University of Niš
FACULTY OF
CIVIL ENGINEERING
& ARCHITECTURE

Serbian Academy of
Sciences and Arts
Local Branch in Niš

SCIENCE
TECHNOLOGY
PARK
NIS

sinarg
2025

International Conference

Synergy of Architecture & Civil Engineering

PROCEEDINGS

VOLUME 1

September 11 – 12, 2025
Science and Technology Park Niš, Serbia

University of Niš
FACULTY OF
CIVIL ENGINEERING
& ARCHITECTURE

САНУ
ОГРАНАК САНУ
У НИШУ

Serbian Academy of
Sciences and Arts
Local Branch in Niš

SCIENCE
TECHNOLOGY
PARK
NIS

sinarg
2025

International Conference

Synergy of Architecture & Civil Engineering

PROCEEDINGS

September 11 – 12, 2025
Science and Technology Park Niš, Serbia

VOLUME 1

Proceedings of the International Conference
Synergy of Architecture and Civil Engineering 2025
SINARG2025
11-12 September 2025
Niš, Serbia
www.sinarg.org
Volume 1

Published by:
Faculty of Civil Engineering and Architecture, University of Niš
Serbian Academy of Sciences and Arts – Branch in Niš

For Publishers:
Slaviša Trajković, PhD
Vlada Veljković, PhD

Editors:
Vuk Milošević, PhD
Andrija Zorić, PhD

Approved to be printed by the Decree of Teaching Counsil of the Faculty of Civil Engineering and Architecture, University of Niš, No. 8/173 on 5 September 2025
Approved to be printed by the Serbian Academy of Sciences and Arts – Branch in Niš, No. 1/25-206-2 on 4 September 2025

Technical Editors:
Miloš Milić, PhD
Lazar Živković

Cover Design:
Jovana Tomić

ISBN 978-86-82810-15-5

Printed by:
Donat Graf DOO Belgrade
100 copies

Organized by:
Faculty of Civil Engineering and Architecture, University of Niš
Serbian Academy of Sciences and Arts – Branch in Niš

In partnership with:
Science and Technology Park Niš

Supported by:
Ministry of Science, Technological Development and Innovation of the Republic of Serbia
Serbian Chamber of Engineers

PREFACE

The SINARG 2025 conference reaffirms its mission to foster a productive synergy between scientific research and practical application in architecture and civil engineering. At a time when the construction industry faces urgent challenges, ranging from sustainability and energy efficiency to resilience and digital transformation, SINARG provides a unique platform where theoretical inquiry directly informs practice. By creating a space for researchers, professionals, and practitioners to engage, the conference ensures that innovation does not remain confined to academic discourse, but instead contributes to tangible advancements in the built environment.

This year has marked an important milestone for SINARG. A total of 230 abstracts were submitted, demonstrating the conference's ability to attract a wide range of research interests and ideas. After a careful and rigorous review process, over 140 full papers have been accepted for publication in these proceedings. The international dimension of SINARG continues to grow. Authors from 15 countries contributed to this year's proceedings, highlighting the diversity and inclusiveness of the conference community. Equally significant is the work of the reviewers, who came from 30 countries and whose expertise and critical evaluation have ensured the scientific rigour and quality of the published contributions. This increasing global engagement confirms the international recognition of SINARG and gives us confidence that future editions will attract even broader participation from around the world.

The success of the conference depends, above all, on its authors. Their research represents the foundation upon which SINARG is built, and without their dedication and willingness to share knowledge, this gathering would not be possible. We extend our deepest gratitude to each contributor for advancing the dialogue on architecture and civil engineering, and for ensuring that SINARG remains a space of intellectual exchange and professional relevance.

We also acknowledge with sincere appreciation the support of our sponsors, whose commitment has made it possible to organize a conference without participation or publishing fees. Their investment in the advancement of science, education, and professional collaboration demonstrates the essential role of industry in fostering innovation. By supporting SINARG, our sponsors have strengthened the link between academic research and real-world practice. Looking ahead, the Organizing and Scientific Committees are already preparing the ground for the next edition of SINARG. Building on the experience of 2025, the aim will be to expand international participation even further, strengthen cross-disciplinary collaboration, and continue positioning the conference as a key meeting point for both researchers and practitioners.

The Editors sincerely thank all who have contributed to the preparation of SINARG 2025, authors, reviewers, sponsors, and organizers, for their indispensable roles in shaping the success of this conference. Together, we have created not only a collection of scientific papers but also a community dedicated to advancing knowledge and applying it in practice for the benefit of society.

Niš, September 2025

Editors

doi.org/10.62683/SINARG2025.034

Research paper

INFLUENCE OF DRAINAGE MEASURES ON THE UPLIFT RESISTANCE OF THE FOUNDATION JOINT OF A GRAVITY CONCRETE DAM

Dušan Stevanović[1], Nikola Mirković[2], Uroš Mirković[3]

Abstract

A common characteristic of concrete as a material used in the construction of dams and the surrounding rock mass, on which such structures are typically founded, is the presence of voids within the material. Buoyancy, as the load exerted by water in the voids of the foundation medium and concrete that presses against the structure, must be reduced and kept at a level where the stability and performance of the structure will not be compromised. The methods most commonly applied to reduce the buoyancy at the foundation interface include the use of an injection curtain on the upstream face and drainage boreholes downstream of the curtain.

The seepage pattern analysis presented in this paper is illustrated through different calculation scenarios and under varying boundary conditions. The analysis was conducted on the structure of the additional hydropower plant of the gravity concrete dam "Iron Gate II," where the initial seepage pattern was analyzed using the finite element method (FEM) model, composed of the concrete section of the additional plant and the associated rock mass. Quantitative parameters illustrating the effects of seepage pattern improvement in other calculation scenarios were obtained after incorporating elements such as the injection curtain and drainage boreholes into the FEM model.

A comparative analysis, conducted under two different boundary conditions, compared the buoyancy values in five different calculation scenarios and calculated the safety factors for the analyzed scenarios. Based on the results, conclusions regarding the effects of changes in the seepage pattern were drawn. In addition to the calculations, the paper also presents a theoretical review of the Eurocode standard, specifically focusing on the calculation of safety coefficients for flotation, which was implemented in the software and used during the analysis presented in this paper.

Key words: *Dam Stability, Safety Factors, Buoyancy, Injection Curtain, Drainage Boreholes, FEM Analysis*

---

[1] MSc Civ. Eng., PhD student, Jaroslav Černi Water Institute, Jaroslava Černog 80, 11226 Belgrade, Serbia, dusan.stevanovic@jcerni.rs, ORCID N/A

[2] PhD, Research Associate, Jaroslav Černi Water Institute, Jaroslava Černog 80, 11226 Belgrade, Serbia, nikola.mirkovic@jcerni.rs, ORCID 0000-0002-5980-3049

[3] PhD, Research Assistant, Jaroslav Černi Water Institute, Jaroslava Černog 80, 11226 Belgrade, Serbia, uros.mirkovic@jcerni.rs, ORCID 0000-0001-6781-5798

1. INTRODUCTION

Materials used for the construction of hydraulic structures, as well as the media in which such structures are founded (soil or rock), are porous materials characterized by the presence of micro- and macro-voids (pores, joints, and cracks). As a direct consequence of these material characteristics, uplift occurs - an action whereby water exerts pressure on the voids within hydraulic structures and foundation interfaces, pushing the structure upward. Uplift, as a load, acts both when water is at rest and when it is seeping; in other words, uplift is present under both hydrostatic and hydrodynamic conditions.

According to the literature [1], uplift can be divided into two components:

- Base uplift U_{BAZ} which represents the hydrostatic pressure of the upstream water;
- Differential uplift U_{DIF} which represents the piezometric difference between the upstream and downstream water levels ($\Delta H = H_G - H_D$).

When considering structural measures to reduce or limit uplift, it is important to note that the base component of uplift cannot be eliminated in an economically feasible way. Therefore, structural measures aimed at reducing uplift are primarily focused on the differential uplift. Engineering solutions adopted in practice depend on the type of foundation medium (soil or rock), the homogeneity or heterogeneity of the considered layer, the geometric characteristics of the structure, the water level in the reservoir, and the elevation of the downstream water.

By analyzing the uplift problem at the foundation interface, an effective reduction of the differential component of uplift can be achieved through the application of grouting methods or drainage.

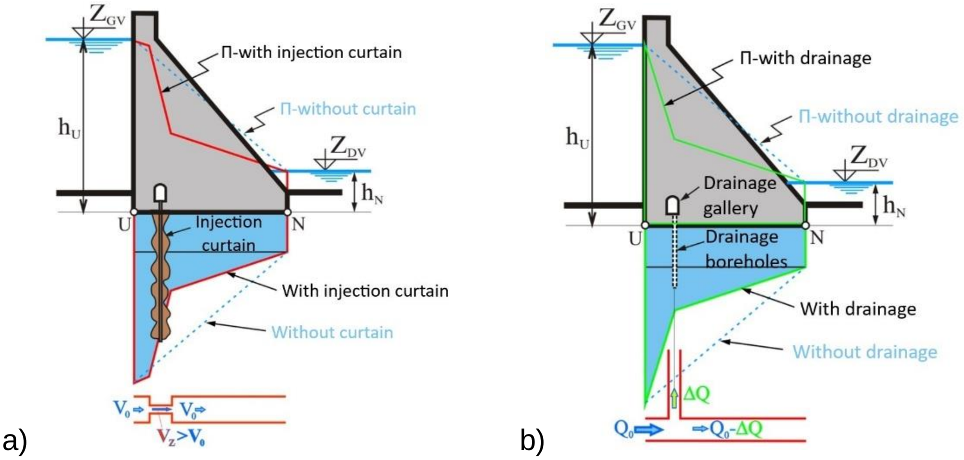


Figure 1. Anti-seepage measures for reducing uplift: a) injection curtain, b) drainage boreholes [1]

The impermeability of rocky media is increased through grouting. The grouting process involves injecting the grout material through pre-drilled boreholes, from which the grout penetrates into cracks, filling them and creating a high impermeability barrier in the form of a vertical seal. Another anti-seepage measure in rocky media is drainage, which is most commonly implemented by a network of boreholes. The boreholes extend to a drainage gallery, from where the infiltrating water is discharged outside the body of the dam [1].

On the dam section of the "Iron Gate II" Hydroelectric Power Plant, in the area between the Romanian Island Mare and the Serbian shore, the following structures are located:

powerhouse buildings with the assembly block, the spillway section of the dam, and the non-spillway section of the embankment dam. The segment encompassing the non-spillway section of the embankment dam consists of three zones, between which are the ship lock structures and the auxiliary power plant [2].

Figure 2. Photo of the HPP Iron Gate II Dam [3]

The subject of the analysis conducted within this paper is the auxiliary power plant, which is positioned on the previously constructed embankment dam, between the lock chamber and the right bank. The auxiliary power plant consists of two units: the turbine-generator block and the assembly block. The plant houses two units, each with a capacity of 27 MW [2].

Figure 3. Photo of the additional hydropower plant [3]

2. FEM MODEL

In the conducted analysis, a three-dimensional FEM model was developed for the marked part of the structure, where the red-marked portion of the structure represents the concrete part of the auxiliary power plant, while the yellow-marked portion represents the modeled corresponding segment of the rock mass.

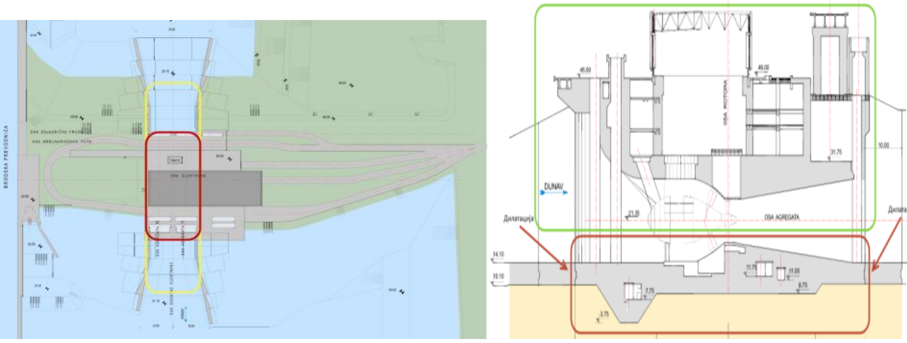


Figure 4. Representation of the boundaries of the modeled part of the additional hydropower plant [2]

The FEM model shown in Figure 5 covers a part of the foundation interface of the auxiliary power plant and the corresponding rock mass (Figure 4). The model dimensions at the base are 128.4 x 38.0 m (marked in red in Figure 4). The green-framed portion of the power plant is excluded from the seepage calculations as it is not considered significant for the filtration processes, while in the uplift safety calculation, the actual value of the total weight of the structure, as well as the corresponding live load, was taken into account. The boundaries of the model were extended 25.0 m upstream and downstream from the outer edges of the foundation interface of the modeled structure, in order to set realistic boundary conditions (marked in yellow in Figure 4) [2].

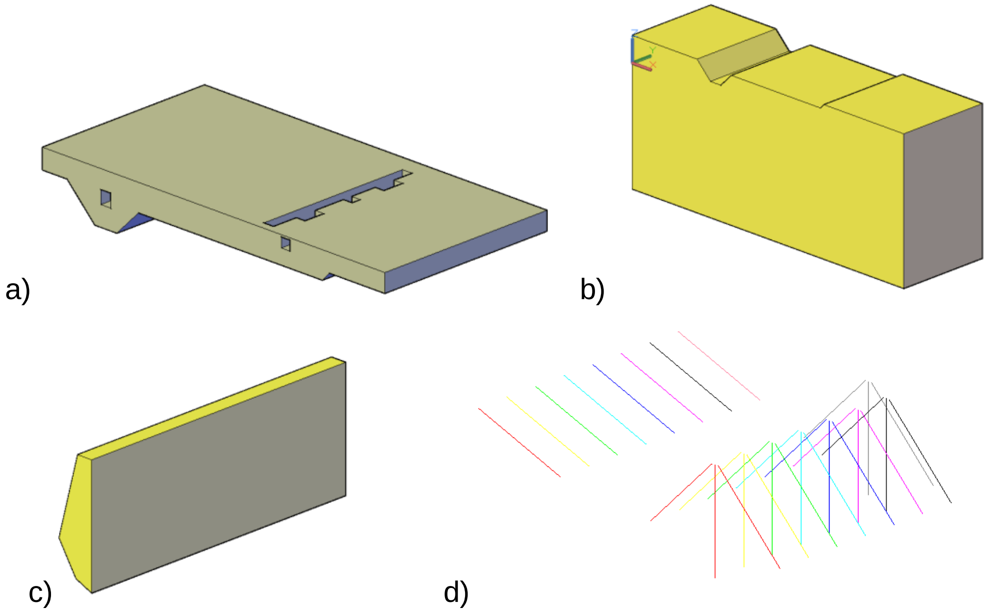


Figure 5. Representation of the FEM model elements: a) foundation joint of the additional hydropower plant; b) rock mass; c) injection curtain; d) drainage boreholes [2]

In addition to the aforementioned parts of the foundation interface and rock mass, the elements of the grouting curtain and drainage boreholes were also modeled for the purpose of analyzing uplift and safety factor calculations. The conducted calculations enabled a comprehensive assessment of the seepage conditions of the considered structure.

The foundation interface of the auxiliary power plant was modeled as a volumetric body using a 3D solid [2]. The corresponding rock mass and grouting curtain were modeled in the same way. The depth of the modeled grouting curtain is 15 m. The drainage boreholes were modeled as linear elements. The FEM model contains 32 boreholes, each 15 m long, distributed across 9 profiles [2].

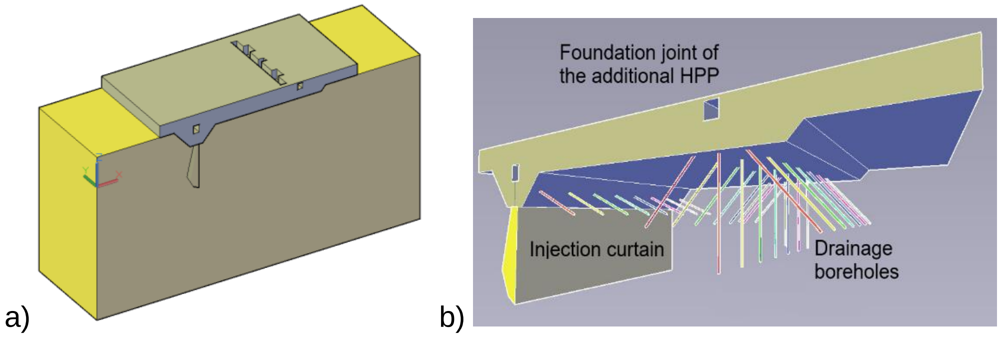


Figure 6. Appearance of the FEM model: a) with the attached rock mass; b) position of the modeled injection curtain and drainage boreholes relative to the 3D solid foundation interface. [2]

The finite element mesh of the considered structure was created using tetrahedral finite elements with mid-nodes (10 nodes per element). The model consists of 280,255 nodes and 205,894 elements [2].

For the purpose of analyzing the seepage conditions on the upstream face of the terrain and the concrete part of the foundation interface, the potential was set equal to the elevation of the upstream water, while on the downstream face of the structure and terrain, the potential was set equal to the elevation of the downstream water (Figure 7) [2].

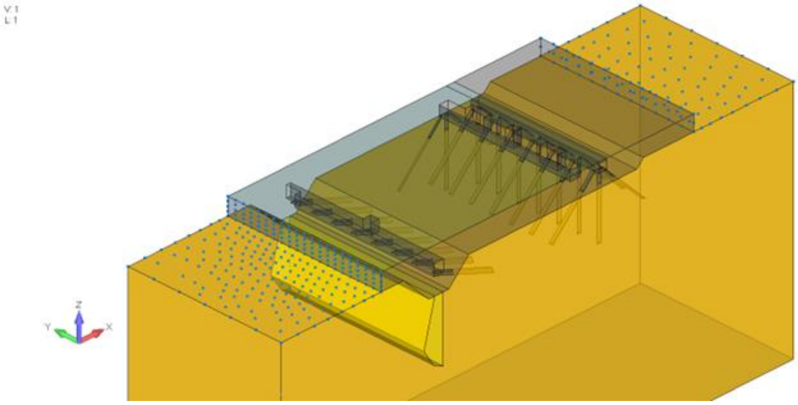


Figure 7. Representation of the assigned potentials corresponding to the upstream and downstream water elevations [2]

At the outlets of the drainage boreholes, the values of the seepage potential corresponding to the coordinates of the nodes at the top of the boreholes are assigned [2].

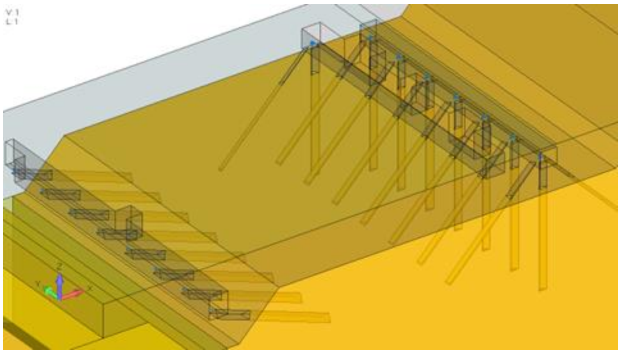


Figure 8. Representation of the assigned potentials at the outlets of the drainage boreholes [2]

On the surfaces of the galleries, the seepage potential values are also assigned, which correspond to the coordinates of the nodes on those surfaces [2].

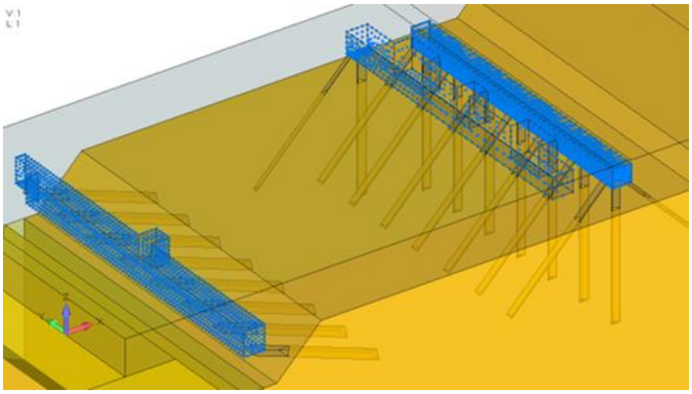


Figure 9. Representation of the assigned potentials on the surfaces of the galleries [2]

The theoretical basis of the seepage process in the considered software is thoroughly explained in the paper [4]. Given this fact, it will not be repeated in this work.

3. ASSESSMENT OF THE SAFETY FACTOR AGAINST UPLIFT OF THE STRUCTURE ACCORDING TO EUROCODE

The inclusion of standardized procedures according to the applicable Eurocode [5] implies that the verification related to uplift must be carried out by checking that the design value of destabilizing actions is ($V_{dst;d}$) smaller than the design values of stabilizing permanent vertical actions ($G_{stb;d}$) and the design values of any additional resistance to uplift. (R_d).

$$V_{dst;d} \leq G_{stb;d} + R_d$$

$V_{dst;d}$ – the design value of the combination of destabilizing permanent and variable vertical actions,

$G_{stb;d}$ – the design value of stabilizing permanent vertical actions,

R_d – additional resistance to uplift

For the foundation interface of the auxiliary power plant, the stabilizing vertical forces are determined, which include the self-weight of the dam and the weight of the additional equipment. The weight of the water over the wetted surface of the dam, which acts favorably in the vertical direction, has been excluded from the analysis in this work, with a detailed explanation in Chapter 4. The destabilizing forces include the buoyant vertical forces acting on the foundation interface, which are a result of seepage forces.

In the case where there is no additional resistance to uplift, the check for the limit state of uplift can be written using the following relation:

$$\frac{G_{stb,d}}{V_{dst,d}} = F_s$$

The conducted seepage calculation aimed to determine the value of $V_{dst,d}$ for different calculation scenarios, depending on the application of anti-seepage measures.

The value of $G_{stb,d}$ was obtained by summing the calculated value of the total weight of the auxiliary power plant structure (1 100 000 kN) and the additional equipment (1 000 kN).

4. DESIGN SITUATIONS WITHIN THE SAFETY ANALYSIS OF THE ADDITIONAL HYDROPOWER PLANT STRUCTURE

In this chapter, Figure 10 shows an illustration of the conditions under which the calculation is performed within the tool. It is important to emphasize that the results presented in this study represent the seepage conditions in a predefined calculation scenario, which corresponds to the moment when the operational gate on the upstream side and the siphon gate on the downstream side are lowered, and there is no flow through the power plant turbines. The authors selected this calculation scenario as the most unfavorable, because at that moment, there is no favorable effect of the water weight on the uplift.

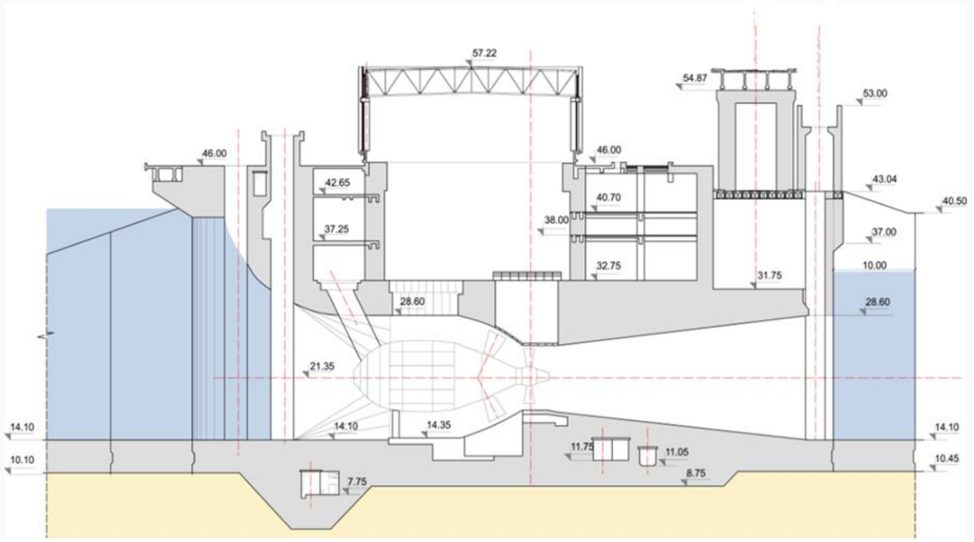


Figure 10. Boundary conditions for which the calculation is performed [2]

For modeling seepage processes in the rock mass within the analysis in this work, the filtration coefficients are defined as the rock parameters, which are given in the following Table 1. The parameters were adopted based on the available documentation about the structure as well as from the technical literature [2].

Table 1. Filtration coefficients of the modeled elements [2]

Material	Filtration coefficient (m/s)
Concrete part of the additional hydropower plant - foundation	10^{-11}
Rock mass	10^{-7}
Injection curtain	10^{-9}
32 drainage boreholes	10^{-3}

It is assumed that the diameter of all drainage boreholes is 85.0 mm. In the performed calculation, the foundation of the auxiliary power plant and the surrounding terrain, i.e., the rock mass, represent elements that had a constant filtration coefficient in all performed calculation scenarios (Table 1). Depending on the combination of including the injection curtain and drainage boreholes, the calculation scenarios were formed, and in them, these elements had different filtration coefficients, depending on whether they were included in the performed calculation or not. The injection curtain was excluded from some seepage calculations by assigning the same filtration coefficient as the surrounding terrain, i.e., the rock mass (10^{-7}). Boreholes were excluded from the seepage calculation by assigning an extremely low filtration coefficient (10^{-13}). Table 2 shows the different calculation scenarios depending on which anti-seepage measures were included. The symbol "✓" indicates that the element is included in the calculation (the filtration coefficients are identical to those in Table 1), while the symbol "✗" indicates that the element is excluded from the calculation, applying the previously mentioned changes in the filtration coefficients.

Table 2. Overview of the considered calculation scenarios of the seepage calculation

Calculation scenarios	Injection curtain	Drainage boreholes
1th	✗	✗
2th	✓	✗
3th	✗	✓
4th	✓	✓
5th	✓	✓*

The first calculation scenario represents the most unfavorable case in terms of the seepage condition and the calculation of the safety factor, as it excludes both the injection curtain and the drainage boreholes from the analysis. The second scenario represents a more favorable case, allowing the assessment of the effects of the injection curtain. The third scenario includes all drainage boreholes while excluding the injection curtain, enabling the evaluation of the effects of drainage boreholes based on the results.

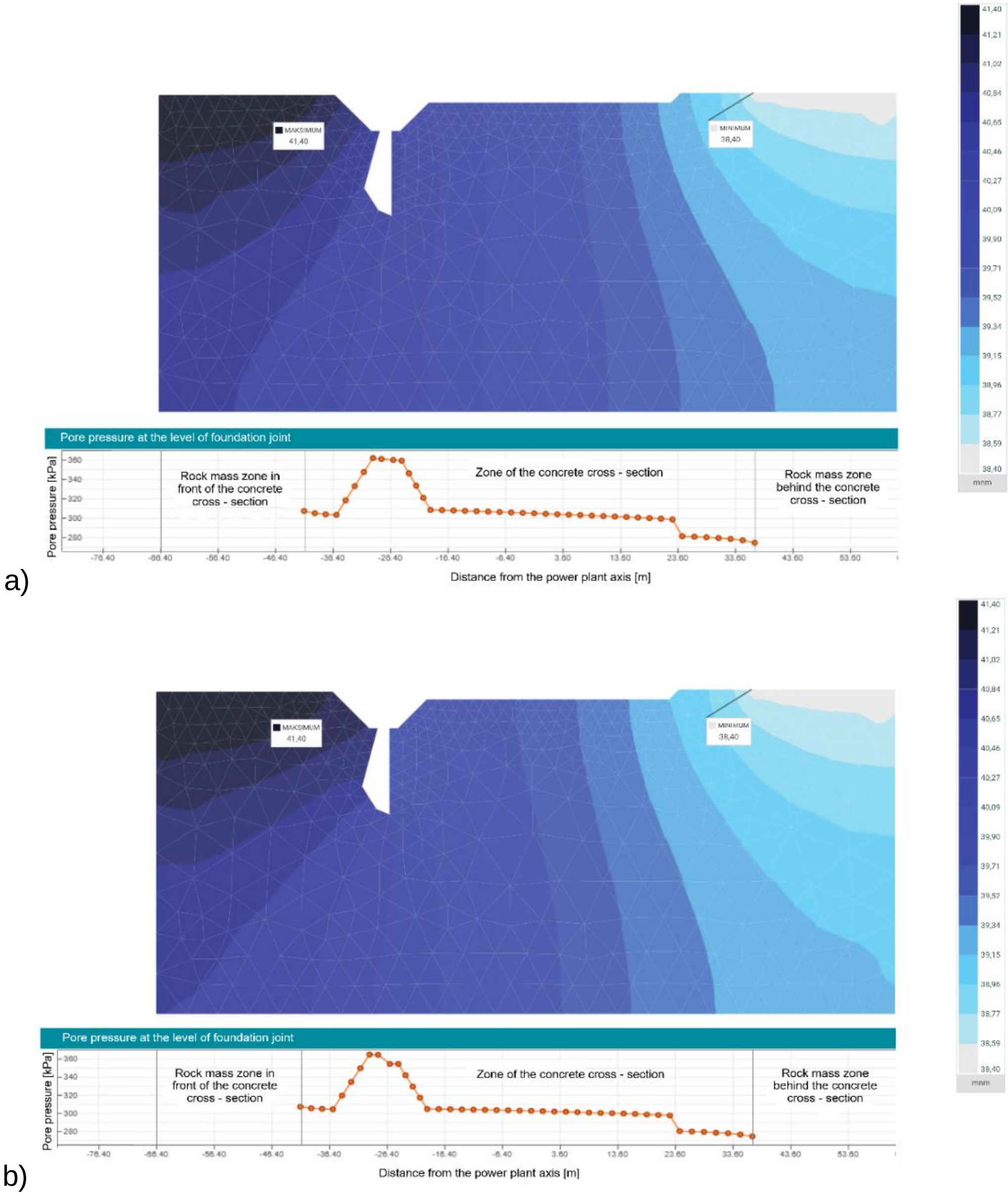
The fourth calculation scenario, which includes both the injection curtain and drainage boreholes, represents the most favorable case and illustrates the extent to which anti-seepage measures can improve the safety factor and seepage behavior of the structure in this specific example.

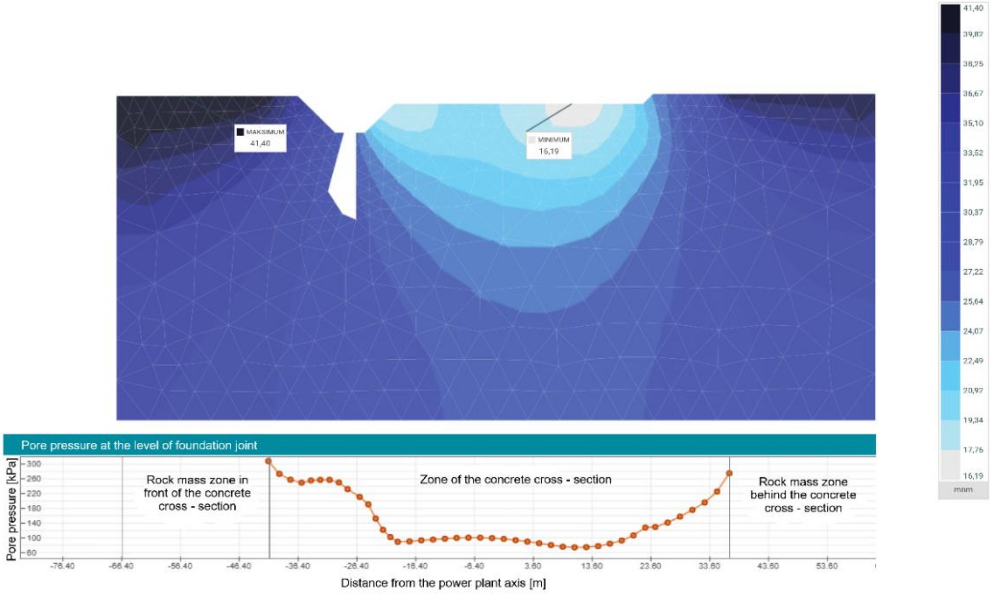
The fifth scenario involves the inclusion of the injection curtain and boreholes in the downstream gallery in selected profiles only, while all boreholes in the upstream gallery at a given elevation are excluded from the analysis.

5. RESULTS OF THE SEEPAGE ANALYSIS

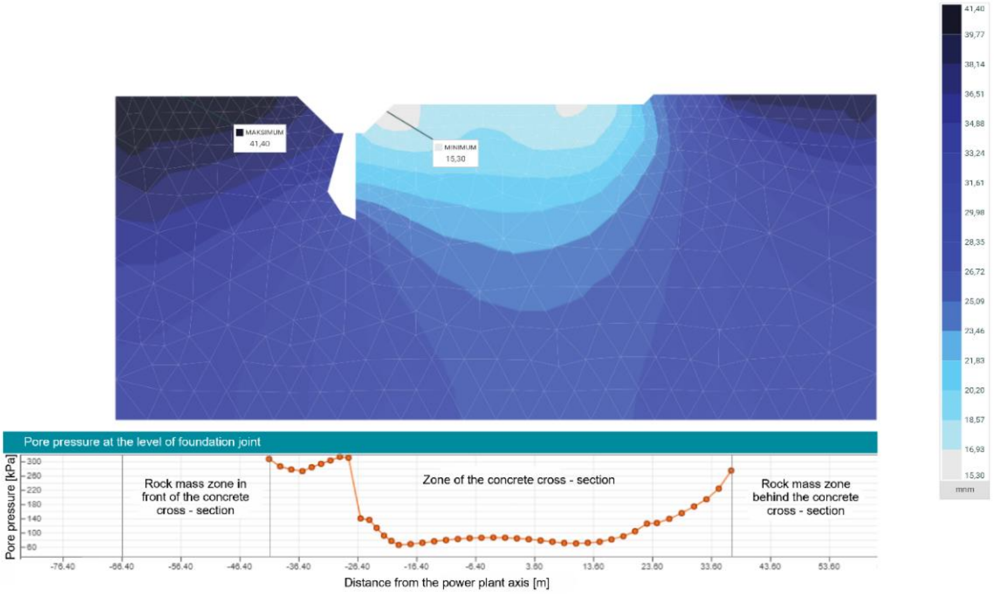
The results of the seepage calculations are presented in two parts within this chapter. The seepage analysis was conducted using the User Tool for the analysis of the condition and safety verification of the additional power plant, which is used during the calculations and analysis at the Jaroslav Černi Water Institute. The calculation was performed in the PAK software package [6, 7].

The first part of the chapter presents the values of piezometric levels and seepage behavior in the form of diagrams for the cross-section along the turbine axis (Figure 11) for calculation scenarios with water levels in the reservoir and the elevation of the downstream water level at 41.40 m a.s.l. and 38.40 m a.s.l., respectively.

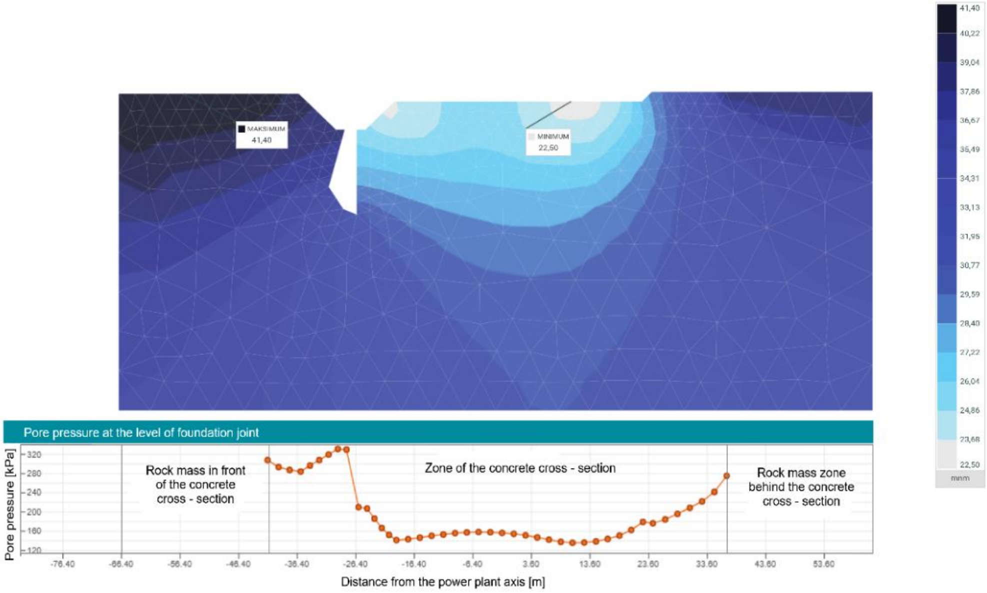



MAKSIMUM
41,40
MINIMUM
16,19
41,40
39,82
38,25
36,67
35,10
33,52
31,95
30,37
28,79
27,22
25,64
24,07
22,49
20,92
19,34
17,76
16,19
mnm
Pore pressure at the level of foundation joint
Pore pressure [kPa]
300
260
220
180
140
100
60
Rock mass zone in front of the concrete cross - section
Zone of the concrete cross - section
Rock mass zone behind the concrete cross - section
-76.40
-66.40
-56.40
-46.40
-36.40
-26.40
-16.40
-6.40
3.60
13.60
23.60
33.60
43.60
53.60
Distance from the power plant axis [m]

c)


MAKSIMUM
41,40
MINIMUM
15,30
41,40
39,77
38,14
36,51
34,88
33,24
31,61
29,98
28,35
26,72
25,09
23,46
21,83
20,20
18,57
16,93
15,30
mnm
Pore pressure at the level of foundation joint
Pore pressure [kPa]
300
260
220
180
140
100
60
Rock mass zone in front of the concrete cross - section
Zone of the concrete cross - section
Rock mass zone behind the concrete cross - section
-76.40
-66.40
-56.40
-46.40
-36.40
-26.40
-16.40
-6.40
3.60
13.60
23.60
33.60
43.60
53.60
Distance from the power plant axis [m]

d)



e)

*Figure 11. Potential (m.a.s.l.) and pore pressure at the foundation joint for:
a) Calculation Scenario I, b) Calculation Scenario II, c) Calculation Scenario III,
d) Calculation Scenario IV, e) Calculation Scenario V*

The second part of the chapter presents in Table 3 the results in the form of values for the buoyant force and safety factor for different calculation scenarios. The results are separated into two different section of table, depending on the water level in the reservoir and the elevation of the downstream water level.

Table 3 Values of Buoyancy Force and Safety Factor for the Considered Calculation Scenario

Calculation scenarios	Water level in the reservoir [m.a.s.l.]	Lower water level [m.a.s.l.]	Buoyancy [kN]	Safety Factor [-]
1th	41.40	38.40	716 731	1.54
2th	41.40	38.40	712 674	1.54
3th	41.40	38.40	276 197	3.99
4th	41.40	38.40	265 049	4.15
5th	41.40	38.40	415 058	2.65
1th	40.50	32.00	636 405	1.73
2th	40.50	32.00	625 018	1.76
3th	40.50	32.00	255 636	4.31
4th	40.50	32.00	244 682	4.50
5th	40.50	32.00	372 710	2.95

6. CONCLUSION

In this study, in addition to the results presented in the work [4], the analysis was expanded by considering the parameters as a function of the safety factor. The objective of this study was to demonstrate the increase in the safety factor depending on the applied anti-seepage measures. The presented results are part of an ongoing research project at the Jaroslav Černi Water Institute, related to the development of the Dam Safety Management System for HPP “Iron Gate II”.

Based on the results shown in Table 3, it can be concluded that all calculated safety factors for the auxiliary power plant structure exceed 1.5, clearly indicating that the uplift forces are lower than the stabilizing vertical forces. Acceptable minimum values of the safety factor for structures that have been in operation for a prolonged period are currently the subject of ongoing research and will be published in future studies, building upon the findings presented in this paper.

The presented diagrams of seepage behavior and safety factor values, as well as their increase after the implementation of anti-seepage measures, highlight the importance of applying injection curtains and drainage wells for a more favorable situation regarding buoyancy calculations.

7. REFERENCES

[1] Savić M. Ljubodrag, **Uvod u hidrotehničke građevine**, *Građevinski fakultet Univerziteta u Beogradu*, Beograd, 2009

[2] Institut za vodoprivredu „Jaraoslav Černi“, Sistem za upravljanje bezbednošću brane HE „Đerdap 2“ v2023, **Knjiga 3 – Izveštaj o analizama izvršenim primenom MKE modela filtracionih i naponsko – deformacionih procesa na dodatnoj elektrani**, Beograd, 2024

[3] https://www.eps.rs/lat/djerdap/Stranice/Galerija.aspx?folder=Galerija%2f2+-+He+%c4%90erdap+2 (24.04.2025.)

[4] Mirković Uroš, Radovanović Slobodan, Divac Nikola, Vulović Snežana: **Uticaj zavese i drenažnih bušotina na filtracionu sliku u temeljnoj spojnici gravitacionih brana**. *Zbornik radova sa nacionalnog simpozijuma DGKS*, Beograd, 2021

[5] **SRPS EN 1997-1:2017, Evrokod 7 – Geotehničko projektovanje – Deo 1: Opšta pravila**, *Institut za standardizaciju Srbije*, Beograd, 2017

[6] Živković Miroslav, Vulović Snežana, Kojić Miloš, Slavković Radovan, Grujović Nenad, **Program for FE Analysis of Flow Through Porous Media**, 2019

[7] Živković Miroslav, Vulović Snežana, Kojić Miloš, Slavković Radovan, Grujović Nenad, **User manual and examples for PAK-P – Program for FE Analysis of Flow Through Porous Media**, *Faculty of Engineering University of Kragujevac*, Kragujevac 2019