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STUDY ON CONDITIONS AND MEASURES FOR THE PROTECTION OF EVENTUAL DEMOLITION OF "STREZHEVO" DAM

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ABSTRACT

This study is part of the project Joint Cross Border Cooperation for Securing Societies against Natural and Man-Made Disasters (J-CROSS) funded by Interreg IPA Cross-border Cooperation Programme "Greece - Republic of North Macedonia 2014-2020."

J-CROSS project is the result of long-standing cooperation between the Region of Western Macedonia, Greece and the Pelagonija Region, Republic of North Macedonia. Both regions are fully aware of the need to secure development initiatives and opportunities, against risks from natural and human-made disasters. The area of Western Balkans is in the epicentre of many development programmes derived from organizations such as the European Union, World Bank, European Investment Bank and others. Big infrastructure projects are planned in the broader area, including transportation (road and rail) networks, natural gas pipelines and logistic centres. The previous years both regions established close cooperation through projects in the fields of economy, environment and social cohesion.

Both regions acknowledged the importance of civil protection in securing big infrastructure projects and investments. Climate change increases the risk from natural hazards, while big infrastructure projects (such as TAP pipeline already under construction) increase the risks of a human-made - human-induced disasters. Refugees' flows also put high pressures to cross border area, being a civil protection priority, as proved by the invitation of Joint European Civil Protection Mechanism to support humanitarian operation in the two countries' border area. Therefore, J-CROSS tackles the challenge to minimize increasing -by climate change- frequency and severity of risks in both regions by jointly planned, developed and implemented practical actions.

The overall J-CROSS objective is to minimize the risks from natural and human-made disasters for the regions of Western Macedonia & Pelagonija in a long-term basis and in a way that can be replicated in other cross border areas, while the purpose of this study is to develop a dam breaking study in the Pelagonija region (Strezevo Dam).

1. PROJECT PROGRAM

Basics

The Strezhevo hydro system is a multipurpose water management system. The basic facilities are: reservoir dam, alimentation (collecting) canal, main supply canal and irrigation pipeline.

The dam "Strezhevo" is built on the river Shemnica, 24 kilometers from the outlet of the river Shemnica in the Crna Reka, 1.5 kilometers downstream from the village of Strezhevo and about 25 kilometers from the city of Bitola. The total catchment area of the accumulation is 182 km^2, while 100 km^2 are in the catchment area of the Alimentation canal which covers the Baba Mountain watercourses.

The main supply canal distributes the water from the reservoir to the consumers. The canal is a closed profile concrete. The maximum canal capacity is 12,31 m^3 / s.

The distribution pipeline irrigation network is under gravitational pressure and is designed for a net area of 20.200 ha.

Electro-energetic usage of water has the status of an integral part of the tasks of HS "Strezhevo". The following power plants have been constructed and put into operation: HPP Strezhevo, HPP Biological Minimum, HPP Filternica, HPP Dovedzik and HPP Exploitation Minimum.

The dam "Strezhevo" is an earthen dam with a clay core. The construction height of the dam is 95 meters and the height from the river bed is 76 meters. The length of the dam at he crown is 632 meters.

The water from the accumulated lake is used for irrigation for the Bitola part of the Pelagonia field, for the water supply of the city of Bitola and for settlements in the vicinity of Bitola, industry, including the power plant REK Bitola, as well as for the production of electricity.

The accumulation is planned for perennial leveling of the water from the river Shemnica and partly for the waters of Baba Mountain, which are collected in the accumulation by collecting canal.

Content

Detailed description of the dam "Strezhevo" with technical data for the dam.

Information and analysis of the most critical dam points, possible dam demolition scenarios, dam demolition history, causes and types of dam failures, parameter estimation, physical demolition methods.

Immersion zones in case of dam demolition. Determination of hydraulic consequences of demolition of the dam "Strezhevo", as the most critical dam in Pelagonia region.

Providing a safe level of water in the accumulation.

Devices and installations and Operational plan for alerting and alerting residents.

Security management procedures etc.

2. INTRODUCTION

The Republic of North Macedonia is divided into eight planning regions, which serve for statistical, economic and administrative purposes. The Pelagonia region, named after the Pelagonia area, is one of them. Located in the southwestern part of the country, it borders Greece and Albania and inland with the Southwest and Vardar regions. The main center of the region is the city of Bitola.

Figure 2-1. Statistical regions and municipalities in RNM

Apart from the regions, the first-tier administrative division of North Macedonia is the municipalities. The Pelagonia planning region encompasses nine municipalities: Bitola, Prilep, Resen, Dolneni, Krushevo, Demir Hisar, Mogila, Krivogashtani, Novaci.

In all municipalities in the region there are artificial accumulations formed by dams for various purposes, among which for water use priority [8] are: water supply to the population through public water supply system, food industry and livestock water supply, irrigation of agricultural land, industry water supply, hydropower needs, flood protection and more.

Most of the dams are small dams that are without exception earthen and are used mainly for cattle feeding and irrigation.

In the category of large dams (dams higher than 15 m) in this region are:

1. Prilep Dam in Prilep Municipality - built in 1966, повеќелачна concrete dam with a height of 35 m above ground and a total water volume of 6 million m^3,
2. Suvodol Dam in Novaci Municipality - built in 1982, earthen embankment with a height above ground of 33.9 m and a total water volume of 7.88 million m^3, and
3. Strezevo Dam in Bitola Municipality - built in 1982, earthen embankment with a height above ground of 76 m and total water volume of 119 million m^3.

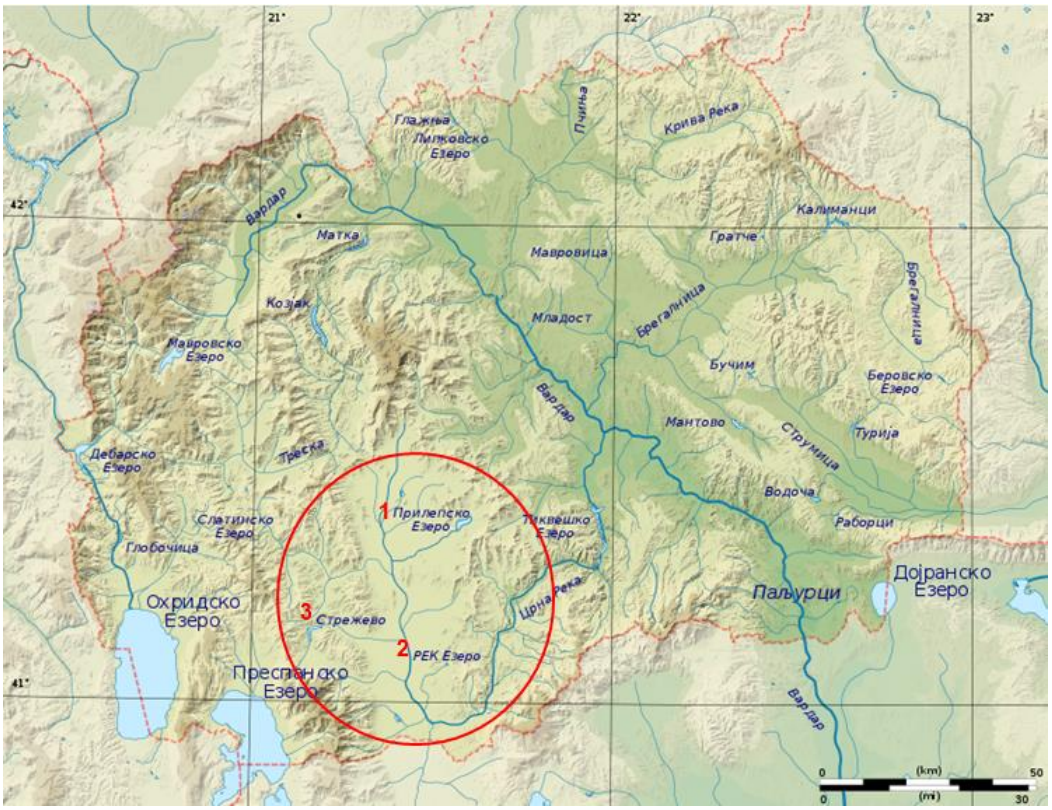

Figure 2-2. Large dams in the Pelagonia region

The purpose of this study is to point out the consequences that might result from the eventual demolition of dams. In this study on the possible consequences of a major dam demolition in the Pelagonia region on people, the environment and on private and social property of the endangered downstream area, as well as on the possible transboundary impact to the Republic of Greece, the "Strezhevo" dam from the three mentioned dams is selected, because the other two have a relatively small volume of water and are significantly lower, i.e. the consequences of their eventual demolition are incomparably smaller.

How important this issue is for an area that is at risk of flooding caused by instant dam demolition, speaks the practice that is present at any high dam to prepare an assessment of the likely damages that would occur as well as of the measures necessary to be taken to minimize the consequences.

In the case of the dam "Strezhevo", after the preparation of the main project for the dam, the competent water management company decided to prepare the Elaborate for alerting and alarming the area threatened by the demolition of the dam "Strezhevo", before the start of its construction. The report was prepared by the Jaroslav Cherny Institute of Water Management in Belgrade in October 1975 [2]. This Elaborate is a key document on the basis of which all plans and activities related to flood protection, evacuation of the population, operational measures to be taken in the conditions of dam demolition are adopted.

It provides information and analysis on critical points of defenses, possible demolition scenarios, flood zones by highlighting the consequences of the demolition of the Strezhevo Dam, as the most critical dam in the Pelagonia region.

Flood hazard conditions define safety management procedures that allow for safe water level in the accumulation.

The problem of determining the zone of danger from sudden dam demolition is one of the most complex hydro-technical calculation procedures, hence regardless of the mathematical models applied, their verification is advisable. In the case of the "Strezhevo" dam, the consequences of sudden dam demolition are made on a large model (length / height ratio, model - nature ratio is 1: 1000/100).

The next phase is the adoption of Operational Plans for Flood Protection ([5], [6]) and Plans for the Evacuation of Population and Material Goods (7) in the event of flood damage caused by dam demolition, so that the community can successfully deal with eventual accidents of this magnitude in an organized manner by minimizing the possible consequences.

The consequences of the sudden demolition of the dams, affecting people, the environment and property, are essential to the shape and speed of the flood wave. In the case of the "Strezhevo" dam it is a flood wave with a vertical forehead[1] of the wave, which initially moves at a speed of about 100 km / h and has enormous destructive power.

The time it takes to reach the first settlements, measured in less than ten minutes, indicates that no alert system can help the population in those neighborhoods, as there is simply no time to evacuate to a safe location.

Sudden dam demolition can occur for objective reasons that cannot be affected, such as earthquakes and floods, but also for subjective reasons such as errors in construction and / or maintenance of the dam, occurrence of landslides directly downstream of the dam[2], or the appearance of a landslide in the accumulation[3], which in a very short time can "squeeze" a large volume of water through the dam.

The risk of earthquakes is addressed through resilience measures for strong earthquakes that are anticipated while designing the dam[4].

The risk of flooding is handled by the design of overflow bodies for the evacuation of large waters with rare repetition[5], and by flood anticipation measures, that is, the timely release of adequate space to accommodate an expected flood wave by discharging water from the accumulation.

The technical observation of the dam - monitoring (auscultation)[6] of the dam and the accumulation space and the area just below the dam is carried out according to the Main project for auscultation of "Strezhevo" dam. Auscultaton is a key, continuous, project-based procedure that is conditioned by the installation of appropriate measuring instruments in the body and surrounding of the dam and which is subject to precise legal

[1]To illustrate, such a wave forehead shape is typical of tsunami waves caused by strong earthquakes in the seas, and the consequences of their devastating power offshore are catastrophic..
[2]The case of the Suvodol Accumulation of REK Bitola, when due to a landslide downstream of the dam in 1996, the existing retention volume was further increased by establishing a lower safe elevation point at 7.5 m above the normal water level.
[3]The case of the Vajont Dam in Italy in 1963, when a landslide in a accumulation caused a flood of 50 million cubic meters of water, from which a flood wave killed about 2000 residents of the downstream town and surrounding villages.
[4]The designer of the "Strezevo" Dam Main Project requested that the stability of the dam presented in the Elaborate be checked [9].
[5]For high dams like the Strezhevo Dam, these are large waters with 10,000-year return periods.
[6]Main project for auscultaton of the dam "Strezhevo", Book VII, Volume 7, Hydroelectric Project (HEP) Skopje, 1978.

regulation[7] for obtaining a permit to use the dam on the basis of an Elaborate for auscultation of the dam, which is made every year and on the basis of which a commission of experts assesses its condition, i.e. whether it is safe to use.

Embankment earth dams can be said to be more resistant to earthquakes than other rigid barriers, such as concrete, reinforced concrete and wall dams, by their character of flexible construction. It has been established from several accidents of demolition at this type of dams that there is no abrupt discharge of all the water from the accumulation due to the very nature of the embankments which, after the leakage of a certain amount of water, results in a "self-sealing" of the cracks in the dam through the disruption of the side material in the opening of the crack, which is a more favorable scenario than a sudden demolition of the dam.

However, all efforts should be made to ensure that demolition fails, and in cases where this cannot be avoided, that the consequences of demolition be as small as possible and that their handling be planned in a timely manner, with precise definition of the responsibilities of the competent authorities, entities and institutions.

2.1. Normative framework - legal provisions

The Republic of North has a long history of building large dams, starting in 1938 when the first large dam was built. The existence of over 24 large dams requires normative regulation of the problems associated with their design, construction and maintenance in order to increase their resistance to any external influences and to reduce the risk of emergencies that may cause them to collapse abruptly and cause major damages in flooded areas downstream.

It can be said that regarding the normative regulation of this issue, especially the bylaws - rulebooks, decrees, etc., we have adopted the most modern practices applied in the world in the field of designing, building and maintaining dams.

The basic guidelines on this issue are contained in the Law on Waters.

Current Water Law [8] in Chapter VIII. Water Management Facilities and Services, Section 4. Dams and Accumulations (Articles 194-200) refer to the establishing provisions relating to: Dams, Technical provisions, Special dams, Dams commission, Dam monitoring, Alarm in case of danger.

Article 194 – Dams, defines the notion of a dam[8], the notion of a large dam[9], which includes the dam "Strezhevo" and states that these dams are "dams of special importance for the Republic of North Macedonia".

Article 195 - Technical Provisions, specifies that "for the purpose of providing **constructive, economic and functional safety**, dams and associated facilities shall be **designed, constructed, exploited (maintained and operated)** and **managed** in a manner specified in the technical documentation for small and large dams prepared in

[7]Law on Waters, Chapter VIII. Water Management Facilities and Services, Part 4. Dams and Accumulations, Articles 194 - 200.
[8]Dam, within the meaning of this law, is a hydrotechnical facility that holds water in order to create a permanent or temporary accumulation of water or other liquid matter at a height of at least 5 meters measured between the downstream scour and the non-wetting crown, or the space next to the crown can store more than 100,000 m³ of water.
[9]A large dam is a hydrotechnical facility with a height of at least 15 meters, ...

accordance with the regulation regulating the necessary measures for the **technical monitoring of dams and associated facilities and accumulations**"adopted by the Minister of the Environment in accordance with the Minister of Transport and Communications and the Minister of Agriculture. Large dams are subject to extensive research and analysis based on modern standards of static stability, high water hazards and earthquakes, including risk assessment.

Article 196 - Dams of particular importance, specifies that "dams located above settlements, roads or other commercial objects or other goods of general interest are under special control and are of importance to the defense".

Article 197 - Commission for dams, states that the Ministry of Environment and Physical Planning "establishes a Commission for dams on issues related to the design, construction and management of dams and accumulations. The Dam Commission is made up of seven members from prominent hydro-technics and dams experts."

Article 198 - Monitoring of dams, states that “legal entities managing dams designated as dams of particular importance are obliged to establish and organize a **technical monitoring of dams** and associated facilities and accumulations, on the basis of a **technical monitoring project (auscultation) of the dam**, associated facilities and accumulations.

The legal entity managing the dams of special importance, associated facilities and accumulations, on the basis of the technical observation data in accordance with the technical monitoring project, is obliged to prepare a special **Elaborate at least once a year for analysis and evaluation of the stability and functionality of the associated dams and the accumulations and the stability of the terrain around the dams, associated facilities and accumulations**.

The report shall be submitted to the MoEPP no later than four months after the end of the year to which it relates, which shall be approved on the basis of a prior **written opinion of the Commission on Dams**.

If during the technical observation or during the preparation of the Report the deficiencies that could endanger the stability of the dam with the accompanying facilities are identified, the legal entity managing the dam is obliged to immediately inform the body of the state administration responsible for carrying out the environmental affairs, as well as the body responsible for protection and rescue.

According to Article 199 - Emergency alert, “the legal person managing the dams of particular importance shall:

1) prepare an Elaborate for analysis of the consequences of flood wave propagation in case of dam collapse or overflow, on which it is obligatory to perform an audit (assessment and evaluation);
2) set up and maintain all alert devices in good working condition;
3) organize and provide announcement and alert in case of danger that may arise due to dam demolition or overflow;
4) connect the systems for announcement, warning and alert with the system for announcement and warning of the Republic of North Macedonia, the municipalities, the municipalities in the City of Skopje and the City of Skopje whose areas are potentially endangered in the event of dam demolition or overflow."

3. DESCRIPTION OF STREZHEVO HYDRO SYSTEM

The Hydro System "Strezhevo" consists of the following basic objects:

- Alimentation (collecting)canal (AC);
- Dam "Strezhevo" with associated facilities;
- Main Supply Canal (MSC);
- Detailed Pipeline Irrigation Network (DPI);
- Intake and water supply for REC “Bitola”;
- Hydroelectric power plants.

Construction of the Strezhevo Hydro System made possible:

- providing the required quantities of water for irrigation of 20.200 ha of non-cultivated surface in the part of Pelagonia,
- supply of raw water to the regional water supply system of the municipalities of Bitola, Mogila and Novaci through PCE "Vodovod" - Bitola,
- supply of technological water to the Bitola Mining and Power Plant (REK Bitola)
- supply of technological water for the part of the industry in the Bitola region,
- electro-energy utilization of the hydropower potential of the waters in the catchment area of the hydro system,
- flood protection for the part of Pelagonia.

With the realized technical solution of the Hydro System "Strezhevo", the required quantities of water for the water users are provided with:

- accumulation of water from: the watershed of the river Shemnica, upstream of the dam "Strezhevo" and the waters in the Alimentation canal from seven water streams from the adjacent basin of Baba Mountain,
- direct water capture of the Dragor River from the local stream at elevation of 666,0 m asl, to meet some of the technological water needs for REK Bitola;
- direct water capture from the Alimentation Canal positioned at km 11 + 502 for the needs of PCE Vodovod.

- **General information on the hydro system**

The area covered by the Strezhevo Hydro System lies in the south-western part of the Republic of North Macedonia, and covers an area of 715 km^2. It includes: the eastern side of the Baba mountain, the watershed area of Shemnica river, the profile of the dam "Strezhevo", and the section of Pelagonia bordered with Shemnica, Crna Reka and the Macedonian-Greek border. According to the new territorial division of the Republic of North Macedonia, the territories of the municipalities of Bitola, Mogila and Novaci are covered in the territory of the Strezhevo Hydro System.

The city of Bitola, as a predominantly populated area, is an administrative, economic and cultural centre in the south-western part of North Macedonia.

In the area of HS "Strezhevo" is included the National Park "Pelister", the first national park in North Macedonia, with endemic flora and fauna and Pelister peak (2601 m asl).

The following types of soils are present in the irrigation area covered by HS "Strezhevo": alluvial (35%), deluvial (15,6%), alluvial-deluvial (17,5%), meadow (4,7%), muddy (10%), meadow-muddy (8.1%), mites (6,7%) and others (2,4%).

The basic hydrological network is formed by the rivers Shemnica and Dragor with their tributaries and watercourses from Baba Mountain, the rivers: Kishavska, Graeshka, Ostreshka, Zlokukanska, StaraReka and Kinderka.

- **Alimentation (collecting) canal**

The alimentation canal of the Strezhevo Hydro System enables water capture from the Baba Mountain watercourses, the rivers: Kishavska, Graeshka, Ostreshka, Zlokukanska, Stara Reka, Kinderka, during the off-vegetation period and the Dragor River during the year, directing them to the Prevalec site and insertion them into the watershed of the Shemnica River through the Gorno Srbetski Poroj.

According to the project documentation, AC's share in the water balance of HS "Strezhevo" is 49.86 million m^3. The water capture of the watercourses is realized by Tyrolean operations.

The alimentation canal has a maximum throughput of 5,0 m^3 / s. The canal extends along the eastern slopes of Baba Mountain and is constructed with a closed (rectangular and circular) transverse cross-section of 56 km and as an open canal with trapezoidal cross-section of km 0 + 000 to km 5 + 334, with compacted or reinforced concrete coating in correlation with local geological conditions. The dominant longitudinal decline is 0.2%.

Figure 3-1 Alimentation canal - open part

Figure 3-2.Tyrolean operation at the Dragor River

The Alimentation Canal is supplying crude water to the regional water supply system operated by PCE "Vodovod" - Bitola, and is also an alternative source of technological water for the needs of TPP "Bitola". According to the current disposition of the facilities of the Hydro System, the water is previously used in the small hydro power plants "Filternica" and "Dovedzik".

The Alimentation Canal incorporates the following objects:

- concrete canal with a total length of	61,502 m
- "Tyrolean" intake facilities with appropriate equipment	7
- 2 siphons with a total length of	324 m
- 33 aqueducts with a total length of	717.6 m
- exploitation and access roads	cca 75 km
- guard houses	6.

- **The main supply canal**

The main supply canal of the Strezhevo Hydro System has the task of transporting and distributing the water from the Strezhevo accumulation to the intake structures of the Hydro System water utilities and is a sloping canal with a total length of 44136 m. The main supply canal incorporates the following objects:

- canal length	39090 m
- intake facilities with suitable hydromechanical equipment	15
- 3 tunnels with total length of	2640 m
- 8 siphons with total length of	1438 m
- 58 aqueducts total length of	1095 m
- audit manholes	127
- side safety dressings	9
- side safety outlets	5

- compensation pools	2
- exploitation and access roads	cca 40 km.

Figure 3-3.The main supply canal - Regulatory objects in running mode flow and overflow

According to the project documentation, the maximum throughput of the canal is determined by the total needs of the water users (11,11 m^3 / s for irrigation, 0,70 m^3 / s for water supply of PCE "Vodovod" and 0,50 m^3 / s for the needs for technological water for REK "Bitola") and amounts to 12,31 m^3 / s.

The main supply canal is a closed canal, made with expansion joints along the entire perimeter of the transverse section at every 20 m, with two basic types of transverse section: horseshoe, 32360 m long and rectangular, 10803 m long, each with its own subtypes, with dimensions correlating with the required throughput. Overall, the longitudinal drop at the bottom of the canal is 0.8%.

The intake structures are mainly of the "duck beak" type and are within the canal control facilities.

The management of the water movement is completed by the control unit which is located in the hydro system management building, using the dynamic regulation method. The dynamic regulation project, in addition to the compensation along the canal (maximum 30000 m^3), which is provided with the regulatory facilities, also provides two compensation pools: "Dovedzik" pool with total volume of 13150 m^3 (useful volume - 10840 m^3) and pool Velushina located at the end of the canal (G5 and SR13 intake) with a total volume of 5010 m^3 (useful volume 3250 m^3).

Figure 3-4. Compensation pool Dovledzik

- **Detailed pipeline irrigation network**

The detailed pipeline irrigation network of HS Strezhevo is watered by the MSC and enables irrigation of 20.200 ha of arable land in the Pelagonia section bounded by the Shemnica River in the north, the Crna Reka in the east, the Macedonian-Greek border in the south and the MSC in the west. Irrigation is by natural pressure on more than 90% of the areas covered.

DPIN is a network of main, distribution and section pipelines with a total length of 534.067 m.

The main pipelines, 11 in total, are 104.487 m long, and with intake structures are directly connected to the Main Supply Canal and they are 2-2.5 km apart, oriented in a west-east direction. They are made of steel, polyester (GRP - glass reinforced plastic) and PVC pipes. The main pipelines are connected to the distribution and section pipelines.

The section pipelines, 428 in total, with a total length of 429.580 m are located at a distance of 600 m, they extend orthogonal to the main pipeline and cover an area of 30 - 60 ha. They are made of PVC pipes. Along the section pipelines, an outlet - a hydrant, is connected to every 100 m to which irrigation equipment joins.

According to the Plan for use of the Hydro-system "Strezhevo", there are around 20 crops out of which: wheat 23,7%, sugar beet 19,6%, alfalfa 17,3%, corn 11,3%, tobacco 6,1% and sunflower with 4,9%, while the share of other crops (garden crops, orchards, hops and vineyards) is 18,1%.

Irrigation equipment consists of linear systems, angular systems, portable rain fixings, automatic typhoon sprinklers and drip irrigation systems.

The DPIN includes all related typical and special facilities, 6.976 m long drainage canals, 50.641 m long exploitation roads, three DPIN maintenance points with buildings, auxiliary warehouses, workshops, mechanization and rolling stock.

Figure 3-5. Detailed pipeline network – linear irrigation system

- **Intake water supply for REK "Bitola"**

The transport of water from HS "Strezevo" to REK "Bitola" is realized through two steel pipelines:

- the "old" pipeline, built in 1982, Ø 660.4 mm and 12.555 m long to Crna Reka, which is supplied from the waters affected by the Tyrolean catch of the Dragor River at an elevation of 666.00 m asl, the affected waters of the MSC at km 25 + 672 and energy consumed waters from HPP Dovledzik, and
- the "new" pipeline, built in 2005, Ø 711.2 mm and total length of 17.256 m, the source of which is the MSC at km 13 + 294 with the newly built G-0 control and regulation facility.

Figure 3-6. Control and regulation facility G-0 on the supply pipeline for REK Bitola

- **Electro-energetic utilization of hydro potential**

Electro-energetic utilization of water has the status of an integral part of HS Strezhevo.

In the past period, the following hydropower plants have been constructed and put into operation: HPP Strezhevo (1992), HPP Biological Minimum (1994), HPP Filternica (1997), HPP Dovledzik (1997) and HPP Exploitation minimum (2013/2014), which will generate approximately 12GWh of electricity annually.

Figure 3-7. HPP “Strezhevo” - electromechanical equipment in the machine building

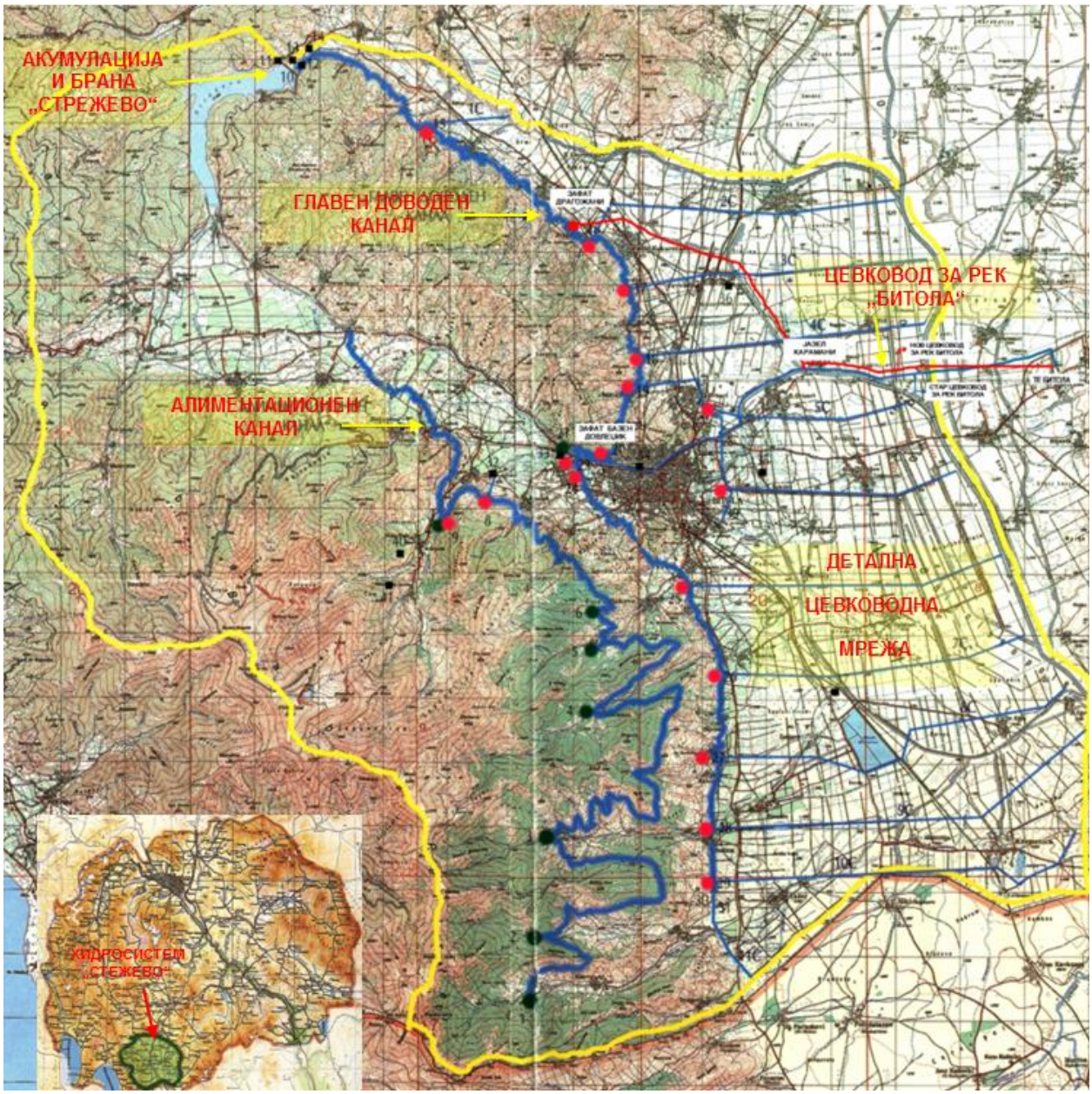

Figure 3-8. View map of the objects in the hydro power system "Strezevo"

4. TECHNICAL CHARACTERISTICS OF STREZHEVO DAM

The dam "Strezhevo" is a high earthen - embankment dam with a central clay core, sand filter zones, upstream and downstream supporting gravel body and stone padding on the upstream and downstream sides. It is built on the river Shemnica, 24 km upstream of its inflow into the Crna Reka and 1.5 km downstream of the village of Strezhevo.

Its construction created a cumulative space with a total volume of 119.23million m^3, of which 108.87 million m^3 is a useful volume.

The dam "Strezhevo" has the following constructive characteristics:

dam crown elevation	741,00 m asl
elevation of normal water level	737,50 m asl
maximum water level elevation	739,00 m asl
minimum water level elevation	694,00 m asl
dam height above river bed	76 m
crest width	10 m
crest length	632 m
upstream slope	1: 2 and 1: 4,4
downstream slope	1: 2
slope of downstream berm	1:10
slope of clay core	1: 0,15
volume of dam	4,219 x 10^6 m^3
gross capacity of reservoir at 737.50 m asl	119,23 x 10^6 m^3
active storage capacity	108,87 x 10^6 m^3
water surface area at 737.50 m asl	432,86 ha
water surface length at 737.50 m asl	6,25 km.

As part of the technical solution of the dam's hydro-node for the capture of accumulation waters, for the evacuation of large waters, and for the discharge of the accumulation itself, the following facilities are foreseen:

• **Intake structure**. The intake structure (intake tower, supply tunnel, shutter, deflector - nozzle for dissipation of water energy and overflow and safety outlet –quick stream with ski-jump) serves to capture the water from accumulation and bringing the same to the Main Supply Canal, which further distributes the water to the users. It is located on the right bank of the dividing line and is provided as a type ofdeep groove with supply tunnel. The water intake is through the intake head with a grid-tower grip and through a tunnel with a diameter of 2.50 m, and a length of 318.64 m, which leads to HPP “Strezhevo” where the water discharge from the accumulation is regulated. After HPP "Strezhevo" the water with previously destroyed energy is discharged into the Main Supply Canal. At 152.42 m from the beginning of the intake tunnel there is a locking tower with a fine grille and a locking board with dimensions of 2.0 / 2.5 m. This tower also has the role of a waterfall.

- **Spillway.** The overflow organ (shaft spillway, tunnel, rapid swelling and hump) allows evacuation of 170 m^3 / s, i.e. part of 0.01% probable catastrophic waters (ten thousand annual waters) determined at 400 m^3 / s. It is located on the left bank of the bulkhead and consists of a vertical shaft spillway with a fixed overflow edge, a horizontal tunnel, rapid swelling and a hump. The shaft spillway has a crown elevation of 737,5 m asl, a crown diameter of 14,0 m and an overflow length of 44,0 m, while the horizontal tunnel has a diameter of 3,30 m and a length of 365,0 m ending with a rapid swelling with a width of 6,0 m and a length of 255,2 m and a hump to destroy energy.

• **Bottom outlet**. A water tunnel located on the right bank of the bulkhead has been constructed to evacuate the water during construction. It has a diameter of 4,60 m and a length of 476,80 m, and is dimensioned for a water volume of 150 m^3 / s. After the construction of the dam the tunnel is pre-adapted into a bottom outlet, intended to discharge the accumulation on one side and discharge water to the biological minimum on the other. The entrance to the main outlet is at an elevation of 684,0 m asl where a coarse grid and auxiliary table sealant are housed, and the coupling to the strut tunnel is via a reinforced concrete inclined tunnel with a diameter of 2.0 m and a length of 21.0 m. In the tunnel itself, starting from the longitudinal axis of the dam, a steel pipe with a diameter of 1500 mm and a length of 252.0 m is freely laminated on concrete supports. The beginning of the pipe is anchored in a concrete plug in the torque tunnel shortly after which a safety disc seal with a diameter of 1500 mm is located, and the end is at the exit of the torque tunnel where a regulating seal board with a diameter of 1500 mm is located.

• **Control gallery**. In the same vertical plane with the longitudinal axis of the dam i.e. at the base of the clay core a control (injection) gallery was constructed whose purpose during construction was to enable the work of the main injection curtain and connective injecting, and during the exploitation period control of dam behavior and possible additional injection work. The control gallery is made of reinforced concrete and has a horseshoe type 3R transverse profile where the parameter R is 1.75 m, while it is 622.30 m long.

The following contents are included in the dam "Strezhevo":

- command building, which houses technical inspection staff of the dam and part of the occupation equipment;
- small meteorological station;
- chemical-bacteriological laboratory;
- California trout fishery (hatchery building and fish ponds) with an annual capacity of 60 t;
- 2.52 km exploitation roads;
- electricity Facilities: HPP Strezhevo and HPP “Exploitation Minimum”, which enable electricity use of water for the needs of the Main Supply Canal and HPP “Biological Minimum”, which enable the use of bio-energy minimum on the Shemnica River.

The technical observation of the dam "Strezhevo" is realized through a system for measuring water oscillations in external and internal piezometers, pore and total pressures, displacements of measuring points in the body, slopes and associated dam structures, as well as with a seismic auscultation system.

Figure 4-1. Accumulation and dam “Strezhevo” panorama

Figure 4-2. Satellite image showing the water surface of the accumulation "Strezevo" in a state close to normal water level

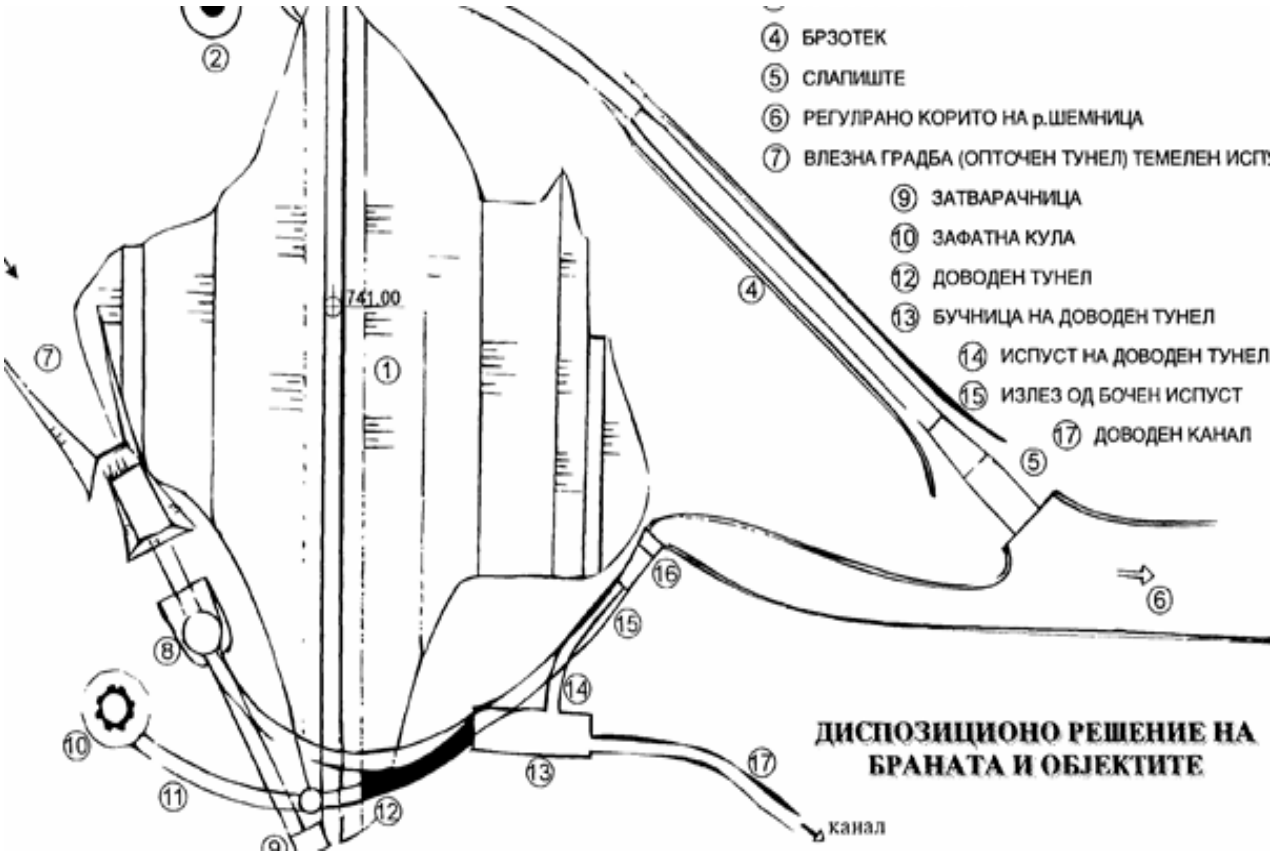

Figure 4-3. Layout of the dam "Strezevo" with the accompanying facilities

Figure 4-4. Dam "Strezevo" with accompanying facilities

Figure 4-5. Dam "Strezevo" with accompanying facilities

Figure 4-6. Intake tower

Figure 4-7. Shaft spillway

5. POSSIBLE CAUSES AND SCENARIOS FOR DEMOLITION OR ACCIDENTS OF THE DAM - CRITICAL POINTS OF THE STREZHEVO DAM

Generally, possible reasons for demolition of the dams are:

- Substandard building materials or construction techniques (**Gleno** dam)
- Overflow design errors (**GlenCanyon** dam)
- Geological instability caused by changes in water levels during recharge or poor observation (**Malpasset** dam).
- Landslide occurrence in the accumulation area of the dam (**Vajont** dam - no dam demolition is caused, but causes almost entire accumulation volume to be extruded and passed through the dam)
- Bad maintenance (**LawnLake** dam, **Val di Stava** dam)
- Extreme inflows (**Shakidor** dam)
- Human, computer or project error (**DaleDike** accumulation)
- Internal erosion or leakage, especially on earthen dams (**Teton** dam)
- Earthquakes.

From the above view the critical (weak) points of embankment dams can be identified: the crown of the dam over which overflows should not be allowed, overflow contact, the contact of the dam with the bottom of the river and the banks for the dam, water leaking through the body of the dam.

Also, from the above review it can be concluded that most of the causes of dam demolition are from human involvement - design, construction and maintenance errors, rather than naturally unpredictable factors such as earthquakes and extreme inflows in the accumulation.

We would briefly comment on the possible causes of the demolition of the "Strezhevo" dam in terms of natural disasters (earthquake, dam overflow as a result of high waters, or as a result of large landslides in the body of the accumulation) and anthropogenic impacts (reckless maintenance, technical surveillance failure, military action).

• Earthquakes

The risk of earthquakes is handled through strong earthquake resistance measures that are foreseen even when designing the dam.

The designer of the Strezhevo Dam Main Project requested to check the stability of the dam presented in the Elaborate [9]: Strezhevo Dam Stability from Earthquake Impact and Calculation of Strains and Shocks, Developed by the Geotechnical Institute at the Faculty of Civil Engineering in Zagreb in 1978.

From the seismological studies [5] regarding the location of the dam "Strezhevo" it is established:

- his area does not appear as a local earthquake hotspot.
- This area does not belong to any of the seismological lines in North Macedonia.
- The nearest earthquakes range from 25 to 30 km and originate from the Bitola Seismic Zone.
- Macroseismic effects of 6–7 degrees can be expected from the earthquakes in Greece at distances of about 150 km.

It is well known that embankment dams as flexible constructions are more resistant to

earthquakes than other rigid barriers, such as concrete, reinforced concrete and wall dams, due to their ability to follow their own deformation in the substrate on which they are based, without to suffer fatal consequences.

Evidence of this is the Bitola earthquake [14] which occurred on 1 September 1994 at 18h 12 min, with magnitude M = 5.2 ° on the Richter scale, i.e. VII degree on the MSK-64 scale, and its effect was felt on the whole territory of the Republic of North Macedonia, which passed without any consequences on the dam "Strezhevo".

The epicenter area of this earthquake was between Bitola and Ohrid, including the mountains Baba, Plakenska Planina and Bigla as well as the valleys of Prespa and Ohrid Lake and Pelagonia.

The Technical Monitoring Service does not detect visible damage to the dam and associated facilities. After the earthquake there was a disturbance of the lake. Lake levels were low, as the quake period is nearing the end of the irrigation season, when significant amounts of irrigation water were pumped from the accumulation.

- **Extreme inflows in the accumulation**

The project documentation for the dam "Strezhevo" as large water adopted a wave of 10000 year water with a maximum ordinance of 470 m^3 / s, which after the transformation through the accumulation, is reduced to 170 m^3 / s, where the flow overflow body of the dam is dimensioned – shaft spillway. The quantity of water is determined in the Study prepared for all planned partition sites in R. North Macedoniafor the needs of UN experts working on the "Integrated Bonyficationof the Vardar River Basin" prepared by the Jaroslav Cherny Institute in 1973.

In the current period of exploitation, the dam "Strezhevo" was flooded in 1985 after the initial filling, and since then the water level has not been affected.

The re-examination of the large waters for the "Strezhevo" accumulation was carried out in 1995 at the request of PE "Strezevo" with the preparation of the Study on the high waters of the Shemnica-profile dam "Strezhevo", by the Institute of Hydro-technics at the Faculty of Civil Engineering, Skopje [17].

The Study [17] analyzed all the hydrological and hydro-meteorological information used in the design and collected during the past period of exploitation. The defined waves of the high waters also provide the transformation of the flood waves as they pass through the accumulation. The Study practically defines the entry of large water into the accumulation at the level of the normal water level, i.e. shaft spillway elevation 737.5 m asl.

In addition, the study explored the issue of wave formation at high water as input to the Strezhevo accumulation and defined those waves. All relevant information from the documentation, the Hydrometeorological Service and the Strezhevo Dam auscultation Service were used in the preparation of the Study. The most up-to-date knowledge of hydrology for the study of large waters has been used methodologically.

For the defined flood waves, the propagation through the accumulation has been analyzed, considering the different ways of water discharge: a) through the intake tower and the hydro power plant, b) through the bottom outlet, c) through the shaft spillway and d) in combination with the indicated evacuation organs. The propagation of floodwaves starts from the most unfavorable baseline state of the accumulation, i.e. the level should

be at the overflow elevation of 737.50 m asl.

Such an assumption is mandatory for the design of the safety overflow organ – shaft spillway. The requirement for a high degree of safety is motivated by the fact that the dam is embanked and any overflow through the crown of the dam's body will also mean its disaster.

Hence the need arose when the accumulation is in a longer period of exploitation to conduct a more detailed hydrological study of the large waters based on detailed studies of its own river basin and hydrological - meteorological information.

Hydrological and hydraulic investigations of the large waters and their evacuation of the "Strezhevo" dam presented in the Study [17] led to the following conclusions:

- The results for the large waters in this Study are defined using all available information and by recommended methodology and in the future the Investor should use them when exploiting the facility;
- Large waters with rare repeatability once every 10,000 years are $Q_{0,01\%}$ = 450 m^3 / s, with a concentration of 5 hours and an 11hours retardation time, which differ from those specified in the project documentation, point 2.7, page 6, for about 3.5 million m^3;
- The evacuation organs of the "Strezhevo" dam safely evacuate the wave at 10,000 years of high water and in case of the most unfavorable starting position at the level - normal level 737.0 m asl. The waves of the smaller waters can be fully or partially transformed into the accumulation depending on the level position and the discharge mode;
- Hydraulic analysis of the evacuation of high waters was carried out for the adopted input hydrogram with a maximum ordinance of 450 m^3 / s, a time base of 16 hours and a volume of 12.8 million m^3. The topography of the accumulation, the capacity of the dam's evacuation organs and the initial level of the acumulation have a major influence on the shape of the output hydrogram. At an initial level of 737.50 m asl (normal level), the output hydrogram has a maximum ordinance of 217.64 m^3 / s, with the overflow organ participating with 157.38 m^3 / s. The maximum level established in the accumulation is 738.96 m asl. In the event that only the overflow organ is involved in the evacuation of high waters then the maximum output hydrogram is 175.03 m^3 / s, and the maximum level established in the accumulation is 739.29 m asl, which confirms the overflow capacity in the project documentation;
- If the bottom outlet and intake construction - the supplying organ, are engaged in work to discharge the accumulation, at indicative states of large waters in the catchment area and at an initial level of 737.5 m asl, the output hydrogram receives a time delay from discharge just 5 hours before the flood wave enters the accumulation, flooding delays 1.65 hours, increasing from 1.85 hours, when there is no pre-discharge, to 3.50 hours. If the discharge begins 10 hours before the entry of high water into the accumulation, the flooding delays 2.55 hours, i.e. it increases from 1.85 hours to 4.40 hours. It is recommended that these and other different conditions be checked by the dam user with the hydraulic model for the evacuation of large waters.
- In the evacuation of large waters the intake construction- supply organ with a maximum capacity of two outlets in the drainage of 2x40 = 80 m^3 / L may participate. It is not recommended to load this organ in such a quantity as the

positive effects on the output hydrogram and the accumulation levels established are insignificant and the damage to facilities near the dam will be large. Namely, the capacity of the Main Supply Canal and the outlet for safe operation, checked by hydraulic model tests is 2x12.3 = 24.6m^3 / L.

- These hydrological and hydraulic investigations have identified an operational need for decision-making to include or exclude a bottom outlet, supplying organ and alimentation canal, imposing a need for rapid information gathering and processing. This necessitates an efficient prognostic model.

A new survey [17] of large waters at the entrance to the Strezhevo accumulation has identified a somewhat lower flood wave (450 m^3/ s) than the flood wave (450 m^3 / s) adopted in the main project for the Strezhevo dam [1], indicating that the hydrological part is slightly overestimated.

In all possible scenarios of floodwave, the starting point is the state of full accumulation, where the water is at the level of the upper edge of the shaft. In all simulated cases, results were obtained confirming that the dam "Strezhevo" is safe for dam overflow in case of occurrence of the adopted 10,000 annual waters.

In the current practice of using the accumulation, larger water inflows are expected in the autumn and especially in the spring period, when besides the spring rains we also have melting snow from the catchment area.

The irrigation season ends in the fall when we have the lowest level in the accumulation, since irrigation is the largest consumer of water, so that the level where the flood wave could start is far below the dam overflow level; hence, it can be considered that during this period there is no possibility of overflowing the accumulation.

In the spring, as temperatures rise, we find melting snow from higher basins and spring precipitation, which can lead to extreme inflows. The usual practice is to keep the accumulation level lower than the overflow elevation level at the beginning of the spring period, depending on the amount of snow in the basin, for a forecast volume expected to come in the next period and with which the accumulation would be filled to normal level, with no overflow. This is done for reasons of protection of the area downstream from the dam, which during this period is exposed to potential floods of the Crna Reka, so by preserving the retention of the accumulation of flood waters of the river Shemnica, which is its largest tributary in the upstream, chances are improved to avoid flooding from the Crna Reka outflow.

- **Military activities**

In the event of a real military emergency it is practicable to discharge the accumulations to a pre-determined level in order to reduce the risk of dam demolition.

There are known military actions in the accumulation area of earthen dams designed to cause large waves that, at high levels of water in the accumulation, can reach a height that can overflow the dam's crown and cause damage.

The body of the embankments is highly resistant to bombardment due to its large mass and inert nature. The associated objects of these dams are more sensitive to these actions, such as water-absorbing organs, water-discharge organs and overflow organs.

- **Landslides**

The danger of dam demolition, especially on earthen dams, can be caused by landslides that occur downstream of the dam, in the dam body and in the accumulation.

Natural causes (earthquakes, heavy rainfall) and anthropogenic human factors, expressed through impacts that can trigger landslides, may be the cause of these events.

The appearance of landslides in the body of earthen dams is a real and expected situation and is prevented by designing stable inclinations on the body of the dam. Static and dynamic analysis of earth dams involves checking the stability of the slope of the dam from relevant possible load impacts: of its own weight, impact of water, impact of earthquake, etc. Particularly dangerous are the cases of sudden discharge of the accumulation, when due to water saturation of the material of the upstream slope, its instability and landslide can be initiated, which can cause serious dam damages and may require large scale repairs.

The rate of discharge of the accumulation also depends on the capabilities of the discharge organs - the discharges for the users, the fundamental discharge and the accumulation inflow. In the event of a forced discharge of the accumulation, the Dam Operator shall, by monitoring the measuring devices for recording the pressures in the dam body (pore and total), enable a controlled discharge process without causing any danger of occurrence of sliding.

The technical service for observation (auscultation) of the dam "Strezhevo" as part of its duties is tasked to monitor all occurrences of possible instability on the ground in and around the accumulation space, as well as immediately downstream of the dam. So far, with the exception of minor local landslides caused by the action of the waves, no landslides have been recorded.

To illustrate the danger of landslides for the stability of the dams we will cite the case of the dam "Suvodol", an earthen embankment with a accumulation volume of 7.879.000 m^3, which is intended for supplying REK "Bitola" with water for technological needs and providing 2.679,000 m^3 retention volume for flood protection over 1000 annual high waters on the surface coal mine, located downstream of the barrier.

In 1996, due to a landslide downstream of the dam, the northeast part of the surface mine of the Suvodol mine caused a damage-breakage of the overflow canal that drains water from the overflow body out of the surface mine area. As there is virtually no overflow organ of the dam (the overflow canal is cut off), the accumulation level should be maintained below 680.00 m asl (the normal elevation level is 687.50 m asl, in order to provide additional retention volume apart of already provided). The dam "Suvodol" is located in the Pelagonia region, in the Municipality of Novaci. Its location is marked under number 2 in Figure 2-2.

- **Internal erosion or leakage**

Regarding the danger of dam demolition as a result of internal erosion or leakage, the following technical auscultation of the dam "Strezhevo" is performed:

• Water filtration through the dam body and the injection curtain

To monitor the effectiveness of the injection curtain, 10 closed piezometers were installed: 5 upstream and 5 downstream of the injection curtain. All 10 piezometers are operational.

For monitoring the filtration waters through the dam body, they are brought to a so-called measuring well where continuous flow monitoring is performed.

• Water filtration through dam banks

To monitor the filtration waters through the dam banks, 13 open piezometers are installed, of which 11 piezometers are currently operational.

Since the beginning of the accumulation charging, until today a total of 9 sources have been discovered and monitored and all of them are at the left side of the dam "Strezhevo". All of these can be said to have a capacity of 0.01 to 0.35 l / s and are correlated with the water level in the accumulation. As a result of many years of observation of the dam "Strezhevo" it can be concluded that all springs dry up at water level in the accumulation below 720 m asl. The entire amount of filtration water (through the dam body and the injection curtain) is brought in and measured in so-called measured well and ranges from 4.0 to 10.8 l / s or annual water filtration rate amount of 0.26 million m^3, which is lower than projected at 1.13 million m^3.

During the conscientious performance of the technical surveillance of the dam "Strezhevo", which includes monitoring the water filtration through the dam body and the injection curtain and water filtration through the dam banks, while simultaneously monitoring the water level in the accumulation, there is no possibility for timely failure. The aforementioned processes will be detected, and in the event of such occurrence, the measures provided for in the Operational Plan such as the State of Emergency Preparedness and Dam Management Duties and, subsequently, the state of general disturbance [2], [5] will follow.

6. ANALYSIS OF HYDRAULIC CONSEQUENCES ON THE PELAGONIA REGION FROM EVENTUAL DEMOLITION OR ACCIDENT OF THE STREZHEVO DAM

An analysis of the consequences on the Pelagonia region of the possible demolition or accident of the "Strezhevo" dam is initially considered in the Report on the alerting and warning of the area threatened by the demolition of the "Strezhevo" dam, developed by the Institute for Water Management Yaroslav Cherny from Belgrad, in october 1975 [2], at the request of the Water management company "Pelagonia" from Bitola, which later resulted in the Public Company "Strezhevo".

The Report was prepared as part of the dam's Main project [1], prior to its construction and is the key project documentation on the basis of which all subsequent flood protection plans, population evacuation plans, livestock and basic tangible assets are based.

The following is a preview of this basic document:

6.1. Technical description

6.1.1.Basic data for the dam

The dam "Strezhevo" is located on the river Shemnica, downstream of the village Strezhevo. The dam is earthen with a clay core.

On the left side of the accumulation shaft tunnel drainage with high-speed flow for evacuation of large waters is designed. The crown elevation level is the normal slow-water elevation. On the right side of the dam is a bottom outlet.

The dam is multipurpose. The water from the accumulation is intended to be used for irrigation of the Bitola Field, for supplying the city of Bitola and the water industry and for the production of electricity.

The accumulation is foreseen for many years to level the water from the river Shemnica and partly to the waters from the Baba Mountain, which are introduced into the accumulation with the Alimentation Canal.

6.1.2. Characteristic profiles

In order to analyze the hydraulic consequences that can occur in case of demolition of the dam "Strezhevo" along the river Shemnica and Crna Reka are selected characteristic profiles which take into account: the characteristics of the valley, the locations of settlements and the locations of important highways:

- profile at km 0 + 000 - Infusion of the river Shemnica in the Crna Reka
- profile at km 4 + 000 - Village of Mogila
- profile at km 6 + 000 - Change in geometrical and hydraulic characteristics of the regulation basin of r. Shemnica
- profile at km 9 + 500 - Concrete bridge on the river Shemnica at the road Skopje - Bitola
- profile at km 12 + 000 - Concrete bridge on the river Shemnica on the road Bitola - Kicevo. (Directly upstream of this bridge regulation completes)
- profile at km 14 + 200 - The bed of the river Shemnica is not clearly expressed.
- profile at km 21 + 000 - Village of Crneec.

The other characteristic profiles of the Shemnica River are selected only to see the

gradual narrowing of the valley. These characteristic profiles show the maximum levels of the water surface in case of dam demolition for adopted initial conditions and for river flow rate of 202 m^3 / s (stationary mode).

6.1.3. Flooding zones

For certain combinations of baseline conditions - adopted flows of the rivers Shemnica and Crna Reka and elevations of the lake levels, given over **4 variants** listed in item 6.2.6. below, on the basis of hydraulic modeling tests, the maximum possible levels of a water surface that may occur in the event of a total and momentary dam demolition are determined. These maximum levels are the basis for determining the zones that can be flooded in the event of a dam demolition. Due to the relative scale of the situation and the characteristic of the valley, especially the Bitola Field, the flooding zones for the four variants examined could not be plotted, so that at 1: 50,000 scale map showing the valley of the Shemnica River from the dam to the Crna Reka, part of Crna Reka and Bitola Field, the lines of contact of the flood wave for variants 1 and 4 are drawn and the area that would be flooded with maximum flow of Shemnica River of 202 m^3 / s is also drawn, see Figure 6-1.

Since variant-1 is the most unfavorable, as the flooding zone is the largest, that variant is appropriate for taking measures to protect the population.

6.1.4. Analysis of the flooding zones from the aspect of possible consequences

The analysis of the maximum flooding zone came to the following concluding view of the threat to settlements and industrial buildings:

- Crneec village, located on the left bank of the Shemnica River, about 2.5 km downstream of the dam, is the first settlement that may be partially affected by the flood wave. It is only about houses that are closest to the river. The maximum height of the flood wave in this part is 12.4 m, which does not mean that the same height is in the part of the settlement. But regardless, the height of the wave is enough to cause all objects to collapse. The width of the flooding zone in the profile of the village of Crneec is about 400 m.
- Downstream of the village of Crneec the flooding zone begins to expand more and more and about 8 km downstream of the dam is 1000 m.
- The village of Crnobuki, on the left bank of the Shemnica River, approximately 13,5 km downstream of the dam is directly exposed to the effects of the flood wave. The height of the flood wave is 8.5 m. As the tide is steep, the consequences can be catastrophic.
- The village of Kukurecani, located to the right of the Shemnica River, about 15 km downstream of the slope dam, can only be partially affected by the flood wave.
- The railway Skopje-Bitola and the Skopje-Bitola road, which cut across the valley, are directly impacted by the waves, whose height is 7.5 m. The width of the flooding zone of this part is high as the flooding of the Bitola Field begins.
- The village of Mogila, just beside the right bank of the Shemnica River upstream of the railway, is also under the hit by the waves. As the valley of the Shemnica River is wide in this part, the maximum increase in water level due to demolition is even smaller and is 5-6 m. However, the height is sufficient to cause demolition of facilities and communications.

- The part of the Bitola Field that is exposed to flooding is large. This is especially true for the area between Crna Reka, the V-canal and Shemnica River. The increments of levels at the feed plant in the entrance zone of the river Shemnica in Crna Reka are about 2 m. Upstream and downstream they decrease. Most of the settlements located in the Bitola Field are exposed to the action of the flooding wave whose maximum height is up to 2 m. The following should be mentioned from the settlements: Trn, Karamani, Orizari, Logovardi, Poeshevo, Opticari, Sredno Egri, Dolno Egri (settlements between Crna Reka, Shemnica and V Canal) and Radobor, Novaci, Ribarci, Gneotino on the left bank of Crna Reka.
- Part of the Bitola Field is exposed to flooding and natural flooding of the Crna Reka. Then, besides the areas under crops, some of these settlements would be under water.
- The area that could be affected by flooding for the most unfavorable variant of the Strezhevo dam demolition is 212 km^2.

6.1.5. Marking the flooding zone on the ground

Only the maximum water level that can appear in the profile considered is marked on the ground. The marking is done with concrete marking pillars, shown in Figure 6-1. At the top of the pillar there is a brass plate on which the number of the mark is written, and the elevation at the maximum water level, which is at the same time the elevation on which the brass plate is placed. 49 pillars (from 1-49) will be placed on the left side of the valley of Shemnica and 37 (from 50-86) on the right side. The distances between the marks in the zone of settlements and buildings are about 300 to 500 m, and in the uninhabited places in the valley between 1000 and 1500 m. Figure 6.1 shows the position of the marks, and Table 6.1 shows the elevations of the marks.

Table6.1 - Pillars-marks for marking the flooding zone

Marking Number	Placement to the Shemnica river	Mark level elevation	Marking Number	Placement to the Shemnica river	Mark level elevation
Left bank			Right bank		
1	23+200	688,00	50	23+200	688,00
2	22+150	665,90	51	22+600	672,50
3	21+000	652,60	52	21+000	652,60
4	20+180	644,60	53	20+000	643,20
5	19+800	641,90	54	19+000	637,20
6	19+000	637,20	55	18+000	632,80
7	18+000	632,80	56	15+000	618,10
8	17+000	628,00	57	14+000	614,40
9	15+600	621,70	58	12+000	607,00
10	15+000	618,10	59	11+000	605,10
11	13+500	612,50	60	10+000	602,90
12	12+400	608,30	61	9+500	602,00
13	11+000	605,10	62	8+800	600,90
14	9+300	601,80	63	7+700	598,30
15	8+900	601,10	64	7+000	596,60
16	8+500	600,20	65	5+800	594,50
17	8+000	598,90	66	5+500	593,80
18	7+000	596,60	67	5+400	593,50
19	6+300	595,40	68	5+300	593,20
20	6+000	594,90	69	5+200	593,00
21	5+300	593,20	70	5+100	590,00
22	3+800	589,30	71	5+000	587,00
23	2+400	585,90	72	4+000	582,60
24	2+000	585,00	73	2+000	582,00
25	1+600	584,00	74	2+000	581,80
26	1+000	582,60	75	1+700	581,00
27	0+000	582,00	76	-	580,50
28	-	581,50	77	-	580,00
29	-	580,80	78	-	580,00
30	-	580,50	79	-	580,00
31	-	580,00	80	-	580,00
32	-	580,00	81	-	580,00
33	-	580,00	82	-	580,00
34	-	580,00	83	-	580,00
35	-	580,00	84	-	580,00
36	-	580,00	85	-	580,00
37	-	580,00	86	-	580,00
38	-	580,00			
39	-	580,00			
40	-	580,00			
41	-	580,00			
42	-	580,00			
43	-	580,00			
44	-	580,00			
45	-	580,00			
46	-	580,00			
47	-	580,00			
48	-	580,00			
49	-	580,00			

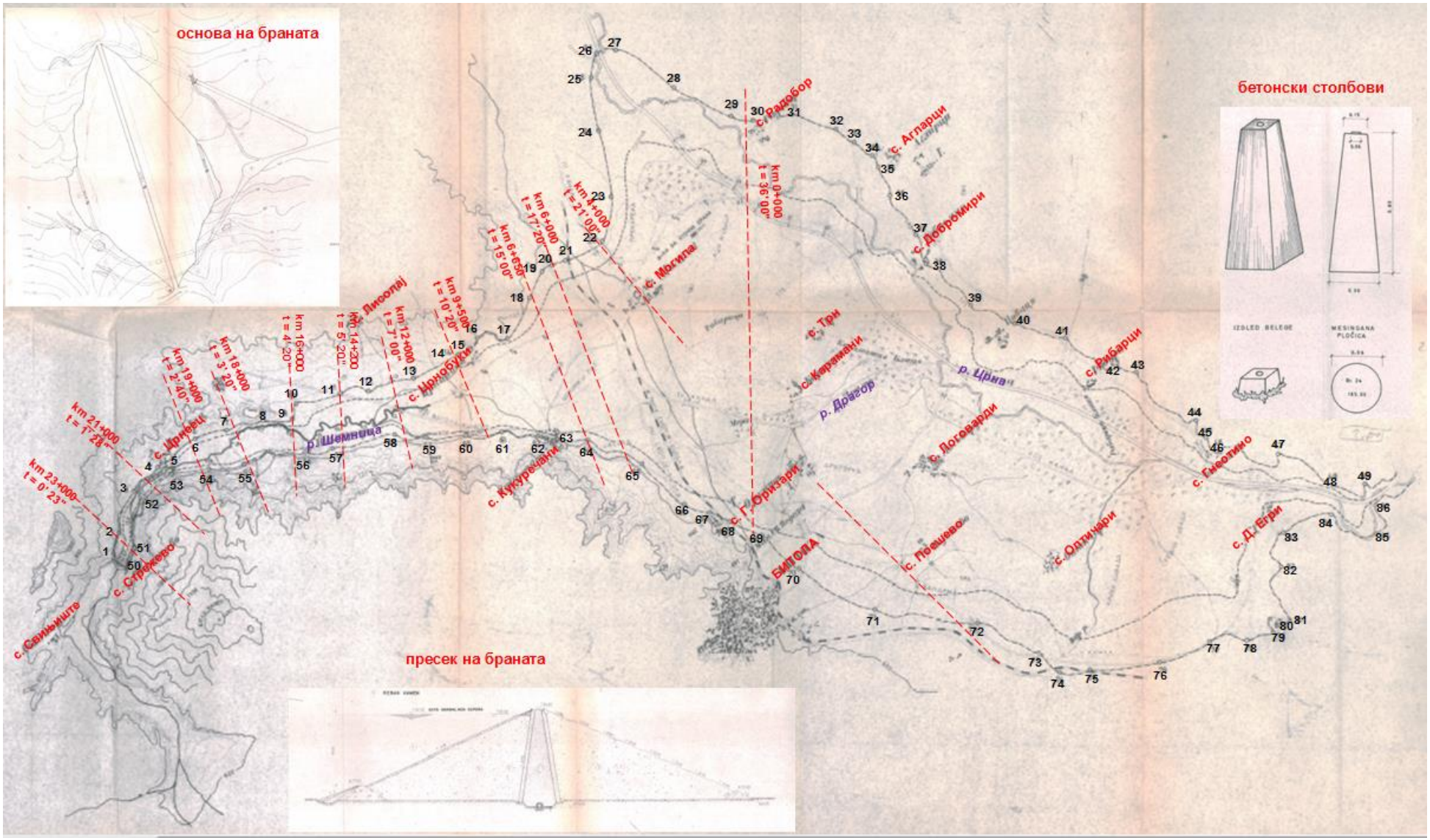

Figure 6-1. Flood demolition zone of "Strezhevo" dam, control profiles and position of concrete markings

6.1.6. Reporting and alarming devices for the population

For the sake of efficiency in reporting and alerting the population, it is envisaged to place sirens in the following locations:

P.S. 1	Dam village Strezhevo
P.S. 2	village Crneec
P.S. 3	village Crnobuki
P.S. 4	village Kukurechani
P.S. 5	concrete bridge on Bitola - Skopje road and Bitola - Skopje railway bridge
E.S. 6	village Mogila
P.S. 7	village Logovardi
E.S. 8	concrete bridge 1.5 km from the mouth of the river Shemnica
P.S. 9	village Radobor
P.S. 10	village Trn
E.S. 11	village Dolno Orizari
P.S. 12	at the mouth of Dragor River
E.S. 13	village Optichari
E.S. 14	village Gneotino
E.S. 15	village Gorno Egri
E.S. 16	village Dolno Egri
	(P.S. –pneumatic siren, E.S. –electric siren)

The sirens can be: electric and pneumatic. The siren arousing is provided by wires and wirelessly.

In the case of air strikes, power plants are usually the first target, so the power system will be the first to fail. Also in case of major disasters (earthquakes, floods, etc.), the power system is switched off. During air strikes electricity is disconnected for obscurity.

Therefore, the system should be independent of the power grid. In the event of a power failure, aggregates are foreseen to be automatically switched on when electricity is disconnected from the grid. The pneumatic and electric sirens described above are intended to be fitted with an EDK electronic remote control system.

A wireless alarm radio-relay connection is provided in addition to the wired connection, where existing lines are unreliable or nonexistent.The arousing is possible simultaneously from the Dam's Command Center, and also selectively.

When designing the alarm system, a dam detector sensor for not-allowed movement of the dam must be provided, which will automatically trigger the alert system. Before designing the system, radio measurements must be made to select the optimal locations of the radio devices. Acoustic measurements must also be performed in order to optimize the locations where the sirens will be positioned.

The flood wave ends within the Bitola part of Pelagonia, next to the village Optichari and there is no danger of overflow in the Republic of Greece.

6.2. DETERMINATION OF HYDRAULIC CONSEQUENCES

6.2.1. Available data

Hydraulic and hydrological data are used which are not of the highest accuracy. Given the complexity of the phenomenon being solved (the influence of many parameters, and the necessary approximations in this respect), it may be considered that basic conditions exist for hydraulic analysis to be performed with satisfactory accuracy.

6.2.1.1. Topographic and morphological data

Layout of the valley of the river Shemnica, upstream and downstream of the dam in the ratio 1:2500 and 1:10000, layout of Pelagonia in the ratio 1:50000 and characteristic transverse profiles of the river Shemnica and Crna Reka are used for the model development. These are the basic data for presenting the morphological characteristics of the two river streams and their valleys.

Analyzing the morphological characteristics of the Shemnica River, it is concluded that the valley is slightly sloping (average fall is about 3 ‰). On the part of the future dam, the valley is narrow, and from the village of Crneec the valley begins to gradually expand. The river bed of the river Shemnica is not expressed until the profile 12 km downstream of the dam. From this profile to the mouth to the Crna Reka the riverbed is regulated. The riverbed is dimensioned on a 20 year high water of 56 m^3 / s. The average fall of the regulated bed is 1.2 ‰.

The outflow of Shemnica River into the Crna Reka is regulated, and so is the Crna Reka. The riverbed of Crna Reka is dimensioned at a flow of 206 m^3 / s, between the river Shemnica and the river Dragor and at 161 m^3 / s upstream from km 32 + 000 to km 45 + 000.

The average slope of Crna Reka on the Bitola Field is about 0.6 ‰.

6.2.1.2. Hydrological and hydraulic data

Hydraulic data are represented by the probability line for large waters for the Shemnica River (Strezhevo measuring profile), and for the 20-year high waters of the Crna Reka.

The probability line for large waters is indirectly used, as the project designates the flow over which the overflow organ is dimensioned. The 202 m^3 / s flow represents 10.000 years of high water reduced for the retention effect of the accumulation pool.

Based on the Guidelines for the development of documentation for the consequence of demolition and overflow of high dams as a single flow, the extreme flow on which the object is dimensioned is adopted. The flow rate corresponding to the installed flow, i.e.to the biological minimum is small, so it can be assumed that the bed is dry.

As far as Crna Reka is concerned, the one that responds to a 20-year high water flow ($Q_{5\%}$ = 206 m^3 / s) has been adoptedas the prevailing extreme flow. No flow has been adopted for less probability because it is unrealistic to assume that the coincidence of extreme high waters of the Crna Reka and the collapse of the Shemnica Dam will occur. The second characteristic flow adopted is a flow corresponding to the mean annual flow of 25 m^3 / s.

As the floodwave caused by the dam's demolition occupies a wider valley, which is partially covered by vegetation (forests and crops), the coefficient of roughness for the Valley according to Maning, especially for the area directly downstream of the dam, is

greater (between n_i = 0.040 and 0.060). On the basis of nature observation, own experience and literature data, the coefficient of roughness was assessed along the flow.

6.2.1.3. Objects

The river Shemnica is regulated on its downstream (from the mouth to km 12 + 000). Crna Reka is regulated upstream and downstream by the inflow of Shemnica River. Because the Crna Reka is dimensioned for 20 years big water, during the less probability flows it comes to overflow of the embankments and outflow of the Crna Reka into the Bitola Field. Along the Shemnica River, several bridges have been built which represent a direct obstacle in the event of large floods. In case of dam demolition these bridges will be demolished.

6.2.2 Population and valley data downstream of the dam

In the valley of the Shemnica River upstream of the dam Strezhevo there are several small settlements: the village of Crneec (about 2.5 km downstream of the dam), the village of Crnobuki (about 13.5 km) and the village of Mogila (about 18.2 km). As these settlements are closest to the dam, in the valley of the river Shemnica, they are also the most endangered. Villages in the area of the inflow of the river Shemnica in the Crna Reka and in the Bitola field, which may also be endangered, but to a significantly lesser extent, are: Radobor, Dobromiri, Novaci, Ribarci, Logovardi, Optichari, Trn, Poeshevo, Orizari, Gneotino, Egri and others.

In the valley of the river Shemnica there are important roads and other facilities: road Bitola - Skopje, road Bitola - Kichevo, railway line Bitola - Skopje, bridges of river Shemnica and Crna Reka, then the network of drainage and irrigation canals, etc.

6.2.3. Selection of a method for determining the hydraulic consequences of dam demolition

Given the fact that the valley of the river Shemnica and the vast Bitola Field are populated and the consequences of dam demolition can be catastrophic, it is very important to determine the consequences more precisely.

Calibrated hydraulic model, in the conditions of correct performance provides the highest accuracy over other possible procedures. However, the hydraulic model also introduces a degree of error. The errors are a consequence of certain inevitable deviations from similarity, especially when it comes to models with greater distortion. In the present case, in addition to the above-mentioned deviations, additional are possible because the model cannot verify the accuracy with which the natural roughness is mimicked.

Since the determination of hydraulic consequences is carried out for extreme cases with respect to the conditions preceding the dam demolition and for the case of total and momentary dam demolition, any model-nature relation errors are negligible with respect to the severity of the initial conditions.

Accordingly, the results obtained from the hydraulic model are sufficiently accurate that measures to protect people and material goods in the valley of Shemnica River and in the Bitola Field be based on them.

6.2.4 Hydraulic model

Since it was difficult for the Bitola Field itself to identify possible flood zones, and it is large in area, an alternative was adopted to represent part of it in the model. When selecting the contours, a sufficiently large area of the field was taken to allow cross-sectional profiles to be used to estimate the flood wave propagation. The model contours of the Bitola Field section are sharply shaped so that the wave height caused by the demolition of the dam can be accurately recorded at the model boundaries.

At the upstream end of the accumulation and the Crna Reka are installed water supply systems with appropriate flow measurement chambers. The dam is represented by a flat barrier, which can be removed immediately.

The bridges are not represented on the model because it is assumed that they will collapse when the flood wave is encountered. The riverbed is fixed, sloping with gravel with a diameter of 3 - 5 cm.

Capacitive probes are used to record the level of the water surface. Levels were recorded at several points simultaneously, and the experiments were repeated two or more times for control purposes.

6.2.5. Determination of hydraulic flow characteristics for stationary conditions

For extreme flow in the Shemnica River $Q_{0,01\%}$ = 202 m^3 / s and characteristic flow through the Crna Reka $Q_{5\%}$ = 206 m^3 / s on the model are recorded water surface levels along the both flows.

6.2.6. Determination of the hydraulic consequences of the demolition of the "Strezhevo" dam

For the adopted baseline and boundary conditions, directly at the model at selected transverse cross-sections and points, changes in the water surface level have been registered as a function of the time since the moment of demolition of the "Strezhevo" dam.

Based on the results (level graphs) the other characteristic values are determined: the maximum wave height, the time of occurrence of the wave's forehead, the average velocity of the wave's forehead, etc.

Initial conditions are the conditions in the accumulation and along the river that precede the dam's demolition.

The tests were performed for 4 combinations of baseline conditions:

Variant1 - Maximum flow in the Shemnica River of 202 m^3 / s.
- Flow in Crna Reka 206 m^3 / s.
- Water level elevation in the accumulation 734 m asl.

Variant 2 - Dry riverbed of Shemnica River.
- Flow in Crna Reka of 25 m^3 / s.
- Water level elevation in the accumulation 732,5 m asl.

Variant3 - Dry riverbed of Shemnica River.
- Flow in Crna Reka 25 m^3 / s.

- Water level elevation in the accumulation 715 m asl.

Variant4
- Dry riverbed of Shemnica River.
- Flow in Crna Reka 25 m^3 / s.
- Water level elevation in the accumulation 700 m asl.

The choice of the last two variants is conditioned by the need to find a so-called "safe elevation level".

For the upper boundary condition a profile is adopted at the end of the accumulation of the Strezhevo Dam.

The lower boundary condition cannot be precisely defined with respect to the river flow, since the direction in which the wave propagated by the dam demolition does not coincide with the river valley of the Bitola Field. For the lower boundary condition, the boundary of the valley of Shemnica and Crna Reka is adopted, presented in the model, for which is assumed that the height of the wave caused by dam demolition is small.

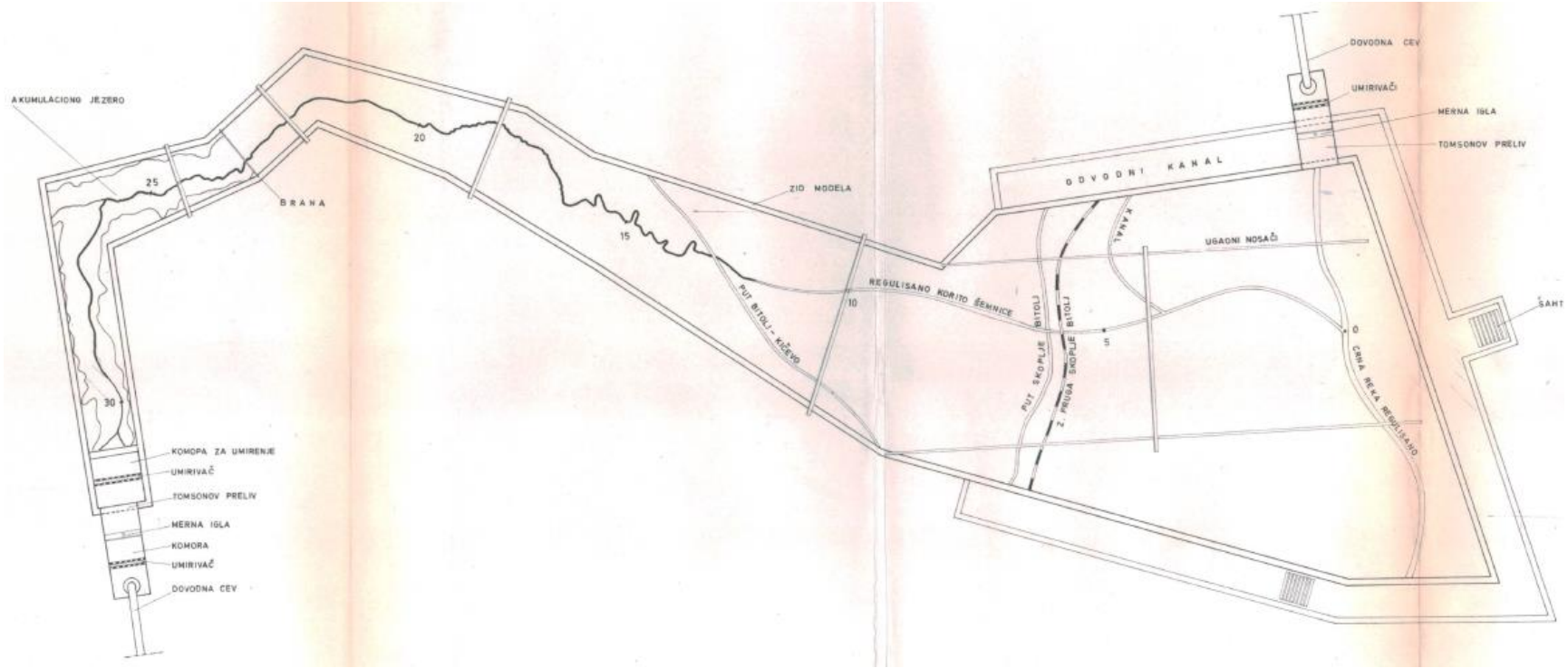

Figure 7-1. Base of the hydraulic model for the investigation of the consequences of the demolition of the "Strezhevo" dam

Figure 7-2. Model layout photos

6.2.7. Analysis of model test results

Level changes have been recorded from the moment of dam demolition along the profiles of one kilometer apart. Along the transverse profiles changes are also registered on the Bitola Field section. Upstream of the dam the changes are registered only for Variant-1, as they represent the midpoint of the registered changes. This is due to the fact that, in addition to the underlying phenomenon, there are some secondary phenomena (surface waves) that are more pronounced on the model than in nature.

6.2.7.1. Level change analysis

To get a picture of the valley level change downstream, each variant is analyzed individually with the center of attention on the variant causing the extreme consequences.

For the case when dam demolition is preceded by: maximum flow in Shemnica River of 202 m^3 / s, Crna Reka flow of 206 m^3 / s and lake elevation level of 734.00 (Variant-1) absolute maximum levels of the water surface downstream of the damare registered.

What is characteristic for all the variants examined is that the wave created by the demolition of the "Strezhevo" dam spreads through the valley of the river Shemnica up to its entrance in the Bitola field. The large expansion of the valley requires the flood wave to be scattered by forming a prominent wave propagation direction to the right of the Shemnica River.

For the variant causing extreme consequences, the depth increment directly downstream of the dam is very large: 43 m. The reason for this is the profile topographic features downstream of the dam. At 570 m downstream of the dam this increase decreases to 22 m. In the profile at 1570 m from the dam (km 22 + 000 from Shemnica inflow) this increase is 13,60 m. The mitigation of the flood wave from this profile is small so that in the profile at 15.5 km downstream of the dam (km 8 + 000) the level increment is 9,30 m. With the widening of the valley of the river Shemnica, that is, with the entry of the flood wave in the Bitola field, the tide is faster, so that in the zone of the river Shemnica, the increase of the level is only 2,1 m. The flooding wave comes to Crna Reka almost normally that cannot be considered as spreading along the Crna Reka. By registering the change in the level along the Crna Reka, elements have been obtained for the analysis of the flood wave displacement on the part of Bitola Field left and right of Shemnica. As can be seen from Annex 11 in the profile of Crna Reka km 35 + 000 (2,5 km upstream of Shemnica inflow) the maximum rise is 1,5 m, and at km 29 + 000 (3.5 km downstream)) is 1,05 m.

The flood wave propagation laterally in relation to the bed of the river Shemnica is also recorded in several profiles of the river Shemnica (km 3 + 000 and km 5 + 000). The maximum levels at km 3 + 000 are as follows: in the riverbed of the river Shemnica 587,40, to the right of the riverbed at 1,4 km 584,20 and at 2,5 km 582,60. At km 5 + 000 the levels are as follows: in the riverbed of Shemnica 592,50, to the left of the riverbed at 1.1 km 587,000 and to the right at 1.8 km 587.00. Based on these results, an assessment was made of the maximum possible levels of parts of the Bitola Field not covered by the model. This mainly refers to a work from the Bitola Field between Canal V and Canal X, south of the Dragor River.

For variant-2, i.e. for lower elevation levels in the accumulation and dry riverbed of the Shemnica River the absolute elevations in the level are slightly lower than for variant-1.

For the other two variants, when the lake elevation level is at 715 and 700 m asl, the wave heights are lower than for variant-2. The absolute elevation of the profile level km 8 + 000 for variant-2 is 598,20 and for variant 4 is 593,00. The height of the waves in the same profile in relation to the river bottom for variant-2 is 9,80 m and for variant-1 4.6 m.

6.2.7.2 Travel time for the forehead of the wave and occurrence time of maximal level

For the analysis of the measures for the protection of the population in the valley downstream in case of dam demolition it is necessary to determine the travel time of the wave forehead, i.e. the appearance of the forehead in individual profiles in the valley. The time of occurrence of the wave forehead in individual profiles is the shortest for variant-1 and for individual settlements in the valley of the Shemnica River and it is:

village Crneec (km 21+200)	1 min
village Crnobuki (km 10+200)	9 min 40 s
village Kukurechani (km 3+000)	13 min
village Mogila (km 5+300)	19 min 20 s
village Trn	35 min
village Radobor (km 10+200)	45 min

Based on the data given, it can be concluded that in the villages of Crneec and Crnobuki it is impossible to do anything to rescue people. In other settlements in the valley of Shemnica it is possible to evacuate the population.

The time of occurrence of the maximum wave height is longer than the time of occurrence of the wave's forehead. Immediately downstream of the dam these differences are small, and downstream they are larger.

6.2.7.3 Analysis of the mean propagation velocity of the wave forehead

For the variants examined, the mean travel speeds of the wave's forehead along the flow are also determined. The maximum wave speed is obtained for variant-1. Immediately downstream of the dam the average speed is about 29 m / s, i.e. about 100 km / h. This velocity gradually decreases to about 11 m / s, i.e. 40 km / h, in the area of the inflow of river Shemnica into the Crna Reka.

6.2.8. General conclusions

Based on the results of the model tests of the hydraulic consequences of the demolition of the "Strezevo" dam on the hydraulic model, the following conclusions were reached:

- The most disadvantageous consequence of dam demolition is that when the dam is preceded by a maximum lake level and extreme river flow.
- The floodwave created by the dam's demolition has all the features of a steep-headed wave along the valley of the Shemnica River to its entrance in the vast Bitola Field. Therefore, his wrecking power in this area is greatest.
- The greatest reduction in the height of the wave is at the part directly downstream of the wave. At a distance of 1,5 km from the dam, the wave is reduced from 43 m

to 13,6 m.

- The decrease in the wave height downstream is smaller, which is certainly a function of the valley characteristic. Significant reduction of the flood wave occurs in the Bitola Field.
- Lowering the lake level significantly reduces the heights of the waves, i.e. the absolute elevations reached by the flood wave, but this does not affect the floodplains in the same way due to the topographic features of the valley and field.
- Even in the naturally high waters of the Shemnica River and the Crna Reka there is also a flood that encompasses valleys of both flows.
- Given the time travel at the forehead of the wave and the location of the settlements, no settlement can be undertaken to rescue the people up to the Shemnica River itself if the disturbance is reported after the dam has been demolished.
- The difference in the time of occurrence of the maximum height of the wave with respect to the appearance of the wave's forehead is increasing with the distance from the dam.
- The average travel speed of the wave's forehead is the highest immediate downstream of the dam, about 100 km / h. The further it decreases.

With respect to this Elaborate [2], it can be said that it is based on a model simulation of the phenomenon of instantaneous dam demolition, on a large scale model, by observing similarity rules, which if properly calibrated, gives reliable results in terms of the phenomenon examined, compared to purely computer-based models.

The research was carried out by a leading scientific institution, the Institute of Water Management "Jaroslav Cherny". Investigations have been made on 4 variants, which take into account different water elevations in the accumulation, and different conditions in the riverbed of Shemnica and Crna Reka.

In the future, the physical model could be checked by a computer model, which would give sufficiently accurate results for the initial and boundary conditions, i.e. by calibrating the results obtained it would calibrate itself. Then, with such a calibrated computer model, simulations could be made for the instantaneous demolition of the Strezhevo dam with different initial conditions that would result from future hydrological and other studies.

7. DETERMINATION OF SAFETY WATER LEVELS IN ACCUMULATION

In order to obtain the elements for determining the so-called "safe elevation level" during the eventual demolition of the "Strezhevo" dam as part of the model investigation [2], two variants of reduced lake water levels, 715 and 710 m asl, were investigated.

For these two variants the maximum possible levels along the flow are determined.

Analyzing the results, it can be concluded that the maximum absolute elevations of the water levels recorded by the profiles are significantly lower than when the lake is full.

For example, the **reduction** in variant-2 is:

- in profile at km 10 + 000, 1,4 m (variant-3) and 4,3 m (variant-4),
- in profile at km 6 + 000, 2,0 m (variant-3), 4,4 m (variant-4) and
- in the inflow zone, 0,70 m (variant-3), 1,9 m (variant-4).

As for the floodplains for the aforementioned variants, they are somewhat smaller but not much. This is explained by the configuration of the Shemnica River on the Bitola Field. From the overview map, it can be seen that the **flood zone obtained for variant-4 corresponds approximately to the flood zone with natural extreme water flow of the Shemnica River of 202 m^3 / s**.

By lowering the water level in the lake, the height of the flood wave decreases, thereby mitigating the consequences. This is not true only for settlements located near the flow of the Shemnica River, as the levels of dam demolition are large enough to cause adverse effects.

Impact analysis for a lower safe level would not be justified because the 694 m asl is the minimum operating level. Due to the filling of the lake with sediment, the consequences determined for testing the variant would certainly be smaller.

From the analysis of the impacts on the flooded area, it is clear that by decreasing the amount of water in the accumulation they decrease. From an economic point of view, keeping higher elevations on the accumulation is justified, while keeping a safe elevation makes sense only when there is a real potential danger to the safety of the dam.

- **Discharge of the accumulation**

When the lake level elevation is lower than the elevation level of the crown of the shaft, the discharge of the lake may be affected through a bottom outlet and through the turbines. In case of simultaneous operation of the bottom outlet and power plant, assuming that the flow from the Shemnica River is 4 m^3 / s, the discharge time of the accumulation from elevation 734 to 694 is approximately 27 days.

8. DAM MONITORING - INSTRUMENTS AND PROCEDURES FOR MONITORING THE STATUS OF DAM, ASSOCIATED FACILITIES AND ACCUMULATIONS

According to the legal provisions [8], the operators (legal entities) managing the dams, designated as dams of special importance, are obliged to establish and organize **technicalobservation of the dams and associated facilities and accumulations**, on the basis of a **project for technical observation** (auscultation) of the dam, and at least once a year to develop a separate **Elaborate for the analysis and evaluation of the stability and functionality of the dams with associated facilities and accumulations, and the stability of the terrain around the dams, associated facilities and accumulations** [11].

The term "technical observation" of high dams means a set of activities aimed at measuring those physical parameters whose knowledge is necessary to determine at a given moment the state of the dam as a whole or individual parts thereof, on the one hand, and the condition of the rock mass just below the dam and in the accumulation itself, on the other hand, both from the standpoint of stability and from the standpoint of water permeability. Of course, regular control of the physico-chemical effect of water on the facility itself and its individual parts, as well as on all hydromechanical equipment, is part of the technical observation.

8.1. Aspects of the technical observation

The purpose of technical observation can be interpreted from various aspects:

- **Security of the facility**. From this point of view, the technical observation aims to provide insight into the behavior of the dam, in order to determine whether it is within "normal" frames, i.e. whether under alternating load and unloading cycles, temperature changes and other external influences on the facility or on its individual parts does not come to such deformations and displacements, accompanied by appropriate stress, which will be an indication of disturbance of the expected (projected) behavior of the facility or its immediate surroundings.
- **Maintenance of the facility**. The conscientious and rational maintenance of the facility is sufficient reason for its technical observation. The works related to the repair of these facilities are generally robust and difficult, and as a rule always expensive. This implies the need for any damage and unwanted changes to the facility to be timely detected and actions to be taken to remove them. When designing these facilities, they are built with a certain life expectancy, while maintaining them correctly, contrary to the present lay thinking that the already constructed facilities are "eternal". Therefore vigilant observation of the facility must not be misleading, otherwise it means taking risks on a larger scale.
- **Getting new insights**. Technical observation enables the acquisition of new technical knowledge regarding the design and maintenance of dams, which should be transferred to dams planned to be built in the future.

8.2. Systems for technical observation (auscultation) of the "Strezhevo" dam

Technical surveillance of the dam "Strezhevo" is completed by the expert service of the PE "Strezhevo" in co-operation with the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje, on the basis of the Main project of the dam "Strezhevo", Book 7, Volume 7 [3], Rulebook for Technical Observation of High Dams [15] and the Rulebook on the Minimum Required Works and Measures for Technical Monitoring of Dams [16].

A report from the Technical observation of the dam "Strezhevo" [11] shall be submitted once a year to the MoEPP at the latest four months after the end of the year to which it relates, which shall be approved on the basis of a prior **written opinion of the Dam Commission**.

The system of technical observation of the dam "Strezhevo" includes registration of the following occurrences:

- **Meteorological phenomena**:
  - **Rainfall**. Their registration is necessary because of the water balance in the accumulation. The intensity of precipitation is recorded with a Helmann rain gauge and an ombrograph is used for continuous time registration.
  - **Air temperature**. It is registered daily at 06^{30}, 13^{30}, and 20^{30}, as well as its extreme values during the day and night using mercury thermometers, and a continuous bimetallic thermograph is used for continuous time registration.
  - **Air temperature**. The water temperature of the accumulation is measured at depths of 0 (accumulation surface), 5, 10 and 20 m.
  - **Evaporation**. It is a necessary parameter for the water balance in the accumulation. A Class A evaporator is used.
  - **Wind direction, strength and speed**. The KVT 60 wind instrument is used to record the direction, strength and speed of the wind. The instrument reads at 06^{30}, 13^{30}, and 20^{30} hours, and in specific cases with strong winds and more often.
  - **Air humidity**. It is registered daily at 06^{30}, 13^{30}, and 20^{30} hours, using a hygrometer, and for continuous time recording a hygrograph is used.
  - **Insulation**. It is registered daily with the help of a Kembel-Stocks heliograph.

- **Hydrological phenomena**:
  - **Water level before entering the accumulation**. In order to know at any moment the total amount of water from the river that flows into the accumulation, just before the accumulation itself, a measuring threshold has been built with a certain flow curve. At the measuring threshold is a lithograph produced by the SEBA-Germany company with witch the level of water passing through the threshold is permanently registered, and with the help of the flow curve of the measuring threshold, the amount of water flowing into the accumulation is recorded at any moment.
  - **Water level in the accumulation**. This level is recorded daily with the help of a water meter slot mounted on the vertical tower of the intake structure, i.e. tower - intake. Knowing the surface curves and volume of the

accumulation, the daily amount of accumulated water is also indirectly determined.

- **Water level at the exit of the accumulation**. Prior to the discharge of water from the accumulation into the Main supply Canal, it was previously used for powering the HPP "Strezhevo" and "Exploitation Minimum", and water discharged as a biological minimum through the HPP "Biological Minimum" located directly adjacent downstream to the HPP “Strezhevo“. Within the plant equipment there are flow meters through which the quantities of water discharged from the accumulation are recorded.

- **Hydrogeological phenomena**:
  - **Groundwater oscillations in external piezometers**. In order to register the groundwater level in the dam and around the dam, 13 open piezometers are installed. Piezometers no. 1,2,3 and 4 are located on the right side of the dam, piezometer no. 1 is upstream and the rest downstream of the injection curtain. The remaining 9 piezometers are embedded on the left side: piezometers no. 8 and 9 upstream, and piezometers no. 5,6,7,10,11,12 and 13 downstream of the injection curtain. Piezometer no. 10 has not been in operation since 1987, and the rest are permanently monitored once a week.
  - **Groundwater oscillations in inner piezometers**. To monitor the effectiveness of the injection curtain, 10 closed piezometers are installed in the control gallery. They are fitted in pairs in five transverse profiles, downstream and upstream of the injection curtain: piezometers no. 1,3,5,7 and 9 downstream, and piezometers no. 2,4,6,8 and 10 upstream of the injection curtain. All 10 piezometers are operational. Groundwater pressures in inner closed piezometers are measured once a week.
  - **Output of springs and filtration waters**. Since the completion of the Strezhevo Dam construction, a total of 9 springs have been registered to date, all on the left bank of the dam. They have a capacity of 0.01 to 0.35 l / s and are correlated with the water level in the accumulation. From many years of observation it has been observed that all springs dry up when the water level in the accumulation is lower than 720 m asl. The entire amount of filtration water (through the dam body and the injection curtain) is brought in and measured in so-called measuring well and ranges from 4.0 to 10.8 l / s or annual water filtration rate of 0.26 million m^3, which is lower than projected at 1.13 million m^3.
  - **Pressures of the pores**. In the drill holes at the base and body of the dam "Strezhevo" a total of 81 pore pressure cells (type MDS-75 manufactured by MAIHAG from Germany) have been installed in four transverse profiles of the dam (A-km 0 + 214.60, BB km 0 + 334.60, CC km 0 + 434.60, and DD km 0 + 514.60). Upper pressure is recorded once every two months. The cell readout is performed by a MDS-910 type measuring station from the same manufacturer.
  - **Total pressures**. In the body of the dam "Strezhevo" in the four measuring profiles (A-A, B-B, C-C, and D-D) are 28 measuring cells (type MDS-78 manufacturer MAIHAG from Germany). The total pressures are read using the same manufacturer's MDS-910 measuring station. Total pressures are recorded once every two months.

- **Displacement of the measuring points in the body of the dam**
  - **Vertical displacements**. The system for measuring vertical displacements in the dam body consists of four plastic pipes embedded in two transverse profiles, pipes V1 and V2 in profile B-B and pipes V3 and V4 in profile C-C, which are installed parallel to the construction of the dam. Around the tubes at precisely fixed height steel plates are placed. The tubes are fitted with a RPS-420 electromagnetic torpedo, registering the height of each of the steel plates at the RPS-400 reception station. Knowing the initial and current elevation position of each of these steel plates provides information on the overall lowering of the dam body in the given profile.
  - **Horizontal displacements - inclination**. The inclination measurement system, i.e. the horizontal displacement of the dam body, consists of rigid plastic pipes embedded in two clay core profiles: pipe V_1'in profile B-B and pipe V_3' in profile C-C. The tubes are with grooves in which the MDS-83 inclinometer MDF-83 product from Germany is lowered, combined with the MDS-910 reception station. Built-in pipes are 80 m in depth registering the displacement of the dam body in two mutually normal directions (upstream-downstream and left bank -right bank direction) at different water levels in the accumulation. Measurements are made every two to three months.
- **Displacement of measuring points on slopes, dam crown and individual objects - Geodetic auscultation**

The vertical and horizontal displacements of the measuring points of the upstream and downstream slope, as well as the measuring points of the dam crown, are determined by **geodetic auscultation**. For that purpose at the downstream and upstream slopes a total of 61 measuring points is placed, 17 points of the micro trigonometric grid for horizontal displacement and 55 points of the leveling grid for measurement of vertical displacement.

Displacement of the measuring points of the associated facilities of the dam. The geodetic auscultation determines the vertical and horizontal displacements of the measuring points of the intake tower and the vertical displacements of: the measuring points of: the bridge to the intake tower, the water tower, the control room of the sloped table locker, the gallery, the nozzle, the shaft spillway and fast flow of the evacuation organ.

- **Seismic auscultation**

According to the Rulebook on Technical Norms for Seismic Turbulence of High Dam (Official Gazette of RM no. 6/1988) it is foreseen to register the dynamic behavior of dam, foundations, forced earthquakes and so called induced seismicity.

Bearing in mind that the area where the dam "Strezhevo" is located in seismological terms is one of the more active areas the possibility of earthquakes and possible damages should always be taken into consideration. Therefore, in the phase of using the dam, it is necessary to take all protective measures against possible earthquake damage.

In this respect, one of the most rational forms and methods of seismic protection is seismic instrumentation of the dam. This is because registrations from these instruments provide basic data on dam behavior during earthquake action, and thus the ability to verify project parameters.

After this a decision should be taken immediately on whether the dam will resume normal exploitation, or whether remediation measures are needed, and may eventually be completely excluded for safety reasons.

As a result of the current seismic investigations of IZIIS, based on earthquakes that have occurred so far (earthquake history of about 95 years) it can be concluded that the area around the location of the dam "Strezhevo" is characterized by the occurrence of earthquakes of moderate magnitude (M 4.0) and this tendency is maintained after the construction of the "Strezhevo" dam. However, it should be emphasized once again that these conclusions refer to a relatively short earthquake history, so determining the parameters of the overall stability of the “Strezhevo” dam requires further auscultation and monitoring of its behavior in the event of near and distant earthquakes, to prevent the unwanted consequences of its possible damage.

For this purpose, PE "Strezhevo" in cooperation with IZIIS - Skopje in 1986 has completed seismic instrumentation of the dam "Strezhevo" in order to register the dynamic behavior of the dam, foundations and forced earthquakes. In this regard, a total of 5 accelerometers of SMA-1 product type were installed by Kinemetriks company from USA, 4 of which were mounted in the body of the dam, and one was positioned about 80 m from the dam foot downstream and all are in operation. The dynamic range of accelerometers is +/- 1 g and the frequency domain is 24 Hz.

Detailed analysis of strong earthquake registration throughout the year is provided in the Report on Maintenance Instruments for Strong Earthquake Registration [11, 12, 13], prepared by the Institute of Earthquake Engineering and Engineering Seismology at the University “Saint Cyril and Methodius" Skopje.

During 1994 at the territory of the Republic of North Macedonia there were several earthquakes with moderate intensity, from which from 01.09.1994 to 01.10.1994 a total of 584 earthquakes were registered and the earthquake that occurred on 01.09.1994 at 18h 12'local time [14] with magnitude Richter 5.2 and intensity per MSK-64 of VII degrees is felt throughout the territory of the Republic of North Macedonia. The registration length is 96.00 s, and the maximum accelerations recorded by the accelerator with serial number 4777 mounted on the dam crown amount to 25.83% g in the north - south direction, 12.52% g in the east - west direction and 16.29 g. % g in a vertical direction.

As can be seen, these values are relatively high, but still not capable of compromising the stability of the dam.

In the Elaborates for auscultaton of the Strezhevo dam [4] a report on the state of the hydro-mechanical equipment housed in a number of associated dam facilities is given:

- tower grip
  - Crane for serving
  - spinning semiportal crane
  - Stoplogs catcher
  - Stoplogs
- inclined board locker
- butterfly locker at the beginning of the pipeline of bottom outlet
- pipeline of bottom outlet
- regulatory locker of the bottom outlet
- water locker

- regulatory nozzles lockers
- F 1300 mm ski jump locker
- automatic diesel engine
- audit gallery
- fine grid.

The statements regarding the instruments and procedures for dam auscultation, the accompanying facilities and for the "Strezhevo" accumulation can confirm that the legal provisions for measuring the parameters that describe the condition of the dam have been complied.

These measurements are the basis for the preparation of the annual Elaborate for auscultation, on the basis of which an assessment of the dam's condition is made.

Some of the measuring instruments require the purchase of more modern ones. Such are the older generation limnigraphs with a paper tape marking system, and the electromagnetic torpedo that is susceptible to frequent breakdowns.

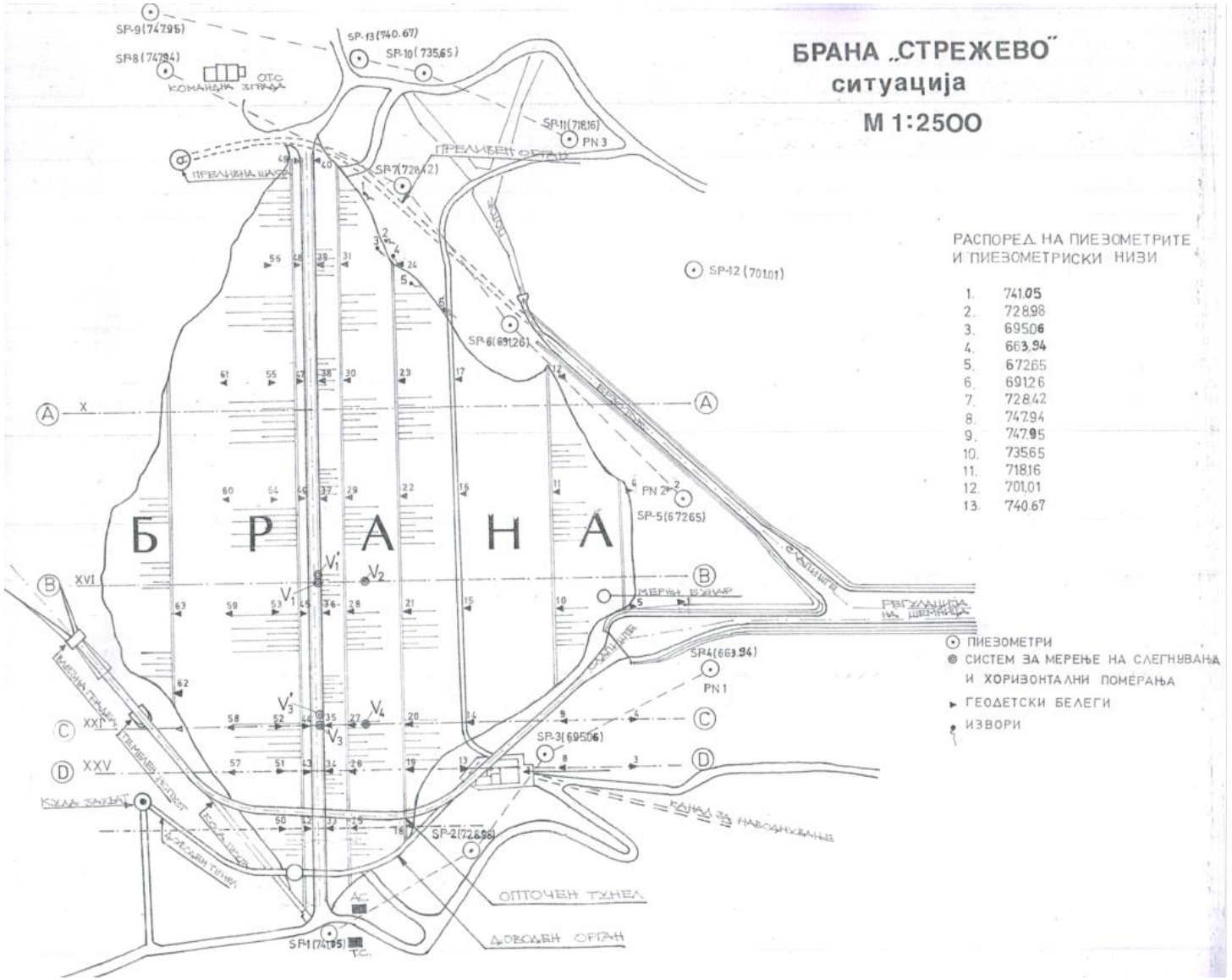

Figure 8-1. Layout of "Strezhevo" dam with locations of measuring points for geodetic and physical auscultation

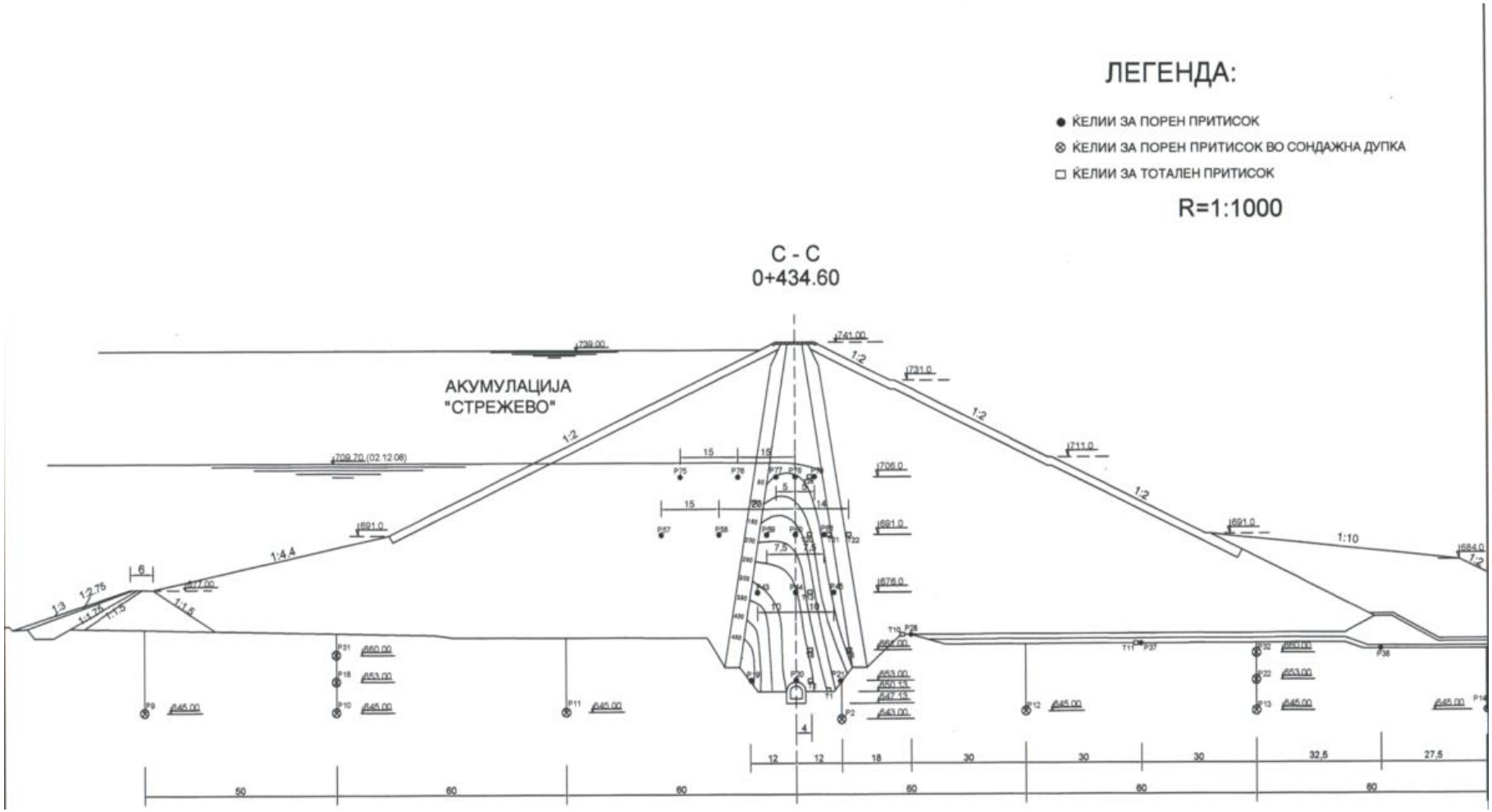

Figure 8-2. Cross-section of the "Strezevo" dam - piezometer location, location of geodetic markers

9. HISTORY OF ACCIDENTS OR INCIDENTS AND THEIR CONSEQUENCES

There were no accidents in the current period of exploitation of the dam "Strezhevo".

As an incident can be cited the malfunction that occurred on 22.07.2003 on the system of lifting of the water locker, with the screw loose of the clutch, which caused the closure of the water supply to the Main supply canal, through which the water users are supplied.

The disruption of the water supply lasted for a day until an alternative water supply to the canal was provided through a pipeline under pressure from the bottom outlet. The same day divers were hired to attach and lift the fallen locker to the cables and the water supply was released. The lifting system was repaired in the following days and the locker was put back into operation.

This malfunction did not cause any damage to the dam's safety, as it was removed in a very short period of time, and water supply after a short break was alternatively resolved.

10. OPERATIONAL PLAN FOR REPORTING THE POPULATION - CRISIS SITUATION MANAGEMENT

The normative regulation of the measure for flood protection and rescue is regulated by:

- Law on Protection and Rescue (Official Gazette of RM no. 36/2004)
- Methodology for the content and manner of hazard assessment and protection and rescue planning (Official Gazette of RM no. 76/2006)
- Decree on Implementation of Flood Protection and Rescue (Official Gazette of the Republic of North MacedoniaNo. 93/2005).

With the construction of the dam, the first Plan for flood protection of the municipality of Bitola was prepared in the conditions of the demolition of the dam of HMS "Strezhevo" [6] as well as a Plan for evacuation (relocation) of the population and material goods of the municipality of Bitola in the event of a flood from the demolition of the dam of HMS "Strezhevo" [7], made by the Headquarters for Civil Protection at the Assembly of the Municipality of Bitola.

The last valid plan is the Operational plan for protection and defense of floods (version 3), PE "Strezhevo" - Bitola [5], prepared in February 2016.

This plan, in addition to the aforementioned laws and bylaws, has been developed in accordance with the Law on Waters [8] and the Main Project for the auscultation of “Strezhevo” dam [3].

The Operational Plan [5] has been submitted to the Ministry of Environment and Physical Planning (MoEPP), the Center for Crisis Management (CCM) and the Directorate for Protection and Rescue (DPR), from which opinions have been received that the plan is accepted and can be applied.

Also, the municipalities of Bitola, Mogila and Novaci, adopt their own Flood Protection Operational Plans, which include the impacts that the demolition of the Strezhevo Dam would have on a precisely defined area in each municipality. These municipal plans provide detailed data on which settlements, how many residents and the number of large and small livestock and other tangible assets are subject to evacuation.

10.1. Operational plan for protection and defense of floods during the demolition of the dam HS “Strezhevo"

The Operational Plan for protection and defense of floods (version 3), PE "Strezhevo" - Bitola from February 2016 [5], is the last adopted plan and is in force.

A brief overview of the plan's content follows, in which sections of the text that have been downloaded from other documents already presented in the Study will only be listed, without transposing or commenting on their content, with a mention of the document from which they have been downloaded.

1. Introduction

According to the Law on Waters, the Strezhevo Dam Technical Monitoring Program and associated facilities as well as the assessment of the population endangerment of the Bitola region of Pelagonia from natural disasters, epidemics, floods, an “Operational Plan for Protection and Defense of Floods for area of system operation” has been prepared.

The plan defines and foresees measures and other actions for protection and defense of floods and the necessary means for its execution, the scope, manner and dynamics of the activities required for:

- definition of the consequences of the flooding wave
- zones of flooding downstream of the dam "Strezhevo"
- plan for alerting and warning
- criteria and levels of warning.

2. Data for the legal entity

3. General data for the dam and facilities

4. Partition profile conditions

-hydrological conditions

The hydrological treatment of Shemnica River was performed on the profile Lysolaj as well as for the profile "Strezhevo". The dam profile basin is 182 km^2. The mean annual flow is 2.14 m^3 / s, and the characteristic large waters are: $Q_{1\%}$= 180 m^3/s, $Q_{0,1\%}$= 300 m^3/s, $Q_{0,01\%}$= 470 m^3/s. High waters occur in March - June, as well as in October and November.

5. Systems for observation of the dam “Strezhevo”

The main project for the embankment dam "Strezhevo" foresees the following system of auscultation:

- measurement of porous pressures
- measuring total pressures
- measuring vertical and horizontal displacements in the dam body
- measurement of deformations on the downstream, upstream slope and banks of the dam, as well as deformation of the associated facilities (geodetic auscultation)
- observation and measurement of the flow waters through the body and the banks of the dam
- observation and measurement of meteorological data
- seismic auscultation
- observation and maintenance of the dam's hydro-mechanical equipment.

The envisaged auscultation system enables measurements to be made to obtain the information needed to assess the behavior of the dam body, the foundations and associated facilities in terms of stress conditions, deformations, filtration phenomena and the like. On the basis of all measurements, each year an "Elaborate for Dam auscultation" is prepared for the previous year and it is submitted to the Ministry of Environment and

formerly to the Ministry of Agriculture-Water Management.

6. Geology

The geological composition of the terrain is described in detail in a separate book that is an integral part of the "Strezhevo" dam Main Project [1].

7. Topographic and morphological data (Elaborate [2])

8. Hydrogeology, hydrological and hydraulic data (Elaborate [2])

9. Seismic

On the dam there are 4 accelerometers type SMA-1 on the body of the dam and one downstream from Bucnica. They are with three component accelerator time histories. These are complex electro-mechanical-optical instruments whose operation is automated and electronically controlled. The instruments are regularly maintained by a team of IZIIS - Skopje, who report regularly.

Seismological studies have shown:

- this area does not appear as a local earthquake hotspot
- this area does not belong to any seismological line in North Macedonia.
- nearest earthquakes occur at 25 to 30 km and originate from the Bitola seismic zone
- the occurrence of macroseismic effects with an intensity of 6-7 degrees can be expected from earthquakes in Greece at a distance of about 150 km.

10. Determination of flood wave (Elaborate [2])

10.1. Analysis of the flooding zones with possible consequences (Elaborate [2])

10.2. Determination of safe water level in the accumulation (Elaborate [2])

10.3. Discharge of the accumulation

When the lake's elevation is below 737.5 m asl - the crown elevation of the overflow of the shaft, the discharge will be through the bottom outlet or through the turbines of the hydropower plants.

10.4. Marking the flooding zones on the ground (Elaborate [2])

11. Reporting and alarming

11.1. Devices for reporting and alarming

For efficient reporting and alarming of the residents, sirens are planned and installed at the following locations: 1-dam "Strezhevo", 2-village Crneec, 3- village Crnobuki, 4-village Kukurechani, 5-concrete bridge on the road Bitola - Skopje and the railway bridge of Bitola-Skopje railway, 6- village Mogila, 7- village Logovardi, 8-concrete bridge 1.5 km from the mouth of the river Shemnica in Crna Reka, 9- village Radobor, 10- village Trn, 11 – village Dolno Orizari, 12- at the mouth of the river Dragor, 13 - village Optichari, 14-village Gneotino, 15- village Gorno Egri, 16- village Dolno Egri.

The sirens are electric with an asynchronous motor, produced by Tegrad Ljubljana.

For this purpose this system has a special project developed by EI "Pionir" Belgrade.

11.2. Operational plan for reporting and alerting residents

The Operational Plan foresees a **state of readiness** and a **state of general alert**.

The state of readiness and the state of the dam's duties are organized in the following cases:

- When the water level in the lake reaches the maximum projected elevation (734.00 m) with a tendency to increase further.
- If measurements show that the vertical deformation and horizontal displacement growth ceases to decrease as a function of time. In this case an expert commission will be formed to investigate the reasons for the observed occurrence.
- When an earthquake has occurred (the dam personnel have sensed it or have been notified by the media or otherwise) the dam monitoring service will perform a **macroscopic** examination of the dam and read the instruments.
- If any changes are identified during the review, an expert committee is convened which, in its assessment, declares a state of readiness. The dam observation service may itself announce a state of alert if it detects dam movements.
- When there is a constant increase in filtration through the dam, under the dam or around the dam, or if the filtered water is blurred or colored.
- Other unforeseen occurrences when the competent authority has assessed that the stability of the dam is in jeopardy.

General alert for the downstream area is advertised in the following cases:

- When it is determined that the level in the accumulation of the maximum permissible elevation (734.00 m) cannot be maintained, as the river inflow is greater than the total inflow power of the evacuation organs.
- "Maximum allowable elevation"means the elevation of the maximum slowdown.
- When a commission investigating the effects of an earthquake estimated that general alert should be declared.
- When the commission, which investigates the causes of horizontal and vertical displacement of the dam, assessed that general alert should be declared.
- When the filtration is visibly increased and dam damage is observed.
- In all cases where it is assessed that there is an immediate danger of dam demolition.

General alert declares authorized person for the dam.

In the event of a military emergency or war, the competent authority shall make a decision to declare general alert and to reduce the level of the accumulation.

When general alert is declared, the population of the endangered areas climbs into the zones above the marked elevations at the highest possible levels and remains there for the duration of the danger.

12. Method for determining the hydraulic effects of dam demolition (Elaborate [2])

13. Analysis of the flooding wave (Elaborate [2])

14.Contribution of the "Pelister Waters" Gathering Canal from HS "Strezhevo" to the reduction of the volume of floods in the плавното подрачје

14.1. Description of the Alimentation (Gathering) Canal "Pelister waters" (This Study, Item 3. Description of HS "Strezhevo")

14.2.Hydrological and Hydraulic Data for the Gathering Canal (This Study, Item 3. Description of HS "Strezhevo")

14.3. Opportunities to influence the Gathering Canal in flood protection of the flooding area

In order to improve the water supply of the Strezhevo accumulation, the affected quantities are transferred from the seven watercourses of Baba Mountain from their immediate basin which directly gravitates into the Crna Reka, into the watershed of the river Shemnica, above the profile of the Strezhevo dam, which enables the accumulation of waters for later use.

The accumulation's retentional capability enables it to serve for the transformation of flood waves into the Shemnica River and other smaller rivers flowing over the dam profile.

In terms of flood hazard the role of the Gathering Canal, given its limited capacity across the individual sections (Table 2), as well as the large flood waters at each catch (Table 3), can generally be said to play a minor role in protection of floods, consisting of the following:

- In case of danger of flooding in the local catchment of each of the separate watercourses whose waters are occupied by the Gathering Canal, the maximum water absorption from the specific catchment can **insignificantly** influence the reduction of the waters in the river downstream of the catchment, taking into account the maximum opportunities for catching and transporting water in the Gathering Canal in relation to the major catchment waters of the respective catch, which are tens of times smaller. During this procedure the catch water is directed to the Strezhevo accumulation.
- In case of danger of flooding which can be caused by overflow or discharge of water through the dam facilities, **water capture will be completely stopped** from all the watercourses covered by the Gathering Canal, i.e. no water is diverted into the accumulation and is left to flow into the natural riverbeds.

15.Plan for reporting and alarming

A successful dam demolition early warning system should detect and report dam failure at an appropriate warning time that allows for safe evacuation of population at flood risk.

Due to regular monitoring and vigilance of the dam "Strezhevo" - Bitola, a professional service is organized which permanently supervises it 24 hours.

The expert service carries out daily surveys, measurements and observations, specified for this type of facility, which are carried out at specific times, and the data are entered into special forms, and are finally processed and some are sent to the Crisis Management Center (CMC) - Bitola and for all situations presenting a possible risk or danger from the accumulation, the regional crisis management center of Bitola should be notified immediately.

In the case of "Strezhevo" dam the time it takes for the flood wave to reach settlements in the river valley of Shemnica, and then in Crna Reka, is very small. Experience in world practice has shown that such a short warning time is unacceptable for the successful evacuation of populations, livestock and material downstream of the dam.

Therefore, the early warning system in such cases should detect a safe state and develop instability after dam safety in order to provide sufficient time for evacuation of the population immediately exposed to the flood wave.

The early warning system includes a reporting component consisting of a network of external warning sirens, as well as notifications by responsible persons by telephone, radio or television alerts, mobile alerts and finally door-to-door alerts.

The reporting systems are integrated in the municipalities and settlements downstream of the dam "Strezhevo" - Bitola, downstream of river Shemnica and Crna Reka, where emergency response and evacuation plans are to be made to effectively target populations outside flood-prone areas, minimizing traffic problems, crowding or panic during evacuation.

According to the analysis, sound alert systems have been installed. These systems are installed in the settlements located in the flood zone and should be taken care of by the local communities (LC) and the municipalities where they are installed.

If we analyze the flood zone, it is concluded that it will be completely found 16, and partly 2 rural local communities: village Crneec and village Kukurechani; fully found in the flood zone are: village Novo Zmirnevo, village Crnobuki, village Mogila, village Radobor, village Thorn, village Karamani, village Dolno Orizari, village Dobrushevo, village Novaci, village Logovardi, village Poeshevo, village Dolno Egri, villageRibarci, village Optichari, village Gneotino and village Sredno Egri. All of these LC should be equipped with sound alarms.

In settlements not exposed to the direct action of a devastating flood wave the alert will be made by telephone from the responsible services of the Municipality of Bitola and the municipalities of Mogila and Novaci and through public media and other forms of reporting.

PE "Strezhevo" regarding the reporting and the alarms downstream of the dam for all settlements has developed a map i.e. a flood wave pattern.

Finally, after the notification and the alarm, an evacuation is conducted, which will be managed by the Crisis Headquarters (CH) of the Municipality of Bitola in correlation with the Directorate for Protection and Rescue, the Crisis Management Center and the Crisis Headquarters of the Municipality of Mogila and the Municipality of Novaci with their settlements.

16.Threat assessment, measures, activities and plan for protection and rescue

- **Preparedness of the rescue and rescue forces**

Experts are assigned to design and use the protection and rescue plan at PE "Strezhevo" - Bitola, who are tasked to prepare a threat assessment with measures and activities, to draft a protection and rescue plan and to define tasks for employees through the formation of protection and rescue forces and their composition.

The plan for protection and rescue against natural disasters and other accidents contains the following documents:

- readiness of protection and rescue forces;

- mobilization of protectionand rescue forces,

- material technical means and equipment;

- engaging protection and rescue forces.

These documents are mutually complied and constitute a whole in terms of gradual or rapid activation in case of the above disasters and other accidents.

- **Measures and activities**

Preparedness of the protection and rescue forces actually means the implementation of measures and activities for the protection and rescue and activation of the appropriate teams and teams in relation to the degree of threat from natural and other disasters. The document on preparedness of forces, measures and activities for protection and rescue is elaborated in three degrees of danger:

In the first level the following activities are planned:

- updating all documents from the protection and rescue plan and flood defense;
- introduction of tasks for protection and rescue on all vital facilities of the Strezhevo system;
- implementation of measures for security, protection and defense against floods;
- termination of the annual leave of the employees on the schedule in the units or teams.

The second level of threat reviews the planned measures and activities and their level of preparedness for protection and defense against floods.

In the third degree of threat, measures, tasks and procedures for full and complete flood defense preparedness are planned.

- carrying out general mobilization of all forces and material- technical means;
- Carrying out the tasks according to the plan for protection and defense against floods.

Executive persons should at all times be prepared to actively perform specific tasks, depending on the type of accident; in our case for flood protection and defense.

The management of the accident is planned and coordinated by listed experts who make a decision based on the assessment of the current state of the accident, carry out further

actions and communicate with the external competent authorities of the municipality, the Directorate for Protection and Rescue and the Center for Crises Management.

- **Mobilization of forces, material and technical means and equipment for flood protection and defense**

The document for mobilization of the forces for protection and defense against floods and the material - technical means and equipment contains the manner of receiving the order for mobilization, calling the executive persons and familiarizing them with their tasks, procedures and directions for further actions.

Mobilization can be carried out both on and off working hours.

Mobilization preparations include tasks, measures and activities that are performed and undertaken before any kind of accident, in our case, flood. Upon receipt of the order, a reminder of the mobilization shall be prepared including the assessment of the conditions and possibilities for its execution.

An overview of the executive persons of the identified tasks and their engagement is being prepared. Material and technical resources and equipment are identified and deployed prior to the preparation of the Mobilization Plan.

For fast and efficient mobilization the PE "Strezhevo" makes available all the engine-technical means.

The forces that will be hired in advance would receive tasks, activities and responsibilities for the particular type of accident and would be trained and capable of carrying out activities.

PE "Strezhevo" permanently monitors the dam "Strezhevo" (24-hour technical service) and for certain anomalies timely reports and appropriate measures are taken.

In case of demolition of the dam "Strezhevo", most of the facilities with DCM and its associated facilities are subject to flooding. For this purpose, an Operational Plan for the Evacuation of the Population has been developed, extending downstream from the dam and there are marked elevations indicating the extent of the flood wave and evacuation sites according to it. The assessment of the flood protection plan elaborates the planned flood protection activities that must be in conjunction with the Municipality of Bitola, the municipalities of Mogila and Novaci and the local communities that would be affected by the flood.

Preventive and operational measures for protection against floods (in conjunction with the Municipality of Bitola and the municipalities of Mogila and Novaci):

- timely cleaning of watercourses;
- regulation of river beds and their maintenance;
- construction of protective embankments in places where frequent spillages are recorded;
- maintenance of the canal network;
- informing the population about the dangers of floods and their training in taking measures and procedures for protection and evacuation in those conditions;
- training and putting into operation the public alarm system;

- filling, training and equipping flood protection and rescue units;
- control of the water supply system from pollution, especially in places where arterial wells and boreholes are used;
- Center for Public Health - Bitola to perform enhanced water quality controls in arterial wells in case of flooding or rising groundwater, which results in pollution.

The operational measures will be implemented by the employees of PE "Strezhevo" according to the plan for protection against floods, with the support and cooperation of the population of the municipalities and the local communities that will be covered by the flood wave and appropriate institutions from the Municipality of Bitola.

For the duration of the danger, in the given situation a sheltering is performed, instructions for evacuation and foster care are followed, and measures to prevent the spread of the danger and its consequences are taken.

After the end of the danger the consequences are eliminated, the rehabilitation of the terrain, the provision of first medical aid to the injured, if the evacuation is planned according to the plan, health-hygienic and epidemiological measures are implemented, motor technical means are checked, assessment is carried out and measures to normalize life and work are taken.

17.Planned funding for implementation of the plan

Planned funds for implementation of the operational plan for flood protection and defense are provided from own funds. The funds are annually reported.

* * *

The rest of the documents will comment on the Plan for evacuation (relocation) of the population and material goods of the municipality of Bitola in conditions of flood caused by the demolition of the dam "Strezhevo" [7], in the part of Annex no. 1 - Overview of evacuation (relocation) and acceptance of endangered population, large and small livestock and other tangible personal property that may be found in the endangered area under the demolition of the “Strezhevo”dam.

From this appendix below, it can be seen that of the total population (8121inhabitants)in the endangered area immediately after the construction of the dam (in 1981), 5777 are actually present in the area and 2373 are temporarily employed abroad. Also, after the construction of the dam, large and fine cattle were counted in the individual village settlements. The number of inhabitants that are endangered is lower than the stated number, as some of these settlements are only partially exposed to flooding.

A similar count should be made for today's situation in the flooded area. It should be noted that the last population census was carried out in 2002, and data for today's period can only be predicted. Population in rural areas has declined in recent years due to rural-to-urban migration and economic migration to more developed countries. However, in order to provide a partially accurate data on the current situation, we have prepared Appendix 2 with **extrapolated data** on the basis of the 2002 census, the counting of livestock from the moment of operation of HS “Strezhevo”, internet sources as well as the statistical report of the Regions in the Republic of North Macedonia for 2019 (in which has aggregated data by region, but used to derive extrapolation proportions)

From the review of the existing documentation for crisis management, such as the flood caused by the demolition of the "Strezhevo" dam, it can be said that it has been prepared in accordance with the legislation regarding the content.

The management of the accident is planned and coordinated by the listed experts from PE "Strezhevo", who make decisions based on the assessment of the current state of the accident, further actions and communication with the external competent authorities of the municipality, the Directorate for Protection and Rescue and from the Crisis Management Center.

Finally, following the notification and alarm, an evacuation is conducted, which will be managed by the Crisis Headquarters (CH) of the Municipality of Bitola in correlation with the Directorate for Protection and Rescue, the Crisis Management Center and the Crisis Headquarters of the Municipality of Mogila and the Municipality of Novaci with their settlements.

Plans are made comprehensively.

Research has defined the scope of flooding, which includes rural settlements, roadways and railways, bridges on those roads and other commercial buildings. In some of the flood-hit settlements, residential and commercial buildings, traffic infrastructure and track structures - bridges will collapse.

APPENDIX NO.1. SUMMARY of evacuation (relocation) and acceptance of the endangered population, big and small cattle and other material in private ownership that may be caught in disadvantaged areas during the demolition of the dam “Strezhevo"

Serial Number	Local community name	Local community from which to evacuate								Local community name	Local community to which to evacuate					
		Number of inhabitants			Number of big and small cattle						No. of citizens evacuated	Number of big and small cattle				
		No. of citizens after the 1981 census	No. of citizens working temporarily abroad	Physically present citizens	Bulls	Cows	Donkeys, horses, mares	Sheep and goats	Other material goods			Bulls	Cows	Donkeys, horses, mares	Sheep and goats	Other material goods
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Crneec	537	96	480	6	36	8	310	*	Crneec	192	4	20	4	193	*
2.	Zmirnevo	163	42	121	15	23	6	240	*	Lisolaj	97	12	18	5	192	*
3.	Crnobuki	871	112	749	25	27	4	420	*		607	20	21	3	336	*
4.	Kukurechani	1637	406	1231	27	30	12	540	*	Kukurechani west par	690	15	17	7	302	*
5.	Mogila	2510	982	1528	8	122	52	2110	*	Dragozhani	422	2	29	12	606	*
										Kukurechani	800	4	68	29	1182	*
6.	Radobor	415	208	207	2	32	16	1453	*	Trap	83	1	13	6	581	*
										Budakovo	83	1	13	6	581	*
7.	Trn	223	86	137	2	11	8	675	*	G. Orizari	110	2	9	6	540	*
8.	Karamani	529	169	360		31	3	1005	*		288		25	2	804	*
9.	D. Orizari	1236	272	964	8	251	55	1920	*		771	6	201	44	1536	*

* the most necessary means for people and cattle existence

APPENDIX NO. 2. EXTRAPOLATE ASSESSMENT of the evacuation (relocation) and acceptance of the endangered population, big and small cattle and other material goods in private ownership that may be caught in disadvantaged areas amid the demolition of the "Strezevo" dam

Serial number	Local community name	Local community from which to evacuate								Local community name	Local community to which to evacuate					
		Number of inhabitants			Number of big and small cattle						Number of big and small cattle					
		No. of citizens after the 2002 census			Bulls	Cows	Donkeys, horses, mares	Sheep and goats	Other material goods		No. of citizens evacuated	Bulls	Cows	Donkeys, horses, mares	Sheep and goats	Other material goods
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Crneec	86			2	15	8	310	*	Crneec	60	2	10	4	200	*
2.	Zmirnevo	41			6	12	3	120	*	Lisolaj	30	4	8	2	80	*
3.	Crnobuki	406			12	14	2	210	*		300	8	10	1	150	*
4.	Kukurechani	966			14	15	6	270	*	Kukurechani west par	450	10	12	4	200	*
5.	Mogila	1526			6	60	40	1500	*	Dragozhani	200	2	10	10	400	*
										Kukurechani	400	4	30	20	600	*
6.	Radobor	145			1	16	8	780	*	Trap	33	1	6	5	300	*
										Budakovo	32		6	3	300	*
7.	Trn	113			1		8	350	*	G. Orizari	50	1	5	4	300	*
8.	Karamani	337				15	1	500	*		110		10	1	400	*
9.	D. Orizari	1834			15	350	80	3000	*		970	10	300	60	2500	*

* the most necessary means for people and cattle existence

11. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The scope of the Study of the conditions and measures for the protection of eventual demolition of the dam "Strezhevo" is determined by the program part - Project program.

The selection of the dam “Strezhevo”, one of the three major dams in the Pelagonia region, as the subject of this study is due to the size of the accumulation that created the floodplain coverage.

The individual parts of the Study elaborate in detail on the basic elements that arise in the issue of sudden demolition of the high dam of the HS “Strezhevo” and the risk to people, the environment and property in the endangered floodplain, the activities of the competent authorities to be undertaken to deal with the consequences in an organized manner, the dam auscultation in order to timely diagnose the processes to which it is exposed, and above all for the early detection of the possible causes leading to the dam demolition.

The following conclusions can be drawn from all the material presented as a result of the eventual demolition of the dam "Strezhevo":

- The legal provisions regarding the preparation of the project documentation for the dam which include the auscultation Project and the Elaborate for reporting and alerting of the area threatened by the demolition of the "Strezhevo" dam have been strictly complied with.
- The Main Project for Auscultation of the dam "Strezhevo" details the way of performing the technical observation and the necessary equipment and measuring devices.
- The competent department in the PE "Strezhevo" directly responsible for dam management and auscultation, performs these activities in accordance with the foreseen legislation and in accordance with the Main Project for Auscultation, with an Elaborate for Dam auscultation being prepared each year and given to inspection in the competent Ministry.
- For the dam "Strezhevo" Operational plans for flood protection and protection are periodically prepared, specifying the competences of all entities that should be involved in case of sudden demolition of the dam, as well as the actions to be taken to deal with the floodconsequences. The latest plan is from 2016 and has been submitted and approved by the Ministry of Environment and Physical Planning (MoEPP), the Center for Crisis Management (CCM) and the Directorate for Protection and Rescue (DPR).

Activities that may be taken in the future to improve the protection against suddendemolition of the Strezhevo dam are:

- Modernization of the equipment used for auscultation of the dam "Strezhevo" in the section for measuring the hydraulic parameters (inflows, water level in the accumulation and outflows) with the transition from analogue to digitalized measurements, with the possibility of real-time remote transfer.
- Installation of several meteorological stations with snowmeasuring profiles in the catchment area of the "Strezhevo" accumulation in order to obtain more accurate data for hydrological analysis of expected water inflows during spring snowmelt.

- Modernization of the geodetic survey of the dam using new available techniques for satellite tracking and monitoring of the terrain in the accumulation and downstream of the landslides appearance with drone geodetic surveying.
- Modernizing the alarm system to connect to a single system at the national level.
- Development of a computer model for flood wave simulation caused by dam demolition that would be calibrated to the modeled test results, and would serve for future analysis with different input and boundary conditions.
- Refreshing operational flood protection plans of the municipalities involved in Pelagonia region with new data on population, households and tangible assets that would result from the projected next census[10].

Finally we would reiterate what has been said about the embankments in the Introduction:

Dams, by their nature of flexible structures, are more resistant to earthquakes than other rigid barriers, such as concrete, reinforced concrete and wall dams.

It has been established from several accident ofdemolition of this type of dams that there is no abrupt discharge of all water from the accumulation due to the very nature of the dams which, after the leakage of a certain amount of water, results in the "sealing" of the cracks in the dam through bumping of the lateral material in the crack opening. This demolition mechanism is a more favorable scenario than abrupt dam demolition and the downstream flood impacts are smaller, corresponding to the volume of water leaking.

However, every effort should be made in the domain of the human factor not to demolish the dam, and in cases where this cannot be avoided, the consequences of the demolition to be as small as possible and to deal with them in planned manner, with precise definition of the tasks of the responsible entities and institutions, as well as of the flooded population.

[10]The 2002 census is the last conducted census in the Republic of North Macedonia. Announcement of new census for 2021.

12. LITERATURE

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