REPORT ON THE STATE OF THE ART IN ADRISEISMIC PARTNER COUNTRIES REGARDING METHODS OF EXPEDITIOUS ASSESSMENT

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 expeditious assessment methods currently used in the PP Countries for the building heritage of their historic centres.
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Definitions & Acronyms

Acronym	Full name
CA	Consortium Agreement
PP	Project Partner
LP	Lead Partner
WPT	Technical Work Package

Executive summary

The ADRISEISMIC project has two specific objectives. The first step is to share methodologies for assessing the seismic vulnerability of existing buildings in historic urban centers, which will offer guidance to engineers in assessing built heritage that could present an unacceptable risk to life safety in future earthquakes. To reach a greater safety level in buildings identified as weak, it is necessary to provide strengthening measures complying with acceptable standards of safety under seismic forces. This leads to the second goal of the project, which is to share simple, effective and economical techniques and strengthening strategies.

The assessment of the seismic safety of existing buildings is one of the topics increasingly investigated by researchers, especially in countries with high seismic risk. In recent years, efforts have been made to establish methods for assessing the seismic safety of buildings, to determine the risks and to suggest their strengthening.

Observations made after the recent earthquakes have confirmed that buildings become less vulnerable to earthquakes with developments in seismic engineering, changes in design methods, availability of new materials and construction technologies, as is normal.

Recent earthquake damage statistics indicate that only a portion of existing buildings suffer severe earthquake damage, while others do not generate substantial life safety hazards. Therefore, in the assessment of seismic vulnerability, the primary efforts should be directed to the identification of safe buildings. Rather simple procedures are desirable to identify safe or unsafe buildings in the first instance, and to use more detailed and sophisticated methods in cases where some deficiencies have been identified.

Deliverable T2.1.1 aims to provide the cataloguing of the expeditious assessment methods for analysing the seismic vulnerability of the building heritage that are available at the state-of-art for each PP. The focus is oriented on the current methods that are used for post-earthquake and pre-earthquake procedures. This study 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 approaches to seismic assessment. 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 analysed structural types, the advantages and limitations of each procedure.

This classification of the actual procedures showed that there are many similarities in the of post-earthquake damage survey, since most partner countries have been affected by recent earthquakes, and the tools that have been used are very similar to each other.

Although these are not usable for the purpose of assessing pre-earthquake vulnerabilities, they were also studied because they are based on the identification of the construction characteristics of the heritage. Combining them with the knowledge of how the buildings were damaged, they allow understanding which are the most relevant factors to be taken into account in the pre-earthquake assessment.

The proposed joint classification made it possible to highlight that no relevant similarities between the methods and processes developed and used for pre-earthquake assessment between the partner countries, even if the local heritage has similar traits. And above all, what has now been proposed in this sense is not accepted from a regulatory point of view, but is only a matter of scientific research applied to certain territories.

The ADRISEISMIC project therefore aims to remedy these discrepancies, proposing a common and shared preliminary tool that can be used in all partner countries, demanding the use of local assessment methods to a second level of analysis.

1 Introduction

In the widespread concept of seismic risk, this is defined as the probability of losses occurring due to earthquakes within a given period of time; these losses can include human lives, social and economic disruption as well as material damage.
Hence, seismic risk can be expressed by the following qualitative expression:

SEISMIC RISK = SEISMIC HAZARD x VULNERABILITY x EXPOSURE

Seismic Hazard may be defined as the probability of a potentially damaging earthquake effect (e.g. ground shaking, ground failure etc.) occurring at a site within a given period of time. It is commonly expressed as a relationship between the level of the seismic effect and the corresponding probability of its occurrence.
Vulnerability is the probability of the occurrence of damage in a building (or building stock) when exposed to a particular earthquake effect. It is therefore typically represented by a relationship between the level of earthquake effect and the level of expected damage.
Exposure is a quantification of the number of people and buildings, the amount of commercial and industrial activity, the amount and type of important infrastructure and buildings concentrated in the assessed area.
In recent years, an increase in the number of earthquake related disasters has manifested; the reason is not the increase in the number of seismic events, but the economic and life losses in earthquakes occurred as a direct or indirect consequence of building and infrastructure collapse. Growing urbanization and poorly built housing, uncontrolled use of land and high population densities, has increased the vulnerability to earthquake effects population exposure. Although an earthquake is a natural phenomenon, the level of losses depends on human activity.
Seismic risk assessment is the evaluation of the current seismic risk, looking at the existing building stock and exposure under a given hazard, and evaluating potential losses.
It is composed of three main parts: Seismic Hazard Assessment (SHA), Seismic Vulnerability Assessment (SVA), Exposure Assessment (EA).
There are many reasons to carry out a seismic risk assessment; firstly, seismic risk assessments are the basis for any plan of mitigation. Hence, governments / development agencies, may look to carry out seismic risk assessments to identify high risk areas to undergo large life and economic losses during an earthquake. Insurers and Re-insurers carry out seismic risk assessments to evaluate the potential losses to their portfolios (being humans, buildings, industry) in the case of an earthquake. Very detailed seismic risk assessments are carried out for very important buildings (such as nuclear power stations, chemical plants, hospitals, key infrastructure and schools), whose consequence has an impact on human life, key economy or the environment.

About the 3 components of the seismic risk, seismic hazard regards consideration on ground shaking, surface rupture, landslides, liquefaction, tsunami. When assessing a certain location, it is important to consider all of these (as well as other natural and man-made hazards).
A seismic hazard assessment is the first step of any seismic risk assessment. Its aim is to provide an estimate and description of the ground shaking that is likely to be experienced by a built environment during its life. It must provide a description of the dynamic characteristics of the ground motion at the site.
Ground shaking is caused by seismic waves, and their characteristics depend on the earthquake source characteristics (such as type of fault, rupture speed and size, magnitude), on the characteristics of the path (e.g. soil layers, distance from source to site) they have taken to reach the site and on the site characteristics

themselves (e.g. soil conditions at site). The determination of the seismic sources and their seismicity in the assessed area forms the basis of any seismic hazard assessment.

Appropriate seismic hazard maps show the relative hazards in different areas. The maps are made by considering past faults and earthquakes, the behavior of seismic waves as they travel through different parts of the crust, the near-surface site conditions at specific locations of interest. Different maps show different probabilities that are selected to provide an idea of the relative range of hazard.

Seismic hazard mapping is standardized in Europe with the implementation of the new EUROCODES system. This system requires that buildings are designed and constructed in accordance with a harmonized and unified approach. The desire for harmonization also motivated an international team of European specialists to create the unified Seismic Hazard Map of Europe (Jiménez et al., 2001) for the expected Peak Ground Acceleration (PGA) for 10% exceedance in 50 years (475-year return period), that was firstly published in 2003 (http://wija.ija.csic.es/gt/earthquakes/). The Unified Seismic Hazard Map of Europe is a very good example of how to achieve a unified methodology for seismic hazard mapping across European regions.

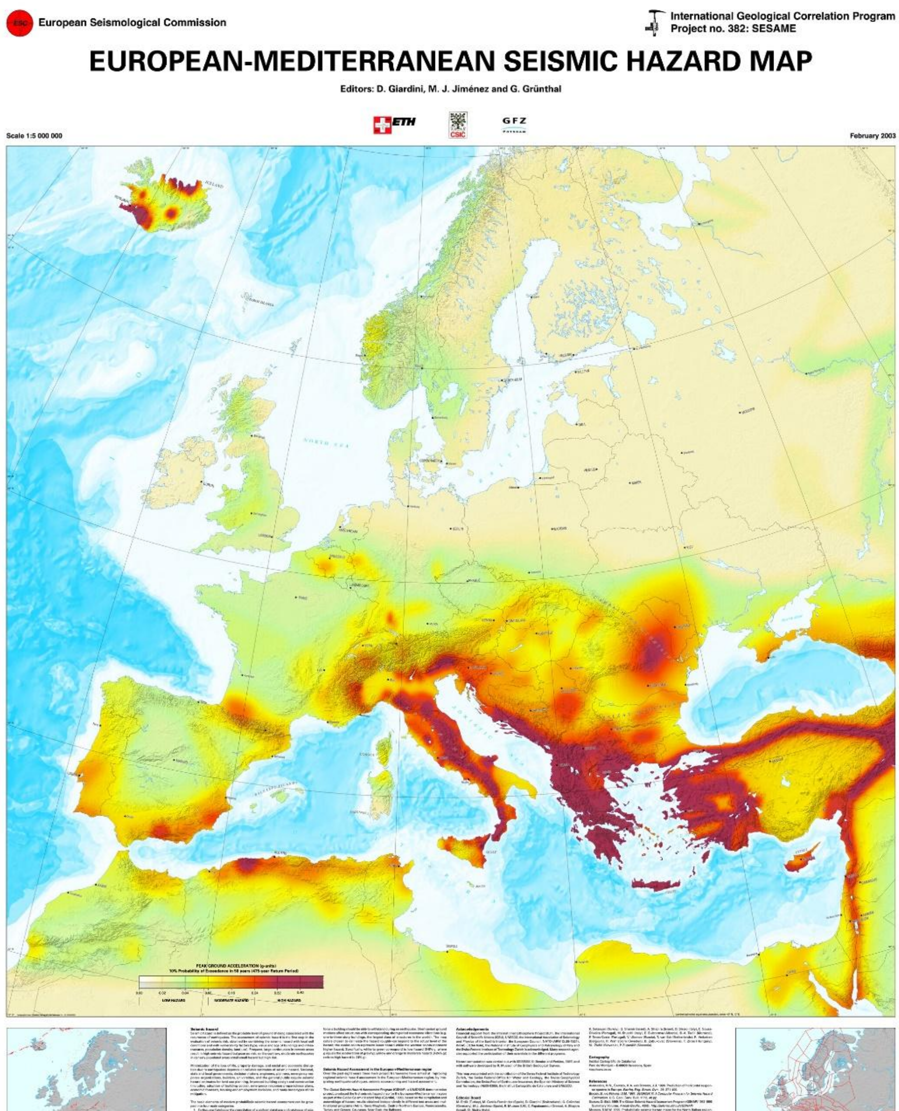

Figure 1 – European-Mediterranean seismic hazard map (2003)

The, the EU-funded SHARE ('Seismic Hazard Harmonization in Europe') project helped in generating the first consistent regional seismic hazard model for Europe (including Turkey). The model, published in 2013, overcomes the limitation of national borders and includes a thorough quantification of the uncertainties.
Seismic hazard data collected for this model consisted of records from more than 30.000 earthquakes with a magnitude of 3.5 and above on the Richter scale which occurred since the year 1000. To fully consider that hazards do not only reflect the mere occurrence of major seismic events, but also the damage they create, the model also factors in the earthquakes' damaging effects. Moderate earthquakes in very densely populated regions can have a major impact. The vulnerability of populations depends on a multitude of factors that go beyond the actual earthquake's magnitude.

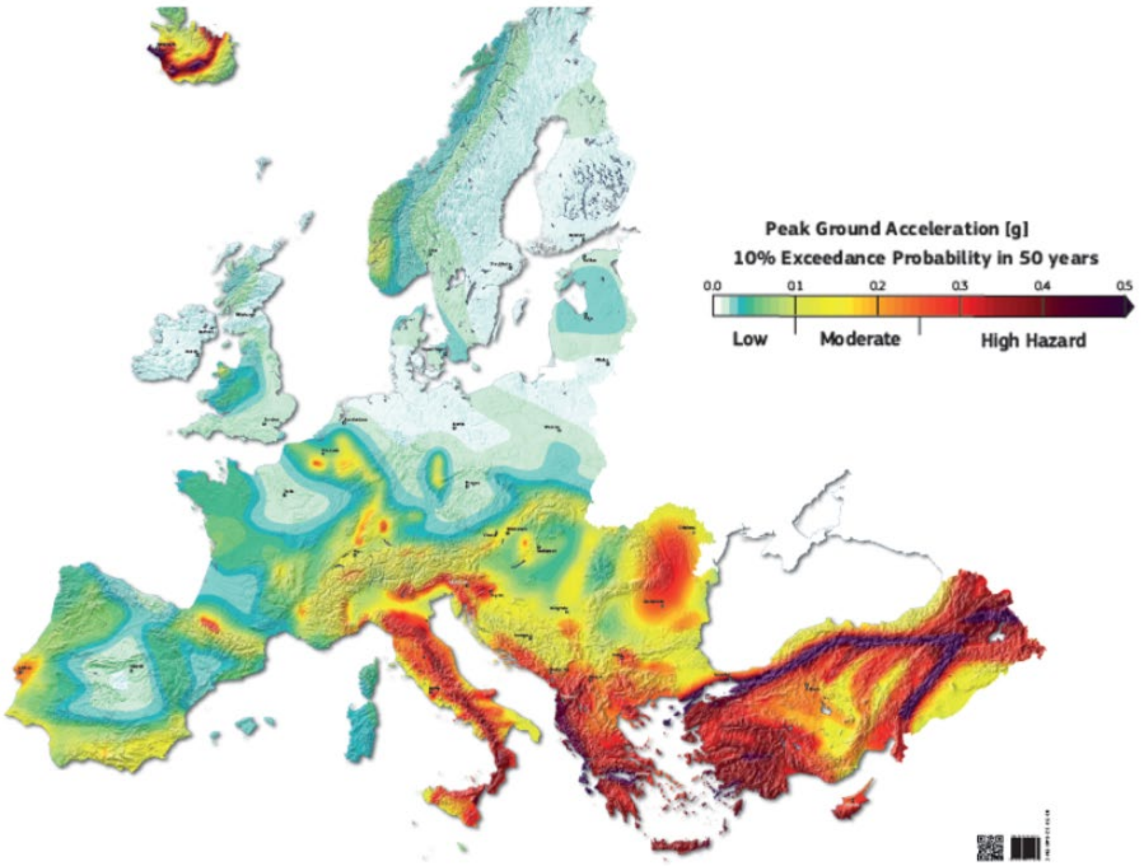

Figure 2 – European Seismic Hazard Map showing the probability of peak ground acceleration exceedance of 10 % in 50 years (SHARE Project

Therefore, the issue of seismic hazard has been studied in depth for several years now, in many countries around the world, and the approach is now standardized. The founding countries of the European Union abide by the mappings and provisions of Eurocode 8 and, in the same way, the recently joined countries had to adapt.
Countries not yet belonging to the European Union are also adapting, by adopting the illustrated mapping. Therefore, there is a uniform database and a uniform treatment of the topic, which is considered to be treated from a homogeneous point of view and with uniform references, which are then normatively derived on the local territory. The topic is well-known and uniformly applied in the partner countries on the basis of specific local provisions.

More complex to assess is the exposure, which refers to people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. Exposure refers to the inventory of elements in an area in which hazard events may occur. Hence, if population and economic resources were not located in potentially dangerous settings, no problem of disaster risk would exist.
Land use and territorial planning are key factors in risk reduction. The environment offers resources for human development at the same time as it represents exposure to intrinsic and fluctuating hazardous conditions. Population dynamics, diverse demands for location, and the gradual decrease in the availability of safer lands mean it is almost inevitable that humans will be located in potentially dangerous places. Where exposure to events is impossible to avoid, land use planning and location decisions can be accompanied by other structural or non-structural methods for preventing or mitigating risk.
In most of the recent studies, the common approach to quantifying the number of people potentially involved in an event is to use data relying on census data on population at the municipal level to characterize the building stock towards territorial risk assessment. Anyway, most studies on population exposure to earthquake hazard only consider census-based resident population (i.e. nighttime) and often fail to integrate population distribution data with actual seismic hazard maps. Therefore, there is an essential need to advance current state-of-the-art exposure assessment by: (i) accounting for spatio-temporal variation of population distribution in urban areas, and (ii) combining more explicitly and in more detail the best demographic data on the potentially affected population with existing seismic hazard maps.
However, these data are locally available, as the census data is now widespread and available to municipal administrations. It is quite simple to have the number of residents in an area, but what is more difficult, as anticipated, is to take into account the variability of presences during the day.
In the project, the same principle will be assumed, and some previous experiences have been studied in this regard, which are presented for the various countries. We will then try to evaluate the weak point, that is the variability of the data in the hours of the day.
The most delicate issue, and also the most controversial, the vulnerability of built heritage. Modern seismic codes have only really been enforced since the mid- 1980's. This means that in Europe (and the rest of the world) the majority of existing buildings is not designed to resist earthquake forces. Nevertheless, most have an inherent lateral resistance, born of over-strength factors in design codes, which may be sufficient to resist their imposed seismic hazard (if this is low to moderate) with an acceptable degree of damage.
Laws governing construction in seismic zones today state that buildings must not be damaged by low-intensity earthquakes, must not be structurally damaged by medium-intensity earthquakes and must not collapse in the event of severe earthquakes despite suffering serious damage.
The kind of damage depends on: the structure of the building, its age, materials, location, vicinity to other buildings and non-structural elements.
After an earthquake, to assess a building's vulnerability, it is enough to inspect the damage caused, associating it with the intensity of the tremor. Whereas assessment of building vulnerability before a seismic event occurs is more complex. This is why statistical and mechanistic methods have been perfected, in conjunction with expert opinions.
Statistical methods classify buildings according to their construction materials and techniques, based on damage observed in previous earthquakes to the same kind of buildings. This technique requires damage data from past earthquakes, which is not always available, and cannot be used to assess the vulnerability of individual buildings, because it is statistical in nature and not specific.
Mechanistic methods, on the other hand, use theory models that reproduce the main characteristics of the buildings being assessed for study of the damage caused by simulated earthquakes.

Finally, some methods use expert opinions to assess the seismic behavior and vulnerability of predefined structural types or to identify the factors that determine the behavior of buildings and assess their influence on vulnerability.
The results of seismic risk assessments can be used to decide on strengthening intervention and help informed disaster management plans to be drawn. Hence, they aid these agencies decide where and how to invest effort and resources, locate important facilities and identify the priorities for investment.
For these reasons, this will be the specific topic covered in this Deliverable.

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 at 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 T2.1.1

The aim of the Deliverable T2.1.1 is the cataloguing of the expeditious assessment methods for analysing the seismic vulnerability of the building heritage that are 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.
Therefore, the analysis topics of the Activity T2.1 were immediately divided into 3 macro-areas: i) representative local building characteristics of the Regions involved (Deliverable T2.1.2); ii) most appropriate analysis methods for the evaluation of the seismic behaviour of existing buildings and aggregates of buildings (Deliverable T2.1.1); iii) new and most used techniques of intervention (Deliverable T2.1.2).
All the data regarding these 3 macro-areas had been collected and systematized, in order to define the local construction techniques reference framework, to be linked to specific structural issues generating vulnerability.
The ADRISEISMIC project specifically focuses on the buildings and aggregates of buildings in the main historic centres, therefore the assessment methods that have been studied are focused on these contexts.

The cataloguing of the assessment methods was developed by UNIBO as Leader Partner (LP) of the 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 expeditious assessment methods in relation to the characteristics of the local construction heritage.

2 The current approaches to seismic vulnerability assessment methods

Models capable of estimating losses in future earthquakes have fundamental importance for emergency and disaster planning by a national authority, in fact, many tools and methodologies have been proposed over the past 30 years for this purpose. The main requirement of a “loss model” is the ability to provide an accurate assessment of building vulnerability.
Assessing the seismic vulnerability of an existing building is a completely different activity from designing a new one. The first is a physical entity, whereas the second, yet to be constructed, exists only in conceptual form.
So, a seismic assessment of an existing building is based on observation. Aspects such as poor construction, poor design and poor integration of secondary elements assume particular relevance on the final result. The advantage, compared to the design of new structures, is the possibility of understanding any practical implications of design and construction. The current standard approach is to establish how existing buildings are likely to behave under an earthquake and then to relate it to the local seismic intensity.
The seismic assessment of existing buildings, due to their lack of performance, has attracted considerable attention in many countries.
Generally, assessment procedures of an existing building are based on the evaluation of the structural system, seismic capacity, ground conditions, plane and elevation regularity, and on data collections. These parameters provide a more or less realistic estimation of the structural behaviour.
The focus of a seismic assessment is to achieve an understanding of the likely behaviour of the building in earthquakes by quantifying the resistance and deformation capacities of the various structural elements and verifying them against the loads/ deformations (demands).
In the evaluation process of existing buildings, it is important to identify the various systems/mechanisms that collaborate in the seismic response and their relationship to each other. The characteristics that lead to the development of the mechanisms are already present and need to be identified and assessed. The parts to be considered most carefully are those elements whose collapse could cause partial or total collapse of the structure.
There are several important aspects to consider:

- A wide range of events that the building may be subject to, implying different levels of performance reliability across a range of shaking levels.
- The presence of severe structural weaknesses provides confidence for the minimum level of performance.
- An appropriate level of detail, taking into account the size of the building, the potential consequence of its failure and the other works that may be undertaken in parallel with, or as an outcome of the assessment.
- Gaining an understanding of the expected mode of failure and its physical consequences is an important consideration for an assessment.
- The focus for assessing existing buildings is on life safety and not on damage prevention; structural elements must not lose gravity support (and, therefore, collapse) once their capacity is exceeded, or if they should collapse, they should not lead to a significant risk to the life safety.
- When assessing an existing structure, realistic values for the material properties, particularly strengths, should be used to obtain the best estimate of the resistance and displacements of members, joints and connections. Seismic assessments make use of probable (expected) element capacities.
- The role of the codes and standards of the day are significant, as they give information about the design and construction process.

The assessment method must ascertain understand the behaviour of the building and the consequences of the failure of its elements.
Existing buildings involve a wide range of structural types, materials and details; so, a number of factors must be considered, including: the construction materials and how these may vary from what was originally intended; the structural form, and how it could have been modified during the execution; the detailing used in design (and as constructed), and how it may modify the intended behaviour; the changes that may have happened over time and how they may impact on reliability and performance.
The seismic vulnerability of a structure can be described as its propensity to damage by ground shaking of a given intensity. Thus, the purpose of the procedure is to obtain the probable damage of a building for a given earthquake.
Many methods for seismic risk assessment were proposed by researchers and they are commonly classified into two major groups: empirical and analytical (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020); hybrid procedures imply the use of both (Calvi, Pinho, Bommer, Restrepo-Véléz, & Crowley, 2006).
In empirical vulnerability methods the damage scale is used as an inquiry approach to develop post-event data that are derived from statistical studies. Analytical methods, on the other hand, are based on limit states and mechanical attributes of structures.
Both methods involve a preliminary phase, which will be more or less thorough in relation to the data accuracy to be obtained. Analytical methods, which lead to obtaining a quantitative vulnerability value, obviously require greater accuracy of the input data.
A further approach is the heuristic one, which relies on expert judgment and on the possibility that a given number of experts will express similar judgment when asked about the seismic performance of the same building typology. This relies on personal observation and experience and it is very useful when no other form of assessment can be carried out, however the reliability of the outcome can be very low. This approach can be repeated over a number of buildings of similar and diverse typologies to create a database which can form the basis for the development of a Vulnerability Index (I_v).

3 The knowledge process

Assessment of existing buildings requires careful information gathering, whose level may vary considerably according to the building type and the purpose of the evaluation. In general, the more complex the building and the more care should be taken to assemble the information required.

It may be possible to complete an assessment also with limited information, achieving a level that may be sufficient to determine whether or not a building is potentially earthquake-prone.

Information gathering is generally iterative. It may be more time efficient in many cases to perform preliminary analysis using relatively approximate data, in order to develop an initial understanding of a building; this may then point the way to more detailed investigations. A targeted information gathering process may then be developed that places more emphasis on the most critical elements.

All assessment involves assumptions, such as: materials used in the original construction, structural mechanisms that will form as the level of shaking increases, founding conditions for the building, alterations to the building over time and so on.

As the assessment proceeds, assumptions are validated or changed to suit what is learned.

The more assumptions that are validated, the greater the knowledge of the building's expected behaviour. Hence the assessment may be considered more reliable. Deciding how much effort should be spent to refine the evaluation depends on the objective set.

The main topics about the acquisition of knowledge are the following:

- **Information collection, initial review, appraisal of building complexity**

To collect relevant information and documents about the building (including drawings, design feature reports, geotechnical data, calculations and specifications, historical material such as test results, previous assessments and inspection reports) is a crucial part of the process. Obtaining this information often involves detailed research of the files in the relevant Territorial Authority's records, the building designer's archives and building owners' records.

If the building has been previously altered or strengthened, all available drawings, calculations and specifications for this work must be collected.

This initial stage will indicate the most suitable assessment strategy and on-site inspection, allowing the practitioner to concentrate effort on the key elements.

Documentation may not be available for all buildings, in which case more reliance needs to be placed on inspections and testing to provide the information required to complete the evaluation.

It is important to note that the documentation provided may not always be the most up-to-date. It is common for construction drawings to considerably vary from what is illustrated in the permit. In addition, old records often contain a mix of structures that were built and others that were not.

- **Site inspection/intrusive investigation**

Detailed building inspections should be made as part of the assessment of an existing building and before the preparation of any strengthening proposals. Visual site inspections to confirm the as-built structure is as documented in the available structural drawings is necessary.

Inspections on the building are a key part of the assessment process, as they are essential to develop a broad understanding of the structure and to verify that the documentation obtained is truly representative of the surveyed construction.

Matters to be considered include:

- verification that the general configuration of the building matches the drawings or assumptions

- checking of dimensions reported in the documentations
- consideration on neighbouring buildings
- consideration of the expected geotechnical conditions and how these may vary with shaking intensity
- consideration on off-site hazards, such as landslide
- general condition assessment (i.e., can key elements develop their probable capacity?)
- identification of key configurational issues, such as irregularity, diaphragm openings, etc.
- identifying the other building elements that need to be assessed and any of those that will require specialised assistance.

Most of the details of the structural configuration required for an analysis should be available on design or construction drawings. The lack of structural drawings is often a source of uncertainty. If specific detailing or material properties are deemed critical to the seismic performance of the building, and are not available from other sources, field measurements and invasive exploration and testing may be necessary.

It is recommended that an initial field measure is carried out to confirm the general adequacy of the available documentation. This should be followed by a more detailed inspection to confirm detailed dimensions and detailing as required for the assessment.

The structural information gathered should include the following:

- plans, elevations and dimensions of frames and walls on each level
- location and size of openings in walls and floors
- identification of load-bearing/non load-bearing walls
- identification of any discontinuities in the structural system
- arrangement of roof and floor trusses, beams and lintels
- identification and location of reinforcing bands, columns and bracing
- dimensions of non-structural components to allow storey masses to be reliably assessed
- location and configuration of precast elements
- lift and stairwell construction and dimensions
- foundation dimensions, type and identification of connections between foundations and between superstructure and foundations
- clearances to adjacent buildings
- evidence of structural modifications, and seismic status of adjacent buildings, if this can be obtained.

Invasive inspection may be required for the verification of key details and for material testing. But, while a minimum level of knowledge is required, the cost of undertaking extensive destructive investigations often cannot be justified by the benefits that the additional knowledge of the building will provide.

In the case of verifications carried out on major details, enough locations throughout the building must be chosen to develop an appropriate degree of confidence in the assumptions that are being made. This may vary depending on the details being investigated, the stage of the assessment and the features of the building. For example, in masonry buildings, the floor-wall connections are critical. At the preliminary stages of assessment, it may be sufficient to check only one or two locations to verify whether there are any connections at all. In later stages, the precise detail and spacing may be critical, in which case further investigation may be required. When the investigation requires a level of destructive testing or exposure of hidden elements, locations should be selected carefully to provide all of the information that may potentially be required. For example, if exposing reinforcement in concrete buildings, locations should be selected to verify not only the size and location of the reinforcement, but also the most important details and conditions that may affect its behaviour. Non-destructive techniques such as electronic scanning of concrete members can often provide an attractive alternative to intrusive investigations.

The following member/element properties should be obtained:

- cross-sectional shape and physical dimensions of the key members/elements and overall configuration of the structure
- type of connections, size and thickness of materials and continuity of load path, particularly for precast elements
- modifications to individual members/elements or overall configuration of the structure
- location and dimensions of braced frames and shear walls
- current physical condition of members/elements and extent of any deterioration present
- reinforcing details in reinforced concrete structures
- connection details for primary and secondary structure.

As written in the list, the actual physical dimensions of the elements should be measured; modifications to members need to be noted including notching, alterations, tack welds, etc. that may modify geometric and material properties. The presence of corrosion, decay or deformation should also be noted. In this way, it is possible to properly characterise capacities in the seismic assessment.

A good starting point for establishing member/element properties could be the available construction documents. In fact, preliminary review of these documents shall be performed to identify the structural system. In addition, site inspections should be conducted to verify the starting condition and to ensure that remodelling has not changed the original design concept. In the absence of a complete set of building drawings, the technician must thoroughly inspect the building to identify these members and elements.

The adequacy of interconnection between the various structural elements will be critical to its behaviour. The type and character of the connections should be determined by a review of the plans and a field verification of the actual conditions. For example, the connection between a diaphragm and the supporting structure is likely to be of prime importance in determining whether or not the separate parts of the building can act together or if vertical-only resistant elements are likely to be sufficiently protected by the lateral-load resisting system (e.g., concrete shear walls).

Realistic values for the material properties must be used to obtain the estimates of the probable resistance and deformation capabilities of members, joints and connections. Recognising the significant cost associated with an extensive material testing programme, it is sometimes possible to use default values (where not otherwise recorded in the construction documentation) making consideration on the most likely material properties. In this case, the testing effort is then concentrated in the structure areas that are likely to yield the greatest benefit in terms of defining the earthquake resistance. Usually, standards provide for a sort of penalty applied to the assessment results (e.g., a lack of knowledge factor). In any case, it is recognised that material variability will always exist and will be difficult to quantify even when extensive testing has been carried out.

The condition of all structural components should be recorded with particular attention given to deterioration such as cracking, spalling, corrosion and decay. Their locations and extent should be recorded.

The foundation soil type should be determined and a careful inspection made to identify any settlement or indications of distress.

Damage from previous earthquakes or other overloads should also be carefully inspected and recorded. It is evident how the impact of any building alterations on the behaviour of the main structural elements should be considered carefully.

In addition, if the building has already been seismically retrofitted it will be necessary to ascertain the extent of this retrofit and the philosophy adopted. For example, in the past, structure may have only been secured rather than fully strengthened or the strengthening scheme would now be considered incomplete or inadequate.

Common issues with previous retrofits include:

- Incomplete documentation: details were often varied to suit conditions found on site, so what is shown on the retrofit drawings may not always be representative of what was actually installed. Site or contract instructions, if available, can be a valuable source of information in this regard.
- Incomplete retrofit: only the most vulnerable issues may have been addressed.
- Poor deformation compatibility between the original structure and the retrofit works: e.g., steel bracing used to strengthen in-plane masonry walls or infilled concrete/steel frames.

- **Geotechnical issues**

They are strictly linked to structural weaknesses. Ground conditions influence the behaviour of buildings in several ways, depending on the nature of the ground, the applied loads and the nature of the earthquake.
The ground influences the seismic actions transmitted to the building, in fact the soil class is a critical input to the spectral shape factor. Ground-foundation-structure interaction effects may significantly influence the assessment where there is significant non-linearity, either through the behaviour of the soils, for example in cases involving liquefaction, or through the behaviour of the building itself, for example where foundation rocking occurs.
The significant settlement resulting from widespread liquefaction may not have any significant impact on life safety, especially if the foundations are well connected and there is an element of toughness in the building superstructure. Conversely, even relatively nominal differential effects may have a significant life safety impact on unreinforced masonry buildings with isolated footings.
The level of geotechnical investigation required may vary from a simple study for small structures for the purposes of determining whether or not a building could be earthquake-prone, to comprehensive studies for large, complex structures.

- **Identify the primary structural systems in the building (both lateral and gravity) and identify potential weaknesses.**

The relative vulnerability of the structure needs to be established in terms of strength and in terms of deformation demands. The various members/elements must be divided into three categories: those that are part of the primary lateral system (primary seismic resisting system), those that are part of the primary gravity system (primary gravity load resisting system), and those that would be considered secondary structural elements. Of course, some components may be categorised as having both a primary seismic resisting function and a primary gravity load resisting function (e.g., moment resisting frames).
The identification of potential weaknesses requires a good understanding of the issues that might be present in buildings of the same generic type. For example, a reinforced concrete wall system may have several potential mechanisms such as foundation uplift, in-plane shear mechanisms, flexural mechanisms, etc.

3.1 Empirical assessment approach

The empirical method relies on knowing past performance of buildings in given seismic events and being able to extract statistical functions that relate the probability of damage suffered by a building type, at a given site, to the expected shaking intensity.
To produce such functions reliably, and to cover the full range of performance for a given building type as a function of possible earthquake intensities, large data sets and multiple observations are required.

Once the functions are available and an earthquake scenario is defined (in terms of shaking intensity), it is then sufficient to score the individual building or typology, based on specific constructional and functional details, to assess its vulnerability.

Although this is an observational method, several uncertainties about the data acquiring and treating limit its applicability at the scale of individual buildings.

The seismic vulnerability assessment, at large geographical scale, has been first carried out in the early 70's, through the employment of empirical methods initially developed and calibrated as a function of macro-seismic intensities. At the time, hazard maps were, in their vast majority, defined in terms of these discrete damage scales (earlier attempts to correlate intensity to physical quantities, such as PGA, led to unacceptably large scatter). Therefore, these approaches constituted the only reasonable and possible way that could be initially employed in seismic risk analyses at a large scale (Calvi, Pinho, Bommer, Restrepo-Véléz, & Crowley, 2006)).

There are three main types of empirical methods that are based on the damage observed after earthquakes:

- Rapid Visual Screening assessment methods;
- Damage probability matrices (DPM), which express in a discrete form the conditional probability of obtaining a damage level due to a ground motion;
- Vulnerability functions, which are continuous functions expressing the probability of exceeding a given damage state, given an earthquake intensity.

Rapid Visual Screening (RVS) assessment methods or screening methods

These methods are the simplest and most immediate rapid assessment approaches. Rapid Visual Screening (RVS), as a qualitative estimation procedure, can be used on a large building stock to classify the vulnerability of the structures. It is based on observations made from the building exterior, without taking into consideration the inside. These procedures represent the first step in the assessment before going into a more detailed evaluation and allow to classify the buildings according to their construction materials and their structural systems. Basically, it is a survey technique for detecting and observing building parameters and calculating the basic structural performance score for determining which constructions must be prioritized in the interventions.

The process starts with the performance score that is calculated on the basis of the building features. There are 17 buildings types and for each type, a Basic Structural Hazard (BSH) score is determined. The BSH score is about the probability of collapse for a structure. The final score is expressed as a negative of the logarithm (Base 10). For example, if the final score would be 2, this signifies the probability of 1% damage. After that, the BSH is modified by adding or subtracting the score modifiers (SMs) of a building. These modifiers are based on the building properties, which have effects on the seismic performance, such as: the number of floors, height, plan irregularity, vertical irregularity, the age of the buildings, and soil types. A construction with a final score of less than 2 should undergo a more detailed investigation (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020).

RVS strategy was developed in US, Canada, Japan, Turkey, Greece, New Zealand, and India. In Canada, the National Research Council has proposed another seismic screening procedure, that is widely used. The purpose of this method is to establish the Seismic Priority Index (SPI) that results from the addition of the structural (SI) and non-structural (NSI) indices. This screening score major factors are: building location, soil type, duration or age of occupancy, falling hazard, and others. The SPI index is categorized into three evaluation stages, if SPI is less than 10 is considered as ''low" detailing assessment, for SPI between 10 and 20, it is considered as ''medium", and for SPI higher than 20, it is considered as ''high" assessment (Allen & Rainer, 1995; Saatcioglu, Shooshtari, & Foo, 2013).

The structural index (SI) is based on the product of five parameters: seismicity Index; effect of soil condition; type of structure; building irregularities; building importance. The non-structural index (NSI) is the product of three parameters: effect of soil condition; building importance; the maximum value between a parameter for falling hazards to life and for hazard to vital operations.

In Japan, the Japanese Seismic Index approach takes the form of three phases of screening assessment to be performed. In the first phase, the compressive strengths of the vertical resisting members are used to quantify the structure's response behaviour during lateral seismic loading. In the second phase, the seismic capacity is evaluated by considering the dynamic properties of the resisting elements only such as ductility and resistance, while in the third phase, the resistance and ductility of the vertical and horizontal members (columns, walls, and beams) are included to evaluate the structural performance during the seismic movements. The Index of the structure (IS) is calculated from the product of Basic Structural (Eo) and the Irregularity Index (SD), as well as the time or deterioration index (T). Once the Seismic Performance Index (IS) is determined, it ought to be compared with the Seismic Judgment Index (IS0) to classify the building as adequate or not to resist seismic forces.

There are two possibilities in comparing IS to IS0: IS > IS0, this means it has low vulnerability condition, and IS < IS0, that means high vulnerability condition (Otani, 2000).

In Turkey, a similar method, the "Priority Index" procedure (Hassan & Sozen, 1997), was developed for each individual building. It comes from the column index (CI), defined as the ratio of column area to the floor area, and the wall index (WI), defined as the ratio between the area of shear and infill walls divided by the floor area. In addition, there is also a methodology (Yakut, 2004) based on: the material and size properties, lateral resisting system, elements orientation, vertical and plan irregularities, column length, and workmanship. From these parameters, the capacity index (CI) can be computed to classify the building risk vulnerability.

The P25 Scoring Method (Bal, Gulay, & Tezcan, 2008) tends to classify the vulnerable buildings to collapse. This procedure was developed on the basis of data collected from 323 constructions that suffered different levels of damages during seismic events. Among the considered parameters for the assessment are: material quality, steel corrosion, vertical and horizontal irregularities, ground conditions, depth of foundation, seismicity, and others. Seven different scores for different failure modes, from P1 to P7, between 0 and 100 varied from worst to best, respectively.

In New Zealand, the society for earthquake engineering in 2012 (NZSEE, 2014) recommended two stages of assessment: Initial Evaluation Procedure (IEP), and a Detailed Seismic Assessment (DSA). To perform them, data such as seismic zone, soil type, construction age, and the design date of the building have to be collected. After producing the % New Building Standard (NBS) values, the assessment is completed. If the %NBS < 33, it implies that the construction is ultimately susceptible and required a supplementary detailed and precise assessment. For %NBS of 67 or more, the surveyed structure is able to withstand future earthquakes. For 33 < %NBS < 67 more evaluation may be required.

These RVS tools are rapid and useful for estimating the seismic response of buildings, but have some disadvantages and drawbacks due to the observed and watched damage information. These methodologies do not involve all the structural typologies as well as the seismic intensities, which are essential to be considered for vulnerability estimation. Moreover, they are generally based on expert judgment and statistical data, thus not always very reliable.

Damage Probability Matrices

(Whitman, Reed, & Hong, 1973) proposed the use of damage probability matrices to predict the effects of earthquakes on buildings. The concept of a DPM is that different buildings of the same structural type will have the same probability of damage from earthquakes of equal intensity.

(Whitman, Reed, & Hong, 1973) compiled DPMs for various structural typologies according to the damaged sustained in over 1600 buildings after the 1971 San Fernando earthquake.
One of the first European versions of a damage probability matrix was produced by (Braga, Dolce, & Liberatore, 1982), based on data recorded after the 1980 Irpinia earthquake. The study introduced the binomial distribution to describe damage distributions of any class for different seismic intensities. The binomial distribution has the advantage of needing one parameter only which ranges between 0 and 1. On the other hand it has the disadvantage of having both mean and standard deviation depending on this unique parameter. The buildings were separated into three vulnerability classes (A, B and C) and a DPM based on the MSK scale was evaluated for each class.
Proposals have been made in Italy to update the original DPMs. (Di Pasquale, Orsini, & Romeo, 2005) switched from the MSK scale to the MCS (Mercalli-Cancani-Sieberg) scale because the Italian seismic catalogue is mainly based on this intensity and the number of dwellings replaced the number of buildings.
An additional vulnerability class (class D) has been included, using the EMS98 scale (Grüntal, 1998), to account for the buildings that have been constructed since 1980. These buildings should have a lower vulnerability as they have either been retrofitted or designed to comply with recent seismic codes.
Damage Probability Matrices, based on expert judgement, were first introduced in ATC- 13 (Applied Technology Council, 1985). More than 50 seismic engineering experts were asked to provide low, best and high estimates of the damage factor (the ratio of loss to replacement cost, expressed as a percentage) for Modified Mercalli Intensities (MMI) from VI to XII for 36 different building classes. The low and high damage factor estimates provided by the experts were defined as the 90% probability bounds of a lognormal distribution. The best estimate was taken as the median damage factor.
Weighted means of the experts' estimates, based on the experience and confidence levels of the experts for each building class, were included in the averaging process, as described in Appendix G of ATC-13 (Applied Technology Council, 1985). A lognormal distribution was then used to calculate the probability of a central damage factor by finding the area below the curve within a given damage factor range. Thus, a DPM could be produced for each intensity level for each building class. Examples of the use of DPMs based on the ATC-13 approach for the assessment of risk and loss include the city of Basel (Fah, Kind, Lang, & Giardini, 2001), Bogotá (Cardona & Yamin, 1997) and New Madrid (Veneziano, Sussman, Gupta, & Kunnumkal, 2002).
Recently, a macroseismic method has been proposed (Giovinazzi & Lagomarino, 2002; Giovinazzi & Lagomarsino, 2004) that leads to the definition of damage probability functions based on the EMS-98 macroseismic scale (Grünthal, 1998). The EMS-98 scale defines qualitative descriptions of "Few", "Many" and "Most" for five damage grades in relation to the level of seismic intensity, ranging from V to XII, defining six different classes of decreasing vulnerability (from A to F).
The problems related to the "incompleteness" of the matrices (i.e., the lack of information for all damage grades for a given level of intensity) and the "vagueness" of the matrices have been tackled by (Giovinazzi & Lagomarsino, 2004) by assuming a beta damage distribution and by applying Fuzzy Set Theory, respectively. The damage probability matrices produced for each vulnerability class have been related to the building stock through the use of an empirical vulnerability index which depends on the building type, the morphological characteristics (e.g., number of floors, irregularity, etc.) and the regional construction practices.
This macroseismic method has already been applied in the risk assessment of the cities, Faro (Oliveira et al., 2004), Lisbon (Oliveira et al., 2005), and Barcelona (Lantada, Pujades, & Barbat, Risk Scenarios for Barcelona, Spain, 2004).
Following the introduction of intensity based DPMs, large-scale seismic risk assessment has become more efficient and convenient: in the past, seismic hazard maps were also defined in terms of macroseismic

intensity, thus speeding up this procedure. The use of observed seismic damage has the advantage that it can be applied to regions with similar characteristics, providing realistic indication.
However, there are various disadvantages associated with the continued use of empirical methods such as DPM's. For example, the derivation of vulnerability functions requires the collection of post-earthquakes building damage statistics at sites with similar ground conditions for a wide range of ground motions: this will often mean that the statistics from multiple seismic events need to be combined. In addition, large magnitude earthquakes occur relatively infrequently near densely populated areas and so the data available tends to be clustered around the low damage/ground motion end of the matrix, thus limiting the statistical validity of the high damage/ground motion end of the matrix.
Moreover, since the method does not lead to the realization of a true model of the structure, it does not allow for decisions regarding the most appropriate retrofit techniques. In addition, seismic hazard maps are now defined in terms of PGA (or spectral ordinates) and therefore it is necessary to link this quantity to intensity, leading to uncertainties, especially in areas where no a priori data are available.

Vulnerability index methods

The "Vulnerability Index Method" (Benedetti & Petrini, 1984) has been used extensively in Italy in the past few decades and is based on a large amount on damage recorded on buildings following an earthquake; this method is 'indirect' because a relationship between the seismic action and the response is established through a 'vulnerability index'.
The main advantage of 'indirect' vulnerability index methods is that they allow the vulnerability characteristics of the building stock under consideration to be determined, rather than base the vulnerability definition on the typology alone. Nevertheless, the methodology still requires expert judgement to be applied in assessing the buildings, and the coefficients and weights applied in the calculation of the index have a degree of uncertainty that is not generally accounted for. Furthermore, for the vulnerability assessment of buildings on a large (e.g., national) scale to be carried out using vulnerability indices, many buildings that are assumed to represent the national building stock need to be assessed and combined with the census data. In a country where such data is not already available, the calculation of the vulnerability index for a large building stock would be very time consuming.
However, in any risk or loss assessment model, a detailed collection of input data is required for application at the national scale.

- **GNDT approach**

  During the last decades, the vulnerability index methodologies have been developed in Italy by ''The National Group of Defense from Earthquakes denoted by GNDT approach" and were classified into two levels (Giovinazzi & Lagomarino, 2002). The methodology of ''GNDT level I" classified the typologies of the buildings and defined the vulnerability classes (A, B, and C). The methodology has been extended by of ''GNDT level II" (Benedetti, Benzoni, & Parisi, 1988; GNDT, 1993; Benedetti & Petrini, 1984).

  In this approach, a large number of damages data and information need to be collected. The field survey is intended to understand the fundamental parameters that influence and control the structural vulnerability of the building. For instance, plan layout and its elevation configurations, type of foundation, material type, structural and non-structural elements, state of conservation and quality. There are eleven parameters, and one of the qualification coefficients Ki or Cvi, is distributed into four vulnerability classes (A, B, C, and D) for each of them. Each parameter assesses one structural attribute that is related to the building response during seismic loading. Then the parameters are weighted by considering the importance of each one, from less significant to the foremost important, where the weight values depend on expert judgment. This information is merged with coefficients to establish the vulnerability index (Iv) that classify building damage under the excitations of an earthquake.

The vulnerability index range of variation is between 0 and 382.5, but generally, it is normalized from 0 to 100 by dividing the values obtained from the weighted sum with 3.825. Where 0 is the minimum value, which signifies the least vulnerable building, and 100 is the worst case, which indicates the most vulnerable building. The derived data from previous earthquake events were utilized to express the vulnerability functions in relation to the vulnerability index (Iv) with respect to damage factor (d) of the constructions. The damage factor is the proportion of the restoration cost to the replacement cost. The damage scale is between (0 < d < 1).

In the 2nd level of the GNDT method, a similar relationship is applied for RC buildings, but the main difference is in the parameters' weights that are all assumed to be equal to 1. These values describe the deficiencies and the faults of the structure depending on expert visual observations. Furthermore, a criterion to describe vulnerability classes from less vulnerable ''A" to most vulnerable ''C" is also proposed. Therefore, to compare the masonry and the RC buildings, vulnerability indices of RC structures Iv* can be transformed in equivalent to masonry vulnerability indices.

Number	Parameters	Ki Classes				Weight
		A	B	C	D	Wi
1	Type and organization of resisting system	0	5	20	45	1.00
2	Resistant system quality	0	5	25	45	0.25
3	Aggregate strength	0	5	25	45	1.5
4	Location and foundation of building	0	5	15	45	0.75
5	Diaphragms horizontal elements	0	5	25	45	Variable
6	Configuration of plan layout	0	5	25	45	0.5
7	Configuration in height and elevation	0	5	25	45	Variable
8	Optimum distance between walls	0	5	25	45	0.25
9	Roof	0	5	25	45	Variable
10	Non-structural elements (NS)	0	5	25	45	0.25
11	Particular terms of maintenance	0	5	25	45	1.00

Figure 3 – Masonry building classes and relative weight of each parameter from GNDT (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020)

Number	Parameters	Classes Cvi			Vulnerability Index
		A	B	C	
1	Type and organization of resisting system	0.00	−1.00	−2.00	$Iv^* = \sum_{i=1}^{i=11} Cvi$
2	Resistant system quality	0.00	−0.25	−0.50	
3	Aggregate strength	0.25	0.00	−0.25	
4	Location and foundation of building	0.00	−0.25	−0.50	
5	Diaphragms horizontal elements	0.00	−0.25	−0.50	
6	Configuration of plan layout	0.00	−0.25	−0.50	
7	Configuration in height and elevation	0.00	−0.50	−1.50	
8	Critical elements connections and links	0.00	−0.25	−0.50	
9	Elements of low ductility	0.00	−0.25	−0.50	
10	Non-structural elements (NS)	0.00	−0.25	−0.50	
11	Particular terms of maintenance	0.00	−0.50	−1.00	

Figure 4 – RC buildings classes and relative weight of each parameter from GNDT (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020)

- **European Macro-Seismic (EMS) approach (RISK-UE)**

  Another approach that has been developed for the vulnerability assessment in Europe is known as the RISK-UE project. This project was financed and supported directly by the European Union (EU). The primary goal has been to define an overall seismic risk assessment methodology in European countries.

This led to the introduction of the vulnerability index method (VIM) which has been successfully used in seven European cities (Mouroux & Le Brun, 2008). This approach is based on the building typology classification that is distributed into six vulnerability classes (A to F) from most to least vulnerable typologies. Such buildings are classified into four general typologies: masonry, reinforced concrete, steel, and wooden.

Besides that, the method categorized the damage scale into five grades denoted by D1, D2, D3, D4, D5 from slightly damaged into fully collapsed (Grünthal, 1998). The EMS-98 scale is planned to clear up the understanding and the definitions of many types of structures. As a methodology, it was established in the context of the RISK-UE project to take into account the current or the old constructions in the areas it covers (Lagomarsino & Giovinazzi, 2006). This method measures the vulnerability of a single or set of structural buildings in terms of (V) considering the typology characteristics. The vulnerability index varies from the least vulnerable to the most vulnerable between 0 and 1. The values of the vulnerability indices are presented for each vulnerability class from A to F as a set of five values. VI* is the most tolerable value for each class of the vulnerability index (VI). Where VI (--), and VI (++) are the top and bottom limits of the tolerable values, while VI (-) and VI (+) are the limits of the uncertainty range for VI*. In this procedure, 15 different building types were considered.

	Building Type	Vulnerability Classes				
		$V_I^{(--)}$	$V_I^{(-)}$	V_I^*	$V_I^{(+)}$	$V_I^{(++)}$
Masonry Buildings	Rubble stone	0.62	0.810	0.873	0.980	1.02
	Adobe bricks	0.62	0.687	0.840	0.980	1.02
	Simple stone	0.46	0.650	0.740	0.830	1.03
	Massive stone	0.30	0.490	0.616	0.793	0.86
	URM (old bricks)	0.46	0.650	0.740	0.830	1.02
	URM + RC-Slabs	0.30	0.490	0.616	0.790	0.86
	Confined Masonry	0.14	0.330	0.451	0.633	0.70
RC Buildings	RC-Frame (No ERD)	0.30	0.490	0.644	0.800	1.02
	RC-Frame (M-ERD)	0.14	0.330	0.484	0.640	0.86
	RC-Frame (H-ERD)	−0.02	0.170	0.324	0.480	0.70
	Shear Walls (No ERD)	0.30	0.367	0.544	0.670	0.86
	Shear Walls (M-ERD)	0.14	0.210	0.384	0.510	0.70
	Shear Walls (H-ERD)	−0.02	0.047	0.224	0.350	0.54
Steel	Steel Structures	−0.02	0.170	0.324	0.480	0.70
Wood	Wooden Structures	0.14	0.207	0.447	0.640	0.86

Figure 5 – Indices of the vulnerability of building typologies in EMS-98 (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020)

As highlighted before by the EMS scale, it is noted that the behaviour of the building depends mainly on the structural system, but there are other factors that influence the building performance. Therefore, the typological vulnerability index (VI*) had to be modified on the basis of some structural modifiers for reinforced concrete and masonry buildings. For example: construction quality, plan and vertical irregularities, number of floors, foundations, and others. These modifiers are known as ‘‘The Behaviour Modifier Factor/The Response Modification Factor” DVm with a score symbolized as Vm. The modifying scores are attributed according to expert judgment. Thus, the total vulnerability index can be computed by adding or summing all the score modifiers.

In addition to the ‘‘Behaviour Modifier Factor”, there is another modifier called the ‘‘Regional Vulnerability Factor” DVR. This factor modifies the VI* based on the historical data and expert judgment.

- **Combined GNDT and macro-seismic approaches**

  Another type of vulnerability index is a combined approach between the two seen before. The correlation between them can be expressed in terms of defining the damage grade (mD) as a vulnerability function. To apply this operational methodology for combining these two approaches, an analytical term was offered by some researchers (Bernardini , Giovinazzi, Lagomarsino, & Parodi, 2007; Giovinazzi & Lagomarsino, 2004; Lantada , et al., 2010; Aziz, Mendes, Lourenco, & Hajisadeghi, 2014; Athmani, Gouasmia, Ferreira, Vicente, & Khemis, 2015) which correlated the seismic hazards with respect to the mean damage grade (mD). This approach composed of six grading damages (0 < mD < 5) in terms of masonry buildings and RC-buildings vulnerability. Thus, it permits to calculate the mean damage grade.

In order to correctly correlate the two approaches, it is fundamental to fasten the damage factor adopted in the GNDT (level II) approach to the degrees of physical damage characterized in the Macroseismic approach. This can be obtained after getting the mean damage grade mD for every building. At the end, the economic damage indicator was found by utilizing the relationship proposed by FEMA-NIBS (Federal Emergency Management Agency). The index of economic damage ranges from 0 (no damage) and 1 (collapse).

As noted, the values of economic indicators related to specific damage grades are different for different methodologies used. After defining the conversion of the peak ground acceleration (PGA) or (y) into the intensity scale of EMS-98, and the transformation of the economic damage index (de), into the mean damage grade, then the correlation between the vulnerability index, (Iv) in the GNDT II approach and the vulnerability index, (V) that were used in the Macro-seismic approach was possible to be derived. This correlation approach is limited in use since it is considered only for masonry structures.

According to this correlation, the vulnerability index (Iv) of the GNDT II can be calibrated into the vulnerability index (V) of the European Macro-seismic approach, allowing the computation of the mean damage grade. In addition to what is mentioned, the vulnerability index can be well-defined as a function of the vulnerability classes according to the EMS-98 scale. For example, reinforced concrete buildings are generally included between vulnerability class C, D, E and sometimes F, while masonry buildings are classified in the most vulnerability classes between A and C.

Furthermore, most of the cities present a heterogeneous mix between masonry and reinforced concrete elements. From this point of view, a correlation is derived between the vulnerability index of the GNDT II approach and the Macro-seismic approach for RC-buildings. The vulnerability index was applied to 91 existing RC-buildings in different countries, such as Japan, China, Italy, Peru, Spain, Turkey, the United States, Haiti, New Zealand, Indonesia, Mexico and Algeria (Ferreira, Vicente, Costa, 2017). After that, a new vulnerability function, named mean damage grades, was adjusted for RC-building typology that combined the macroseismic intensity (IEMS-98) and vulnerability index.

Continuous Vulnerability Curves

Continuous vulnerability functions based directly on building damage from past earthquakes were introduced slightly later than DPMs; one obstacle to their creation is that macroseismic intensity is not a continuous variable. This problem was overcome by (Spence, Corburn, & Pomonis, 1992) through the use of their Parameterless Scale of Intensity (PSI) to derive vulnerability functions based on the observed damage of buildings using the MSK damage scale. (Orsini, 1999) also used the PSI ground-motion parameter to derive vulnerability curves for dwellings in Italy. Both studies subsequently converted the PSI to PGA using empirical correlation functions, so that the input and the response were not defined using the same parameter.

(Sabetta, Goretti, & Lucantoni, 1998) used post-earthquake surveys of approximately 50.000 buildings damaged by destructive Italian earthquakes to derive vulnerability curves. The database was sorted into three structural classes and six damage levels according to the MSK macroseismic scale. A mean damage index, calculated as the weighted average of the frequencies of each damage level, was derived for each municipality where the damage occurred and each structural class. Empirical fragility curves with a binomial distribution were derived as a function of PGA, Arias Intensity, and effective peak acceleration. (Rota et al., 2006) have also used data obtained from post-earthquake damage surveys carried out in various municipalities over the past 30 years in Italy to derive typological fragility curves for typical building classes (e.g., seismically designed reinforced concrete buildings of 1-3 storeys). Observational damage probability matrices were first produced and then processed to obtain lognormal fragility curves relating the probability of reaching or exceeding a given damage state to the mean peak ground acceleration at the coordinate of the municipality where the damaged buildings were located. The PGA has been derived using the magnitude of the event and its distance based on the attenuation relation by (Sabetta & Pugliese, 1987), assuming rock site conditions.

Alternative empirical vulnerability functions have also been proposed, generally with normal or lognormal distributions, which do not use macroseismic intensity or PGA to characterise the ground motion but are related to the spectral acceleration or spectral displacement at the fundamental elastic period of vibration (Rossetto & Elnashai, 2003; cawthorn, Iemura, & Yamada, 1981; Shinozuka, et al., 1997).

The latter has been an important development because the relationship between the frequency content of ground motion and the fundamental period of vibration of the building is taken into consideration. In general, this has been found to produce vulnerability curves which show improved correlation between the ground motion input and damage.

3.2 Analytical assessment approach

The analytical procedures for determining the seismic vulnerability of structures may be intended as theoretical approaches and as opposed to empirical approach. There are several analytical methods to accurately assess the behaviour and performance of building structures during seismic movements. They include linear static, linear dynamic, nonlinear static, and nonlinear dynamics analyses.

These procedures rely on the possibility of determining the response of a particular building, representative of a typology, by using structural analysis techniques and numerical tools. This approach is particularly suitable when studying a single building or a single typology. The reliability of the results is affected by the availability of specific data that fully characterise the material and structural behaviour of the assessed typology or specific building.

The more sophisticated the structural modelling and analysis, the greater the need to verify the model and validate the input data and assumptions. It is highly recommended that advanced structural analysis is cross-checked with simpler ones, as part of the verification process.

After having reached a level of knowledge suitable for the vulnerability assessment, the appropriate analysis methodology must be decided (e.g., simplified hand calculation, elastic computer model, nonlinear hand calculation, nonlinear static procedure) and the boundary conditions must be established (e.g., restraints at foundation level). As part of the assessment, the practitioner can select the analysis methodology that most appropriately investigates the issues. However, the aim remains to find the maximum ground motion intensity that can be sustained by the building.

From the structural analyses the global seismic capacity of the building is determined. The capacity typically takes the form of lateral resistance or deformation capacity of the structure towards the life-sustaining limit state (the precise definition depends on the reference standard). It is recommended to start with simple analyses, progressing to greater sophistication only as necessary. In general, the complexity and extent of the analysis should reflect the complexity of the building.

Seismic assessment requires a clear understanding and reliable evaluation of the existing load paths, the probable inelastic deformation mechanisms, the probable "collapse mechanism", and the available ductility/displacement capacity of the structure. This relies on an understanding of the hierarchy of strength and sequence of failure of a structure during a seismic event. The comparison of capacities between various mechanisms and between connected elements (e.g., wall to foundation) generally provides an indication of the hierarchy of strength and the likely post-elastic behaviour of a building.
There are a number of analysis techniques that can be used in the seismic assessment of existing buildings to determine the distribution of actions due to lateral forces and gravity loading. The primary decision is whether to use a nonlinear analysis technique over the conventional elastic analysis that is more commonly used for designing new buildings.
The most suitable procedure depends on the circumstances, and many buildings not require – or justify – the use of lengthy and detailed analysis. However, the focus, in all cases, should be on determining the displacement of the structure and inelastic lateral support mechanisms during "severe" earthquakes. The internal actions generated, such as shear, moment and axial load, should be considered as consequences of this deformation.
Some indication for the choice may be:

- For simple systems with easily identifiable inelastic mechanisms (e.g., a timber frame structure or URM building in a region of low seismicity) a simple elastic based calculation of the capacity, using force-based assessment procedures, may yield a conservative, but adequate, result.
- The presence of a non-ductile, gravity only, load resisting system that may be susceptible to failure under significant lateral displacement will require specific consideration.
- When parallel systems of varying ductile capability are present, a displacement based seismic assessment is likely to be more appropriate to address the deformation compatibility issues.
- For complex structural systems a dynamic analysis may be necessary.

The assessment procedures can be divided into two categories, each with a corresponding selection of analysis techniques. These are:

- Elastic-based assessment procedures (force-based), which employ analysis techniques such as:
    - simplified nonlinear pushover analysis
    - equivalent static analysis (linear static)
    - modal response spectrum analysis (linear dynamic)
    - pseudo-nonlinear static pushover analysis
- Non-linear assessment procedures (displacement-based):
    - simplified non-linear pushover analysis
    - non-linear static pushover analysis
    - non-linear time history analysis (non-linear dynamic)

Force-based and displacement-based procedures involve great effort to perform and should be approached with specific objectives. Nonlinear analyses require a clear understanding of the probable inelastic behaviour and building response that will depend on both lateral forces and deformation.
Force-based and displacement-based assessments are two ways of looking at the same issue:

- In the linear/force-based approach, the behaviour of the various components is assessed by comparing the acting forces with the resistance of the structural elements. This procedure relies on an indirect assessment of the local and global ductility capacities of the system. The conventional force-based assessment procedure is typically used for the design of new buildings. In this procedure, an elastic analysis is made, with seismic loads reduced considering the assumed ductility of the system. The problem with this approach is that, for existing buildings, it is not easy to understand the non-linear behaviour of the structure. Moreover, it is even more complicated when there is a concentration of ductility demand, for example the presence of soft or weak planes or torsion potential.

- In the non-linear/displacement-based approach, the response of the building structure is considered from the outset on the basis of the structural displacements resulting from the ground shaking. These are then used to examine the effect on the structural elements, again using rules to measure the limits of integrity and performance. Displacement-based assessment procedures focus on establishing the probable displacement capacity of the primary lateral system. It utilises displacement spectra to be able to quantify the excursions in the plastic field of the elements.
  Displacement-based methods use the same methods as force-based assessment to determine the force-displacement response of the structure. However, the expected displacement demand is based on the structural characteristics (effective stiffness and equivalent viscous damping) at the assessed displacements rather than on initial elastic characteristics.
  Displacement spectra set for different levels of elastic damping or ductility are used rather than the acceleration spectra reduced for ductility that are used for force-based design.
  The displacement-based approach enables degrading strength and the influence of poor hysteretic response characteristics to be incorporated in the analysis. Similarly, the concepts can be extended to seismic retrofit design.

Elastic-based assessment procedures

In general, linear elastic analyses, including equivalent static analysis and modal response spectrum procedures, are applicable when the structure is expected to respond in an elastic manner or when the non-linear response and ductility demand is generally uniform throughout the structure.
Elastic linear analysis is likely to be the easiest to be carried out; its advantage is that practitioners are familiar and comfortable with these assumptions and the simplified analysis techniques often allow for analysis inputs to be minimised. On the other side, they must be aware of the limitations of the method; specifically, the results of linear analyses can be very misleading when applied to buildings with some of the following characteristics:

- highly irregular structural systems, either on plan/horizontal or vertical irregularity
- displacement incompatibility and mixed ductility responses (e.g., ductile steel frames in parallel with unreinforced masonry)
- a complex sequence of failure mechanisms and inability of the structure to redistribute the lateral loads without compromising the gravity load path (e.g., premature shear failure of coupling beams which leads to softening of the coupled wall system, so the overall building has higher lateral displacement demand).

The effect of these characteristics may be to concentrate ductility demands to a greater extent than assumed when setting a global ductility factor. As a result, the ductility demands in some parts of the building may exceed the hypothesis made.
The analysis will need to consider the likely impacts of plan eccentricities (mass, stiffness and/or strength) and the ability of the floors to resist and distribute the resulting actions.
Linear static and dynamic analysis techniques are likely to be sufficient for most buildings. It is to consider that for some complex circumstances, where even explicit non-linear analysis is unable to predict the behaviour

well, specific post-processing checks are required to complement the analysis techniques used (e.g. torsional instability of irregular and ductile systems).

Elastic procedures include:

- **Equivalent static method**: the lateral seismic forces are assumed to be distributed over the building height; the corresponding internal forces and building displacements are determined using a linear elastic static analysis.
- **Modal response spectrum analysis**: it is a linear dynamic analysis and is commonly used for new building design. This technique is appropriate for structures that are expected to respond elastically to the input seismic action. In addition, it is also suited for structures with well-defined and distributed plastic mechanisms, such as ductile frames, or for assessing recently designed structures (i.e., that meet capacity design or other modern seismic design requirements). It is generally only in such circumstances that an assumed initial level of global ductility will be able to be relied on to limit element/member ductilities to the required limits.

  It is generally not appropriate for mixed-ductility systems. However, it can be a useful method to complement nonlinear static pushover analysis as it enables some consideration of higher mode effects.
- **Pseudo-nonlinear static pushover analysis**: it is a technique in which a non-linear static pushover analysis is completed using a series of progressive elastic analyses. Using this technique, the equivalent static earthquake forces are increased from zero until the first plastic hinge forms. The lateral seismic force corresponding to the development of the first plastic hinge gives a lower bound to the probable lateral force capacity of the structure. This lower bound estimate will always be less than, or equal, to the actual lateral force capacity. In reality, moment redistribution will permit higher lateral seismic forces to be resisted while further plastic hinges form.

  The lateral load and displacement at the point of the first plastic hinge formation is recorded and plotted on the pushover capacity curve.

  The elastic analysis model is updated by releasing the member constraint at the point of the first hinge formation (e.g., the end of the beam or column) and by assigning an external moment (equivalent to the overstrength flexural capacity of the hinge). This will allow any additional moment to redistribute and the overall building softens. The elastic analysis is then re-run with increased force or displacement vectors until the formation of the next plastic hinge.

  This sequential analysis is continued until a significant life safety hazard is identified. This marks the end of the pseudo-nonlinear static pushover analysis.

  This analysis technique does not automatically track the actual ductility demand at individual hinges and assumes that all hinges can sustain some level of ductility. If the hinge is non-ductile in nature (e.g., a shear mechanism on coupling beams) the practitioner can elect to release the member constraints without assigning any external moment. This is valid as long as the gravity load carrying capacity is not compromised by the local inelastic mechanism.

Non-linear assessment procedures

Nonlinear structural analysis models can vary significantly depending on several factors that can be controlled (the objective of the analysis, outputs required, the level of structural non-linearity that is modelled, the level of resources available, and the simplification adopted), and that cannot be controlled (such as the ability of available analytical models to capture specific mechanisms).

A non-linear analysis technique is appropriate for existing buildings and when high levels of non-linear behaviour are anticipated. If non-linear pushover analyses are used, the practitioner should include appropriate allowances in the analysis for anticipated cyclic strength and stiffness degradation.
Non-linear time history analyses, which are dynamic analyses, should be used with care. They require specific inputs to account explicitly for such factors as cyclic strength, stiffness degradation, higher modes, and inelastic dynamic behaviour (e.g., torsion). They are very complex and their results can be very sensitive to the input parameters, which may be associated with significant variability including within the modelling approach, such as uncertainties in input ground motions, input hysteresis models, etc.
To precisely assess the seismic demands of structures, the nonlinear analysis is the method that is usually required to be used. Generally, it can be categorized into two groups:

- **Non-Linear Static or Pushover Analysis** (NLSA/POA): in the earthquake engineering field, the non-linear static analysis method has become very popular due to its simplicity. It becomes an active engineering tool for estimating the structural safety against earthquake struck-induced collapse.
  The non-linear static analysis refers to the pushover analysis that will result in a curve identified as ‘‘Capacity Curve”. The ultimate goal of this approach is to obtain the structure’s dynamic properties such as stiffness, resistance, and ductility under seismic loading.
  In non-linear static analysis (POA), the model of the structure will consider the non-linear force and displacement behaviour of its structural elements explicitly. After that, a relationship would be developed between base shear and displacement via exposing the structure to lateral forces monotonically increasing until the displacement of the model exceeded or reached the allowable displacement that described a predefined structural damage. As a definition, the allowable displacement is known as the target displacement. A global failure could happen when the slope of the curve becomes negative (but this consideration depends on the limits given by the laws of each country, in Italy, for example, the indications are different for steel and concrete structures from those of masonry buildings).
  From this method, the in-elastic response behaviour is determined considering that of an equivalent single degree of freedom (SDOF). This implies the need to transform the starting system, multi-degree of freedom (MDOF), into a simplified one, that limits the applicability of this approach.
  Some similar but modified procedures are: Modal Pushover Analysis (MPA) and Modified Modal Pushover Analysis (MMPA), Adaptive Modal Pushover Analysis (AMPA), Consecutive Modal Pushover (CMP) and Modified Consecutive Modal Pushover (MCMP), Extended N2 procedure, the Envelope-based Pushover procedure, and Improved Modal Pushover Analysis (IMPA) (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020).
  It is generally applicable for the assessment of low to medium rise regular buildings, where the response is dominated by the fundamental (first) mode of vibration. It is less suitable for taller, slender or irregular buildings, where multiple vibration modes affect the behaviour. It is recommended that elastic modal response spectrum analysis is carried out to complete the analysis if dynamic response and higher modes are considered to be significant.
  When using the pushover procedure, the lateral seismic forces acting on the frame are gradually increased until the formation of a mechanism. The behaviour of the structure is in the elastic range until the first plastic hinge forms and then the post-elastic deformations at the plastic hinges need to be taken into account. The number of plastic hinges forming increases with an increase in lateral force until a mechanism develops, giving the probable lateral force capacity.

- **Non-Linear time history analysis (NLTHA) - incremental dynamic analysis (IDA):** the NLTHA is the most exact and precise method to assess the seismic performance of a structure/infrastructure. Recently, the computational methods were in rapid development, and the incremental dynamic analysis (IDA), as an improved and extended version of NLTHA methodology, has become a powerful tool in evaluating the dynamic behaviour of the structures subjected to earthquake motions.
  The main advantages of this method are the capacity to model wide diversity of non-linear material behaviour, irregularity in structures with geometric non-linearity, pounding buildings behaviour, and higher mode effects in tall buildings that can be done precisely only with the non-linear dynamic procedure. However, this type of analysis also has disadvantages such as: it needs a complex platform to create the analytical model, consuming time to accomplish the analysis, lack of supercomputers readily to do the analysis, and a large number of ground motions are necessary to perform the analysis.

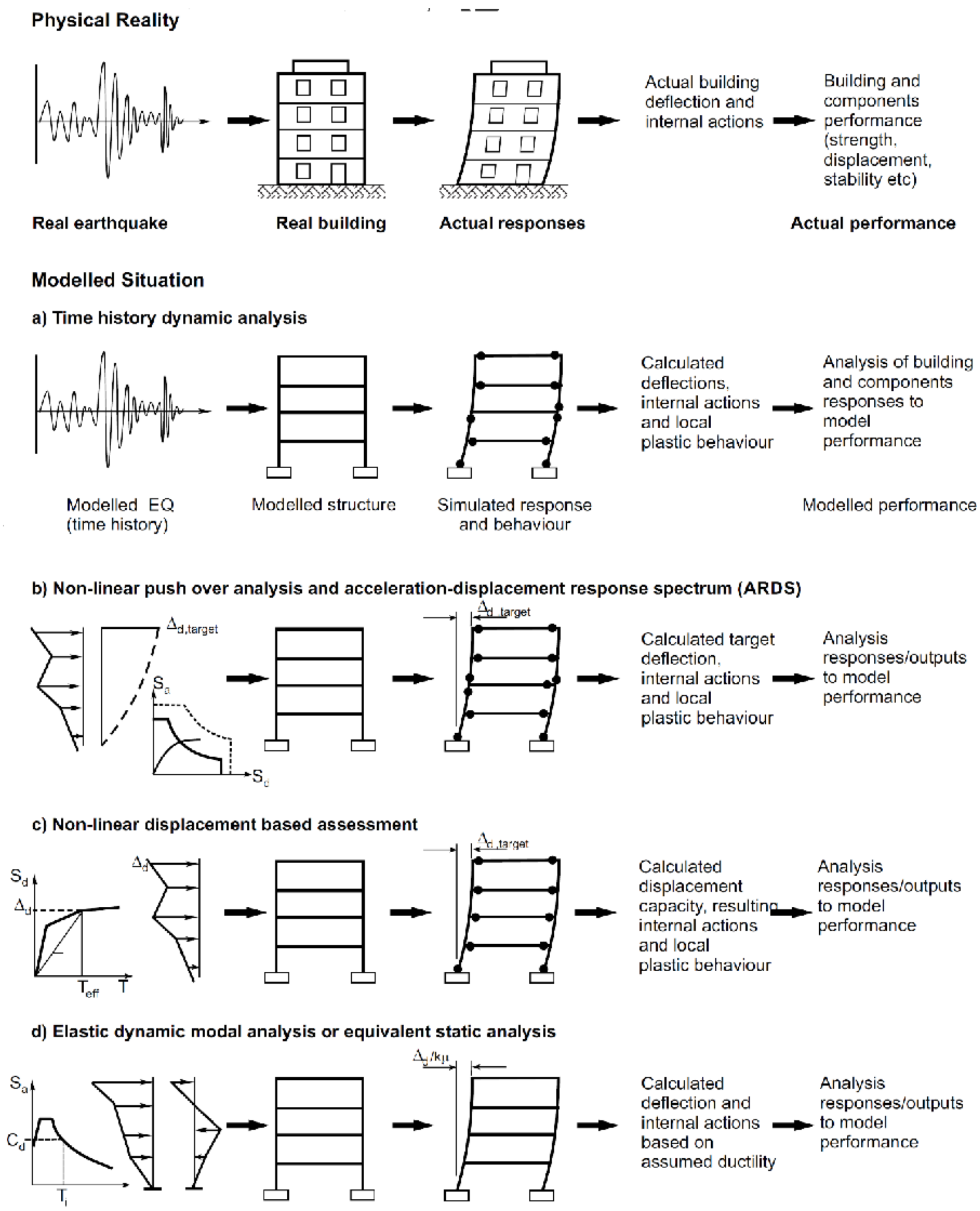

Figure 6 – Real and modelled responses of buildings to earthquakes (NZSEE, Part C2, 2017)

Method	Advantages	Disadvantages
Empirical	Observational damage during the event which shows realistic vulnerabilities.	Missing data or lack of data, Not clear vision to investigate the damages, not accurate, and mainly depend on expert decisions with different opinions.
Analytical	The most accurate method, all type of uncertainties can be considered	Time-consuming, very sensitive to modeling and analysis approach, and computational inefficient

Figure 7 – Advantages and disadvantages of the empirical and analytical methods in developing vulnerability curves (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020)

Analytically-Derived Vulnerability Curves and DPMs

Although vulnerability curves and damage probability matrices have traditionally been derived using observed damage data, recent proposals have used computational analyses to overcome some of the drawbacks of the methods highlighted in the previous section.

(Singhal & Kiremidjian, 1998) developed fragility (or vulnerability) curves and damage probability matrices for three categories of reinforced concrete frame structures using Monte Carlo simulation. The probabilities of structural damage were determined using non-linear dynamic analysis with an ensemble of ground motions. For the DPMs, Modified Mercalli Intensity was used as the ground-motion parameter, whilst spectral acceleration was used to generate fragility functions.

The major components of the methodology are:

- characterisation of the structure when subjected to dynamic loads;
- characterisation of the potential ground motions
- quantification of the structural response taking into account the variability of the ground motion and the uncertainty of the structural response.

Non-linear dynamic analyses were performed using a set of time-histories, corresponding to a given level of ground motion, for many buildings with random structural characteristics. The output of each non-linear analysis was used to calculate a global damage index (related to a particular damage state). The statistical analysis of the damage indices led to the evaluation of the probabilities of different damage states and then the fragility functions and DPMs were evaluated.

The analytical vulnerability curves produced by (Singhal & Kiremidjian, 1998), for low-rise frames, were subsequently updated on the basis of the observational data obtained from a survey of 84 buildings damaged by the 1994 Northridge earthquake. It was used a weighting system to take into account the reliability of different data sources (Singhal & Kiremidjian, 1998).

(Masi, 2003) employed a similar procedure to characterise the seismic vulnerability of different types of reinforced concrete frames that were designed for vertical loads only. The structural models employed in this study were representative of the buildings designed and constructed in Italy over the past 30 years. A simulated project of the structures was performed with reference to design codes, available handbooks and known practice at the time of construction. The seismic response of the prototype structures, subjected to ground motions of various levels of intensity, was estimated through non-linear dynamic analyses with artificial and natural accelerograms, while the vulnerability was characterised through the use of the European Macroseismic Scale (EMS98).

(Rossetto & Elnashai, 2005) used adaptive pushover curves to evaluate some European buildings by applying the capacity spectrum methodology to obtain the performance point, which was then correlated to a damage state through a damage scale calibrated to experimental data (Rossetto & Elnashai, 2003). This procedure was repeated using the acceleration-displacement spectra of many ground-motion records. In this way, the variability in the structural characteristics of the buildings was modelled using a response surface method, thus leading to the derivation of analytical displacement-based vulnerability curves.
(Dumova-Jovanoska, 2004), instead, produced vulnerability curves/damage probability matrices for reinforced concrete buildings built in the Skopje region. These damage-intensity relationships, produced by seismic events, were derived by analytically modelling the representative RC buildings and by running the dynamic non-linear analysis with a set of 240 earthquake records. The degree of damage to the structures was measured using the damage index and corresponding individual discrete damage states. A normal probabilistic distribution was assumed for the probability of occurrence of damage.
One of the main disadvantages of deriving analytical vulnerability curves is that the procedure is extremely computationally and time consuming; therefore, the curves cannot be easily developed for different areas or countries with diverse building characteristics. However, this method has frequently been used to support, rather than to replace, the empirical DPMs and vulnerability curves based on the observational damage data, leading to what are known as hybrid methods.

Collapse Mechanism-Based Methods

Many recent proposals for analytical vulnerability assessment methods use collapse multipliers calculated from mechanical concepts to ascertain whether a mechanism will form and thus damage will occur; these procedures have been particularly applied to masonry buildings.
VULNUS is a method that has been proposed for the vulnerability assessment of unreinforced masonry buildings using the fuzzy-set theory and the definition of collapse multipliers (Bernardini, Gori, & Modena, 1990). A collapse multiplier for in-plane behaviour with shear failure at the ground floor is defined as the ratio of the in-plane shear strength of the system of walls to the total weight. The collapse multiplier for the out-of-plane behaviour is found from the ratio of the out-of-plane flexural strength of the most critical external wall to the total weight, evaluated by summing the resistance of the vertical and horizontal strips.
Following the calculation of the two collapse multipliers, a third index is calculated, which is the weighted sum of the scores of seven partial vulnerability factors.
Failure Mechanism Identification and Vulnerability Evaluation (FaMIVE) method (D'Ayala & Speranza, 2002) is another procedure based on collapse multipliers, which is aimed to the assessment of the vulnerability of historic buildings and town centres. The most probable collapse mechanism is found for both in-plane and out-of-plane failures by calculating the load factor, or collapse multiplier, through an equivalent static procedure. A number of possible out-of-plane collapse mechanisms are assumed, then the equivalent shear capacity is calculated for each façade wall of the building under consideration with reference to each collapse mechanism. The most likely mechanism is identified as that with the lowest capacity.
(Cosenza, Manfredi, Polese, & Verderame, 2005) presented a mechanics-based approach for the assessment of reinforced concrete buildings, which is also based on the formation of collapse mechanisms. First, the seismic capacity of a generic building model is defined, then the predefined assumed mechanisms are established and the corresponding base shear is calculated assuming a linear distribution of horizontal seismic forces. The overall seismic behaviour is represented by the base shear coefficient (i.e., base shear divided by seismic weight) and the corresponding lateral drift (i.e., roof displacement divided by building height).

The seismic capacity of building stock varies significatively from the generic building (they have different morphologic/geometric/structural configurations and material properties). Hence, many building models are generated on the basis of the most probable distribution of the structural parameters. A simulation technique is applied to calculate “probabilistic capacity curves” which express the possibility of having a capacity lower than the assigned value: this can be likened to the percentage of buildings with a value of capacity lower than a given threshold value.

A clear framework for the treatment of uncertainty in the geometric and material properties in an urban environment is considered in the method by (Cosenza, Manfredi, Polese, & Verderame, 2005), in contrast to the VULNUS and FaMIVE procedures. The main disadvantage of the procedure of (Cosenza, Manfredi, Polese, & Verderame, 2005) and also of FaMIVE, is that no clear indication is given on how the capacity is to be related to the demand to calculate the probability of exceeding given limit states. The VULNUS procedure does allow the estimation of the probability of damage, but only for one limit state, i.e., the collapse limit state. Thus, the use of these collapse-mechanism methods within a loss assessment model appears to be somewhat limited at present.

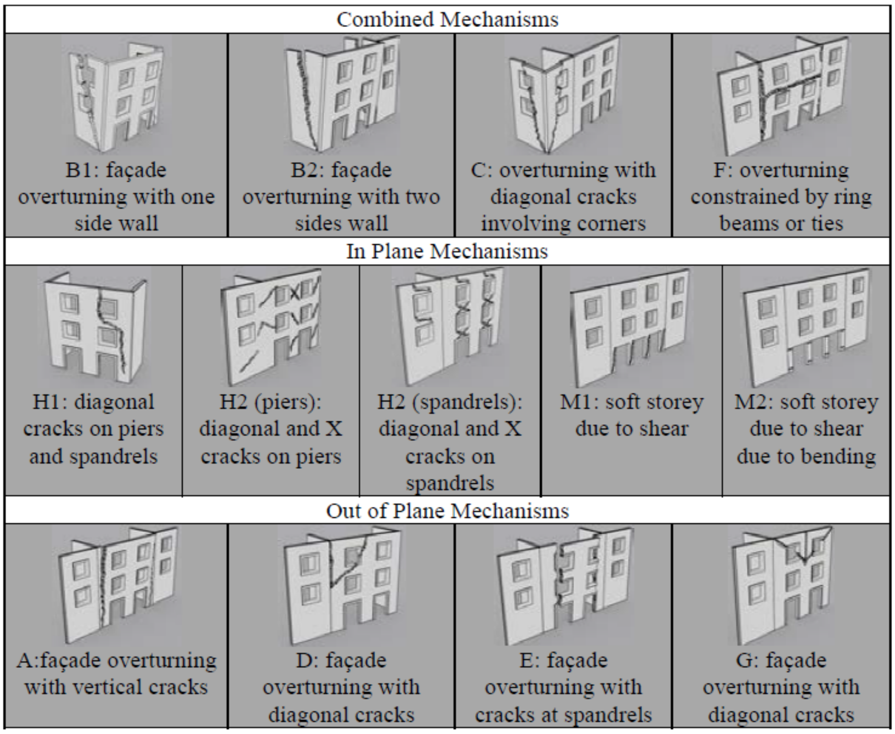

Figure 8 – Collapse mechanisms identified by FaMIVE for computing the limit lateral capacity of masonry façades (D'Ayala, Galasso, Minas, & Novelli, 2015)

Capacity Spectrum-Based Methods

HAZUS (Hazard US) is the outcome of a project conducted for the National Institute of Building Science (NIBS), in cooperation with the Federal Emergency Management Agency (FEMA), to develop a nationally applicable methodology for estimating potential losses from earthquakes (Whitman, et al., 1997). The main modules of the methodology are as follows:

- **The estimation of the Potential Earth Science Hazards (PESH):** it includes ground motion, ground failure (liquefaction, landslides and surface fault rupture) and tsunami.

- **The inventory**: that divides buildings, facilities, transportation systems, utility systems, and hazardous material facilities. The inventory is then further partitioned into pre-defined building classes with similar damage/loss characteristics.
- **Direct physical damage calculation**: it is done for each building class to find the probability of none, slight, moderate, extensive and complete structural and non-structural damage due to each type of PESH.
- **Induced physical damage determination**: taking into account events like inundation, fire, hazardous materials and debris.
- **Direct economic/social losses estimation:** due to casualties, persons rendered homeless, and economic losses, which can be directly correlated to the damage.
- **Indirect economic losses estimation:** due to downtime, that causes a chain reaction through the regional economy.

The vulnerability assessment is contained within the direct physical damage module and is based on the Capacity Spectrum Method of ATC-40. In this method, the Performance Point (PP) of a building type, in a particular ground-shaking scenario (or PESH), is found from the intersection of the acceleration-displacement spectrum, representing the ground motion, and the capacity spectrum (pushover curve), representing the horizontal displacement of the structure under increasing lateral load (Kircher, Nassar, Kustu, & Holmes, 1997). The demand spectrum is reduced for both damping and duration effects. This is applied to consider the hysteretic damping that occurs during inelastic behaviour of the structure, where the damping is based on the area enclosed by the hysteretic loop at peak response displacement and acceleration. A reduction factor is applied to the hysteretic damping as a function of shaking duration to simulate degradation (e.g., pinching) of the hysteresis loop during cyclic response.
The capacity spectrum has been developed for each building class using model designed for different levels of safety levels according to the America Standard. The PP obtained from this average structure provides the displacement value into the limit state vulnerability curves to give the probability of being in a given damage band. The vulnerability curves are lognormal function with a total logarithmic standard deviation, which combines the uncertainty in the damage state threshold, the variability in the capacity (response) properties of the model building type and the uncertainty in the response due to the spatial variability of the ground-motion demand. Since the damped demand spectrum is dependent on the building capacity, due to the non-linearity of the capacity response and thus energy dissipation, the last two components of the variability are inter-dependent and therefore need to be combined using a complex process of convolution of the probability distributions.
Once the proportion of buildings in each damage band (none, slight, moderate, extensive, and complete) has been obtained, a composite measure of damage, which aims to provide an idea of the expected overall rebuilding cost, is calculated by summing the proportions which are weighted by 0% for no damage, 2% for slight damage, 10% for moderate damage, 50% for extensive damage, and 100% for complete damage.
The HAZUS methodology was originally derived as a tool for estimating the impact of individual earthquake scenarios. It has been subsequently adapted to a full loss assessment methodology wherein the hazard from all possible earthquakes, derived from probabilistic seismic hazard assessment (PSHA), is considered. In this case, the variability in demand is already modelled in the PSHA and needs to be removed from the vulnerability curves to avoid double counting.
The use of PSHA in regional loss models, although computationally efficient, is theoretically less robust than the representation of the seismic hazard by evaluating a large number of earthquake scenarios that are compatible in magnitude, location and associated frequency of occurrence with the regional seismicity.

A potential weakness of the method is that the capacity curves and vulnerability functions published in the HAZUS manual have been derived for buildings in the US having a limited range of storey heights. This limits the application of the method to other parts of the world, requiring further research. Therefore, the capacity curves and vulnerability functions should be derived for the building stock under consideration; however, there is difficulty involved in obtaining a physically realistic representation of the inelastic response of the structure using pushover analysis.

Although this aspect can be somewhat improved using the displacement-based adaptive pushover techniques, a faithful representation of the real structural behaviour requires a great deal of information about the structure, including reinforcement details, which are difficult to be known for a large building stock.

HAZUS has been adopted all over the world for the loss assessment of urban areas. The methodology in itself is the same, but the capacity curves and fragility functions have been calibrated to the building stock under consideration. Examples include the loss assessment of Turkey carried out by (Bommer, et al., 2002), the seismic risk assessment of Oslo documented by (Molina & Lindholm, 2005), the loss estimation of Taiwan (using a modified version of HAZUS called Haz-Taiwan) as discussed in (Yeh, Jean, & loh, 2000), and the RISK_UE project for the risk assessment of 7 European towns.

The LNECloss tool is an automatic seismic scenario loss estimation methodology that uses the capacity spectrum method and has been implemented in a GIS environment (Sousa, Campos Costa, Carvalho, & Coelho, 2004).

An equivalent approach to the capacity spectrum method to evaluate the PP has been implemented in the LNECloss code. This alternative scheme starts with the definition of an input motion in terms of a power spectral density function (PSDF) and an equivalent stationary duration. The seismic input needs to be defined in terms of response spectra, associated to some damping coefficient and, thus, a linear stochastic approach has been implemented in LNECloss to accomplish this transformation. This methodology is being developed and implemented within the LESSLOSS Integrated Project (Calvi & Pinho, 2004) under the earthquake disaster scenario predictions and loss modelling for urban areas sub-project. It was applied to the city of Lisbon.

(Giovinazzi, 2005) presented a mechanical procedure for the risk assessment of both masonry and reinforced concrete frames. This uses simplified bilinear capacity spectra (capacity or 'pushover' curves converted spectral acceleration plots versus spectral displacement), which are derived using the equations and parameters available in seismic design codes.

The base shear coefficient, which can be related to the yield spectral acceleration, is generally a function of the seismic zone, soil conditions, building dynamic response, structural type, and building importance, all of which can be obtained from the codes.

The yield spectral displacement is a function of the yield spectral acceleration and the yield period of vibration; the latter is calculated using the simple formulae available in seismic design codes which usually give the period as a function of the building height. The ultimate spectral displacement is a function of the yield displacement and the building ductility capacity, which has been assumed to be 2.5 for the reinforced concrete buildings that have not been seismically designed, or can be derived as a function of the behaviour factor specified in the codes. The use of seismic design codes to calculate simplified pushover curves of the building stock is a cost-effective way to calibrate the vulnerability of buildings designed with different design codes. However, standards-based definitions of the yield period of vibration and base shear capacity of RC structures may differ significantly from the actual properties of the building stock. In many countries the existing building stock has been constructed without even conforming to any design code.

In the approach of Giovinazzi, once capacity spectra for the building classes have been derived, it is possible to use the Capacity Spectrum Method, which has been developed and employed in HAZUS. The PP of the building class is obtained by comparing the capacity spectrum with the inelastic Acceleration- Displacement

Response Spectrum (ADRS), which is produced using coded spectral shapes, anchored to the PGA obtained from the hazard analysis. Once the PP is calculated, it is inserted into the vulnerability curves to obtain the probability of exceeding pre-defined damage states.

The method proposed by Giovinazzi at this stage of the risk assessment differs from that proposed in HAZUS: the mean values for the displacement thresholds are functions of yield and ultimate displacement.

The thresholds have been based on expert judgement and have been verified on the basis of the results of pushover analyses performed on prototype buildings. To model the variability in the estimation of the damage suffered by a building (which is due to the uncertainty in the capacity curve, the damage state definition and the seismic demand spectra), rather than combining the logarithmic standard deviations assigned to each of these uncertainties (as carried out in HAZUS).

Indeed, the authors believe that forcing the damage distribution to follow a binomial distribution may lead to erroneous damage predictions in many cases, especially when non-ductile reinforced concrete frames are considered in a loss model. The observed damage distribution can be easily understood by considering the behaviour of such frames: once the first/yield limit state has been exceeded, the inadequate confinement in these buildings will ensure that they will very rapidly fail the higher limit states also due to the low levels of attainable limit state strains (and consequently low levels of ductility). For this reason, the vulnerability curves for the different damage states for these frames should be steep and close together. It is therefore expected that the damage distribution will show larger proportions at the extreme damage bands (i.e., slight and complete damage), with lower proportions being predicted for the intermediate damage states for moderate ground-motion inputs. For well-designed buildings, however, there should be a greater separation between the curves, representing the greater postyield capacity due to the higher limit state strains of adequately confined members. Thus a binomial/normal/lognormal type of damage distribution could be expected.

3.3 Hybrid methods

Hybrid damage probability matrices and vulnerability functions combine post-earthquake damage statistics with simulated, analytical damage derived from a mathematical model of the building typology under consideration. These methods can be particularly advantageous when there is not enough data about damages at certain intensity levels for the geographical area under consideration. Furthermore, the use of observational data reduces the computational effort that would be required to produce a complete set of analytical vulnerability curves of DPMs.

(Kappos, Pitilakis, & Stylianidis, 1995) have derived damage probability matrices using a hybrid procedure, in which parts of the DPMs, for each intensity level, were constructed using the available data from past earthquakes following the “Vulnerability Index Procedure”. The remaining parts of the DPMs were derived using the results of non-linear dynamic analysis of models that simulated the behaviour of each building class. The time-history records were scaled to PGA values estimated by the seismic hazard analysis; intensity and PGA were correlated using empirical relationships. A global damage index was derived to correlate the structural response from the dynamic analysis (ductility factors, displacements, etc.) with loss, expressed in terms of the cost of repair. A total of 120 analyses of typical Greek buildings designed with the 1959 code were run (6 structures, 10 ground motions and 2 intensities). Finally, the statistical damage results were combined with the observed damage from the 1978 earthquake in Thessaloniki.

(Barbat, Yépez Moya, & Canas, 1996) used the Italian “Vulnerability Index Methodology” for a hybrid vulnerability assessment of Spanish urban areas. A post-earthquake study was initially performed for two earthquakes with a maximum intensity of VII on the MSK scale. The structural and non-structural damage to masonry structures was analysed and correlated to the vulnerability and damage indices used in the Italian methodology. Statistical analyses were then performed to obtain the vulnerability function for the MSK intensity level VII. A computer simulation process was subsequently used to obtain the vulnerability functions for the other intensity levels. In this procedure, sixty hypothetical buildings, with characteristics obtained from the building heritage, were considered to simulate the behaviour of a complete urban zone. The vulnerability index was calculated for each structure; this was plotted in relation to the global damage index (based on the capacity/demand ratios of the structural elements) for the MSK intensity level VII. With this procedure a curve was obtained by regression analysis, that was then re-calibrated so as to match the field observations. The difference between the functions observed was assumed to be due to the use of the proposed weighting factors for Italian buildings, so the weighting factors were modified such that the detected and calculated vulnerability functions matched. Once the calibration with the 60 random buildings had been performed, the vulnerability functions for the other intensity levels were then produced using 2000 hypothetical constructions in conjunction with the calibrated weighting factors.

The main difficulty in the use of hybrid methods is probably related to the calibration of the analytical results, considering that the two vulnerability curves include different sources of uncertainty and, therefore, are not directly comparable. In the analytical curves the sources of uncertainty are clearly defined during the generation of the functions, while the specific sources, and levels of variability, in the empirical data are not quantifiable. The method used to calibrate the two curves should depend on whether the aim is: to include the additional uncertainty present in the empirical data which is not accounted for in the analytical data or whether the aim is in fact to improve the analytical model used to define the capacity of the building stock.

If the main goal is the last one, then, perhaps it would be preferable to calibrate the vulnerability curves considering the median (50 percentile) values, and an adaptation of the analytical model could be made such that the two median values coincide. In this way, the observational data is used to calibrate the analytical model, but analytically-derived vulnerability curves with their known and specified sources of uncertainty are used in the loss model. This can be of use when only the uncertainty related to the capacity of the building stock is required and not that related to the ground motion. For example, such curves are needed when a probabilistic seismic hazard assessment is used to define the ground motion, as this will ensure that the latter variability is not double counted.

4 Principles of expeditious methods

As highlighted in the previous chapter, seismic vulnerability can be assessed using various methods. The choice depends, first of all, on the level of in-depth study to be achieved and the pursued objective. For instance, if the goal is to quantitatively assess the building vulnerabilities, and measure its seismic performance up to the determination of the Risk Index, then it is necessary to use the methods of structural analysis, with finite elements models (FEM). For these models, to be representative of the real structure, they must be based on an adequately extensive and detailed knowledge of the building, which can only be derived from surveys, documentary research and investigations on materials. This way is obviously expensive, both economically and in terms of time, so it can be prohibitive and incompatible with the available resources. In fact, a public administration dealing with the management of dozens of strategic or important buildings cannot carry out this type of extensive analyses on all properties.

An alternative is to perform procedures that require less information on the structures and which however provide general indications. These methods, referred to as expeditious evaluation methods, are therefore less expensive and quicker to perform. This approach is particularly useful when the goal is to examine a great number of buildings to establish priorities: for example, a public administration that wants to carry out a preliminary vulnerability assessment to decide which ones should be subjected to more in-depth examinations first. Therefore, the choice of the procedure to be performed must be made primarily in relation to the purpose of the study.

All methods for assessing the seismic vulnerability are based on an explicit link between cause and effect, that is, between the magnitude of the action and the severity of the consequent damage. As already seen, there are various possible classifications of these methods; further simplifying, one type of classification is based on the output of the assessment. They are distinguished in:

- direct techniques: they provide the result in a single step, consisting in the prediction of the damage caused by the seismic event. They are the closest to the classic definitions of vulnerability.
- indirect techniques: they are divided into two steps, each of them corresponding to a result. With the first step, an appropriate vulnerability index is determined; while, with the second step, a correlation is established between earthquakes and consequent damage, according to the vulnerability index defined previously.
- conventional techniques: they are exhausted in a single step, similarly to direct techniques, but the result is a vulnerability index without an associated damage prevision. These techniques are especially useful for comparing the vulnerability of different buildings located in areas of equal seismicity.

A second classification is based on the type of measure. In this sense, we have:

- quantitative techniques: they are the most common and express the probability of damage or the equivalent deterministic relations in numerical terms (the "capacity" of the structure and the "demand" imposed on it are calculated and compared).
- qualitative techniques: they describe the vulnerability in terms of "low", "medium", "high" or similar. These techniques are usually based on direct investigations conducted by experts, and therefore have an empirical nature.

A third classification focuses on the way the building is assimilated. We have:

- typological techniques: they classify the building in a typological class, defined according to the construction technique, the materials or other similar factors. They have the advantage of being inexpensive, requiring simple field investigations and using large observed databases. On the other hand, since they do not distinguish a single building within the typological class, they cannot be compared. Their natural use is to acquire information on urban areas considered as a whole.
- mechanistic techniques: they evaluate the structure through its theoretical mechanical model and are the closest to the usual engineering approach. These techniques can allow, by making gradual refinements, from the examination on an urban scale, to results valid for single buildings.
- semeiotic techniques: they consider the building as an organism whose vulnerability can be described through the examination of the symptoms. In general, they introduce a number of vulnerability factors (such as the general organization and quality of the resistant system, the state of deterioration of the building, etc). A certain level is assigned to the building for each of the aforementioned factors: the increase in levels indicates an increase in vulnerability. These are potentially very versatile techniques, because they synthesize a large amount of information, but, at the same time, imply a certain expertise. Moreover, their reliability depends also from the rational explanation of a relationship between the levels and the expected seismic damage.

A further classification considers the prevailing source of knowledge among those used to determine vulnerability. They are distinguished:

- **empirical methods**: they are based on the statistical processing of collected data: the assessment of the expected damage for a given building type is based on the observation of the damage suffered during past seismic events. In addition, the assessment takes into account several vulnerability indicators, such as: typological, morphological elements, dimensions and materials. The nature of the action is mainly macroseismic, while the damage is either cost-based or macroseismic.
  Different empirical methods can be distinguished for the assessment of seismic vulnerability:
    - Damage Probability Matrices (DPMs);
    - Vulnerability functions;
    - Methods based on the so-called "vulnerability index";
    - Observational methods (screening methods).
- **analytical methods**: they are based on the calculation of the seismic response by means of structural mechanics: the relationships between seismic intensity and expected damage are provided by a model with direct physical meaning and the damage predictions are formulated on analytical calculations of the seismic response. The deformation and stress state corresponding to the measurement of the seismic action are expressed by the maximum ground acceleration or by analogous numerical quantities. The damage measurement is quantified by mechanical variables.
- **techniques based on the subjective judgment of experts**;
- **hybrid techniques**: which combine multiple sources.

The reliability of the observed data allows empirical methods to give a realistic indication of the expected damage, as they are applied to buildings with similar characteristics to those used for their calibration. They are particularly suitable for structures not designed with anti-seismic criteria, where the resistance of the materials is difficult to assess, but provided of numerous statistical damage data from previous seismic events suffered by buildings of the same type. The real observed data are the most realistic source of information, taking into account many characteristics inherent to buildings and seismic phenomenon (for example, structural type, soil effects, characteristics of the site, source of the earthquake and path of propagation).
Regarding the limits of these methods: it should be noted that they do not allow to consider the dynamic characteristics of buildings and do not explicitly model the different sources of uncertainty.
The collection of data on the buildings damage after a seismic event, necessary for the determination of any empirical relationship between seismic intensity and expected damage, may present some shortcomings: the non-homogeneity of the available data or errors due to inadequate compilation of post-earthquake evaluation forms. In addition, empirical methods do not allow to model the influence of improvement-adaptation solutions on vulnerability, given by an increase in the structural response.
In order for the data to be truly meaningful and realistic, they must meet certain principles. It is necessary that the set is as large as possible, to reduce the gaps and approximations in the results (the statistical relationships are only meaningful for buildings classes whose data sample is sufficiently large). Furthermore, the data must cover several structural types and derive from different seismic events. The information must be collected in a standard format, with a complete and consistent qualitative and quantitative interpretation of the damages. Combining data deriving from various seismic events, or using data from a single earthquake, are two sensitive issues.
The use of an analytical algorithm to assess structural vulnerability allows, instead, to directly consider the various characteristics of the buildings and, also, the uncertainties included in the assessment procedure. An analytical approach can include, in the vulnerability assessment, structures with different (or new) construction practices, as well as the influence of interventions on the response of existing structures. In

addition, these methods can take advantage of advances in seismic hazard assessments, such as the derivations of seismic risk maps in terms of spectral ordinates, different from macroseismic intensity.
However, analytical methods require a greater amount of detailed data and a higher computational effort than empirical methods. It should also be considered that many of the collapses observed after seismic events are due to construction errors and defects, which are not normally considered in an analytical model.

Many further classifications and considerations on the available methods could be made, but it is necessary to concentrate the study for the purposes of the ADRISEISMIC project, i.e. the expeditious assessment of portions of historic towns, challenging the current approach of the partner countries.
From the literature, it can be derived that the seismic assessment approaches have been used to estimate the structure's capacity to withstand an earthquake (pre or post- event). However, the task could be very complicated. The empirical methods such as Rapid Visual Screening (RVS) and the vulnerability index approach seem to be unreliable tools because they were based on the observed damage data which may be limited or inaccurate. In addition, they do not cover all building typologies, intensities and vulnerability parameters, thus, the outcome is very dependent on expert judgment.
Analytically, there are still a few "extraordinary issues" to be addressed with the analytical strategies, such as: the potential and the ability of the quantitative models to precisely foresee the behavioural response of the real structure and the precision in converting numerical computational models into real structural damage and vice versa. Therefore, it seems that accuracy in predicting the vulnerability level of a structure could be possible if the it is obtained by using finite element modelling and by applying the non-linear analysis tools.
Further challenges include the correlation or transformation of field damages by applying an analytical approach. This can be achieved by designing the parameters that have a direct impact on the structural behaviour or by considering the past damage observations or predicting the damaged spot in the structure. Thus, it can be done by developing an analytical vulnerability index as a measuring criterion that can classify the seismic vulnerability classes by weighting the modelling parameters of a particular building. Many researchers have dealt with this concept, since there are many parameters that influence the physical vulnerability of the structure.
Anyway, we can state that the first step in any building evaluation should be a qualitative assessment. The qualitative assessment is also a fundamental step in the case of quantitative analysis. It informs the practitioner of the state of the key elements of the building and assists in focusing the subsequent detailed assessment.
This requires consideration not only of mechanisms that may have been anticipated by the original designer, but also the combined effect of unrecognised load paths, structural incompatibilities and the impact of alterations over time. The latter may include the effects of time itself. That is, aging of the building and maintenance (or lack of it).
The assessment procedure should be determined according to a number of factors, including:

- The objectives of the study. If the main purpose is simply to provide information to establish whether a building is prone to earthquake, it may be sufficient to complete an expeditious procedure, based on relatively generic information.
- The complexity of the building. Although scale may determine the risk (as it affects the numbers of occupant), the complexity of the structural shape is a more significant factor in determining the assessment methodology.
- The degree of influence of soil conditions. This can be a significant influence, particularly when there is potential for major differential settlement, with or without liquefaction. The analysis of buildings should include appropriate allowance for soil non-linearity, foundation flexibility and possible variations (through sensitivity analysis).

Parameters Influencing the Building Response		Methods for assessing vulnerability					
		Empirical Assessmesnt		Expert-Judgment Assessment		Analytical Assessment	
		Required	Desirable	Required	Desirable	Required	Desirable
Construction System	Type of load-bearing elements	✓		✓		✓	
	Type of non-load-bearing elements		✓		✓	✓	
Dimension properties	Number of stories					✓	
	Load-bearing elements					✓	
	Non-load bearing elements					✓	
Material properties used in construction	Load-bearing elements					✓	
	Non-load bearing elements						✓
Structural detailing	Load-bearing elements					✓	
	Non-load bearing elements						✓
Age of construction		✓					
Observed damage data from prior earthquakes		✓					

Figure 9 – Parameters used in assessing the building structure's vulnerability (Moufid Kassem, Nazri, & Noroozinejad Farsangi, 2020)

Then prior starting the quantitative assessment, the results of the qualitative evaluation should be reviewed, with emphasis on what might need to be included in a detailed assessment, including consideration of:

- Are further investigations required to confirm the assumptions made in the qualitative assessment?
- What boundary conditions have been or will be assumed and how do these relate to reality?
- What foundation conditions have been assumed?

Geotechnical conditions are a key consideration for quantitative analysis, requiring a suitable degree of investigation to validate assumptions and to provide the inputs necessary for the detailed evaluation.

5 Cataloguing of the assessment methods

The development of the spreadsheets for the cataloguing of methods for the assessment of existing buildings in the historical town centres started from the understanding of the relevant characteristics for the analysis.
The in-depth study of the available thematic references and direct experiences made it possible to identify, on the one hand, the strengths and weaknesses of each method, and on the other, the compatible construction systems. In parallel to this study, the techniques that characterize the historic centres of the partner countries were identified (ref. Deliverable T2.1.2) and, among the studied and compared assessment methods, those most suitable for the existing construction techniques were selected.
The most common structural types for buildings and aggregates in historic centres have been identified as:

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

Therefore, spreadsheets were prepared to quickly and effectively identify all the parameters useful for an informed classification of the assessment methods currently used. Therefore, some of the methods that have been used in the past or that are currently used for the assessment of existing buildings under the action of the earthquake have been collected.
This organization will make it possible to prepare an outline in a second phase, so as to rapidly create a classification of assessment methods suitable for existing buildings in historical centres, referring to large portions of the urban fabric.
Since many of the studied methods can be used both on masonry buildings and reinforced concrete structures, they were considered without making a clear distinction. However, this was given as a parameter in the classification.

In each spreadsheet, all the characteristics useful for the subsequent identification of the assessment methods were stored.
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 the characteristics for their country, adding information on local assessment methods that had not already been registered.
The document is divided into three parts: the first one includes the methods intended to detect post-earthquake damage. It was decided to include these procedures too (even if they are not assessment methods) because some of these can provide interesting aspects to speed up the assessment phase, thanks to the identification of recurrent damage mechanisms. The second tab contains instead some of the methods used, or in use, for existing buildings according to the current standards. The third sheet includes some methods deriving from research activities that have been experimented but are not included in the current standards.
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.

5.1 Post-earthquake assessments

The assessment and census of post-seismic damage are carried out using well-established procedures, methodologies and tools, whose results are summarized through expeditious forms. They are compiled by practitioners from both public administrations and with specific professional skills and suitably trained for the inspection activities.
In the post-earthquake emergency, the priority is:

- to identify and classify the damage;
- to define the usability of buildings (which buildings can be used and which are a risk for the inhabitants);
- to prepare emergency measures.

These tools are therefore aimed at these purposes. However, they have also been taken in the past as a starting point for the proposal of assessment methods based on the detection of the damage on classes of buildings, following earthquakes that occurred in past years. For this reason, their classification has also been proposed.
This type of assessment focuses on verifying the load-bearing capacity of residential, commercial and industrial buildings after an earthquake, in order to ensure adequate protection for people and property in, and around, the buildings damaged by the earthquake. The goal is to assess whether a construction is habitable, with or without restrictions, or uninhabitable. Various aspects must be considered, in particular also the consequences of potential aftershocks.
The building assessment is a particular challenge because of the many characteristics associated with an earthquake:

- Large number of buildings to be assessed.
- Various types of construction and use of buildings to be assessed.
- Urgency: buildings need to be assessed as quickly as possible to ascertain the need for temporary accommodation (for example, as a benchmark, it is assumed a maximum of two hours for the evaluation of an average building, from three up to six flats).
- Lack of information and lack of resources, especially in the first days after the earthquake.
- Seismic-related hazards that pose certain risks for verifiers and that could hinder access to buildings.

Good preparation is therefore essential to perform the post-seismic assessment of buildings efficiently.

The spreadsheets want to help in the identification of all the parameters useful to propose the applicability of these methods, inferring the building characteristics in order to propose methods of preventive assessment of the damage that construction, with the same characteristics, may suffer.
The contents of these methods, in fact, allow highlighting the basic construction features, to link them to the building vulnerability and to verify the links with the damages incurred during previous earthquakes.
Knowing how they work is therefore very important.

The spreadsheet contains a series of data relating to all the assessment methods that are currently used, or that had been used, for assessing seismic vulnerability of existing buildings; they are:

- IDENTIFICATION CODE: it allows the quick identification of each assessment method
- DESCRIPTION: brief description and identification of the method
- MAIN CHARACTERISTICS: the functioning of the method is briefly described
- POSSIBILITY OF APPLICATION: type of buildings in which the method can be applied
- PROCEDURE: it briefly describes the method setting and the steps that need to be performed to conduct the assessment
- INVESTIGATED AREAS: it indicates the main parameters that the assessment estimates
- DEFINITION PERIOD: it indicates when the method was developed
- COMPILER: it indicates who is in charge of the compilation
- COMPLEXITY: it indicates whether the assessment is of low, medium or high complexity
- LIMITS: it indicates, as objectively as possible, what are the limits that the method has in terms of expeditious assessment
- ADVANTAGES: it indicates, as objectively as possible, what are the advantages that the method has in terms of expeditious assessment
- CURRENTLY USED: it indicates whether the method is currently used or not
- LINK: a link has been inserted to find documents that can be used to understand the method
- APPLICATION: it indicates where the methods have been applied
- USED METHOD: it indicates whether the methods are currently used or not

5.2 Pre-earthquake assessments

In technical terms, seismic vulnerability is represented by an indicator that relates the resistance capacity and the demand in terms of seismic resistance and / or displacement.
The procedures for assessing the seismic vulnerability can be conducted with different levels of detail and calculation complexity: from more qualitative assessments, based on the survey of the main characteristics of the building's constituent elements, to complex numerical analyses using linear and non-linear calculation methods.
The assessment of the seismic vulnerability index must consider a series of parameters, depending on the complexity of the analysis chosen:

- a knowledge investigation, through plan-altimetric and structural surveys, which defines the current state of the building including damage and deformation state;
- a historical-critical analysis, which guides the technician in reconstructing the current state of stress considering the changes that have affected the building over time;
- the mechanical characterization of materials, through investigations carried out on site or in laboratories;

- the definition of the levels of knowledge, by defining corrective coefficients of the mechanical properties that progressively decrease as the depth level of the investigations increases;
- structural analysis and determination of the vulnerability of the existing structural system;

These phases could be followed by the proposal of interventions to improve the seismic behaviour and to evaluate the optimal cost / benefit ratio.
The seismic vulnerability index is a numerical value that is used to summarize the results of the seismic assessment, at least from a numerical point of view. The indicator is given by the ratio between the resistant capacity of the building and the demand in terms of resistance (or displacement), therefore the outcome is positive if the indicator is greater than or equal to 1, negative if it is less than 1.
Also in relation to the construction type of the building, the checks to be carried out are different and the vulnerabilities can be multiple. The indicator summarizes the numerical shortcomings in a single value, which, however, is not exhaustive, since the numerical checks do not include non-structural vulnerabilities, for example the fall of chimneys.
This class of assessment methods is really varied and includes all those presented in the previous chapter 2, plus others that have not been yet fully illustrated, but which will be discussed in the following chapter 5, if proposed in the partner countries.
The classification of these assessment methods is the same as that of post-earthquake assessment methods; methods currently recognized by local technical standards have been included in this class.

The spreadsheet contains a series of data relating to all the assessment methods that are currently used, or that had been used, for assessing seismic vulnerability of existing buildings; they are:

- IDENTIFICATION CODE: it allows the quick identification of each assessment method
- DESCRIPTION: brief description and identification of the method
- MAIN CHARACTERISTICS: the functioning of the method is briefly described
- POSSIBILITY OF APPLICATION: type of buildings in which the method can be applied
- PROCEDURE: it briefly describes the method setting and the steps that need to be performed to conduct the assessment
- INVESTIGATED AREAS: it indicates the main parameters that the assessment estimates
- DEFINITION PERIOD: it indicates when the method was developed
- COMPILER: it indicates who is in charge of the compilation
- COMPLEXITY: it indicates whether the assessment is of low, medium or high complexity
- LIMITS: it indicates, as objectively as possible, what are the limits that the method has in terms of expeditious assessment
- ADVANTAGES: it indicates, as objectively as possible, what are the advantages that the method has in terms of expeditious assessment
- CURRENTLY USED: it indicates whether the method is currently used or not
- LINK: a link has been inserted to find documents that can be used to understand the method
- APPLICATION: it indicates where the methods have been applied.
- USED METHOD: it indicates whether the methods are currently used or not

5.3 Assessment from research

This class brings together empirical or analytical assessment methods that have been proposed in recent years through academic research processes, but which are currently not incorporated into local technical standards.

The analysis and assessment of the seismic vulnerability of existing buildings, especially historical ones, is an indispensable tool for assessing safety and structural capacity. In particular, also following the seismic events that hit various European areas, researchers from well-known Universities and Research Centres have directed their studies to support extensive campaigns to assess the vulnerability of buildings or aggregates of building. The classification of these assessment methods is the same carried out for the pre-earthquake and post-earthquake assessment methods.

The spreadsheet contains a series of data relating to all the assessment methods that are currently used, or that had been used, for assessing seismic vulnerability of existing buildings; they are:

- IDENTIFICATION CODE: it allows the quick identification of each assessment method
- DESCRIPTION: brief description and identification of the method
- MAIN CHARACTERISTICS: the functioning of the method is briefly described
- POSSIBILITY OF APPLICATION: type of buildings in which the method can be applied
- PROCEDURE: it briefly describes the method setting and the steps that need to be performed to conduct the assessment
- INVESTIGATED AREAS: it indicates the main parameters that the assessment estimates
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- LIMITS: it indicates, as objectively as possible, what are the limits that the method has in terms of expeditious assessment
- ADVANTAGES: it indicates, as objectively as possible, what are the advantages that the method has in terms of expeditious assessment
- CURRENTLY USED: it indicates whether the method is currently used or not
- LINK: a link has been inserted to find documents that can be used to understand the method
- APPLICATION: it indicates where the methods have been applied
- USED METHOD: it indicates whether the methods are currently used or not

6 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 June 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 assessment methods that were not already included.
The result of the data collection performed by each PP is presented here.

6.1 Italy – PP1 (UNIBO) and PP2 (IIPLE)

In the Italian territory, the assessment of the seismic vulnerability of existing buildings is a topic of particular interest, due to the presence of a vast building and monumental heritage that had been built, in general, without following the principles of seismic design due to its antiquity.
The study of this issue is important to determine the safety level of existing structures following a seismic event and to carry out scenario studies, identifying the most seismic-prone buildings and planning useful interventions to direct first aid towards the most vulnerable areas.

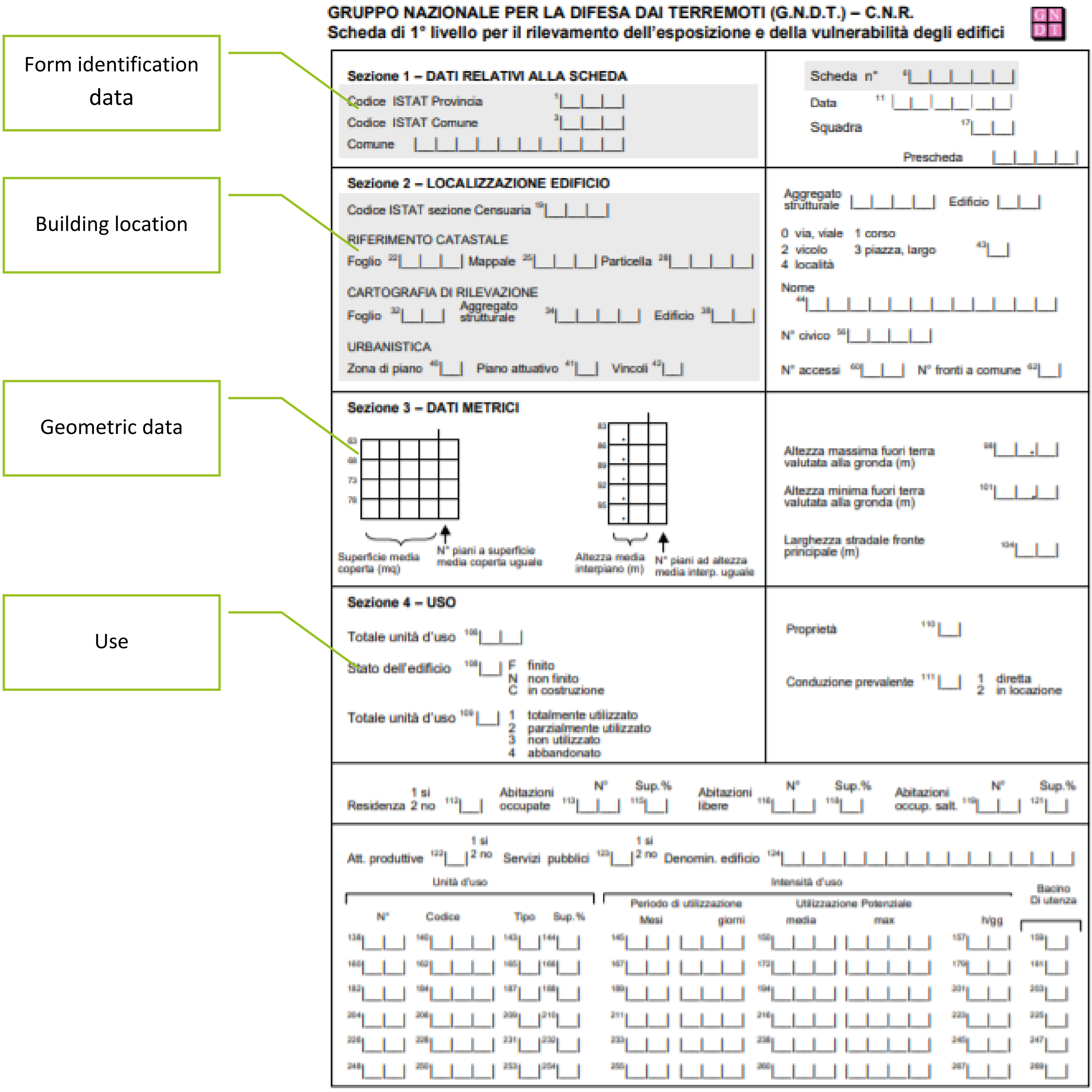
The scientific and normative evolution that has taken place in the last 20 years has certainly made it possible to design structures capable of satisfying the required limit states. However, most of the existing constructions in Italy predate this period, when the knowledge of structures, materials and actions was limited and supported by not adequate regulatory standards from a technical and institutional point of view.
Numerous Italian researchers have studied the problem of assessing structures and they have turned their attention, above all, to masonry buildings.
The methodologies available today to address the problem are linked to the historical evolution of vulnerability studies, starting with the 1980 Irpino-Lucano earthquake (Braga, Dolce, & Liberatore, 1982). Attention was initially paid to residential buildings, trying to capture the statistical aspects of the problem. In widening the attention towards specialized typologies, such as monumental, industrial and public buildings (Benedetti & Petrini, 1984), an attempt was made to grasp the specific characteristics that can most affect their seismic resistance.

Post-earthquake survey

The first methods used were those based on expert judgment. An example are the forms developed as part of the activities of the GNDT (*Gruppo Nazionale per la Difesa dai Terremoti*, that is National Group for Earthquake Defence) not with the aim of an evaluation of the usability of buildings, but to facilitate the execution of a cognitive survey of the state of damage.
The forms are classified according to their purpose:

- pre-form, for the collection of preliminary information for the vulnerability census;
- expeditious census of vulnerabilities, for masonry or reinforced concrete buildings;
- 1st / 2nd level form for detecting the exposure and vulnerability of buildings (masonry or reinforced concrete);
- 1st / 2nd level form for detecting the exposure and vulnerability of particular buildings (industrial warehouses, churches, etc.);
- 1st level form for damage detection, prompt intervention and usability for ordinary buildings in post-earthquake emergency.

The 1st level forms are generally used for statistical examinations of entire urban areas, while the 2nd level ones are more in-depth and are used to examine a smaller number of buildings.
In all the survey forms there is an introductory section aimed at identifying the building (region, province, city and related ISTAT codes, address, position on the cadastral maps) to allow easy cataloguing and therefore the creation of an accessible database.
The 1st level form for detecting the exposure and vulnerability of buildings (masonry or reinforced concrete), is generally considered as a support for post-earthquake inspection. In fact, it contains a section dedicated to the coding of the extent and level of damage and a section dedicated to the coding of the structural type.
These parts allow to provide information on the building damage and on the vulnerability factors related to the building type and therefore also to carry out censuses aimed at assessing macro-seismic intensity. Conversely, the information is not sufficient to draw precise indications of usability or emergency measures on individual buildings.
Really, the 1st level form seems to be designed for purposes completely different from emergency management: it is aimed at censuses on large populations of buildings, to obtain exposure and seismic risk statistics. In fact, it includes a section with the main metric data, a complex section relating to the use of the building and a section with the state of the finishes and plants.



GRUPPO NAZIONALE PER LA DIFESA DAI TERREMOTI (G.N.D.T.) – C.N.R.
Scheda di 1° livello per il rilevamento dell'esposizione e della vulnerabilità degli edifici

Sezione 1 – DATI RELATIVI ALLA SCHEDA
Codice ISTAT Provincia
Codice ISTAT Comune
Comune
Scheda n°
Data
Squadra
Prescheda

Sezione 2 – LOCALIZZAZIONE EDIFICIO
Codice ISTAT sezione Censuaria
RIFERIMENTO CATASTALE
Foglio | Mappale | Particella
CARTOGRAFIA DI RILEVAZIONE
Foglio | Aggregato strutturale | Edificio
URBANISTICA
Zona di piano | Piano attuativo | Vincoli
Aggregato strutturale | Edificio
0 via, viale; 1 corso; 2 vicolo; 3 piazza, largo; 4 località
Nome
N° civico
N° accessi | N° fronti a comune

Sezione 3 – DATI METRICI
Superficie media coperta (mq) | N° piani a superficie media coperta uguale
Altezza media interpiano (m) | N° piani ad altezza media interp. uguale
Altezza massima fuori terra valutata alla gronda (m)
Altezza minima fuori terra valutata alla gronda (m)
Larghezza stradale fronte principale (m)

Sezione 4 – USO
Totale unità d'uso
Stato dell'edificio: F finito; N non finito; C in costruzione
Totale unità d'uso: 1 totalmente utilizzato; 2 parzialmente utilizzato; 3 non utilizzato; 4 abbandonato
Proprietà
Conduzione prevalente: 1 diretta; 2 in locazione
Residenza 1 si 2 no | Abitazioni occupate N° Sup.% | Abitazioni libere N° Sup.% | Abitazioni occup. salt. N° Sup.%
Att. produttive 1 si 2 no | Servizi pubblici 1 si 2 no | Denomin. edificio
Unità d'uso: N° | Codice | Tipo | Sup.%
Intensità d'uso: Periodo di utilizzazione (Mesi, giorni) | Utilizzazione Potenziale (media, max) | h/gg
Bacino Di utenza

Figure 10 – 1st level GNDT form, first part

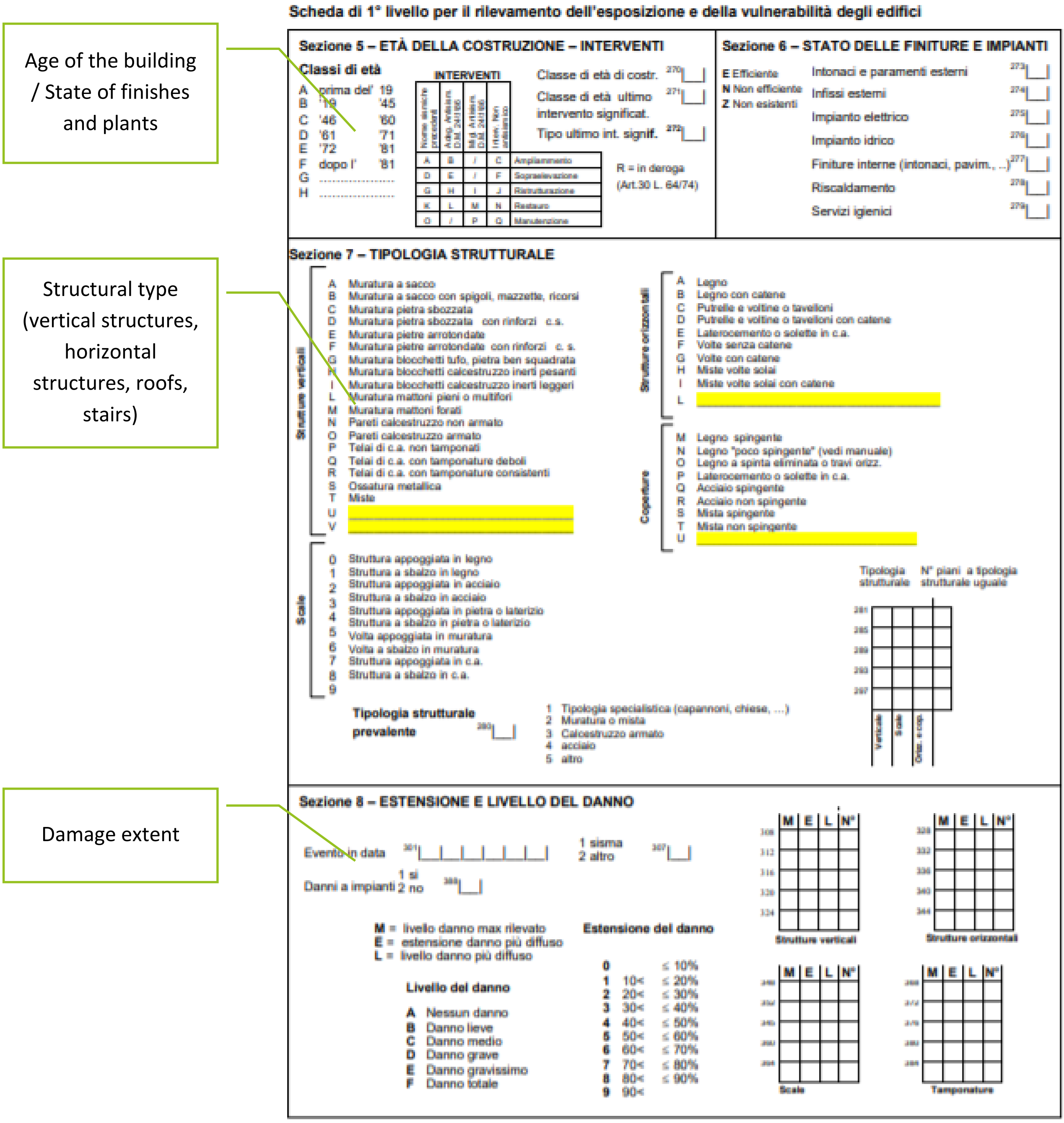


Figure 11 – 1st level GNDT form, second part

In the following years (1996-1997), the GNDT and the National Seismic Service (SSN) started a joint working group to define a new type of summary form aimed at providing indications for expeditious post-seismic safety interventions of ordinary buildings. The latter, in its preliminary version, was adopted by the Civil Protection Department during the operations following the earthquake of September 26, 1997 in Umbria and Marche. The form was updated in June 1998, supported by brief and preliminary compilation instructions.

Still used in the following years (Pollino, Patti, Frignano, Monti Tiburtini), the form then underwent some changes until the final version of November 2000 prepared by the **AeDES** (Accessibility and Damage in the Seismic Emergency), with its compilation manual.
The AeDES (Agibilità e Danno nell'Emergenza Sismica) 1st level data sheet for the detection of damage, emergency intervention and accessibility of ordinary buildings in earthquake emergencies, is aimed at detecting the typological characteristics, damage and usability of ordinary buildings in the emergency following an earthquake. The buildings are intended as structural units for housing and / or services; therefore, specialized or monumental construction (industrial warehouses, sports buildings, theatres, churches, etc.) are excluded.
The advantage of these forms is the possibility to perform an expeditious survey and a first cataloguing of the building heritage, by having typological and metric data. Combined with the damage data, this information is also useful for an initial assessment of repair and / or improvement costs, allowing the preparation of cost scenarios for different unit contributions associated with different damage thresholds. The form represents a valid aid to the usability evaluation, whose final judgment remains strictly pertinent to the survey team. In fact, it keeps track of the inspections and their outcome, tries to establish a common language in the description of the damage and vulnerability, provides a guided path that leads to the risk assessment, and therefore to the judgment of usability.
However, this approach has some limitations:

- impossibility of providing all possible types of construction elements in the form;
- difficulty in recognizing the different types;
- variability of types within the same building;
- variability of the seismic behaviour of similar types.

The compilation manual attached to the survey form provides useful information for assessing the various damage conditions of masonry buildings. They are divided as follows:

- D0: no damage - cracks due to plaster shrinkage, signs of minor damage that occurred in the past, repaired and not reactivated;
- D1: light damage - damage that does not significantly change the strength of the structure and does not affect the safety of the occupants due to the falls of non-structural elements (width <1 mm);
- D2-D3: medium / severe damage - damage that could also significantly change the strength of the structure, without approaching the limit of partial collapse of the main structural elements. Lesions up to 1 ÷ 1.5 cm for lintels; 2 mm ÷ 1 cm for shear in walls; up to 2 ÷ 5 mm for detachment of passing walls; a few cm for the extraction of the beams of the floors;
- D4-D5: very serious damage - damage that modifies the strength of the structure, bringing it close to the limit of partial or total collapse of the main structural elements. They are characterized by expulsion of structural material in significant quantities and / or localized collapses of load-bearing walls, side walls and wall edges. Facade overturning mechanism close to activation, very serious diagonal cracks, striking separation between the floor and walls, roofs and / or vaults. Total collapse of the building.

The indications of the damage levels are similar also for masonry buildings of particular types, such as churches and palaces, where it is always necessary to evaluate not only typical vulnerabilities, but also specific ones, especially when moving from an expeditious evaluation to a more detailed level analysis.

AeDES cards are currently used throughout the country for the detection of damage when a seismic event occurs. The emergency management of the seismic events that affected Central Italy starting from August

2016, required over 220,000 inspections to assess the impact and damage on buildings. These surveys were only partially carried out using the AeDES cards, as an exception derogation procedure was envisaged, with the introduction of a further simplified form ("FAST"), due to the need to shorten the times.

On the one hand, the experience gained has definitively confirmed the validity of the system based on the AeDES and Gl-AeDES forms (the latter, for buildings with large spans); on the other hand, it has confirmed the need to provide for measures to rationalise, simplify and acceleration the procedures.

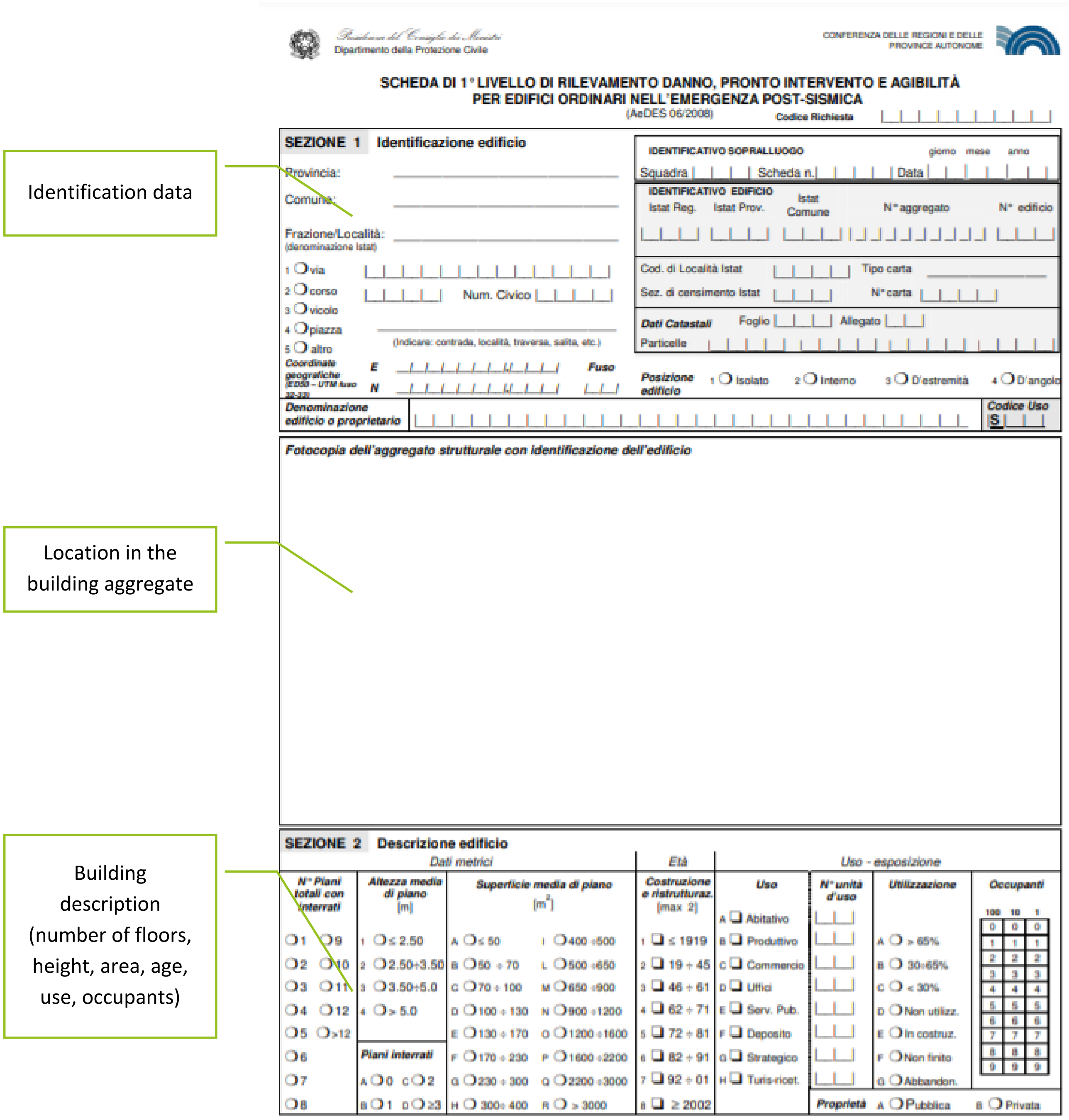


Figure 12 – AeDES form, first part

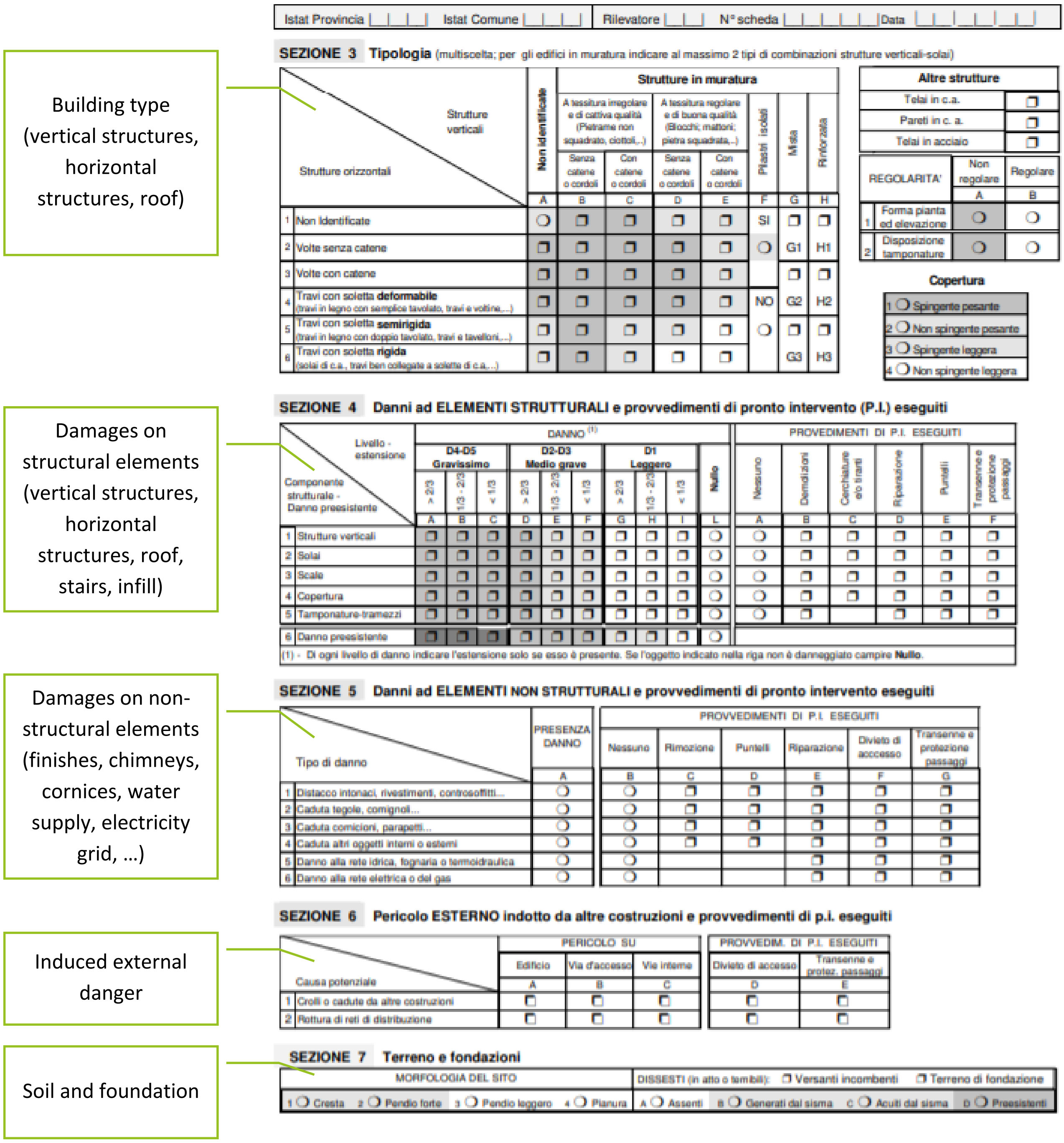
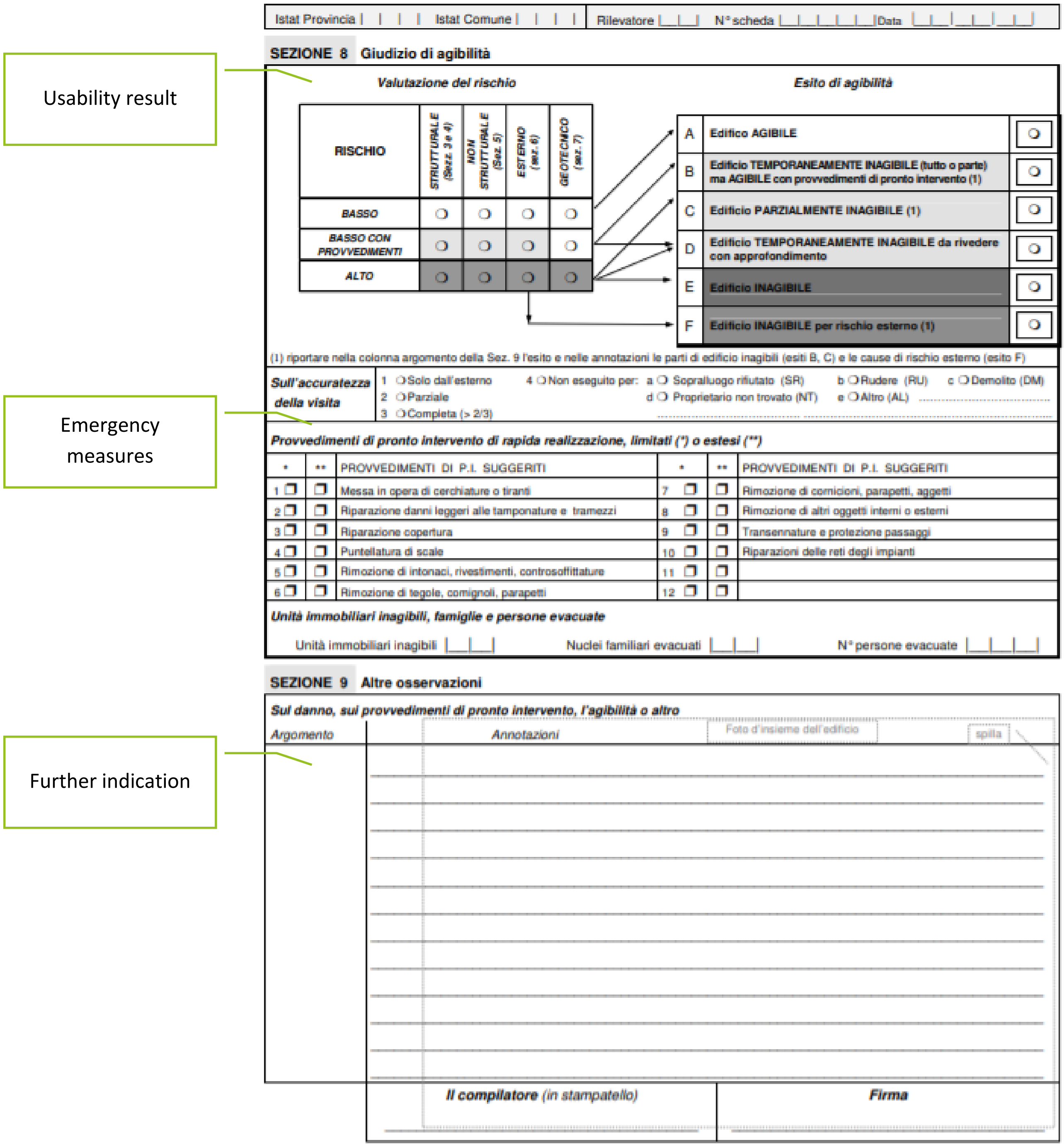


Figure 13 – AeDES form, second part



Istat Provincia | | | | Istat Comune | | | | Rilevatore |__|__| N° scheda |__|__|__|__|__| Data |__|__|__|__|__|__|

SEZIONE 8 Giudizio di agibilità

Valutazione del rischio

RISCHIO	STRUTTURALE (Sezz. 3 e 4)	NON STRUTTURALE (Sez. 5)	ESTERNO (sez. 6)	GEOTECNICO (sez. 7)
BASSO	❍	❍	❍	❍
BASSO CON PROVVEDIMENTI	❍	❍	❍	❍
ALTO	❍	❍	❍	❍

Esito di agibilità

A	Edifico AGIBILE	❍
B	Edificio TEMPORANEAMENTE INAGIBILE (tutto o parte) ma AGIBILE con provvedimenti di pronto intervento (1)	❍
C	Edificio PARZIALMENTE INAGIBILE (1)	❍
D	Edificio TEMPORANEAMENTE INAGIBILE da rivedere con approfondimento	❍
E	Edificio INAGIBILE	❍
F	Edificio INAGIBILE per rischio esterno (1)	❍

(1) riportare nella colonna argomento della Sez. 9 l'esito e nelle annotazioni le parti di edificio inagibili (esiti B, C) e le cause di rischio esterno (esito F)

Sull'accuratezza della visita: 1 ❍ Solo dall'esterno; 2 ❍ Parziale; 3 ❍ Completa (> 2/3); 4 ❍ Non eseguito per: a ❍ Sopralluogo rifiutato (SR); b ❍ Rudere (RU); c ❍ Demolito (DM); d ❍ Proprietario non trovato (NT); e ❍ Altro (AL) ....

Provvedimenti di pronto intervento di rapida realizzazione, limitati (*) o estesi (**)

*	**	PROVVEDIMENTI DI P.I. SUGGERITI	*	**	PROVVEDIMENTI DI P.I. SUGGERITI
1 ❒	❒	Messa in opera di cerchiature o tiranti	7 ❒	❒	Rimozione di cornicioni, parapetti, aggetti
2 ❒	❒	Riparazione danni leggeri alle tamponature e tramezzi	8 ❒	❒	Rimozione di altri oggetti interni o esterni
3 ❒	❒	Riparazione copertura	9 ❒	❒	Transennature e protezione passaggi
4 ❒	❒	Puntellatura di scale	10 ❒	❒	Riparazioni delle reti degli impianti
5 ❒	❒	Rimozione di intonaci, rivestimenti, controsoffittature	11 ❒	❒	
6 ❒	❒	Rimozione di tegole, comignoli, parapetti	12 ❒	❒	

Unità immobiliari inagibili, famiglie e persone evacuate

Unità immobiliari inagibili |__|__| Nuclei familiari evacuati |__|__| N° persone evacuate |__|__|__|

SEZIONE 9 Altre osservazioni

Sul danno, sui provvedimenti di pronto intervento, l'agibilità o altro

Argomento | *Annotazioni* | Foto d'insieme dell'edificio | spilla

Il compilatore (in stampatello) | *Firma*

Figure 14 – AeDES form, third part

Interesting approaches also come following seismic recent events.

The so-called **Operational Level** (OL) was introduced by Ordinance No. 19 of the 7th of April 2017 for the Abruzzo Region, following the 2016 earthquake in Central Italy. The general objective is to provide parametric reconstruction costs, but it also supplies an interesting model for calculating the vulnerability of buildings damaged by the earthquake. This procedure defines damage thresholds, vulnerability degrees, operational levels and parametric costs using diversified tables for masonry, RC and mixed structures. The damage threshold is calculated on the basis of the extent and quantity of cracks, collapses, wall displacement,

foundation lowering and the extent of detachments between orthogonal walls. The various conditions are listed in special tables; a single condition is enough to assign the corresponding damage threshold.
A further table contains the shortcomings of residential buildings with masonry structure. Each element is combined with a weight (α or β) and it is sufficient to count the value α and β to determine the vulnerability level; the presence of a deficiency of type α is sufficient to have a significant vulnerability level.
The different operating levels arise from the combination of Damage Status and Degree of Vulnerability. Each one is associated with the parametric cost and the type of reconstruction intervention, such as seismic improvement or local strengthening associated with damage repair. By crossing the vulnerability level with the damage state, the corresponding operational level is defined, which can be L1, L2, L3, L4.
The level L4 involves the execution of demolition and reconstruction or seismic adaptation. The operating levels L1, L2 and L3, likewise, require seismic improvement interventions within the safety limits established by the Ministry of Infrastructure. The level L0 contemplates only the execution of local strengthening interventions.

	Stato di danno 1		Stato di danno 2	Stato di danno 3	Stato di danno 4
Vulnerabilità Bassa	L0		L1	L2	L4
Vulnerabilità Significativa	L0		L1	L3	L4
Vulnerabilità Alta	L0		L2	L3	L4

Figure 15 – Table 5, operating levels of mainly residential buildings with masonry or RC structures

The method is interesting for the analysis of the construction vulnerabilities, which correspond to easily detectable construction deficiencies, both for masonry buildings and for RC buildings.

- *Deficiencies of mainly residential buildings with masonry structure*:
  - main deficiencies (α): single-headed load-bearing walls (or with thickness ≤ 15 cm) for more than 40% of the length of a perimeter wall; poor quality of the masonry (chaotic, rough-hewn without recourse and horizontality, absence of diatons, ...), for an amount ≥ 40% of the total resistant surface; presence of a floor (excluding the last one) with a ratio between the resistant wall surface in one direction and the covered surface of less than 4%; load-bearing brick masonry with a high percentage of voids <55% for an extension ≥ 50% of the resistant surface at that level; widespread absence, or irregularity, of connections in the edges; absence of connections of the horizontal elements to the load-bearing vertical structures; presence of thrusts on the roof for an extension greater than 30% of the covered surface; presence of masonry and / or columns directly on floors or vaults, which affects, at least, 15% of the bearing walls on the same floor.
  - secondary deficiencies (β): single-headed load-bearing walls (or with thickness ≤ 15 cm) for more than 20% and less than 40% of the length of a perimeter wall; double-faced load-bearing walls (without effective connections - diatons between the two faces), each with 1 head (or in any case with a thickness of ≤ 15 cm) for more than 40% of the length of a perimeter wall; poor quality of the masonry (chaotic, rough-hewn without recourse and horizontality,

absence of diatons, ...), for an amount <40%, but> 20% of the total resistant surface; masonry columns subjected to average compressive stresses, in the SLU combination, greater than 40% of the average compressive strength for more than 30% of the resistant elements; distance ratio between successive load-bearing walls / masonry thickness ≥ 14 (with the exception of semi-solid brick walls) or distance between successive walls > 7 meters; staggered floors with a difference in level > 1/3 inter-floor height, within the structural unit or contiguous structural units; presence of vaults or arches with non-contrasted thrust; presence of thrusts on the roof for an extension greater than 5% and less than 30% of the covered surface; serious and widespread maintenance deficiencies on structural elements.

- *Deficiencies of mainly residential buildings with RC structure*:
  - main deficiencies (α): plan irregularity (ratio between the rectangle sides circumscribing the building greater than 5); irregularities in elevation, with an increase of more than 100% of the stiffness and / or resistance when passing from a level to the next (also taking into account the stiffness offered by the infills); evident and widespread vulnerability of the infills (by position, geometry, etc.) in terms of the possibility of overturning out of plane or of shear generated on pillars; non-existent or ineffective connections, in a widespread way, between non-structural elements and the structure; presence of seismically ineffective technical joints.
  - secondary deficiencies (β): stiffness of the floors and / or their conformation (holes, etc.) which do not allow the distribution of seismic actions between the resisting elements; distance between the centre of gravity and that of the stiffnesses greater than 20% of the size of the building in that direction (also taking into account the stiffness offered by the infills); irregularities in elevation, with an increase of more than 50% of the stiffness and / or resistance passing from one level to the next (also taking into account the stiffness offered by the infills); a clear possibility of fragile breakages (squat pillars, false pillars, etc.) for more than 20% of the resistant elements at the same level; a clear possibility of fragile breakages (squat pillars, false pillars, etc.) for more than 10% of the resistant elements at the same level; serious and widespread maintenance deficiencies on structural elements; pillars subject to average compressive stresses, in the SLV combination, greater than 40% of the calculation resistance stress, for more than 30% of the resistant elements; pillars subjected to average compressive stresses, in the SLV combination, exceeding 40% of the calculation resistance stress, for more than 15% of the resistant elements.
- *Deficiencies of mainly residential buildings with mixed structures*: for mixed structures, the deficiency levels are defined by considering the prevailing construction type.

The results of the survey on the assessment methods are summarized in the following table:

DESCRIPTION	*1st level G.N.D.T FORM*	*DAMAGE DETECTION LEVEL 1, AeDES FORM*	*FORM FOR THE SURVEY OF CULTURAL HERITAGE - DAMAGE TO CHURCHES*	*Qualitative assessment form for possible local effects in strategic and monumental location sites (INGV - Gruppo Nazionale per la Difesa dai Terremoti)*	*"Livello operativo" (Operational level) according to Ordinance no. 19 of April 7, 2017*
CODE	A.1	A.2	A.3	A.4	A.5
MAIN CHARACTERISTICS	The data are intended mainly for statistical processing and, therefore, their use for analysis of individual buildings may be possible with the awareness of their level of approximation and using caution in the processing. The document is prepared for buildings with a prevalence of residential use.	It provides for the classification of the various types of construction elements.	It is used for the damage survey, but it provides for the classification of the various types damage mechanisms for churches.	Form for estimating the occurrence of local soil effects following the earthquake	Damage to buildings is classified according to levels L0, L1, L2, L3 and L4. The different operational levels arise from the combination of the Damage Status and the Degree of Vulnerability established by the Ordinance. Each operating level is associated with the parametric cost and the type of reconstruction, seismic improvement or local strengthening associated with damage repair.
POSSIBILITY OF APPLICATION	Isolated buildings and aggregates of buildings; masonry buildings, RC buildings and steel buildings	Isolated buildings. It is used for ordinary structural typologies, i.e., in masonry, reinforced concrete, steel or wood. It cannot be applied to industrial buildings, such as prefabricated sheds, churches, tanks and infrastructures.	Cultural heritage (churches)	Strategic and monumental buildings	Any kind of structure
PROCEDURE	EMPIRICAL EXPEDITIOUS METHOD - Compilation of pre-formed factsheet, on the basis of instructions indicated in the "MANUAL FOR THE DETECTION OF SEISMIC	EMPIRICAL EXPEDITIOUS METHOD - The form is completed by considering an entire 'sky-earth' building, differentiating it from the others on the basis of some criteria, such as: difference in	EMPIRICAL EXPEDITIOUS METHOD - Compilation of preformed factsheet, on the basis of the attached abacus	EMPIRICAL EXPEDITIOUS METHOD - Compilation of preformed factsheet, on the basis of the attached instructions	EMPIRICAL EXPEDITIOUS METHOD - The damage on the structural elements is estimated on the basis of the extent of the injuries, while the vulnerability is estimated on the basis of the

	VULNERABILITY OF BUILDINGS. Instructions for filling in the 1st level form"	height, age of construction, misaligned floors. It is made up of 9 sections, and it is filled in by ticking the boxes both in the case of a single choice and in the case of a multiple choice.			construction deficiencies.
INVESTIGATED AREAS	Location; metric data; use; period of construction and interventions; state of finishes and plants; structural type (18 types of vertical structures and 9 types of horizontal structures); extension and level of damage	Location; building description (number of levels; average floor height; average floor area; use; period of construction; number of users); structural type (vertical and horizontal structures); damage to structural elements and emergency measures; damage to non-structural elements and emergency measures; external danger induced by other constructions; soil and foundation; compliance with safety standards	Location of the building; use; site features; infrastructure; presence of external risks (landslides, floods, etc.); types of artistic goods; photographic documentation; general maintenance status; survey of seismic damage on the various positions and its extent; damage indicators calculated on the basis of the number of damages detected and their extent; suitability judgment; recommended interventions; estimate of the cost of the interventions	Location; morphological, lithological and hydrogeological information; surfacing lithology; hydrogeology; morphogenetic processes; photos	In addition to the estimate of the extent of the lesions, the following are assessed for the deficiencies: thin wall thicknesses; bad quality of the walls; absence of connections in the masonry; presence of masonry columns; excessive size of the rooms; ineffective connections between floors and walls; presence of arches and vaults; presence of thrusts on the roof
DEFINITION PERIOD	1980 - 2000	1997 - today	1995 - 2000	2000	2016 - 2017
COMPILER	Civil Protection Technicians	Civil Protection Technicians	Civil Protection Technicians	Civil Protection Technicians	Technician in charge
COMPLEXITY	LOW	LOW	LOW	LOW	LOW
LIMITS	Impossibility of describing all the possible types of buildings within the factsheet, even if it is a restricted environment (regional or national); difficulty in recognizing the types of construction elements, due to	It refers exclusively to the assessment of the post-seismic usability of buildings	Data exclusively quantified on the basis of the number of damages detected and their extension	Factsheet referring only to the soil, which must be integrated with other building related factsheets; very superficial and only visual analysis	The real purpose is to obtain funding for the reconstruction, it does not have a purpose of estimating vulnerability

	the variability of the types within the same building, and to the variability of the behaviour of a building due to the earthquake				
ADVANTAGES	Very quick; it allows a simple cataloguing of construction aspects	Very quick; it allows a simple cataloguing of construction aspects	Precise identification of the church damage schedule, with 18 different types of damage	It is the only one that takes the soil into consideration	The criteria used to identify the deficiencies take into account the real vulnerabilities of existing masonry buildings
CURRENTLY USED	NO	YES	YES	NO	YES
LINK	https://emidius.mi.ingv.it/GNDT2/Pubblicazioni/Lsu_96/vol_1/schede.pdf	http://www.protezionecivile.gov.it/resources/cms/documents/Scheda_AEDES.pdf	https://emidius.mi.ingv.it/GNDT2/Strumenti/Schede/Schede_vulnerabilita/Scheda_danno_chiese.pdf	https://emidius.mi.ingv.it/GNDT2/Strumenti/Schede/Scheda_effetti_locali/GNDT_Scheda_EFFETTI_LOCALI.pdf	https://sisma2016.gov.it/wp-content/uploads/2019/12/Ordinanza-ricostruzione-privata-n-19-del-7-4-20171.pdf

Pre-earthquake assessment approved by standards

According to the national standards in force, the local and global behaviour of structures are analysed through a series analysis, defined by the legislation itself, which allow to describe the seismic response of the structure. These are analysis methods based on the mechanical behaviour of the structures, as:

- Linear static analysis: it represents the simplest of the methodologies allowed by the standards, and consists in the application of a system of equivalent static forces that simulate the seismic action.
- Dynamic modal analysis: it allows to identify the vibration modes of the structure. These represent an intrinsic characteristic and are defined through the solution of the motion equations system, considered in the elastic range and without external forces (free oscillation condition). Through the definition of the vibrating modes, we can identify the way in which the structure deforms. The modes that excite the most mass are the most significant. The standards require to consider all the modes that excite at least 5% of the total mass and, in any case, a number of modes such as to excite at least 85% of the total. The response spectrum of the site defines the maximum effects that the earthquake may generate for each mode of vibration, these are combined with a system of probabilistic nature.
- Non-linear static analysis: it is one of the most popular methods for evaluating the seismic response of structures. Compared to non-linear dynamic analysis, this has a considerable application because it is easier to apply and less demanding in terms of interpreting the results. It is also called push-over. This analysis provides the maximum displacement of the control point (usually the most significant node on the top floor) that may reach the structure. The goal of the analysis is to push the construction to collapse, or until a defined deformation control parameter reaches a predefined limit. The external forcing is increased monotonously and is represented by a system of forces or displacements.
- Non-linear dynamic analysis: it is the most precise type of analysis to define the seismic response of the building. In fact, to a building is applied a natural or artificial earthquake and the evolutionary

analysis over time allows to capture all the dynamic mechanisms that are generated. Basically, during this analysis, the motion equation is integrated over time, including the effects of geometric non-linearity and mechanical non-linearity.

These methods are not included among the expeditious ones and cannot be applied on large building fabrics, as they refer to specific analyses on individual structures.
In an ideal assessment process, where it is advisable to proceed to further investigations and analysis, these constitute the last level of survey.
However, more expeditious evaluation processes have been included in the current standards, which are now intended only for specific classes of buildings.
According to the DPCM of 2011, 9th February, " *Valutazione e riduzione del rischio sismico del patrimonio culturale con riferimento alle Norme tecniche per le costruzioni di cui al decreto del Ministero delle Infrastrutture e dei trasporti del 14 gennaio 2008* (that is "Assessment and reduction of the seismic risk of cultural heritage with reference to the Technical standards for buildings referred to in the decree of the Ministry of Infrastructure and Transport of 14 January 2008") , for cultural interest assets that are exposed to seismic actions, it is appropriate to define a reference level of seismic safety, differentiated according to the characteristics of the buildings, their use and the consequences of their damage due to a seismic event.
These guidelines are intended only for structures that are part of the Italian cultural heritage. Still they proceed to the evaluation of single buildings, and not complex urban fabrics, even if the DPCM proposes different levels of assessment.
To assess the seismic safety level, the procedure starts from the formulation of the reference period VR as defined by NTC2008. For each protected building, in relation to the reference period VR and the considered limit state, a probability of exceeding PVR in the predetermined reference period is associated, so that the reference return period of the seismic action TR can be evaluated.
It is possible to define a seismic safety index, defined by the ratio between the return period of the seismic action leading to the generic limit state and the corresponding reference return period, calculated as previously reported. Particularly significant is the seismic safety index referred to the SLV: $I_{S,\,SLV} = T_{SLV} / T_{R,\,SLV}$
A value of $I_{S,\,SLV}$ greater than or equal to 1, represents a safety condition; values below 1 highlight situations that deserve attention.
The use of this index is different if an assessment of the seismic safety of the complex of protected assets present in a given territory is being carried out (LV1) or if a seismic improvement intervention is being planned on a particular building (LV2, LV3).
In the first case, it allows to define a risk ranking, useful to highlight the need for further investigations and to plan interventions for risk mitigation. In the case of planning a seismic improvement intervention (LV2, LV3), the value of the seismic safety index is not a parameter for a mandatory verification ($I_S \geq 1$), but an important quantitative element to be considered in an overall qualitative judgment, which balances the needs of philological conservation, the desire for seismic protection and the safety needs related to the use and function performed.
The guidelines illustrate, through examples, the procedures to be followed with simplified mechanical models for the assessment of the entire cultural heritage on a territorial scale. The purpose is a preventive risk assessment.

- *Palaces, villas and other structures with spine walls and intermediate floors*: this structural type refers to constructions with even complex planimetric layouts, consisting of a system of perimeter and internal load-bearing walls, arranged in different directions and of a system of intermediate floors, which may perform a connecting function. The simplified mechanical model allows a quantitative assessment of the collapse acceleration, assuming that this occurs due to the breaking of the walls in their own plane, as part of a global behaviour of the building. In the event that the building is more vulnerable to some local mechanism (due to lack of connections) the horizontal acceleration leading to the ultimate limit state of that macro-element must be evaluated and compared with that obtained by the simplified model. The shear resistance of the building is assumed to be the lowest calculated for the two main directions. The model consists in considering, for each direction, the vertical bearing wall panels and in assuming that the collapse occurs when the average tangential tension reaches an appropriate share of the shear strength of the masonry material.

- *Churches and other structures with large halls, without intermediate floors*: the systematic analysis of the damage suffered by churches during the main Italian seismic events, starting from Friuli (1976) up to the most recent ones, has shown how the seismic behaviour of them can be interpreted through architectural elements (called macro-elements). These elements are characterized by a substantially autonomous structural response (facade, hall, apse, bell tower, dome, triumphal arch, etc.). Uncertainty in the prior choice of the collapse mechanism (or mechanisms) is a critical point in the kinematic approach, but it is very limited in this case, thanks to the in-depth knowledge of the damage to the structures.
  The guidelines advise to use parameters of the damage and vulnerability survey form card that are already consolidated; the maximum ground acceleration corresponding to the different limit states can be correlated to a numerical indicator, the vulnerability index Iv, obtained through an appropriate combination of scores assigned to the various elements of vulnerability and anti-seismic protection.
  The method considers 28 damage mechanisms, associated with the different macro-elements that can be present in a church. It is necessary to detect those typological and construction details that play a fundamental role in the seismic response of the building; in particular, the construction details are considered vulnerability indicators and anti-seismic protection.
- *Towers, bell towers and other predominantly vertical structures*: this type of construction is generally distinguishable by its prevalent vertical development and constitutes a significant set of the heritage built in Italy. The seismic behaviour is dependent on some specific factors: the slenderness of the structure; the level of wall connection; the possible presence of adjacent lower structures, unable to provide a horizontal constraint; the presence at the top of slender architectural elements (spiers, bell sails, battlements, etc.) or in any case vulnerable (bell cells). Vulnerability is also influenced by other factors, for example by vibrations induced by bells or by problems in the foundation.
  The development of simplified mechanical models capable of analysing these mechanisms, in real situations, is not feasible, so it is suggested to carry out specific checks, even if approximate. For a quantitative evaluation with simplified mechanical models, it is possible to refer to the collapse by pressure-bending, or to consider the tower as a shelf, stressed by a system of horizontal forces and by its own weight, which can collapse in a generic section.
  The pressure-bending check is carried out by comparing the calculation moment with the ultimate resistant moment defined assuming the non-resistant traction and an appropriate non-linear distribution of compressions. The check must be performed, according to the two main directions of inertia of the section, at different heights, as it is not possible to previously identify the most critical section. The verification should be carried out in each of the main directions because in the direction of greater stiffness the vibration period, being shorter, could generate higher seismic demand.
- *Masonry bridges, triumphal arches and other arched structures*: arched (or vaulted) elements are widespread in the monumental heritage both as single structures (triumphal arches) and as characterizing parts of more complex buildings (masonry bridges). The collapse of arch bridges under

seismic action can be evaluated through the limit equilibrium analysis. The static approach is quite complex from an operational level, since each increase in the horizontal seismic component corresponds to a new search of the pressure curve. The kinematic approach, certainly simpler in its application, presents considerable pitfalls, especially in bridges with many arches, as the identification of the collapsing kinematic system depends on many hinges and the response can be very sensitive to their positioning, especially in the arches.

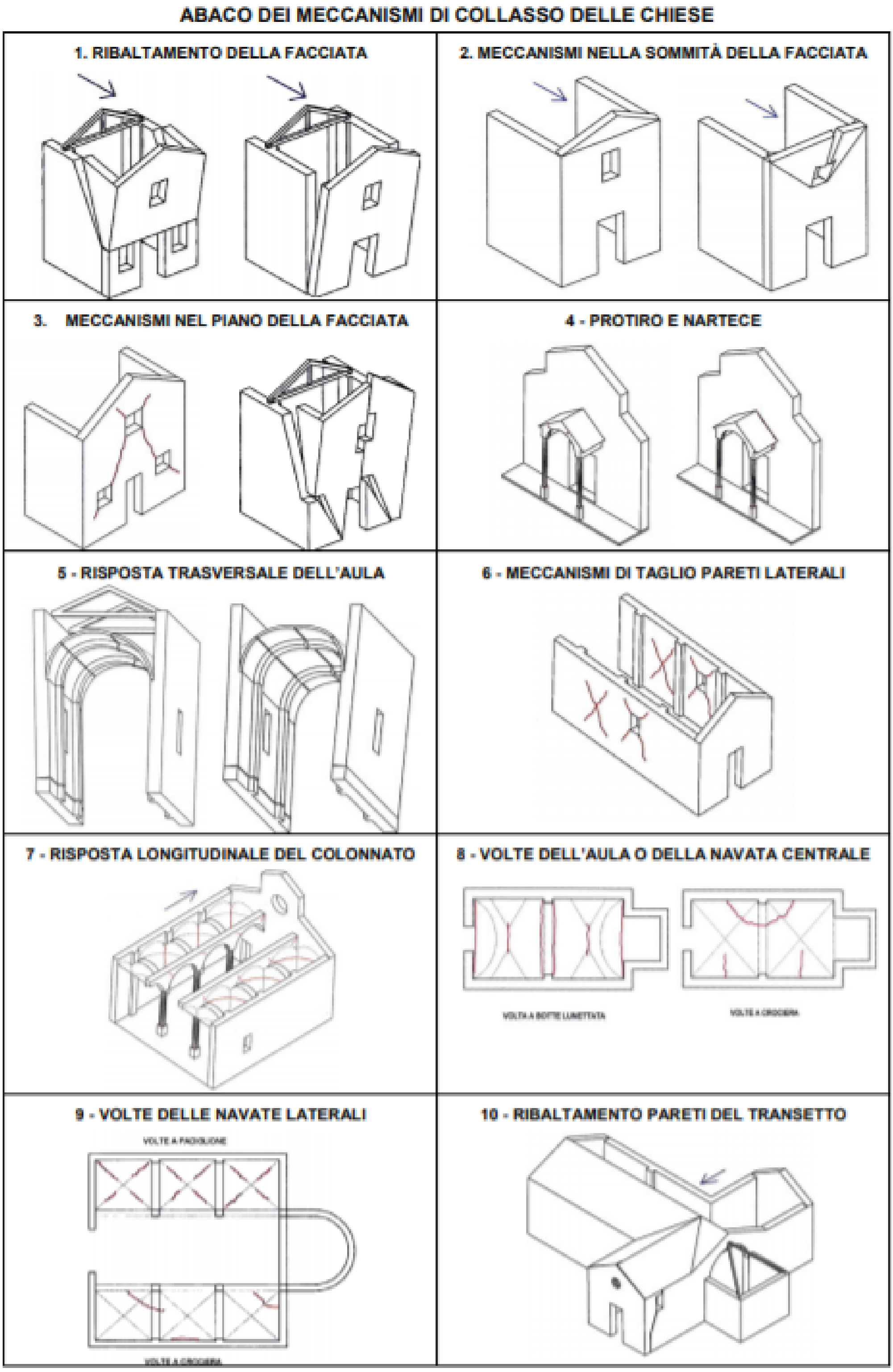


Figure 16 – Form for the of the damage survey on churches, first part

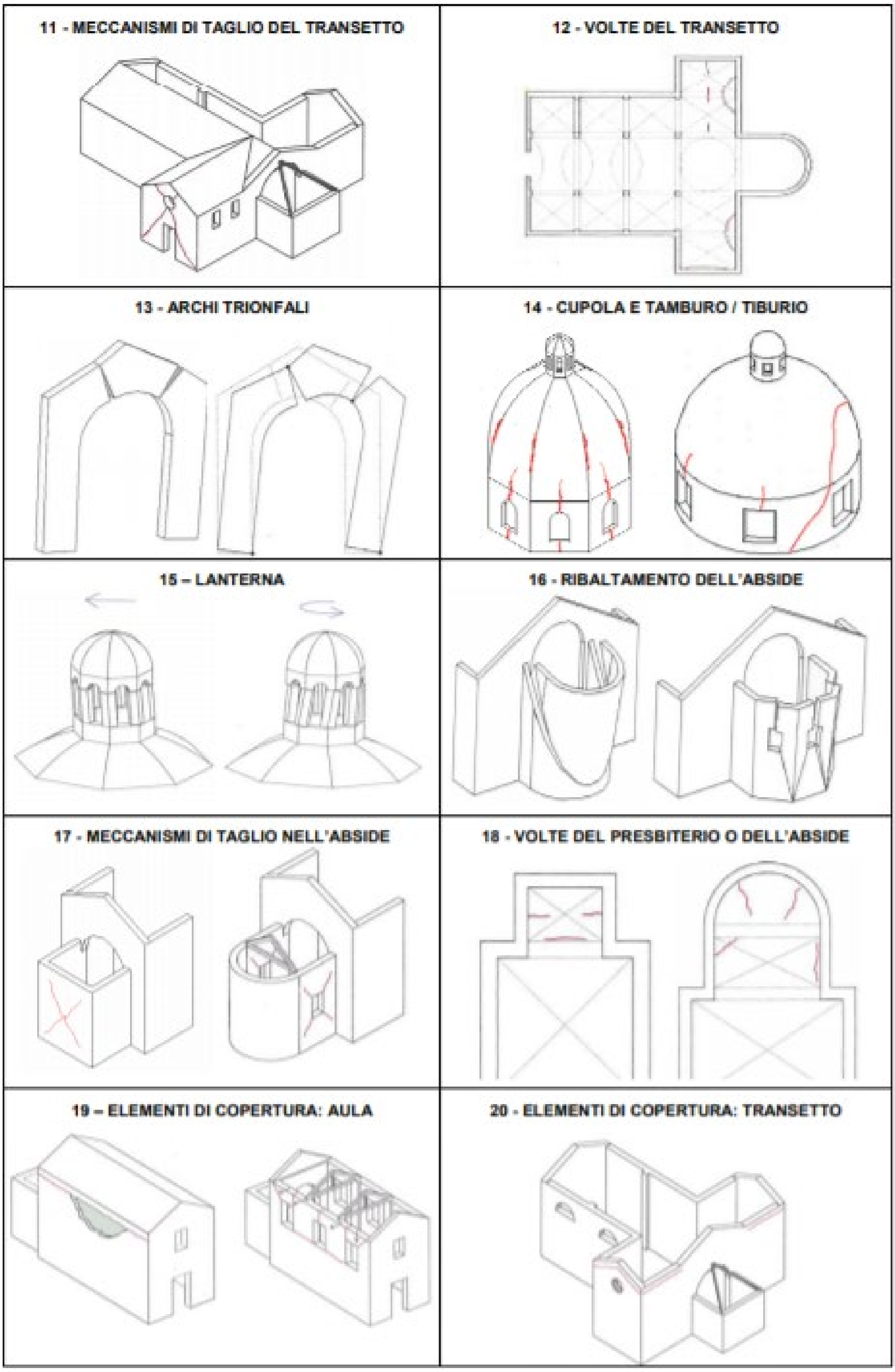


Figure 17 – Form for the of the damage survey on churches, second part

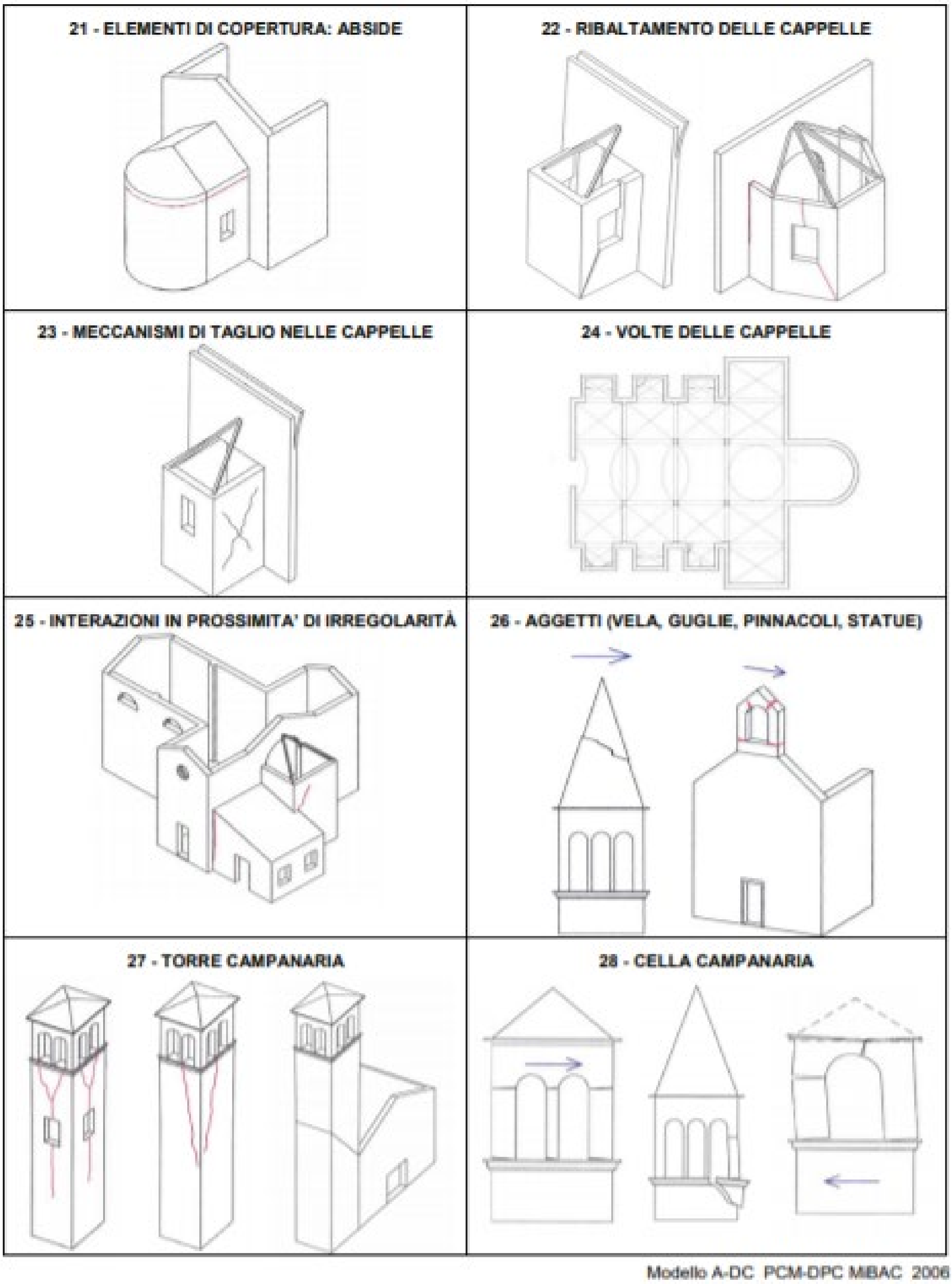
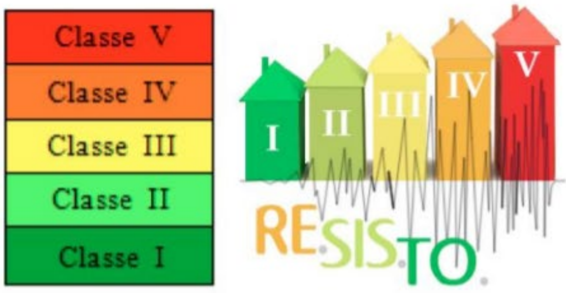


Figure 18 – Form for the of the damage survey on churches, third part

Among the procedures that are currently recognized at the regulatory level, we report the RE.SIS.TO® method, originating from academic research, but recently acquired by the municipality of Bologna. As a consequence of the obligation to perform seismic vulnerability checks of strategic buildings (schools, institutional offices, barracks, bridges, viaducts, etc ...) as required by the NTC2008, the Municipality of Bologna has adopted the method within the "Strategic Metropolitan Plan" in order to obtain a qualitative map of seismic vulnerability of existing buildings in the metropolitan area.
The preferential scope of application of this methodology is represented by buildings of significant numerical consistency to define a maximum seismic vulnerability and to monitor, in real time, the state of damage caused by the occurrence of a possible seismic event.

RE.SIS.TO® is an expeditious method for assessing the seismic vulnerability of masonry and reinforced concrete buildings as part of the ReLUIS 2010-13 Project (Chinni, Mazzotti, Savoia, & Perri, 2013). It was born following the series of laws and ordinances aimed at assessing the seismic vulnerability of strategic Italian buildings, which began with OPCM 3274 of 2003. According to them, the initial request for an in-depth analysis of this kind of buildings was subsequently flanked by the possibility of carrying out preliminary "Level 0" assessments, at least capable of providing knowledge of their general characteristics.
It is a method that allows to identify an order of priority for the interventions, whether they are more in-depth and complete investigations of seismic vulnerability or real interventions.
The seismic classification is obtained through the use of a fast method that takes advantage of the second level summary sheet introduced by the GNDT.
Through a procedure completely similar to those already mentioned, the definition of the ground acceleration that determine the attainment of the limit condition is achieved. The new aspect of this method consists in the simplified determination of the resistant shear actions.
For example, in the case of RC structures, the resistant shear is defined starting from the moment of resistance of a typical pillar, in the considered floor, which is detected in its weakest end section. This moment value, knowing the mechanical and geometric characteristics of the pillar, is obtained through a classic M-N interaction domain for an assigned normal stress value. This simplification is to be carried out for all floors of the building and in both directions.
With the expeditious method, once the value of the resistant shear has been obtained in an approximate manner, they allow to identify the weakest plane and to define the resistance of the building in terms of spectral acceleration. However, this acceleration value will be highly conventional, since it does not consider the real complexity of the construction.
The adjustment of the conventional capacity to a realistic value is carried out, in the case of a RC building, using the four parameters of the second level GNDT form. In the case of masonry buildings, ten of the eleven parameters contained in that form sheet are used. The parameters are used to obtain a reduction coefficient (C_{rid}) of the building resistance, which is determined starting from each of the parameters associated to four vulnerability classes, therefore four scores and the relative weight between the parameters. Once the vulnerability classes have been defined, the generic i-th value will correspond to a score, pi, and a weight, wi. Therefore, for each parameter the product Ki = pi ·wi is evaluated.
Finally, demand and capacity are compared as the ratio between PGAc and PGAd, whose values are generally between 0 and 1 for existing buildings. The lower this ratio, the more the building presents structural vulnerabilities in the occasion of a seismic event. To improve the immediacy of the perception of the analysis results a simplified classification called RE.SIS.TO® (Total Seismic Resistance) is introduced, where the buildings are framed within five homogeneous categories by level of seismic vulnerability, and therefore by intervention criticality.
Any local vulnerabilities / criticalities of the building that emerged from the inspections, not assessed in the previous phase, but which may represent weak points in the behaviour of the structure under, are considered in this phase. In fact, a higher class (and therefore worse) must be reassigned to the critical elements identified. This allows, even if in a simplified way, to evaluate, for example, also local phenomena such as overturning of masonry walls, lack of brackets in the pillars, serious geometric or structural irregularities, etc.



PGA_c / PGA_d	Classe di resistenza
0% - 25%	V
25% - 50%	IV
50% - 75%	III
75% - 100%	II
> 100%	I

Figure 19 – Classification with the RE.SIS.TO® method

Interesting approaches also come as tools specifically developed to incentivise private individuals to undertake seismic improvement interventions.

The tax incentives provided starting from the 2017 Budget Law, with the so-called "Sismabonus", represent a first important response to the urgent need for seismic safety of the existing heritage. In the "Guidelines for the classification of the Seismic Risk of buildings", the necessary tools are provided to be able to perform an assessment of existing buildings.

The fundamental aspect for accessing the reductions is the preliminary knowledge of the building's risk class. To this end, the standard introduces 8 risk classes, from A + to G, in a similar way to the Energy Classification, and also defines two alternative methodologies for their determination: a conventional procedure and a simplified one.

The first method is applicable to any type of construction and is based on the adoption of the usual calculation provided by the Technical Standards. The second method represents the real novelty: it allows to derive the Risk Class of a building exclusively on the basis of knowledge of its construction characteristics and, subsequently, with a simple careful observation of its state.

First of all, it is necessary to specify that the application of this simplified method is limited: in fact, it can only be used in the case of masonry buildings. However, the great advantage offered by this method is that it does not require the development of the building model and the execution of the usual mathematical analyses and experimental investigations on existing materials. This results into a simplification of the classification procedure and a consequent reduction in time and costs.

The first step for the correct application of the simplified methodology is to identify the typological classification of the building. The definitions to be used are derived from the EMS European Macroseismic Scale, in the edition released in 1998. Unlike the magnitude scales, which express the energy released, the macroseismic scales provide an estimate of the earthquake on the basis of the effects produced, i.e., in terms of levels and spread of damage. With regard to masonry buildings, the EMS-98 scale identifies 7 distinct types:

- Stone masonry without binder (dry);
- Raw earth brick masonry (adobe);
- Rough stone masonry;
- Massive stone masonry for monumental constructions;
- Brick and stone masonry;
- Brick masonry and high stiffness floors;
- Reinforced and / or confined masonry.

Each type of masonry is associated with a specific vulnerability class ranging from 1 to 6. Furthermore, oscillations around the most probable categories are possible, which may be more or less probable or even exceptional.

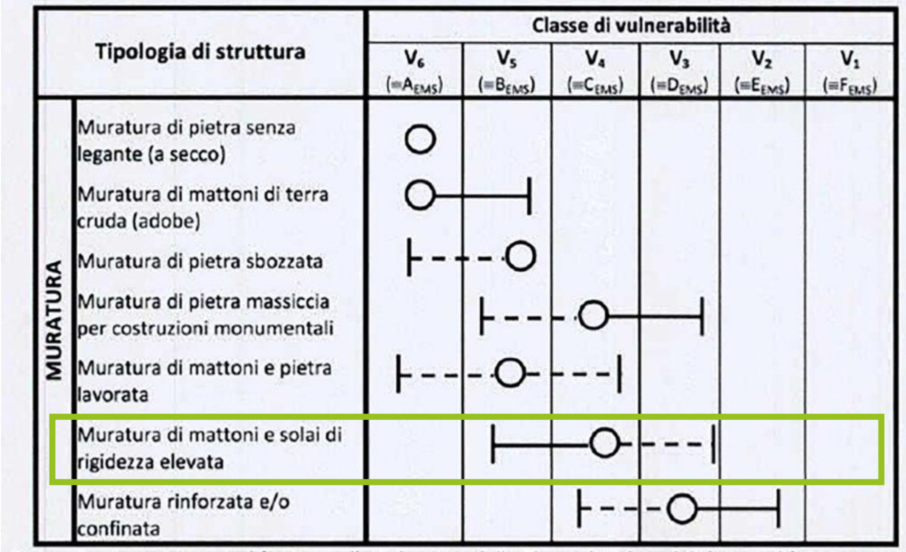


Figure 20 – Vulnerability classes for the masonry types

TIPOLOGIA STRUTTURALE	INERTI / MAGLIA MURARIA	PECULIARITÀ CARATTERISTICHE DELLA TIPOLOGIA STRUTTURALE	CLASSE MEDIA DI VULNE-RABILITÀ GLOBALE	POSSIBILI MECCANISMI LOCALI	PECULIARITÀ NEGATIVE PER LA VULNERABILITÀ LOCALE/GLOBALE	PAS-SAGGIO DI CLASSE
MURATURA	pietra grezza	• Legante di cattiva qualità e/o assente • Orizzontamenti di legno o comunque caratterizzati da scarsa rigidezza e/o resistenza nel proprio piano medio e scarsamente collegati con le pareti portanti	V_6			
	mattoni di terra cruda (adobe)	• Orizzontamenti di legno o di mattoni ma comunque caratterizzati da scarsa rigidezza e/o resistenza nel proprio piano medio e scarsamente collegati con le pareti portanti • Eventuale presenza di telai di legno	V_6			
	pietra sbozzata	• Accorgimenti per aumentare la resistenza (ad es. listature). • Orizzontamenti di legno o comunque caratterizzati da scarsa rigidezza e/o resistenza nel proprio piano medio e scarsamente collegati con le pareti portanti	V_5	Ribaltamento delle pareti Meccanismi parziali o di piano	• Scarsa qualità costruttiva • Elevato degrado e/o danneggiamento • Spinte orizzontali non contrastate • Pannelli murari male ammorsati tra loro • Orizzontamenti male ammorsati alle pareti • Aperture di elevate dimensioni intervallate da maschi di ridotte dimensioni • Presenza di numerose nicchie che riducono significativamente l'area resistente della muratura • Pareti di elevate dimensioni (larghezza e altezza) non controventate a sufficienza	da V_5 a V_6
	mattoni o pietra lavorata	• Orizzontamenti di mattoni o di legno caratterizzati da scarsa rigidezza nel proprio piano medio e scarsamente collegati con le pareti portanti	V_5			
	pietra massiccia per costruzioni monumentali	• Orizzontamenti a volta o di legno caratterizzati da scarsa rigidezza e/o resistenza nel proprio piano medio	V_4			da V_4 a V_5
	mattoni + solai d'elevata rigidezza nel proprio piano medio	• Funzionamento scatolare della costruzione • Orizzontamenti di calcestruzzo armato o comunque caratterizzati da elevata rigidezza nel proprio piano medio ben collegati alla muratura	V_4	Ribaltamento delle pareti Meccanismi parziali o di piano	• Scarsa qualità costruttiva • Elevato degrado e/o danneggiamento • Pannelli murari male ammorsati tra loro • Orizzontamenti male ammorsati alle pareti • Pannelli murari a doppio strato con camera d'aria • Assenza totale o parziale di cordoli • Aperture di elevate dimensioni intervallate da maschi di ridotte dimensioni • Presenza di numerose nicchie che riducono significativamente l'area resistente della muratura • Pareti di elevate dimensioni (larghezza e altezza) non controventate a sufficienza	da V_4 a V_5
	armata e/o confinata	• Elevata qualità delle muratura, rinforzata da reti o barre di acciaio, e/o realizzata tra travi e colonne che la racchiudono in corrispondenza di tutti e quattro i lati • Orizzontamenti di calcestruzzo armato o comunque caratterizzati da elevata rigidezza nel proprio piano medio	V_3	Meccanismi dovuti, ad esempio, ad un'errata disposizione degli elementi non strutturali che possono ridurre la duttilità globale	• Scarsa qualità costruttiva • Elevato degrado o danneggiamento • Elevata irregolarità in pianta e/o in altezza • Presenza numerosa di elementi non-strutturali che modificano negativamente il comportamento locale e/o globale • Aperture di elevanti dimensioni intervallate da maschi di ridotte dimensioni • Pareti di elevate dimensioni (larghezza e altezza) non controventate a sufficienza	da V_3 a V_4

Figure 21 – Masonry constructions: average classes of global vulnerability and class changes

For example, the table shows that, in the case of brick masonry and high stiffness floors, the most probable class is V_4 (represented by the rectangle). However, it is possible that, based on the state of the building, the class could be worse (and therefore switch to V_5, solid line) or, reality very unlikely, that the class is better (namely the V_3, dotted line).

Thanks to the previous table, it is possible to immediately identify the structural type of the building and, subsequently, the most likely vulnerability class. The latter, however, does not represent the final Risk Class

attributable to the construction. In fact, it is necessary to ascertain the presence of any negative peculiarities that may worsen the average vulnerability class. Here it is important to carefully observe the state of the building and to know its characteristics.
The Guidelines, for this purpose, provide a useful table, to define the negative peculiarities and therefore the consequent effects in terms of class transition.
It is important to note that the method allows, as a precautionary measure, the deviation from the middle class, only in pejorative terms, therefore with an increase in the vulnerability class. Once determinated, it is possible to derive the actual Risk Class by combining the two pieces of information, based on the hazard of the site where the building is located. For this purpose, it is necessary to identify the seismic zone. The following figure illustrates the correlation table.

Classe di Rischio	PAM	Zona 1	Zona 2	Zona 3	Zona 4
A+*	PAM ≤ 0,50%				$V_1 \div V_2$
A*	0,50%<PAM≤1,0%			$V_1 \div V_2$	$V_3 \div V_4$
B*	1,0%<PAM≤1,5%	V_1	$V_1 \div V_2$	V_3	V_5
C*	1,5%<PAM≤2,5%	V_2	V_3	V_4	V_6
D*	2,5%<PAM≤3,5%	V_3	V_4	$V_5 \div V_6$	
E*	3,5%<PAM≤4,5%	V_4	V_5		
F*	4,5%<PAM≤7,5%	V_5	V_6		
G*	7,5%≤PAM	V_6			

Figure 22 – PAM class according to the vulnerability class of the building and the seismic area

The PAM class represents the Expected Average Annual Loss, a fundamental parameter in the application of the conventional method, where it is obtained in an analytical way. In the case of the simplified method, the PAM class is practically fixed and pre-calculated.
In summary, the whole procedure can be summarized in three simple steps:

- Identification of the masonry type and of the medium vulnerability class;
- Search for possible negative peculiarities and consequent change of class;
- Identification of the seismic zone and, finally, of the final Risk Class.

The simplified method allows to evaluate the positive effects deriving from interventions on the building. However, it is necessary to specify which conditions are considered:

- The interventions do not involve substantial changes to the overall behaviour of the structure. They can therefore be only local strengthening interventions;
- The execution of the interventions can lead to the improvement of a single risk class.

It is clear that the simplified method has the advantage to allow a rapid allocation of the Class but, at the same time, it can evaluate only local interventions and therefore access to the lowest range of tax deductions provided for by the Sismabonus.

The results of the survey on the assessment methods are summarized in the following table:

DESCRIPTION	*Qualitative analysis with simplified mechanical models (LV1), for the "Palaces, villas and other structures with internal walls and intermediate floors" typology, according to the «Guidelines for the assessment and reduction of the seismic risk of cultural heritage (…)»*	*Qualitative analysis with simplified mechanical models (LV1), for the "Churches, places of worship and other structures with large halls, without intermediate floors" typology, according to the «Guidelines for the assessment and reduction of the seismic risk of cultural heritage (…)»*	*Mechanical methods*	*RE.SIS.TO. Project - Resistenza Sismica Totale*
CODE	B.1	B.2	B.3	B.3
MAIN CHARACTERISTICS	The seismic assessment is carried out with simplified methods capable of estimating the seismic safety index. A seismic safety index value greater than 1 indicates that the building is suitable to withstand the seismic action of the site (defined with criteria consistent with those adopted by the NTC, according to the nominal life and class of use); on the contrary if IS <1, the safety is lower.	The systematic analysis of the damage suffered by the churches during the main Italian seismic events of the last decades has shown how the seismic behaviour of this type of buildings can be interpreted through their breakdown into portions (called macro-elements), characterized by a structural response substantially independent from the church as a whole (facade, hall, apse, bell tower, dome, triumphal arch, etc.).	They predict the seismic response of the building by using an appropriate mechanical model of the whole building or of an individual structural element	RE.SIS.TO. allows to assess seismic vulnerability with a modern approach aimed at managing the existing building heritage. It is a method developed by the University of Bologna, which fulfils the requirements of the OPCM (Order of the President of the Council of Ministers) n. 3274/2003 and the subsequent calls for improvement and seismic interventions
POSSIBILITY OF APPLICATION	Protected masonry buildings with complex planimetric layout, consisting of a system of perimeter and internal load-bearing walls, arranged in different directions, and a system of intermediate floors, which often also perform a connecting function. A similar method is available for "Towers, bell towers and other structures with predominantly vertical development"	In most churches it is scarcely significant to assume a uniform and overall behaviour; therefore, a simplified mechanical model for assessing seismic safety is defined, based on a limited number of parameters. The parameters of the damage and vulnerability survey form are used (ref. class A3); the maximum ground acceleration corresponding to the different limit states can be related to a numerical indicator, the vulnerability index, which is obtained through a suitable combination of scores assigned to the different elements of vulnerability and anti-seismic protection	Any kind of structure; for aggregates of buildings, the single structural units are considered	The RE.SIS.TO. methods assess all types of existing buildings: masonry, reinforced concrete, prefabricated buildings, steel and mixed structures

PROCEDURE	ANALYTICAL CALCULATION METHOD - The simplified mechanical model allows a quantitative evaluation of the period which corresponds to the achievement of the SLV (and the relative peak acceleration on the ground), in the hypothesis that this occurs due to breakage of the walls in their own plane, in the context of an overall structure behaviour.	EMPIRICAL EXPEDITIOUS METHOD - The methodology considers 28 damage mechanisms, associated with the different macro-elements that may be present in a church. The standard lists the 28 mechanisms, together with a list of principals and vulnerability indicators in relation to the characteristic aspects of the individual church or building in the geographical area. The seismic behaviour of the entire building is represented, on a statistical basis, by a vulnerability index, variable between 0 and 1, which is defined as the weighted average of the behaviour of the different parts of the church.	Modelling of the entire building or aggregate of buildings using a finite element calculation software	This methodology intends to combine the "expert" qualitative assessments with the mechanical aspects, by filling in the existing condition survey form (Level II GNDT). The different structural types that are considered are: masonry, reinforced concrete up to 7 floors and prefabricated buildings with a deepening in the study of 5 different types of nodes
INVESTIGATED AREAS	Shear strength; q factor; total seismic mass; participant mass fraction on the first vibration mode; shear-resistant area of the walls on each floor, in the x and y directions; relationship between the resultant of the seismic forces on each floor and the total seismic force; irregularity coefficient; homogeneity of stiffness and strength of the masonry walls	Overturning of the facade; mechanisms at the top of the facade; mechanisms in the plane of the facade; transversal response of the hall; shear mechanism in the side walls; vaults of the central nave; triumphal arches; shear mechanisms in the presbytery; vaults in the presbytery or apse; mechanisms in the roof elements; bell tower; bell cell	Methods belonging to this group are the limit state method, such as the so called "kinematic" approach that identify by the lowest value of the multiplier load the weakest mechanism and, consequently, the most probable to occur	The result of the RE.SIS.TO. analysis offers customers a security index that can be used to carry out a risk assessment in workplaces or other places that may be crowded, to evaluate improvement plans and the final safety (Risk = RE.SIS.TO. Safety index * Exposure)
DEFINITION PERIOD	2008 - 2018	2008 - 2018	1993 - TODAY	2009 - 2015
COMPILER	Technician in charge	Technician in charge	Technician in charge	Technician in charge with a specific training
COMPLEXITY	MEDIUM	LOW	HIGH	MEDIUM
LIMITS	Calculation method based on the overall collapse of the building due to shear stresses, which does not directly include an assessment for local mechanisms; therefore, the verification for local mechanisms must be carried out in parallel	Data exclusively quantified on the basis of the prevision of the damages that may occur, with very limited calculations	Non-expeditious methods that require specialized analysis to reach an in-depth knowledge of the characteristics of the materials	Method requiring a specific authorization for the professional technician who uses it

ADVANTAGES	Simplified calculation method that allows to obtain a seismic safety index with a faster procedure than modelling with a finite element software	It clearly identifies all the local mechanisms that affect this type of building	Methods accepted by current legislation	It is a simplified expeditious analysis in compliance with the NTC 2018 /C8A.1.B.3 regulations; the implementation is simple and quick thanks to the online website
CURRENTLY USED	YES	YES	YES	YES
LINK	http://www.protezionecivile.gov.it/resources/cms/documents/LineeGuida_BBCC_2010_11_26_1.pdf	http://www.protezionecivile.gov.it/resources/cms/documents/LineeGuida_BBCC_2010_11_26_1.pdf	https://emidius.mi.ingv.it/GNDT2/Strumenti/Schede/Scheda_effetti_locali/GNDT_Scheda_EFFETTI_LOCALI.pdf	https://www.resistoproject.com/en/resisto/

Pre-earthquake assessment from research activities

Over the years, countless seismic vulnerability assessment methods have been proposed around the world. In this paragraph (as well as in those of the subsequent partner countries) are illustrated those that originated in the country under consideration or commonly applied here.

The 2nd level GNDT forms identify typological and construction information on each individual building, allowing the quantification of the "Iv" Vulnerability Index (0 <Iv <1). The compilation of this form requires the prior filling in of the 1st level form. The form is aimed at preventive analyses of seismic vulnerability, for example to support cost/benefit assessments of systematic building improvement works.
The 2nd level form defines several parameters (11 in the case of masonry buildings and 4 for reinforced concrete buildings) that are associated with a quality index and a class, corresponding to score and a weight. The maximum achievable vulnerability, in the most unfavourable hypotheses, is 393.75 (Iv = 1) while the minimum is 0 (Iv = 0).
Within each parameter, the real situations are grouped into four classes. The first (class A) collects those that can be considered adherent to the requirements of the seismic legislation; in the other classes (B, C, and D) vulnerable situations are collected increasingly. The scores for the various parameters are multiplied by appropriate weights and then added in order to obtain an overall vulnerability value, taking into account the different importance that the various parameters assume for the purposes of the seismic behaviour of the structure.
It should be noted that, with this approach, the information necessary to define the seismic resistance is not obtained.

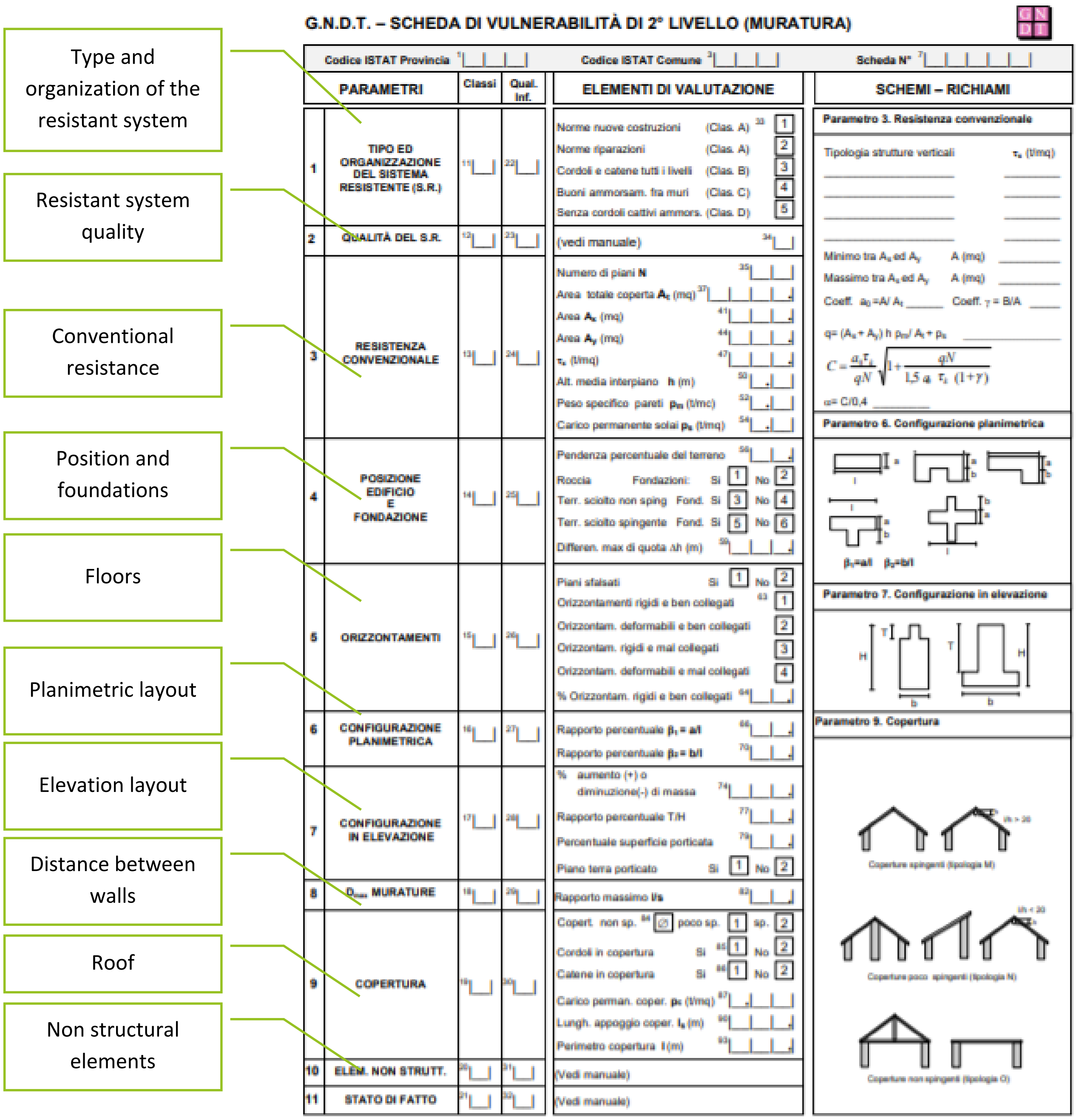
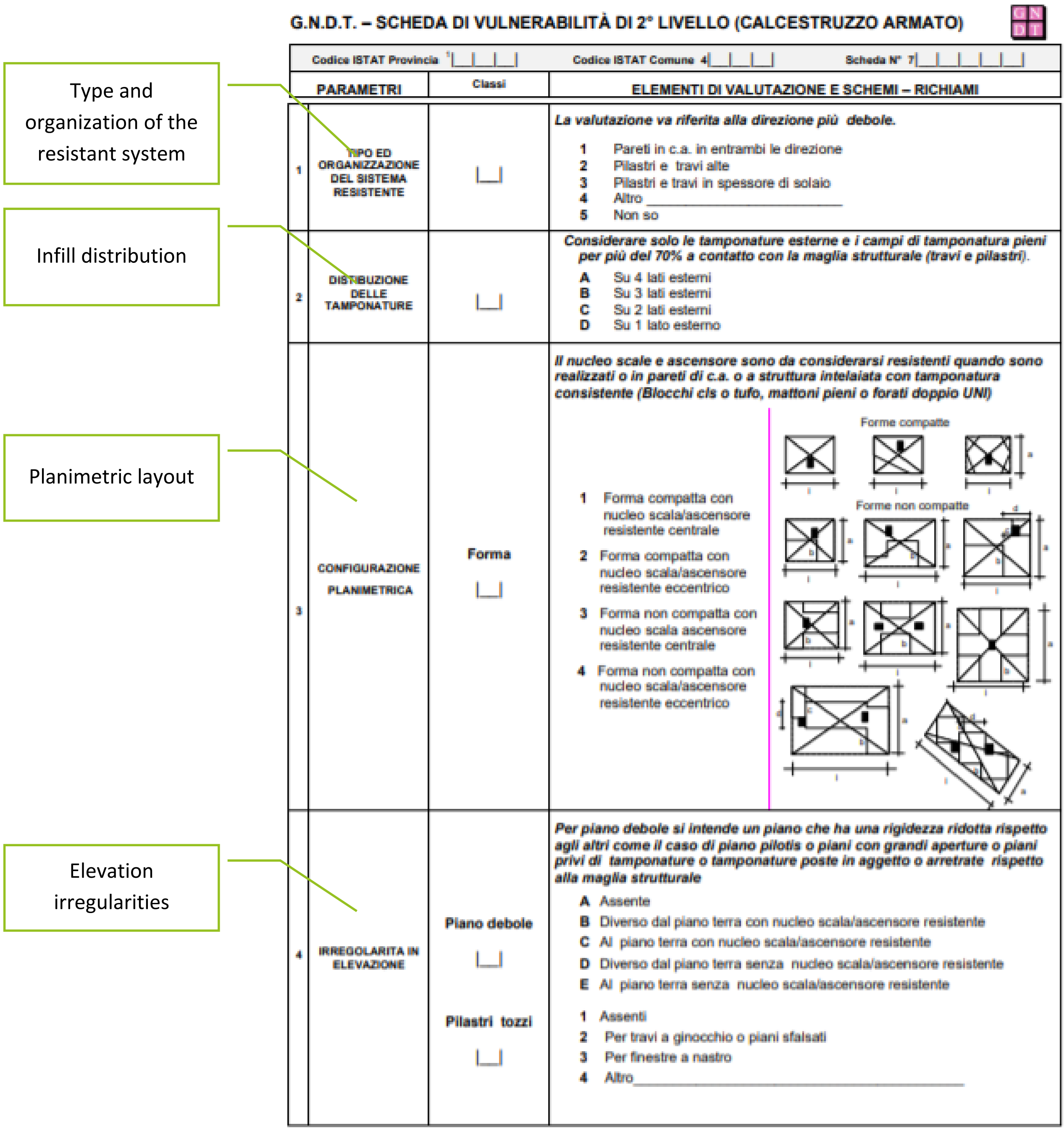


Figure 23 – 2nd level GNDT form for masonry buildings



G.N.D.T. – SCHEDA DI VULNERABILITÀ DI 2° LIVELLO (CALCESTRUZZO ARMATO)

Codice ISTAT Provincia 1 | Codice ISTAT Comune 4 | Scheda N° 7

	PARAMETRI	Classi	ELEMENTI DI VALUTAZIONE E SCHEMI – RICHIAMI
1	TIPO ED ORGANIZZAZIONE DEL SISTEMA RESISTENTE	|__|	*La valutazione va riferita alla direzione più debole.* 1 Pareti in c.a. in entrambi le direzione 2 Pilastri e travi alte 3 Pilastri e travi in spessore di solaio 4 Altro ______ 5 Non so
2	DISTRIBUZIONE DELLE TAMPONATURE	|__|	*Considerare solo le tamponature esterne e i campi di tamponatura pieni per più del 70% a contatto con la maglia strutturale (travi e pilastri).* A Su 4 lati esterni B Su 3 lati esterni C Su 2 lati esterni D Su 1 lato esterno
3	CONFIGURAZIONE PLANIMETRICA	Forma |__|	*Il nucleo scale e ascensore sono da considerarsi resistenti quando sono realizzati o in pareti di c.a. o a struttura intelaiata con tamponatura consistente (Blocchi cls o tufo, mattoni pieni o forati doppio UNI)* 1 Forma compatta con nucleo scala/ascensore resistente centrale 2 Forma compatta con nucleo scala/ascensore resistente eccentrico 3 Forma non compatta con nucleo scala ascensore resistente centrale 4 Forma non compatta con nucleo scala/ascensore resistente eccentrico Forme compatte Forme non compatte
4	IRREGOLARITA IN ELEVAZIONE	Piano debole |__| Pilastri tozzi |__|	*Per piano debole si intende un piano che ha una rigidezza ridotta rispetto agli altri come il caso di piano pilotis o piani con grandi aperture o piani privi di tamponature o tamponature poste in aggetto o arretrate rispetto alla maglia strutturale* A Assente B Diverso dal piano terra con nucleo scala/ascensore resistente C Al piano terra con nucleo scala/ascensore resistente D Diverso dal piano terra senza nucleo scala/ascensore resistente E Al piano terra senza nucleo scala/ascensore resistente 1 Assenti 2 Per travi a ginocchio o piani sfalsati 3 Per finestre a nastro 4 Altro ______

Figure 24 – 2nd level GNDT form for RC buildings

The **Damage Probability Matrix method** (DPM: Damage Probability Matrix), was developed on the basis of the damage detected following the Irpinia earthquake of November 23, 1980. An extensive survey was carried out for that earthquake, recording approximately 38,000 buildings in the 41 municipalities. Statistical processing of the data allowed to define the DPMs for the most common building types in the affected areas. The assessment of structural vulnerability using the DPM method is quantitative, typological, statistical and direct. It is quantitative, because it provides the result in a numerical form (probabilistic or deterministic); it is typological, because it evaluates the seismic behaviour of buildings by attributing them to a certain structural type, identified by a few essential characteristics (i.e. type of vertical and horizontal structures); it is statistical, because it seeks the result through the statistical processing of observed data after seismic events; it is direct,

because it provides the result as a prevision between the intensity of the earthquake and the probability of damage to buildings. The DPM express the probability of occurrence of a certain level of damage for each seismic intensity.
The MSK 76 scale represents the first form, even if incomplete, of the DPM, generated for three categories of constructions. The first distinction for buildings is proposed according to three classes of vulnerability, identified on the basis of the construction material: stone constructions are defined as type A, brick constructions of type B and reinforced constructions of type C, where C is the less vulnerable.
The attribution of the earthquake intensity in the MSK scale is carried out on the basis of the damage scenarios found in the area; the damage level is divided into 6 degrees:

1. No damage
2. Slight damage: fall or cracking of the plaster;
3. Average damage: cracks in the walls and falling plaster;
4. Severe damage: large and deep cracks in the walls;
5. Destructive damage: collapse of partitions and partial collapses;
6. Total damage: collapse of the building.

The MSK scale provides 12 degrees of seismic intensity. The first 4 are associated with phenomenological aspects caused by ground motion (with zero damage to buildings) and faithfully reproduce the descriptions of the MCS scale corresponding to its intensities from I to IV. The eleventh and twelfth grade also correspond to the MCS descriptions. Starting from the fifth to the tenth degree, however, the intensity of the earthquake is linked to the extent of the damage caused to the structures, classified according to the damage scale. The macroseismic intensities of the scale are attributed according to the damaged percentage of buildings in each category and the level of damage they have suffered. By grouping the amount of damaged buildings into three percentage ranges, calculated on the total number of buildings belonging to each class, and corresponding respectively to:

- Few buildings (about 5%),
- Many Buildings (about 50%)
- Most of the buildings (about 75%)

The MSK scale provides the frequency of the different damage levels as a function of the generic type and intensity. This method therefore has the advantage of not being linked to a specific area, but the typological classes do not take into account the most modern construction technologies (steel constructions etc.), and the criteria for attribution to the three classes, based solely on the construction material, are rather coarse. Furthermore, the percentages of damaged building provided by the three damage intervals are too approximate and furthermore the description of the scale is not complete, as it is not articulated on all the damage levels for the various intensities.
The DPM can be obtained by referring to observed damage data or analytically. In the last case, it leads to the construction of real fragility curves, even if in a discrete form, for each category of buildings. The classical origin of DPM, however, involves the statistical processing of data and information on the built structure obtained from field observations. The possibility of constructing these matrices is subject to the availability of a large sample of observations and / or damage classification for each class considered and for different levels of seismic intensity.
The DPM are very useful when used to determine the vulnerability of a building, based only on the identification of the relative class. Therefore, they prove to be a valid support for the execution of risk assessments on a territorial scale as allow, in a relatively short time, to draw a quantitative estimate of the

extent of the damage that could occur for a hypothesized seismic scenario (i.e., for given macroseismic intensities).
The construction of the **fragility curves** for a particular structural system allows to estimate the expected damage for each level of seismic intensity, thus representing the conceptually clearest, and also the most complete, way to estimate the vulnerability of a single building. In general, a building fragility curve represents, as the seismic intensity varies, the probability that the building will reach a particular limit state.
For each building it is possible to construct several fragility curves, each corresponding to a predetermined limit state. However, it is necessary to distinguish the case of study of a single building, taking into account all its details and the characteristics, from the case of a sample of buildings in a certain area, represented by a typological class.
In the first case, in fact, given the completeness and accuracy of the input data, it is possible to reach high levels of detail and obtain the fragility curves for given damage levels through numerical simulations on the seismic response of the building. In general, due to the great computational and modelling burden, this operation is aimed at constructions with particular strategic or historical monumental value.
In the second case since the study of a class of buildings can be represented by macro-parameters (such as shape, size, year of construction, etc.), the result is the study of an "average" building with difficulties to consider with an analytical approach all the macro-parameters that affect the seismic behaviour of the structure. For this reason, the fragility curves of typological classes of buildings are constructed empirically through a statistical analysis. They consider data on the behaviour of buildings all attributable to the same class.

The **semi-quantitative method proposed by Calvi** in 1999 is a method to estimate the vulnerability of building typologies and it is applicable for the assessment of damage scenarios on large portions of the territory, it is only reliable when used on a vast scale, with several buildings considered.
The method is designed to be used without the need for field surveys; consequently, the level of information required is minimal and can be deduced from easily accessible databases (as ISTAT data, for example). It allows to determine the probability of reaching a certain level of damage for each class of buildings and for each assumed seismic intensity degree.
The classification of the building stock in the different building types depends on the type of analysis to be performed; in fact, since the method is mechanical, an analytical study of the seismic behaviour of the structure is envisaged and, for this purpose, an appropriately characterized 'equivalent' model is adopted for each type of structure.
Therefore, three types of classes are considered:

1. RC buildings designed according to seismic regulations (class I);
2. RC buildings not designed according to seismic regulations (class II);
3. Masonry buildings (class III).

All masonry buildings belong to a single class, with the assumption that none of them were built following specific seismic requirements. This constitutes a limitation of the method. It is therefore expected that the seismic behaviour of them can be 'modelled' by adopting the same equivalent system (changing some characteristics depending on the limit state) and that the response will be different exclusively as a function of macroscopic parameters, such as the number of floors.
For RC buildings, it is not possible to make the same hypothesis, as their behaviour can be substantially different depending on the quality of the structural system. A construction that follows the modern principles of capacity design, and with correct construction details, in fact, performs better than a building in which these aspects have been neglected. For the classification of the built heritage, simple information is sufficient to

identify the respective class of each structure, such as the construction material (masonry or reinforced concrete), the number of floors and the year of the project. The vulnerability assessment depends on the extent of the expected damage in a scale scanned according to pre-established limit states. In particular, four limit states are considered for the study of damage scenarios.
The method follows a displacement approach: the vulnerability is determined by comparing capacity and demand that are expressed in terms of deformation thresholds. The limit states are defined in relation to the deformation capacity of the elements. Due to the significant impact that damage to non-structural parts of a building (infill, fixtures, etc.) can have on the quantification of losses, they are also explicitly evaluated.
On the basis of the indications reported in the literature and in the regulatory prescriptions, and following a re-elaboration based on experience and qualitative considerations on the real behaviour of the structures, quantitative indications are provided for each limit state about the aforementioned deformation limits.
Structural damage of RC constructions is traced back to the crisis of the respective sub-elements. On the base of this consideration, the deformation limits are suggested in terms of maximum deformation of steel and concrete. The analysis is carried out for building classes, whose essential geometric characteristics (such as height of floor, cross section of columns, etc.), which are not assigned deterministically as input to the mechanical analysis performed, necessarily present a certain variability within recurring intervals. For example, it is assumed that the height of the columns of RC buildings vary between 3 and 4.5 m, while the cross section can vary between 0.3 and 0.5 m.

The results of the survey on the assessment methods are summarized in the following table:

DESCRIPTION	***2nd level GNDT FORM***	***Vulnus and C-Sisma Automatic procedure for seismic vulnerability analysis of masonry buildings - University of Padua***	***FaMIVE method (Failure Mechanism Identification and Vulnerability Evaluation)***	***SP-BELA METHOD - SIMPLIFIED PUSHOVER-BASED EARTHQUAKE LOSS ASSESSMENT FOR MASONRY BUILDINGS by European Centre for Training and Research in Earthquake Engineering (EUCENTRE), Pavia, Italy and Università degli Studi di Pavia, Italy***
CODE	C.1	C.2	C.3	C.4
MAIN CHARACTERISTICS	They are more in-depth than the 1st level, as they analyse a specific building. The compiling of the form often follows the compilation of the 1st level form.	Automatic seismic vulnerability assessment procedure, implemented in a Visual Basic environment and updated in accordance with the requirements of the Italian seismic legislation	FaMIVE method evaluates the vulnerability of masonry buildings located in historical centres by considering the possible collapse mechanisms and the related importance factors associated to them	Simplified pushover-based earthquake loss assessment method for the definition of vulnerability curves
POSSIBILITY OF APPLICATION	Isolated buildings; masonry buildings, RC buildings	It is a methodology for assessing the global vulnerability of sufficiently regular masonry buildings with limited height, both isolated and grouped in aggregates that interact with each other	Masonry existing buildings and adobe masonry buildings	Conceptually, the method may be applied to any structural typology; it is employed to study the vulnerability of masonry buildings

PROCEDURE	EMPIRICAL EXPEDITIOUS METHOD - Compilation of preformed factsheet, on the basis of instructions indicated in the "MANUAL FOR THE DETECTION OF SEISMIC VULNERABILITY OF BUILDINGS. Instructions for filling in the 2nd level form"	ANALYTICAL EXPEDITIOUS METHOD - Vulnus evaluates the critical level of horizontal acceleration corresponding to the resistance of two systems of parallel, or almost parallel, walls (index I1) and to the activation of out-of-plane collapse mechanisms of the single walls, constrained by orthogonal walls, floors and any tie rods (index I2). Local acceleration is estimated assuming a proportional distribution to the height. The program gives the values of the two indices that allow a preliminary analysis of seismic vulnerability. It allows to obtain a global judgment on the vulnerability of the buildings and the set of units that compose them: a third vulnerability index (I3) is flanked by the two indices I1 and I2 which provides additional qualitative information on the buildings and soil characteristics. This index is obtained from the factors derived from the G.N.D.T. of 2nd level for the assessment of the vulnerability of ordinary masonry buildings	ANALYTICAL EXPEDITIOUS METHOD - FaMIVE uses a non-linear pseudo-static structural analysis with a degrading pushover curve to estimate the performance points using a variant of the N2 method, included in EC8 part 3	ANALYTICAL EXPEDITIOUS METHOD - For the determination of the capacity curve, the resistance of the building and the displacement values associated with predetermined damage limit conditions are defined. Three reference limit states have been taken into account in relation to structural damage only. These are: • Limit State 1 (SL1) - Limited damage: the building hit by a seismic event is still usable without the need for repairs and reinforcements; • Limit State 2 (SL2) - Severe damage: the building cannot be used after an earthquake has occurred, but needs repairs and reinforcement; • Limit State 3 (SL3) - Collapse: beyond this limit condition, the building is no longer safe for the safety of the occupants. The structural capacity is defined through the pushover curve with a behaviour similar to a piecewise linear curve
INVESTIGATED AREAS	Type and organization of the resistant system; resistant system quality; conventional resistance; location of the building and foundation; horizontal structures; planimetric configuration; elevation configuration; roof; non-structural elements; actual state. Each parameter is counted through a factor, based on the influence it has on the global seismic behaviour	It allows to obtain a measure of the probability of reaching and / or exceeding a certain level of damage: this damage is associated with local rupture or collapse mechanisms, and therefore it is possible to consider the D2 degree of damage, with reference to the classification of the apparent damage provided by the EMS98 macroseismic scale	FaMIVE yields as output collapse multipliers which identify the occurrence of possible different mechanisms for a given masonry construction typology, given certain characteristics. It is based on a suite of 12 possible failure mechanisms directly correlated to in situ observed damage and laboratory experimental validation. The methods can quantify also the effect of strengthening and repair intervention on reduction of vulnerability	To characterize the behaviour of masonry buildings, the collapse mechanisms are classified into collapse mechanisms in the plane and collapse mechanisms out of the plane. The hypothesis is that, in order for the building to have a global collapse mechanism, i.e., involving the entire structure, the collapse mechanisms in the floor must be activated before the out of plane collapse mechanisms

DEFINITION PERIOD	1990 - 2010	1989 - today	1996 - today	2008-2017
COMPILER	Civil Protection Technicians	Technician in charge	Technician in charge	Technician in charge
COMPLEXITY	LOW	MEDIUM	MEDIUM	MEDIUM
LIMITS	It is an attempt to move to a behavioural approach. The expected behaviours are few, since the typologies of the same structural element would be various (for example, in the case of masonry, the material, the texture, or the components of the mortar). At the same time, a strong simplification is generated, which leads to obtaining data in a much simpler and therefore reliable way	Vulnus is based on a hybrid vulnerability model: the results of the structural calculation are considered as indicators of the vulnerability. The method is not only based on collapse mechanisms and static calculations, but also on qualitative judgments and statistical calculations. However, the main limitation of this procedure is the static treatment of the dynamic stress of the earthquake: in particular, the duration of the stress is not taken into account, it is considered only roughly in the vulnerability model	Method used so far post-earthquake assessments on earthquakes that have occurred, even if for preventive purposes	Method used so far post-earthquake assessments on earthquakes that have occurred, even if for preventive purposes
ADVANTAGES	Very quick; it does not require complex calculations and special tools	Method developed on a numerical quantitative basis, although approximate	Method developed on a numerical quantitative basis, although approximate	Method developed on a numerical quantitative basis, although approximate
CURRENTLY USED	NO	As a research activity	As a research activity	As a research activity
LINK	https://emidius.mi.ingv.it/GNDT2/Pubblicazioni/Lsu_96/vol_1/schede.pdf	https://www.researchgate.net/publication/275955763_ANALISI_DI_AGGREGATI_COMPLESSI_PER_VALUTAZIONI_DI_VULNERABILITA_SISMICA_IL_CASO_DI_CASTELLUCCIO_DI_NORCIA	https://books.google.it/books?id=xZVwAgAAQBAJ&pg=PA339&lpg=PA339&dq=FaMIVE+method&source=bl&ots=2rY39GKduh&sig=ACfU3U1CRAy-fagVGTRrfxK611zYj65VFA&hl=it&sa=X&ved=2ahUKEwiU0rCwxdTpAhWPDuwKHdRNDlEQ6AEwDnoECAoQAQ#v=onepage&q=FaMIVE%20method&f=false	https://www.researchgate.net/publication/233375391_Simplified_Pushover-Based_Earthquake_Loss_Assessment_SP-BELA_Method_for_Masonry_Buildings
APPLICATION		Campi Alto di Norcia, (IT); Castelluccio di Norcia (IT); l'Aquila (IT); Belluno (IT)	Nocera Umbra (IT); Instanbul (TR); Bhuj (IN); Abruzzo (IT); Algeri (DZ)	7 regions in Italy where earthquakes occurred between 1976 - 2009

DESCRIPTION	***SISMA (System Integrated for Security Management Activities) - Progetto INTERREG IIIB SISMA (2004-2007) for the "Promotion of risk management and disaster prevention"***	***Giovinazzi and Lagomarsino method***	***Ferreira, Vicente, Varum***	***Quagliarini, Lucesoli, Bernardini***
CODE	C.5	C.6	C.7	C.8
MAIN CHARACTERISTICS	Approaches and methodologies developed by the various partners (3 Italian regions including Emilia-Romagna and 5 European territorial bodies, Lead Partner was the Umbria Region) for integrated seismic prevention actions in historic centres	A damage probability matrix has been produced for six different classes of decreasing vulnerability (from A to F) and contains a qualitative description of the typology of buildings belonging to each damage grade for different levels of intensity, according to the EMS-98 macroseismic scale	Assessment method for the seismic vulnerability of masonry façade walls that is based essentially on the vulnerability index method (VIM), an “indirect” method because the relationship between the seismic intensity and the building response is establish through the vulnerability index Iv	Rapid methodology to obtain a unique vulnerability index for a building aggregate, VL.Agg and VF.Agg, coming from the detailed assessment procedure developed by VIM methods of Lagomarsino and Ferreira
POSSIBILITY OF APPLICATION	Aggregates of buildings in historic centres even with a medium-large demographic dimensions	This method can be applied both for the analysis of single building or set of building	The method can be applied to isolated buildings and to aggregates of buildings	Aggregates of buildings
PROCEDURE	Definition of an integrated methodological process for the assessment of the vulnerability of the historic centre system and its components, with regard to seismic events, aimed at creating tools and preventive actions for risk reduction, which can be implemented by the institutions that have the task of managing the territory. The Project also proposes the training and information of the population in order to strengthen the concept of "citizen as first aid for himself", to increase awareness in the EU territory in the face of disastrous events, obtaining his own safeguard and	In order to complete the vulnerability index Iv, which contains only structural information from the typology classification of buildings of EMS-98, three specific indices have been added as suggested: the ΔVr is a regional vulnerability factor, introduced to take into account the typifying of some building typologies at a regional level; ΔVm is evaluated as the sum of the scores Vm,k of the recognized behaviour modifiers; the filter function ΔVf is defined depending on the quantity and quality of the available data in order to represent an acceptable approximation of the final vulnerability index value	According to this vulnerability formulation, the vulnerability index of the façade wall (I*vf) can be then obtained by the weighted sum of 13 parameters, related to 4 classes of increasing vulnerability: A, B, C and D	The vulnerability value is calculated for the structural units composing the same building aggregate; the method includes: • VL,SU or VF,Agg calculated according to Lagomarsino Giovinazzi (2006) and Ferreira, Vicente, Varum; • the last vulnerability value is summed and weighted considering the ratio between the volume of each single structural unit (VolSU) and the one of the whole aggregate (VolAgg). • the parameter d considers the more frequent masonry typology within the aggregate and evidences the presence of structural units having different masonry typologies; • 1/q represents a corrective factor (> 1), that takes into account the number of structural units within

	collaboration with civil protection			the aggregate due to the impact of the interference effects among them
INVESTIGATED AREAS	Quantitative information deductible from seismic micro-zonation investigations; assessments on the seismic behaviour of technological networks (due to functional models and technical characteristics); expeditious assessments of the average building vulnerability in the territorial units (homogeneous by urban morphology) identified within the historic centre for the overall assessment of vulnerability of urban systems	Two further behaviour modifier factors have to be computed in the vulnerability index evaluation in order to consider specific features of historical urban context: the historical centre behaviour modifier factor ΔVhc and the aggregate behavior modifier ΔVa. The first one, ΔVhc is closely linked with the local constructive traditions and moreover with the subsequent modifications suffered by the historical center. The second one, ΔVa takes into account the interaction between adjacent buildings considering the irregularity in plan and in elevation (different height of adjacent buildings or staggered floors)	The vulnerability parameters are arranged into four group, each of them describe the most important constructive characteristics influencing building seismic response: facade geometry, openings and interaction; masonry materials and conservation; connection efficiency; elements connected to the wall facade	Aggregates' features that may influence the vulnerability value: volumes ratio, differences in building typologies, total number of structural units
DEFINITION PERIOD	2004 - 2007	2004 - 2005	2014	2019
COMPILER	Municipal employees or technicians in charge	Technician in charge	Technician in charge	Technician in charge
COMPLEXITY	LOW	LOW	LOW	LOW
LIMITS	It is a synthetic method that takes into account a limited number of vulnerability indicators	The method is influenced by the subjectivity of the compiler	The method has currently been empirically applied on contexts not affected by earthquakes	A structural unit with high vulnerability index, but with smaller volume in respect to the total aggregate does not influence the overall aggregate vulnerability like a structural unit with the same vulnerability level but with more extended dimensions. Only the more frequent masonry type is considered
ADVANTAGES	It is expeditious and takes into account the construction features	The vulnerability is evaluated in terms of construction features	The parameters of group 1 and 2 are substantially replicated from the previous formulation of the methodology proposed for Portuguese masonry buildings by Vicente (2014). This	The purpose is to simplify the vulnerability assessment through the implementation of expeditious methods, which require simple information, easily available by just an

			procedure specifies with the group 3 the relevance of the connection of orthogonal elements in order to avoid out-of-plane failure mechanisms. With the same aim, also group 4 represents the effective connection between horizontal and vertical structural elements in those cases where it is possible individuate strengthening action by inspection from outside	external view of buildings It aims at evaluating the entire urban centre focusing on aggregates, without losing in reliability
CURRENTLY USED	NO	NO	NO	As research activity
LINK	http://territorio.regione.emilia-romagna.it/urbanistica/vulnerabilita-urbana/il-test-del-centro-storico-di-forli-all2019interno-del-progetto-interreg-iiib-sisma-2004-2007	https://www.researchgate.net/publication/255620187_A_MACROSEISMIC_METHOD_FOR_THE_VULNERABILITY_ASSESSMENT_OF_BUILDINGS	https://core.ac.uk/download/pdf/15566975.pdf	https://reader.elsevier.com/reader/sd/pii/S1296207418309178?token=60587A21A0315A958305273F4FE58B386453C4CDF87FF17E0B2B7E83CEF55B4777164FCD48F7A326F3D223FB62334670
APPLICATION	Historic centres of Santa Sofia (FC), San Piero in Bagno (municipality of Bagno di Romagna-FC) and Forlì, Italy		Coimbra (PT)	Central Italy

DESCRIPTION	***Formisano, Florio, Landolfo, Mazzolani***	***Mochi and Predari***
CODE	C.9	C.10
MAIN CHARACTERISTICS	Vulnerability assessment for masonry building aggregates on the basis of 15 parameters. In particular, it considers the structural or typological heterogeneity, the interaction effects and the different opening areas among adjacent structural units when they are subjected to seismic actions	Vulnerability assessment method for building aggregates in historical centre based on the determination of synthetic indicators providing a prior prevision of collapse mechanisms under earthquake (I mode in-plane and II mode out-of-plane) by identifying the fragilities of masonry buildings
POSSIBILITY OF APPLICATION	Building aggregates	Building aggregates
PROCEDURE	The vulnerability index Iv is calculated for each structural unit of a building aggregates, as the weighted sum of 15 parameters. In order to obtain a form totally homogeneous with the previous one. The scores and weights assigned were calibrated numerically on the basis of the results of specific numerical parametric non-linear analyses performed by the 3MURI software, which uses the	The assumption is that the seismic damage of the historical building derives from the loss of stability of individual components as rigid blocks, then, from the insufficient shear strength of the walls. It is essentially a scoring method that combine the empirical approach, due to the validation of the parameters by observation damage data and expert judgment, and mechanical/kinematic approach. Two different procedure have proposed to assess the

	Frame by the Macro-Elements (FME) computational method	vulnerability: the expeditious method applied on the façade of the building aggregates and the analytical method calculated on the SUs composing the building aggregate
INVESTIGATED AREAS	organization of vertical structures; nature of vertical structures; location and type of foundation; distribution of plan resisting elements; in-plane regularity; vertical regularity; type of floor; roofing; details; physical conditions; presence of adjacent buildings with different height; position of the building in the aggregate; number of staggered floors; structural or typological heterogeneity; percentage difference of opening areas	out-of-plane collapse of the façades; out-of-plane collapse of the gable; cracks due to the rafters; disconnection of wall, deriving essentially from the historic transformation processes; hammering due to constructive irregularities (as the presence of buildings having a reinforced concrete structure inside the aggregate); weak shear strength, due to insufficient width of the masonry walls
DEFINITION PERIOD	2015 - 2016	2012 - 2020
COMPILER	Technician in charge	Technician in charge
COMPLEXITY	LOW	LOW
LIMITS	Designed exclusively for building aggregates but derived from a method initially proposed for isolated buildings	The synthetic vulnerability indicators require an exhaustive knowledge phase to be acquired, including a preliminary bibliographical research and an on-site survey in order to outline the evolutionary processes suffered by each aggregate
ADVANTAGES	It considers the construction features and elements that can affect the interaction of adjacent structural units in elevation and in plan	It takes into account the construction features and how the aggregate fabric has transformed
CURRENTLY USED	As research activity	As research activity
LINK	https://reader.elsevier.com/reader/sd/pii/S0965997814001628?token=A630A0B6670E115518FA98B464A66C0EAFF0C1EF2040350B0FC664B5E2BCA5B2E838284D6D4344547FA72AC50AF3B81F	http://artecweb.org/ojs2/index.php/TeMA/article/view/198
APPLICATION	Italy: Poggio Picenze (Aq); Romania: Timisoara	Italy: Mirandola, Castelfranco Emilia, Crevalcore, San Giovanni in Persiceto, Carpi, Imola, Lanciano, Lucera, Pergola

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability, due to the close interconnection existing between adjacent buildings. To address this complexity, some assessment methods have been proposed, but do not exist a clear regulatory definition yet. In fact, the current regulations prescribe the subdivision of the building aggregates as single structural units.

Vulnus and c-Sisma have been developed by the University of Padova, they process the data obtained from the survey of a sample of buildings, both isolated and in aggregate, and give the values of the two indices that allows a preliminary analysis of the seismic vulnerability. These procedures evaluate the critical level of mean horizontal acceleration corresponding to the activation of collapse mechanisms in-the-plane of two systems of parallel, or almost parallel, walls (index I1) and out-the-plane of individual walls constrained by the orthogonal walls, by the floors and by any tie rods (index I2) (Munari, et al., 2011; Valluzzi, Munari, Modena, Cardani, & Binda, 2007; Munari, Valuzzi, & Modena, 2009).

The Vulnus procedure allows to obtain a global judgment of the vulnerability of building aggregates and of the individual constructions composing them. Starting from the parameters obtainable from the level 2 G.N.D.T. for the assessment of ordinary masonry buildings, it allows the calculation of further indexes representative of the vulnerability of the individual buildings and of the group of buildings, as well as the calculation of the expected values of serious damage, through fragility, and the development of damage scenarios comparable to those relating to the EMS 98 macroseismic intensity scale.

The automatic c-Sisma procedure, on the other hand, automates the analysis of elementary damage mechanisms, that is, the kinematics characteristic of the mechanical behaviour of the structural macro-elements that can be identified in a building. This methodology, based on the systematic cataloguing of the most probable damage mechanisms, allows the local study through the possibility of choice between 14 out-of-plane damage mechanisms for vertical masonry, 6 out-of-plane damage mechanisms for horizontal masonry strips, 5 types in-plane failure and 4 out-of-plane collapse conditions for walls whose texture is known.

For each selected kinematics, the program returns the calculation of the coefficient c = a/g, i.e., the seismic mass multiplier that activates the mechanism considered.

The most recent version of the procedure also makes it possible to automatically perform the safety checks of the local mechanisms required for the ultimate limit state by the regulation in force (O.P.C.M. 3431), checking the evolution of the kinematics up to the actual collapse conditions.

FaMIVE method (Formisano, Marzo, Marghella, & Indirli, 2016) evaluates the vulnerability of masonry buildings located in historical centres by considering the possible collapse mechanisms and the related importance factors associated to them. Each mechanism is evaluated with reference to the probability of occurrence, which depends on the walls type and materials. Then, an equivalent static analysis should be performed aiming at the evaluation of the collapse multiplier related to each mechanism. Subsequently, a prevision about damage levels for single constructions or for aggregates can be defined. Finally, the vulnerability reduction obtained with seismic protection technique can be quantified.

The MEDEA form (Formisano, Marzo, Marghella, & Indirli, 2016) is conceived for post-earthquake damage evaluation, but it is useful even in pre-seismic case, for both masonry and RC buildings. With reference to masonry buildings, 23 types of damages have been defined for vertical, Vi, elements (walls, tympani, etc.) and 13 for horizontal ones, Hi, (vaults, floors, stairs, etc.). The analysis of both vertical and horizontal damages allows the identification of 16 collapse mechanisms (Mi), associated to a seismic event: 10 of them are global mechanisms, involving many structural elements which produce a global static and dynamic un-equilibrium; the remaining 6 mechanisms are local ones and involve secondary elements only, subjected to possible local collapses.

On the other hand, the MEDEA forms for RC buildings define ten types of damages for vertical structures (CVi), four types for horizontal ones (Chi), four types for the partition walls (CTi) and three types for the walls (CPi). In addition, the method considers several structural features that can increase the vulnerability of the analysed building.

This methodology consists on the following steps:

- identification and labelling of the SUs; this operation requires an in-depth survey considering the interconnection between adjacent constructions
- qualitatively evaluation of any elements which increase the structural vulnerability, according to the typical cases proposed

- definition of both vertical and horizontal cracking maps according to the damage/collapse mechanisms scale considered. This activity requires particular attention about the identification of the more significant mechanisms
- classification of the damage levels according to the EMS98 scale for masonry structures (from d1 to d5 corresponding to slow, middle-slow, middle, severe and very heavy damage, respectively).

Since 2012, the development of a protocol for the rapid assessment of the seismic vulnerability on masonry building aggregates is being implemented by Mochi and Predari within the Department of Architecture of the University of Bologna (Mochi & Predari, 2016; Predari, Mochi, & Gulli, 2014). This method is based on the determination of synthetic indicators that provide a preventive quantification of the possible earthquake damage; these parameters are defined by identifying expeditious evaluation procedures based on the typical evolutionary processes suffered by each aggregate in its planimetric and height development, on the construction techniques and on the design concepts used in the local area. These aspects are directly correlated to the failure modes.
The final result of the evaluation is an overall index, which is basically the sum of partial indices, each multiplied by its own weight, which is a sort of quantification of the relevance of each indicator, initially determined on an experiential basis and subsequently refined on a statistical one.
First of all, the method is based on the assumption that the seismic damage of the historical building derives from the loss of stability of individual components, seen as rigid blocks that move due to the ground acceleration. Then, it results from the insufficient shear strength of the walls.
This second deficiency of the structures derives from issues related to the building materials, while the first derives essentially from the formation and modification processes of the building fabrics. Consequently, the comprehension of the transformation phases becomes the key-point for the behaviour prevision.
The identification of the transformation phases, starting from the first layout of the urban settlement, is the initial point of this process, leading to the current situation through the comprehension of the layout extensions, super-elevations, demolitions and reconstructions.
This initial phase can also only be hypothesized when there is no specific, historical or archaeological documentation, although some indirect sources can provide an interesting reference base.
The assessment of the seismic vulnerability of building aggregates follows the collection of data.
Vulnerability has been defined through indicators that are significant for their causal relationship with damage: out-of-plane collapse of the façades and of the tympanums, cracks due to the rafters, hammering due to constructive irregularities (as the presence of buildings having a reinforced concrete structure inside the aggregate), weak shear strength due to insufficient width of the masonry walls.
In addition to these, there is another essential indicator which is included in the global aggregate behaviour; referring to the entire construction, not only to the façades.
This indicator is the wall disconnection index, which allows to understand the possible damage to the internal parts of the buildings composing the aggregate.
The wall disconnection index is also essential as it allows to define the portions of façades that may be subjected to out-of-plane collapse and the width of the fronts to be considered effective for the shear mechanism.
The basis for the graphic representation of the method are drawings of plans and elevations of the current state, suitable for the transfer of all the necessary information regarding the constructive solutions and transformation processes.

Since this is a quick assessment procedure, whose application is useful for entire and extensive historical fabrics before carrying out a detailed quantitative analysis, in the same way the operational tools must derive from rapid procedures and not from complete direct surveys of the urban fabric.
For the planimetric reconstruction of the buildings, the most recent plants belonging to the cadastral archives are used, while the quickest and precise choice for the survey of the facades consists in the use of photo-modelling.

6.2 Croatia – PP3 (Grad Kaštela)

The Republic of Croatia is among the most seismic countries in Europe, yet the current activities related to the assessment of potential earthquake risk and its reduction are individual and insufficient (Atalić, Šavor Novak, & Uroš, 2019). Currently, there are several existing and ongoing disaster risk assessments, conducted by various authors with different approaches.
Inadequate building inventories are recognized as the main obstacle in reliable seismic risk assessment in Croatia. The situation is further complicated by characteristic problems such as widespread illegal construction, undocumented reconstructions and renovations, and the lack of some critical attributes such as those related to specific local construction practices, for example age of the building stock and critical infrastructure facilities, poor system organisation, lack of funding, etc. (Atalić, Šavor Novak, & Uroš, 2019).

Until 2014, comprehensive and integrated seismic risk assessment studies were not among the priorities in Croatia, but rather limited to certain individual efforts. However, becoming a member state of the European Union, Croatia adopted numerous obligations, including those related to disaster risk management. The Faculty of Civil Engineering of the University of Zagreb became the lead executive for preparation of the seismic risk assessment. The initial step for a unitary approach was made in 2015, when a report entitled "Disaster risk assessment for the Republic of Croatia – Earthquake risk was prepared" (Atalić & Hak, 2014). With this study, the seismic risk, together with potential negative impacts from flood and fire risks, was rated as unacceptable for the country (Atalić, Šavor Novak, & Uroš, 2019).
In 2018, the risk management process continued with the "Assessment of the risk management capability for the Republic of Croatia", while the "Disaster risk assessment for the Republic of Croatia – earthquake risk" was updated ((Atalić, Šavor Novak, & Uroš, 2018).
Nowadays, a variety of documents are currently available, each using a different approach.

The first studies on seismic risk date back to the 1970s, when the frequency of strong earthquakes in the Mediterranean countries contributed to the increase of research activities in the field of earthquake engineering and to the improvements in the seismic hazard assessment and calculation procedures. Projects such as the *Survey of the Seismicity of the Balkan Region* (UNESCO/UNDP) achieved in the 1970s, *Seismic Risk Reduction in the Balkan Region* (UNDP/UNESCO) implemented in the 1980s and Building *Construction under Seismic Conditions in the Balkan Region* (UNDP/UNIDO) conducted in collaboration with the US National Science Foundation from 1979 to 1985, led to the publication of numerous results (books, manuals, scientific papers) (Penelis, et al., 1984; Simeonov, et al., 1985), which summarized the experience gained during their implementation.
Local experts also initiated numerous studies and guidelines, such as instructions for post-earthquake inspection of structures (Milutinović, 2019).
Another example is the 1988 monograph entitled *Rehabilitation, seismic retrofitting and structural repair of cultural monuments in the old urban core of Dubrovnik*, published by the Institute for Restoration of Dubrovnik

with the aim of systematising modern scientific advances relating to seismic issues (Aničić, Mihaliov, & Velkov, 1988). Encouraged by the experience gained after the destructive earthquake in Montenegro, the book organised the know-how on seismic risk determination, microzonation, structural investigations, seismic resistance analysis, retrofitting, etc. The monograph analysed all components of risk, from hazard to exposure, including detailed analyses of building vulnerability. Two years later, the first scientific book on the seismic resistance of buildings in Croatia (1963-1990) was published (Aničić,, 1990).

The situation in Croatia changed considerably with the outbreak of the internal war in 1991-1995, when the seismic risk was not a priority and the previous studies were set aside.

As regards Croatian cities, the first research was published in the 1992, with the seismic risk assessment for the City of Zagreb (Aničić, 1992), although most of the contents had been conducted already in 1983 but were not published. The aim was to assess potential damage to building stock, the number of victims, the level of preparation and the definition of respective strategies. Depending on the time and method of construction, buildings were classified into different categories: masonry buildings, confined masonry buildings, reinforced-concrete frame buildings, reinforced concrete buildings with load-bearing walls, and reinforced-concrete frame buildings with reinforced-concrete load-bearing walls. The percentage of buildings belonging to a particular structural system was estimated based on experience, as data was not available. The damage to buildings was assessed using vulnerability matrices with six damage levels corresponding to each of the assumed building types. Each type was then assigned a percentage of damage with regard to the total number of buildings.

The results of this study, although a first attempt in seismic risk assessments, are still used as a basis for estimating disaster risk for counties and towns.

There are currently several ongoing projects and project proposals underway that are expected to trigger considerable improvements. All of these initiatives have the same basic objective: to systematically create a high-quality inventory containing representative attributes of the existing building stock. It can be concluded that the lack of reliable data is probably the biggest challenges, since they constitute the key element for accurate seismic risk assessment. The most recent projects funded by Croatian Science Foundation, which will upgrade the knowledge on seismic risk in Croatia, are dealing with the assessment procedures and renovation of existing building stock (p*roject: Assessment and rehabilitation of existing structures – development of contemporary methods for masonry and timber structures, project leader M. Stepinac, University of Zagreb*), seismic risk of cultural heritage (*project: Seismic risk assessment of cultural heritage buildings in Croatia, project leader Snježana Markušić, University of Zagreb*), geology and seismology (*project: Geological and seismological aspects of geodynamics in Kvarner area – Unveiling of the Kvarner fault, project leader: Tvrtko Korbar, Croatian Geological Institute*) and about the seismic risk itself (*New fragility models to typical buildings in urban areas: applications in seismic risk assessment and targeted reinforcement methodology, project leader Mario Uroš, University of Zagreb*).

All studies conducted in recent years, or in progress, have as a common basis the understanding that the objective of risk assessment is to determine the probability of occurrence of a certain level of damage in a given type of buildings as a result of the seismic action. In Croatia, the modern risk assessments, classified into empirical, analytical and experts' judgment methods, are well known. Most often, they describe the level of physical vulnerability of buildings through vulnerability curves that are usually defined as the probability of loss given by a level of ground shaking, and/or through fragility curves representing the probability of exceeding a specified limit state, e.g., the percentage of physical damage given a level of ground shaking.

Empirical assessment methods are based on the observation of damage sustained during past seismic events. A complete database of observed damage would be necessary to apply such approaches; however, this is only possible in areas of high seismicity where adequately performed post-earthquake surveys are available.

Empirical or qualitative methods are used to assess the seismic vulnerability of a large group of buildings in a general manner and provide a quantification in terms of seismic vulnerability that could range from low to high. Traditionally, seismic loss studies exclusively relied on empirical observations based on a macroseismic intensity scale. The main types of empirical methods (with the works implemented method) are: Damage probability matrices (DPM), Vulnerability Index Method and Screening Methods.

Analytical methods are used when a single building is evaluated in a detailed way and in numerical terms (displacement capacity, ultimate force etc.). Accordingly, probabilistic analyses of computer-generated structural responses, obtained by applying nonlinear analysis procedures to representative buildings, provide fragility curves, damage probability matrices and vulnerability functions. Types of analytical methods are: Analytically-Derived Fragility Curves, Capacity Spectrum-Based Methods, Collapse Mechanism-Based Methods and Fully Displacement-Based Methods (Hadzima-Nyarkoand & Kalman Šipoša, 2017).

The main difference between the detailed and rapid methods is the number of inputs for risk derivation. In addition, the results are mostly expressed in an absolute manner in detailed analysis and are represented as a ranked list, of examined cities or areas, with an emphasis on the most vulnerable areas or the cities in rapid methods.

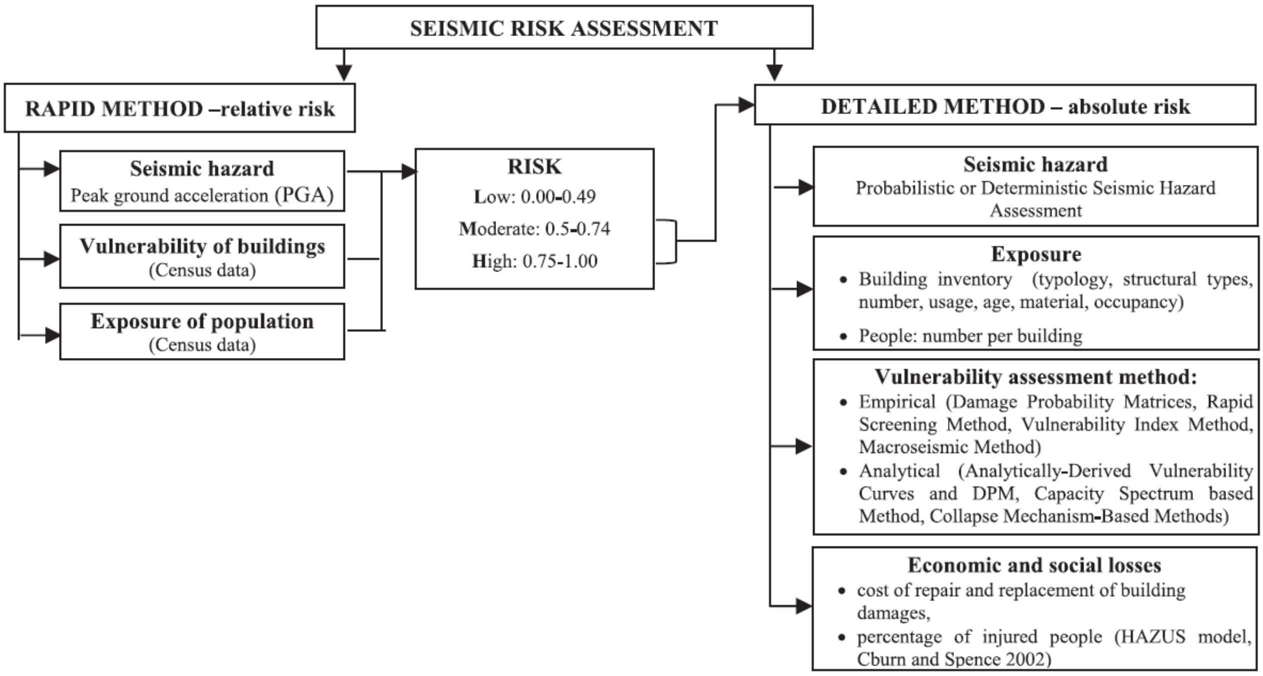


Figure 25 – Overview of seismic risk assessments: rapid vs. detailed (Kalman Šipoš & Hadzima-Nyarko, 2017)

Despite the several approaches for the assessment of physical vulnerability of buildings, it is important to consider the specific conditions of the study area (town, region, country) to establish the risk model. The local building stock, the construction practices, the most recent information about the seismic hazard and the existing data about past earthquakes have to be taken into account.

The lessons of the past earthquakes before the year 2020 seem forgotten and, although Croatia lies in a seismically active area, major earthquakes appear infrequently and the public perception of the disaster they can cause is almost totally neglected. Hazard awareness is at a deficient level even if 30% of Croatian territory is exposed to severe seismic actions (Vlada Republike Hrvatske, 2017), an area where almost 60 % of the population lives (Stepinac, et al., 2021). Considering the recent earthquakes in Croatia, the modern analytical procedures for vulnerability estimation will be greatly updated with the rapid post-earthquake damage assessments obtained after the Zagreb and Petrinja earthquakes.

The creation of a database of relevant vulnerability curves for individual countries is crucial for a more reliable risk assessment. Therefore, it is significant to refer to initiatives that involve the systematization of vulnerability curves in the form of applicable databases, such as HAZUS, GEM, ER2, etc. (including guidelines for their implementation). However, the use of these datasets is only valid for the regions where they were developed, according to the local building tradition and practices. In fact, the data required for the development of vulnerability curves strongly depend on local characteristics of a particular country or region, i.e., the construction methods historically applied in the area (quality of construction, specific structures, etc.), change of regulations and building codes, available materials, local soil conditions, etc. In Croatia, the need for a building inventory is directly related to the problems of assessing the vulnerability of existing building stock, or in other words, it is difficult to evaluate the expected behaviour of structures if input data are unreliable. Vulnerability curves are currently investigated at the universities of Osijek and Zagreb.

Damage probability matrices related to earthquake intensity and structural system have almost always been used in the damage assessment (Aničić, 1992), for example from the assessment made for the City of Zagreb in 2016.

An important initiative to refer to is the study on seismic risk reduction in the City of Zagreb (Atalić, Krolo, Damjanović, Uroš, Sigmund, Šavor Novak, Mušterić, 2018), that is related to the realisation of the Project No. 11 of the City Office of Emergency Management. The objective was to create real preconditions for mitigation and recovery of earthquake effects, since a strong seismic event is potentially the most significant disaster that could affect the City of Zagreb. This study was conducted in the scope of the development strategy of the City of Zagreb in accordance with prevailing regulations and in collaboration with the Faculty of Civil Engineering – University of Zagreb.

A number of issues related to pre- and post-earthquake activities were discussed by numerous experts during the six years of work. These activities include: creation of a high-quality database of existing structures (definition of methodology, forms, key attributes, organisation of city into characteristic parts – map preparation, training of surveyors, etc.), development of methodology for a rapid initial assessment of seismic vulnerability (identification of key parameters, creation of respective forms, etc.), detailed assessment of seismic resistance of buildings based on experimental and numerical analysis with identification of critical spots, seismic retrofitting, organisation of inspection of earthquake damaged structures (preparation of inspection forms, organisation of the system, education, participation in field exercises, etc.) and other related activities.

Among the many issues, the creation of a building inventory database is an objective. According to results of systematic research of Statistical Yearbooks, Croatia's national building stock consists of approx. residential 800 000 buildings and 125 000 non-residential buildings. More than 75% of the building stock is older than 30 years, that corresponds to a life-time requiring at least some renovation or modification of primary structural components. More than 40% of the building stock is older than 50 years, meaning that the service life of the structure is expired. In the building sector in Croatia, finally, it is recognized that up to 40% of the expenses are dedicated to the rehabilitation, modification and demolition of existing structures (Stepinac, Kisicek, Renić, Hafner, & Bedon, 2020). The main characteristics of Croatian buildings constructed in the period before the 1970s is the use of traditional constructional techniques and materials, such as masonry and timber. Buildings were built as full-brick masonry structures, with mostly wooden ceilings, and 30–60 cm thick walls, resulting in statically satisfactory structural assemblies. In the 1960's, reinforced concrete (in combination with timber and steel) started progressively to replace traditional constructional materials. Actually, most of the residential structures are still built as a combination of concrete, masonry and timber load bearing components (Stepinac, Kisicek, Renić, Hafner, & Bedon, 2020).

Particular attention is paid on detailed experimental and numeric analyses of the selected buildings, since the generated results can be extremely useful for a number of purposes. During the process of selecting candidate buildings, attempts were made to include characteristic building types based on the period of construction, materials used, height, design code applied, as well as buildings with specific local features: towers, significant and essential constructions (historic buildings, fire stations, hospitals, industrial buildings, student dormitories, concert halls, theatres, schools, other public buildings, etc.) and other elements of critical infrastructure.
The selected buildings were analysed through the experimental study of dynamic parameters using state-of-the-art methods (Damjanović, Bartolac, Duvnjak, Košćak, & Krolo, 2018), followed by the creation of complex numerical models. It should be noted that visual inspection often revealed that the actual conditions are not identical to the available documentation, i.e., buildings were often modified either during the construction or use and these changes were not subsequently documented. Considering this and other potential unknowns regarding structural details, it was concluded that the experimental determination of dynamic parameters was extremely useful for the calibration of numerical models.
The results of the numerical analyses were used to provide a general assessment of the expected behaviour of the considered buildings when subjected to a seismic action with a return period of 95 and 475 years (according to EMS-98 scale). The results of the detailed analyses can also be extrapolated for several of buildings of the same, or similar, structural type and, by linking them to a city district and the number of people residing in each building, useful information can be obtained contributing to a more accurate risk assessment.

Post-earthquake survey

The territory of Croatia is located in a highly earthquake-prone area with the threat of seism producing ground accelerations of up to 0.36g.
The area characterized by a possibility for earthquakes with PGA of 0.3g or higher occupies 5.53% of the Croatian territory and has about 21.02% of residents. The areas threatened by earthquakes with PGA of 0.2g to 0.3g cover 30.89% of the territory, where 41.66% residents live. On more than half of Croatian territory (56.22%) there is the possibility for an earthquake with PGA of 0.1–0.2g, on which more than one-third (1.633.529) of the total Croatian population live (Kalman Šipoš & Hadzima-Nyarko, 2017).
Despite this high seismicity, post-earthquake damage observations were relatively scarce before the recent earthquakes in Zagreb and Petrinja. The preliminary post-earthquake damage and usability assessment procedure was developed after the Zagreb earthquake and was based on Italian experiences and EMS-98. As the earthquake awareness in Croatia is very low, so was the preparedness for such disaster and immediate actions. At the time of the earthquake, there were no systematic data on the number of buildings, floor plans, cross-sections, construction material, purpose, and the like, even for the country's capital. Post-earthquake damage inspection consisted of a quick visual inspection of individual elements of the load-bearing structure, stating the appropriate degree of damage and deciding on the classification of the building into one of six possible categories:

- N1 (red colour): Not usable due to external risk - The building is dangerous due to the possibility of a collapse of massive parts of the adjacent building. Due to such a danger, it is recommended not to stay in such facilities (especially given a large number of earthquake aftershocks).
- N2 (red colour): Not usable due to damage - The building is dangerous due to the large damage, collapse, and failures in the load-bearing system. The structure has reached its load-bearing capacity and exhausted ductility and cannot be used in any part. This does not necessarily mean that the damage cannot be repaired and that the building must be demolished.

- PN1 (yellow colour): Temporarily unusable - detailed inspection required - The building has moderate damage without likely collapse. The load-bearing capacity is partially impaired, and it is not recommended to stay in the building. A shorter stay in the building is possible and a structural engineer provided recommendations for future actions.
- PN2 (yellow colour): Temporarily unusable - emergency remediation measures required - The building has moderate damage without likely collapse but cannot be used due to the possibility of failure of certain elements from the building itself. The structural engineer identified emergency intervention measures and gave instructions to users. The building or part of it is not usable until the measures are implemented. Temporary usability can only apply to some parts (units) of the building.
- U1 (green colour): Usable without restrictions - The building can be used. There is no damage, or there is little damage that does not pose a danger to the building's load-bearing capacity and usability.
- U2 (green color): Use with precaution - The building can be used following the intended purpose, except in certain parts where there is an immediate danger to a part of the building. The construction expert gave recommendations for removing the threat and advised users for temporary residence restriction in certain parts of the building. Once the danger has been removed, the building can be used without limitations.

The category U2 was implemented in the procedure after day 2 when it was noticed that many chimneys or decorative non-structural parts of buildings were damaged and could pose a danger to passers-by and residents. It was necessary to remove these parts as soon as possible. After removing the chimneys and non-structural damaged parts, the building was without any danger of use.

The detailed process and the attributes for the post-earthquake assessment is more deeply explained by (Stepinac et al. 2021; Uroš et al., 2020; Šavor Novak et al., 2020)

DESCRIPTION	***Recommendations after the Zagreb earthquake***
CODE	A.6
MAIN CHARACTERISTICS	Damage to buildings is classified according to the usability of structure. Although, there were recommendation not to use this kind of system, preparedness for such events in Croatia was very low and the “red-yellow-green” markers were adopted also for the assessment of damage. The main reason is misunderstanding of the usability and damage among society and engineers who don’t have enough experience in the earthquake engineering. The 6 levels exist: N1 (red colour): Not usable due to external risk N2 (red colour): Not usable due to damage PN1 (yellow colour): Temporarily unusable - detailed inspection required PN2 (yellow colour): Temporarily unusable - emergency remediation measures required U1 (green colour): Usable without restrictions U2 (green colour): Use with precaution The different operational levels arise from the combination of the Damage Status and the Degree of Vulnerability established by the Ordinance.
POSSIBILITY OF APPLICATION	Any kind of structure
PROCEDURE	The damage on the structural elements is estimated on the basis of the extent of damaged area and visual inspection of an engineer. The vulnerability is estimated on the basis of the construction deficiencies.

INVESTIGATED AREAS	In addition to the estimate of the extent of the lesions, the following are assessed for the deficiencies: thin wall thicknesses; bad quality of the walls; absence of connections in the masonry; presence of masonry columns; excessive size of the rooms; ineffective connections between floors and walls; presence of arches and vaults; presence of thrusts on the roof
DEFINITION PERID	2020 - 2021
COMPILER	HCPI – Croatian centre for earthquake engineering and the, certificated civil engineers
COMPLEXITY	LOW
LIMITS	The real purpose is to obtain funding for the reconstruction. Although, the vulnerability is not the primarily targeted value, it can be assessed.
ADVANTAGES	The criteria used to identify the deficiencies take into account the real vulnerabilities of existing masonry buildings
CURRENTLY USED	YES
LINK	http://www.casopis-gradjevinar.hr/archive/article/2969

Pre-earthquake assessment approved by standards

A prerequisite to assess the seismic vulnerability of an area or country is the existence of a catalogue of building types. This enables to analyse the shortcomings of each building type, including the influence of the geometric and/or structural modifiers. Unfortunately, a standard building typology catalogue for Croatia has not been generated (Hadzima-Nyarkoand & Kalman Šipoša, 2017). This lack of current building stock data was also pointed out in the NERA project (2011), where six European countries were identified for such an analysis by Cambridge Architectural Research Ltd. (CAR)-Iceland, Switzerland, Serbia, Bosnia and Herzegovina, Montenegro and Croatia.

However, an attempt was made in the "Disaster risk assessment for the Republic of Croatia – earthquake (2015)", where special forms, similar to the 2nd level GNDT forms proposed in Italy, were prepared to overcome the lack of building inventories (database of buildings/structures). These forms for damage assessment of characteristic building types at the level of return periods, harmonized with design regulations, were used to systematize all available data, including statistical data from 2011. The forms include the analysis of characteristic construction types for city districts or municipalities with regard to: the type of structure, time of construction, intensity of earthquake loading (reference load and design load), height (number of floors), horizontal and vertical regularity, load bearing elements for horizontal and vertical load, type of foundations, soil type, etc. For the hazard definition the map of earthquake-prone areas in Croatia was used, without including the additional influence of soil.

Analyses were made by preparing initial assessments according to EMS-98 classification procedure, complemented by expert estimates based on knowledge of the design of similar structures and, especially, based on the knowledge of specific "local" conditions in particular which is otherwise not covered in EMS-98 (including, for instance, faults, landslides, quality of construction, specific construction typology, etc.).

The analysis is still rather approximate as it only considers different types of structures per city district, but it represents nevertheless a step forward in building vulnerability analyses as it uses more detailed data about the structure (load-bearing system). These forms have proven to be satisfactory considering the predefined criteria (category of consequences), although they constitute only a first step towards state-of-the-art risk assessment methods.

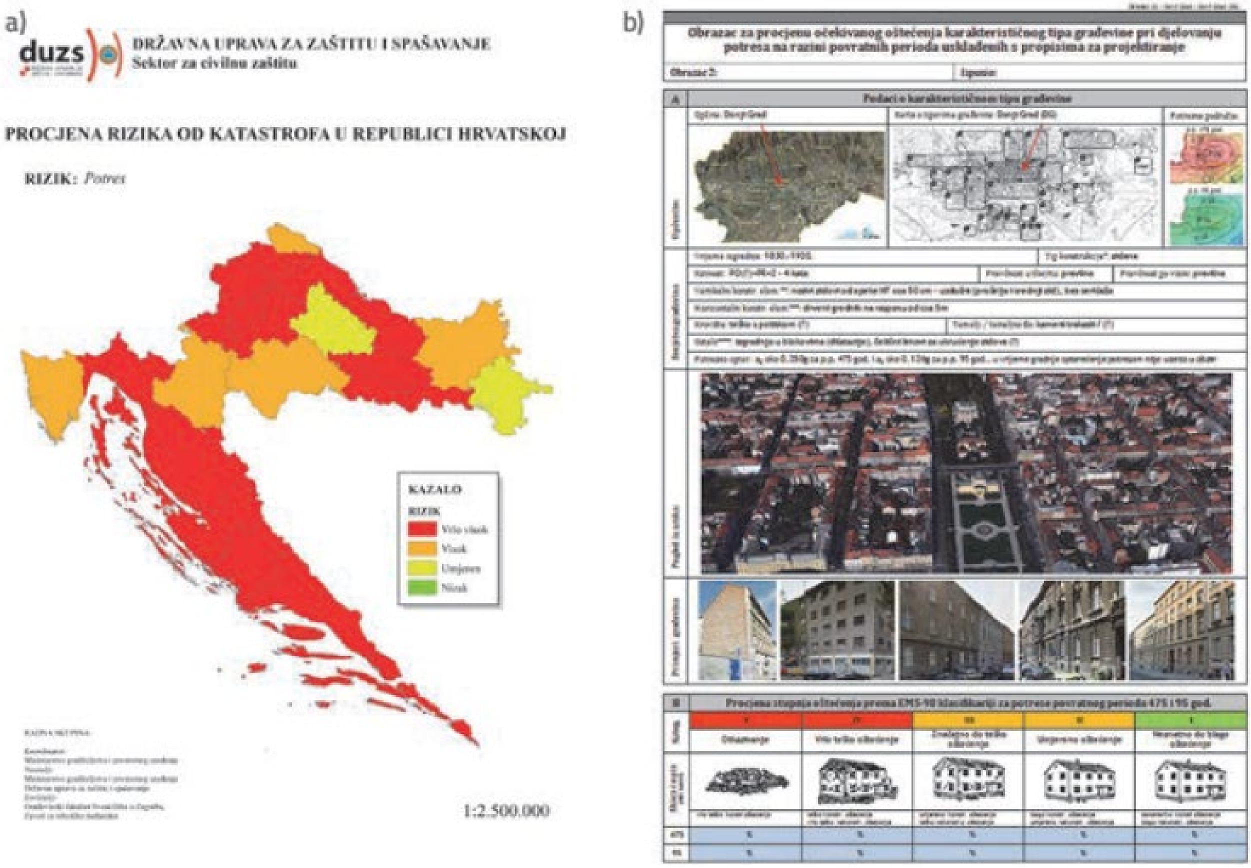


Figure 26 – On the left, rough risk assessment for counties; on the right, forms for the damage assessment of characteristic building types at the level of return periods harmonized with design regulations (Atalić, Šavor Novak, Uroš, 2019)

DESCRIPTION	***2nd level GNDT FORM***
CODE	B.4
MAIN CHARACTERISTICS	They are more in-depth than the 1st level, as they analyze a specific building. The compiling of the form often follows the compilation of the 1st level form.
POSSIBILITY OF APPLICATION	Isolated buildings; masonry buildings, RC buildings, timber buildings
PROCEDURE	EMPIRICAL EXPEDITIOUS METHOD - Compilation of preformed factsheet, on-site investigations and numerical modelling, on the basis of instructions indicated by “Post-earthquake damage assessment of buildings – procedure for conducting building inspections” (Uroš et al., 2020) and by the “Law on Reconstruction of Damaged Buildings in the City of Zagreb, Krapina-Zagorje, and Zagreb County” (Zakon o Obnovi Zgrada Oštećenih Potresom Na Području Grada Zagreba, Krapinsko-Zagorske Županije i Zagrebačke Županije, 2020)
INVESTIGATED AREAS	Type and organization of the resistant system; resistant system quality; conventional resistance; location of the building and foundation; horizontal structures; planimetric configuration; elevation configuration; roof; non-structural elements; actual state, response of each element, material properties of the investigated building. Each parameter is counted through a factor, based on the influence it has on the global seismic behaviour
DEFINITION PERID	2020 -

COMPILER	HCPI – Croatian centre for earthquake engineering and the, certificated civil engineers
COMPLEXITY	HIGH
LIMITS	It is an attempt to move to a behavioural approach. The expected behaviours are few, since the typologies of the same structural element would be various (for example, in the case of masonry, the material, the texture, or the components of the mortar). At the same time, a strong simplification is generated, which leads to obtaining data in a much simpler and therefore reliable way. Very complex, it requires on-site investigation followed by numerical modelling
ADVANTAGES	Very good insight in the state of the building itself
CURRENTLY USED	YES
LINK	https://www.zakon.hr/z/2656/Zakon-o-obnovi-zgrada-o%C5%A1te%C4%87enih-potresom-na-podru%C4%8Dju-Grada-Zagreba%2C-Krapinsko-zagorske-%C5%BEupanije%2C-Zagreba%C4%8Dke-%C5%BEupanije%2C-Sisa%C4%8Dko-moslava%C4%8Dke-%C5%BEupanije-i-Karlova%C4%8Dke-%C5%BEupanije
APPLICATION	

Pre-earthquake assessment for research activities

Although individual studies on earthquake risk assessment in Croatia had started long before the EC requirement, they had never been conducted in a systematic way. Currently, several risk assessments are available based on different methodological approaches and conducted by experts from various disciplines (Atalić, Šavor Novak, & Uroš, 2019).

The University of Osijek plays an important role in the field of seismic risk due to its long-standing research, especially for the rapid assessment of the seismic risk in urban areas in Croatia. Intended as a potential first step in the identification of high-risk areas and in the preparation of the building database for the City of Osijek (fourth-biggest city in Croatia with about 110,000 inhabitants). More than 1500 buildings have been included in this database so far (Hadzima-Nyarko, 2019). The analysed buildings/structures were divided into fifteen distinct typologies including schools, kindergartens, suburban buildings, old city core buildings. Specific vulnerability curves were also developed for some of these building.

Among the various assessment methods for the analysis of seismic vulnerability, that proposed by the Faculty of Civil Engineering, University of Osijek, was based on the vulnerability index.

Trying to briefly describe such experiences: the first analysed procedure is a relatively simple and fast analysis of potential seismic vulnerability proposed by Croatian researchers **Morić, Hadzima and Ivanušić** (Morić, Hadzima, & Ivanušić, 2002). The research provides a detailed analysis of the basics of seismic vulnerability analysis, especially introduces the notion of damage index (DI) as a numerical value indicating the level of structural damage (Morić, 2002).

Damage models aims to quantify the structural damage as a result of seismic action. They are based on state variables, which should be able to describe the degradation/the state of the structure during the loading. Examples of these variables are displacements between plans, deformations at member or section level, ductility demand, stiffness, energy dissipated etc.

Alternatively, damage index (DI) is a value capable to quantify the amount of damage, it can involve one or more variables. Damage indices can be determined based on the response of the structure to a particular loading pattern or based on the dynamic response of a structure. The overall seismic response indicators summarise the complexity of structural response in a single value. Therefore, DI is a mathematical model for

the quantitative description of the damage state of the structures and, in most cases, it correlates with the actual damage in earthquakes.
Therefore, Morić proposed that the seismic response analysis of regular structures is acceptable if it is performed through a simplified non-linear dynamic analysis with the time history function of ground motion as input load, and through an SDOF model with known weight, elastic stiffness, damping, elastic base shear capacity and post-elastic stiffness representing the structure. A deterministic formula of the DI was defined as a linear combination of plastic deformations, stiffness degradation and energy dissipation of a structure during an earthquake.
In order to relate the parameters of real buildings, seismic loads and DI, a detailed analysis of the dynamic properties and post elastic parameters of vertical and horizontal structural RC elements (columns and walls) was also performed. This was done using the available databases of the experiments carried out with standard cyclical loading: one database containing the results of tests of 265 RC columns with rectangular cross-section and the second database containing the results obtained on RC walls. All results were displayed in the form of load-displacement curves, which were used to define post-elastic stiffness and yield base shear. Finally, using the results and database obtained during these researches, a software program was created for RC frame and wall structures (Earthquake Damage Analysis of Building Structures (EDABS)). It relates structural dimensions with the dynamic properties and the global DI of structures for various earthquakes.
(Hadzima-Nyarko, Nyarko, Draganić & Morić, 2011a) implemented the DI values in pre- and post-earthquake damage analysis by relating the DI values with the values of damage level identification according to the EMS-98.

In 2016, (Hadzima-Nyarko, Pavić & Lešić, 2016) performed a method using collected information and parameters that influence the building vulnerability (plan, type of foundation, structural and non-structural elements, type and quality of materials). The method is indirect because through the vulnerability index, which was acquired by combining data from different building types of a specific area collected by observation in situ, the relation between seismic action and the response is obtained. While the seismic action is defined in terms of macroseismic intensity, the building's seismic quality has to be described by means of a vulnerability index VI.
This index depends on the behaviour of the structural system. For each typology, a vulnerability index (VI) is defined by the most likely value (VI*) attributable to the type (e.g., the typological vulnerability index), which is computed as the centroid of the membership function.
The behaviour modifier, Vm, which modifies the building vulnerability, is associated to geometrical features of the construction (number of stories, roof loads, plan irregularities, irregularities in vertical planes, length of facade), the state of conservation and to its position in relation to the adjacent buildings.
A regional vulnerability factor, Vr, takes into account building typologies at a regional level that affects the vulnerability due to traditional construction techniques in different areas.
An analytic expression is defined for the operational implementation of the methodology; accordingly, the mean damage grade, μD, is defined as a function of the macroseismic intensity I and depends on two parameters: the vulnerability index VI and the ductility index Q.

Kalman Šipoš and Hadzima-Nyarko stated (Kalman Šipoš & Hadzima-Nyarko, 2017) that developed countries have resources for accurate quantification of the expected damage with a detailed risk analysis with precise description of the actions that are implemented in the organization of risk management of threatened cities. However, developing countries, like Croatia, have resources and available data with no earthquake disaster preparedness. Therefore, for a developing country that does not have the funds to implement all the measures in all the cities, the reduction of seismic risk at local (municipality) level is unnecessary. In a first stage, identification of problems and awareness raising towards the social and political context of cities can be implemented through a rapid evaluation of seismic risk.

So, the main aim of their study is to determine the seismic risk for Croatia as relative rapid methodology through convolution of hazard and exposure.

The assessment was based on previous research (Carreño, Cardona, & Barbat, 2007; Salgado-Gálvez, et al., 2016) where urban seismic risk was developed with a holistic approach. They developed a conceptual multidisciplinary framework for the seismic risk analysis of urban centres. In this method, where the risk by indices is achieved affecting the physical risk with an impact factor, available data on socioeconomic fragility and lack of resilience at urban level are necessary.

The concept of index-based urban seismic risk assessment based on a set of factors is the basis of the method. The calculation of aggravating factors and of weights, which represent the relative importance of each factor by means of the Analytic Hierarchy Process (AHP), is carried out using transformation functions.

The application of this concept on a new urban area requires a large number of data that are not available in all countries. Therefore, a rapid relative seismic risk assessment is an adaptation of the previous methodology that can be obtained for every country based only on statistical census data for buildings and population.

The major objectives of the study by Kalman Šipo and Hadzima-Nyarko are:

- to develop an assessment for rapid prediction of seismic risk for an observed region based on general risk inputs: hazard, building age and population data.
- to explore and validate the possibility of using the developed methodology for a different region.

The development of rapid assessment includes the seismicity, possible vulnerability of the building stock and population density.

Cardona and Barbat defined the risk (Rie|T) as the probability of loss or as the loss average in an exposed element and as a consequence of the occurrence of an event with intensity larger than or equal to i during an exposition period T. Hazard (Hi|T) is defined as the probability or as the average expected rate of occurrence of an event with an intensity greater than or equal to i during an exposition period T.

Vulnerability (Ve) is defined as the intrinsic predisposition of the exposed element to be affected or to be susceptible to suffer a loss following the occurrence of an event with intensity i.

Using these definitions, risk is a function (f) of the convolution between hazard Hi and vulnerability Ve during an exposition period.

Thus, for this study, seismic risk is an interaction between seismic hazard and vulnerability (humans or their built environment) and therefore can be expressed qualitatively as: $R = H \cdot V$.

High seismic hazard does not necessarily mean high seismic risk and vice versa. There is no risk if there are no buildings with inhabitants, even though there is a high seismic hazard.

Therefore, a risk assessment is defined under seismic excitation that has a direct influence on vulnerability:

$R_{build} = F_H \cdot V_{build}$

$R_{pop} = F_H \cdot E_{pop}$

Where R_{build} and R_{pop} represent the risk regarding the building potential damage and the threatened population respectively, V_{build} and E_{pop} are building and population vulnerabilities, F_H is a factor that presents seismic hazard for the observed region or city.

Regarding buildings, they stated that seismic vulnerability is one of the main causes of death during an earthquake; therefore, buildings must be safe in order to reduce the loss of human lives. The element of risk can be a single dwelling in a building, a collection of them or similar buildings (apartment block, part of a village), or public services in a particular area. In a large number of elements, like building stocks, vulnerability may be defined in terms of the number (or percentage) of threatened buildings.

The age of construction parameter for buildings identifies the conditions of design standards as well as the requirements of the building codes, thus it is directly related to the vulnerability.

In order to assess the vulnerability of buildings throughout Croatia, statistical methods were used with the acquisition of standard data regarding the age of dwellings. Regarding this issue census data are available for every municipality and city in Croatia and were used in the application of the relative rapid assessment method. On this base, the age distribution of the dwellings for Croatia was determined.

The vulnerability of buildings V_{build} depends on the weighted sum of a set of eight factors related to the construction age, $F_{build,i}$, that are multiplied with weights, wi, which represent the relative importance of each factor. The maximum value of V_{build} is taken as 1.

$$V_{build} = \sum_{i=1}^{8} w_i \cdot F_{\mathrm{build,\,i}}$$

Impact factors for dwellings vulnerability $F_{build,i}$ are defined according to building construction age data (empirical) from census data. These functions standardise the gross values of dwellings in municipalities and cities in Croatia for 8 time intervals by transforming them into commensurable factors with cumulative lognormal functions.

If the construction period of the building group is known, it is clear that an approximate conclusion on their seismic resistance and on the effect of seismic action could be made. To identify the weight of impact factors for the vulnerability of buildings (dwellings) and the most influenced building classes, previous studies were reviewed.

Based on the construction age distribution it is possible to assign the distribution of vulnerability classes using the EMS-98 scale.

Country	Σ	$F_{build,1}$[a] before 1919	$F_{build,2}$ 1919–1945	$F_{build,3}$ 1946–1960	$F_{build,4}$ 1961–1970	$F_{build,5}$ 1971–1980	$F_{build,6}$ 1981–1990	$F_{build,7}$ 1991–2000	$F_{build,8}$ after 2001
Croatia	1,496,558	112,217	84,963	138,858	288,563	325,203	247,084	129,687	143,535
%	100	7.63	5.78	9.45	19.63	22.12	16.81	8.82	9.76

Figure 27 – Construction age distribution for dwellings in Croatia (Kalman Šipoš & Hadzima-Nyarko, 2017)

EMS-98 vulnerability class		A	B	C	D	Sub-indicators for AHP method
Building class		Stone masonry, earthen buildings	Brick masonry	Masonry with RC slabs, pre-code RC frames	Post-code RC frames	
Age	Before 1919	**76%**	24%	-	-	$w'_1=1.0$
	1920-1945	**62%**	38%	-	-	$w'_2=1.1$
	1946-1960	46%	**49%**	5%	-	$w'_3=2.0$
	1961-1970	18%	38%	**44%**	-	$w'_4=3.0$
	1971-1980	5%	40%	**55%**	-	$w'_5=3.4$
	1981-1990	-	38%	**57%**	5%	$w'_6=3.6$
	1991-2000	-	28%	**62%**	10%	$w'_7=3.8$
	After 2001	-	18%	**69%**	13%	$w'_8=4.0$

Figure 28 – Modified vulnerability and building class distribution for the buildings in Lorca by construction age (Kalman Šipoš & Hadzima-Nyarko, 2017)

It can be concluded that since the structures are newer, their physical vulnerability is lower due to better construction practice and design standards. As no such data existed for the country, and assuming similar construction methods in time intervals in Croatia and Spain, the data were used for Croatia.

The method uses these information as an aid in the Analytic Hierarchy Process to generate scales of weight ratios. The weights, wi, that indicate the importance of every $F_{build,i,}$ are subdivided from w1 to w8 (for eight construction age time intervals) and calculated by means of the Analytic Hierarchy Process (AHP) which is used to derive ratio scales from pair-wise comparisons.

The Analytic Hierarchy Process (AHP) is a widely used technique for multi-attribute decision making. It allows the decomposition of a problem into hierarchies and ensures that both qualitative and quantitative aspects of a problem are incorporated into the evaluation process, during which opinion is systematically extracted by means of pair-wise comparisons. AHP is a compensatory decision methodology because alternatives, which are efficient with respect to one or more objectives, can be compensated by their performance with respect to other goals. This procedure transforms the application of data, experience, insights, and intuition in a logical and thorough way within a hierarchy as a whole.

The core of AHP is an ordinal pair-wise comparison of attributes, sub-indicators in this context, in which preference statements are addressed.

For a given objective, comparisons are made for pairs of sub-indicators by first asking the question "Which of the two is the more important?" and secondly "By how much?". The strength of preference is expressed on a semantic scale of 1–4, which keeps measurement within the same order of magnitude. A preference of 1 indicates equality between two sub-indicators while a preference of 4 indicates that one sub-indicator is 4 times more important than the other.

The comparisons are being made between pairs of sub-indicators where is easy enough to make a distinction. The most important aids were prevailing percent of buildings for a given vulnerability class. These comparisons led to the proposed values of the sub-indicators for the AHP method: for scale from 1 to 4 means that buildings (dwellings) with factor 1 (older buildings from stone masonry – w'1) have 4 times higher possibility for vulnerability in regard to buildings build after 2001 (w'8). Respectively, buildings that were built between 1946 and 1960 (w'3) have 2 times higher possibility and so on. Consequently, the same vulnerability class indicated a similarity in possible behaviour that led to a small change in the preferences of the sub-indicators (w'1–w'2; w'5–w'8). These defined values resulted in comparison matrix W' which has 8 rows and 8 columns.

In columns, values are calculated according to ratio wi/wi = 1,..,8, which derives ratios with value 1 on matrix diagonal. Therefore, every number represents the relative contribution (weights) of the two sub-indicators.

The relative weight values wi from the comparison matrix are calculated using an Eigen vector technique: each element of the matrix is divided with sum of its column, so this gives the normalized relative weight of each element. The results of averaging the values between the rows are the relative weights wi for impact factors of dwellings vulnerability.

One of the advantages of this method is that it is able to check the consistency of the comparison matrix by calculating the eigenvalues. AHP tolerates inconsistency through the amount of redundancy. For a matrix of size n×n, only n-1 comparisons are needed to establish the weights for n indicators.

The Consistency Index (CI) is obtained by first calculating the Eigen value λmax derived from the sum of the products between each element of that vector and the sum of columns of the Comparison matrix. Finally, a CI can be calculated from (λmax-n)/(n-1), where in our case λmax and n are equal to 8. The True Consistency Ratio (CR) is calculated by dividing the CI by the Random Index (RI = 1.41, for n = 8, by Saaty) for the corresponding matrix W'. The CR was equal to zero, which means that the judgments are perfectly consistent.

The number of dwellings by age construction is obtained from Census data. The impact factors $F_{build,}$,in fact, is derived from cumulative lognormal functions and then multiplied with relative weights for each factor. The V_{build} of 0.763 indicates the possible vulnerability according to buildings construction age.

The impact on human beings is the most important component for any kind of disaster. Since the risk assessment depends on the number of exposed people and their vulnerability, it is necessary to know the updated and detailed population exposure data of the observed area.

It is very important, also, to acquire the spatial information of the distribution of people in order to understand the impact and potential consequences of any natural disaster. The main source data on local population is the national census with data from all cities or municipalities in Croatia.

Usually, these data are available at the administrative level and provides the population data by residence or dwelling. The residential population databases are useful for exposure assessment purposes with the assumption that the majority of the people are in their homes. Since the census data represents the night-time population as residential people, the use of these information in population casualty estimation may produce considerable error for day-time scenarios; in any case it results in worst possible risk scenario. Population distribution was captured in form of population density (people/km^2) and taken from census data.

After creating the indicators for vulnerability of buildings and population, the final task is to derive the results and highlight the potential risk areas from the aggregation of the indices.

As illustrated before, data of population exposure were derived from Census data and then transformed into E_{pop} according to cumulative lognormal distribution. An expected earthquake excitation for every city was defined according to Seismic hazard map for Croatia. The hazard factor was obtained and then, after multiplication with V_{build} and E_{pop}, the relative potential risks were calculated in terms of risks for buildings according to their construction age R_{build}, and population R_{pop} , related to population density. Average relative risk R is the mean value of individual risks R_{build} and R_{pop} per city in Croatia.

The evaluation of seismic risk of 127 cities in Croatia was performed using the proposed methodology for Counties with low risks (< 0.5) and cities with moderate (0.5–0.75) to high (> 0.75) individual risk.

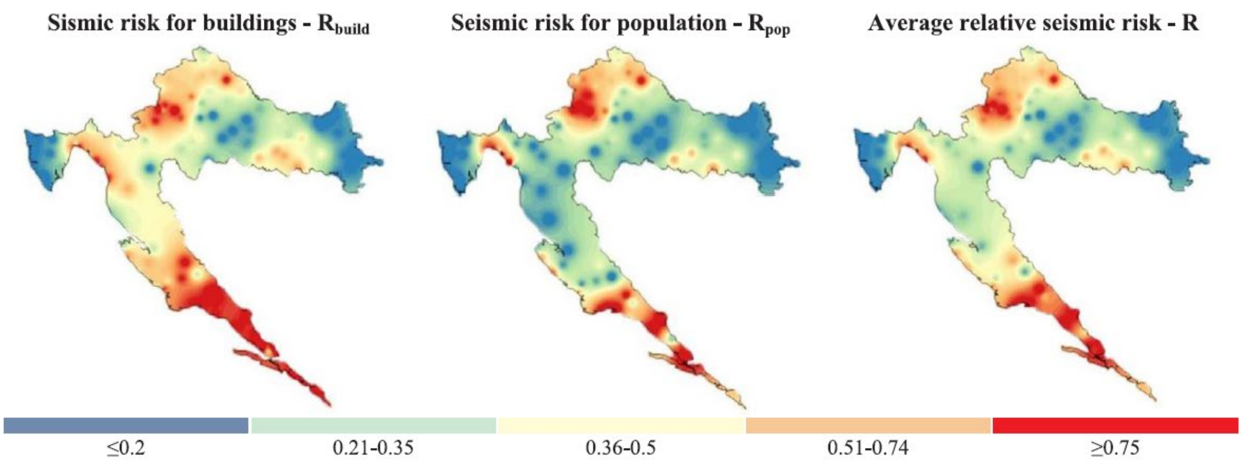


Figure 29 – Seismic risk for Croatia according to Relative RAPID seismic risk assessment (Kalman Šipoš & Hadzima-Nyarko, 2017)

The result show that the eastern and central localities in Croatia have the least critical situation, from the point of view of physical and social seismic risk, because the risk indicator is negligible. The localities with a greater risk factor are the north and west of Croatia. The highest values of the risk index, in addition to capital city of Zagreb, are the localities of south Croatia, on the Adriatic coast, where during the summer holidays the number of tourists can double the population density (higher potential risk of the population).

All risks considered can have a very strong direct or indirect impact on pre-disaster emergency within the affected area, thus for regions with moderate to high seismic risk, a detailed approach is necessary with mandatory early warning or post-disaster emergency and relief actions.

At the initiative of the Croatian Crisis Management Association (HUKM), an assessment was made for four cities, within the EMSN-039 (2017), for Zagreb, Split, Rijeka, and Dubrovnik, through the activation of the Risk and Recovery Mapping component of the Copernicus Emergency Management Service.
The assessment was conducted by Indra Sistemas S.A. based in Madrid, Spain. The basic idea behind this assessment was to make use of data obtained mainly through satellite imagery combined with support of other available services, e.g., OpenStreetMap. The seismic hazard was defined on the base of the existing Map of earthquake-prone areas in Croatia and data from the 2011 census were used to create the exposure layer of information. The geostatic raster layer with 100 m accuracy was used for visualisation of input and output parameters.
The available building data were classified according to height, type and material. Appropriate weighting factors were used (ALARP principle) and, finally, the level of vulnerability at city block level was obtained overlapping different maps and by means of risk matrices. The results obtained in this way provide only a relative vulnerability relationship, which is a very rough estimate and cannot be used to quantify the negative impacts.
According to the available information, the authors of the study plan to correct the present shortcomings and further adapt the results to requirements of emergency response planning (e.g., evacuation routes).

The updated "Risk assessment for the Republic of Croatia" is the most recent risk assessment work for Croatia (2018); it represents a significant step toward more accurate estimation of disaster risks.
It is based on the risk assessment study conducted in 2015. However, the aim of this updated assessment was to correct the previously observed deficiencies, especially those related to exposure and respective vulnerabilities, as well as to include all available data from all existing risk assessments. This updated assessment was carried out by the Faculty of Civil Engineering as the main executive in collaboration with the Faculty of Science, both with the University of Zagreb. The scenario "Ground shaking in the City of Zagreb caused by the earthquake at the level of return period harmonized with regulations for the design of seismic resistance", used in the assessment made in 2015, was also adopted in this assessment as well due to the exceptional significance of the City of Zagreb.
Seismic hazard was defined in accordance with the "Map of earthquake prone areas in the Republic of Croatia" for horizontal peak ground acceleration with return periods of 475 and 95 years and evaluated at the centroid of each local board of the City of Zagreb. The influence of local soil conditions was not taken into account as the detailed micro-zonation activity was still in progress.
The inventory of the building stock was conducted over a more detailed administrative classification of the city, involving 218 local boards, was used in this updated assessment.
The biggest step forward in this assessment is the focus on the identification of specific data on the structural systems of buildings. Thus, those most frequently encountered in the city were first clearly identified (14 typologies), and then the proportion of each type in the total number of residential occupancy buildings was defined. The procedure included selection or group of buildings with similar properties and assignment of the corresponding load-bearing system.
At the level of individual local districts, each type of structural system was associated with the respective number of residents so that the number of casualties could be estimated from the expected number of heavily

damaged and collapsed buildings. In the second phase of the study a building categorisation scheme with 42 typologies was introduced.

The vulnerability analyses of the exposed buildings and evaluation of the respective economic losses were carried out using fragility and vulnerability curves. A set of curves was associated to each individual structural type and the procedure was conducted according to the macroseismic method as reported in the RISK-UE project. The classification of damage was conducted following the EMS-98 scale with five damage states and the vulnerability of buildings was communicated by means of vulnerability index.

Damage factors (DF) were then assumed in order to relate the economic losses to the expected structural damage. DFs associate the cost of repair for each damage state with the total replacement cost of the building. Thus, vulnerability curves for each building type were obtained by convolving building fragility curves with the cumulative cost of a given damage state.

These vulnerability curves for characteristic building types represented the basis for estimation of economic losses and fatalities for seismic scenarios in Zagreb.

Just before the earthquakes in Zagreb in Petrinja in 2020, Stepinac et al. (Stepinac, Kisicek, Renić, Hafner, & Bedon, 2020) published the research paper dealing with the methods for the assessment of critical properties in existing masonry structures under seismic loads. They stated that the main characteristic of Croatian buildings constructed in the period before the 1970s is represented by the use of traditional constructional techniques and materials, such as masonry and timber. Buildings were built as full-brick masonry structures, with mostly wooden ceilings, and 30 – 60 cm thick walls, thus resulting in statically satisfactory structural assemblies. 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.

European Union directives clearly suggest the energy renovation of existing structures, but structural aspects are somewhat ignored and/or disregarded. At the moment, a number of existing structures are in fact under energy renovation and/or energy upgrading processes. Besides such a consideration for energy performances, however, structural assessment and/or structural upgrading is mostly disregarded. According to an estimate of total investments in Europe, for the period between 2014 and 2049 (including initial investment expenditures, maintenance and replacement of worn-out equipment), around 3×10^9 Euros will be dedicated to energy processes. In such an expected scenario, it is thus clear that structural updating and retrofitting can (and must) represent an additional value for the energy renovation of buildings. This is especially the case in existing masonry structures, which, in most cases, need robust seismic strengthening interventions.

At the moment, there is a huge knowledge gap in the assessment methods and design checks of existing structures. Without appropriate guidelines, it is difficult to approach the problem, and this often leads to the wrong interpretation of collected data, and, thus, wrong decision scenarios for the reinforcement and rehabilitation of existing structures. The development of investigation techniques for the updating of material properties will help in reducing the uncertainty associated with the prediction of the structural behaviour of existing structures after or before the earthquake. Their research project will provide knowledge about the building stock in Croatia, assessment of existing masonry structures and prediction of material properties from NDT. In addition, one of the current project goals is to evaluate updating methods of properties for the application of the assessment and verification methods for structures, including consideration of time-dependent behaviour and the influence of environmental conditions. Further research on material properties (and also its variability), risk assessment and modelling is, hence, necessary. It is important to clearly define which parameters must be tested, and which may be calculated (i.e., is it necessary to measure mortar characteristics or are they similar for the Croatian building stock? Is it necessary to measure shear strength or will the well-known expressions approximate the values appropriately?). In this regard, case studies after the earthquakes are examined and exact procedure for the post-earthquake damage assessment and modelling should be developed.

Assessments of building damage and usability were of primary importance after the Zagreb earthquake of 22 March 2020. Due to deficiencies of preparatory phase, where education of experts was not carried out before the earthquake, but later on, the assessments contained certain subjectivity and interpretations, based on knowledge and experience, but also on intuition of individuals. Detailed methodology, which should improve rapid assessments and detailed engineering inspections to be performed before reconstruction, is highlighted in the paper by Uroš et al. (Uroš, et al., 2020). This methodology may be utilized if another devastating earthquake occurs, which could happen already tomorrow.

The papers by Stepinac et al. (Stepinac, Kisicek, Renić, Hafner, & Bedon, 2020) and Šavor Novak et al. (Šavor Novak, et al., 2020) are having the focus on post-earthquake assessment, damage classification, and failure patterns of residential buildings in Zagreb after the earthquake. Furthermore, the data collected in the rapid post-earthquake assessment were analyzed and discussed. These researches are based on the data from HCPI database (HCPI - Hrvatski Centar Za Potresno Inženjerstvo, 2020) and the authors' collections. The papers are also discussing construction typologies and valid standards throughout the history in the city of Zagreb. In the city of Zagreb, about 29 % of housing units were built before the first seismic code was implemented (1964), 28 % of the housing units were built considering the first seismic code (1965 − 1980), 39 % were built considering the improved seismic code and ENV. Housing units built after 2013 were designed according to EN 1998 code.

The Law on Protection and Rescue (Vlada Republike Hrvatske, 2017) requires an assessment of the endangerment of the population, material and cultural goods, and the environment from disasters and major accidents in Zagreb. The law includes natural disasters such as floods, earthquakes, droughts, snow, landslides, etc. However, the law is somewhat incomplete and does not mention the damage to housing units but it is more related to agricultural and industrial assets. The new Ordinance on guidelines for the preparation of risk assessments for natural disasters and large accidents for the Republic of Croatia and local and regional administrative units represents a step toward harmonization with the EC guidelines. A brief overview of the risk assessment indicates that earthquakes are superficially considered together with the analysis of several other risks selected for the areas under study.

The earthquake critically damaged buildings that are important architectural achievements and ruptured Zagreb's historically recognizable city center. The vast majority of buildings built after the first mandatory earthquake regulations in the former Yugoslavia (i.e. since 1980s) survived the earthquake without damage or suffered little damage. However, most of the buildings in the historic center (Upper and Lower Town) were severely damaged. It is estimated that 72 % of the whole building stock was damaged in zone A and more than 40 % in Zone B - 6,651 damaged buildings in total (Zones A and B are historical city center of the Zagreb). According to the previously explained post-earthquake classification (red or N, yellow or PN, green or U), of 2,889 damaged buildings in zone A, 1,561 were green-tagged, 1,088 were yellow-tagged and 240 were red-tagged, while in zone B of 3,762 damaged buildings, 2,927 were green-tagged, 737 were yellow-tagged and 98 were red-tagged. The residential buildings with usability tags are presented on the 3d map of the historical city center in Figure 12, while Figure 13 presents a typical building block. In this block 37 buildings (43 % of all damaged buildings) were green-tagged, 40 (47 %) were yellow tagged and 9 (10 %) were red-tagged.

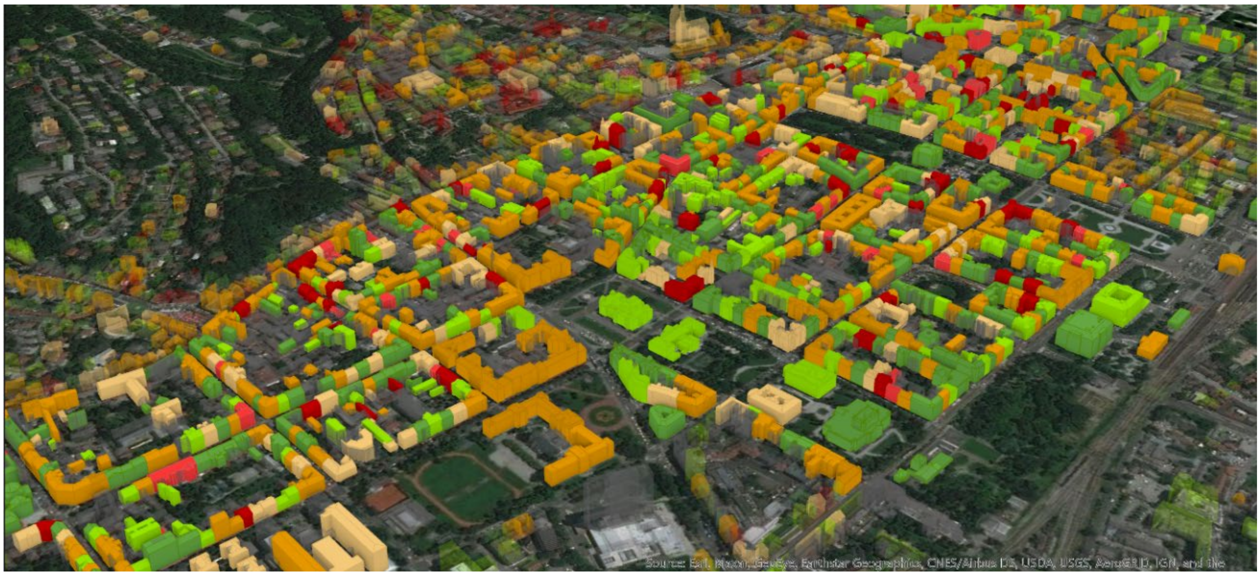


Figure 30 – Detail of the evaluation of the usability of buildings in the historic center of Zagreb (Stepinac, Lourenco, Atalić, Kišiček, Uroš, baniček & Šavor Novak, 2021)

The papers are analysing the preliminary data used from the database, which was supplemented by field engineers. A procedure for rapid post-earthquake assessment was not previously defined in the country, meaning that specific education of engineers and other relevant experts was missing. The rapid assessments' results need to be further calibrated and harmonized with the detailed reviews provided by the new Act for the reconstruction of Zagreb. The general conclusions are that the damaged buildings are generally old and built before the adoption of seismic regulations. The materials in them are deteriorated. Furthermore, the buildings are usually inadequately maintained and often seismically poorly constructed and intervened (if applicable). The most common failure modes are local (not global) in-plane and out of plane mechanisms. Significant damage is observed in secondary and/or decorative parts of buildings, such as chimneys, roof tiles and gable walls. The global collapse of buildings was very rare. Besides issues related to the existing vulnerable building stock developed with pre-seismic codes, the level of damage was increased due to unauthorized adaptation of ground floors for commercial activities, addition of new floors to buildings, removal of load-bearing components, and other structural modifications. There seems to be a general lack of awareness and perception of seismic risk within the community, coupled with a lack of prevention targeted to awareness-raising actions. Informal settlement and construction without valid permits were not taken into account in this paper, even if those buildings were heavily damaged during the earthquake. This earthquake exposed Croatian building stock's vulnerability that should be mitigated as efficiently as possible in the coming years. Novel approaches in assessment procedures should be applied together with state-of-the-art repair and reconstruction of the damaged buildings. The earthquake also initiated numerous activities that will help in the adequate rehabilitation and reconstruction of the city. Raising the level of knowledge is the key to success in achieving these goals. Numerous workshops and consultations have been organized, books and manuals were published, and a new Law on Reconstruction of Damaged Buildings in the City of Zagreb, Krapina-Zagorje, and Zagreb County was recently published, prescribing procedures and minimum requirements for proper rehabilitation. Several city centre residents were forced to act quickly and repair the damaged parts of the building so they could continue to live there. Some reconstructions were done inadequately or not consistent with the conservation guidelines, changing the appearance of the urban protected core, despite the fact that most of the city centre is a protected cultural heritage.

Regarding the rapid assessment methods, Stepinac and Gašparović (Stepinac & Gašparović, 2020) published a paper on possibilities of emerging technologies for an assessment of safety and seismic vulnerability and damage detection of existing masonry structures. In their research the literature review on modern technologies for the assessment of seismic safety and vulnerability of existing structures is explained. Special focus is set on unmanned aerial vehicles (UAV) and supporting equipment, as well as, photogrammetry and close-range remote sensing. The automatic building damage detection and mapping based on the photogrammetric 3D methods and remote sensing techniques are discussed and explained on a case study of one damaged building in Zagreb after the earthquake.

A combination of the data from "traditional" assessments with the results from modern techniques can help us in the identification of weak structural parts and components (faults, big cracks, and openings, short cantilevers, and walls, short columns, soft storeys). With the knowledge of the architectural background and styles of the city, a quick estimation of the period when the building was built can be obtained, i.e., in Croatia, tall windows can tell us that the building was built during the Austro-Hungarian times. This data can relate to construction methods, wooden ceilings, lack of glazing and confiners, greater wall thickness, different material quality, etc. All these important factors are influencing the seismic behaviour of the existing structure. With measurement data of foundation settlings, soil stiffness can be assessed or may indicate some differential settling. In addition, the building stiffness can be estimated, which can lead to an estimation of the number of internal walls. Assessment of roofs with UAVs can identify the deformation of roof plates and can serve as a basis for the identification of internal walls, which can also lead to estimation of stiffness. With thermography, different building materials can be identified (masonry vs. concrete) and existing confining elements with their dimensions and location in the structures can be pointed out. With a combination of methods, and estimation of wall thicknesses (with basic geometry) quick interpretation of structural safety can be estimated. Deformation of outer walls obtained by photogrammetry combined with energy losses by thermography and architectural rules of the construction period, and with expert opinions can lead us to a rough estimation of the number of walls (considering the knowledge of load-bearing plate system). All of the mentioned activities can give us the level of seismic vulnerability and safety of the existing structures. The obtained data, new procedures, and techniques can help us in the estimation of seismic risks of bigger regions or building blocks (Stepinac & Gašparović, 2020).

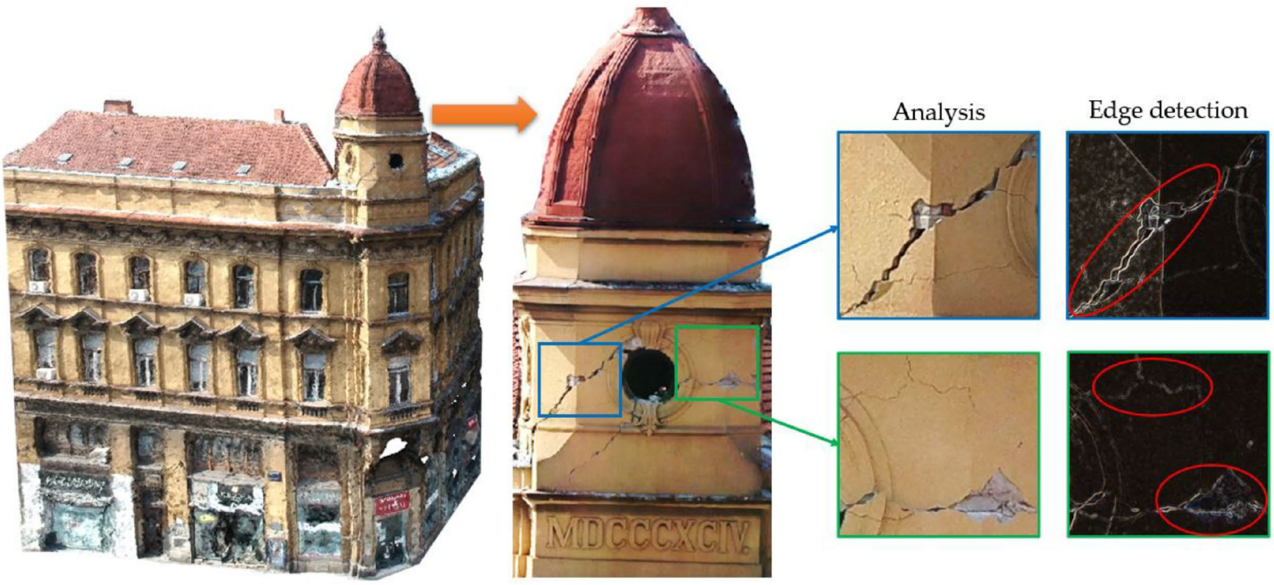


Figure 31 – Automatic building damage detection and mapping based on the photogrammetric 3D methods and remote sensing techniques (Stepinac & Gašparović, 2020)

DESCRIPTION	***Rapid procedure for seismic damage assessment and vulnerability analysis of masonry buildings - University of Zagreb***	***SP-BELA METHOD - SIMPLIFIED PUSHOVER-BASED EARTHQUAKE LOSS ASSESSMENT FOR MASONRY BUILDINGS by European Centre for Training and Research in Earthquake Engineering (EUCENTRE), Pavia, Italy and Università degli Studi di Pavia, Italy***
CODE	C.12	C.13
MAIN CHARACTERISTICS	The method evaluates the vulnerability of masonry buildings located in mostly historical centres by considering the possible collapse mechanisms and the related importance factors associated to them	Simplified pushover-based earthquake loss assessment method for the definition of vulnerability curves
POSSIBILITY OF APPLICATION	Masonry existing buildings and adobe masonry buildings	Conceptually, the method may be applied to any structural typology; it is employed to study the vulnerability of masonry buildings
PROCEDURE	ANALYTICAL EXPEDITIOUS METHOD - it uses a non-linear pseudo-static structural analysis with a degrading pushover curve to estimate the performance points by way of a variant of the N2 method, included in EC8 part 3	ANALYTICAL EXPEDITIOUS METHOD - For the determination of the capacity curve, the resistance of the building and the displacement values associated with predetermined damage limit conditions are defined. 3 reference limit states have been taken into account in relation to structural damage only. These are: • Limit State 1 (SL1) - Limited damage: the building hit by a seismic event is still usable without the need for repairs and reinforcements; • Limit State 2 (SL2) - Severe damage: the building cannot be used after an earthquake has occurred, but needs repairs and reinforcement; • Limit State 3 (SL3) - Collapse: beyond this limit condition, the building is no longer safe for the safety of the occupants. The structural capacity is defined through the pushover curve with a behavior similar to a piecewise linear curve
INVESTIGATED AREAS	Identifying the occurrence of possible different mechanisms for a given masonry construction typology, given certain characteristics. Itallows to obtain a measure of the probability of reaching and / or exceeding a certain level of damage: this damage is associated with local rupture or collapse mechanisms, and therefore it is possible to consider the D2 degree of damage, with reference to the classification of the apparent damage provided by the EMS98 macroseismic scale	To characterize the behavior of masonry buildings, the collapse mechanisms are classified into collapse mechanisms in the plane and collapse mechanisms out of the plane. The hypothesis is that, in order for the building to have a global collapse mechanism, i.e. involving the entire structure, the collapse mechanisms in the floor must be activated before the out of plane collapse mechanisms
DEFINITION PERID	2020 - today	2008 - 2017
COMPILER	Technician in charge	Technician in charge
COMPLEXITY	MEDIUM	MEDIUM
LIMITS	Method used so far post-earthquake assessments on earthquakes that have occurred, even if for preventive purposes	Method used so far post-earthquake assessments on earthquakes that have occurred, even if for preventive purposes
ADVANTAGES	Method developed on a numerical quantitative basis, on-site investigation and numerical modelling	Method developed on a numerical quantitative basis, although approximate

CURRENTLY USED	As a research activity and in the reconstruction of the damaged areas	As a research activity
LINK	http://www.casopis-gradjevinar.hr/archive/article/2969	https://www.researchgate.net/publication/233375391_Simplified_Pushover-Based_Earthquake_Loss_Assessment_SP-BELA_Method_for_Masonry_Buildings
APPLICATION	Regions affected by the earthquakes in 2020 based on the database https://www.hcpi.hr/	Whole Croatia

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability; the conducted literature search showed that there have been no significant studies in Croatia on this topic.

6.3 Albania – PP4 (Gjirokaster)

Interesting data for the study of the current approach to the topic of seismic vulnerability assessment methods in Albania come from the implementation of the DesInventar methodology, developed through funding by the Global Facility for Disaster Reduction and Recovery (GFDRR), a partnership between Australia, Canada, Denmark, the European Commission, Finland, France, Germany, Italy, Japan, Luxembourg, Norway, Spain, Sweden, Switzerland, the United Kingdom, the United Nations International Strategy for Disaster Reduction , the USAID Office of US Foreign Disaster Assistance, and the World Bank. The GFDRR mandate is to help developing countries reduce their vulnerability against natural hazards. UNISDR, CIMA Research Foundation and the General Directorate for Civil Emergencies have completed the historical collection of disaster loss data for the entire Albanian territory. These data have been collected using the DesInventar methodology, a conceptual tool for the construction of databases of losses, damages and effects caused by emergencies or disasters (Toto & Massabò, 2014). This document helps us to understand the impact that seismic events have had on the country's-built heritage over the past 160 years. More than 4.000 events have been recorded for Albania in the entire period from 1851 to 2013. The country is vulnerable to multiple disasters ranging from geophysical, hydrological, meteorological, climatological and technological.

Meteorological events are the most commons (33% of the total), followed by climatic events (22%), Hydrological events (21%) and Landslides (14%). However, this study is focused on earthquake data.

The Institute of Geoscience, Energy, Water and Environment (IGEWE) has a database containing historical data on the occurrence and losses due to earthquakes. This data includes seismic events from 1851 to the present. Few records of disasters are available for the period from 1851 to 1945 and most of them are related with the historical earthquake database. The series of records show a high number of registered events in the last 20 years. However, this may be a reflection of the scarcity of data before 1993 when only major disasters were reported and recorded. The average number of events per year is 4.5 with a maximum of 17 in 2009 (Toto & Massabò, 2014).

In the country, the most affected districts are Tropoje (12 events) and Diber (14 events), while the municipalities are Peshkopi (4 events) and Fierze, Himare, Berat, Margegaj, Hekal, Polis (with 3 events each). Earthquakes affect nearly 20% of the communes, confirming the high seismicity of the area.

The analysis of the time trend of house damages from 1946 to 2013 shows that two major earthquakes destroyed/damaged more than 50,000 dwellings (35,000 in 1982 and 17,000 in 1979). In the last 20 years, the

houses damaged are 5 times the houses destroyed. On average there are almost 120 houses destroyed, or damaged, per year with a peak of 1,200 houses destroyed or damaged in 2009.
However, when considering the entire time-series (from 1851 – 2013), the number of houses destroyed or damaged rise to almost 500 per year and 600 per event, with a maximum of about 17,000 houses destroyed in 1982 and 17,000 houses damaged in 1979 (Toto & Massabò, 2014).
Furthermore, earthquakes are the events with the highest mortality.

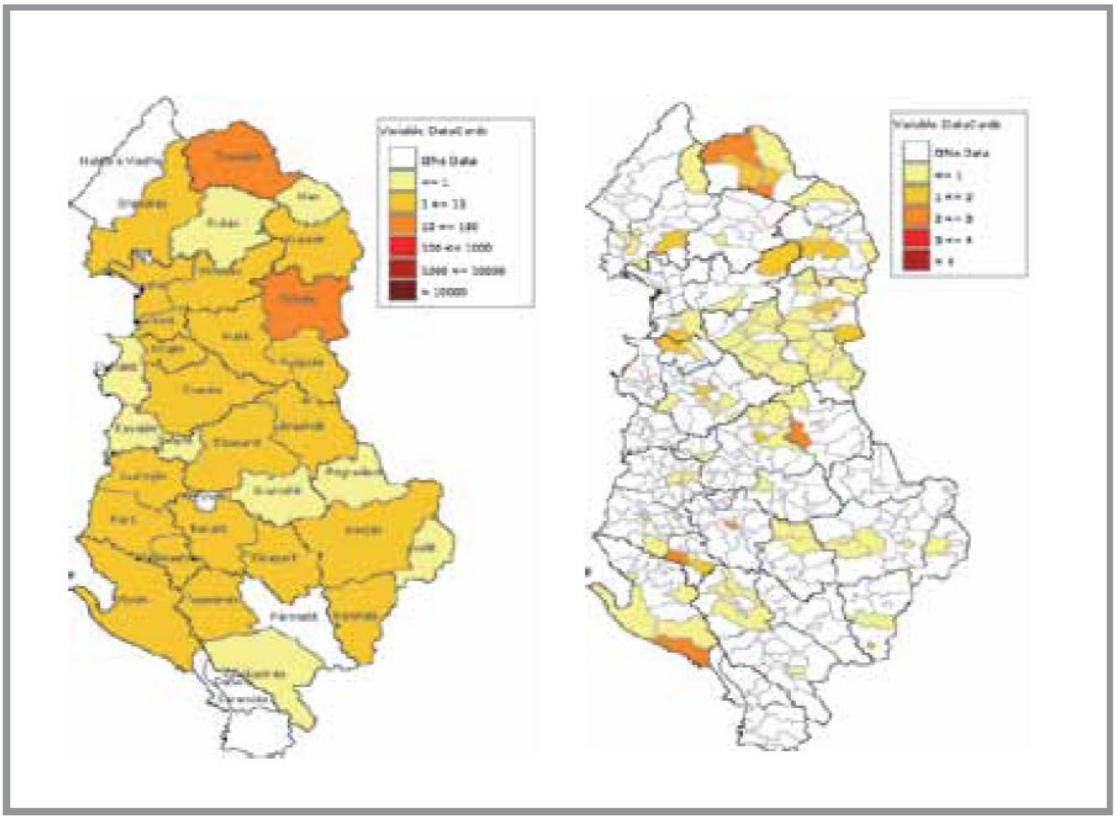


Figure 32 – Spatial distribution of earthquakes in the districts and municipalities (Toto & Massabò, 2014).

According to the housing 2001 census, the Albanian building stock is mainly composed of four typologies: prefabricated, bricks and stones, wood, and other construction materials. The bricks and stones category represents the vast majority of the building stock.
Although it is not the most updated one, is the last census providing a building classification based on construction materials. In contrast, when referring to the most recent census (2011), information on building materials is not included, and constructions are classified according to their (low- to high-) height and year of constructions. The latter is an important parameter to identify the design code adopted for the individual building class. Although the available data may be obsolete, they show that a large percentage of Albanian buildings were constructed before 1990 and thus before the introduction of the 1989 seismic code. After 1990, a significant growth in the number of buildings is observed. However, between 1990 and 2000, due to poor law enforcement and a lack of compliance with design standards, many buildings were likely constructed without permission, or even adequate engineering assurances. Therefore, it is to be expected that buildings constructed during this time have deficiencies affecting their seismic performance.
The last high intensity earthquake detected in the Albanian area was on 26th of November 2019, and it constitutes the most recent experience in terms of assessment methods; the study of what happened during

this earthquake allows us to confirm that the approach to seismic vulnerability in recent years has been more oriented towards the damage survey rather than prevention.
Immediately after the event, a rapid post-disaster damage assessment consistent with the GRADE (Global RApid post-disaster Damage Estimation) methodology, was undertaken by the World Bank (World Bank, 2019). The objective was to estimate the economic impact of the earthquake, including its spatial distribution, to support recovery and reconstruction. Subsequently, in December 2019 and January 2020, this assessment was further developed in the form of a Post-Disaster Needs Assessment (PDNA) that was implemented through collaborative efforts of the Government of Albania and its international partners: the European Union, the United Nations agencies and the World Bank.

Post-earthquake survey

In the context of seismic vulnerability study, many methodologies are available for rapid pre- and post-earthquake visual inspection of structures, while the most popular and widely used is the FEMA method for Rapid Visual Screening (RVS) or Rapid Visual Inspection (RVI) of Buildings (FEMA P-154, 2015; FEMA 356, 2000). The NZSEE (NZSEE, 2017), the Japan Building Disaster Prevention Association (1990) and the GNTD (GNDT, 1993) are also widely applied methodologies for Rapid Visual Screening (ETAM, 2019).
The FEMA-prescribed RVI procedure uses a methodology based on building inspection and requires the completion of a data collection form based on visual observation of the building from the outside and, if possible, from the inside. The two-page data collection form includes building identification information (i.e., usage, area, floor number, etc.), a photograph of the building, sketches, and documentation of pertinent data related to seismic performance. Based on the data collected during the survey, a score is calculated that provides an indication of the expected seismic performance of the building.
Simple survey procedures for seismic risk assessment are proposed and applied to urban building stocks to provide damage statistics (Sucuoglu & Yazgan, 2003). After the 2019 earthquake, the team composed of experienced and qualified civil engineers from the Hellenic Association of Earthquake Engineering (HAEE/ETAM) in collaboration with the Earthquake Planning and Protection Organization (EPPO/OASP), the University Network of Seismic Engineering Laboratories of Italy (ReLUIS) and the University of Bristol (UoB), used the Post-Quake RVI (SAFER) app: a tool developed by the University of Bristol following its first pilot application during the 2016 central Italy earthquake (Sextos, et al., 2018; Stewart, et al., 2017). A rapid visual survey tool was required to perform Post-Quake RVI in order to store the relative information in an online database.
For each building inspected, the app retrieves the GPS location (Sextos, Kappos, & Stylianidis, 2008), while the user stores (and the app wirelessly transmits) external and internal photos and general building information affecting its seismic performance (structural system, extent of damage, number of storeys, soil conditions, etc.). Furthermore, information about the type of damage (e.g., beam flexural or shear damage, panel out-of-plane cracking, etc) is also collected for each building. The data from all inspected buildings is then saved and uploaded to a central data server that is accessible through a dedicated WebApp (ETAM, 2019).

Figure 33 – Post-Quake RVI (Safer) mobile app (ETAM, 2019)

The RVI was performed for selected buildings using the Post-Quake RVI application (SAFER). The buildings were inspected mainly from the exterior and, in some cases, also from the inside.

The extent of the damage was classified as light, moderate, severe (major) and collapse in accordance to the four pre-earthquake performance objectives defined in FEMA 356 against which the post-earthquake damage description is classified.

Since a number of parameters such as: the structural system and materials used, age of construction, building height (number of storeys), the existence of irregularities in plan and elevation, construction phases, soil type, etc.; strongly affect the structural performance, they were also collected as part of the assessment. However, for most cases, where architectural and design drawings were not available, or for cases where it was impossible to inspect the interior of the buildings and identify the structural configuration on site, the report does not provide any explicit interpretation of the damage mechanisms (ETAM, 2019).

Target Building Performance Levels	Post-earthquake Damage	Qualitative description (FEMA 356)
Immediate Occupancy Level (1-B)	*Light*	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of facades, partitions, and ceilings as well as structural elements. Elevators can be restarted. Fire protection operable
Life Safety Level (3-C)	*Moderate*	Some residual strength and stiffness left in all stories. Gravity-load- bearing elements function. No out-of- plane failure of walls or tipping of parapets. Some permanent drift. Damage to partitions. Building may be beyond economical repair.
Collapse Prevention Level (5-E)	*Severe (major)*	Little residual stiffness and strength, but load- bearing columns and walls function. Large permanent drifts. Some exits blocked. Infills and unbraced parapets failed or at incipient failure. Building is near collapse.
	Collapse	-

Figure 34 – Qualitative description of damage states according to FEAM 356 (ASCE, 2000) and association with observed post-earthquake damage states (ETAM, 2019)

During the field inspection, the data were combined with those collected by the Earthquake Engineering Field Investigation Team (EEFIT, UK) and resulted into inspection surveys for 75 buildings mainly in Durrës and Thumanë. Even if the area considered in Adriseismic does not correspond to the locality most intensely affected by the 2019 earthquake, some results of the survey can help us to understand what the construction characteristics could be and, consequently, the seismic performance of similar buildings in the Gjirokastra area.

The categories of structural systems considered are similar to the ones prescribed in FEMA 154 (FEMA P-154, 2015). Most of the 75 buildings inspected were reinforced concrete (RC) buildings and the most common structural systems were RC4 (RCMRF - Modern Code-24%) and URM2 (Unreinforced Brick Masonry with RC slabs-19%). When the classification considers the height of the buildings, the most common structural typologies of low-level buildings (i.e., less than 5 stories) are URM1 (Unreinforced Brick Masonry -29%) and URM2 (Unreinforced Brick Masonry with RC slabs-23%). For taller buildings with more than (or equal to) 5 stories, the most common structural typology was RC4 (RC-MRF - Modern Code-38%) and RC2 (RC-MRF - Old Code -19%).

It should be noted that the sample of buildings inspected during the field survey referred mostly to damaged buildings, so the statistical distribution and conclusions should be evaluated considering that the sample was not unbiased in terms of seismic performance.

Most RC buildings designed with old codes (RC2) and unreinforced brick masonry (URM1) suffered severe damage. Buildings designed with modern codes (RC4) and unreinforced (confined) masonry with RC slabs (URM2), perform better, but there were cases where they suffered light or moderate damage. When building height (number of floors n) is introduced as a classification criterion (with a threshold of n=5), it is evident that for low to medium buildings (n < 5) the damage extend is greater in URM buildings with the majority of URM1 and URM2 developing major damage or collapse. The latter were mainly unreinforced brick masonry (URM1) and RC buildings designed with old codes (RC2), while those designed with modern codes (RC4) experienced a lower level of damage. In the case of buildings of medium to high height (n ≥ 5), most RC buildings designed with modern codes (RC4) suffered only slight to moderate damage, while most older RC buildings (RC2) and unreinforced brick masonry with RC slabs (URM2), suffering moderate to major damage (ETAM, 2019).

The extend of the damage is greater for lower buildings (n < 5, T~0.5sec) in accordance with the response spectra, where for both cases (i.e., earthquake records at Tirana (TIR) and Durres (DURR) station), the spectral amplification is higher for a period range T=0,2~0,5sec.

The described damage statistics on the limited sample of 75 characteristic buildings inspected are in good agreement with the comprehensive post-earthquake inspection campaign in Tirana (World Bank, 2019). It is also noted that the distribution of tags (green, yellow, red) between the city and the municipality of Durrës was also similar (approximately 60% deemed 'safe').

The most frequent type of damage for both buildings of medium-low height (H<5m), URM (unreinforced masonry) and medium-high RC (H>=5m) was in-plane and out-of-plane wall failure. As expected, beam and column, bending and shear damage were more frequent for buildings designed with the old codes (RC2).

Both low-medium and high-medium height buildings develop in-plane and out-of-plane failure of infill panels, while in-plane failures are more frequent for low-rise buildings, which can be expected given the flexibility of high-rise buildings. Moreover, RC column bending failure is more frequent in medium-high height buildings, while shear and short column failure are more frequent for low-medium height ones, as expected (ETAM, 2019).

Overall, the damage level developed can be characterized as disproportionate to the seismic intensity. However, the damage patterns developed are similar to observed cases after strong seismic events in other parts of the world, where poor construction quality was also reported.

The Earthquake Engineering Field Investigation Team (EEFIT) also decided to organise a reconnaissance mission to the Albanian region following the 2019 earthquake, visiting the areas of Bubq, Laç and Lezhë, Durrës Beach, and the village of Thumanë (Freddi, Novelli, & Gentile, 2021).

The rapid visual survey of the structures affected by the November 2019 Albanian earthquake was undertaken through a quick, external-only survey. The focus was on identifying the location of building, general information about geometry, building typology (including the structural system, the roof and floor typologies), and general comments about the failure mechanism (if any). With particular reference to the qualitative damage assessment, the European macro-seismic scale (EMS-98; Grünthal 1998) was adopted. This provides five damage states—from DS1, light damage, to DS5, total collapse, in addition to the of no damage state (DS0)— defined for buildings with mixed structural systems, RC frames, prefabricated large panel, URM and CM walls, as well as historical assets (Freddi, Novelli, & Gentile, 2021).

During this mission, the information was stored in a spreadsheet and uploaded on a server at the end of each day. Moreover, the team decided to experiment the use of two damage assessment apps, under development at the time of the mission, to provide feedback to the developers.

During the four days of field mission, approximately 70 structures were inspected; the majority of these were RC frames (without any core wall or with a small core) and URM, which approximately represent respectively 65% and 30% of the inspected building portfolio. Other building typologies identified include prefabricated large-panel and CM buildings (Freddi, Novelli, & Gentile, 2021).

70% of the inspected buildings are residential while the remaining are public buildings including schools, hospital, and fire brigades. The EEFIT team also visited selected cultural heritage sites including several towers, and religious buildings, and fortification walls. One bridge was also included in the mission, representing the only assessed infrastructure (Freddi, Novelli, & Gentile, 2021).

Most of the investigated buildings in Durres are made of RC, while URM ones are encountered almost uniformly in all visited areas. Within the investigated stock, the URM ones are characterised by a maximum of five storeys. As expected, most of these buildings were built before the 1990. About 10 of the inspected URM buildings were assigned to DS4 due to the serious structural failure observed on the masonry walls and slabs.

Only a few CM buildings were surveyed and only one of these showed a diffuse damage condition and was assigned to DS4.

The RC buildings vary between 2 and 12 storeys, with 10-storeys ones being the most frequent among those inspected. Approximately 30 of the inspected RC buildings were built after the 2000s, while less than 10 were built between the 1980s and 1990s.

The vast majority of the RC buildings were assigned to DS3, mainly due to the cracks in the infill walls, often with expulsion of individual infill panels. It is worth mentioning, however, that no structural damage (or very little) to RC members was observed.

Many 5-floors prefabricated large-panel buildings were identified in Durrës and the other districts, some of which have been visited during the field investigation. The year of construction of these structures is probably around the 1980s. All the prefabricated large-panel buildings (RC prefabricated in the figures) have shown a negligible damage condition consistent with DS1. Only small cracks were found in the joints between the panels, with no observed damage in the dowel connections (Freddi, Novelli, & Gentile, 2021).

Pre-earthquake assessment approved by standards

Albania has a long history of code-regulated seismic design. The first seismic standards, accompanied by the first seismic zonation of Albania, were adopted in 1952. The 1963 revision increased the seismic design requirements, while the 1978 revision with the KTP 2-78 did no bring significant improvements. In 1989, the new seismic design code, KTP-N.2-89, was published and is currently the official seismic design code in Albania. KTP-N.2-89 covers a wide range of structural configurations and, for each of them, provides design provisions. Consistent with modern seismic provisions worldwide, KTP-N.2-89 is based on the design concept of providing the structure with adequate ductility, allowing the dissipation of the seismic input energy through nonlinear cyclic deformations without compromising its integrity. It includes principles common to many modern seismic design codes for building structures, such as regularity in plan and elevation, considerations on the mass and stiffness distribution, symmetry, simplicity, etc.

Considering the code as a whole, it can be stated that KTP-N.2-89 shares common principles with modern seismic design codes such as Eurocode, but it lacks several detailed recommendations. For example, it requires columns to be stronger with respect to the adjacent beams but does not provide a quantitative formulation to perform this hierarchy check. To overcome these issues, in more recent years, the community of structural engineers often uses the good practices from Eurocode 8 as integration to the KTP-N.2-89 in their daily practice.

It is worth noticing that the above conditions focus on protecting the structures from collapse, while no detailed recommendations are provided regarding damage limitations. In fact, no inter-storey drifts limits are provided by the code to protect the infills from in-plane loads, even though it requires that they maintain their integrity during seismic events.

The study of bibliographic references allows us to state that currently, in the Albanian territory, vulnerability assessments on existing buildings are conducted according to standard requirements, i.e. through analytical procedures, based on the performance-based design approach, and that no expeditious procedures are currently applied.

This design method involves a set of procedures through which a building structure is designed in a controlled manner so that its behaviour is assured at predefined performance levels under seismic loading. A non-linear analysis tool is required to evaluate earthquake demands at various performance levels. Pushover analysis is widely adopted as the main tool for such nonlinear analysis because of its simplicity compared to dynamic procedures (Baballëku, 2006).

The basic idea of performance-based design is to design a structure so that it behaves in a specified way when subjected to various levels of earthquake. The aim is to couple the structural requirements with performance expectations, to ensure that the hazard is dealt with consistently and to recognize the financial losses associated with damages as well as the failure to perform as expected (Baballëku, 2006).

DESCRIPTION	***Mechanical methods***
CODE	B.5
MAIN CHARACTERISTICS	They predict the seismic response of the building by using an appropriate mechanical model of the whole building or of an individual structural element
POSSIBILITY OF APPLICATION	Any kind of structure; for aggregates of buildings, the single structural units are considered
PROCEDURE	Modelling of the entire building or aggregate of buildings using a finite element calculation software
INVESTIGATED AREAS	Methods belonging to this group are the limit state method, such as the so called "kinematic" approach that identify by the lowest value of the multiplier load the weakest mechanism and, consequently, the most probable to occur
DEFINITION PERIOD	1989 - TODAY
COMPILER	Technician in charge
COMPLEXITY	HIGH
LIMITS	Non-expeditious methods that require specialized analysis to reach an in-depth knowledge of the characteristics of the materials
ADVANTAGES	Methods accepted by current legislation
CURRENTLY USED	YES
LINK	

Pre-earthquake assessment for research activities

A very interesting previous experience in terms of research comes from the TRANSISMIC project (2007), born from an intuition of the researchers who produced the recovery plan from the historic Old Albanian city of Gjirokastra, when they realised the risks associated with the collection of an important part of the city which, due to its historical values, has some serious problems in the reuse of buildings.

As part of the project activities, it was decided to set up a fast seismic risk screening in the Old Town, at relatively low cost, limiting the investigations to the outside of the buildings, without going inside.

The program, through the use of GIS maps, is designed to return data such as analysis tables and design-based mapping; it also helps to quickly identify the interventions that are of prioritized over others.

The project has mapped numerous aspects of the Gjirokastra site, such as the geological, morphological and lithological characteristics of the soils, the subsoil characteristics in terms of classification, the seismic amplification factors, hydrography.

As regards the buildings, extensive analyses were conducted on the seismic hazard (identifying 42.95% of the buildings falling into the lower level, i.e. level 1; 40.78% in level 2; respectively 14.75% and 1.52% in levels 3 and 4). The vulnerability of buildings was divided into 5 classes on the basis of typological characteristics (low, medium-low, medium, medium-high, high) with most of them in the low-medium class (42.3%), but a high number even in the high class (26.25%).

These data were combined with a classification of the state of conservation (with most of the buildings in the low vulnerability class, equal to 41.43%, and medium-low, equal to 30.18%), the number of floors, the vulnerabilities related to the construction system (also in this case the prevalent percentage falls into the low class, equal to 43.38%). The high vulnerability class is instead the prevailing one for the vulnerability linked to the resistant system (equal to 71.8%), probably due to the traditional stone construction techniques that characterize the local heritage.

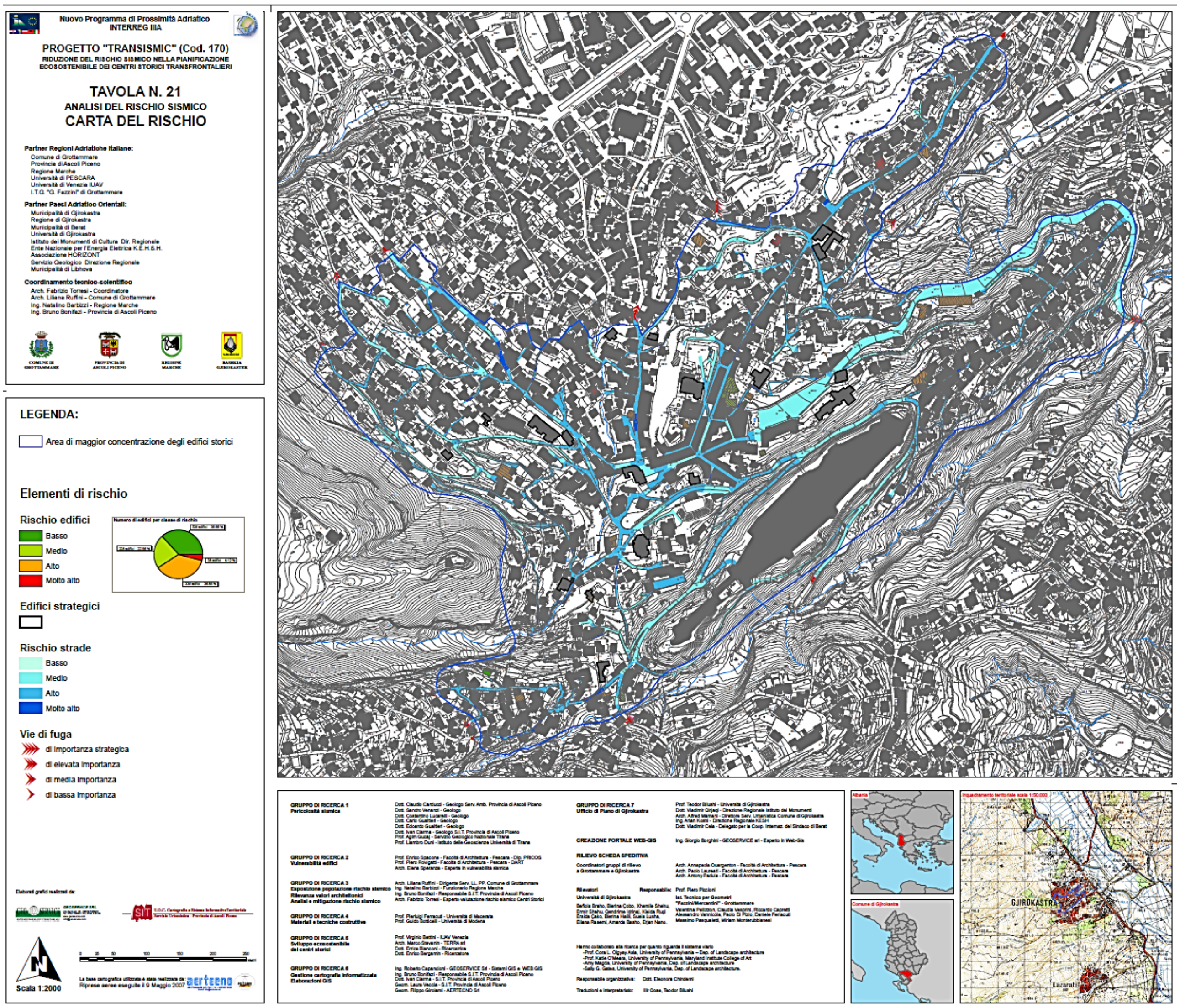


Figure 35 – Table 21 of the TRANSEISMIC project, with the identification of the seismic risk of buildings and roads

The final vulnerability of buildings derives from the previous classifications: 54.12% are in the medium class, 22.56% in the low class, 21.04% in the high class and 2.28% in the very high class.

The combination with the mapping of the exposure class and the direct and induced vulnerability of the road system leads to the definition of the overall seismic risk of the building in the historic centre, with most of the buildings in a low and high risk class (for both, the value is 36.66%), mainly medium or high risk roads.

Finally, the identification of buildings with relevant historical-architectural elements leads to the definition of intervention lines for the reduction of seismic risk, with 7 priority risk areas for the highest levels of buildings vulnerability, associating each of them with the methods of seismic vulnerability assessment and recommended interventions.

The exposure of the population at risk came form the definition of the number of citizens who suffer any damages related to the earthquake. The data were linked to the single building to facilitate the final synthesis. The elements for the definition of risk exposure are: S = Surface (detected from the maps); H = building height (measured from the survey form); D = Destination of buildings (taken from the survey form); V = estimated volume; NA = estimated settlement Capacity (Number of Inhabitants).

The historical and architectural relevance is the element of continuity with the recovery plan; it allows to assess the importance of the building in the historical context, assigning it a value compared to historical memory. The elements for the definition of risk exposure are: IP - Buildings of Public Interest; CO - Buildings in contrast; TM - Buildings of minor importance; CU - Buildings of Cultural Interest; ST - Buildings of typological interest; TU - Protected buildings.

DESCRIPTION	***TRANSISMIC project - THE ASSESSMENT AND REDUCTION OF THE SEISMIC RISK IN THE HISTORICAL CENTER, AS A NECESSARY CONDITION FOR THE REUSE OF THE HISTORICAL CONSTRUCTION HERITAGE.*** *The idea of the TRANSISMIC project was initiated by the intuition of respective group which, prior to this project, had already published the Recovery Plan of the Historical Centre of the Museum City of Albania – Gjirokastra.*
CODE	C.14
MAIN CHARACTERISTICS	It represents a non-definite final step towards reaching for the concern related to THE SEISMIC RISK AT A SPECIAL PART OF THE CITY WHICH IS CHARACTERIZED BY THE PRESENCE OF MANY ANTIQUE BUILDINGS.
POSSIBILITY OF APPLICATION	Historical Centre, Stone-based building, Stone and wood buildings, Masonry buildings, Cobblestone-streets
PROCEDURE	SPEDITIVE FILES – Use of matrix to determine the vulnerability of the buildings in order to further proceed on a total survey of the building. Gathering a large amount of information within a short period of time by not-that-expert personnel and trained within a short period of time. Less effect on data processing caused by subjective analysis of the personnel. The survey was limited only on the outer part of the buildings.
INVESTIGATED AREAS	Risk assessment of the historical area its respective antique buildings. The used approach: conducting a series of surveys on site. Gathering data concerning the lithological and seismic response of the terrain. Such data is put together with the morphological elements.
DEFINITION PERID	2000 - today
COMPILER	A group of the restoration architects lead by Fabrizio Torresi.
COMPLEXITY	HIGH
LIMITS	The impossibility of accessing the antique buildings in the historical area. Lack of data with regards to the ceiling of the buildings affects the interpretation of Vulnerability analysis. High cost of the analysis method in the TRANSISMIC project deprives the research to be deepened in its investigation.
ADVANTAGES	Precise cataloguing method; highly detailed; it provides a clear image of the seismic vulnerability of the historical area of Gjirokastra
CURRENTLY USED	YES
LINK	Not available (Available only as a PDF document, or as a hard copy)
APPLICATION	Gjirokastra

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability; the conducted literature search showed that there have been no significant studies in Gjirokastra on this topic.

6.4 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. 1979 Montenegro earthquake (M 6.9) and the 1977 Vrancea, Romania earthquake (M 7.2). In the last 100 years more than 10 earthquakes with magnitude (M) 5.0 or higher occurred in Serbia. The strongest earthquake in the 20th century (M 6.0) hit Serbia in 1922 with the epicentre close to Lazarevac. The most damaging earthquake in the 21st century was the 2010 Kraljevo earthquake (ML 5.4), which caused 2 fatalities and more than $US 100 million in damages (World Bank, 2016). Several other earthquakes affected rural areas, e.g. Rudnik, 1927 (M 5.9), Kopaonik, 1980 (M 5.8) and Mionica, 1998 (ML 5.7). The World Bank has estimated that national annualized capital losses in Serbia resulting from earthquakes are $40 million. This figure is an average value, and actual losses due to earthquakes are concentrated into specific catastrophic events. 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).

The Emergency Management Sector (EMS), Ministry of Interior Affairs, Government of Serbia (http://prezentacije.mup.gov.rs/svs/) is the government organization responsible for implementing relevant laws issued by the Government of Serbia related to disasters and emergency situations (Gazette Serbia 2018, 2015, 2012). There is also a National strategy for prevention and rescue in emergency situations (Gazette Serbia 2011). The EMS has initiated an effort to assess risk due to earthquakes and other natural disasters, which was approved by the Government of Serbia in 2019 (EMS, 2019).

Post-earthquake survey

Detailed post-disaster inspection of community infrastructures and building inventory is a common practice in all earthquake-prone countries, and it is the first activity in the reconstruction process because it provides required input for estimation of the economic losses incurred by the earthquake.

Most recent damaging earthquake hit Serbia on November 3, 2010 with the epicentre close to the city of Kraljevo (population approximately 68.000). The earthquake had the magnitude ML=5.4, and according to the international classification it is a moderate intensity earthquake. The energy released during the Kraljevo earthquake is about one-half of that released by the 1998 Mionica, Serbia earthquake (ML = 5.7), about 11 times less than the energy of the 1963 Skopje, Northern Macedonia earthquake (ML = 6.1), and about 250 times less than the energy of the 1979 Montenegro earthquake (ML = 7.0). The Kraljevo earthquake caused the collapse of significant number of single-family dwellings and damages of many other structures, including multi-family housing, educational and health facilities, heritage structures, etc. The Seismological Survey of Serbia documented the consequences of the 2010 Kraljevo earthquake (RZS, 2010).

The existing buildings in the Kraljevo region were built using various construction materials and structural systems (masonry, reinforced concrete, wood, mixed, etc.), which have different loadbearing capacities, rigidity and ductility characteristics, and consequently different earthquake performance. The experience gained from previous earthquakes of similar magnitude in the former SFRY showed that the earthquake should have caused structural damage only in older and/or poorly built masonry and wooden structures. In well-built modern masonry and wooden buildings, only minor structural damage is expected, while reinforced concrete structures should have remained undamaged in most cases. Based on the inspection of damaged buildings after the 2010 Kraljevo earthquake it was noticed that the main causes of severe damage and/or collapse of single-family masonry buildings were: 1) inadequate design of the basic load-bearing structural system and/or the horizontal/vertical extension, 2) poor quality of construction materials and improper execution of details and connections, 3) inadequate building maintenance, and 4) various combinations of the previously mentioned causes (Manić & Bulajić, 2013).

Multi-family residential buildings also experienced damage due to the earthquake, particularly masonry buildings with vertical extensions (additional floors) which were built before the first seismic code of SFRY was issued in 1964 (PTP, 1964). The main cause of damage was a lack of compliance with the provisions of existing regulations by the investors and designers involved in the design of extensions, or by the investors and contractors during the construction. In addition to the older buildings with extensions, structural damage was observed even in new multi-family apartment buildings with modern RC structures; the damage was mostly due to lack of competence or failure to comply with basic design and construction principles related to seismically resistant structures, poorly executed construction details and connections, and/or poor quality of materials and construction (Manić & Bulajić, 2012; Manić & Bulajić, 2013).

The post-earthquake damage survey contained data on building damage, classified into four damage states (DS) ranging from slight damage to collapse, as follows: DS0 - no damage, DS1 - slight damage, DS2 - moderate damage, DS3 - heavy damage, and DS4 – collapse (Serbian Chamber of Engineers, 2010). The survey was performed by local experts and civil and other qualified engineers who were summoned from all Serbian universities (Marinkovic et al., 2018). The first round of investigations (rapid survey) started almost immediately after the earthquake and it was focused on ensuring life safety of the occupants. The second round of surveys was performed to establish the damage states using two locally-developed survey forms (the “long” and “short” ones). The survey was performed within 6 months after the earthquake: 90% of the constructions were inspected during that period, averaging around 80 buildings per day. The use of “short” survey forms focusing on building safety was rapid, but it did not provide sufficient information to guide the recovery process. On the other hand, the “long” survey forms contained unnecessary, yet time-consuming, information (Marinkovic, Stojadinovic, Kovacevic, & Stojadinovic, 2018).

The City of Kraljevo coordinated collection of damage inspection reports, reconstruction funding, applications for repair permits, costs and durations of interventions, and the results of repair activities in terms of the return of the inhabitants to their repaired or new homes (City of Kraljevo, 2010). However, due to the problematic damage assessment approach the final information on the total number of damaged buildings has never been published. It should be noted that the building assessment was carried out by the commissions under the authority of the local government of the City of Kraljevo, while the damage estimation for other buildings and facilities was carried out by the commissions from the ministries who owned those buildings. Due to an absence of adequate analysis of the data of the examined buildings, critical information related to the consequences of this earthquake is not available, including natural (number and surface area) and material (monetary value) damage indicators, as well as the numerical distribution of damaged objects by the structural systems and damage extent (Manić & Bulajić, 2012).

In May 2014 Serbia suffered another disaster - the most severe flooding in 120 years. The disaster affected 22% of the total population and the estimatted losses were 1.35 billion €, corresponding to 4.8% of Serbia’s GDP (Nedeljković, Žugić, & Dragojević, 2021). The methodology for damage assessment that was utilised after the 2014 floods involved collecting available secondary information from different Government and private sources, verified and supplemented by the field visits of the assessment teams, to estimate the value and

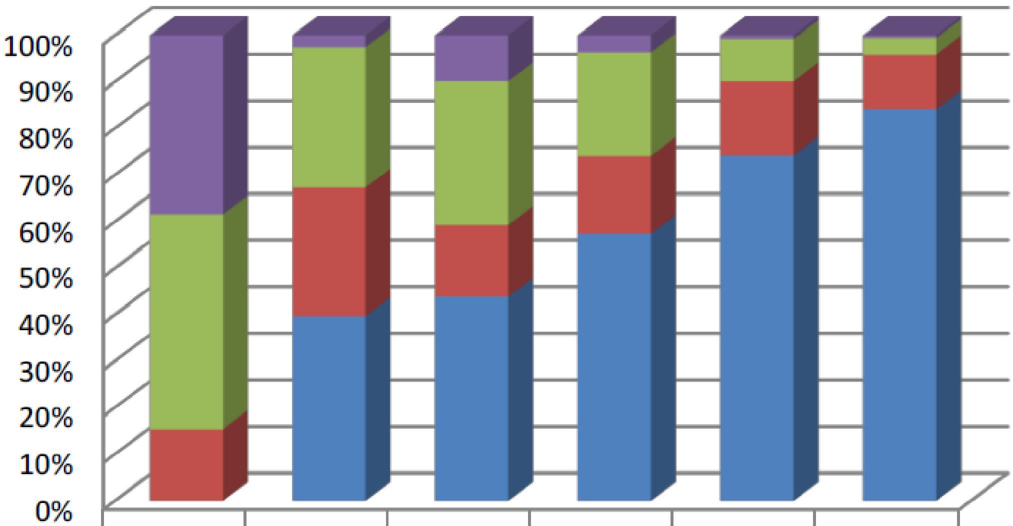
extent of physical assets destroyed and the changes in production flows of all affected activities (World Bank, 2014).
Currently post-disaster damage assessment process in Serbia is prescribed by the national Law of reconstruction (Gazette Serbia, 2015) as follows: local self-government units should form the required number of commissions to assess the damage caused after natural and other disasters on citizens' property in accordance with the Government act regulating the uniform methodology for assessing damage from natural and other disasters. The Public Investment Management Office (PIMO) verifies the damage assessment performed by commissions formed by the local self-government unit. The Serbian reconstruction law defines the verification process as an expert procedure which implies confirmation of the accuracy of damage assessment performed by the commissions formed by the local self-government unit (Nedeljković, Žugić, & Dragojević, 2021).

A major research study on residential buildings damaged in the 2010 Kraljevo earthquake was performed by Marinkovic et al. (Marinkovic, Stojadinovic, Kovacevic, & Stojadinovic, 2018). The information from the post-earthquake survey forms was used to classify the residential building stock into six types (BT) based on the architectural layouts and structural features:

- BT1: Traditional, stone foundation, wooden superstructure buildings (pre-1950's)
- BT2: Masonry structures, the old brick format (pre-1933)
- BT3: Masonry structures, the new brick format (post-1933)
- BT4: Masonry structures, horizontally reinforced concrete ring beams (1963-1975)
- BT5: Masonry str., horizontally and vertically reinforced concrete beams (1975-1990)
- BT6: Masonry str., horizontally and vertically reinforced concrete beams (1990-today)

A database of 1193 damaged buildings was created by the authors. The distribution of damage states across the building types shows that the traditional constructions (BT1) suffered the most extensive damage (84% of the database entries were in the DS3 and DS4 states, while the most recent masonry buildings types with reinforced concrete ring beams (BT5 and BT6) suffered only slight damage (90% and 96% of the database entries are in DS1 and DS2 states combined), see Figure 36.

In 2017, Stojadinovic (Stojadinovic, Kovacevic, Marinkovic, & Stojadinovic, 2017) used earthquake damage data from the Kraljevo earthquake reported by Marinkovic et al. (Marinkovic, Stojadinovic, Kovacevic, & Stojadinovic, 2018) to develop an earthquake damage and repair cost prediction framework for individual residential buildings and portfolios of residential buildings. The framework was developed using a machine-learning algorithm, and gives as an output both the individual building fragility and the aggregate portfolio-level vulnerability data. The calculation of the expected repair cost for each building type was done using an expert-defined matrix that specifies average repair costs for each building type and damage category.



	BT1	BT2	BT3	BT4	BT5	BT6
DS4	38%	3%	10%	4%	1%	1%
DS3	46%	30%	31%	22%	9%	4%
DS2	15%	28%	15%	17%	16%	12%
DS1	0%	40%	44%	57%	74%	84%

Figure 36 – The distribution of observed damage states for all building types based on 1193 buildings surveyed after the 2010 Kraljevo earthquake (Marinkovic et al., 2018).

DESCRIPTION	***Post-earthquake surveys for assessment of category and level of building damage***
CODE	A.7
MAIN CHARACTERISTICS	Damage inspection after the 2010 Kraljevo earthquake was organized and documented by the local municipal government. It was perfomed by local experts and qualified engineers and academics from Serbia. The first round of surveys (rapid survey) was focused on ensuring life safety of the occupants (short forms). The second round of surveys was focused on categorization of building damage states using two locally-developed survey forms (long forms).
POSSIBILITY OF APPLICATION	The surveys were mostly concerned with residential buildings (single family or multi-family) and to a lesser extent with other buildings (e.g. commercial, industrial, administrative). The surveys covered the following building construction types: wooden, adobe, masonry and RC.
PROCEDURE	Survey factsheets were compiled and filled for each inspected building. Survey forms contained information about the damage classified into 4 different categories ranging from slight damage to collapse.
INVESTIGATED AREAS	Detailed survey (long form): Information about property owner; building location; age of construction; occupancy; period of construction; number of storeys; building construction type, including basic information about the type of load-bearing system, floor and roof construction and foundations; qualitative description of damage observed; category of damage (ranging from slight damage to collapse); building usability; pictures of damaged building
DEFINITION PERIOD	2010
COMPILER	Serbian Chamber of Engineers (2010)
COMPLEXITY	LOW

LIMITS	Not all structural building types can be covered by the factsheets; hard to collect all relevant building-specific details; survey forms do not contain information about vertical building expansions that are very common in Serbia; factsheets are missing information about geotechnical and site conditions as well as information about prior damage and retrofit.
ADVANTAGES	Expeditious method; it allows for preliminary detection of damage and helps with assignment of priorities in emergency response
CURRENTLY USED	NO
LINK	

Pre-earthquake assessment approved by standards

Current Serbian standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability.

Pre-earthquake assessment for research activities

There are currently no published studies related to seismic vulnerability of existing buildings in Serbia which would be relevant for this project. However, within an ongoing project "Serbia National Disaster Risk Management Program: Scaling Up Resilient Infrastructure Project" (PIMO, 2018) there is an initiative to assess seismic safety of schools in Serbia.

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability; the conducted literature search showed that there have been no significant studies in Serbia on this topic.

6.5 Slovenia – PP6 (ZAG)

In the field of seismic vulnerability methods, the Slovenian approach is rich in experience and multidisciplinary research, stimulated by the needs for robust emergency management and characterized by many practical results to potentially save lives.

Numerous research projects have been developed, most recently culminated in the Slovenian national research project "Earthquake Risk in Slovenia" (Lutman, et al., 2013) and Ljubljana's municipal research project "Earthquake Risk Assessment" (Banovec, et al., 2012). After many years of research on hazard (Šket Motnikar & Zupančič, 2010), structural vulnerability and seismic risk, a joint research project with practical applications brought together previous projects that had been conducted separately by different scientific disciplines and professions.

Bringing together civil engineering, seismology, geology, mathematic, computer science and disaster management was a hard work, but the effort led to several project results, improving knowledge on possible earthquake effects in Slovenia and producing tools to tackle some of them.

Thanks to the knowledge on structural vulnerability, derived from the analysis of numerous buildings and supported by the know-how on seismicity, seismic micro-zonation and the fundamental period of buildings, it was possible to obtain assessments of the entire building heritage, applying mathematical and computer models using data from the Slovenian National Real Estate Registry.

This knowledge became the basis for the development of a series of disaster management tools, including risk assessment with different scenarios to be used for planning and preparing the population. There are internet-based applications: one provides information on possible structural damage of an individual building after an earthquake, another is dedicated to Early Post-Earthquake Damage Assessment coupled with online data collection on the effects of the earthquake and a support system for construction inspection (Lutman, et al., 2014).

Post-earthquake survey

Actions to eliminate the consequences of an earthquake can only be effectively implemented after analysing the actual situation in the affected area. Reliable information on the usability of buildings, from residential houses to important public buildings, industrial and municipal infrastructure, is crucial. When assessing the usability of damaged structures, it is necessary to know how earthquakes affect individual types of building structures and what damage critically reduces their stability and seismic resistance, always taking into account the possibility of strong aftershocks.

It is also important to know how these injuries are repaired. Based on local and international experience, building structures are classified as usable, temporarily unusable and unusable after the earthquake.

For Slovenia, a two-round system for assessing the usability of buildings has been proposed: in the first, damaged buildings are inspected and classified into individual categories as soon as possible. In the second, temporarily unusable and uninhabitable objects are inspected again, describing in detail the damage to structural elements and the condition of the structure as a whole (Tomaževič & Lutman, 1996).

The usability of a building after an earthquake is determined not only by the condition of the load-bearing structure, but also by the condition of non-structural elements and equipment. This is especially true for structures whose functioning is crucial for the proper conduct of first aid and rescue operations, as well as for the elimination of consequences in the immediate aftermath of an earthquake.

When making decisions about the usability of buildings after a seismic event, the possible negative effects of the foundation soil must also be taken into account. The usability of the building therefore depends primarily on the type, significance and extent of actual, expected or unexpected damage to the load-bearing structure.

In order to be able to intervene effectively after an earthquake, the assessment of the usability of damaged structures must be made quickly and reliably. The commissions that identify damage and assess the usability of damaged facilities must be composed of experts trained for their work.

Experience has shown that the procedure for determining damage and habitability cannot be carried out completely after an earthquake. In fact, in Slovenia (Kozjansko and Posočje), a quick assessment of the situation was carried out in the first days after the earthquake, providing first aid. However, for a more accurate assessment of the damage and the amount of funds for post-earthquake reconstruction, the procedures were repeated (in the case of Posočje because of the repeated shocks, which overturned the initial assessment of the situation).

Experience shows that, depending on the damage caused by the earthquake, buildings can be classified as:

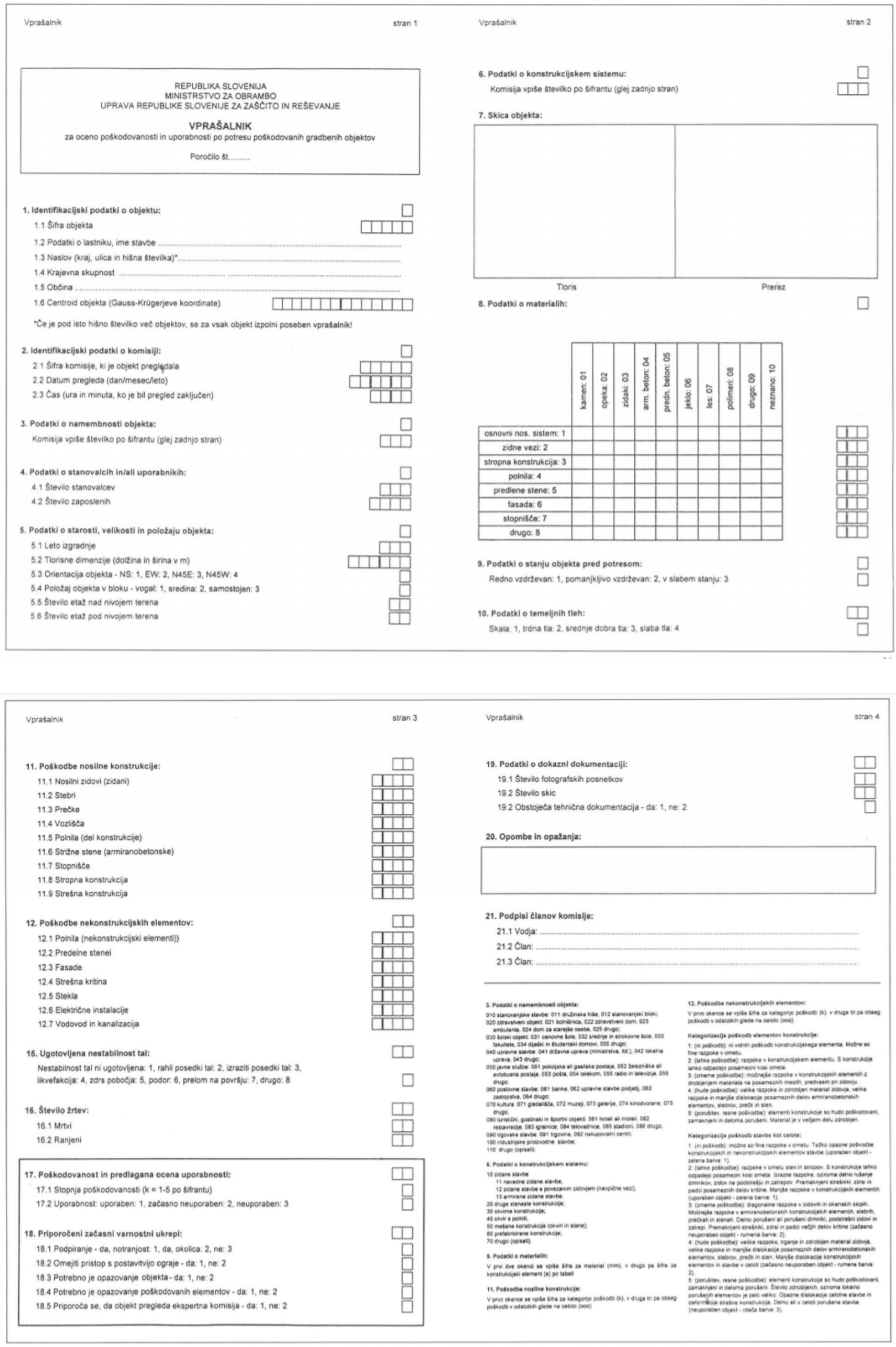
- usable buildings that have been practically undamaged by the earthquake
- temporarily unusable structures that have been damaged by the earthquake to such an extent that they could be destroyed by a stronger aftershock; only owners wishing to temporarily relocate equipment at their own risk, and to technical teams that inspect the facility and subsequently rehabilitate it, are allowed entry;
- unusable buildings that have been destroyed or damaged by the earthquake to such an extent that they can no longer be rehabilitated.

In the earthquakes of the second half of the Twentieth century, although they were not extremely severe, the extent of the injuries was such that the local authorities launched actions to eliminate the consequences. The task of the Institute for Research of Materials and Structures (now ZAG) was, among other things, to study, develop and experimentally confirm technological solutions for the rehabilitation and earthquake reinforcement after earthquake-damaged buildings.
For the needs of the national commission for the assessment of damaged to buildings by the earthquake, the Institute for Research of Materials and Structures and the Computing Centre at the Faculty of Architecture, Civil Engineering and Geodesy, after the seismic event in Kozjansko prepared a special questionnaire, which had to be filled out for each object separately by a four-member commission, which inspected the damaged structures (Tomaževič & Lutman, 1996).
Buildings have been divided into four categories according to the degree of damage, with:

- I. category - meaning only a slightly damaged building,
- II. category - when non-structural elements were damaged,
- III. category - when elements of the load-bearing structure were damaged,
- IV. category - demolished or so badly damaged buildings that had to be rebuilt.

The Commission first entered basic information about the construction, its owner and occupants, then assessed the necessary repairs and quantified them according to the category of damage and, in some cases, even evaluated their value. There is no direct mention in the questionnaire of the utility of the inspected structure.
After the earthquake in the Soča region in May 1976, the questionnaire was refined and adapted to computer data processing. The Commission did not have to enter any answers to the questions, since some of them were already written and only had to be circled. The consequences of the earthquake were not described as an inventory of damage to the load-bearing and non-load-bearing parts of the building, but as interventions which, in the opinion of the three-member commission that inspected the construction, were necessary to rehabilitate and strengthen it. The Commission has estimated the amount of materials needed for the interventions or the percentage of individual elements that would need to be repaired or replaced. Finally, it also assessed the usability of the building.
The questionnaires used by the expert commissions after the Kozjansko and Posočje earthquakes were adapted to take into account the known and agreed prices, which were applied for individual elements and reinforcement measures, as well as other construction measures and handicraft, produced by the Bureau of Civil Engineering. The scope was to assess the cost of rehabilitation and reinforcement.
According to the agreement at the time, the obtained amount obtained represented the damage caused by the earthquake to the inspected building.
After the 1979 Montenegro earthquake, which was much stronger than those in Kozjansko and Posočje, and affected a much larger number of buildings, it was necessary to determine the usability of the damaged buildings as soon as possible. The questionnaire therefore consisted of two parts: in the first, the expert commission provided the main information about the construction and, based on the classification of damage, determined the usability (usable, temporarily unusable or unusable facility). In the second part they answered questions about the type of construction and materials. The Commission did not provide any information on the damage to provide the costs of rehabilitation and reinforcement or the damage caused by the earthquake (Tomaževič & Lutman, 1996).
After the earthquake in Montenegro, the damage was assessed on the basis of sample rehabilitation projects of randomly selected buildings, representing various types of typical damaged constructions, built in different parts of the earthquake-affected area. The questionnaire, which was used to assess the usability after the

earthquake in Montenegro, was then later used by the Institute for Earthquake Engineering and Engineering Seismology IZIIS from Skopje as a basis for the preparation of an internationally accepted methodology.
In 1994, the project Earthquake Threat and Earthquake Protection was presented in Ujma, which was initiated by the Administration of the Republic of Slovenia for Protection and Rescue and funded by the Ministry of Defense and the Ministry of Science and Technology, the Institute of Civil Engineering, the Institute of Structures, Earthquake Engineering and Computer Science at the Faculty of Civil Engineering and Geodesy of the University of Ljubljana and the Anton Melik Geographical Institute at the SAZU Science and Research Centre. The program of the two-year project also included the preparation of a methodology for assessing the usability of buildings damaged after the earthquake.
As previously illustrated, a two-round usability assessment system was proposed to be adopted in Slovenia. This means that immediately after the earthquake, expert commissions quickly inspected all construction facilities in the area affected by the earthquake and assessed their usability, without detailing the damage. For structures that were classified as temporarily unusable or unusable in the first round of assessment, they prescribed the necessary precautionary measures. In the second round, the commissions re-inspected only those facilities that were classified as temporarily unusable or uninhabitable during the first inspection, describing in detail the type and extent of the damage.
The data had to be collected in such a way that they could be read and analysed in a simple way. This applies both to the results of the first round of assessment and to a more detailed assessment of the condition of severely damaged buildings in the second round.
The first part of the questionnaire contained identification data on the inspected building, data on the commission, and technical data. Damage data were included after the completion of the assessment in the second round.
The first part of the questionnaire represented the identification and technical part of the "identity card". If this information was not prepared in advance, the questions asked in the second part of the questionnaire were answered by the commission in the first round of evaluation. This part of the questionnaire contained questions about the purpose and age of the inspected building, its dimensions (floor area, number of floors, etc.), the type of construction and materials, and the condition of the building before the earthquake (Tomaževič & Lutman, 1996). In the second part of the questionnaire, the commission included its conclusions on the usability, recommendations for emergency safety measures, if necessary, and various notes.
These questions were answered in full in the first round of evaluation. The second part of the questionnaire contained other questions that the commission only answered in that phase. These issues were related to the severity and extent of damage caused by the earthquake to the load-bearing structure and its elements, as well as non-structural parts of the building, which must take into account the possibility of collapse and fall in repeated earthquakes. The answers to these questions only justify the commission's decision on the level of usability of the building immediately after the earthquake, which was made by the commission after the first round of assessment and recorded in the second part of the questionnaire, when it did not inspect the building. If the commission had doubts about its initial decision, its chairman could call in a panel of experts for assistance. The questions to be answered by the commission during the second inspection of the damaged building were prepared in such a way that it was possible to make an approximate damage assessment based on the prepared assessment of the extent of each category of damage and the description of the structure from the first part of the questionnaire. The damage could also be assessed on the basis of the extent of the damage, expressed as a percentage of the area of the entire building.
The questionnaire was also designed graphically for practical use. After the catastrophic earthquake, which affected a larger area, a great number of buildings were damaged, possibly several tens of thousands. This required the daily processing of a mass of data.



Vprašalnik stran 1

REPUBLIKA SLOVENIJA
MINISTRSTVO ZA OBRAMBO
UPRAVA REPUBLIKE SLOVENIJE ZA ZAŠČITO IN REŠEVANJE

VPRAŠALNIK
za oceno poškodovanosti in uporabnosti po potresu poškodovanih gradbenih objektov

Poročilo št..........

1. Identifikacijski podatki o objektu:
1.1 Šifra objekta
1.2 Podatki o lastniku, ime stavbe ....
1.3 Naslov (kraj, ulica in hišna številka)* ....
1.4 Krajevna skupnost ....
1.5 Občina ....
1.6 Centroid objekta (Gauss-Krügerjeve koordinate)

*Če je pod isto hišno številko več objektov, se za vsak objekt izpolni poseben vprašalnik!

2. Identifikacijski podatki o komisiji:
2.1 Šifra komisije, ki je objekt pregledala
2.2 Datum pregleda (dan/mesec/leto)
2.3 Čas (ura in minuta, ko je bil pregled zaključen)

3. Podatki o namembnosti objekta:
Komisija vpiše številko po šifrantu (glej zadnjo stran)

4. Podatki o stanovalcih in/ali uporabnikih:
4.1 Število stanovalcev
4.2 Število zaposlenih

5. Podatki o starosti, velikosti in položaju objekta:
5.1 Leto izgradnje
5.2 Tlorisne dimenzije (dolžina in širina v m)
5.3 Orientacija objekta - NS: 1, EW: 2, N45E: 3, N45W: 4
5.4 Položaj objekta v bloku - vogal: 1, sredina: 2, samostojen: 3
5.5 Število etaž nad nivojem terena
5.6 Število etaž pod nivojem terena

Vprašalnik stran 2

6. Podatki o konstrukcijskem sistemu:
Komisija vpiše številko po šifrantu (glej zadnjo stran)

7. Skica objekta:

Tloris Prerez

8. Podatki o materialih:

	kamen: 01	opeka: 02	zidaki: 03	arm. beton: 04	predn. beton: 05	jeklo: 06	les: 07	polimeri: 08	drugo: 09	neznano: 10
osnovni nos. sistem: 1										
zidne vezi: 2										
stropna konstrukcija: 3										
polnila: 4										
predelne stene: 5										
fasada: 6										
stopnišče: 7										
drugo: 8										

9. Podatki o stanju objekta pred potresom:
Redno vzdrževan: 1, pomanjkljivo vzdrževan: 2, v slabem stanju: 3

10. Podatki o temeljnih tleh:
Skala: 1, trdna tla: 2, srednje dobra tla: 3, slaba tla: 4

Vprašalnik stran 3

11. Poškodbe nosilne konstrukcije:
11.1 Nosilni zidovi (zidani)
11.2 Stebri
11.3 Prečke
11.4 Vozlišča
11.5 Polnila (del konstrukcije)
11.6 Strižne stene (armiranobetonske)
11.7 Stopnišče
11.8 Stropna konstrukcija
11.9 Strešna konstrukcija

12. Poškodbe nekonstrukcijskih elementov:
12.1 Polnila (nekonstrukcijski elementi))
12.2 Predelne stenei
12.3 Fasade
12.4 Strešna kritina
12.5 Stekla
12.6 Električne instalacije
12.7 Vodovod in kanalizacija

15. Ugotovljena nestabilnost tal:
Nestabilnost tal ni ugotovljena: 1, rahli posedki tal: 2, izraziti posedki tal: 3, likvefakcija: 4, zdrs pobočja: 5, podor: 6, prelom na površju: 7, drugo: 8

16. Število žrtev:
16.1 Mrtvi
16.2 Ranjeni

17. Poškodovanost in predlagana ocena uporabnosti:
17.1 Stopnja poškodovanosti (k = 1-5 po šifrantu)
17.2 Uporabnost: uporaben: 1, začasno neuporaben: 2, neuporaben: 3

18. Priporočeni začasni varnostni ukrepi:
18.1 Podpiranje - da, notranjost: 1, da, okolica: 2, ne: 3
18.2 Omejiti pristop s postavitvijo ograje - da: 1, ne: 2
18.3 Potrebno je opazovanje objekta - da: 1, ne: 2
18.4 Potrebno je opazovanje poškodovanih elementov - da: 1, ne: 2
18.5 Priporoča se, da objekt pregleda ekspertna komisija - da: 1, ne: 2

Vprašalnik stran 4

19. Podatki o dokazni dokumentaciji:
19.1 Število fotografskih posnetkov
19.2 Število skic
19.2 Obstoječa tehnična dokumentacija - da: 1, ne: 2

20. Opombe in opažanja:

21. Podpisi članov komisije:
21.1 Vodja: ....
21.2 Član: ....
21.3 Član: ....

3. Podatki o namembnosti objekta:
010 stanovanjske stavbe: 011 družinske hiše, 012 stanovanjski bloki;
020 zdravstveni objekt: 021 bolnišnica, 022 zdravstveni dom, 023 ambulanta, 024 dom za starejše osebe, 025 drugo;
030 šolski objekt: 031 osnovne šole, 032 srednje in strokovne šole, 033 fakultete, 034 dijaški in študentski domovi, 035 drugo;
040 upravne stavbe: 041 državna uprava (ministrstva, itd.), 042 lokalna uprava, 043 drugo;
050 javne službe: 051 policijska ali gasilska postaja, 052 železniška ali avtobusna postaja, 053 pošta, 054 telekom, 055 radio in televizija, 056 drugo;
060 poslovne stavbe: 061 banke, 062 upravne stavbe podjetij, 063 zastopstva, 064 drugo;
070 kultura: 071 gledališča, 072 muzeji, 073 galerije, 074 kinodvorane, 075 drugo;
080 turistični, gostinski in športni objekti: 081 hoteli ali moteli, 082 restavracije, 083 igralnice, 084 telovadnice, 085 stadioni, 086 drugo;
090 trgovske stavbe: 091 trgovine, 092 nakupovalni centri;
100 industrijske proizvodne stavbe;
110 drugo (opisati).

6. Podatki o konstrukcijskem sistemu:
10 zidane stavbe
11 navadne zidane stavbe,
12 zidane stavbe s povezanim zidovjem (navpične vezi),
13 armirane zidane stavbe.
20 druge stenaste konstrukcije;
30 okvirne konstrukcije;
40 okvir s polnili;
50 mešane konstrukcije (okviri in stene);
60 prefabricirane konstrukcije;
70 drugo (opisati).

8. Podatki o materialih:
V prvi dve okenci se vpiše šifra za material (mm), v drugo pa šifra za konstrukcijski element (e) po tabeli

11. Poškodbe nosilne konstrukcije:
V prvo okence se vpiše šifra za kategorijo poškodb (k), v druga tri pa obseg poškodb v odstotkih glede na celoto (ooo)

12. Poškodbe nekonstrukcijskih elementov:
V prvo okence se vpiše šifra za kategorijo poškodb (k), v druga tri pa obseg poškodb v odstotkih glede na celoto (ooo)

Kategorizacija poškodb elementov konstrukcije:
1: (ni poškodb): ni vidnih poškodb konstrukcijskega elementa. Možne so fine razpoke v ometu.
2: (lahke poškodbe): razpoke v konstrukcijskem elementu. S konstrukcije lahko odpadejo posamezni kosi ometa.
3: (zmerne poškodbe): močnejše razpoke v konstrukcijskih elementih z drobljenjem materiala na posameznih mestih, predvsem pri zidovju.
4: (hude poškodbe): velike razpoke in zdrobljen material zidovja, velike razpoke in manjše dislokacije posameznih delov armiranobetonskih elementov, stebrov, prečk in sten.
5: (porušitev, resne poškodbe): elementi konstrukcije so hudo poškodovani, zamaknjeni in deloma porušeni. Material je v večjem delu zdrobljen.

Kategorizacija poškodb stavbe kot celote:
1: (ni poškodb): možne so fine razpoke v ometu. Težko opazne poškodbe konstrukcijskih in nekonstrukcijskih elementov stavbe (uporaben objekt - zelena barva: 1).
2: (lahke poškodbe): razpoke v ometu sten in stropov. S konstrukcije lahko odpadejo posamezni kosi ometa. Izrazite razpoke, oziroma delno rušenje dimnikov, zidov na podstrešju in zatrepov. Premaknjeni strešniki, zdrsi in padci posameznih delov kritine. Manjše razpoke v konstrukcijskih elementih (uporaben objekt - zelena barva: 1).
3: (zmerne poškodbe): diagonalne razpoke v zidovih in okenskih slopih. Močnejše razpoke v armiranobetonskih konstrukcijskih elementih, stebrih, prečkah in stenah. Delno porušeni ali porušeni dimniki, podstrešni zidovi in zatrepi. Premaknjeni strešniki, zdrsi in padci večjih delov kritine (začasno neuporaben objekt - rumena barva: 2).
4: (hude poškodbe): velike razpoke, trganje in zdrobljen material zidovja, velike razpoke in manjše dislokacije posameznih delov armiranobetonskih elementov, stebrov, prečk in sten. Manjše dislokacije konstrukcijskih elementov in stavbe v celoti (začasno neuporaben objekt - rumena barva: 2).
5: (porušitev, resne poškodbe): elementi konstrukcije so hudo poškodovani, zamaknjeni in deloma porušeni. Število zdrobljenih, oziroma lokalno porušenih elementov je zelo veliko. Opazne dislokacije celotne stavbe in deformacije strešne konstrukcije. Delno ali v celoti porušena stavba (neuporaben objekt - rdeča barva: 3).

Figure 37 – Earthquake-damaged buildings assessment form, pages 3 and 4 (Tomaževič & Lutman, 1996).

Therefore, both questions and answers were prepared in such a way that they could be processed by computer. If the usability assessment commissions did not have notebooks (laptops) and the questionnaire was not prepared in the form of a data-base program, which allowed the answer to be entered directly into the computer and real-time data analysis, the questionnaires had to be printed out. They were prepared in such a way as to be transparent, and the questions and answers were appropriately coded, to allow subsequent data entry into the computer and computer processing (Tomaževič & Lutman, 1996).

A relevant implementation came with an earthquake damage estimation tool that was first developed for Slovenia via a web application, which can be used by civil protection authorities to assess general damage both immediately after an earthquake and as a tool for training and planning purposes, the so-called **Early Post-Earthquake Damage Assessment Tool**. This consists of complex mathematical models combined with large publicly available databases, expert knowledge on earthquake resistance construction and online data from seismographic sensors.

The input data for the damage assessment tool are multiple databases describing the age, size and construction parameters of the building, the location based on the seismic micro-zonation, the registered inhabitants of each construction and the intensity of the earthquake at the epicentre. The tool calculates the impact of the earthquake for each individual building using mathematical models and the intensity attenuation model.

The results are then grouped into larger areas (for example, municipal areas), where the buildings and inhabitants are presented in specific tables and on a map. They contain the number of damaged constructions for each area and the number of inhabitants within four different categories: the number of buildings and inhabitants to be relocated, permanently housed and in need of medical care; the number of buildings and inhabitants to be relocated, and temporarily housed; the number to be relocated; the number of buildings and inhabitants that cannot be estimated due to lack of data.

The important part in the definition of the damage assessment tool was the optimization of mathematical models and algorithms, with the goal that the complete assessment would be performed in less than 30 seconds for every seism that hits Slovenia.

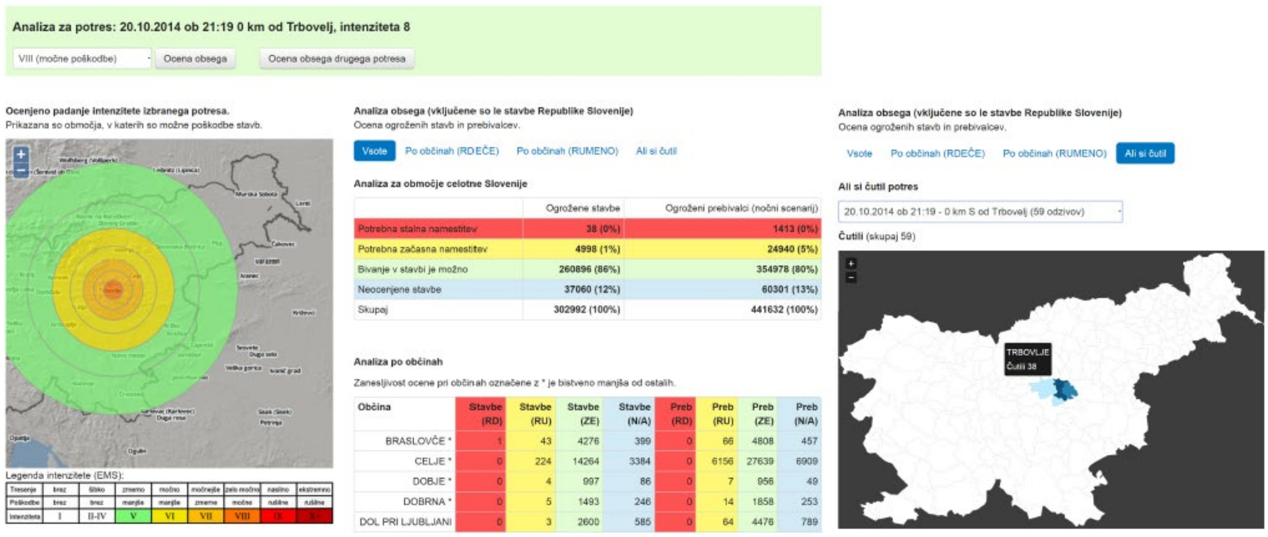


Figure 38 – Web window system of Early Post-Earthquake Damage Assessment Tool. On the left: calculated impact; on the right: reported effects (Lutman et al., 2014).

The tool also features online data collection from the public on the effects of the earthquake and the results are analysed and visualised. Thus, by comparing the images, it is possible to provide the civil protection authorities with a faster and more correct assessment of earthquake effects.

The Early Earthquake Damage Assessment Tool is designed as a useful tool in most parts of the accident life cycle: response, mitigation, planning and preparedness. The system quickly calculates the size of the affected area and makes an assessment of the number of damaged buildings and the population at risk, including the rapid activation of the civil protection mechanism.

It also serves as a risk assessment tool for producing seismic scenarios as input emergency management planning and exercise. The tool was widely used in the national exercise "Earthquake 2012" with a large earthquake scenario (Jeraj & Lotrič, 2014).

One of the objectives of the project was to renovate the existing Slovenian module for post-earthquake building safety assessment. The module was shortened to reduce the time required for the evaluation of a single building and was adapted for EMS.

Within the revised module, a new software tool was developed to support the post-earthquake building safety assessment process (Banovec, et al., 2014). The tool can be run on any computer without an Internet connection. The application is available on a USB stick.

The main objective is to provide support for filling in and printing questionnaires with updated data derived from different national public registers to facilitate the collection, aggregation, dissemination and visualization. The application is a complete update and allows civil protection authorities to quickly use the collected data by returning: maps of the area; pre-printed forms for each building with data from the land register; rapid processing of data from the modules that can be performed by a barcode reader or manually with the basic data relevant for the first analysis (usable building, temporarily unavailable, partially or totally collapsed), on temporary accommodation needs and on the removal of some debris; processing of the form can be done anywhere and exported data can be emailed or transferred from a USB stick for import / export, allowing authorities to collect and analyse all data; quick data analysis can be performed directly from the instrument and thanks to the data export function more detailed analyses can be carried out with other applications; the tool supports a "training mode" and a "real world mode" where the first mode includes only test building data which is depersonalized and slightly modified and the second mode is password protected and includes access to the entire data set for the whole country, which is encrypted and stored on a USB stick; publicly available datasets can be easily renewed if they become outdatated; implementation of standardized classifications (real estate register), standardized procedures (EMS) and the option to export/import data allows to further use them in other systems (e.g. integration with the Slovenian national system for damage registration - AJDA).

DESCRIPTION	***First level of Damage and Usibility Assessment in the Post-Earthquake emergency (Ocena poškodovanosti in uporabnosti po potresu poškodovanih gradbenih objektov.)***
CODE	A.8
MAIN CHARACTERISTICS	The procedure is used in the first phase after an earthquake. Information on building identification data, year of construction, dimensions and location, usability and persons who live or work in the building, structural classification, the pre-earthquake condition, assessed damage post-earthquake, usability assessment, number of casualties, proposed safety measures, scope and thoroughness of the visual inspection.
POSSIBILITY OF APPLICATION	The application is used in one step for all types of individual buildings. If larger historical city centre is damaged, the entire affected area is closed for a shorter period, at least until the period of aftershocks is over. Then buildings are assessed individually.

PROCEDURE	1. Forms are pre-completed and prepared in PDF for printing. 2. Only empty fields of the forms need to be filled on-site. 3. Completed forms are entered into the database (scanned or manually). 4. Quick built-in analyser, accuracy increases with the number of enters. 5. Import and export data are possible.
INVESTIGATED AREAS	Identification data (municipality, address, name of owner), year of construction, dimensions (size of layout, number of stories) and location, usability and persons who live or work in the building, structural classification, the pre-earthquake condition, assessed damage post-earthquake, usability assessment, number of casualties, proposed post-earthquake safety measures, scope and thoroughness of the visual inspection
DEFINITION PERIOD	1998 (with some changes and upgraded with application in 2013) - today
COMPILER	Civil Protection Technicians
COMPLEXITY	LOW
LIMITS	It refers exclusively to the assessment of the post-seismic usability of buildings
ADVANTAGES	Very up-to-date and time efficient, since the application has the option for the automatic prefilling of forms with data, taken from current state of National Building Register has been prepared. It will provide a more efficient fulfilment of forms in field on one hand and a faster data entering and evaluation of earthquake effects in the information centre on the other hand. The application also has a map of squares added for easy orientation.
CURRENTLY USED	YES
LINK	http://potrog2.vokas.si/udat

Pre-earthquake assessment approved by standards

Currently, Slovenian standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability.

Pre-earthquake assessment for research activities

In the recent project in which Slovenia participated, several methods for the assessment of seismic resistance and vulnerability were developed, suitable for different types of load-bearing structures.

The older method “RAN-Z” (Peruš, Fajfar, & Reflak, 1995) was used for seismic vulnerability assessment of buildings. These methods were first applied to important civil building in the City of Ljubljana: historical buildings in the old centre or in other districts (health centres, fire stations, school buildings and kindergartens, residential buildings and public buildings).

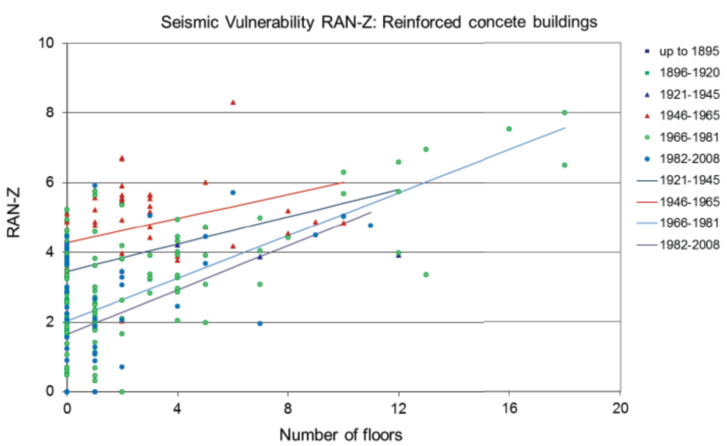
A correlation was established between the seismic vulnerability “RAN-Z” and the EMS. Taking into account the description of the EMS vulnerability classification, the appropriate class was chosen. This innovative procedure represents an important upgrade and the expected damage grade according to the EMS can be assessed. Relevant information about the building stock was used to estimate the damage distribution among constructions in a certain area in Slovenia, which was hit by an earthquake of certain intensity. However, it is not suitable for damage assessment of individual buildings.

Finally, the entire model for the assessment of seismic risk was established using the correlations obtained from database of the Slovenian National Building and Civil Engineering Institute, definitions of EMS, micro-zonation maps and publicly available databases, such as Real Estate Register and the Central Population Register.

A parametric method "PO-ZID" was developed for the assessment of the seismic resistance of masonry buildings (Lutman, Peruš, & Tomaževič, 2002).
The method “PO-AB” (Lutman & Peruš, 2002) is suitable for assessing the seismic resistance of reinforced concrete buildings, and its results are comparable to those of the “PO-ZID”.
The acronyms PO-ZID and RAN-Z refer, in Slovenian, to the seismic resistance and seismic vulnerability of masonry buildings. The first one is based on a well-considered choice of parameters and a suitable database. The input parameters are determined on the basis of the known mechanical properties of masonry, the amount and distribution of the structural walls and the weight of the building. The only output parameter is the seismic resistance coefficient, which is the ratio between the seismic resistance to the weight of the building.
The database was assembled from the results of the seismic resistance analysis of existing buildings, mainly heritage masonry buildings, located in the Municipality of Ljubljana, as well as in other parts of Slovenia. It was applied to several groups of older masonry buildings, many of them with public use, such as fire stations, older elementary school buildings and kindergartens, and some buildings belonging to local or national authorities.

The seismic resistance of older masonry high-rise buildings was evaluated using a nonlinear analytical method (Lutman, 2012) and a NASK computer program (Lutman, 1996), which uses the push-over method. A large number of public buildings have been assessed in recent years (Lutman, et al., 2013). They are mainly located within the areas of ag >= 0.225 g. Stone buildings in Posočje region, which were affected by the two recent and most damaging earthquakes in Slovenia, were also included in the database. Since these constructions were repaired and strengthened after the earthquake, they represent a specific part of the whole database and can be very useful for verifying the reliability of the method.

a)



b)

Period of construction / No. of floors	up to 1895	1896-1920	1921-1945	1946-1965	1966-1981	1982-2008
0	1	1	1	1	0	0
1	2	2	2	1	0	0
2	3	3	2	2	0	0
3	3	3	3	3	1	0
4	3	3	3	3	1	
5	4	4	4	3	1	
6	4	4	4	4	2	
7				4		
8				4		
9				4		
10				5		

Figure 39 – (a) The correlation between the seismic vulnerability RAN-Z and the number of stories for reinforced concrete buildings; (b) Part of the model for the assessment of the damage grade, valid for the brick masonry buildings in the City of Ljubljana, stricken by an earthquake of EMS VIII (Lutman, et al. 2014).

The estimates of seismic resistance and vulnerability created a valuable database. These results are valid for Slovenian buildings and reflect the influence of design codes, professional knowledge and construction practices of the period when particular buildings were constructed. However, a building which was designed for higher seismic loads is expected to be more resistant than a building designed to withstand lower seismic loads. Consequently, the seismic hazard maps used in the design practice at different times were considered.

Reasonable correlations have been identified within the database. Several correlations were established between the seismic vulnerability value of RAN-Z and the number of floors for different types of vertical load-bearing structures and for different periods of construction. Regarding the types of the material of vertical structures there are: stone masonry buildings, brick masonry buildings, reinforced concrete structures, combined structures (load-bearing walls and reinforced concrete vertical elements) and metal structures (Lutman, et al., 2014).

Six construction periods were selected: up to 1895, 1896-1920, 1921-1945, 1946-1965, 1966-1981 and 1982-2008. As expected, newer buildings are less vulnerable, while the most vulnerable reinforced concrete building in the data base were built closely after the Second World War (Lutman, et al., 2014).

Correlations have been established for a rough assessment of the building stock in different areas of the country with ag >= 0.225 g. Reliable data on these constructions are available in the national Real Estate Register for the year of construction, structural type and number of floors (which are the basic three characteristics).

Another experiment concerns the micro-tremor measurements to identify the fundamental period of a building, a parameter that influences the seismic load of a construction and consequently its vulnerability and risk assessment. Micro-tremor measurements and their analyses (Gosar , Rošer , Šket Motnikar , & Zupančič , 2010) were applied to estimate the fundamental period of more than 300 structures in Slovenia. The method is cheap, fast and efficient. The ratio of amplitude spectra between the highest floor and the basement was calculated for both horizontal components. The frequency of the maximum value in the floor spectral ratio is considered to be the fundamental frequency of the building. Based on a sample of 300 measured buildings, the regression equations for fundamental building period as a function of height were determined for masonry, reinforced-concrete and combined type of construction (also taking into account residential or non-residential use). In this way, the fundamental period of most buildings that are described in the Real Estate Register can be estimated, which allows further study of the risk. Additionally, in the Ljubljana area, free-field measurements were carried out outside each building and in a 200 x 200 m^2 grid of free-field points, resulting in a map of the fundamental frequency of the sediments. By overlying this map on the fundamental frequencies of buildings, the locations of possible soil-structure resonance were identified.

An interesting assessment of seismic risk was carried out on Ljubljana, the capital city and largest agglomeration of the Republic of Slovenia. According to the Central Population Register (2012) there are 299,483 permanent or temporary residents living in the city surrounding, that is about 15% of the Slovenian population.

A seismic risk assessment model was developed for the city using data input from the Real Estate Register and the Central Population Register. The result is information on: how many people are likely to be directly affected by an earthquake of a certain intensity; how many people are likely to need temporary shelter; how many are likely to need urban search and rescue, medical care and permanent housing; how many temporary housing (tents etc.) is needed and how much land is needed to set it up; how much debris are likely to need processing; how many light, medium and heavy urban search and rescue teams could be needed; how much fuel to run the equipment, etc (Banovec, et al., 2012). The results are used for urban planning, emergency management, rescue operations planning and for table-top exercises (Jeraj & Lotrič, 2014).

An early improvement of the validity of risk assessment was represented by the first estimate of the daily occupancy of the buildings. Data on daily commuters from Statistical Office of the Republic of Slovenia was used, supplemented by data from the vehicle counting system and data on secondary school pupils and students. The main commuter traffic in Ljubljana consists of about 110,000 workers, about 50.000 other

commuters (students, tourists, etc.) and about 15.000 people who are travelling to work in other municipalities. According to these data, it is estimated that about 150,000 people commute to Ljubljana, which forms the basis for the evaluation of the daily earthquake scenario (Lutman, et al. 2014).
As the destinations of the commuters also remain largely unknown, the seismic risk assessment was made on the basis of the fact that occupancy of buildings is increased by 50%, according to data taken from the Central Population Register. Thus, instead of about 300.000 people, a daily scenario is based on 450.000 people for the same constructions as the night scenario.
The reason for studying this is that there is no need to provide temporary or permanent accommodation for commuters, but it is necessary to provide search, rescue, and medical care. A possible way to improve the daily scenario may be to use mobile phone occupancy.
For proper planning of emergency management and implementation of rescue operations, a risk assessment of the rescue services is necessary. Assessment of seismic vulnerability of their premises (mainly fire stations and health care facilities) was performed and indicated that some of these building could not be safe after a seismic event. A further hypothesis is that emergency and life-line services personnel will not be fully available because they will be affected by the earthquake in their home. According to the analysis of their homes, half of the City's rescue personnel will be available after a strong earthquake (VIII EMS).

A comprehensive model of occupancy of buildings for different occupancy types of buildings, which includes the daily dynamics (day / night), weekly dynamics (weekday, weekend) and seasonal dynamics (summer, other seasons) has been developed. The model was developed based on a website survey and its data obtained on the individual average daily occupancy of more than 1,000 public and commercial buildings with different occupancy types in 13 municipalities in the areas under consideration. The model uses data from various databases of data: Central Population Register, Building Registry, and Register of Addresses of Buildings (Lutman, Kreslin, Banovec, & Cerk, 2016).

Web portal POTROG (http://potrog2.vokas.si/) has been established for a common access to all applications that have been developed within projects POTROG, as well as the instructions for all individual applications were prepared. The application "Assessment of Earthquake Consequences" was upgraded with previously prepared analyses for the planning of pre-earthquake measures and the management and reporting during and after an earthquake. The application can be used for the evaluation of different scenarios of earthquakes. One of the analyzes showed that the consequences of the earthquake would be the most extensive if the epicenter was in Ljubljana (http://potrog2.vokas.si/, February, 2021). In case of a severe earthquake with epicenter in Ljubljana and epicentral intensity VIII the consequences are likely to be as follows:

- 2.5‰ of all buildings in the affected area are the most vulnerable and could be damage to DG4 and DG5 (red).
- 9046 residents, which live in the most vulnerable buildings are likely to be permanently homeless and in need of rescue, medical care and rehousing. Since the most vulnerable buildings are large and tall, the proportion of their residents to all the residents in the affected area is higher than the proportion of the buildings.
- Further 5.8% of all buildings in the affected area are likely to be temporarily out of use (yellow). These buildings house 15% of all residents in the affected area.

This comparative study showed that consequences of an earthquake with the epicenter in Ljubljana would be significantly more extensive than the consequences of an earthquake with the epicenter in Lepena, which is near the epicenters of the earthquakes in 1998 and 2004.

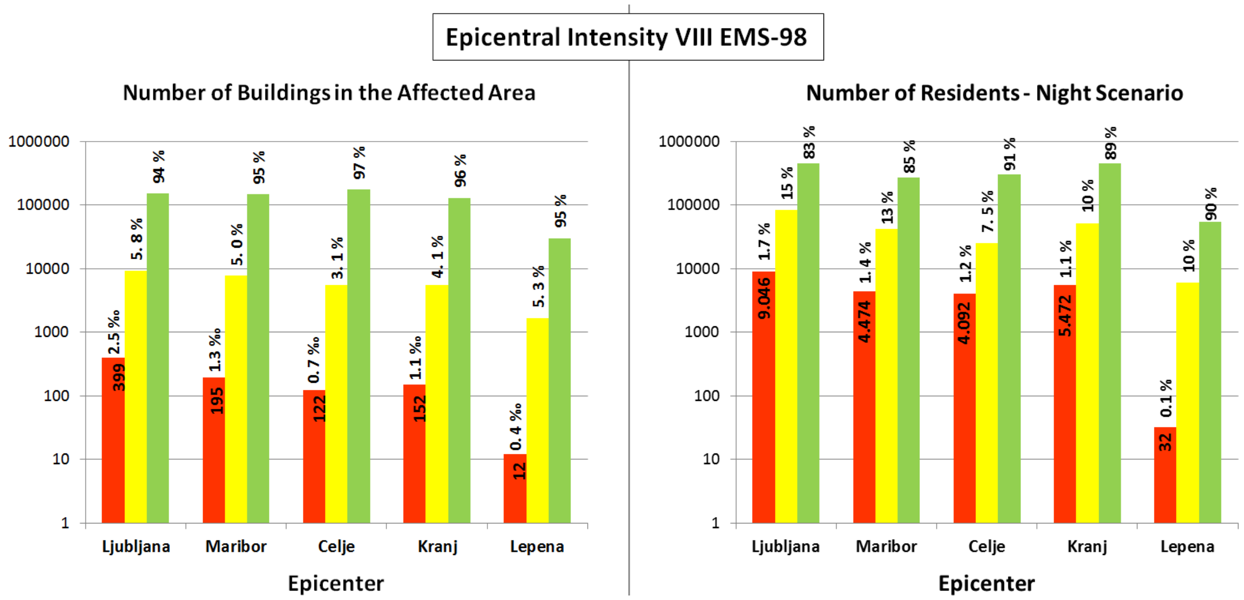


Figure 40 – Results of "Assesment of Earthquake Consequences" for earthquakes of epicentral intensity VIII EMS-98 and epicentres in different loactions in Slovenia: number of buildings and residents in buildings with expected damage grade 4 and 5 (DG4 and DG5) - red, DG2 and DG3 (yellow) and DG1 and DG0 (green), respectivelly. (http://potrog2.vokas.si/, February, 2021).

DESCRIPTION	***RAN-Z Seismic vulnerability assessment method (1995)***	***PO-ZID Seismic resistance of masonry buildings assessment method (2001)***	***PO-AB Seismic resistance of reinforced concrete buildings assessment method (2002)***
CODE	C.15	C.16	C.17
MAIN CHARACTERISTICS	Parametric method, based on the expert knowledge and the use of neutral network.	Parametric method, based on the database of nonlinear pushover analysis, carried out for typical masonry buildings, and the use of neutral network.	Numerical evaluation and verification of possible failure mechanisms.
POSSIBILITY OF APPLICATION	This method is used for individual masonry or reinforced concrete buildings.	This method is used for individual masonry buildings.	This method is used for individual reinforced concrete buildings.
PROCEDURE	It is a parametric method, where parameters are: the amount of walls, the type of masonry, the confinement, the distribution of walls in layout and the height of building. These parameters are assessed upon the judgement of the assessor with values between 0 and 1. The only output parameter is seismic resistance with a numerical value between 0 and 10. The method itself is based on the use of neural network, for which the database was created on the knowledge of top experts	This method uses neural network, but it was based on data and results of a large number of existing masonry buildings, systematically investigated and analysed at ZAG in last 35 years. All these buildings were analysed with the same limit states method and push-over analysis. With these buildings a valuable database of the input and output parameters has been created and this database is used with this method. The input parameters are determined on the basis of mechanical properties of masonry, the amount and distribution of the	This is a simplified method for the estimation of the seismic resistance coefficient on the basis of the design project (structural model, design seismic load and design internal forces) and the assessed capacities of potentially critical elements.

	in earthquake engineering in Slovenia. The result of this method is a numerical value of seismic vulnerability between 0 and 15.	structural walls, and the weight of the building. The only output parameter is the seismic resistance coefficient.	
INVESTIGATED AREAS	Input parameters: the amount of walls, the type of masonry (mechanical characteristics), the confinement with wall ties, the distribution of walls in layout (layout regularity) and the height of building. The output parameter: Seismic vulnerability.	The amount of walls, the type of masonry (mechanical characteristics), bending or shear type of behaviour of walls, the confinement with wall ties, the distribution of walls in layout (layout regularity) and the weight of the building. The output parameter: The seismic resistance coefficient.	All potentially critical elements are verified for flexural failure and shear failure, which are the most common failures in structures of this type. Input data: dimensions of critical elements, its reinforcement, mechanical characteristics of steel and concrete. Output parameter: The seismic resistance coefficient.
DEFINITION PERIOD	1995 - today	2001 - today	2002 - today
COMPILER	Technician in charge	Technician in charge	Technician in charge
COMPLEXITY	LOW	MEDIUM	MEDIUM
LIMITS	The method is influenced by the subjectivity of the assessor.	Basic technical documentation is needed (wall distribution in layout, weights of floors).	The design project is needed, certain experience in pushover analysis practice.
ADVANTAGES	The method is simple to use and its numerical type of the result (seismic vulnerability) is simple to understand for non-experts.	It needs only some basic computational procedures, but gives a very good estimation of the results of a more accurate push-over analysis.	It is objective, since it is not influenced only by the judgement of the assessor.
CURRENTLY USED	YES, by experts in earthquake engineering.	YES, by experts in earthquake engineering.	YES, by experts in earthquake engineering.
LINK		https://www.tandfonline.com/doi/abs/10.1080/15583050902934965	https://plus.si.cobiss.net/opac7/bib/739687
APPLICATION	Slovenia	Slovenia	Slovenia

DESCRIPTION	***POTROG "Assess Your own Building" - Seismic risk of individual building (2013)***	***POTROG "Assessment of Earthquake Damage" - Seismic risk of built-up area, hit by an earthquake (2013)***
CODE	C.18	C.19
MAIN CHARACTERISTICS	Web application for earthquake damage assessment, based on the selected set of data and the database of more than 1600 typical buildings in Slovenia, individually assessed previously.	Web application for earthquake damage assessment, based on the selected set of data and the database of more than 1500 typical buildings in Slovenia, individually assessed previously.
POSSIBILITY OF APPLICATION	This method is used for individual buildings	This method is used for the assessment of the damage to buildings and people due to different earthquake scenarios.

PROCEDURE	The use of web application, the needed data, entered by the interested user are Building material of vertical elements (stone masonry, brick masonry, concrete, r.c., combination, other), Number of floors (0, 1, 2, ...) and the Year of Construction, the Irregularities of Building in plan, the Irregularities of Building in elevation, the Ground condition on site, Structural Interventions, Seismic hazard of the location.	The use of web application, the needed data in the National Register of Building (REN) are Building material of vertical elements (stone masonry, brick masonry, concrete, r.c., combination, other), Number of floors (0, 1, 2, ...) and the Period of construction (up to 1895, 1896–1920, 1921–1945, 1946–1965, 1966–1981, 1982–2008, 2009 ->) and Correlations between seismic vulnerability and some these basic data, available in REN. It also uses the Central Population Register.
INVESTIGATED AREAS	Input parameters: all relevant properties of a building that can be assessed by a non-expert user are asked by a web questionnaire. Output is the set of values for the probability of damage of all EMS-98 damage grades due to a given earthquake on the building under consideration.	Input parameters are the location of the earthquake event and its EMS-98 intensity. The results are numbers of buildings in the affected area, classified by their post-earthquake usability and damage grade-DG (not safe - "red": DG5 or DG4, for a limited use - "yellow": DG3 and DG2, and habitable - "green": DG1 or undamaged), how many people will probably need temporary shelter and permanent housing, number of people in life-risk and injury-risk.
DEFINITION PERIOD	2013 - today	2013 - today
COMPILER	Non-expert individuals	Employees of the "Administration of the Republic of Slovenia for Civil Protection and Disaster Relief" and non-expert individuals
COMPLEXITY	LOW	LOW
LIMITS	Some basic technical knowledge and information about the history of the building under consideration is needed.	No limits
ADVANTAGES	Web available, free, simple to used, questions and possible answers are well illustrated.	Web available, free, simple to used, the results are well described and illustrated.
CURRENTLY USED	By any interested user.	YES, by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief and any interested user.
LINK	potrog2.vokas.si; https://www.sciencedirect.com/science/article/pii/S2212567114009885?via%3Dihub; www.sos112.si/slo/tdocs/ujma/2014/201.pdf	potrog2.vokas.si; https://www.sciencedirect.com/science/article/pii/S2212567114009885?via%3Dihub; www.sos112.si/slo/tdocs/ujma/2014/201.pdf
APPLICATION	Slovenia	Slovenia

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability; the conducted literature search showed that there have been no significant studies in Slovenia on this topic.

Some studies on seismic vulnerability of a part of old historical centre and some older residential areas in Ljubljana have been carried out in Slovenia (Sheppard & Lutman, 1988). Seismic vulnerability of buildings of different medium sized groups was actually assessed individually for each building. A simple parametric method was developed and used, in which the estimated parameters were evaluated with weighted summation. Some information on individual buildings and estimates from these studies have been collected and according to the possibilities transformed and inserted into the database of assessed buildings (Lutman, et al. 2013).

6.6 Greece – PP7 (UoC) and PP8 (ROC)

Greece is the most seismically active region in Europe and a significant effort has been made by the authorities to assess and record the effects of earthquakes on buildings.

Over the last three decades, several earthquakes caused damage in various parts of Greece. Within the Greek territory, a M5 earthquake occurs on a monthly basis and a M6 earthquake every year (Makropoulos , Kaviris, & Kouskouna , 2012).

Most of the seismic damage and casualties in this century are due to moderate earthquakes very close to major population centres. The most relevant example is the Sept. 7, 1999 Ms=5.9 earthquake, with epicentre in the Metropolitan area of Athens, which is considered a low seismicity region. As a result of this event, about 6500 buildings collapsed or had to be demolished and more than 50.000 had to be repaired. These were relatively small residential or industrial RC buildings with no seismic resistance (O Ozcebe, et al., 2000).

The issue of heritage vulnerability comprises a set of prevailing or consequential conditions, composed of physical and socio- political factors that negatively affect a community.

Seismic events occurred in the last 20 years (1995 Kozani, 1999 Athens, 2003 Lefkas, 2014 Cephalonia) confirmed the complexity of seismic hazard in Greece, proved the limitations of effective provisions and thus the need to build small-scale models, employing detailed building vulnerability assessment, site condition analyses and worst-case scenario estimates, incorporating new knowledge and international experience.

Assuming these scenarios, four aspects are essential to be determined in detail and further combined: locally based seismic hazard, vulnerability of structures, site effects and socio-economic considerations (population density, level and nature of the exposed building stock, economic activities located in the earthquake risk zones, etc.). Today, the requirement of a large amount of data is the principal obstacle.

The vulnerability of structures represents the susceptibility of structural systems to potential damage from seismic shaking. Resistance of buildings in Greece has been controversially demonstrated in several cases of earthquakes during the last decades, as the severity of destruction is not only due to the intensity of the seismic event, but also to the urbanization of the affected region and the vulnerability of certain types of buildings (Manos, 2011).

Nowadays, it is estimated that 80% of buildings in the country were constructed before 1985, without or with moderate earthquake resistant design; these buildings have been proven to be quite susceptible and in need of strengthening measures that are lacking (Spence, 2004).

Pre-seismic inspection appears problematic; a rapid inspection of all public buildings was ordered by the central government after the devastating 1999 Athens earthquake, but only 15% of them had been inspected until 2015. 50% of schools and hospitals were built before the current building code and an important issue exists for the industrial buildings, where mandatory inspections are not performed and are often inappropriate for use and/or are operated without a license (Kassaras & Sotirhos, 2015).

Furthermore, the experience of several recent earthquakes has shown that damage is highly related with the topography and ground conditions of the building location (Kassaras & Sotirhos, 2015).

In Greece, various vulnerability assessment approaches have been utilized on an individual basis. However, the 1999 Athens earthquake highlighted the need for a more widely accepted and well-defined vulnerability assessment approach for general use.

The retrofitting of reinforced concrete structures in Greece has a history of more than twenty years following the Thessaloniki earthquake disaster of 1978. This earthquake was crucial for the identification of design and construction practices that could have a detrimental influence on the seismic performance of structures commonly erected in Greece. These were also substantiated by other earthquake disasters that followed.

Moreover, it gave the opportunity for technology transfer for certain repair techniques and retrofit practices that had not been widespread in the past (injections with epoxy resins, shotcrete, reinforced concrete jacketing etc.). This initiated a long research effort that brought significant experience to specialized research groups, such as that of AUTH (Aristotle University of Thessaloniki) to investigate their application and to build and operate specialized structures for this purpose. Special repair techniques for the monumental buildings were also investigated, initiating a long research effort on old masonry and mortars.

Finally, the recognition of the usefulness of strong ground motion recordings became apparent for engineering structures. This recognition was followed by the establishment of a national strong movement network authority with a clear engineering orientation. Moreover, it created the necessary support for the instrumentation of engineering structures such a bridges, buildings, special pipelines etc, in order to obtain realistic data from monitoring their dynamic and earthquake response.

Post-earthquake survey

Seismic disaster response and reconstruction were drastically revised after the experiences gained in June 1978 in Thessaloniki and in February-March 1981 in the Corinth Bay. The Earthquake Planning and Protection Organization of Greece (EPPO), was established in 1983 to deal with the task to deal with matters related to earthquake safety and to coordinate private and public actions for earthquake protection. EPPO formally introduced the first post-earthquake building safety assessment procedures for the usability of buildings in Greece in 1984. Three safety-usability categories and the corresponding posting (tagging) scheme ("green" for usable; "yellow" for temporarily unusable and "red" for unusable/dangerous) and six categories of damage, were defined. There were four grades of damage in structural elements (light, significant, serious and heavy damage) and an explicit description of the damage in each grade and structural element was issued, aiming at a uniform classification. A manual was issued and distributed to engineers, administrators and agencies involved in post-earthquake inspection of buildings (EPPO, 1984).

In 1997, EPPO proposed a new post-earthquake building inspection procedure for first-level rapid response damage and usability assessments (which largely maintained but simplified the 1984 inspection form) while keeping the three-colour categorization of building safety. For more detailed second-degree inspections (which take place for buildings that have the "yellow" or "red" damage grade) the 1984 EPPO guidelines remain in use (EPPO, 1997).

A basic tool to conduct good inspections and achieving reliable assessments of the safety of a building is the inspection form Earthquake Damage Inspection Form (EDIF), proposed by (Anagnostopoulos & Moretti, 2008), which guides the engineers to check all the factors that influence the safety in order to achieve reliable assessments with uniformly applied criteria. The general criteria are followed by detailed rules based on quantitative descriptions of damage in the various elements and supplemented by appropriate sketches and photographs. The form has the following objectives (Anagnostopoulos & Moretti, 2008):

- To have only one form for both rapid and detailed inspections. Only the vertical boxes are filled in on the quick inspection, while both vertical and slanted boxes are completed with the detailed inspection.
- To include only the necessary information about the building, so that it can be filled in easily, while, at the same time, provide the authorities with the necessary data.
- To guide the engineer to check all the information needed for a reliable assessment. This information includes not only the damage in the various types of structural and non-structural elements, but also the type of structural system, existence or not of shear walls, etc.
- To be self-explanatory and to include on its back all the data needed, such as use categories, structural types and detachment explanations.

The form has six groups of information to be provided by the inspectors, in separate sections.

- Section A (Building location and ID) - most of the items in this section are filled during the rapid inspection. In the detailed inspection they are only filled in if the information is missing or incorrect.
- Section B (Description of the building) - Information such as number of flats, floor area, year of construction, etc., can be found by asking the inhabitants, otherwise it should be estimated. For the type of structural system and its use, the instructions accompanying the inspection form should be consulted. Information on the number of basements and multi-level foundation (detailed inspection) should only be filled in if available from the building owners or by inspection if access to the basement is safe.
- Section C (Damage) - for the quick inspection the ''extent'' of the damage is not explicitly entered. It is estimated only in the detailed inspection. The most serious damage for each type of item is recorded. Damage assessment is made on the basis of tables.
- Section D (Overall assessment for use) - the overall assessment for use should be made taking into account 2 tables, which combine the severity of element damage (highest observed) with an estimate of its extent (number of elements having suffered the particular level of damage) as recorded in Section C of the form. Relevant photos should also be consulted. The final assessment should be based on sound engineering judgment, keeping in mind that the safety of the occupants, not the cost of repair, is the basic criterion and that the correlations given between the damage assessment and posting colour based on severity and extent is indicative and should not be followed blindly. If the building is generally safe except that some local hazard is present (Section F marked), the building is posted as Green (safe) with restrictions. If ground problems are present and their severity cannot be assessed, the building is marked as Yellow or Red. In case of doubts, inspectors are instructed to be conservative, but not on a systematic basis. It should be noted that a detailed inspection may change the posting made to a rapid evaluation.
- Section E (Human losses) - Information is typically obtained from residents.
- Section F (Action to take) - Any urgently measures required along with the degree of urgency are specified here, unless such measures have already been taken (due to a previous rapid inspection). These could be urgent demolition of the whole building, removal of a local hazard (e.g. removal of a hazardous chimney, parapet wall), urgent support, etc. In addition, if utilities must be disconnected, inspectors should take care of this and if they cannot, they should indicate this on the form. In addition, hazardous areas around the building must be properly barricaded.

Table 1
Typical damage severity for reinforced concrete buildings

Damage severity	Damage description
1 = None	1. No signs of any distress 2. Very light non-structural damage 3. Fine cracks in few infill walls and in mortar. Light spalling of concrete
2 = Slight	1. Small cracks ($d \leqslant 3.0$ mm) in a few infill or partition walls 2. Cracks and/or spalling of concrete in some structural elements. Indicative crack widths are: Beams: $d_{diag} \leqslant \sim 0.5$ mm, $d_{vert} \leqslant \sim 2.0$ mm Columns: $d_{diag} \leqslant \sim 0.5$ mm, $d_{horiz} \leqslant \sim 2.0$ mm Shear walls: $d_{diag} \leqslant \sim 0.5$ mm, $d_{horiz} \leqslant \sim 1.0$ mm Stairs: $d \leqslant \sim 3.0$ mm Slabs: $d \leqslant \sim 1.0$ mm 3. Disturbance, partial sliding or falling down of roof tiles. 4. Cracking or partial failure of chimneys and parapets 5. Inclination of building barely visible
3 = Moderate–Heavy	1. Extended large diagonal or other cracking in partition or infill walls ($d > 3.0$ mm) in one or more stories. Detachment or partial failure of walls. 2. Spalling-partial disintegration of concrete. Larger cracks in several structural elements. Indicative crack widths are: Beams: $d_{diag} \leqslant 2.0$ mm, $d_{vert} \leqslant 4.0$ mm Columns: $d_{diag} \leqslant 2.0$ mm, $d_{horiz} \leqslant 5.0$ mm Shear walls: $d_{diag} \leqslant 1.0$ mm, $d_{horiz} \leqslant 3.0$ mm Stairs: $d \leqslant \sim 10.0$ mm Slabs: $d \leqslant \sim 2.0$ mm Joints: $d \leqslant \sim 2.0$ mm 3. Dislocation and/or partial collapse of chimneys and parapets. Sliding and/or failure of roof tiles 4. Visible inclination of building. Slight dislocation of structural elements 5. Minor ground movement but no signs of foundation failure
4 = Severe–Total	1. Partial or total collapse 2. Widespread failure of infill walls or severe cracking visible from both sides in one or more stories. 3. Large number of crushed structural elements and connections, exposure and buckling of reinforcement in several locations, disintegration of concrete, Indicative crack widths are: Beams: $d_{diag} > 2.0$ mm, $d_{vert} > 4.0$ mm Columns: $d_{diag} > 2.0$ mm, $d_{horiz} > 5.0$ mm Shear walls: $d_{diag} > 1.0$ mm, $d_{horiz} > 3.0$ mm Stairs: $d > \sim 10.0$ mm Joints: $d_{diag} > 2.0$ mm 4. Collapse of chimneys and parapets. Extensive damage and/or sliding of roof 5. Considerable dislocation of structural elements, residual drift in any story or dislocation of the whole building 6. Substantial ground movement, uplift of footings or fracture of foundation

Notation: d_{diag}—width of diagonal cracks (inclined to the axis of the element). d_{vert}, d_{horiz}—width of vertical and horizontal cracks (to the element axis), respectively.

Figure 41 – Typical damage severity for reinforced concrete buildings (Anagnostopoulos & Moretti, 2008).

Table 2
Typical damage severity for masonry buildings

Damage severity	Damage description
1 = None	1. No signs of any distress 2. Hairline cracks in partition walls visible from one side only
2 = Slight	1. Small cracks in partition walls visible from both sides (width $d \leqslant 3.0$ mm) 2. Small cracks in bearing walls, starting mostly at the corners of a few openings ($d \leqslant \sim 3$ mm). 3. Patches of mortar falling from ceilings or walls 4. Disturbance, partial sliding and falling down of some roof tiles
3 = Moderate–Heavy	1. Substantial cracking of partition walls ($d > \sim 3.0$ mm) 2. Diagonal cracking in bearing walls ($d < \sim 5.0$ mm), but not so extensive as to constitute failure 3. Movement, separation or local failure of roof and floor framing supports 4. Dislocation and/or partial collapse of chimneys, parapets or roofs 5. Local heavy damage in some part of the building
4 = Severe–Total	1. Bearing walls with large cracks ($d > \sim 5.0$ mm), visible from both sides 2. Partial or total failure of bearing walls, floors and/or roof 3. Walls out of plumb 4. Failure of floor and roof support areas and dislocation of their framing 5. Any type of damage indicating considerable danger for collapse

Notation: d—width of cracks.

Figure 42 – Typical damage severity for masonry buildings (Anagnostopoulos & Moretti, 2008).

LOCAL AUTHORITY .... CrewNo: . ...
OFFICE.. Report No: ....
TEL........................

INSPECTION FORM:	**RAPID INSPECTION (1st) ☐**	**DETAILED INSPECTION * (2nd) ☐**

***The information in italics need not be filled in during the rapid (1st) inspection**

A. BUILDING LOCATION AND ID

Street.. No. ....Postal Code............ Town/Municipality ....
Section No: ....Block No:................Or Streets surrounding block: 1...
2....................................3..4.......................................5................................

Position of building in block: ☐ 1=Free 2=Middle (2 opposite sides free) 3=Corner (2 or 3 sides free)

B. DESCRIPTION OF THE BUILDING

Number of stories ☐☐ Number of apartments ☐☐ Area of story (m2, approx.) ☐☐☐ Year of construction* ☐☐☐☐

Type of structural system: (see back page) ☐☐ **Usage:** (see back page) GROUND STORY ☐☐
STORIES ☐☐

Soft or weak story (e.g. pilotis, etc) YES ☐ NO ☐ *Irregularity* ☐ *0=None 1= In height 2= In layout 3= Both*

Semi-basement YES ☐ NO ☐, *Number of basements* ☐ *Multi-level foundation YES ☐ NO ☐*

* If built in phases (e.g later additions of stories, strengthening, etc.) use latest year and explain in COMMENTS below.

C. DAMAGE (a) SEVERITY (1st BOX) : 1 = None 2 = Slight 3 = Moderate - Heavy 4 = Severe –Total
(b) ***EXTENT (2nd BOX) :*** *1 = None 2 =1 to Few 3 = Few to several 4 = Several to many*

COLUMNS ☐ ☐ SHEAR WALLS/ ELEV. SHAFT ☐ ☐ FRAME JOINTS ☐ ☐ BEAMS ☐ ☐
STAIRS ☐ ☐ BEARING WALLS ☐ ☐ INFILL WALLS (masonry, ecc) ☐ ☐
ROOF ☐ CHIMNEYS, PARAPETS ☐ ☐ BUILDING OUT OF PLUMB ☐

Apparent ground problems: ☐ 1= None 2 = Settlement 3 = Liquefaction 4 = Slope movement
5 = Ground fissures 6 =Rockfalls 7 = Other (explain) ....

Indirect damage: ☐ 1=None 2=Pounding to adjacent building 3=Fire 4=Other (explain)..........................

Inspected: Exterior ☐ Ground story ☐ *1st story* ☐ *Other stories* ☐

D. OVERALL ASSESSMENT FOR USE (See back page for explanations):

Safe for use (GREEN) ☐	**Unsafe for use (YELLOW)** ☐	**Dangerous for use (RED)** ☐

The assessment made is : for the whole building: ☐ for part of the building: ☐

E. HUMAN LOSSES (if known): Number of deaths ☐☐☐ Number of injuries ☐☐☐

F. ACTION TO TAKE: ☐ 1 = None 2 = Remove local hazards* 3 = Urgent support required
4 = Combination of actions 2 and 3 5 = Urgent re-inspection required. 6 = Urgent demolition required

Urgency: ☐ 1 = Low 2 = Medium 3 = High
* The following elements should be demolished or removed ....
Access to the following areas is prohibited and must be blocked...
The following utilities must be disconnected: electricity ☐ water ☐ gas ☐

COMMENTS: ....
....
....

INSPECTION TEAM DATA
1. Signature.. 2. Signature ....
Name/ Title.. Name/ Title......... ....

INSPECTION FORM RECEIVED BY: Owner ☐ Building manager ☐ Other ☐
Recipient's Signature .... Name .... Date ....

(a)

Fig. 2. (a) Front page and (b) back page of the Earthquake Damage Inspection Form (EDIF).

Figure 43 – Front page of the Earthquake Damage Inspection Form (EDIF) (Anagnostopoulos & Moretti, 2008).

Data for filling the form

USAGE

10 =	Residential	11 = Open (pilotis)		
20 =	Office			
30 =	Commercial shop			
40 =	Hospital/clinic	41= Social welfare (retirement home, daycare center, etc.)		
50 =	Administrative	(central or local government) except critical services		
		51 = Police	52 = Fire station	53 = Communications
		54 = Energy production or distribution		55 = Water distribution-management
60 =	Public Assembly	61 = Schools	62 = Historical and religion	63 = Sports
		64 = Culture / Entertainment (museum, theatre, etc)		
70 =	Hotel	71 = Restaurant, Café, Bar, etc		
80 =	Industrial	81 = Small production units		
90 =	Parking	91 = Other (specify)		

TYPE OF STRUCTURAL SYSTEM

10 =	Masonry	11 = Wooden floors and roof, no belts	
		12 = Wooden floors and roof, with horizontal belts	
		13 = Concrete floors and roof, no belts	
		14 = Concrete floors and roof, with additional belts	
		15 = Concrete floors, no belts	
		16 = Concrete floors, with additional belts	
20 =	Reinforced Concrete cast in place	21 = Frame type with infill walls (brick, etc)	
		22 = Frames and shear walls with infill walls (brick,etc)	
		23 = Frame type with lightweight partitions	
		24 = Frames and shear walls with lightweight partitions	
		25 = Frames with infill walls and lightweight partitions	
		26 = Frames and shear walls with infill walls and lightweight partitions	
30 =	Prefabricated concrete	31 = Frame type	32 = With panels
40 =	Steel frames		
50 =	Mixed	51 = Composite (Concrete and steel)	52 = Masonry and concrete
60 =	Wood frames		

EXPLANATIONS FOR POSTING (Correlation with damage in Tables A1 to A4 of the Field Manual)

Safe for use (GREEN)	The building is generally safe and may be used subject to any posted restrictions.
Unsafe for use (YELLOW)	The building has suffered damage as indicated and must not be used before a detailed (2nd) inspection is performed. Entry permitted at own risk and only for a limited period of time. Aftershocks may cause injury or even death. Safety measures stated herein must be taken immediately.
Dangerous for use (RED)	Danger of partial or total collapse of the building and serious danger of injury or death. Entry is prohibited. Safety measures stated herein must be taken immediately. Detailed inspection will follow. **This posting does not necessarily imply demolition of the building.**

COMMENTS: ....
....
....

(b)

Figure 44 – Front page of the Earthquake Damage Inspection Form (EDIF) (Anagnostopoulos & Moretti, 2008).

The various damage descriptions listed in the tables are indicative of the corresponding level and that the presence or absence of a given type of damage in a list does not necessarily imply classification or no classification in the respective category.

The severity damage of the various structural and non-structural elements for different types of buildings, reinforced concrete or masonry, is decided with the help of the guidelines given in Tables 1 and 2, respectively. The extent of damage refers to the number of elements with the particular damage severity marked. In case there are different damage levels for the same type of element, (e.g., damaged columns with level of severity 2–4) the heaviest damage severity level is indicated and the respective damage extent is recorded.

Based on the element damage, the overall assessment for use, taking into account the damage severity and extent, is again made following the appropriate guidelines (Tables 3 and 4).
It is of fundamental importance that the inspector first identifies the type of structural system (section B) from which the ‘‘criticality’’ of each load-bearing element can be assessed. Then the damage must be recorded, as required by Section C of the EDIF. It is only then that the assessment of the safety of the building can be made with sufficient degree of confidence.
Although it is quite difficult to automate this assessment on the basis of observed (and recorded) damage alone, an effort has been made to make the evaluation as objective as possible, on the basis of the outlined general safety and usability criteria. The procedure depends on the recorded damage for load-bearing and other elements (reinforced concrete members, bearing walls, infill walls, chimney, parapets, roofs) and on the contribution of such elements to the seismic capacity of the building and the hazard they represent.
In summary the steps for assessing the safety of the construction are:

- The severity of the damage (1–4) and its extent (1–4), which are recorded in Section C of the inspection form;
- An assessment of damage for individual elements is made, based on the criteria given in Table 3, which relate the damage severity (and extent) to the elements;
- An ‘‘Overall Assessment for Use’’ of the building (Green, Yellow or Red; Section D of the inspection form) is made as indicated in Table 4 taking into account the partial ‘‘overall damage assessment classifications for the individual elements’’.

Cast in place reinforced concrete buildings constructed before modern codes (in Greece before 1980) can be quite vulnerable to strong earthquakes, especially if they were built with poor quality control. Most of multi-story buildings that have collapsed in catastrophic earthquakes belong to this category and are responsible for most of the recorded human losses.
Their design, not based on the modern concepts of ductile behaviour, good confinement, strong columns-weak beams, strong shear walls with specially detailed boundary elements, etc., makes them much more vulnerable than new buildings designed according to modern codes.
Older structures are likely to have poor detailing, so that an earthquake with several cycles of strong shaking could cause damage to the vertical load-bearing members and, consequently, lead to rapid strength deterioration.
In many of the RC buildings the partition walls are brick infills which are not normally accounted in the design (according to normal practice so far). Experience of damaging earthquakes in Greece has shown that such infills has had a very beneficial effect which may have saved several poor-quality buildings from collapse. Because they are quite rigid, brick infills attract most of the earthquake-induced forces in the first cycles of shaking, resulting in extensive cracking. This cracking contributes to increased damping and, thus, to a reduction of the forces transmitted to the concrete members. The infills act as a first line of defence against the earthquake, offering substantial protection to the load-bearing concrete structure. Heavily damaged infill walls, however, can be very hazardous and pose a threat to people. Thus, since the safety of the occupants is the main objective of the emergency inspection, damage to infills should be assessed accordingly. For instance, no visible damage in the main structural elements but heavily cracked infills is a case that would normally be reported as Yellow or Red since the seismic capacity of the building is obviously reduced.
Prefabricated concrete buildings are damaged typically in their connections, which must be the first areas to be inspected. In Table 1 the damage severity levels of RC buildings are related to the observed types of damage in the various elements.

Masonry buildings may have been built from a variety of materials (e.g., stone, hollow or solid bricks, special concrete blocks) and in a variety of ways (e.g., with or without steel reinforcement, with or without horizontal or other belts, etc.).
In Table 2 the damage severity levels of masonry buildings are related to various types and levels of damage (in the walls, roof, floor, etc). Photos will help inspectors to reach valid assessments.
The guidelines provided are general enough to cover all cases, but special attention should be paid as well, taking into account the great variability in the mechanical properties of the bearing masonry walls.

Table 3
Criteria for assessment of element damage (for notation see text)

Type of damage	Assessment	Damage severity	Damage extent
A. Bearing elements columns, beams, shear walls, frame joints, masonry walls	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	3	3, 4
		4	2, 3, 4
B1. Stairs	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	3	3, 4
		4	2, 3, 4
B2. Infill masonry walls	Green	1, 2	1, 2, 3, 4
		3	2
	Yellow	3	3, 4
		4	2
	Red	4	3, 4
B3. Parapets, roofs, chimneys	Green	1, 2	1, 2
	Yellow	2	3, 4
		3	2
	Red	4	2, 3, 4
C. Building out of plumb	Green	1, 2	
	Yellow	3	
	Red	4	
D. Ground problems	Green	1	
	Yellow or Red	2, 3, 4, 5, 6	

Figure 45 – Criteria for assessment of element damage (Anagnostopoulos, Moretti, 2008).

Table 4
Criteria for overall assessment for different types of damaged elements according to Table 3 (for notation see text)

No.	Damage assessment of the various element categories (A–D)	Overall assessment of the building
1	A, or B1, or B2: Red	Red
2	A, or B1, or B2: Yellow and B3: Green	Yellow
3	A and B: Green and C or D: Yellow or Red	Yellow or Red
4	A and B: Yellow and C or D: Yellow or Red	Red
5	A and B1 and B2: Green and B3: Yellow or Red (and C or D: Green)	Green
		For part of the building Need for intervention in …
6	A and B1 and B2 and B3: Green	Green

Figure 46 – Criteria for overall assessment for different types of damaged elements (Anagnostopoulos, Moretti, 2008).

DESCRIPTION	***Pre Earthquake Seismic Monitoring of Buildings of Public Use***
CODE	A.9
MAIN CHARACTERISTICS	The guidelines included in this certain norm are intended to offer guidance to civil engineers towards recording the structural condition of buildings of public use. This has become obligatory for buildings of public As for buildings of private use, it is not obligatory, but these guidelines can serve as guidance
POSSIBILITY OF APPLICATION	All the buildings that belong to the public authorities or private buildings that house public authorities. Can be performed on 1st, 2nd and 3rd stage
PROCEDURE	EMPIRICAL EXPEDITIOUS METHOD - Compilation of pre-formed factsheet, on the basis of instructions indicated in the "MANUAL FOR THE DETECTION OF SEISMIC VULNERABILITY OF BUILDINGS. Instructions for filling in the 1st level form"
INVESTIGATED AREAS	Structural and non-structural investigation and monitoring of buildings of public use. Can be applied on various types of buildings (RC, masonry, complex, ..)
DEFINITION PERID	1997-today
COMPILER	Public sector civil engineers
COMPLEXITY	LOW
LIMITS	1st stage monitoring offers a quick assessment of the structural buildings condition, based on plans of the building and experience of those performing the monitoring. The possibility of ignoring or not assessing as serious some aspects of the building 's condition is always present. A 2nd and 3rd stage monitoring should be carried out, which is usually not the case. Also, as mentioned in the Italian case, Impossibility of describing all the possible types of buildings within the factsheet, even if it is a restricted environment (regional or national); difficulty in recognizing the types of construction elements, due to the variability of the types within the same building, and to the variability of the behaviour of a building due to the earthquake
ADVANTAGES	Very quick; it allows a simple cataloguing of construction aspects
CURRENTLY USED	YES

LINK	https://www.oasp.gr/node/74

Pre-earthquake assessment approved by standards

Currently, Greek standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability. Existing general regulations can be used, ie KANEPE (National Regulation for Interventions in RC buildings), EAK 2000 (Greek Antiseismic Regulations) and KADET (Regulation for Assessing of Structural Condition and Interventions on Masonry Buildings)

DESCRIPTION	***KANEPE (National Regulation for Interventions in RC buildings)***	***EAK 2000 (Greek Antiseismic Regulations)***	***KADET (Regulation for Assessing of Structural Condition and Interventions on Masonry Buildings)***
CODE	B.6	B.7	B.8
MAIN CHARACTERISTICS	Provides systematized methods for assessing structural condition of RC buildings and forms on intervention	Provides guidelines for building or seismically reinforce RC or masonry buildings	Provides systematized methods for assessing structural condition of masonry buildings and forms on intervention
POSSIBILITY OF APPLICATION	Any kind of masonry or RC building / structure	Application on every type of building and structural type (masonry, RC, wooden complex)	Any kind of masonry building / structure
PROCEDURE	Detailed description of methods of assessment of seismic vulnerability of RC buildings and methods of interventions	Offers guidelines of building design/ interventions according to the expected seismic threat / seismic acceleration of the area	Modelling of the entire building
INVESTIGATED AREAS	All of the building	All of the building	All of the building
DEFINITION PERIOD	2017 - today	2000 - today	2018 - today
COMPILER	Civil engineer in charge	Civil engineer in charge	Civil engineer in charge
COMPLEXITY	MEDIUM	MEDIUM	MEDIUM
LIMITS	Applied to all RC buildings	Applied to all buildings	Applied to masonry buildings. Not yet approved by the Greek legislation but widely used among technicians
ADVANTAGES	Collection of vast experience of civil engineers, thus providing all the necessary tools for assessing the seismic vulnerability and intervention techniques of the building	It clearly identifies all the local mechanisms that affect this type of building	Methods accepted by current technicians / civil engineers
CURRENTLY USED	YES	YES	YES (informally, not yet approved)
LINK	https://www.oasp.gr/node/92	https://www.oasp.gr/userfiles/EAK2000.pdf	https://www.oasp.gr/userfiles/1_%CE%9A%CE%91%CE%94%CE%95%CE%A4_%CE%9C%CE

			%91%CE%A1%CE%A4%CE%99 %CE%9F%CE%A3_2019.pdf

Pre-earthquake assessment for research activities

Structural vulnerability assessment based on observed damage was first proposed in the form of damage probability matrices (DPMs). DPMs express, in a discrete form, the conditional probability of achieving a damage level (e.g., collapse or serious structural damage, etc.), due to a ground motion of certain intensity. Vulnerability (fragility) curves were then derived from the analysis of various observed damage datasets obtained after earthquakes, expressing the probability of exceeding a given damage degree at distinct levels of ground motion severity.

In addition to the aforementioned methods by (Spence, Corburn, & Pomonis, 1992), (Rossetto & Elnashai, 2003), (Lagomarsino & Giovinazzi, 2006), and (Colombini, 2008), fragility curves, for Greek buildings, have also been derived from hybrid methodologies (Panagopoulos & Kappos, 2006), based on a combination of actual observed damage data and analytical models. The Greek "hybrid" methodology is based on a combination of the empirical/statistical and the analytical/mechanical approaches (Dolce, Kappos, Masi, Penelis, & Vona, 2006).

In addition, intensity-based DPM's were proposed for Greek buildings by (Kappos, Pitilakis, Morfidis & Hatzinikolaou, 2002) and (Eleftheriadou & Karabinis, 2008), the latter based on post-earthquake damage surveys from the 1999 earthquake near Athens.

Recently, (Karababa & Pomonis, 2011) proposed a new set of empirical fragility curves resulting from damage data observed in the 2003 Lefkas Island earthquake.

Vulnerability models in form of curves or DPMs concerning typical structural types were proposed by National Technical Chamber of Greece in 2006 (7 structural building types in 3 different damage scenarios) and also by Eleftheriadou (Eleftheriadou, 2009) on the recently developed Damage Probability Matrices (5 structural building types and 1 damage scenario) (Eleftheriadou & Karabinis, 2012). The three damage scenarios of NTCG are based on the researches of city of Volos by (Kappos, Pitilakis, Morfidis & Hatzinikolaou, 2002), by ITSAK-AUTH (2004) and (Panagopoulos & Kappos, 2006). The NTCG vulnerability curves were derived from a hybrid approach, which combines statistical data with appropriate results from non-linear dynamic or static analyses, allowing the extrapolation of statistical data to PGAs and/or spectral displacements for which no data are available. On the other hand, the mentioned DPMs were obtained from the empirical (or statistical) seismic method of vulnerability analysis based on processing of a large damage database after the elaboration of the results from post-earthquake surveys carried out after Parnitha earthquake of 7th of September 1999. The database comprises 180,945 buildings that developed damage of varying degree, type and extent. The damage calibration of the damage dataset was initially based on the instructions provided by Earthquake Planning and Protection Organization of Greece (EPPO) and referred to the qualitative characterization for damage registration in the post-earthquake surveys in Greece (see description below). In a recently proposed damage scale, a measurable calibration of seismic damage was presented according to the physical description and also in terms of structural and economic damage index. By comparing the total number of damaged buildings with the total number of buildings in the affected area, it is concluded that the dataset covers 24% of the total number of buildings in the studied area, which is a very large and reliable statistical sample for buildings (Eleftheriadou, Baltzopoulou, & Karabinis, 2016).

DPMs can be processed in different ways; the basic steps in the hybrid methodology for deriving damage probability matrices (DPMs) based on statistical data and inelastic time-history analysis of appropriate models are:

- Construct columns (corresponding to specific earthquake intensities) of each DPM for which statistical data from past earthquakes are available, using the standard empirical procedure. Direct use of data in terms of repair and replacement cost ratios is recommended (for loss assessment), while quantitative descriptions of physical damage states, with subsequent correlation with cost, is also an option.
- Construct the remaining parts of the DPM on the basis of the results of the inelastic time-history analysis of models that simulate as closely as possible the behaviour of each building class, and subjected to input motions that have been derived for the site under consideration, also taking into account local soil conditions. Since dynamic analysis typically provides quantities of structural response (such as ductility factors, displacements etc.), appropriate models for correlating structural parameters to direct loss (expressed in terms of cost of repair) are needed in the post-processing stage. Such models were proposed by researchers to relate the economic damage index for RC members to the ductility demand in each critical region, and the economic damage index for masonry infill panels to the inter-storey drift.

If intensities greater than 10 have to be considered, expert judgement should be used to construct the corresponding columns of the DPM, since empirical data are extremely scarce and analytical data tend to be unreliable.

The selection of input motions for performing the time-history analysis should be done in a meaningful way, consistent with the overall approach used. If DPMs are to be developed in terms of intensity ("traditional" approach), the input motions used for each set of analyses must correspond to a particular intensity. Clearly, the options are numerous and, in practical terms, the choice largely depends on the scope of the project. Whenever the problem is addressed in the context of micro-zonation and/or scenario studies, typically a scenario earthquake input motion is first estimated at bedrock and then filtered through the various soil layers in each zone of the area studied to arrive at the surface motions that can be used for the time-history analysis.

The pushover analysis has the main advantage that there is no need to select an appropriate number and type of input motions, and there is no need to consider hysteretic models for the members; most the other issues and problems are similar in both static and dynamic inelastic analysis. On the other hand, the definition of the seismic input in pushover analysis is clearly a problem for which several solutions have been suggested. Pushover analysis is a valid procedure to tackle the assessment of structures for which time-history analysis is cumbersome, if at all feasible, such as masonry buildings in general, and R/C buildings for which a spatial (3D) model is needed for their assessment.

If a refined scheme is envisaged, a substantial number of curves are required and feasible but realistic inelastic models are clearly preferred.

(Dolce, Kappos, Masi, Penelis, & Vona, 2006) presented an interesting comparison between Italian and Greek methods for DPMs, highlighting that the Italian approach produces more "destructive" scenarios as the Italian DPMs, for a given intensity and for a specific building type, predict a higher vulnerability than the Greek ones, which suggests that either the Italian construction practices (for the considered building stock) are inferior to Greek ones, or that the intensities attributed to specific events from which the DPMs were derived are defined inconsistently in the two studies, or both.

Of course, several other parameters interfere, such as differences in the correspondence of building types, in the interpretation of damage levels, in local construction practices.

A recent experience for vulnerability assessment is based on three different existing damage scenarios proposed by NTCG in 2006 and also one on relatively recently developed **Damage Probability Matrices – DPMs** (Eleftheriadou & Karabinis, 2011; Eleftheriadou & Karabinis, 2012). The vulnerability curves were derived from a hybrid approach, combining statistical data with appropriately processed results from non-linear dynamic or static analyses, which allow the extrapolation of statistical data to PGA and/or spectral displacements for which no data are available.

The DPMs are based on a damage database that was created after processing the results of the post-earthquake surveys carried out after the Parnitha earthquake of the 7th of September 1999 and includes 180945 buildings with damage of various degree, type and extent (Baltzopoulou, Eleftheriadou, & Karabinis, 2012).

The calibration of the damage dataset was initially based on the instructions provided by Earthquake Planning and Protection Organization of Greece (EPPO) and referred to the qualitative characterization for the damage recording in post-earthquake surveys in Greece, using the method of Rapid Visual Screening (R.V.S.).

This is based on a macroscopic inspection of the building to define whether the seismic resistance of the building is adequate against future expected seismic forces.

The correlation between macroseismic intensity and peak ground acceleration PGA could make it possible to compare the vulnerability models proposed by EPPO. The parameter that characterizes the seismic input, in EPPO models, was the ratio ag/ao, where ag is the evaluated PGA from the macroseismic intensity and ao is the unique value that characterizes each municipality in the Greek hazard map.

The studied building stock (750085 buildings) referred to 122 regions of Attica; most of the regions belong to low intensity areas and only a few are located in the zone encircled by high intensity isoseismals. The assumption that each region (municipality) has a certain level of seismic severity was necessary for the development of DPMs (Baltzopoulou, Eleftheriadou, & Karabinis, 2012).

Regarding the methods using fragility curves, in the method by **Pomonis, Gaspari and Karababa** (Pomonis, Gaspari, & Karababa, 2014) the fragility curves were set on the combination of damage data from earthquakes that occurred in different parts of Greece and at different times for 10 different types of structures commonly found in the country (1986 Kalamata, 1993 Pyrgos, 1995 Aegion, 2003 Lefkas Island).

The database contains about 29,000 buildings subjected to ground motion intensity in the range VI to IX. The datasets consist of low-rise URM buildings (mostly cut and / or rubble stone and adobe blocks) as well as buildings of mixed structure (types of URM mixed with RC frame extensions in the horizontal and /or vertical direction or masonry confined in vertical and /or horizontal RC structural elements) or masonry with mixed materials (e.g., adobe and rubble, stone or brick and concrete block, etc.). They also contain RC frame structures with masonry infill panels with or without soft-storey of 1 to 7 floors, built according to three different seismic codes and before their application in Greece (first introduced in 1959).

The development of homogenized damage scales for masonry and RC structures, through the detailed qualitative descriptions of the original damage scales, allowed a more accurately definition of the damage grade distribution for all available structural classes and events. The proposed damage scales for masonry and RC structures contained 5 and 4 damage grades respectively. Particular emphasis was given to obtain accurately the number of collapsed buildings that are responsible for the greatest part of human casualties in Greek earthquakes.

Furthermore, the database allowed cross-event comparisons, improved estimation of macroseismic intensities and observed damage-based vulnerability analysis to be made. As a result, fragility curves were obtained for the defined damage grades for 10 structural types common in Greece that constitute about 50% of the existing

building stock in the country. A good fit was obtained only for 5 of the 10 examined structural classes, as data are not sufficient for some classes (e.g., new RC buildings or mixed structure buildings).
The vulnerability analysis showed that stone masonry buildings in Greece that are more than 50 years are quite vulnerable and need strengthening measures. Greek RC frame structures constructed before 1985 are also shown to be more vulnerable than their more recent counterparts.
The problem of RC buildings with soft-storeys is another concern, as these buildings are quite common (approximately 25% of Greek RC buildings have this feature) and have been shown to be more vulnerable than their counterparts with regular ground floors especially when built before 1985.

The pre-earthquake assessment methods for research activities derive however from the rules mentioned above (KANEPE, EAK 2000, KADET). So specific tables are not necessary.

Building aggregates

The issue of building aggregates is a further complexity in the study of seismic vulnerability; the conducted literature search showed that there have been no significant studies in Greece on this topic.

7 Conclusions

In recent years, many efforts have been made to define methods for assessing the seismic resistance of buildings, to determine the seismic risk and to suggest strengthening interventions on existing buildings to withstand seismic forces. Nowadays, several methodologies have been developed for the detailed study of the seismic behaviour of existing buildings.

However, these seismic assessment methods often take into account the local conditions of the country of origin and the methodologies developed in one country may not simply be applicable in other territories, due to differences in the quality of construction materials, local construction practices, local architectural features, etc. For this reason, in the Adriseismic project it was immediately decided to analyse in detail the aspects related to local construction practices, to identify whether or not there are concordances between the built heritage of the PP countries. As widely explained in Deliverable T2.1.2, it is possible to recognize deep correspondences, which makes it possible to study and propose shared methods and processes.

The concepts for the seismic assessment of existing structures are the subject of continuous research and are recent initiatives, which will soon provide their contribution. Although the study of seismic vulnerability assessment for various types of structures has been performed in all earthquake-prone countries using various approaches based on different principles, systematic research in this area has only begun to be addressed in the last two decades, with the first methods developed in the United States and Japan.

These last decades have shown a growing interest in the assessment of seismic vulnerability and associated risk also in many European cities; it is not a coincidence that this interest was stronger in southern Europe, where the continent's greatest seismic activity is noted. As a result, a number of earthquake damage scenario studies have been developed, and some of the more advanced techniques have been applied to a number of European cities or parts of them.

The in-depth study of the current way of dealing with the seismic problem in the partner countries has led to outlining its trends, highlighting very different approaches. The main correspondences were found in the area of post-earthquake damage, as generally all PP have implemented these methods in the occasion of recent earthquakes, and currently they are all using them. It was decided to also include these procedures (even if they are not assessment methods) because some of these can provide interesting aspects to speed up the assessment phase, thanks to the identification of recurrent damage mechanisms. And this choice was favourable, given that we find a certain uniformity in this area.

Particularly interesting is the Slovenian approach, where a two-round assessment system was proposed to be adopted. This means that immediately after the earthquake, expert commissions quickly inspect all construction facilities in the area affected by the earthquake and assess their usability, without detailing the damage. For structures that were classified as temporarily unusable or unusable in the first round of assessment, they prescribe the necessary precautionary measures. In the second round, the commissions re-inspect only those facilities that were classified as temporarily unusable or uninhabitable during the first inspection, describing in detail the type and extent of the damage. This allows a quick check of the state of conservation of the heritage, and a subsequent more detailed study of how it was damaged due to the earthquake. A similar method, with a two-round assessment, is available also in Greece.

The use of dedicated web applications (used both in Slovenia and in Albania) is very useful, as they allow easier compilation and above all the constant online availability of data. The combination with GIS platforms also allows a very simple localization of buildings, and a quick view of the results on a large scale.

Referring to seismic vulnerability before the earthquake occurs, as highlighted in the previous chapters, it can be assessed using various methods. The choice depends, first of all, on the level of in-depth study to be achieved and the pursued objective. For instance, if the goal is to quantitatively assess the vulnerabilities of a building, and measure its seismic performance, then it is necessary to use the methods of structural analysis, with finite elements models (FEM). To be representative of the real structure, they must be based on an adequately detailed knowledge of the building. This way is obviously expensive in terms of time, so it cannot be proposed for vast building stocks.

Expeditious evaluation procedures require less information on the structures and consequently are less expensive and quicker to perform, but they provide general indications. This approach is particularly useful when the goal is to examine a great number of buildings to establish priorities.

Therefore, this seems to be the most suitable approach for the issues addressed in the ADRISEISMIC project, since large areas of the urban fabric are being investigated. On this scale, proposing the use of analytical assessment procedures is not possible.

However, as already stated, expeditious methods give more general and less precise results than the analytical methods. Referring to extended built heritage, such as those of historic cities studied in ADRISEISMIC project, a reliable seismic assessment procedure should consist at least of two phases, progressively more detailed.

These are:

a) A quick screening based on simple tools,

b) A more refined evaluation process.

The adoption of a method capable of operating on priority scales, starting from a first phase of rapid analysis of the entire building stock, allows to identify the cases that present major criticalities or structural deficiencies; on these, then the second phase of analysis follows.

This kind of methodology is not easy to set up, given the complexity of the built heritage: there are, in fact, different structural types, often located in different urban contexts. The first screening is an essential part of this process because, at this level, the extension of the existing building stock is managed and buildings deemed inadequate for life safety are identified. This step requires the identification of the structural features that can be considered dangerous from the seismic safety point of view. Basic building data (such as state of conservation, number of floors, type of structure, critical dimensions of building elements, etc.) can be considered for as many buildings as possible. The level of in-depth analysis achieved in this phase will be an expression of the reliability of the seismic safety assessment and the effectiveness of the proposed improvement interventions.

Once this quick preliminary method has been applied, a building safety level is defined. The second level of analysis can then be applied only to buildings with the lower security level. A deeper study of the basic level of assessment requires more resources, and above all time. So the adoption of quick methods for large built heritage allows carrying out investigations capable of defining the more detailed assessment to reduce the high seismic risk.

Unfortunately, this type of procedure has so far been little applied in the Partner Countries, and above all it has only been applied experimentally in a few cities.

In **Italy** (PP1 and PP2), some tools falling within this first level of analysis are available, but so far they have been applied to a limited number of cases. The methods included in the "*Assessment and reduction of the seismic risk of cultural heritage with reference to the Technical standards for buildings referred to in the decree of the Ministry of Infrastructure and Transport of 14 January 2008*" are a technical-regulatory reference, but they are not so quick to be compiled, especially those relating to the "palace" type. And above all, they are mandatory only for listed buildings, therefore they cannot nowadays be applied to buildings not belonging to the protected heritage.

Among the procedures that are currently recognized at the regulatory level, the RE.SIS.TO® method, was recently acquired by the municipality of Bologna for the seismic vulnerability check of strategic buildings.

RE.SIS.TO® is presented as an expeditious method for assessing the seismic vulnerability of masonry and reinforced concrete buildings, allowing to identify an order of priority for the interventions.
The seismic classification is obtained through the definition of the ground acceleration that determine the attainment of the limit condition, thanks to a simplified determination of the resistant shear actions. This is certainly reliable as a result for reinforced concrete buildings, but evidence from previous earthquakes has shown that for masonry buildings it is not the low shear strength that leads to collapse, but rather the vulnerabilities related to construction details. For this reason, generally, the damage to masonry buildings occurs by local mechanisms. Furthermore, the procedure requires a certain number of numerical calculations which consequently take time, and cannot be extended to large parts of the urban fabric in a short time. Rather, it is a preliminary assessment level for individual buildings (hence its application to local strategic buildings).
Finally, the simplified method of "Sismabonus" for masonry buildings is faster, and based on the identification of the masonry type which is associated with a specific vulnerability class and to the presence of any negative peculiarities that may worsen the average vulnerability class. This procedure is very easy and fast, but it should be taken into account that its application is limited to masonry buildings, and not to RC ones, and it is used for tax reductions in case of a seismic improvement intervention on private buildings.
Many other methods have been developed as academic research, but experimentally applied in limited contexts; some are rapid, others are rather complex. The advantage of the Italian territory is that even procedures valid for building aggregates have been studied, and not only for isolated building; this approach seems not to have been developed in the other investigated countries so far.
In **Croatia** (PP3), there are currently no expeditious assessment methods included in local regulations. A first step was the "Disaster risk assessment for the Republic of Croatia – earthquake (2015)", where special forms were prepared to overcome the lack of building inventories. They included all the basic data for the analysis of characteristic construction types (type of structure, time of construction, intensity of earthquake loading, height, horizontal and vertical regularity, load bearing elements for horizontal and vertical load, type of foundations, soil type, etc). For the hazard definition the map of earthquake-prone areas in Croatia was used. This analysis represents a step forward in local building vulnerability studies and they constitute only a first step towards state-of-the-art risk assessment methods.
Within the research activity, currently several risk assessments are available based on different methodological approaches and conducted by experts from various disciplines; also in Croatia, they have been experimentally applied in limited contexts. Among these, the methods proposed by Hadzima-Nyarko et al. (2016) and y Kalman Šipoš and Hadzima-Nyarko (2017) seem to be mostly based on the observation of the damage deriving from previous earthquakes and on the period of construction, and consequently of the construction features that influence the seismic response of buildings.
In **Albania** (PP4), currently, vulnerability assessments on existing buildings are conducted according to standard requirements, i.e. through analytical procedures, based on the performance-based design approach, and that no expeditious procedures are currently applied. Research activities were performed through the TRANSISMIC project (2007) for the recovery plan from the historic Old city of Gjirokastra. A fast seismic risk screening was performed in the Old Town, following a quick procedure that permitted to identify the areas at greatest risk, therefore with priority in terms of intervention. However, the study is limited to the historic centre of Gjirokastra.
Currently, among those investigated, **Serbia** (PP5) is the country that has developed less experience in the field of seismic risk analysis. Interesting studies have been carried out on the mapping of the existing heritage, which are undoubtedly a fundamental starting point, but current Serbian standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability and there are currently no published

studies related to seismic vulnerability of existing buildings in Serbia which would be relevant for this project. However, within an ongoing project "Serbia National Disaster Risk Management Program: Scaling Up Resilient Infrastructure Project" (PIMO, 2018) there is an initiative to assess seismic safety of schools in Serbia.

Also in Slovenia (PP6), national standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability. Anyway, the field of scientific research on this topic is very active and very interesting, and stimulating contributions for the project have been proposed in recent years. In particular, PO-ZID and PO-AB because they are fast, objective, and need only some basic computational procedures and give a very good estimation of the results. However, in order for the results to be reliable, basic technical documentation is needed, and in particular the design project for RC buildings.

About Greece (PP7 and PP8), national standards do not contain any specific reference to methods for expeditious assessment of seismic vulnerability; the assessments are carried out according to general rules in national standards. These are also the basis for scientific research assessments, confirming that the Greek approach is mainly analytical. Although faster methods than mechanical ones are studied, they still have a strong computational component, since they are mainly based on Damage Probability Matrices.

At the end of the examination of the current approach among the partner countries, we must highlight that expeditious pre-earthquake assessment procedures approved by local standards are available only in some of them. However, their application is limited, aimed at specific cities or particular types of buildings.

There are numerous scientific approaches with different levels of speed; recent research has often focused on the study of fragility curves for certain types of buildings, but these studies become quick when a large number of buildings are modelled. The speed is achieved only in a second phase, when the detailed modelling has already been performed. Furthermore, they are applicable for specific building types, and it is therefore necessary to study a large number of possible case studies.

Consequently, it is believed that the ideal approach to analyse the vulnerability of the vast existing heritage in historic urban centres should be carried out on several levels, with a first basic level of assessment that identifies the buildings or urban portions at greatest risk, and subsequent analyses to refine the assessment, which can certainly be the fragility curves.

This process is currently not fully available in any of the partner countries, and anyway there is no compatibility between the current processes. Therefore, the ADRISEISMIC project aims to propose shared ideas and guidelines to face in a similar way the study of a heritage that has strong similarities between the various territories, as evident in Deliverable T.2.1.2.

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