Southeastern Europe Tunnelling Conference (SETC-2025)
1-3 October 2025, Belgrade, Serbia

https://doi.org/xxxx

Geological-geotechnical problems during the design stage of reservoir side portal of Babakaya water transmission tunnels

R. Emre Cakir[a], S. Mirac Karademir[a], Ilbuke Yalcinkaya[a], Orkun Er[a], Fevzi Tosun[a], I. Gorkem Tunay[a], Candan Gokceoglu[b*]*

[a] Yüksel Proje A.Ş. Birlik Mah. 450 Cad. No: 23 06610 Çankaya, Ankara, Türkiye; e-mail: (rcakir, mkarademir, IUSLU, oer, ftosun, igtunay)@yukselproje.com.tr
[b] Cappadocia University, 50420 Mustafapasa, Urgup, Nevsehir, Türkiye; e-mail: candan.gokceoglu@kapadokya.edu.tr

Abstract: Silvan Dam constructed by State Water Affairs of Türkiye (DSİ), the largest irrigation dam in the Southeastern Anatolia Project after the Atatürk Dam, was planned to have a reservoir volume of 7 billion cubic meters. The dam will provide agricultural water to an area of 235 thousand hectares. The height of the dam was 174.5 m while its crest length was 440 m. The irrigation water will be transmitted with Babakaya tunnels. The portal of the Babakaya tunnels is located on a slope with a height of 300 m, approximately 700 m northwest of the dam body in the reservoir. A water intake structure and two shafts will also be constructed in the portal area. The upper levels of the slope consist of high strength limestones, while the lower levels consist of weak and practically impermeable mudstone-claystone lithologies. Between these two lithologies, there is a transition unit with a thickness of approximately 15 m with weak strength. This lithological sequence has caused a very steep slope angle at the upper levels of the slope and lower slope angle at the lower levels. The project site is located in a region with high seismic activity. From this perspective, three basic engineering problems have emerged. These are; (a) rockfall problems, (b) slope stability and deterioration problems of the transition zone, and (c) stability problems and rapid dropdown problems of slopes that will remain under the dam water. In the present study, these problems are described clearly, and the necessary engineering measures are described and analyzed in detail. Consequently, an extremely complex engineering structure was defined in terms of both engineering geology and construction, and its possible measures are presented through analysis and interpreted with engineering principles.

Keywords: portal; rockfall; slope stability; clay-bearing rock mass; rapid dropdown condition

1. Introduction

According to Aygar and Gokceoglu (2021), portal excavation is one of the most crucial steps in tunnelling because a failure that may occur during portal excavation will completely interrupt the whole tunnel excavation. For this reason, tunnel portal designs were the subject of various scientific studies in addition to their special importance (Alija et al., 2014; Taromi et al., 2018; Khan et al., 2019; Ayounlou et al., 2019; Can et al., 2022). Sometimes, due to compelling reasons, tunnel portals are designed in locations with extreme difficult geological-geotechnical conditions. The purpose of the present study is to present the design of a complex portal of the Babakaya water transmission tunnels. The Babakaya transmission tunnels are the part of the Silvan Dam. The Silvan Dam, one of the largest irrigation investments in Türkiye, which is located in Diyarbakır (Fig. 1), is the second-largest dam after the Atatürk Dam in the Southeastern Anatolia Project, which aims to increase the productivity of agricultural lands in the southeastern region of the country. The project aims to increase agricultural activity in the region by 2 to 3 times (DSI, 2025).

*Corresponding author.
E-mail addresses: candan.gokceoglu@kapadokya.edu.tr (C. Gokceoglu).

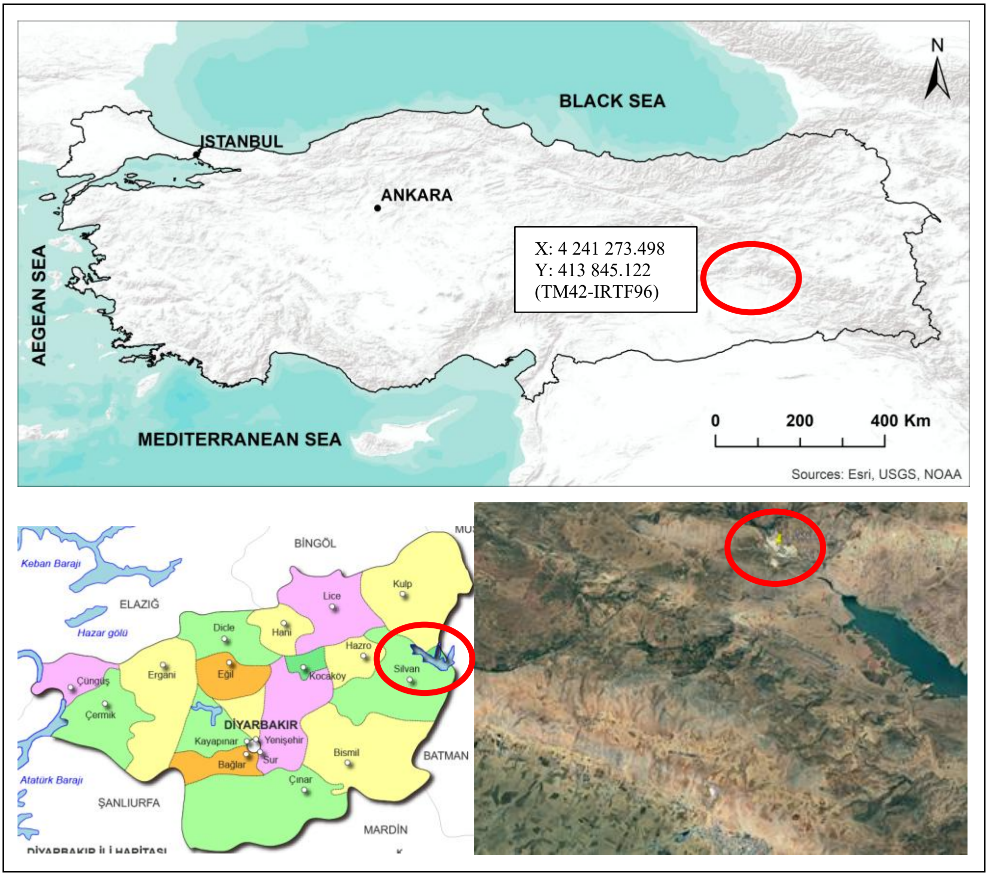


Fig. 1. Location Map of Project Site

When the dam is completed, it will enable the irrigation of a total area of 235,000 hectares in the left-bank plains of the Tigris River. The project aims to provide employment for 308,000 people, and its annual contribution to the national economy is expected to be approximately 1 billion dollars (DSI, 2025). The dam has a reservoir capacity of 7 billion cubic meters, a dam height of 174.5 meters, and a crest length of 440 meters. In addition to the dam structure, the project includes two tunnels and one open canal.

Water will be transported from the right bank of the dam through the 5,280-meter-long Babakaya Tunnels to the open canal and then distributed to the irrigation areas via the 13,500-meter-long Silvan Tunnel. The Babakaya Tunnel is designed as a twin-tube TBM tunnel with an internal diameter of 7.0 meters, while the Silvan Tunnel is a single-tube TBM tunnel with an internal diameter of 10.0 meters. The upstream portal of the Babakaya Tunnel, located 700 meters northwest of the dam body, stands out as a critical area due to its complex structural and geological conditions (Fig. 2). The portal excavation will be carried out on a 300-meter-high slope, where twin-tube irrigation tunnels and one gate shaft per tube are planned. Moreover, for maintenance purposes there is an access tunnel at the shaft elevation. The (Fig. 3).

Fig. 2. General view of the portal area

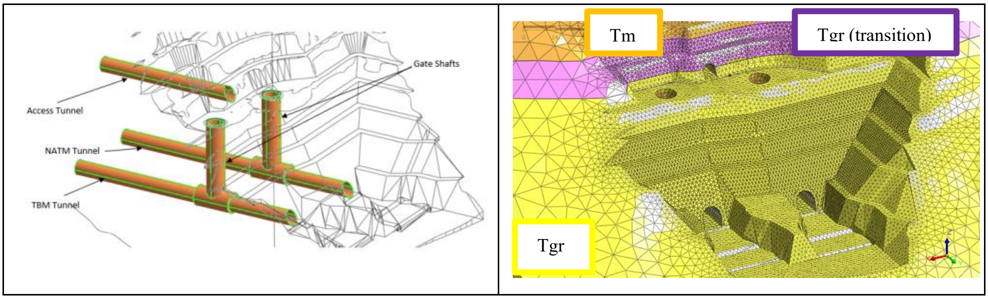


Fig. 3. 3D view of the general structures of the portal area

Consequently, the study presents a complex portal design of a transmission tunnel twin in the difficult geological and geotechnical conditions.

2.Geological and Geotechnical Conditions

The portal considered in the study is located in the reservoir of the Silvan dam and toe of a high slope. General geological setting of the study area is represented by Paleocene Gercüş Formation overlain conformably by middle Eocene Midyat formation. Gercüş formation is mostly composed of reddish colored claystone, sandstone, mudstone and conglomerate alternation. Mudstone is red, brown color, generally composed of sandy mudstone and shows vertical and horizontal transitions with claystone levels. Midyat formation is represented by cream, gray and white colored limestone, clayey and chalky limestone unit. Between Gercüş and Midyat formations, there is a weak transition unit with a thickness of approximately 15 m (Fig. 4).

According to exploratory studies, Gercüş Formation generally comprises reddish brown - red colored, moderately - occasionally slightly weathered, competent mudstone, sandstone, conglomerate, claystone units. Discontinuities are inclined into the slope with ~ 5° - 15° and are clay infilled.

Geomechanical properties revealed after exploration studies regarding Gercüş Formation are summarized below.

Total Core Recovery : 70% $\leq$ TCR $\leq$ 100%
Rock Quality Designation : 40% $\leq$ RQD $\leq$ 84%
Uniaxial Compressive Strength : 9.85 MPa $\leq$ UCS $\leq$ 49.33 MPa
Unit Weight : 2.24 $gr/cm^3 \leq \gamma \leq$ 2.46 gr/cm^3

The transition zone between the two major formations is represented by claystone and clayey limestone levels. These units are generally yellowish brown - beige - yellow colored, highly weathered and weak. RQD values obtained in boreholes are generally below % 25.

The uppermost sequence belongs to Midyat formation which is basically composed of gray - white - beige colored, hard, moderately weathered and resistant limestone, clayey limestone levels, for which geomechanical properties are summarized below.

Total Core Recovery : 67% $\leq$ TCR $\leq$ 100%
Rock Quality Designation : 10% $\leq$ RQD $\leq$ 68%
Uniaxial Compressive Strength : 20.6 MPa $\leq$ UCS $\leq$ 71.5 MPa
Unit Weight : 2.18 $gr/cm^3 \leq \gamma \leq$ 2.47 gr/cm^3

In scope of subsurface investigation, groundwater level is measured 12.00m – 54.00m below the surface. Groundwater circulation is probable through discontinuity systems in the Midyat formation whereas, Gercüş formation is considered practically impermeable proven by lugeon tests having $L_u \leq 2$.

Apart from the geomechanical characteristics of lithologies, seismicity is another major component in the design. The portal area is located 12 km from the Kozluk Segment of the Southeastern Anatolia Thrust Fault Zone, posing additional geotechnical and structural challenges for design and construction. According to site specific seismic risk analysis, 475 year PGA = 0.27g is adopted in relevant engineering assessments. A horizontal seismic acceleration coefficient of k_h=0.162g was used for the pseudo-static analysis of slopes considering the data obtained from the site-specific seismic hazard assessment report.

The Midyat formation comprising limestone is more resistant to weathering compared to underlying the Gercüş formation where mudstone is the dominant lithology. Thus, upper levels are stable in natural slope whereas, lower levels are easily weathered causing instability problems in limestones. Although the Midyat limestone is stable in general, rock fall problem requires to be handled before construction stage. When morphology, lithological aspects of limestone unit, discontinuity character, seismicity etc. are considered, rock fall is an expected risk.

Engineering slopes will mostly be established in lower levels in the Gercüş formation which is mostly prone to degradation against groundwater. Although groundwater can be modelled in slope stability calculations, long-term deformability of clay bearing lithologies needs to be considered in design. Disintegration of the clay bearing lithologies in the Gercüş formation under cyclic wetting and drying process shows that geomechanical strength will diminish when in contact with groundwater, a critical scenario for the engineering slopes under dam water.

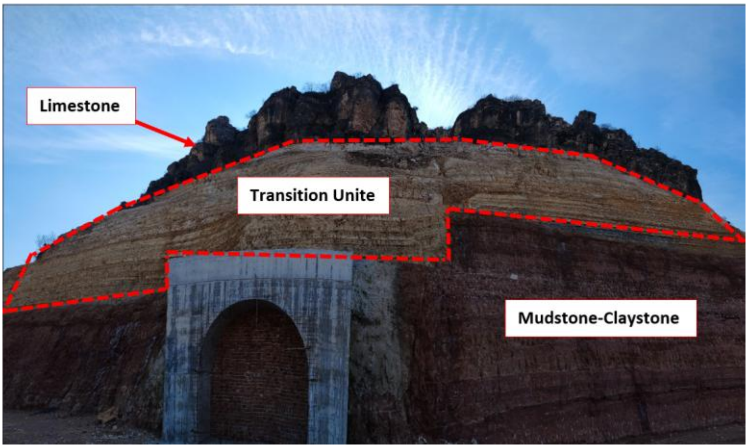


Fig. 4. Close view of the lithologies encountered in the Babakaya tunnel upstream portal area

3.Slope Stability Assessments

Slope stability analyses were performed considering the geomechanical properties of the formations and different scenarios that may occur during the service life of the structure. The design principals considered in the present study are summarized as follows:

The slopes were planned to be formed with a geometry of 1/2 (H/V) in the Gercüs formation. Limit-equilibrium based analyses were performed with the SLIDE2 (ver. 9.036) software and the GLE/Morgenstern–Price method. Circular failure modes were employed considering the highly jointed and weathered condition of the layers. During the analyses, the Hoek-Brown material model was used for rock masses. A disturbed zone of approximately 6.0 m is considered in the analyses taking into account the disturbance due to excavations and wetting/drying process during the design of the slopes. The target safety factors were selected as 1.30, 1.50 and 1.0 for temporary static, permanent static and extreme cases (such as seismic conditions, rapid drawdown etc.), respectively. A support pattern was selected which satisfies all the factor of safety presented above. As a general guideline for the internal stability of the support elements, such as pull out, tensile capacity etc., FHWA Soil Nail Walls Reference Manual (2003) was considered. In addition to geotechnical properties, four different groundwater configuration was considered in the design. These are (a) actual groundwater level; (b) the groundwater level is at the minimum water level of the dam; (c) the groundwater level is at the maximum water level of the dam; and (d) the rapid drawdown case (the water level is at the minimum level of the dam while the slope is under saturated condition due to the very low permeability of the rock mass. Self-drilling rock bolts were planned to use in order to maintain the stability of the drilled hole.

The stability analyses were performed considering all the design principles described above and the support properties are determined according to the most critical case which governs the design. It was found that the most critical case is the case with groundwater level configuration that represents the rapid drawdown and the design earthquake loading is applied simultaneously. In general, it is not a straightforward method to combine two different extreme events (such as rapid drawdown and seismic condition). On the other hand, it was found necessary to combine these effects since, these events may occur at the same time considering the operational scenarios. A sample analysis result is given in Fig. 5 which represents the most critical case which resulted in a factor of safety value just above unity. Material and support properties are given in Table 1 and 2.

According to the analysis results, the following support pattern was designed:

-Self drilling rock bolt type - IBO R38 N
-Length of the rock bolts, L=15.0 m
-Horizontal and vertical spacing, $s_h=s_v$ = 2.0 m
-Wall facing: Shotcrete t=20 cm + double layer of wire mesh (2x Q443/443)

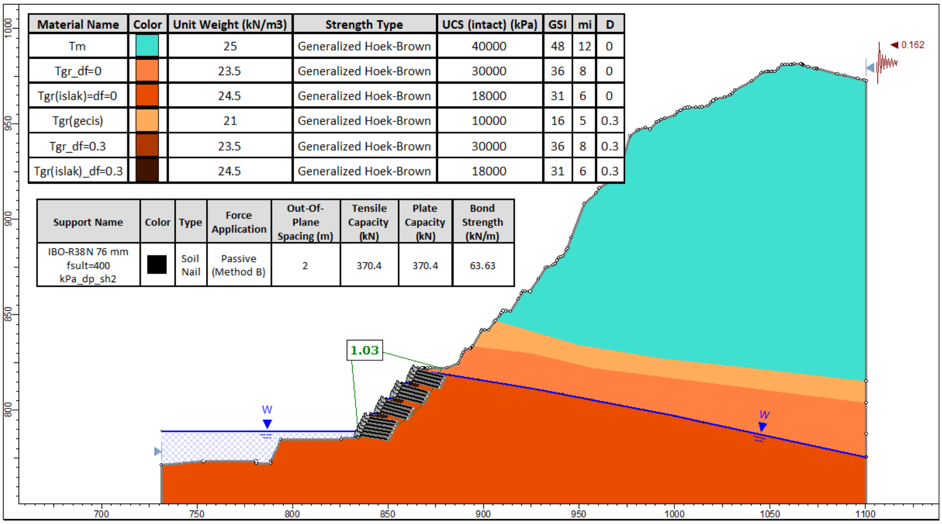


Fig. 5. Limit-equilibrium analysis result for the most critical case

Table 1. Material properties for the analysis

Material	Unit Weight (kN/m^3)	Strength Type	UCS (intact) (kPa)	GSI	mi	D
Tm	25	Generalized Hoek Brown B	40000	48	12	0
Tgr – df=0	23.5	Generalized Hoek Brown	30000	36	8	0
Tgr (wet) -df=0	24.5	Generalized Hoek Brown	18000	31	6	0
Tgr (transition) - df=0	21	Generalized Hoek Brown	10000	16	5	0.3
Tgr – df=0.3	23.5	Generalized Hoek Brown	30000	36	8	0.3
Tgr (wet) – df=0.3	24.5	Generalized Hoek Brown	18000	31	6	0.3

Table 2. Support properties for the analysis

Support	Out of Plane Spacing (m)	Tensile Capacity (kN)	Plate Capacity (kN)	Bond Strength (kN/m)
IBO – R38N - fs_{ult}=400 kPa	2	277.8	277.8	47.73

4. Rockfall Assessments

General geological – geotechnical conditions and accompanying engineering problems are introduced previously. As stated, one of the main problems in the portal area is rockfall on upper levels (Fig. 7). Limestone unit belonging to the Midyat formation is associated with rockfall problem evident by morphology, and weathered discontinuity conditions. Considering the stabilization or removal of blocks that have the potential to fall on the slope surface of the portal, analyses were conducted by modeling potentially falling blocks from the source area behind the slope crest. As a result of rock fall analysis, 2000 kJ barrier with a height of 6.00 m was confirmed to be sufficient to prevent rockfall hazard to jeopardize construction of shafts and relevant structures.

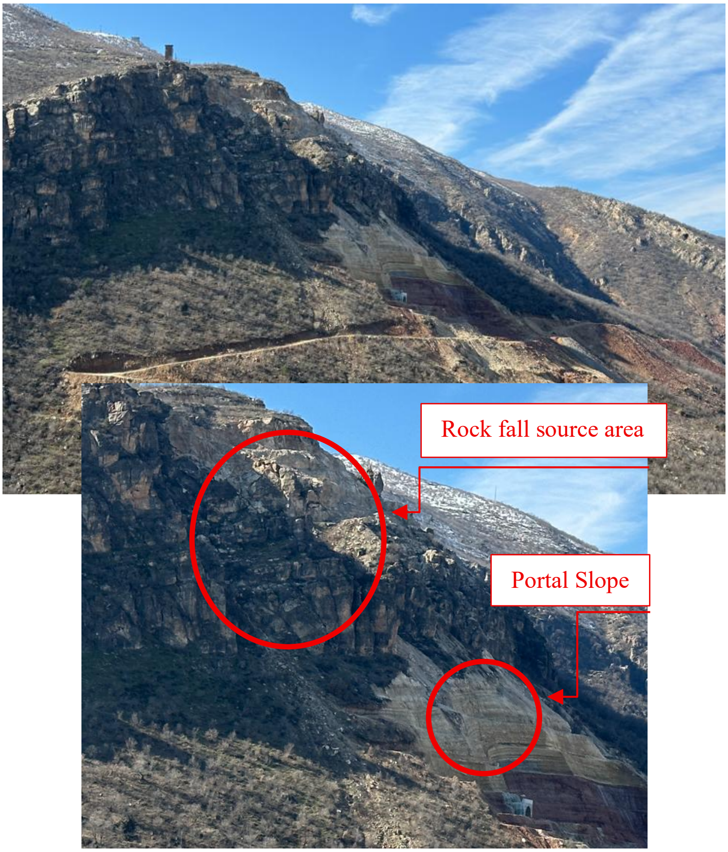


Fig. 7. General view of the portal area under rockfall hazard

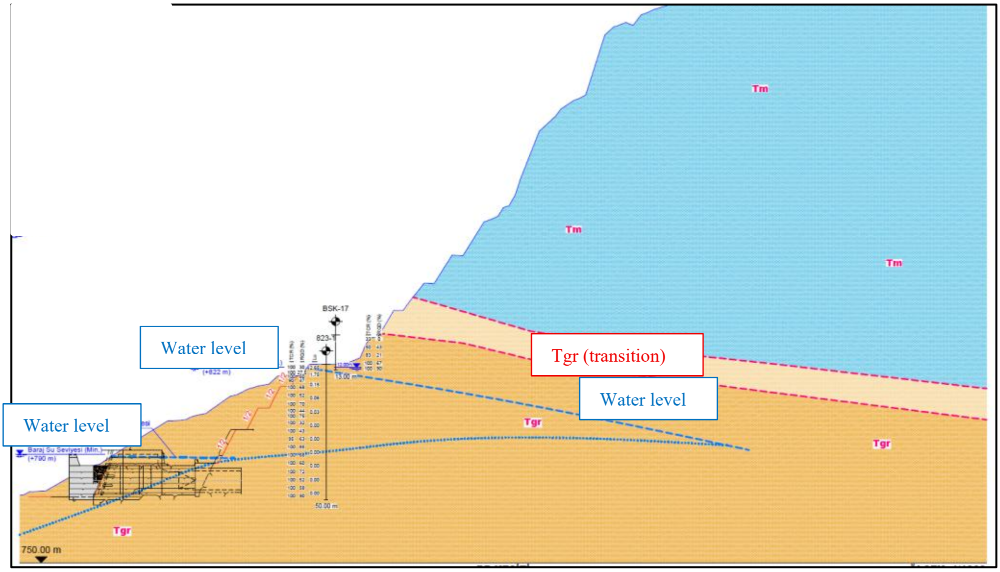


Fig. 8. Tunnel geological cross-section

Initially, 2D rockfall analyses are conducted for the critical cross section adopting various size rock groups having potential rock fall risk (Fig. 9). The maximum total kinetic energy in the shaft location is determined as 1850 kJ (Fig.10a). Bounce height of free blocks in the same area is determined as 18m (Fig. 10b).

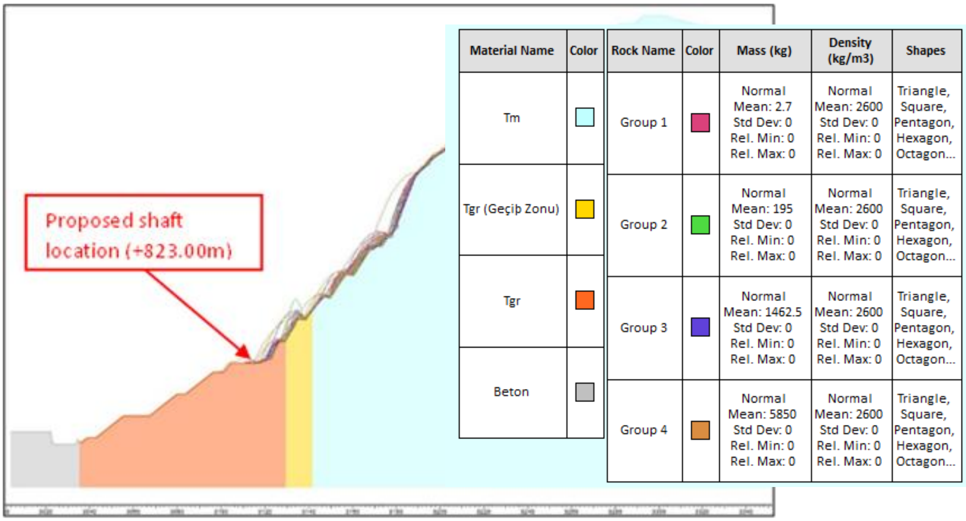
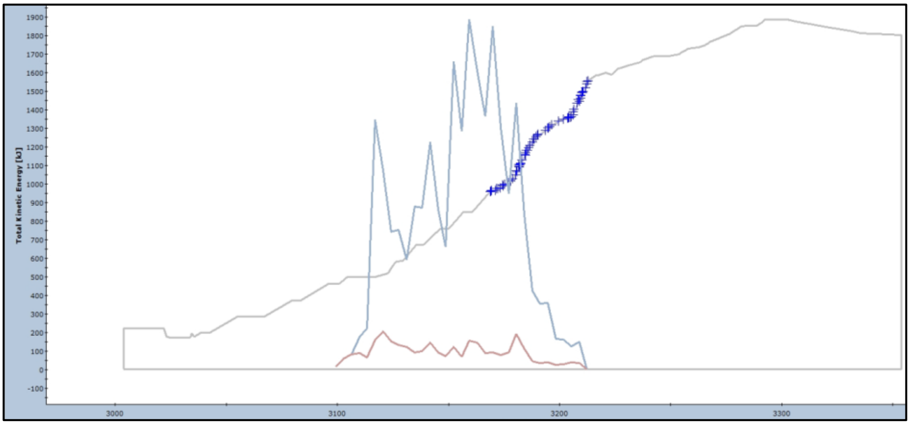
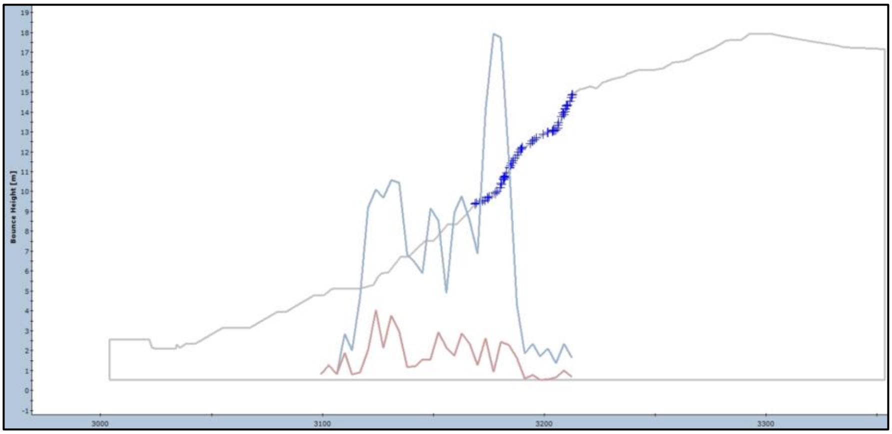


Fig. 9. Result of the rockfall analysis on the most critical section



(a)



(b)

Fig. 10. Graphs showing the results of the rockfall analysis on the most critical section: (a) total kinetic energy and (b) bounce height

Rockfall barriers are proposed to eliminate rockfall problems on the slope which is a practical and economical solution. Based on rockfall analyses, optimum dimension and setting of rockfall barriers are determined (Fig. 11).

As a result of rock fall analysis, 2000 kj barrier with a height of 6.00 m was confirmed to be sufficient to prevent rockfall hazard to jeopardize construction of shafts and relevant structures.

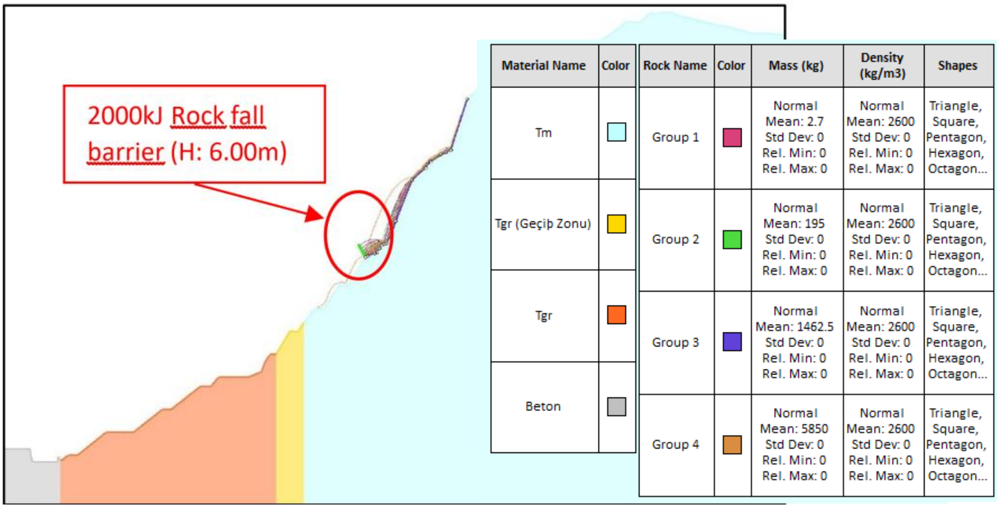


Fig. 11. Result of the rockfall analysis on the critical section with barrier

5. Conclusion

Dams planned in mountainous regions with high seismic activity provide serious benefits, as well as challenging projects for engineers due to the serious geological and geotechnical problems they pose. In this study, it is aimed to discuss the geological-geotechnical problems of the reservoir portals of the Silvan Dam water transmission tunnels in the seismically active Southeastern Anatolian thrust zone and to present the engineering measures against to the possible problems described in the study.

The slopes will be constructed in weak-medium quality, clay-bearing rock masses. This situation may cause additional weakening in the rock mass during the service life of the dam. In addition, rapid dropdown conditions will cause additional water pressures and result in a serious decrease in the factor of safety. The design was performed by taking these issues into consideration. Since the planned slopes will remain under water after the dam is filled, the consequences of any failure will be very difficult to compensate. In addition, another important natural hazard is rockfall. Necessary analyses were applied for rockfall hazard and engineering measures were proposed.

Another important issue is that the portal area contains many engineering structures such as water intake structures, tunnels and shafts. It is very important to perform 3D numerical analyses to understand the interaction of all these structures with each other and with the natural environment. These analyses should be performed and their results should be assessed in future studies.

Acknowledgements

The authors would like to express the gratitude to officers of Irrigation Department Directorate of State Hydraulic Affairs of Türkiye and the site crew of Kalyon Construction J.S.C. for their supports.

References

Alija, S., Torrijo, F.J., Quinta-Ferreira, M., 2014. Study of the unexpected collapse of Ampurdan tunnel (Spain) using finite element model. *Bull Eng Geol Environ*, 73, 451–463. https://doi.org/10.1007/s10064-013-0534-z

Aygar, E.B., Gokceoglu, C., 2021. Effects of Portal Failure on Tunnel Support Systems in a Highway Tunnel. *Geotech Geol Eng,* 39, 5707–5726. https://doi.org/10.1007/s10706-021-01859-z

Ayoublou, F., Taromi, M., Eftekhari, A., 2019. Tunnel portal instability in landslide area and remedial solution: a case study. *Acta Polytech*, 59(5), 435–447.

Can, A., Baskose, Y., Gokceoglu, C., 2022. Stability assessments of a triple-tunnel portal with numerical analysis (south of Turkey). *Geotechnical Research,* 9 (2), 116-128. https://doi.org/10.1680/jgere.21.00028

DSI (State Hydraulic Affairs of Türkiye), 2025. Silvan Barajında Çalışmalar Aralıksız Devam Ediyor. https://www.dsi.gov.tr/Haber/Detay/8912 (accessed on April 5, 2025)

Geotechnical Engineering Circular No.7 Soil Nail Walls, 2003, Federal Highway Administration

Khan, R.M.A., Mad, Z., Jo, B., 2019. Tunnel portal construction using sequential excavation method: a case study. *MATEC Conferences* 138, 04002.

Slide2 User Guide, https://www.rocscience.com/help/slide2/overview (accessed on April 5, 2025)

Taromi, M., Eftekhari, A., Hamidi, J.K., Aalianvari, A., 2017. A discrepancy between observed and predicted NATM tunnel behaviors and updating: a case study of the Sabzkuh tunnel. *Bull Eng Geol Environ*, 76(2),713–729.