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CHOICE OF GROUT CURTAIN TYPE OF DAM "REČANI" ON ORIZARSKA RIVER – KOČANI

Igor Peševski[1], Stevčo Mitovski[1], Jovan Br. Papić[1], Miloš Marjanović[2]

[1]*Ss. Cyril and Methodius University in Skopje, Faculty of Civil Engineering, Partizanski odredi 24, MK 1000, Skopje, Republic of Macedonia*
[2]*Univsersity of Belgrade, Faculty of Mining and Geology, Đušina 5, Belgrade, Republic of Serbia*
pesevski@gf.ukim.edu.mk

A b s t r a c t: In the frames of Preliminary design for choice of dam type for dam "Rečani" on river of Orizarska near Kočani, three types of embankment dams were elaborated. Based on the results from geological, hydrogeological, geotechnical investigations and recommendations of the geotechnical model, possible alternatives of the grout gallery and curtain were designed. Structural and geotechnical analyses were performed for each of the solutions. At the end, total costs of dam construction and grout works were calculated. Comparing all important factors, optimal design of the grout curtain was proposed. The selection of the optimal type of embankment dam and grouting curtain was also done with application of multi-criteria optimization, by applying of the method of compromise programming.

Key words: grout gallery; grout curtain; embankment dam; optimal choice

INTRODUCTION

Realization of the hydrosystem (HS) Orizarska River is of vital importance for the development of the municipalities of Kočani, Vinica, Češinovo-Obleševo and Zrnovci, located in the eastern part of R. Macedonia (Fig. 1). The sole object that makes the system controllable, apropos enabling time transformation of the water of catchment area of the Orizarska River is the live storage of reservoir Rečani.

Fig. 1. Location of HS Orizarska River in region of municipality Kočani

Creation of the reservoir Rečani will improve management of the water resources of Orizarska River that will provide: (1) qualitative water supply of the population (around 90,000 habitants) and industry of the municipalities: Kočani, Vinica, Češinovo-Obleševo and Zrnovci; (2) irrigation with increased reliability on favorable areas for intensive agricultural production; (3) electric energy production; (4) ennobling of small water; (5) flood protection, and (6) development of tourism, sport and recreation activities.

The complex of the HS Orizarska River is composed of several sub-systems as independent civil engineering parts. A multistage project realization approach has been chosen considering the aspect of satisfaction of: a) time criteria (project realization in less time) and b) financial limitations (actual limited funds for completion of the total technical documentation–investigations and design). In that way, the realization of the HS Orizarska River is divided in six stages, according to the following schedule:

- First stage – access road.
- Second stage – hydraulic scheme Rečani (dam Rečani with appurtenant structures: diversion tunnel and upstream cofferdam, spillway structure and bottom outlet).
- Third stage – alimentation conduit (headrace, Tyrolean intake at Golema River, tunnel with length 800 m and surface pipeline that will enable water intake of catchment areas not graviting towards Orizarska River to reservoir Rečani).

- Fourth stage – water supply (joint near intake type and joint main headrace to division point, main headrace with water treatment plant for water supply of Kočani, main headrace with water treatment plant for water supply of Vinica and surrounding settlements).
- Fifth stage – energy production (small hydropower plants [HPP] 1 – reservoir plant of near dam type, HPP 2 – derivation plant of discharge type and eventual HPP 3, estimated to produce total average annual electricity of 19.7 GWh/year).
- Sixth stage – irrigation (main headrace for irrigation and secondary irrigation pipelines, estimated agricultural area of 1,500 ha to be irrigated).

The hydraulic scheme Rečani is composed of dam with H = 77 m height above the ground level and appurtenant structures: diversion tunnel, upstream cofferdam, bottom outlet and spillway structure. In accordance with the available technical documentation and time frame of the chosen dynamic for realization of HS Rečani, "the decision maker" adopted the following basic parameters of hydraulic scheme Rečani: (a) normal water level in the reservoir at 646.0 m a.s.l, (b) dam site location at around 500 m downstream of the joint of Bela and Crna River and (c) at the dam site to be applied embankment dam type.

Three types of embankment dams were adopted to be analyzed: (1) earth rock dam with clay core, (2) rockfill dam with asphaltic core and (3) rockfill dam with geomembrane facing.

The choice of dam type (along with grout gallery and curtain) was done based on the criteria of "minimization of the investment cost" where all alternatives should have same threshold of technical analysis and to have same level of structural, seepage, hydraulic and hydrologic safety. Having in consideration that, beside on the economy valorization, dam type has effect also on other measurable and non-measurable parameters, it was decided to additionally check the chosen optimal dam type by method of multi-criteria optimization [1].

ENGINEERING GEOLOGY DATA OF SITE

The rock mass at the dam site is presented by micaschists from the Precambrian period are which tectonically trusted over the older rifej – Cambrian green schist's. Younger Quaternary sediments are present in the form of alluvium of the river Orizarska, occurrences of cone shaped proluvium, and thin soil debris layer covering the bedrock.

With the specific study of structural-tectonic forms, it was concluded that the dam site is characterized with complex tectonic setting. Analysis of fracture systems was performed on the base of the detailed engineering geological mapping of the terrain and the core from the investigation drillholes. Two genetic types of discontinuities were determined: tectonic fractures and mechanical fractures. The tectonic fracturing is presented by several systems of joints among which most characteristic are systems with dip elements 348°/84° and 141°/80°. Fractures have decimeter to hectometer dimensions, mostly with opening of 1–10 cm, filled with detritus material. These systems appear to be parallel with spacing of 0.5–3.0 m. Other systems with dip elements 139°–143°/78°–80°; 348°–349°/83°–85° are less present. Mechanical fractures are present near the surface of the terrain and they are usually filled with products from mechanical and chemical weathering. Generally, the fracturing at the dam site is not intensively developed, and the character of the discontinuities is in accordance with the lithological setting of the terrain.

Based on all geological, engineering-geological, hydrogeological and geotechnical investigations, numerous thematic cross-sections were prepared. These include: engineering geological cross section by lithology and fracturing parameter, as well as engineering-geological model by permeability parameter (Fig. 2).

According to the properties of the rock masses from the above mentioned cross-sections, a geotechnical model for the dam site was prepared (Fig. 3). This model shows the zones for several geotechnical interventions: zone of excavation, zone of contact grouting, and zone of curtain grouting.

ANALYZED DAM TYPES

As mentioned, considering all factors (including geological and geotechnical), three types of embankment dam were elaborated [2]. Basic geometrical data for the analyzed solutions were obtained over analysis of three typical cross sections for the embankment dams, according to the layout on Fig. 4.

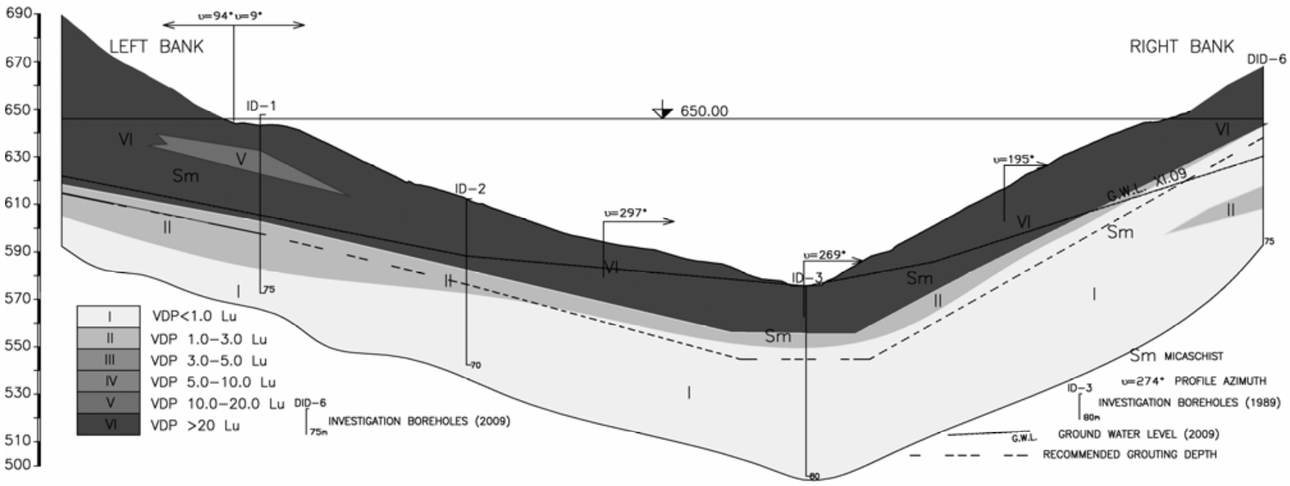


Fig. 2. Engineering geological model by parameter of permeability for rockfill dam alternative with upstream geomembrane facing

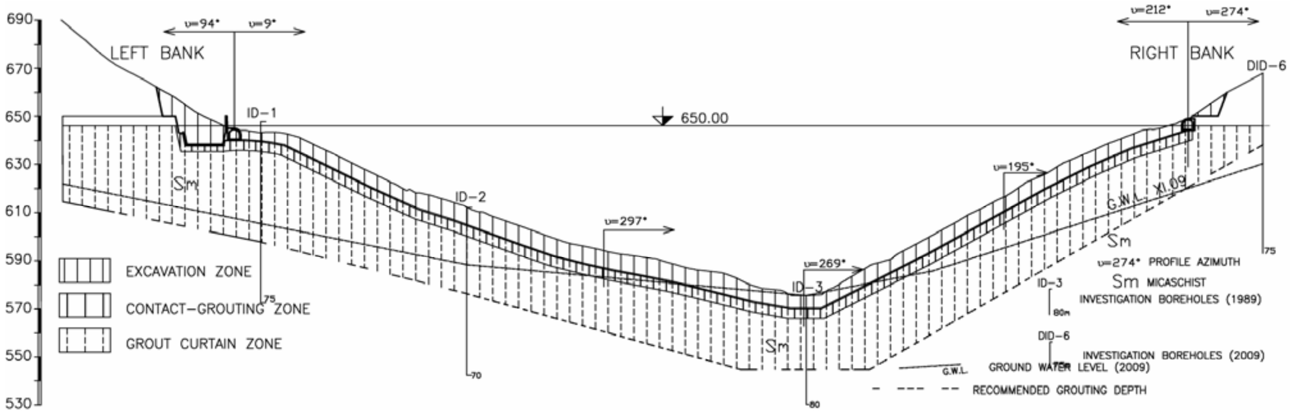


Fig. 3. Geotechnical model of the dam profile for rockfill dam alternative with upstream geomembrane facing

Typical elevations and foundation data are: (1) elevation of the terrain near the downstream toe of the dam 570.0 m a.s.l.; (2) elevation of the terrain near the upstream toe of the dam 576.0 m a.s.l.; (3) depth of alluvial deposit in the river bed 3.0 m; (4) depth of soil debris on left and right river banks on the dam profile 1.0 m. The design of the grout gallery and grout curtain depends on the geometry of the adopted dam type.

The cross section of earth rock dam with clay core (Fig. 5) consists of central clay core, filter layers and dam shell. The clay core is founded on rock foundation at elevation 586 m a.s.l., width of core bottom section of 22 m and width at core crest of 4.0 m. At contacts of the core and dam shells two filter layers (fine and coarse) are planned, with thickness of 3 m. Dam shell is planned to be constructed of rockfill. Upstream dam slope is 1:2, and the downstream 1:1.9. Dam crest width is 10 m.

The cross section of rockfill dam with asphalt core (Fig. 6) consists of central asphalt core, filter layers and dam shell. Asphalt core is thick 0.60 m, founded on concrete plinth, placed on the top section of the grouting gallery, at elevation of 591.5 m a.s.l.. Two filter layers are planned at the contacts of the core and dam shell: fine, with thickness of 1.5 m and coarse, with thickness of 3 m. Dam shell is planned to be constructed of rockfill. Upstream dam slope is 1:1.9, and the downstream 1:1.8. Dam crest width is 10 m.

The cross section of rockfill dam with geomembrane facing (Fig. 7) consists of rockfill dam shell, filter layer and geomembrane facing. The geomembrane facing is planned to be installed on the upstream slope of the dam, placed over filter layer with thickness of 2.5 m. The facing is composed of layer of lean concrete, with thickness 14 cm and geocomposite (geotextile+geomembrane+geotextile), with total thickness of 1 cm, covered with concrete plates, with thickness of 10 cm. Upstream dam slope is 1:1.8, while the downstream is 1:1.7. Dam crest width is 10 m. The geocomposite extends along and over the grout gallery also.

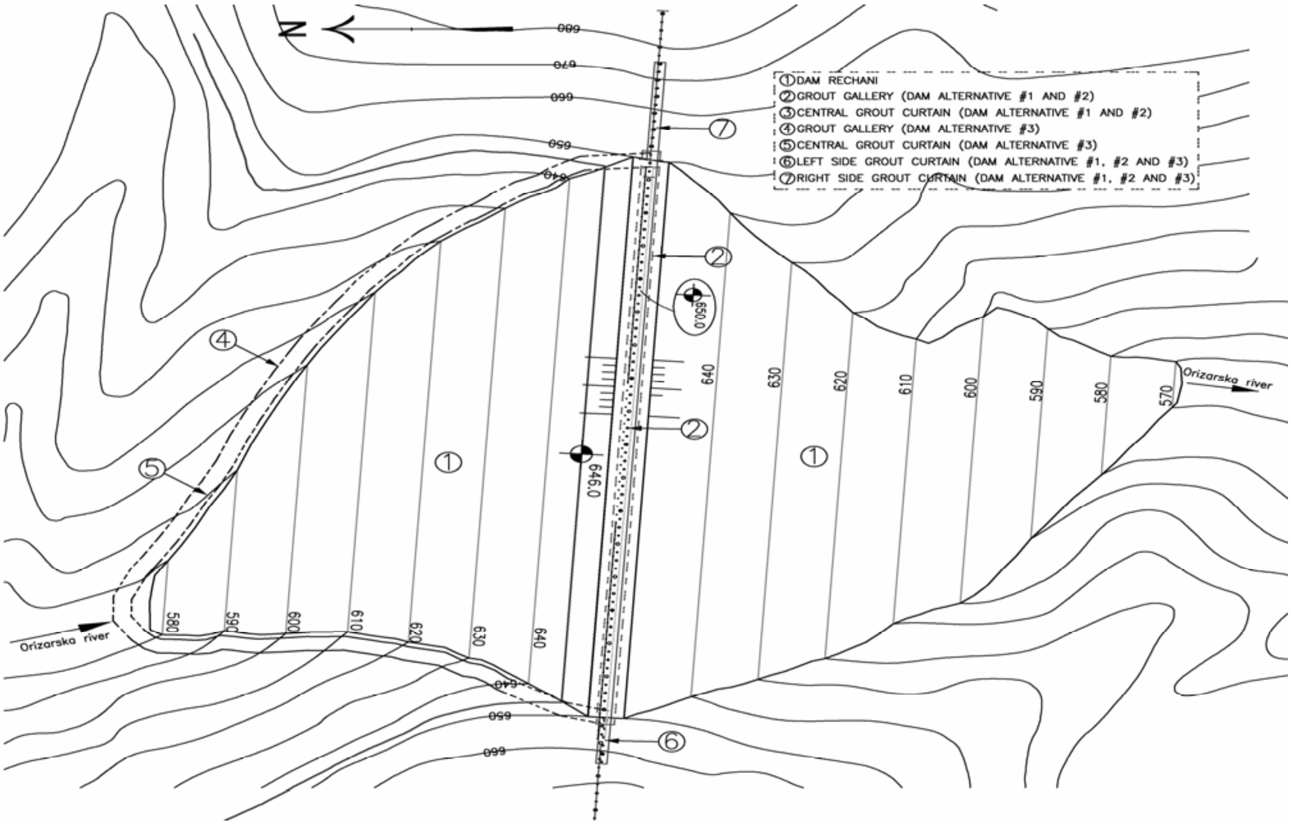


Fig. 4. Layout of rockfill dam alternatives with possible solutions of the grout galleries and curtains

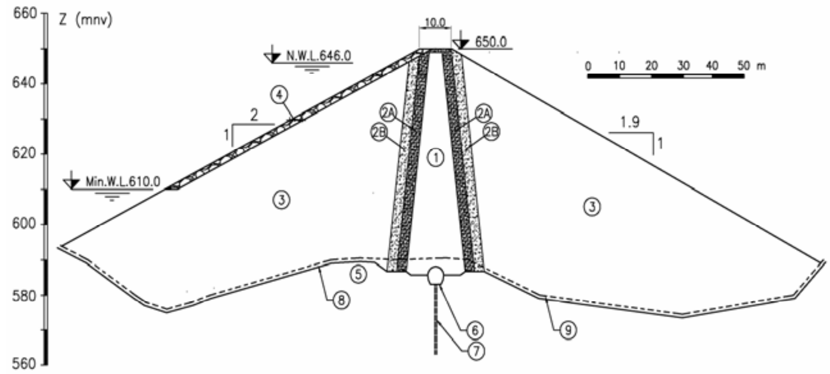


Fig. 5. Cross section of earth rock dam with central clay core. (1) clay core, (2A) fine filter layer, (2B) coarse filter layer, (3) dam shell, (4) rip rap, (5) rock, (6) grouting gallery, (7) grouting curtain, (8) excavation line, (9) natural ground

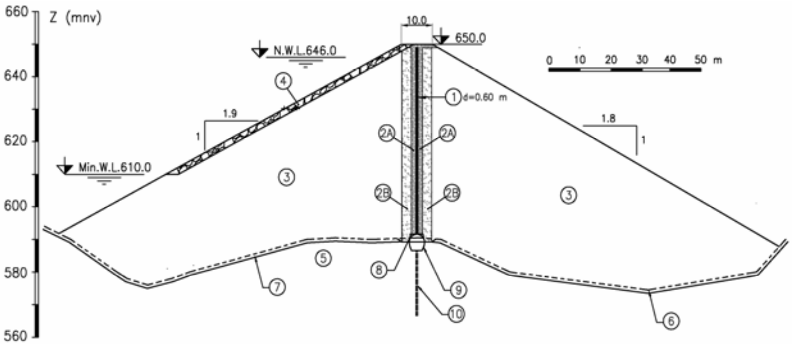


Fig. 6. Cross section of rockfill dam with asphalt core. (1) asphalt core, (2A) fine filter layer, (2B) coarse filter layer, (3) dam shell, (4) rip rap, (5) rock, (6) natural ground, (7) excavation line, (8) concrete plinth, (9) grouting gallery, (10) grouting curtain

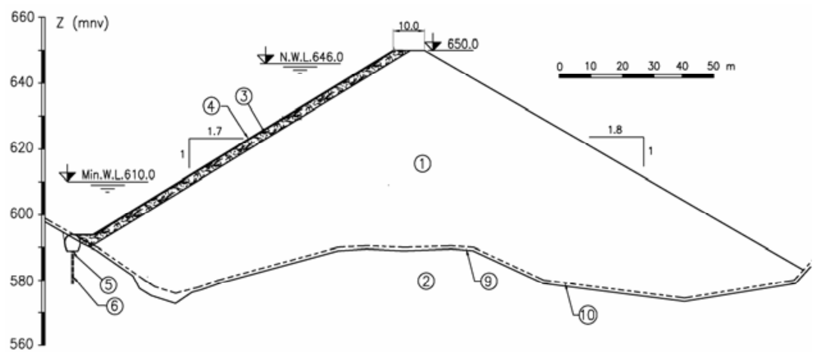


Fig. 7. Cross section of rockfill dam with geomembrane facing. (1) dam shell, (2) rock foundation, (3) filter layer, (4) geomembrane facing, (5) grouting gallery, (6) grouting curtain, (7) natural ground, (8) excavation line

CROSS SECTIONS AND DISPOSITION OF THE GROUT GALLERY

The grout gallery cross section is horse shoe type, planned to be constructed of reinforced concrete. The cross section of the grout gallery, which will also serve as control and drainage gallery of the embankment dam, is structurally adopted. The inside geometry of the gallery (Fig. 8) is placed in the plane of the impermeable section of the dam and shaped with two radiuses of curvature. The width and the height of the grouting gallery is 5.0 m.

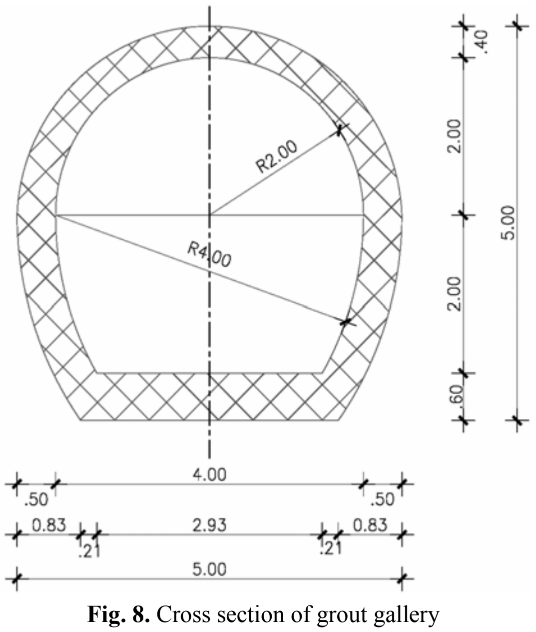


Fig. 8. Cross section of grout gallery

For the alternative of earth rock dam with clay core (Fig. 9), the axis of the grout gallery is in the plane of the dam site profile and it is founded at elevation of 566.4 m a.s.l. The outer height is 5.0 m, with 2.4 m entering into the clay core, founded at elevation of 569.0 m a.s.l., while 2.4 m of the gallery height are founded in the rock foundation.

For the alternative of rockfill dam with asphalt core (Fig. 10), the axis of the grout gallery is placed in the dam site profile and founded at elevation 567.4 m a.s.l. Its outer height is 5.0 m, so the gallery crest meets the foundation of the asphalt core at elevation 572.4 m a.s.l. For this case, in order to secure parallel embedment of the layers of the asphalt core and first filter layer, part of the gallery crest is planned as horizontal surface of 4 m width.

For the alternative of rockfill dam with geomembrane facing (Fig. 11), the downstream edge of the grout gallery is placed on the contact of the facing with the bedrock (if the facing is extrapolated to elevation of 573.0 m a.s.l). The gallery is founded at elevation of 570.4 m a.s.l. Its outer height is 5.0 m, so the gallery crest meets the horizontal section of the facing.

Grout tunnels, which are analyzed for some of the possible solutions, will serve for grouting of the left and right curtains in the banks of the river valley; they start from the left and right plateau respectively, with elevation of their foundation at 650.0 m a.s.l. (same as dam crest elevation). For the alternative of rockfill dam with geomembrane facing, the grout curtain in the base below the dam will be performed from grout gallery placed along the contact of the upstream slope of the dam with the rock. Prospective entrance (and exit) structures of the grout gallery will be on the downstream part of the dam, on the left and on the right part. The elevation of the foundation of the grout gallery at the entrance (exit) must be less than 650.0 m a.s.l.

For the solutions of rockfill dam with clay and asphalt core, the grout curtain in the base below the dam will be performed from grout gallery placed along the longitudinal cross section of the dam, i.e. the cross section of the impermeable profile. Entrance (and exit) structures of the grout gallery will be at the downstream part of the dam, at the left and the right bank of the river valley, at elevation which is under the dam crest elevation of 650.0 m a.s.l. Elevation of the top of the grout gallery at the entrance (exit) structure must be at 648.0 m a.s.l.

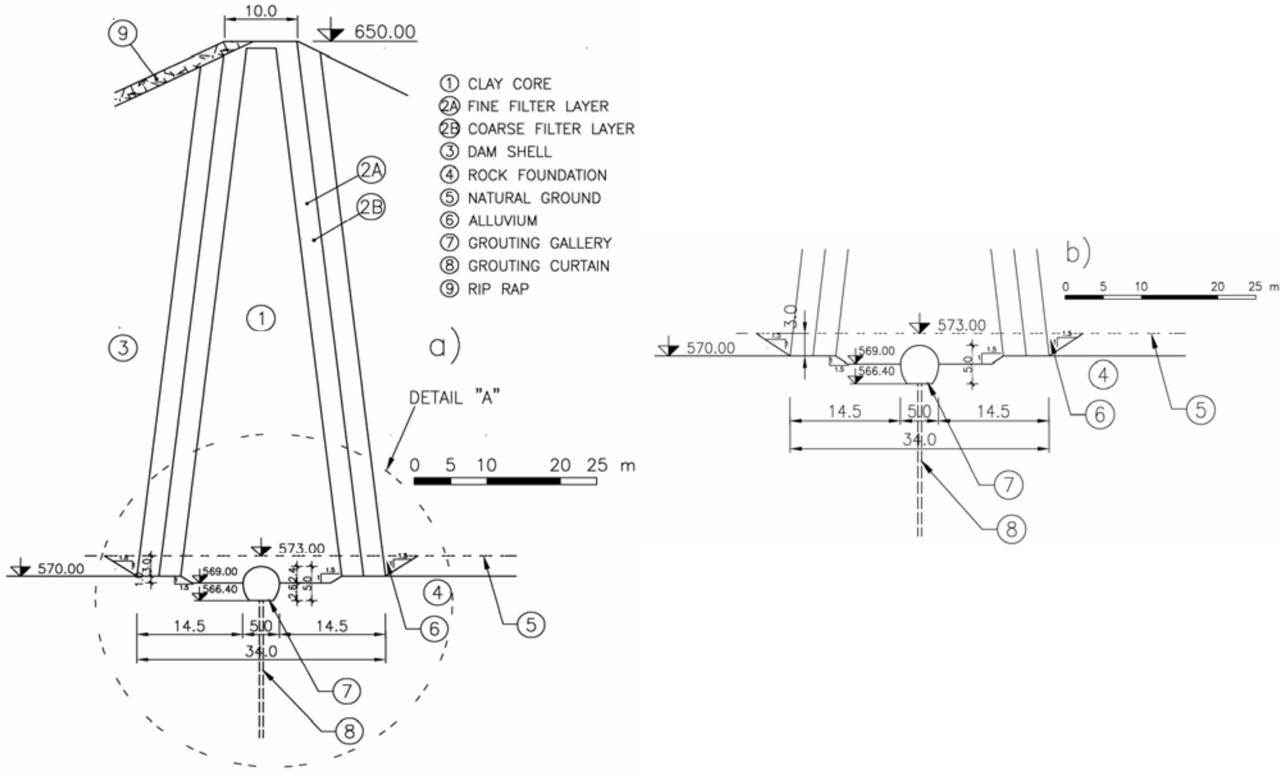


Fig. 9. a) Disposition of the grout gallery in cross section of rockfill dam alternative with clay core. b) Detail of the grout gallery

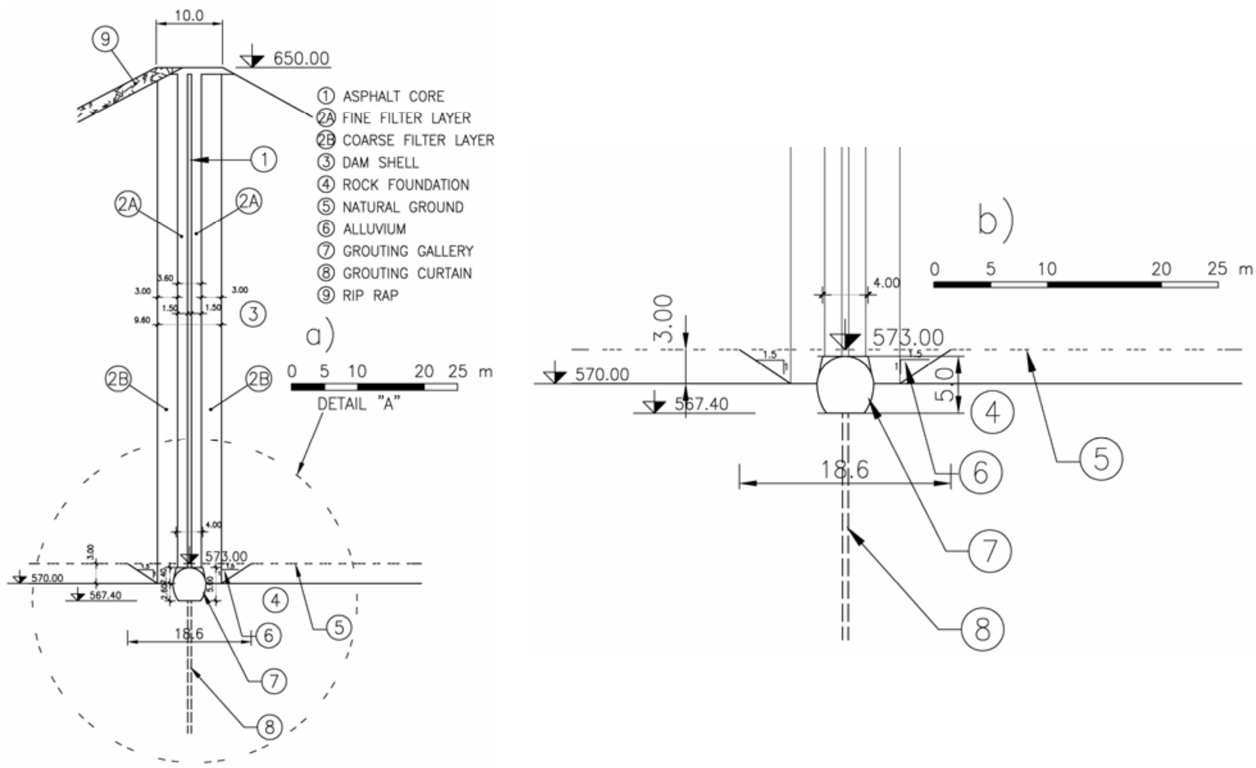


Fig. 10. a) Disposition of the grout gallery in cross section of rock fill dam with asphalt diaphragm. b) Detail of the grout gallery

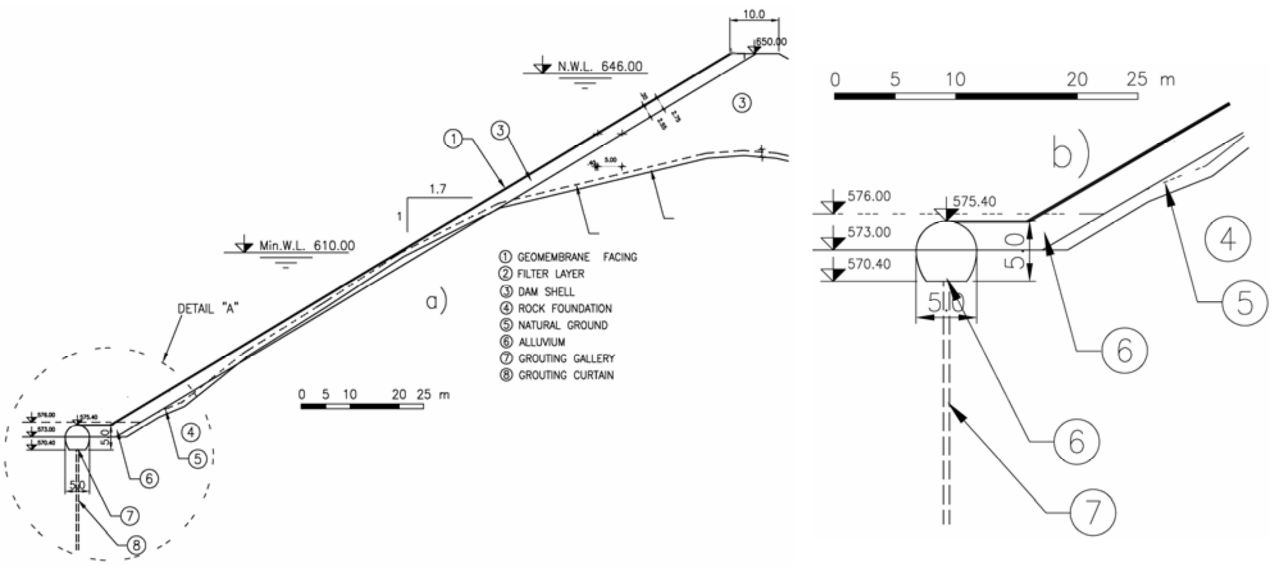


Fig. 11. a) Disposition of the grout gallery in cross section of rockfill dam alternative with geomembrane facing.
b) Detail of the grout gallery

PARAMETERS OF THE GROUT CURTAIN ALTERNATIVES

In the technical solution for the grouting works, following concept is adopted for all of the analyzed cases:

- curtain grouting to depths which present practically impermeable zones of the terrain, separated in zones: left, right and central zone of the curtain,
- contact grouting in the zone of the grout gallery,
- classical cement-bentonite mix (95% cement and 5% bentonite) will be used. This will be mixed with water in ratio 1:0.8 to 1:3 (dry mix:water),
- grouting pressure will be in the range from 5 to 30 bars, depending on the depth,
- drilling, water permeability tests and grouting will be performed in stages of 5 meters; the stages can be shortened to less then 5 m in the zones with higher permeability,
- minimal diameter of the grout holes is 56 mm,
- while in case of the core drilled grout holes is 86 mm. In some alternatives, barren drilling can be performed.

The general grouting concept (with scheme of phase flow) is shown on Fig. 12.

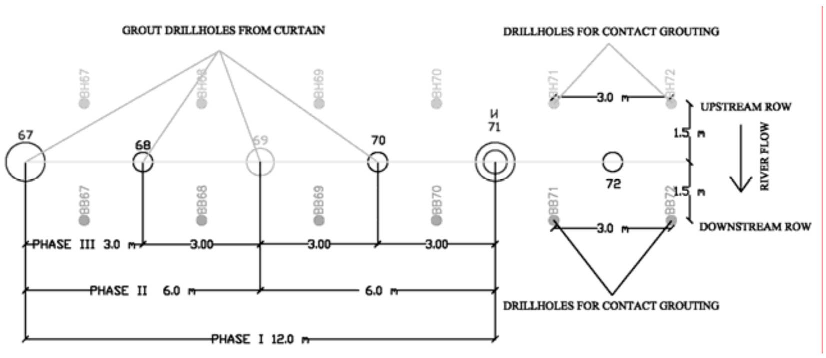


Fig. 12. Scheme of the phase flow of grouting for all analyzed alternatives

Generally, one row grout curtain with grout holes located in the axis of the gallery is designed; mutual spacing between the grout holes is 3.0 m. The depths to which these grout holes are drilled is shown on Fig. 13 through 14. Generally, in the first phase of grouting, grout holes are drilled and grouted at a distance between each other of 12 m; in the second phase the distance between grout holes is shortened to 6 meters and in the third phase the mutual distance of grout holes is 3 m. Part of the grout holes will have investigation and control character in order to confirm the success of the grouting; for this purpose, certain number of additional control holes is also predicted.

For the dam alternatives with central clay or asphalt core, the same solution is presented, having in mind that the water permeable part will be performed from gallery which is connected with the grout curtain. For performing of grouting works on the left and the right grout curtain, two alternatives are analyzed: grouting from grout galleries of different lengths, and with drilling from the surface of the terrain. Possible alternatives are shown on Fig. 13a and and Fig. 13b.

For the alternative of dam with upstream geomembrane facing, grout holes in the zone of the left and right curtain zones will be performed from grout galleries (left and right), with some of the grout holes performed in the form of fan (Fig. 14).

Grouting in form of fan has dual advantage: first – all grout holes are performed from one point, and second – it enables shortening of side gallery.

Contact grouting will be performed from the grout gallery in the central zone of the grout curtain, with shorter inclined grout holes according to the scheme displayed on Fig. 15.

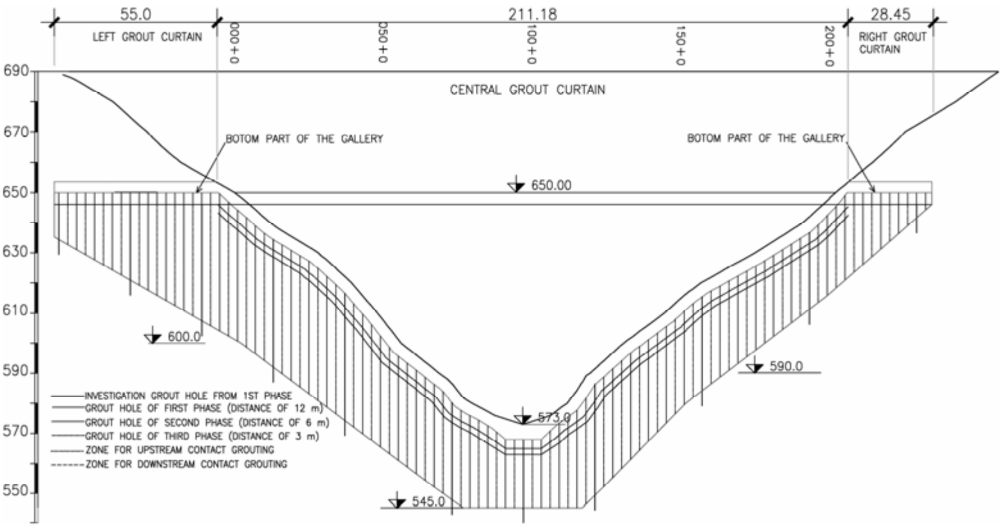


Fig. 13a. Grout curtain for dam alternative with clay core and asphalt core. Scheme of alternative with grouting of left and right zones from side galleries

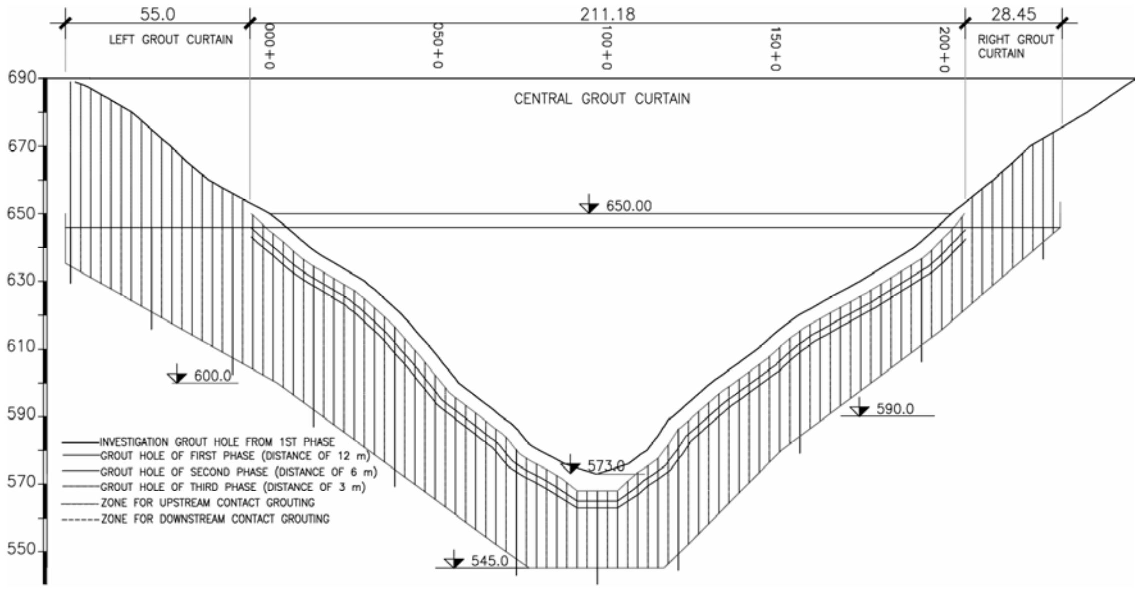


Fig. 13b. Grout curtain for dam alternative with clay core and asphalt core. Scheme of alternative with grouting from terrain surface

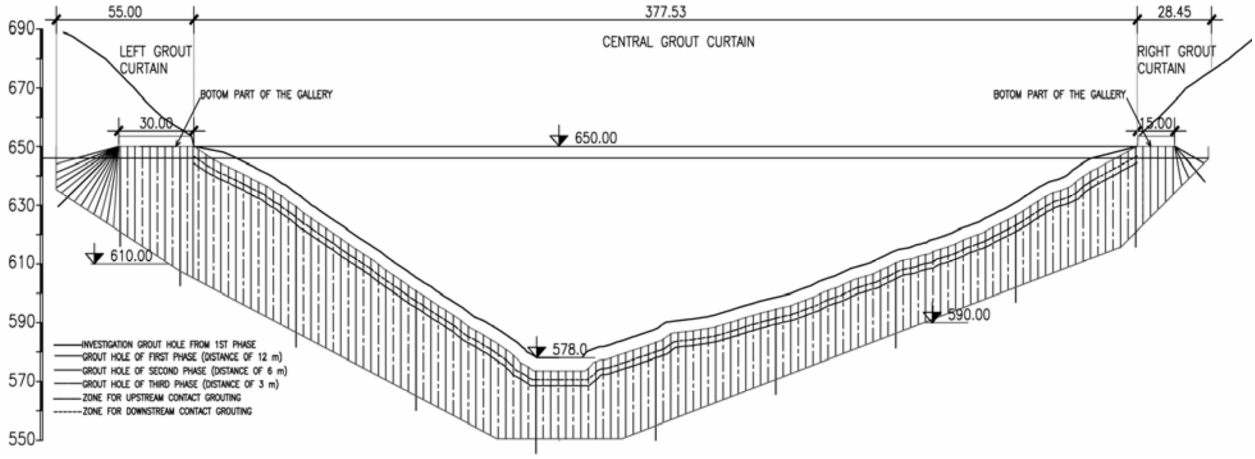
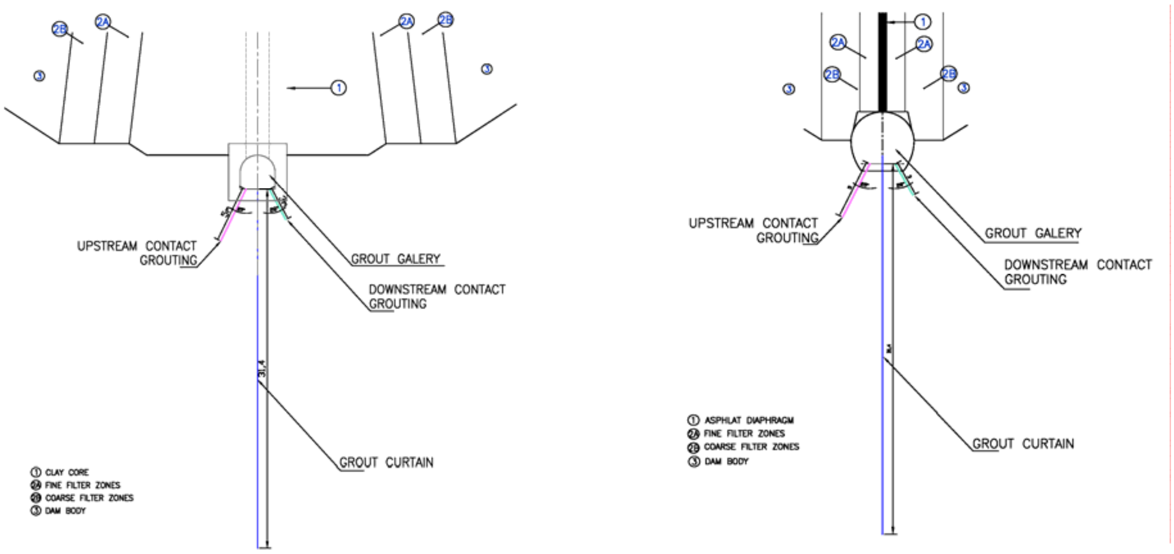


Fig. 14. Scheme of contact grouting for dam alternative with geomembrane facing.
(Some of the grout holes in side galleries are performed in form of fan)



a) b)

Fig. 15. Scheme of contact grouting for dam alternative with clay (a) and asphalt core (b)

COST ANALYSIS OF GROUT CURTAIN AND SELECTION OF OPTIMAL DAM TYPE

The analysis of total cost for construction of the grout gallery and grout curtain showed that dam alternatives with clay and asphalt core have price about 30% lower than the dam alternative with upstream geomembrane facing. This is due to several facts, among which most important is the length of the grout gallery. This clearly gives advantage of the solutions with clay or asphalt core alternative.

The optimal dam type is chosen from the identified three types of embankment dams, according to the standard technical-economic analysis. In this case, it was dam with geomembrane facing. The most economical solution was additionally checked with application of the concept of multi-criteria optimization.

In case of practical problems there is no solution that maximizes all criteria functions in same time, due to which the concept of "non-inferior solution" is introduced. The solution is non-inferior if there is no other better solution in the same time according to all criteria. By determination of all non-inferior solutions, the mathematical problem of determination of the vector maximum is being solved. Afterwards, "preference setup" is introduced in the optimization procedure, by which the wishes of the “decision maker” are closely formalized and then the solution is called superior or “preferred optimal”. From various methods of multi-purpose optimization, the method of compromise programing is applied in this task. In this optimization task following criteria were adopted (measurable and non-measurable):

Investment. This criteria is measurable, reported in millions euro (M€) and has dominant influence on the choice of most dam type.

Influence on the environment. This criterion is non-measurable, but it has priceless influence and this is why it is pondered with highest value. In this particular optimization task with this criteria, solution by which natural earth fond for agricultural development is damaged should be dissimulated. For example, with exploitation of the quarry for clay material with average depth of 3.5 m for the needs of clay core with volume of 85,170 m^3, 24,334 m^2 of agricultural area will be irrecoverably destroyed.

Safety of hydraulic fracture of the water impermeable element. This criteria is non-measurable (reported by degree) with the applied methods. But if we consider the high steepness of river valley banks, there is a possibility of “hanging” phenomena of the soft clay core on the stiff rock foundation. This unfavorable intensive stress transfer for full reservoir state (with maximum hydrostatic pressure) can cause hydraulic fracture in the core, which leads to progressive seepage and instability of the structure.

Stability on earthquake damage of the water impermeable element. This criteria is non-measurable (reported by degree) with the applied pseudo-static analysis. But the fact that smallest form of crack in the water impermeable element of artificial material (asphalt-concrete or geomembrane) in zone deeper than normal water level will have more catastrophic consequences then the appearance of “hydraulic fracture” in the clay core should be taken into consideration.

Performance of construction by domestic civil engineering companies. This criteria was treated as non-measurable (reported by mark) in order to give advantage to solution that can be fully realized by domestic civil engineering companies in this moment.

Time frame of the construction. By this measurable criteria (reported in months) additional calculation are not done and it is determined on base on estimation in accordance with the dam site and the influence of the time conditions on the construction dynamics.

With the economic analysis [2], the cost of hydro-scheme Rečani – dam and appurtenant structures for dam alternative with geomembrane facing was estimated at 24.9 M€, while the dam alternative with asphalt core is more expensive for amount of 2.0 M€. By application of the multi-criteria optimization, the total cost for all elaborated dam types was calculated; the alternative with geomembrane facing gave the lowest construction cost.

CONCLUSION

In the actual case study three dam type alternatives along with the appropriate grouting galleries and curtains were elaborated. The optimal dam type (as well as appropriate grouting gallery and curtain) was chosen by the criteria of “minimal investment cost”, with the standard technical-economic analysis, later additionally checked and confirmed by application of multi-purpose optimization. An integral approach was applied and dam with facing of geomembrane was selected as optimal dam type, although the appropriate grouting gallery and curtain, as longer, were more expensive then the other two alternatives.

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Р е з и м е

ИЗБОР НА ТИПОТ НА ИНЈЕКЦИОНАТА ЗАВЕСА ЗА БРАНАТА „РЕЧАНИ" НА ОРИЗАРСКА РЕКА – КОЧАНИ

Игор Пешевски[1], Стевчо Митовски[1], Јован Бр. Папиќ[1], Милош Марјановиќ[2]

[1]*Универзитет „Св. Кирил и Методиј", Градежен факултет,*
бул. Партизански одреди бр. 24, МК 1000, Скопје, Република Македонија
[2]*Универзитет во Белград, Рударско-геолошки факултет, Ѓушина 5, Белград, Република Србија*
pesevski@gf.ukim.edu.mk

Клучни зборови: инјекциона галерија; инјекциона завеса; насипна брана; оптимален избор

Во рамките на идејното проектирање на насипната брана „Речани" на Оризарска Река во близина на Кочани, разгледувани се три типа насипна брана. Врз основа на резултатите од геолошките, хидрогеолошките, геотехничките истражувања и испитувања, како и препораките од подготвениот геотехнички модел, проектирани се можните варијанти на инјекциона галерија и инјекциона завеса. За секое од предложените решенија се извршени конструктивни и геотехнички анализи. Накрај, пресметани се вкупните трошоци за чинење на изградба на браната и на инјекционите работи за сите понудени решенија.

Со споредба на сите значајни фактори, предложено е оптимално решение за инјекционата завеса. Потоа е извршена и селекција на оптималниот тип на насипна брана и тоа со примена на мултикритериумска оптимизација со примена на методот на компромисно програмирање. Во наредната фаза на проектирање (Основен проект), инјекционите работи се проектирани подетално за одбраното решение, додека инјекционите работи за тунели и други конструкции ќе бидат проектирани во фазата на Изведбен проект.