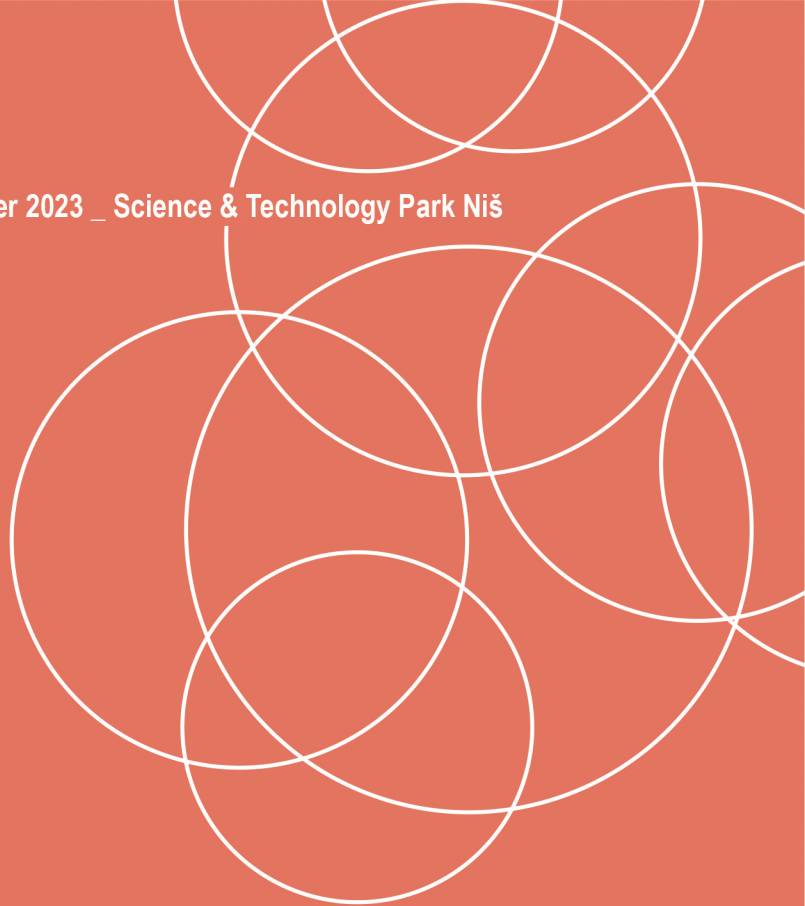




Niš (SERBIA) _ 14-15 September 2023 _ Science & Technology Park Niš



International Conference

Synergy of Architecture & Civil Engineering

Volume 2

Proceedings

THE INTERNATIONAL CONFERENCE
SYNERGY OF ARCHITECTURE & CIVIL ENGINEERING
SINARG 2023

PROCEEDINGS

VOLUME 2



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**Synergy of
Architecture &
Civil Engineering**

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SYNERGY OF ARCHITECTURE & CIVIL ENGINEERING
SINARG 2023**

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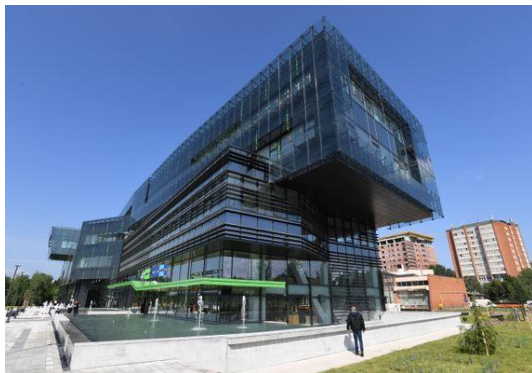
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CONFERENCE VENUE



International Conference

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Niš (SERBIA) - Science & Technology Park Niš - September 14-15, 2023

PREFACE

The primary goal of the SINARG 2023 conference is to present contemporary achievements in the scientific and practical aspects of architecture and civil engineering. The organizers of the conference aimed to facilitate the participation of both national and international professionals in theoretical and experimental research related to the processes of design, project management, construction, and building maintenance within the construction industry.

Simultaneously, this scientific conference serves as a platform for exchanging experiences and information regarding innovations and advancements in planning, design, new materials, and construction and reconstruction technologies within the fields of architecture and civil engineering.

Therefore, this conference should serve as a forum where experts from civil engineering, architecture, and other related fields have the opportunity to present the results of their research. In that context, conference topics have been carefully selected to provide focus on current issues in the field and encourage productive discussion bringing fresh and original insights and concepts to the forefront.

More than 180 paper proposals have been submitted to the conference. A single-blind review process was used to assess the full papers. The reviewers are esteemed scientists holding PhD degrees in the same field as the paper's topic. There are more than 70 reviewers from ten countries who have significantly contributed to the scientific quality of the conference, and their names are printed in the proceedings.

*A total of 142 full papers have been accepted for publication. Some of the papers have been selected for publication in our journals, with nineteen papers in *Facta Universitatis: Architecture and Civil Engineering* and nine in the *Journal of the Faculty of Civil Engineering and Architecture*. The conference proceedings consist of 114 papers divided into two volumes.*

The total number of authors and co-authors accepted for publishing at SINARG 2023 exceeds 320. Out of this number, more than 80 authors come from abroad, representing 19 countries (Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Germany, Greece, Hungary, India, Indonesia, Netherlands, North Macedonia, Montenegro, Oman, Poland, Romania, Serbia, Slovakia, Turkey, United Kingdom).

The editors express their gratitude to all the authors for their participation and to the reviewers for their valuable comments, which have contributed to the improvement of the original manuscripts and have enhanced the overall quality of the conference..

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HYDROTECHNICAL TUNNELS AT DAMS

Zlatko Zafirovski¹, Marija Petkovska²

Abstract

Performance of the construction work for each structure needs to be in accordance with a project documentation, for which a construction permit has been granted. Sometimes there's a need for a change of basic design, not only for rough construction work, but for all construction works.

In this paper hydrotechnical tunnels are mainly covered. First, there is a description of construction of one diversion tunnel, then the explanation of construction of two hydrotechnical tunnels from dams with accumulation, these dams are still being built in North Macedonia. The main part of this paper thesis is comparison between the changes in the construction work and the design of the tunnels.

Key words: Structures, Diversion tunnel, Project documentation, Performance, Comparative analyses

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1. INTRODUCTION

1.1. Scientific justification of the topic

The standard process for designing dams involves the occurrence of certain structures during performance planning. A dam with accumulation contains the following structures: dam body, injection tunnel, diversion tunnel, entrance construction, spillway, etc.

The diversion tunnel is located below the dam body and it is converted to dam outlet during the period of exploitation.

Each structure is exposed to numerous impacts, caused by a variety of reasons, which results with execution difficulties, followed by prolonged deadlines. Therefore, a need of additional financial resources arises and finally, the project documentation suffers certain changes [1,2].

1.2. Purpose of the investigation

The purpose of this paper, is comparing different diversion tunnels in their construction phase, with more thorough analysis of few characteristic problems that occur during the construction works. These examples, can contribute in future designs by predicting their appearance in the design phase. In this way, these problems will be avoided during the construction works performed on hydrotechnical tunnels [3,4].

2. ANALYSIS OF HYDROTECHNICAL TUNNELS

2.1. "Otinja" Dam

The "Otinja" Dam is located in the eastern region of the Republic of North Macedonia, more accurately, at a distance of 300 m over the town of Shtip, and in front of the entrance of the River Otinja. The barrier site is consisted of hilly terrain, with a good storage space in the river bed, which makes it an ideal location for building a dam. The Otinja River waterflow will be used to fill the accumulation.

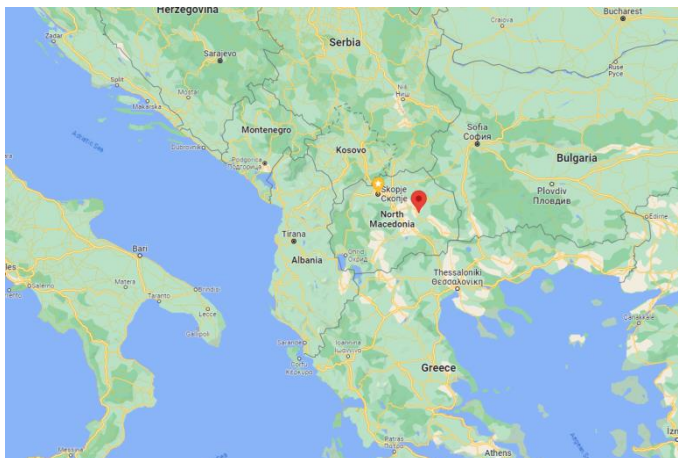


Figure 1. Location of the dam on the territory of R.N. Macedonia, Shtip

The dam belongs in embankment (rock fill) type of dams, built from rocks of different sizes on the outer side and a clay core in the middle. The dam has a height of $H=32.50$ m and a total length of $L=167.79$ m.

The "Otinja" Dam is intended to provide flood protection, regulation of the catchment area of the River Otinja, change of climate conditions in the town of Shtip, water supply with technological water for watering parks and greenery, recreation of the population and development of tourism [5,6].

2.1.1. Design of the diversion tunnel

The diversion tunnel is located on the left bank of the River Otinja, with the length of $L=186$ m, elevation varying from 307.00 m MSL* (at the entrance) to 303.20 m MSL (at the exit) and a longitudinal slope of 2.42 %.

The alignment of the tunnel is composed of two straight sections and one circular curve with radius $R=60$ m. The light opening of the tunnel pipe has a diameter $D=1.7$ m and thickness of the concrete cover of $d=0.40$ m.

The purpose of the tunnel is to evacuate the River Otinja waterflow during the construction phase. In the exploitation period, the tunnel will be converted into a dam outlet. At the tunnel exit, a hydrotechnical structure is planned for manipulation of the water discharge. The tunnel pipe ends with a gate valve, which is intended for incidental, partial or complete emptying of the accumulation [9,10].

The dam outlet is consisted of three sections:

- The first section is an entrance construction - a vertical shaft with a square shape with dimensions 3.0×3.0 m and a height of $H=3.85$ m. The square section turns into a circuit pipe with a diameter of $D=1.7$ m at a height of $H=3.85$ m.
- The second section is the circuit pipe, with a constant cross-section along the entire length of $L=156.6$ m. The internally placed pipe has a diameter of $D=1.70$ m and a concrete cover around the pipe with dimensions $a=2.50$ m and a height of $h=2.70$ m.
- The third section is an exit structure, where the pipe has a diameter of $D=400$ mm, length of $L=4.60$ m, and it is placed inside the outlet structure and the water discharge equipment.

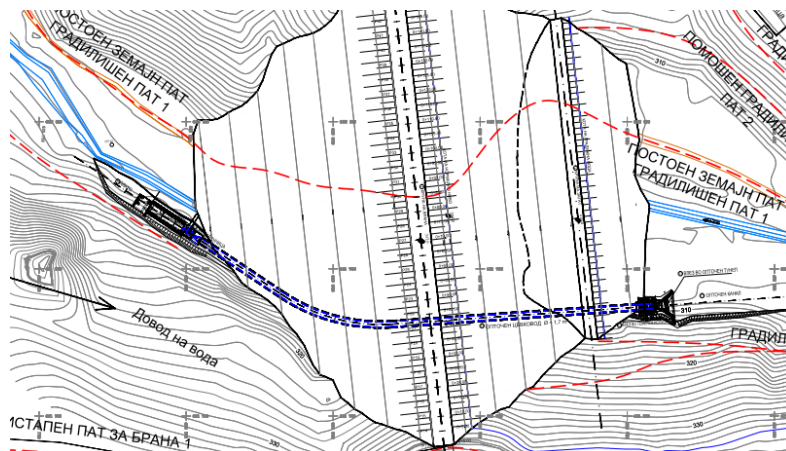


Figure 2. Situation of diversion tunnel

* Mean Sea Level (MSL) is the datum for measurement of elevation and altitude.

2.1.2. Construction of a tunnel

1) Placement of steel stiffening rings.

In order to provide better contact surface between the concrete and the steel pipe placed inside, steel stiffening rings are preferred. These rings are placed at a length of 3 m along the pipe. In the first phase, the steel pipe is lifted and placed in the appropriate place using a crane. In addition, anti-corrosion protection is needed for the pipe, as well as control of the welds on the steel rings [7].



Figure 3. Welding of steel rings in a factory



Figure 4. Installation of steel pipe

2) A change in the technical solution has been made.

In order to ease and fasten the execution, cones and elbows for joining in the entrance construction were foreseen.



Figure 5. Elbow installation for the connection of entrance construction and steel pipe

The entrance cone is performed as a steel cover with thickness of $d=7.1$ mm, and dimensions $\phi 2500 / \phi 1720 \times 3850 \times 7.1$ mm. During construction phase, the cone serves as a formwork for the concrete layer, and later, in the exploitation phase, it's used as protection against adverse effects (cavitation) in the concrete construction. The entrance part of the cone is performed in round shape, instead of rectangular, in the purpose of easier performance and a better connection with the steel pipe.



Figure 6. Installation of a cone for entrance construction

Diameter of the entrance part equals $D=2500$ mm, i.e. $D=1700$ mm at the junction with the elbow. This makes the shape of a truncated cone with dimensions $\phi 2500/\phi 1700 \times 3850$.

2.1.3. Software analysis of the tunnel

The software package SAP 2000 was used for conducting the static analysis of the diversion tunnel. The calculation follows the rules given in the Eurocodes. Mathematical 3D model of the construction is made by using appropriate shell elements and realistic material characteristics. The stress-strain analysis is conducted by the finite elements method [8,11]. Final goal of the analysis is calculating the necessary reinforcement in all concrete sections, and control of the limit states (ULS and SLS)*.

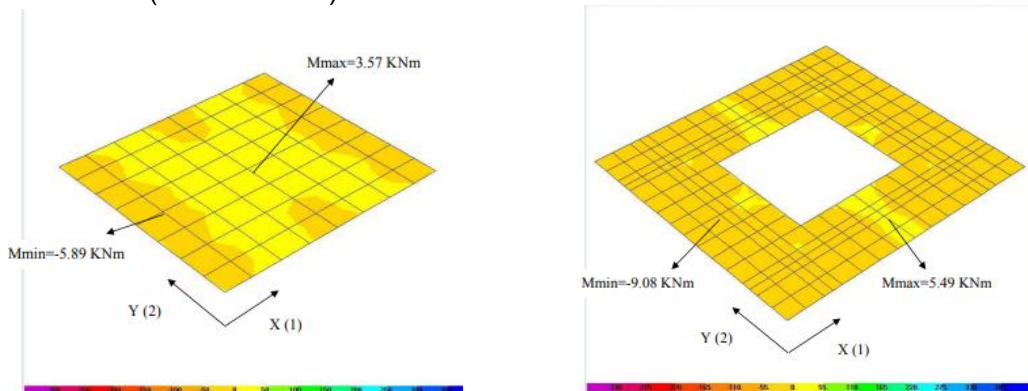


Figure 7. Display of M11 envelope moments in plate

Comment: The opening in the plate, causes a higher intensity of the bending moments compared to those in plate.

Concrete class of MB30 and ribbed reinforcement with designation RA 400/500-2 are used. A graphic part is created, drawings in which the formwork plan and the reinforcement plan can be shown in detail separately for all positions of the tunnel [12,13].

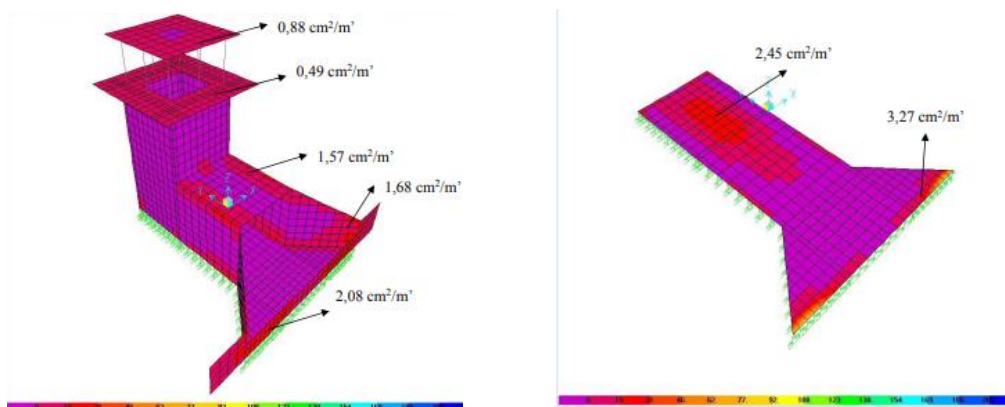


Figure 8. View of reinforced concrete for entrance construction

*Limit state design requires the structure to satisfy two principal criteria: the ultimate limit state (ULS) and the serviceability limit state (SLS)

Comment: Considering the relatively small influences, the entire construction is structurally reinforced with: RA $\varnothing 12/15$ cm with area of $A_a = 7.54 \text{ cm}^2/\text{m}'$.

2.2. “Konsko” Dam

The “Konsko” Dam is located at 20 km from town of Gevgelija. The accumulation should provide water supply to the Municipality of Gevgelija and irrigation by pumping for 8000 ha of agricultural land.

This project, also will contribute in improvement of the hydrological condition of the Dojran Lake.

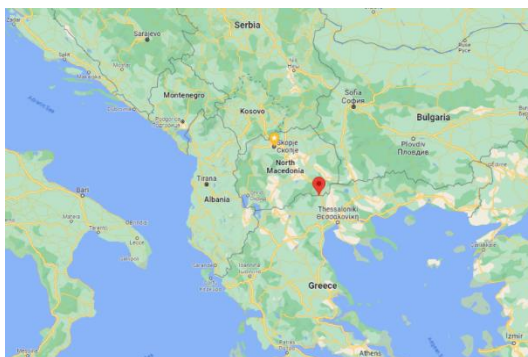


Figure 9. Location of the structure in the territory of R.N. Macedonia, Gevgelija

The dam belongs in the embankment (rock fill) type of dams, built from rocks in different sizes on the outer side and a central asphalt core and three filter layers.

The dam is designed with an external spillway, injection tunnel, diversion tunnel and entrance construction. The height of the dam is $H=80.0$ m and will be composed of a total of $\approx 1\,400\,000 \text{ m}^3$ of embankment material.

The area of the accumulation equals 80 ha and it is predicted to contain $21\,000\,000 \text{ m}^3$ of water.

2.2.1. Design of the diversion tunnel

The diversion tunnel is designed in the bottom of the embanked "Konsko" Dam. The tunnel is positioned along the left bank of the valley, which will be placed under the dam body in the exploitation period.

The tunnel consists of a total of 40 parts, two plugs, an entrance or mouth of the tunnel, a slab, wings, a frame and a valve.

The tabular valve has dimensions of 4.0×4.0 m for entrance construction for diversion tunnel. This valve is needed for the start of re-adaptation of the tunnel into a dam outlet.

The total length of the tunnel is $L=269.87$ m and is designed with a longitudinal slope of 2 %.

The external dimensions of the diversion tunnel are chosen in relation to the loads acting upon the tunnel. The light opening of the tunnel has constant dimensions:

- width $B=4$ m;
- height $H=4$ m;
- diameter = 2 m.

The thickness of the tunnel the thickness of the concrete tunnel lining is variable, depending on the loads acting upon it. Therefore, three types of the thickness of the concrete tunnel lining are constructed:

type 1: $t/d = 60/80$ cm;

type 2: $t/d = 80/100$ cm;

type 3: $t/d = 90/100$ cm.

where:

t - thickness of the vault and vertical walls and

d - thickness of floor plate.

The exit structure is designed as a reinforced the thickness of the concrete tunnel lining with variable dimensions along the length.

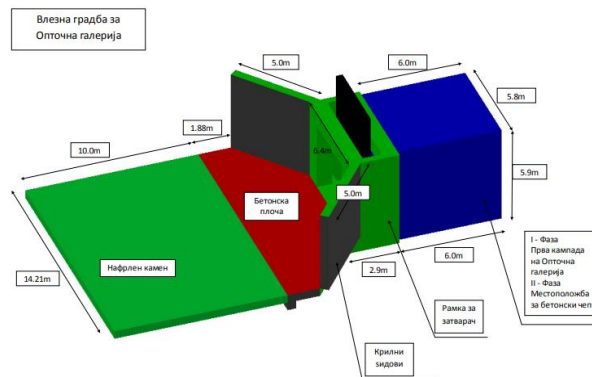


Figure 10. Entrance construction for diversion tunnel

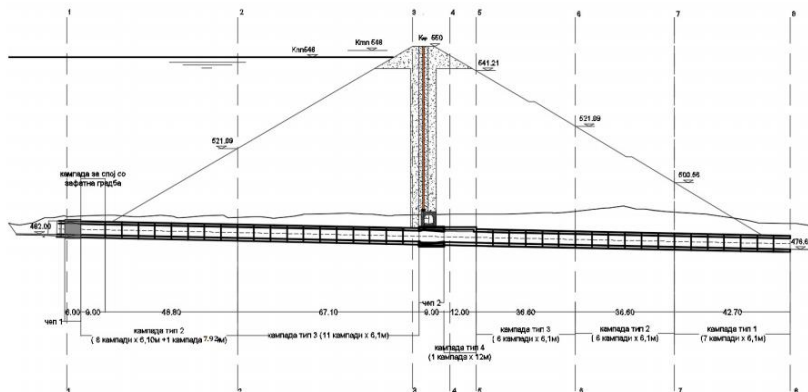


Figure 11. The diversion tunnel in cross section of the Dam

2.2.2. Construction of the tunnel

- 1) Underground water has occurred.

As a solution, two wells with a depth of $D_f=2.0$ m were drilled. The water is pumped out of the wells and then is taken from outside the structure location and diverted into the river bed of the River Konsko.

The water must be removed from the excavated section, because it creates problems during the funding structure and adversely affected the working conditions.



Figure 12. The diversion tunnel in construction

- 2) Occurrence of fault zones - poor material on which to build.
For this reason, a bigger/deeper excavation was made, in order to get into a soil material that meets the required bearing capacity. For the purpose of funding the whole tunnel length at one foundation level, lean concrete MB20 with variable thickness was used.



Figure 13. Diversion tunnel exit

2.2.3. Software analysis of the tunnel

The software package “Robot Structural Analysis” is used for the static and dynamic analysis of this diversion tunnel. The mathematical model contains the tunnel structure and the rock foundation, represented by the appropriate material characteristics. The weight of the dam embankment on the tunnel is applied as a load, so it is taken into account in the analysis.

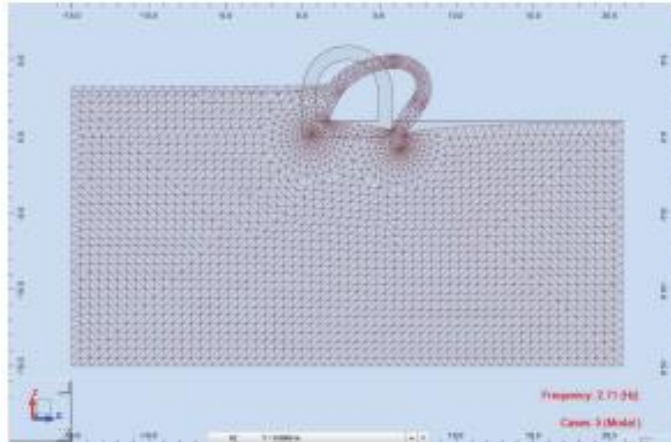


Figure 14. First period - translation, $f=2.71$ Hz; $T=0.37$ s

The stress-strain analysis is conducted by the finite elements method. Final goal of the analysis is calculating the necessary reinforcement in all concrete sections, and control of the limit states (ULS and SLS)* according to the Rulebook for CRC'87*.

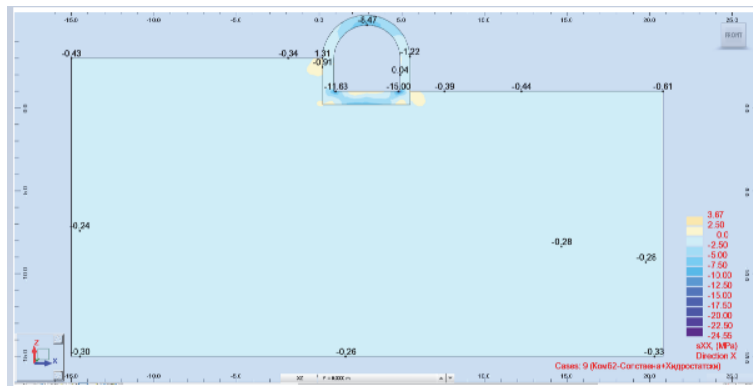


Figure 15. Stresses σ_x - Comb.2*

* CRC'87- Rulebook for concrete and reinforced concrete from 87

*Limit state design requires the structure to satisfy two principal criteria: the ultimate limit state (ULS) and the serviceability limit state (SLS)

*Comb.2 – (1.6) self weight + (1.8) hydrostatic pressure

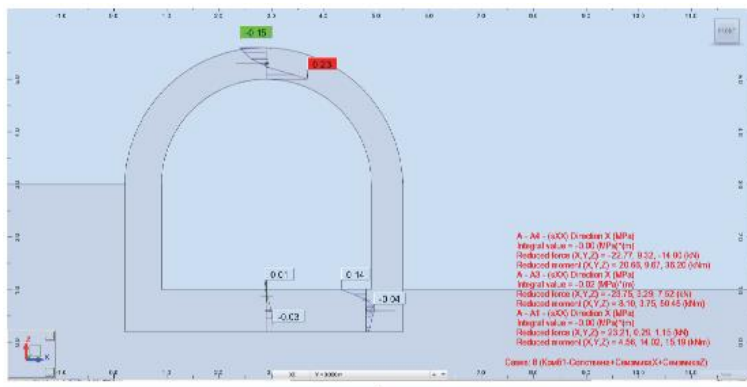


Figure 16. Bending moments and axial forces, sections - Comb.1*

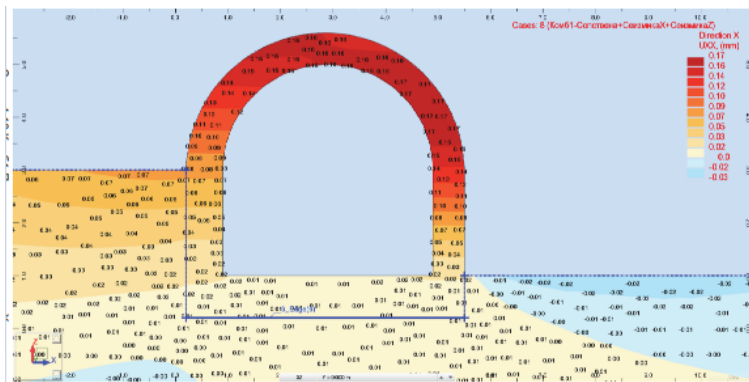


Figure 17. Displacement in X direction - Comb.1*

*Comb.1 – (1.3) self weight + (1.3) seismic X + seismic Z

3. RECOMMENDATIONS AND CONCLUSIONS

According to the previously mentioned differences in geometry and size, between the two diversion tunnels, a different amount of reinforcement and concrete for the tunnels construction is expected.

Considering that the “Konsko” Dam is 2.6 times larger than the “Otinja” Dam, it requests a larger diversion tunnel, following larger cross sections and quantity of material, more constructive positions, etc.

It is interesting to mention that although both tunnels differ in size, they were built in approximately the same period of time. The easier and faster execution is a result of creating a better dynamic plan, hiring a greater number of workers, engaging better mechanization, better weather conditions, ect.

In order do decrease the number of changes during construction on site, we should strive for more realistic designs, which include more accurate and precise layouts, investigations and results. Also the quality of the the project documentation, in great amount, depends on the given deadlines for conducting the design.

The authors of this paper come up with the idea to analyze exactly this, thanks to the opportunity to visit the sites during the construction of these two structures and being able to encounter the performance difficulties and the given solutions. Sometimes, much better solutions were given during construction, opposite to the

design due to easing the performance of certain position. These solutions can contribute in future designs of such structures.

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