes repeated after a few decades in the same areas, has shown the effectiveness or not of a previously followed approach.

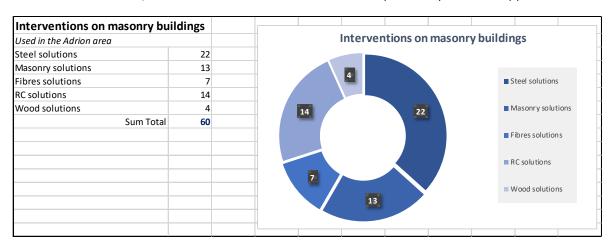


Figure 41 – Summary of the intervention techniques for masonry buildings that have been catalogued for the Adrisesmic area.

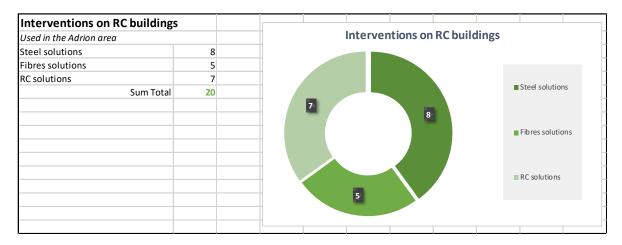


Figure 42 – Summary of the intervention techniques for RC buildings that have been catalogued for the Adrisesmic area.





This is, for example, the **Italian case** (PP1 and PP2), where strong earthquakes hit the same territories, showing the criticalities or the functionality of previously implemented interventions. Here, from the 1970s to the present, a new sensitivity has developed to address structural and seismic safety issues. The main objective is the preservation not only of the asset but also of the ascertained structural functioning.

This new sensitivity denies the previous approach for interventions up to the end of the 90s, when the most common practice was to intervene on existing masonry buildings with diffuse use of reinforced concrete.

However, these interventions were discouraged by the first seismic national legislation of 2008, as they are considered invasive, non-reversible, problematic in their execution, not respectful of the original structural concept and techniques; furthermore, they increase significantly the building stiffness. These interventions have shown all their limits on some recent earthquakes, when the buildings consolidated in this way have suffered devastating damage.

The classification of intervention techniques on existing masonry buildings led to the enumeration of 22 different methods of intervention on masonry buildings with steel elements, 13 using other masonry elements, 7 with fibre-based composite materials, 14 using reinforced concrete, and 4 in wood. The seismic improvement techniques using steel are currently very widespread in Italy, especially for historic buildings, as they are reversible, minimally invasive and easy to build. They can be applied to various parts of the structure and are able to solve most of the problems that existing masonry buildings can present: they create the connection between floor and walls, avoiding the overturning of the facades; they provide stiffening to the floors, reducing their deformations; they reinforce the vertical elements or permit the creation of new openings for doors or windows through hoops.

Interventions based on brick and wood represent a reference to traditional construction techniques, while the use of fibres in seismic improvement is spreading in recent years, since they are considered to be minimally invasive and removable.

When intervening on RC structures, 8 different techniques has been classified using steel elements, 5 of then use fibre-based composite materials, and 7 foresee the use of RC elements. The use of steel reinforcements is one of the classic methods of intervention, and the most widespread in Italy. Fibre solutions are also spreading in the last 10 years as they are very light and thin, and therefore they do not vary the structural weight. Considering the recent diffusion, the costs are higher than the other techniques in steel and RC; the latter, are commonly used too, their compatibility with the existing structure, the easy availability of materials and the lack of need for skilled workers.

About **Croatian approach** (PP3), the analysis of the references and the consultation of specific projects for seismic improvement allows to highlight that all the classified techniques with different materials are known and used, without particular differences with the Italian case. We also note that interventions using fibres are known and widespread, and that, even in Croatia, interventions based on reinforced concrete on masonry buildings are discouraged.

Regarding the buildings of Gjirokastra (PP4), we remind that here we are dealing exclusively with masonry buildings. The most used techniques are those employing steel, and in particular the insertion of tie rods, anchor plates, and tie rods in the thickness of the wall. All the other steel techniques are not used. Masonry solutions are rarely used, as in the Gjirokastra territory the buildings are made of stone, and not of bricks, and these techniques often use brick, due to its greater versatility. So, only the local dismantling and reconstruction is used, when needed, and the replacement of walls with solid bricks or rough or squared stones. Also lime grout injections with mortar mixtures are used, as they are highly compatible with stone walls.





No techniques using fibres is documented. The interventions using reinforced concrete are not commonly used, as it is well known that they alter the normal functioning of the wall structure; anyway, in the Gjirokastra area sometimes it is possible to find the insertion of new RC tie beams in the floors and widening of the masonry foundations.

The techniques using wood find the greatest correspondence, presumably due to the fact that most of the existing floors are made of this material and the need to preserve it leads to intervene on the horizontal elements rather than on the vertical elements.

Analysing the **Serbian context** (PP5), 14 of the 22 techniques that use steel for strengthening interventions on masonry buildings are used; for example, steel ties are used for rehabilitation of churches and monasteries in Serbia. Horizontal steel braces are used for seismic strengthening of floors. Steel tie beams, stitching, insertion of steel beams, pillars confinement, strengthening of architraves and bracings in roof systems are not used. About the use of masonry solutions, there is a very limited experience related to their application in Serbia. Many of the listed techniques are not used, except for the realization of new walls, the grout injections, and the structural repointing.

Fibre Reinforced Polymer (FRP) products are available in Serbia and could be used for many applications, but their application for structural/seismic interventions is very limited as of this writing. Application of interventions using wood are very limited in Serbia.

The most common approach for intervention on existing masonry buildings in Serbia is the use of RC solutions; for example, insertion of RC tie-beams is a common type of intervention for non-heritage buildings. Stiffening of existing floors by constructing new a reinforced concrete slab and the construction of new structural elements (reinforced concrete shear walls) are also used on structural rehabilitation projects.

Jacketing, in the form of a reinforced plaster overlay with steel reinforcement mesh, has been used to repair and retrofit the buildings damaged in the 2010 Kraljevo earthquake.

The most common type of intervention on foundations is the construction of a new reinforced concrete beams for lateal expansion of the existing foundation.

In terms of RC structures, interventions using steel solutions are recommended in Serbia, but practical applications are very limited. Similarly, structural/seismic interventions involving FRP products are available but also limited in terms of the application scale. RC solutions (jacketing) are currently most commonly used in Serbia.

The spreadsheet filling for the **Slovenian territory** (PP6) highlights the Country's different approach to the issue of interventions on existing buildings. In fact, some of the most used and recommended techniques in Italy, especially for protected buildings, are not suggested in Slovenia, because they are considered not effective. For example, tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall and steel box frame connected to masonry walls, to create new openings.

Others are considered incompatible for protected buildings, while in Italy they are recommended as they are considered to be easily removable; for example, confinement of pillars and columns through the application of steel hoops reinforcements and strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados.

Therefore, this approach testifies a different custom and technical conception than what is believed in Italy today.

For the masonry solutions, the spreadsheet for the Slovenian territory confirms some differences; on the whole, these techniques seem less widespread than in Italy.





Regarding the interventions using fibres, there is an almost perfect correspondence, except for the strengthening of architraves and jack arches by applying carbon fibre strips or meshes to the intrados, whose effectiveness is considered low. This positive result, in terms of comparison, probably derives from the recent study and the recent diffusion of this type of interventions, which have therefore developed and spread almost in the same way in all national contexts.

Finally, we note that the prevailing techniques when intervening on existing masonry buildings are those using reinforced concrete. Insertion of tie beams and entire RC floors, new structural elements and reinforced plasters are very common in Slovenia. This trend does not appear so strong in any of the other partner countries.

In the case of RC structures, interventions using steel on existing RC structures are recommended in Slovenia. If properly sized, they are also considered effective but interventions using reinforced concrete are more common.

The analysis on the **Greek territory** (PP7 and PP8) highlight the different approach to the issue of intervention on existing masonry buildings, as happens for the Slovenian Country. In fact, we recognize the same trend of not recommended intervention in Greece, as tie beams made with steel profiles, anchored with vertical reinforced perforations to the masonry wall; steel box frame connected to masonry walls to create new openings; reinforcement intervention on arches with steel elements; substitution of existing architraves and jack arches with steel profiles. The reasons are the absence of regulations and specialized staff to apply such reinforcements. Anyway, all the listed techniques are used, both for steel and masonry solutions.

As for interventions with fibres, it is evident that in Greece these are almost never recommended for masonry buildings. Probably the reasons are identified in the lesser effectiveness compared to other techniques or in the lack of compatibility with the existing material. As a result, these are less common than the other techniques.

Interventions with RC solutions are not recommended for masonry buildings and they are considered difficult to apply.

The reasons are identified in the lack of compatibility with the existing material and in the high rate of irreversibility of the intervention. However, these are quite widespread on the territory.

Regarding RC structures, all the listed intervention techniques are used, and fibre-based intervention are more used than in all other countries.

So, to conclude, the theme of securing, rehabilitating and improving existing buildings, whether they are masonry or reinforced concrete buildings, is very much felt in all the countries. However, the current approaches are much more uneven than those previously observed for existing construction techniques. Each country, in recent years, has developed its own particular approach, according to its cultural trends, but also to the training of the technicians, and the operations of the companies operating in the sector.

We can affirm that the interventions using steel are very widespread, both for masonry buildings and for reinforced concrete, in almost all countries. The use is limited only in Gjirokastra, but this is due to the fact that the investigation was limited only to the historical fabric of the urban centre of the city.

The more traditional intervention techniques (ie those that use pre-modern materials, such as brick and wood) are still widely used, but those that use reinforced concrete on masonry buildings are also known and used.





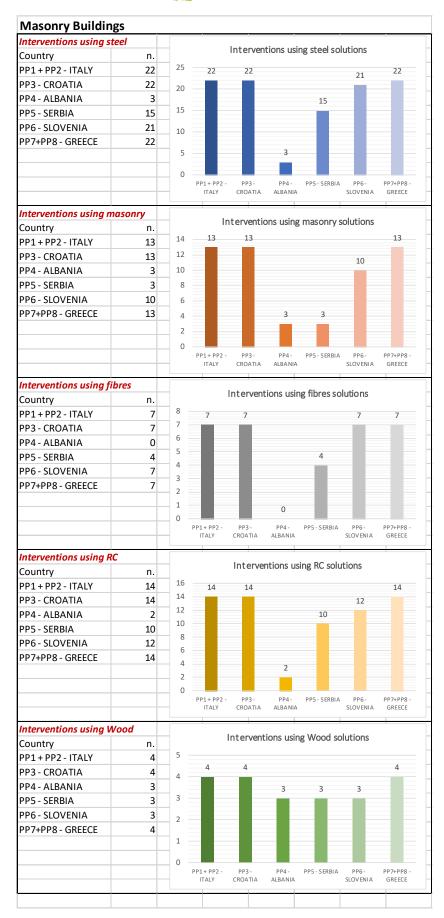


Figure 43 – Comparison of the intervention techniques trends for masonry buildings tin the PP countries.





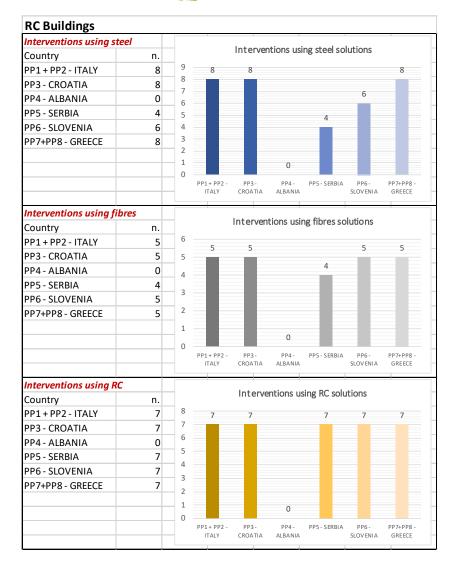


Figure 44 - Comparison of the intervention techniques trends for RC buildings tin the PP countries.

However, it may be interesting to compare these data with how much each intervention is recommended or not; Figure 45 shows, in fact, how there are strong differences in considering the interventions not recommended in Italy, Croatia and Albania, while they are among those most recommended in Serbia, Slovenia and Greece.

In these same countries, we note that interventions that use steel for load-bearing masonry buildings are less recommended, confirming the different approach that characterizes them.

Finally, some considerations can be made on the current diffusion of the listed interventions (Figure 46). We note that most of those using steel on masonry buildings still have a low diffusion in the PP countries, and this is probably due to the distrust on the combination of steel and masonry, or to the fact that this approach is still recent.

The same goes for interventions using fibres, which are still very recent and therefore not very used.

The trend is instead the opposite for interventions that use reinforced concrete: most of them are in fact very widespread in the context of the various countries, proving both the trust placed in them in some contexts and the long tradition in their use.







Figure 45 – Comparison of the intervention techniques trends for masonry buildings tin the PP countries.





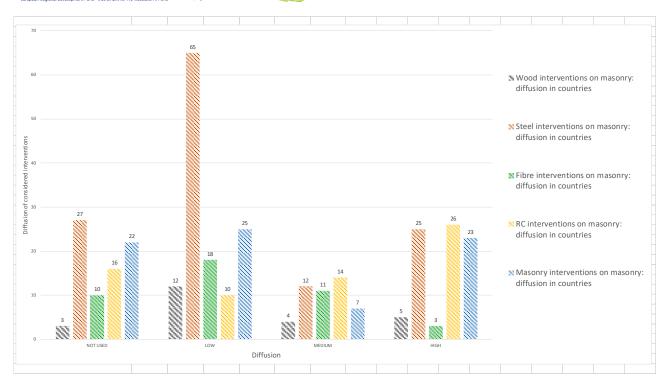


Figure 46 – Diffusion of the considered intervention in the PP countries.

Respecting these variability of approaches, it is not possible to define which is correct and incorrect, but all current choices must be respected. Consequently, the in-depth understanding of what are the local choices in terms of seismic improvement will make it possible to build a very articulated database in terms of interventions, as an effective component of the ADRISEISMIC methodology and respectful of the approaches dedicated to the topic by the various countries.



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Annexes

Summary table of the comparisons made between the PPs countries



Α	Vertical Structures - Masonry types											
CODE	DESCRIPTIO	N AND STRUCTUR	RAL CHARACTERIST	TICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
	Rubble stone masonry (pebbles, erratic and irregular stones), not well organized and without connection		Installation of elements	Trasversal section	Connections	Thickness	usually 40 - 70 cm	60 - 120 cm	20 - 40 cm	Not Used	Usually 40 - 100cm	Usually 40 - 70 cm
A.1	between the two wall surfaces. High vulnerability for out of plane actions, with the risk of detachment due to instability of the single badly connected or unconnected wal surfaces under vertical loads; poor resistance for inplane actions, due to both the low resistance of the	and an all tons and an	Messy texture and random pose	Two juxtaposed or slightly connected layers	Weakly effective in corners with blocks of dimensions similar to masonry and poor grip	Period of construction	Medieval period - about 1950	Medieval period - about 1950	About 1200 - 1800	Not Used	About 1000-1900	Up to about 1950
	materials (and in particular the mortar) and the low friction that can develop between the stone elements.					Main geographical location	Mountain areas; Central and Southern Italy	Central and Southern Croatia	South-east, south-west and south of Albania	Not Common - Except for church and fortresses	Everywhere in Slovenia	Mainly in rural areas in the whole Greek territory
	external surfaces, with the presence of edges, bundles	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 40 - 70 cm	40 - 120 cm	Not Used	Not Used	Usually 40 - 100cm	Usually 40 - 60 cm
A.2	and / or courses in square stone or solid bricks. High vulnerability for out of plane actions, with the risk of detachment due to instability of the single badly connected or unconnected wal surfaces under vertical loads; poor resistance for in-plane actions, due to both	regular medium size,	Irregular horizontal courses with stone wedges and absence of strips	Two juxtaposed or slightly connected layers with incoherent infill core	Weakly effective in corners with blocks of bigger dimensions	Period of construction	Medieval period - about 1950	1500 - about 1950	Not Used	Not Used	About 1000-1900	Up to about 1950
	the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements.					Main geographical location	Mountain areas; Central and Southern Italy	Central and Southern Croatia	Not Used	Not Common - Except for church and fortresses	Everywhere in Slovenia	In the whole Greek territory
	with bricks, with the presence of edges, bundles and / or	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 40 - 60 cm	40 - 120 cm	Not Used	Not Used	Usually 40 - 60 cm	40 - 60 cm
A.3	rses in square stone or solid bricks. High vulnerability Limestone stones of plane actions, with the risk of detachment due	olane actions, with the risk of detachment due lity of the single badly connected or slightly roughed in the surfaces with stone dwal surfaces under vertical loads; poor intill earn and bridge, worders and absorbed in the surfaces with stone layers with the risk of detachment due regular medium size, courses on the slightly considerable and surfaces and absorbed in the surfaces with stone layers with the risk of detachment due regular medium size, courses on the slightly considerable and surfaces with stone layers with the risk of detachment due regular medium size, courses on the slightly considerable and surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers with the risk of detachment due regular medium size, courses on the surfaces with stone layers and a surface and a		layers with incoherent	Weakly effective in corners with blocks of bigger dimensions	Period of construction	Medieval period - about 1950	Medieval period - about 1950	Not Used	Not Used	Medieval period - about 1950	Up to about 1950
	resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements.	surfaces; lime mortar	of strips			Main geographical location	Lowland areas; Northern Italy	Continental Croatia	Not Used	Not Common - Except for church and fortresses	Not Common in Slovenia	In the whole Greek territory
	Rubble masonry with bricks on the surfaces and in the internal core, well organized but without connection between the two external surfaces realized with bricks	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 42 - 56 cm	30 - 120 cm	Not Used	Not Used	usually 42 - 56 cm	42 - 56 cm
A.4	and the internal core. High vulnerability for out of plane actions, with the risk of detachment due to instability of the single badly connected or unconnected wal surfaces under vertical loads; poor resistance for in-plane actions,	Bricks; lime mortar	Regular horizontal courses	More juxtaposed or slightly connected layers made with bricks	Weakly effective in corners	Period of construction	Medieval period - about 1950	1500 - about 1950	Not Used	Not Used	Medieval period - about 1950	Up to about 1950
	due to both the low resistance of the materials (and in particular the mortar) and the low friction that can develop between the stone elements.					Main geographical location	Lowland areas; Northern Italy	Continental Croatia	Not Used	Not Used	Not Common in Slovenia	Lowland areas in the whole Greek territory
		Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 30 - 50 cm	40 - 100 cm	Not Used	Not Used	40 - 100 cm	usually 30 - 50 cm
A.5	Cut stone with good bonding . Medium vulnerability for out of plane actions; medium resistance for in-plane actions	Limestone stones of regular medium size, slightly roughed; lime mortar	Regular or irregular horizontal courses with stone wedges and absence of strips	Two juxtaposed, well or slightly connected layers	Effective in corners with blocks of bigger dimensions	Period of construction	About 1500 - about 1950	About 1500 - about 1950	Not Used	Not Used	About 1500 - about 1950	Up to about 1950
						Main geographical location	Mountain areas; Central and Southern Italy	Continental Croatia	Not Used	Not Common - Except for church and fortresses	Everywhere in Slovenia	In the whole Greek territory





ODE	DESCRIPTION	ON AND STRUCTUR	RAL CHARACTERIST	TICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
		Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 14 - 56 cm	usually 14 - 60 cm	Not Used	Usually 14 - 56 cm	usually 20 - 30 cm	usually 14 - 56 cm
A .6	Masonry in rammed earth blocks. High vulnerability for out of plane actions, as the wall is usually not correctly constrained above and below to rigid or semi-rigid floors; poor resistance for in-plane actions, due to the low	and clay	Regular or irregular horizontal courses	Well organized thickness	Effective in corners with rammed earth blocks	Period of construction	Medieval time - 1800	1400 - 1950	Not Used	Medieval time - 1920	1800 - 1950	Up to about 1900
	resistance of the materials.					Main geographical location	Central Italy	Continental Croatia	Not Used	The whole territory of Serbia	East part of Slovenia	In the whole Greek territory
		Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 30 - 50 cm	Not Used	80 - 120 cm	Not Used	usually 30 - 50 cm	Not Used
A.7	Tuff masonry . Medium vulnerability for out of plane actions; medium resistance for in-plane actions.	Tuff stones of regular size; lime mortar	Regular horizontal courses with stone wedges and absence of strips	Well organized thickness	Effective in corners	Period of construction	About 1500 - about 1950	Not Used	About 1300 - about 1850	Not Used	About 1500 - about 1950	Not Used
						Main geographical location	Central and Southern Italy	Not Used	South-East; South- West; South of Albania	Not Used	This Technique is very rare	Not Used
		Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 30 - 40 cm	30 - 70 cm	Not Used	usually 30 - 40 cm	30 - 60 cm	usually 30 - 50 cm
A.8	ssed rectangular (ashlar) stone masonry. Medium sonerability for out of plane actions; medium resistance in-plane actions.	Medium-sized squared limestone; lime mortar	Regular horizontal courses with stone wedges and absence of strips	Two juxtaposed and well connected layers	Effective in corners with blocks of bigger dimensions	Period of construction	About 1700 - about 1950	1700 - 1950	Not Used	About 1800 - about 1930	About 1500 - about 1950	Up to about 1950
						Main geographical location	Mountain areas; Central and Southern Italy	Southern Croatia	Not Used	The whole territory of Serbia for buildings of special importance	Mediterranian Coast	In the whole Greek territory
	Solid brick masonry with lime mortar . Low vulnerability for out-of-plane actions, if the wall is correctly	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 14 - 56 cm	12,5 -70cm	Not Used	usually 14 - 56cm	40-120 cm	usually 14 - 56cm
A .9	constrained above and below to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior; medium or high resistance for in-plane actions, thanks to the resistance of the	Bricks and lime mortar	Regular horizontal courses	Well organized thickness in continuity with the external surfaces	Effective in corners with bricks	Period of construction	About 1700 - about 1950	About 1800 - 1950	Not Used	About 1880 - about 1930	About 1500 - about 1900	About 1700- about 195
	materials (in particular the mortar) and / or the friction that can develop between the elements.					Main geographical location	Lowland areas; Northern Italy	Continental Croatia	Not Used	Urban Centres of Serbia	East part of Slovenia	In the whole Greek territory
	Solid brick masonry with cement mortar. Low vulnerability for out-of-plane actions, if the wall is	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 13 - 40 cm	12,5 -60cm	Not Used	usually 13 - 40 cm	Usually 12,5 - 45 cm	usually 13 - 40cm
A.10	Inerability for out-of-plane actions, if the wall is rrectly constrained above and below to rigid or semi-	cly constrained above and below to rigid or semi- loors, capable of redistributing seismic actions to cement mortar Bricks blocks and cement mortar Courses Well organized thickness in continuit with the external		thickness in continuity with the external	e external	Period of construction	1850- today	1900 - 1950	Not Used	1930- today	1850- today	1900 - Today
	of the materials and / or the friction that can develop between the elements.					Main geographical location	Whole Italian territory	The whole Croatian territory	Not Used	The whole territory of Serbia	Everywhere in Slovenia	In the whole Greek territory





	Vertical Structures - Masonry types											
CODE	DESCRIPTION	ON AND STRUCTUR	RAL CHARACTERIST	TICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
	Masonry in brick or cement blocks with cement mortar. Low vulnerability for out-of-plane actions, if the wall is	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 25 - 45 cm	usually 25 - 45 cm	Not Used	usually 25 - 45 cm	usually 20 - 30 cm	usually 25 - 45 cm
A.11	correctly constrained above and below to rigid or semi- rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior; medium or high resistance for in-plane actions, thanks to the resistance	Blocks and cement	Regular horizontal courses	Single-layer masonry	Effective in corners with bricks blocks	Period of construction	1980- today	1980- today	Not Used	1960- today	1970- today	1980- today
	of the materials (in particular the mortar) and / or the friction that can develop between the elements.					Main geographical location	Recent construction in the whole territory	The whole Croatian territory	Not Used	The whole territory of Serbia	Everywhere in Slovenia	Recent constructions in the whole Greek territory
	Reinforced masonry with distribution reinforcement.	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 25 - 45 cm	usually 16 -45 cm	Not Used	Not Used	usually 25 - 45 cm	usually 25 - 45 cm
A.12	Low vulnerability for out-of-plane actions, if the wall is correctly constrained above and below to rigid or semi-rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior; high resistance for in-plane actions, thanks to the resistance of the	coment mortar:	Regular horizontal courses, with reinforcement horizontally	Single-layer masonry	Effective in corners with brick blocks or small RC pillars	Period of construction	1980- today	1980- today	Not Used	Not Used	1950 - 1980	1980- today
	plane actions, thanks to the resistance of the aterials.		distributed in the mortar joints and vertically in the holes of the blocks			Main geographical location	Recent construction in the whole territory	Recent construction in the whole Croatian territory	Not Used	Not Used	This Technique is very rare	Recent construction in the whole territory
	Confined masonry with concentrated reinforcement.	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 25 - 45 cm	usually 16 -45 cm	Not Used	usually 25 - 45 cm	usually 19 - 29 cm	usually 25 - 45 cm
A.13	Low vulnerability for out-of-plane actions, if the wall is correctly constrained above and below to rigid or semi- rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior; high resistance for in-plane actions, thanks to the resistance of the	cement mortar:	Regular horizontal courses, with reinforcement horizontally	Single-layer masonry	Effective in corners with small RC pillars	Period of construction	1980- today	1980- today	Not Used	1964- today	1982- today	1950- today
	materials.		distributed in the mortar joints and vertically in specific small pillars			Main geographical location	Recent construction in the whole territory	Recent construction in the whole Croatian territory	Not Used	The whole territory of Serbia; this is called confined masonry	Recent construction in the whole territory	Recent construction in the whole territory
	Timber reinforced masonry (added by PP7 + PP8). Low vulnerability for out-of-plane actions, if the wall is	Constituent material	Installation of elements	Trasversal section	Connections	Thickness	usually 30 - 45 cm	Not Used	Not Used	usually 30 - 45 cm	Not Used	usually 40 - 60 cm
A.14	correctly constrained above and below to rigid or semi- rigid floors, capable of redistributing seismic actions to the walls, with a monolithic behavior; medium or high resistance for in-plane actions, thanks to the resistance	Timber elements; limestone stones of regular medium size, slightly roughed; lime		Two juxtaposed layers, connected by the timber reinforcement	Effective in corners with blocks of bigger dimensions, or with timber elements	Period of construction	Medieval period (very rare)	Not Used	Not Used	15th - 20th century	Not Used	up to about 1950
	sistance for in-plane actions, thanks to the resistance sligh the materials (in particular the mortar) and / or the iction that can develop between the elements.	or clay mortar.	diagonal braces; regular or irregular horizontal courses with stone wedges			Main geographical location	Northern italy	Not Used	Not Used	The whole territory	Not Used	In the whole Greek territory





В	Vertical Structures - Reinforced cor	crete types										
CODE	DESCRIPTIO	ON AND STRUCTUR	AL CHARACTERIST	TICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
B.1	Frame structures with reinforced concrete beams and pillars, with infill walls made with solid bricks. High vulnerability is possible if the nodes are not conceived as perfect joints and if there is a lack of reinformcements;	Concrete with variable composition			Connections More or less effective, depending on the	Thickness Period of construction	usually 30 - 50 cm	usually 30 - 50 cm	Not Used Not Used	usually 30 - 50 cm	usually 30 - 50 cm 20th century	usually 30 - 50 cm
•	probable high vulnerability if there is a lack of stirrups in the elevation of the pillars; probable high vulnerability in presence of pilotis or squat pillars induced by the infills	construction period		solid brick masonry can contribute to the overall strength	conformation of the reinforcements in the nodes	Main geographical location	Urban contexts of large cities	Urban contexts of large cities, continental Croatia	Not Used	Urban contexts of large cities	Very rare, urban areas	Urban contexts of large cities
	Frame structures with reinforced concrete beams and	Constituent material		Static Behaviour	Connections	Thickness	usually 30 - 50 cm	usually 30 - 50 cm	Not Used	usually 30 - 50 cm	usually 30 - 50 cm	usually 30 - 50 cm
B.2	pillars, with infill walls made with hollow bricks. High vulnerability is possible if the nodes are not conceived as perfect joints and if there is a lack of reinformcements; probable high vulnerability if there is a lack of stirrups in the elevation of the pillars; probable high vulnerability in	composition depending on the construction period	Hollowbrick masonry		More or less effective, depending on the conformation of the reinforcements in the nodes	Period of construction	1950 - today	1960 - today	Not Used	1960 - Today	20th century	1950 - today
	presence of pilotis or squat pillars induced by the infills	reinforcements		the overall strength	noues	Main geographical location	Urban contexts of large cities	The whole territory of Croatia	Not Used	Urban contexts of large cities	Very rare, urban areas	Urban contexts of large cities
		Constituent material		Static Behaviour	Connections	Thickness	usually 15 - 25 cm of thickness	15 - 30 cm of thickness	Not Used	usually 15 - 25 cm of thickness	usually 15 - 25 cm of thickness	usually 15 - 25 cm of thickness
B.3	Reinforced concrete wall structures. Low vulnerability; medium vulnerability is possible if the nodes are not conceived as perfect joints and if there is a lack of reinformcements	composition	Absent	Vertical continuous elements	Usually effective for the continuity of the material	Period of construction	1950 - Today	1930 - Today	Not Used	1965 - Today	20th and 21th century	1951 - Today
		reinforcements				Main geographical location	Urban contexts of large cities	the whole teritory of Croatia	Not Used	Urban contexts of large cities	Common structures all around the country	Urban contexts of large cities
		Constituent material	Infill elements	Static Behaviour	Connections	Thickness	usually 30 - 60 cm of thickness	usually 30 - 60 cm of thickness	Not Used	Not Used	usually 40 - 60 cm of thickness	usually 40 - 60 cm of thickness
B.4	Unreinforced concrete wall structures . High vulnerability for the absence of reinformcements.	depending on the construction period	Absent	Vertical continuous elements working only for compression	Uneffective for the absence of reinforcements	Period of construction	1910 - 1930	1910 - 1930	Not Used	Not Used	1955 - 1965	1910 - 1930
		and metal reinforcements				Main geographical location	Urban contexts of large cities	Urban contexts of large cities	Not Used	Not Used	Urban contexts of large cities	Urban contexts of large cities
		Constituent material	Infill elements	Static Behaviour	Connections	Thickness	usually 30 - 60 cm of thickness	usually 30 - 60 cm of thickness	Not Used	usually 30 - 60 cm of thickness	usually 30 - 60 cm of thickness	usually 30 - 60 cm of thickness
B.5	Prefabricated reinforced concrete structures. High vulnerability for the low level of connection between the elements; probably vulnerability by extended corrosion.	High strenght concrete and metal reinforcements	Solid bricks masonry or hollow bricks masonry		Non effective for horizontal actions due to the low onnection between pillars and	Period of construction	1950 - today (actually the constraint is a hinge)	1940 - today	Not Used	1960 -1990	1950 - today (actually the constraint is a hinge)	1950 - today (actually the constraint is a hinge)
					beams	Main geographical location	Industrial areas	Industrial areas	Not Used	Major urban centres	Industrial areas	Industrial areas





C Horizontal elements (floors and roofs) PP3 - CROATIA PP5 - SERBIA PP7+PP8 - GREECE PP1 + PP2 - ITALY PP4 - ALBANIA PP6 - SLOVENIA CODE **DESCRIPTION AND STRUCTURAL CHARACTERISTICS** Specificities 4 m for double timber Constituent material Static Behaviour Connections Maximum Spar 6 m 6 m floor and 11 m for single 6 m 6 m 6 m timber floor Single or double timber floors (beams and joists) with Timber beams and simple wooden plank. Very flexible floor, usually not joists; wooden planck; correctly connected to the walls, which does not leveling layer in loose Deformable floor Beams and joists are Period of usually found in a construction Medieval period - Today | Medieval period - Today 1300 - 1800 Medieval period - 1945 Medieval period - Today Up to today constitute an effective constraint for the retention of outsimple support constraint on the walls of-plane mechanisms. Single floor: The whole national Main erritory, both urban and rural. The whole national The whole national The whole national The whole national geographical In the whole Greek ouble floor: Northern Albania territory, both urban and territory, both urban and territory, both urban and territory, both urban and location (widely used); some parts of territory rural rural rural rural southern Albania too (in Maximum Span Constituent material Static Behaviour Connections 6 m 6 m Not Used Not Used Not Used 6 m Single or double timber floors (beams and joists) with Timber beams and Deformable floor Beams and joists are Period of brick tiles. Very flexible floor, usually not correctly joists; brick tiles with connected to the walls, which does not constitute an lime or plaster based usually found in a construction Medieval period - Today 1500 - Today Not Used Not Used Not Used Up to today simple support effective constraint for the retention of out-of-plane mortar; leveling layer constraint on the walls mechanisms in loose mixed Main material geographical Northern italy, both Mainly in islands, in the Continental Croatia Not Used Not Used Not Used location whole Greek territory urban and rural Constituent material Static Behaviour Connections 9 m Not Used 9 m Maximum Spar 9 m Floors with metal beams and vaults made with brick Steel beams; brick Deformable floor Beams and joists are Period of tiles. Very flexible floor, usually not correctly connected tiles arched arranged, usually found in a construction About 1850 - 1940 About 1850 - 1940 About 1870 - 1945 About 1850 - 1960 About 1850 - 1940 Not Used to the walls, which does not constitute an effective with lime or plaster simple support constraint for the retention of out-of-plane mechanisms. based mortar; leveling constraint on the walls layer in loose mixed The whole national The whole national The whole national Mainly in urban areas: in material geographical Urban areas, not very territory, both urban and erritory, both urban and Not Used territory, both urban and the whole Greek location rural; both urban and rural common territory this is called Pruski svod Constituent material Static Behaviour Connections Maximum Span 9 m Not Used 9 m Not Used 9 m 9 m Floors with metal beams and hollow bricks. Very flexible Steel beams; hollow Deformable floor Beams are usually Period of floor, usually not correctly connected to the walls, which bricks with lime or found in a simple construction About 1850 - 1940 About 1870 - 1945 About 1850 - 1940 About 1850 - 1940 Not Used Not Used support constraint on does not constitute an effective constraint for the cement mortar; retention of out-of-plane mechanisms leveling layer in loose the walls mixed material Main The whole national Mainly in urban areas; in geographical Urban areas, not very lot as common in Serbia as Not Used erritory, both urban and Not Used the whole Greek location solution C.3 common territory rural Constituent material Static Behaviour Connections Maximum Span 5 m $5\,m$ Not Used 5 m 5 m 5 m Bricks arranged in an Deformable floor The vaulted structures Period of Brick vaults. The vaulted structures generate thrusts on arched pattern, with a are grafted onto the construction Medieval period - 1900 | Medieval period - 1800 Medieval period - 1800 | Medieval period - 1900 Not Used Up to about 1950 the supporting walls different thickness supporting walls and curvature Main Mainly urban area in The whole national geographical Lowland areas; in the Central and Southern Continental Croatia Not Used Not common in Serbia territory, both urban and location whole Greek territory

Italy





C Horizontal elements (floors and roofs) PP3 - CROATIA PP1 + PP2 - ITALY PP4 - ALBANIA PP5 - SERBIA PP6 - SLOVENIA PP7+PP8 - GREECE CODE **DESCRIPTION AND STRUCTURAL CHARACTERISTICS** Specificities Constituent material Static Behaviour Connections Maximum Spai 5 m 5 m Not Used Not Used 5 m 5 m Flat stones arranged in Deformable floor The vaulted structures Period of **Stone valuts** . The vaulted structures generate thrusts on an arched pattern, are grafted onto the construction Medieval period - 1800 | Medieval period - 1950 Medieval period - 1800 Not Used Not Used Up to about 1950 the supporting walls with a different supporting walls thickness and Main The whole national Mainly urban area in In the whole Greek Limited to monumental curvature geographical Southern Croatia territory, both urban and Not Used Northern Italy territory heritage location rural 4 m for slab only; 10 m 6-7 m for slab only; 11-12 4 m for slab only; 10 m 4 m for slab only; 10 m 4 m for slab only; 10 m Constituent material Static Behaviour Connections Maximum Span Not Used with RC ribs m with RC ribs with RC ribs with RC ribs with RC ribs Cast-in-situ reinforced concrete slab. Floor whose Reinforced concrete Rigid floor The slab is in Period of behavior can be considered rigid in its plan, with a heavy for the whole continuity with the construction 1930-today 1900 - 1930 Not Used 1900 - present 1900 - present 1910 - today thickness of the floor reinforced concrete weiaht structure or with a Main semi-joint constraint Mainly urban area in the Mainly urban area in the Mainly urban area in In the whole Greek geographical Mainly urban area Not Used whole Italian terrtory whole Serbian territory whole Slovenia territory on the walls location Constituent material Static Behaviour Connections Maximum Span 6 m 6 m Not Used 6 m 6 m Not Used Hollow clay block floor without reinforced concrete Reinforced concrete Deformable floor The floor is in Period of slab. Floor whose behavior cannot be considered rigid in ribs with hollow bricks continuity with the construction 1900 - 1950 1930 - 1950 Not Used 1960 - 1970 1900 - 1950 Not Used reinforced concrete its plan, with a medium weight structure or with a Mainly urban area in the Mainly urban area in the Mainly urban area in semi-joint constraint geographical Mainly urban area Not Used Not Used whole Italian terrtory whole Serbian territory whole Slovenia on the walls location Constituent material Static Behaviour Connections Maximum Span 6 m 7 m Not Used 10 m 10 m 10 m Hollow clay block floor with reinforced concrete slab. Reinforced concrete Rigid floor The floor is in Period of Floor whose behavior can be considered rigid in its plan, ribs with hollow bricks continuity with the construction 1910 - Today 1930-today Not Used 1970-today 1910-today 1910 - today and upper reinforced reinforced concrete with a medium weiaht concrete slab structure or with a The whole national The whole Serbian Mainly urban area in the In the whole Greek semi-joint constraint Mainly urban area in the geographical erritory, both urban and Not Used whole Italian terrtory whole Slovenia on the walls territory territory location rural Constituent material Static Behaviour Connections Maximum Spar 12 m 12 m Not Used 12 m 12 m 12 m Prefabricated reinforced concrete floor. Floor whose Reinforced concrete Rigid floor The floor is not in Period of behavior can be considered rigid in its plan, but that is for the whole continuity with the construction not well connceted wth the supporting system; it has a thickness of the floor 1950 - Today 1950 - Today Not Used 1960 - Today 1950 - Today 1950 - Today reinforced concrete high weight structure; the Urban building connection with the geographical Industrial Areas Industrial Areas Industrial Areas Industrial Areas Not Used construction supporting structure is location Constituent material Static Behaviour Connections Maximum Span 8 m 8 m Not Used 12 m 12 m 12 m Hollow brick floor with prefabricated joists. Its behaviour cannot be considered rigid in its plan, for the Reinforced concrete Rigid floor The floor is not in Period of 1920 - 1945 (Herbst) and continuity with the probable absence of a reinforced concrete slab, and for the whole construction 1930 - 1950 1931 - 1950 Not Used 20th century 1950 - Today 1945 - 1965 (Avramenko) joists are not well connected with the supporting system; thickness of the floor reinforced concrete it has a medium weight structure; the Urban building connection with the Mainly urban area in the geographical Mainly urban area Not Used Industrial Areas Industrial Areas whole Italian terrtory construction supporting structure is location





	Foundation System										
CODE	DESCRIPTION AND	STRUCTURAL CHAR	ACTERISTICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Type A (Rock outcrops or very rigid soils) and Type B (Soft rocks or coarse- grained or very consistentthick-grained soils)	Type A (Rock outcrops or very rigid soils) and Type B (Soft rocks or coarse- grained or very consistentthick-grained soils)	Not Used	Type A (Rock outcrops or very rigid soils) and Type B (Soft rocks or coarse- grained or very consistentthick-grained soils)	Type A (Rock outcrops or very rigid soils) and Type B (Soft rocks or coarse- grained or very consistentthick-grained soils)	Type A (Rock outcrops or very rigid soils) and Type B (Soft rocks or coarse- grained or very consistentthick-grained soils)
D.1	Stepped foundation, engraved in the rock	The shaped rocky terrain, where the elevation structures of the walls rest	Rock-based soils	Masonry structures, both in stone and bricks	Depth	About 1 - 1,5 m	About 1 - 1,5 m	Not Used	About 1 - 1,5 m	About 1 - 1,5 m	About 1 - 1,5 m
					Period of Construction	Medieval period - today	Medieval period - today	Not Used	Medieval period - today	Medieval period - today	Medieval period - today
					Main geographical location	Mountainous areas in the whole national territory	Mountainous areas in the whole national territory	Not Used	Not Common in Serbia	Mountainous areas in the whole national territory	Mountainous areas in the whole national territory
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type B (deposits of coarsely thickened or coarse-grained fine-grained soils)		Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	thick coarse-grained or medium-fine or fine- grained soils) and Type B (deposits of coarsely	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type B (deposits of coarsely thickened or coarse-grained fine-grained soils)
D.2	Regular stone masonry foundation	Preparation of the laying surface by leveling or a wooden trellis filled with inert	Sufficiently compact clay soils (incompressible soil)	Masonry structures, predominantly in stone	Depth	Generally about 1 - 1,5 m; greater depth for particular buildings	Generally about 1 - 1,5 m; greater depth for particular buildings	40 cm	Generally about 1 - 1,5 m; greater depth for particular buildings	Generally about 1 - 1,5 m; greater depth for particular buildings	Generally about 1 - 1,5 m; greater depth for particular buildings
		material at the bottom of the excavation; foundation made with regular stone blocks			Period of Construction	Medieval period - today	Medieval period - today	1450 - 1800	Medieval period - today	Medieval period - today	Medieval period - today
					Main geographical location	Areas where stone is mainly used as a building material for elevation structures	Areas where stone is mainly used as a building material for elevation structures	Gjirokastra + Orthern and Southern Albania	Areas where stone is mainly used as a building material for elevation structures (typically monumental buildings)	-	Areas where stone is mainly used as a building material for elevation structures
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained		Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained
D.3	Irregular stone masonry foundation	Preparation of the laying surface by leveling; foundation made with rubble	Generally clay soils	Masonry structures, both in stone and bricks	Depth	Generally about 1 - 1,5 m	Generally about 1 - 1,5 m	Not Used	Generally about 1 - 1,5 m	Generally about 0,7 - 1,2 m	Generally about 1 - 1,5 m
		stone masonry (pebbles, erratic and irregular stones)			Period of Construction	Medieval period - 1800	Medieval period - 1800	Not Used	Medieval period - 1800	Medieval period - 1900	Medieval period - 1800
					Main geographical location	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking	Not Used	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking (typically monumental buildings)	The whole national territory, both urban and rural	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking





	Foundation System					DD4 - DD2 - ITALY	DD2 CDCATIA	DD4 ALDANIA	DDE CERRIA	DDC CLOVENIA	DD7. DD0 CD5555
CODE	DESCRIPTION AND S	STRUCTURAL CHAR	ACTERISTICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification		Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	1		Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained
D.4	Stone rubble foundation with concrete binder	Preparation of the laying surface by leveling; foundation made with rubble stone masonry	Generally clay soils	Brick masonry structures	Depth	Generally about 1 m	Generally about 1 m	Not Used	Generally about 1 m	Generally about 1 m	Generally about 1 m
		(pebbles, erratic and irregular stones) and lean concrete as binder			Period of Construction	Medieval period - 1800	Medieval period - 1800	Not Used	Medieval period - 1800	1800 - 1900	Medieval period - 1800
		binder			Main geographical location	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking	Not Used	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking (typically monumental buildings)	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking - eastern part of Slovenia	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)		Not Used	Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained	thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained
D.5	Brick masonry foundations	Bricks organized in a regular way, with slightly larger width than the thickness of the upper walls	Generally clay soils	Masonry structures, both in bricks and stone	Depth	Generally about 30 - 60 cm	Generally about 30 - 60 cm	Not Used	Generally about 30 - 60 cm	Generally about 70 - 130 cm	Generally about 30 - 60 cm
		and apper mans			Period of Construction	Medieval period - 1900	Medieval period - 1900	Not Used	Medieval period - 1900	Medieval period - 1900	Medieval period - 1900
					Main geographical location	I	Areas where bricks is used as a building material for elevation structures	Not Used	Areas where bricks is used as a building material for elevation structures (typically monumental buildings)	Areas where bricks is mainly used as a building material for elevation structures and resistant stones are lacking - eastern part of Slovenia	Areas where bricks is used as a building material for elevation structures
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Any type (A, B, C, D)	Any type (A, B, C, D)	Not Used	Any type (A, B, C, D)	Any type (A, B, C, D)	Any type (A, B, C, D)
D.6	Continuous reinforced concrete foundations (strip	for the whole foundation structure	Any kind, compressible or incompressible	Both masonry and reinforced concrete structures	Depth	In relation to the consistency of the soil; generally 1 - 1.5 m	In relation to the consistency of the soil; generally 1 - 1.5 m	Not Used	In relation to the consistency of the soil; generally 1 - 1.5 m	In relation to the consistency of the soil; generally 1 - 1.5 m	In relation to the consistency of the soil; generally 1 - 1.5 m
	footings)				Period of Construction	1920 - today	1920 - today	Not Used	1900 - today	1920 - today	1920 - today
					Main geographical location	Whole Italian territory	Whole Croatian territory	Not Used	Whole Serbian territory for modern buildings	Whole Slovenian territory	Whole greek territory





CODE	DESCRIPTION AND	STRUCTURAL CHAR	ACTERISTICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
CODE	DESCRIPTION AND	Constituent material		Compatibility with the elevation	Type of soil	Type C (Deposits of medium thick coarse-grained or medium-fine or fine-grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained	Not Used	Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained	Type C (Deposits of medium thick coarse-grained or medium-fine or fine-grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)
D.7	Wooden piles	Wooden piles driven into the ground to increase its compactness	Generally compressible clay soils, having poor quality	Masonry structures, mainly in bricks	Depth	Generally about 3 - 5 m for the piles	Generally about 3 - 5 m for the piles	Not Used	Generally about 3 - 5 m for the piles	Generally about 3 - 5 m for the piles	Generally about 3 - 5 m for the piles
					Period of Construction	Medieval period - 1800	Medieval period - 1800	Not Used	Medieval period - 1800	Medieval period - 1900	Medieval period - 1800
					Main geographical location	Lowlands area in the whole territory	Lowlands area in the whole territory	Not Used	Not Common in Serbia	Areas with clay terrain- coastal towns, capital Ljubljana	Lowlands area in the whole territory
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification		Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Not Used	1	Type C (Deposits of medium thick coarse-grained or medium-fine or fine-grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Type C (Deposits of medium thick coarse-grained or medium-fine or fine-grained soils) and Type D (Deposits of coarse-grainec soils that are not very thick or thin-grained)
D.8	Reinforced concrete piles	Prefabricated steel or concrete piles	Generally compressible clay soils, having poor quality	Reinforced concrete structures	Depth	10 m	10 m	Not Used	10 m	10 m	10 m
					Period of Construction	1970 - today	1970 - today	Not Used	1950 - present	1970 - today	1970 - today
					Main geographical location	Whole Italian territory	Whole Croatian territory	Not Used	Whole Serbian territory	Whole Slovenian territory	Whole Greek territory
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	Not Used	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)
D.9	Inverted beams foundation	Reinforced concrete for the whole foundation structure	Any kind, compressible or incompressible	Both masonry and reinforced concrete structures	Depth	About 1 - 1,5 m	About 1 - 1,5 m	Not Used	About 1 - 1,5 m	About 1 - 1,5 m	About 1 - 1,5 m
					Period of Construction	1910 - today	1910 - today	Not Used	1950 - present	1910 - today	1910 - today
					Main geographical location	Whole Italian territory	Whole Croatian territory	Not Used	Whole Serbian territory	Whole Slovenian territory	Whole Greek territory



D	Foundation System										
CODE	DESCRIPTION AND S	TRUCTURAL CHAR	ACTERISTICS		Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	Not Used	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)	thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely	type C (deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and type B (deposits of coarsely thickened or coarse-grained fine-grained soils)
D.10	Isolated footing	Reinforced concrete for the whole foundation structure	Any kind, compressible or incompressible	Both masonry and reinforced concrete structures	Depth	About 1,5 - 2 m	About 1,5 - 2 m	Not Used	About 1,5 - 2 m	About 1,5 - 2 m	About 1,5 - 2 m
					Period of Construction	1910 - today	1910 - today	Not Used	1950 - present	1910 - today	1910 - today
					Main geographical location	Whole Italian territory	Whole Croatian territory	Not Used	Whole Serbian territory	Whole Slovenian territory	Whole Greek territory
		Constituent material	Type of Soil	Compatibility with the elevation	Type of soil according to local classification	Type C (Deposits of medium thick coarse-grained or medium-fine or fine-grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Type C (Deposits of medium thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Not Used	Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)	Type C (Deposits of medium- thick coarse-grained or medium-fine or fine- grained soils) and Type D (Deposits of coarse-grained soils that are not very thick or thin-grained)
D.11	Slab foundation	Reinforced concrete for the whole foundation structure	Generally compressible clay soils, having poor quality	Both masonry and reinforced concrete structures	Depth	About 1 m	About 1 m	Not Used	About 1 m	About 1 m	About 1 m
					Period of Construction	1910 - today	1910 - today	Not Used	1950 - present	1910 - today	1910 - today
					Main geographical location	Whole Italian territory	Whole Croatian territory	Not Used	Whole Serbian territory	Whole Slovenian territory	Whole Greek territory





Α	Interventions using steel solutions								
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	YES	YES	YES	YES
	Single tie-rods consisting of metal elements (bars, flat		DIFFUSION	HIGH	HIGH	HIGH	LOW	MEDIUM	HIGH
A.1	bars, rebars, profiles) in galvanized or stainless steel or normal steel, with the possibility of tensioning the tie rod thanks to anchoring elements, consisting of plates or	REDUCTION OF THE HIGH DEFORMABILITY OF THE	TECHNICAL COMPLEXITY	LOW	LOW	LOW	LOW	LOW	LOW
		INTERVENTIONS ON ROOFS	COST	LOW	LOW	LOW	MEDIUM	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	YES	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES	DIFFUSION	HIGH	HIGH	NOT USED	LOW	MEDIUM	HIGH
A.2	on the two sides of the wall connected together with	REDUCTION OF THE HIGH DEFORMABILITY OF THE	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
	Steer bars and external aneits: plates	FLOORS; INTERVENTIONS ON ROOFS	COST	LOW	LOW	NOT USED	MEDIUM	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
	Tie-rods in the thickness of the wall, made with metal bars or steel cables passing through a hole injected with	FLOORS;	RECOMMENDED	YES	YES	YES	YES	YES	NO
			DIFFUSION	HIGH	HIGH	HIGH	LOW	LOW	MEDIUM
A.3			TECHNICAL COMPLEXITY	LOW	LOW	LOW	MEDIUM	MEDIUM	MEDIUM
	non simminoreals	INTERVENTIONS ON ROOFS; IMPROVEMENT OF RESISTANCE IN	COST	LOW	LOW	LOW	MEDIUM	MEDIUM	LOW
		WALLSINTERVENTIONS ON ROOFS	EASILY APPLICABLE	NO	NO	NO	NO	NO	NO
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
	Floor connections made with coupled steel profiles on		DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
	steel rebars, ribbed metal plates, and bolts		соѕт	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.5	Crossed steel bands in the thickness of the floor	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS;	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
		INTERVENTIONS ON ROOFS	COST	LOW	LOW	NOT USED	LOW	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





ODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
			DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	HIGH
A. 6	He-roas for arches and vaults made with steel bars, with	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES	TECHNICAL	LOW	LOW	NOT USED	LOW	LOW	LOW
•	the possibility of tensioning them	AND VAULTS	COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	NO	NO
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	LOW	MEDIUM
7.7		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	TECHNICAL	LOW	LOW	NOT USED	NOT USED	LOW	MEDIUM
Ą	vertical reinforced perforations to the masonry wall	INTERVENTIONS ON ROOFS	COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES AND VAULTS; IMPROVEMENT OF RESISTANCE IN WALLS	RECOMMENDED	NO NO	NO	NOT USED	NOT USED	NO	NO
	Stitching, through reinforced perforations made with steel bars								
∞			DIFFUSION	LOW	LOW	NOT USED	NOT USED	LOW	LOW
A.8			COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	MEDIUM	MEDIUM	NOT USED	LOW	LOW	MEDIUM
A.9	lot nurlins or ridae heams with the walls of the	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS;	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
	tympunumy	INTERVENTIONS ON ROOFS	COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES	DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.10		AND VAULTS; REDUCTION OF THE HIGH DEFORMABILITY OF THE	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
		FLOORS; INTERVENTIONS ON ROOFS	COST	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	YES	NOT USED	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES	DIFFUSION	HIGH	HIGH	HIGH	NOT USED	HIGH	HIGH
A.11	Application of steel anchor plates	AND VAULTS; REDUCTION OF THE HIGH DEFORMABILITY OF THE	TECHNICAL COMPLEXITY	LOW	LOW	LOW	NOT USED	LOW	LOW
		FLOORS; INTERVENTIONS ON ROOFS	COST	LOW	LOW	LOW	NOT USED	LOW	LOW
			EASILY APPLICABLE	YES	YES	YES	NOT USED	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	LOW	LOW
A.12	Replacement of floor and roof slabs with iron floor and brick planks or wooden boards	FLOORS;	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
		INTERVENTIONS ON ROOFS	COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	HIGH
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
	Stiffening of floors with metal strips	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS	RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.13			TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
A.14	Adding beams of the same type as existing ones (steel beams)	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
			RECOMMENDED	YES	YES	NOT USED	YES	NO	NO
		IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT	DIFFUSION	HIGH	HIGH	NOT USED	LOW	MEDIUM	HIGH
	Steel box frame connected to masonry walls to create new openings	STRENGTHENING OF THE WALL PORTIONS AROUND THE	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
		OPENINGS	COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NO	YES	NO





CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
		1000000	RECOMMENDED	YES	YES	NOT USED	YES	NO	NO
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.16	Reinforcement intervention on arches with steel elements	IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS;	TECHNICAL	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
∢		STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
	Painforced renainting combining the traditional		DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.17	repointing with the inclusion, within the bed joints, of reinforcing bars.	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
	.c.nyo.c.ng saro.		COST	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
		IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS; PILLARS AND COLUMNS	RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	YES
			DIFFUSION	HIGH	HIGH	NOT USED	NOT USED	LOW	HIGH
A.18	Confinement of pillars and columns through the		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	LOW
			COST	LOW	LOW	NOT USED	NOT USED	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	NO
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	LOW	LOW
A.19	Strengthening of architraves and jack arches by applying sheets, plates or metal sheets to the intrados	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	NOT USED	HIGH	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	LOW
			EASILY APPLICABLE	NO	NO	NOT USED	NOT USED	NO	NO
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO
			DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	MEDIUM
A.20	Substitution of existing architraves and jack arches with steel profiles	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
			COST	LOW	LOW	NOT USED	LOW	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





Α	Interventions using steel solutions		1					1	
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	NOT USED	NOT USED	NOT USED	YES
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
A.21	Bracing of the roofing structures with steel cables or bars	INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	NOT USED	NOT USED	MEDIUM
			COST	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	NOT USED	YES
			RECOMMENDED	NO	NO	NOT USED	NO	NO	NO
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
A.22	Advanced anti-seismic techniques (base isolation systems, dissipative bracing systems)	ADVANCED ANTI-SEISMIC TECHNIQUES	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			COST	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO



B Interventions using masonry solutions PP1 + PP2 - ITALY PP3 - CROATIA PP5 - SERBIA PP6 - SLOVENIA PP7+PP8 - GREECE DESCRIPTION PP4 - ALBANIA CODE **FUNCTIONS Specificities** RECOMMENDED YES YES NOT USED NOT USED YES NO DIFFUSION LOW LOW NOT USED NOT USED LOW LOW REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; TECHNICAL Tie beams in reinforced masonry, with concrete and steel HIGH HIGH NOT USED NOT USED MEDIUM MEDIUM INTERVENTIONS ON ROOFS COMPLEXITY COST LOW LOW NOT USED NOT USED LOW LOW **EASILY APPLICABLE** YES YES NOT USED NOT USED YES YES RECOMMENDED NOT USED NOT USED NOT USED YES YES YES DIFFUSION LOW LOW NOT USED NOT USED NOT USED MEDIUM REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF UN-CONTRASTED THRUST OF ARCHES TECHNICAL AND VAULTS; Buttress and slubs on masonry walls NOT USED LOW LOW NOT USED NOT USED LOW COMPLEXITY IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS COST LOW LOW NOT USED NOT USED NOT USED LOW EASILY APPLICABLE NO NO NOT USED NOT USED NOT USED NO RECOMMENDED YES YES YES NOT USED YES YES DIFFUSION NOT USED **MEDIUM** HIGH HIGH HIGH HIGH Local dismantling and reconstruction with flat bricks or IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT rough or squared stone with mechanical characteristics VERTICAL ELEMENTS; TECHNICAL similar to the existing one (called "scuci-cuci" = "unstitch-LOW LOW LOW NOT USED LOW LOW COMPLEXITY stitch") NOT USED LOW COST LOW LOW LOW LOW **EASILY APPLICABLE** YES NO NO NOT USED YES YES RECOMMENDED NOT USED YES YES YES YES YES DIFFUSION LOW LOW NOT USED MEDIUM MEDIUM HIGH IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT TECHNICAL Realization of new structural elements (masonry walls) LOW NOT USED LOW LOW LOW LOW VERTICAL ELEMENTS: COMPLEXITY MEDIUM COST MEDIUM MEDIUM NOT USED MEDIUM MEDIUM **EASILY APPLICABLE** NOT USED YES YES YES YES NO RECOMMENDED YES YES NOT USED NOT USED YES YES DIFFUSION LOW LOW NOT USED NOT USED LOW LOW Thickening of the walls with solid bricks or rough-hewn or IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT TECHNICAL squared stone having the same mechanical VERTICAL ELEMENTS; NOT USED NOT USED LOW MEDIUM MEDIUM LOW COMPLEXITY IMPROVEMENT OF RESISTANCE IN WALLS characteristics as the existing one NOT USED NOT USED **MEDIUM** COST MEDIUM MEDIUM MEDIUM

EASILY APPLICABLE

YES

NOT USED

YES

NOT USED

YES

NO





CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	YES	NOT USED	YES	NO
			DIFFUSION	LOW	LOW	LOW	NOT USED	LOW	LOW
B.6	Replacement of walls with solid bricks or rough or squared stones with mechanical characteristics similar to		TECHNICAL COMPLEXITY	HIGH	HIGH	HIGH	NOT USED	MEDIUM	MEDIUM
_	the existing ones	COLUMNS	COST	MEDIUM	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	YES	NOT USED	YES	NO
			RECOMMENDED	YES	YES	YES	NOT USED	YES	YES
			DIFFUSION	HIGH	HIGH	HIGH	NOT USED	HIGH	HIGH
B.7	Lime grout injections with mortar mixtures based on hydraulic limes of calcareous or marly origin and pozzolan with the addition of suitable binders and the		TECHNICAL COMPLEXITY	LOW	LOW	LOW	NOT USED	MEDIUM	MEDIUM
-			COST	LOW	LOW	LOW	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	YES	NOT USED	YES	YES
		IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS; IMPROVEMENT OF RESISTANCE IN WALLS; PILLARS AND COLUMNS	RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
			DIFFUSION	HIGH	HIGH	NOT USED	MEDIUM	HIGH	HIGH
B.8	Localized grout injections of mortars or resins		TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	YES
	Structural repointing, through the partial but deep		DIFFUSION	HIGH	HIGH	NOT USED	HIGH	MEDIUM	HIGH
B.9	removal of deteriorate lime mortar in bed joints and substitution with new mortar (possibly with better	IMPROVEMENT OF RESISTANCE IN WALLS; PILLARS AND	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
	mechanical properties and durability)		COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	NO
			DIFFUSION	HIGH	HIGH	NOT USED	NOT USED	HIGH	LOW
B.10	Substitution of existing architraves and jack arches with reinforced brick masonry	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	NOT USED	LOW	LOW
æ.			COST	LOW	LOW	NOT USED	NOT USED	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	NO





В	B Interventions using masonry solutions								
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	NOT USED	NOT USED	NOT USED	YES
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
B.11	Execution of masonry foundation below the existing one	IMPROVEMENT IN THE FOUNDATION STRUCTURES	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	NOT USED	NOT USED	HIGH
			COST	HIGH	HIGH	NOT USED	NOT USED	NOT USED	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NOT USED	NOT USED	NO
			RECOMMENDED	NO	YES	NOT USED	NO EVIDENCE FOUND	YES	NO
		REALIZATION OF SEISMIC JOINTS	DIFFUSION	LOW	LOW	NOT USED	NO EVIDENCE FOUND	LOW	LOW
B.12	Separation of masonry structures to create seismic joints		TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	NO EVIDENCE FOUND	HIGH	HIGH
			COST	MEDIUM	MEDIUM	NOT USED	NO EVIDENCE FOUND	MEDIUM	LOW
			EASILY APPLICABLE	NO	YES	NOT USED	NO EVIDENCE FOUND	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	NOT USED	YES
			DIFFUSION	HIGH	HIGH	NOT USED	NOT USED	NOT USED	MEDIUM
B.13	Construction of small brick walls (frenelli) for vaults stiffening	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
			COST	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	NOT USED	YES





CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	MEDIUM	MEDIUM	NOT USED	LOW	MEDIUM	LOW
C.1	ltipers)	FLOORS;	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
		INTERVENTIONS ON ROOFS; PILLARS AND COLUMNS; INTERVENTIONS ON THE STAIRS	COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	NO
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	LOW	LOW
C.2	LIE DEAMS IN DYICK AND ERP	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	NO
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	LOW
C.3	,	AND VAULTS;	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	HIGH
		IMPROVEMENT OF RESISTANCE IN WALLS	COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
C.4	Stiffening of floors with FRP fibers	INTERVENTIONS ON THE STAIRS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO
		REDUCTION OF UN-CONTRASTED THRUST OF ARCHES	DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	MEDIUM
C.5	ISTRINS TO VALUITS LIPPINTORCEA TINIPS L	AND VAULTS; INTERVENTIONS ON THE STAIRS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





С	Interventions using composite fibro	es solutions							
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	YES
		IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT	DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
C.6	Jacketing, through a reinforced plaster with fibres mesh	VERTICAL ELEMENTS; IMPROVEMENT OF RESISTANCE IN WALLS; INTERVENTIONS ON THE STAIRS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
			RECOMMENDED	YES	YES	NOT USED	YES	NO	NO
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
C.7	Strengthening of architraves and jack arches by applying carbon fibre strips or meshes to the intrados	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





D	Interventions using concrete reinfo	orced solution							
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED	NO	NO	NO	YES	YES	NO
			DIFFUSION	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
D.1	Reinforced concrete tie beams	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	LOW	LOW	LOW	LOW	LOW	LOW
			COST	LOW	LOW	LOW	LOW	LOW	LOW
			EASILY APPLICABLE	YES	YES	YES	YES	YES	YES
			RECOMMENDED	NO	NO	NOT USED	NOT USED	NOT USED	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS:	DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
D.2		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS; INTERVENTIONS ON THE STAIRS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	HIGH
			COST	LOW	LOW	NOT USED	NOT USED	NOT USED	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	NOT USED	NO
			RECOMMENDED	NO	NO	NOT USED	YES	YES	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS	DIFFUSION	LOW	LOW	NOT USED	MEDIUM	LOW	MEDIUM
D.3	Replacement of floor and roof slabs with reinforced concrete slab		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO
			RECOMMENDED	NO	NO	NOT USED	YES	YES	NO
		REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS;	DIFFUSION	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
D.4	Stiffening of floors with a reinforced concrete slab	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS; INTERVENTIONS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
		ON THE STAIRS	COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO
			RECOMMENDED	NO	NO	NOT USED	NO	NO	NO
			DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	HIGH
D.5	Reinforced concrete box frame connected to masonry walls to create new openings	IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS; STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
		. S.M.S.A. ANOSAR THE OF ENINGS	COST	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO





CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
CODE	DESCRIFTION	TORCHONS	RECOMMENDED	NO NO		NOT USED	YES	YES	
			RECOMMENDED	NO	NO	NOTUSED	YES	YES	NO
			DIFFUSION	LOW	LOW	NOT USED	HIGH	HIGH	LOW
D.6	Realization of new structural elements (reinforced concrete walls or pillars)	IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
			COST	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO
			RECOMMENDED	NO	NO	NOT USED	NOT USED	YES	NO
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	HIGH	LOW
D.7	concrete elements	IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS; STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	NOT USED	HIGH	HIGH
			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	NO
	Jacketing, through a reinforced plaster with welded steel	IMPROVEMENT IN THE DISTRIBUTION OF RESISTANT VERTICAL ELEMENTS; IMPROVEMENT OF RESISTANCE IN WALLS	RECOMMENDED	NO	NO	NOT USED	YES	YES	NO
			DIFFUSION	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
D.8			TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO
			RECOMMENDED	YES	YES	NOT USED	NOT USED	NOT USED	YES
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
D.9	Intramural tying, through the application of punctual confinement to the wall with prefabricated reinforced		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
	concrete or steel cylinders (artificial diatons)		COST	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	NOT USED	YES
			RECOMMENDED	YES	YES	NOT USED	NOT USED	YES	YES
	Intramural tying, through the application of punctual		DIFFUSION	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
D.10	confinement to the wall with transversal iron or steel bars inside holes that are injected within cement mortar	IMPROVEMENT OF DESISTANCE IN WALLS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	NOT USED	HIGH	MEDIUM
	in a confining socket (anti-expulsion tie-rods)		COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES





D	O Interventions using concrete reinforced solution									
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE	
			RECOMMENDED	NO	NO	NOT USED	YES	YES	NO	
			DIFFUSION	HIGH	HIGH	NOT USED	MEDIUM	HIGH	HIGH	
D.11	Substitution of existing architraves and jack arches with a reinforced concrete beam	STRENGTHENING OF THE WALL PORTIONS AROUND THE OPENINGS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	MEDIUM	
			COST	LOW	LOW	NOT USED	LOW	LOW	LOW	
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO	
			RECOMMENDED	YES	YES	YES	YES	YES	NO	
	Execution of reinforced concrete beams for the lateral expansion of the existing foundation		DIFFUSION	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	
D.12		IMPROVEMENT IN THE FOUNDATION STRUCTURES	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	
			COST	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	
			EASILY APPLICABLE	YES/NO	YES/NO	YES/NO	YES	YES/NO	YES/NO	
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO	
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	HIGH	HIGH	MEDIUM	
D.13	Execution of a reinforced concrete foundation below the existing one	IMPROVEMENT IN THE FOUNDATION STRUCTURES	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH	
			COST	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH	
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO	
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO	
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW	
D.14	Execution of foundation by micropiles	IMPROVEMENT IN THE FOUNDATION STRUCTURES	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH	
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	HIGH	
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO	





Ε	Interventions using wood solutions									
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE	
			RECOMMENDED	YES	YES	YES	YES	YES	YES	
			DIFFUSION	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW	
E.1	Stiffening of floors with the addition of an orthogonal or diagonal layer of wooden planks	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS	TECHNICAL COMPLEXITY	LOW	LOW	LOW	LOW	LOW	MEDIUM	
			COST	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	
			EASILY APPLICABLE	YES	YES	YES	YES	YES	YES	
			RECOMMENDED	YES	YES	YES	YES	YES	YES	
			DIFFUSION	LOW	LOW	LOW	LOW	LOW	MEDIUM	
E.2	Adding beams of the same type as existing ones (wooden beams)	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW	
			COST	LOW	LOW	LOW	LOW	LOW	LOW	
			EASILY APPLICABLE	YES	YES	YES	YES	YES	YES	
			RECOMMENDED	YES	YES	NOT USED	YES	YES	NO	
			DIFFUSION	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH	
E.3	Stiffening of roofs with the addition of an orthogonal or diagonal layer of wooden planks	REDUCTION OF THE HIGH DEFORMABILITY OF THE FLOORS; INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	MEDIUM	
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH	
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO	
			RECOMMENDED	YES	YES	YES	NOT USED	NOT USED	YES	
			DIFFUSION	LOW	LOW	LOW	NOT USED	NOT USED	LOW	
E.4	Timber tie beam	REDUCTION OF THE DEFICIENCIES OF THE CONNECTIONS; INTERVENTIONS ON ROOFS	TECHNICAL COMPLEXITY	LOW	LOW	LOW	NOT USED	NOT USED	LOW	
			COST	LOW	LOW	LOW	NOT USED	NOT USED	LOW	
			EASILY APPLICABLE	YES	YES	YES	NOT USED	NOT USED	YES	





F	Interventions using steel solutions								
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED					YES	
	Steel jacketing for column and beam strengthening,		DIFFUSION	HIGH	HIGH	NOT USED	NOT USED	LOW	HIGH
F.1		MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	NOT USED	MEDIUM	MEDIUM
	grout	ENDS	COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
			RECOMMENDED					YES	
			DIFFUSION	LOW	LOW	NOT USED	NOT USED	LOW	LOW
F.2	Plating with metal plates to increase the load bearing capacity of the beams with structural epoxy adhesive	BENDING REINFORCEMENT	TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	NOT USED	LOW	LOW
			COST	LOW	LOW	NOT USED	NOT USED	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES
		REDUCTION OF MOVEMENTS; REDUCTION OF THE RISK OF FRAGILE MECHANISMS	RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
F.3	LAGGITION OF PRACING SYSTEMS		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	HIGH	HIGH	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	NO
			RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
F.4	LAddition of dissinative bracina systems	SEISMIC ENERGY DISSIPATION; REDUCTION OF THE RISK OF FRAGILE MECHANISMS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			COST	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
			RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
F.5	II) iccinative external cyctems	REDUCTION OF MOVEMENTS; REDUCTION OF THE RISK OF FRAGILE MECHANISMS	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	нідн	HIGH
L			COST	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO





F	Interventions using steel solutions								
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
			RECOMMENDED				NOT USED	NOT USED	
	Bandaging of reinforced concrete walls and pillars with		DIFFUSION	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
		STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
	creates circles under tension which induce an active three dimensional confinement.	ENDS	COST	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	NOT USED	YES
			RECOMMENDED				NOT USED	NOT USED	
		INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR ENDS	DIFFUSION	LOW	LOW	NOT USED	NOT USED	NOT USED	LOW
F.7	of the Artifacts")		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
	,, ,		COST	MEDIUM	MEDIUM	NOT USED	NOT USED	NOT USED	MEDIUM
			EASILY APPLICABLE	NO	NO	NOT USED	NOT USED	NOT USED	YES
			RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	LOW	LOW	LOW
ж. 8:	Advanced anti-seismic techniques, as base isolation systems	ADVANCED ANTI-SEISMIC TECHNIQUES	TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			соѕт	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO





G	G Interventions using composite fibres solutions											
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE			
			RECOMMENDED				YES	YES				
		INCREASE IN THE STIFFNESS AND STRENGTH OF THE	DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	HIGH			
6.1	strengthening, through the application of external fabric	STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW			
		ENDS	COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM			
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES			
			RECOMMENDED				YES	YES				
		INCREASE IN THE STIFFNESS AND STRENGTH OF THE	DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	MEDIUM			
G.2	strengthening, through the application of external strips	STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR ENDS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW			
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM			
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES			
		BENDING REINFORCEMENT	RECOMMENDED				YES	YES				
			DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	MEDIUM			
6.3	Reinforcement of the floor joists with carbon fibers		TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW			
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM			
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES			
			RECOMMENDED				YES	YES				
			DIFFUSION	HIGH	HIGH	NOT USED	LOW	HIGH	HIGH			
6.4	Bending and shear reinforcement of beams with carbon fibres	BENDING REINFORCEMENT	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	LOW			
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	MEDIUM			
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES			
			RECOMMENDED					YES				
			DIFFUSION	HIGH	HIGH	NOT USED	NOT USED	LOW	MEDIUM			
G.5	Anti-overturning system for infill walls	REDUCTION OF THE RISK OF FRAGILE MECHANISMS	TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM			
U			COST	MEDIUM	MEDIUM	NOT USED	NOT USED	MEDIUM	MEDIUM			
			EASILY APPLICABLE	YES	YES	NOT USED	NOT USED	YES	YES			





ODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
	strengthening, through the addition of an external layer	INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS; INCREASE IN THE DUCTILITY OF THE PILLAR ENDS	RECOMMENDED				YES	YES	
			DIFFUSION	HIGH	HIGH	NOT USED	MEDIUM	HIGH	HIGH
H.1			TECHNICAL	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
_			COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
	Istittening of floors with a reinforced concrete slah	INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE	RECOMMENDED				YES	YES	
			DIFFUSION	HIGH	HIGH	NOT USED	HIGH	HIGH	MEDIUM
Н.2			TECHNICAL	LOW	LOW	NOT USED	LOW	LOW	LOW
I			COMPLEXITY			NOTOSED			LOW
			COST	LOW	LOW	NOT USED	LOW	LOW	MEDIUM
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES
	Realization of new structural elements (reinforced concrete walls or pillars)	INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE; REDUCTION OF THE RISK OF FRAGILE MECHANISMS	RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	HIGH	LOW	MEDIUM
H.3			TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
	Replacement of structural elements	INCREASE IN THE STIFFNESS AND STRENGTH OF THE STRUCTURE	RECOMMENDED				YES	YES	
			DIFFUSION	LOW	LOW	NOT USED	MEDIUM	LOW	LOW
H.4			TECHNICAL COMPLEXITY	HIGH	HIGH	NOT USED	HIGH	HIGH	HIGH
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	NO
	Replacement of non-structural elements	REDUCTION OF THE RISK OF FRAGILE MECHANISMS	RECOMMENDED				YES	YES	
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
H.5			TECHNICAL COMPLEXITY	LOW	LOW	NOT USED	LOW	LOW	LOW
			COST	LOW	LOW	NOT USED	LOW	LOW	LOW
			EASILY APPLICABLE	YES	YES	NOT USED	YES	YES	YES





Н	Interventions using concrete reinfo	rced solution							
CODE	DESCRIPTION	FUNCTIONS	Specificities	PP1 + PP2 - ITALY	PP3 - CROATIA	PP4 - ALBANIA	PP5 - SERBIA	PP6 - SLOVENIA	PP7+PP8 - GREECE
	Execution of reinforced concrete beams for the lateral expansion of the existing foundation	IMPROVEMENT IN THE FOUNDATION STRUCTURES	RECOMMENDED				YES	YES	
			DIFFUSION	HIGH	HIGH	NOT USED	MEDIUM	HIGH	MEDIUM
H.6			TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
			COST	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	YES
	Execution of foundation by micropiles	IMPROVEMENT IN THE FOUNDATION STRUCTURES	RECOMMENDED				YES	YES	
			DIFFUSION	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	MEDIUM
Н.7			TECHNICAL COMPLEXITY	MEDIUM	MEDIUM	NOT USED	MEDIUM	MEDIUM	HIGH
			COST	MEDIUM	MEDIUM	NOT USED	HIGH	MEDIUM	HIGH
			EASILY APPLICABLE	NO	NO	NOT USED	NO	NO	YES