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Remediation measures for motorway bridge piers damaged by rock sliding in the Republic of Kosovo

Mesures d'assainissement des piliers de ponts d'autoroute endommagés par le glissement de la roche á République du Kosovo

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ABSTRACT: The rock sliding occurred in the Republic of Kosovo, in February 2017, on the part of motorway under construction. Landslide mass, in the area of 0.9 ha, came down the slope above viaduct piers in construction and pushed on them. The immediate result was the tilting and structural failure of viaduct's pier. Following the event, extensive soil investigation works were carried out and remediation were proposed. Rock slide happened on mountain section, where terrain is composed of tectonically crushed gneiss rock and weakly bound and unbound deluvial sediments and colluvium masses. Accepted solution included removing damaged piers and construction of new ones, with protection, retaining structures, which would resist sliding mass and protect piers from its influence (Szavits-Nossan, 2009). In designing, 2D geotechnical and 3D structural models were used to predict behaviour of arch shaped retaining structures. Designing was supported with monitoring from site and the works successfully continued.

RÉSUMÉ : En février 2017, on avait le glissement de la roche du côté de l'autoroute en construction, á République de Kosovo. Dans la zone de 0,9 ha, la masse du glissement de terrain est descendue sur la pente au-dessus des piles de viaduc en construction, et poussé sur eux. Le résultat immédiat été le basculement et la défaillance structurelle de la pile de viaduc. À la suite de l'événement, on a réalisée de vastes travaux d'étude des sols et on a proposée des mesures d'assainissement. Le glissement de la roche avait eu lieu sur une section de la montagne, où le terrain est composé de roche de gneiss écrasé tectoniquement, et des sédiments et masses de colluvions déluviales et faiblement liées et non liées. La solution acceptée consistait l'enlèvement des piles endommagées, la construction des nouvelles avec une protection des structures de retenue qui résisteraient à la masse glissante et protégeraient les piles de son influence (Szavits-Nossan, 2009). Tandis de développement de la conception, on a utilisé des modèles 2D géotechniques et 3D structurels, pour prédire le comportement des structures de retenue en forme d'arche. Le développement de la conception a été appuyée par une surveillance depuis de la site et les travaux poursuivaient avec le succès.

Keywords: landslide; remediation; retaining structure; viaduct

1 INTRODUCTION

Figure 1. View on the landslide above piers S3 of the viaduct B055 from the opposite hill

Subject of this paper is remediation of a landslide which occurred in the construction phase above piers S3 of the viaduct B055 on section C3, Prishtine - Hani i Elizit motorway in the Republic of Kosovo.

Landslide occurred on 07.02.2017, when the sliding mass moved down on the excavation cut for the foundation, pressed the piers and caused the tilting of pier S3D (see Figure 1 and 2).

At the time, construction of foundations and piers finished, but the spans of the viaduct have not been put in place. Foundation was made of concrete slab, resting on bored piles with a diameter of 1.2 m, in pile length of 12.0 meters. Slope protection for foundation cut higher than 30 m consisted only of wire mesh.

Examination after the accident indicated that concrete pier closer to slope cracked at the level of foundation slab due to pressure of the sliding mass.

After landslide accident, construction of the viaduct was suspended until causes were determined and slope stabilized, so remediation of bridge‘s piers could be constructed.

Figure 2. Landslide mass causing structural failure and tilting of viaduct‘s pier

1.1 Investigation data

Extensive engineering-geological mapping of landslide was conducted (Civil Engineering Institute “Macedonia”, 2017), following geodetic survey of the terrain.

The measured dimension of the landslide area was about 0.9 ha, with dimensions of about 60 m wide and about 150 m long. The overall slope angle was approximately 30º to 32º, with local areas as steep as 40º. The elevation difference between the crest (at the road level) and the toe of the slide was 120 m. The thickness varied, but it appeared to be about 3 – 4 m thick in the upper portion to about 8 – 10 m in the lower part of the landslide.

Based on the engineering-geological mapping and existing borehole and geophysical data, the landslide area is composed of intact rock: gneiss (Gn) and marble (Mb), overlain by weakly bound and un-bound deluvial sediments (d/Q) and colluvium masses (k/Q) (see Figures 3 and 4).

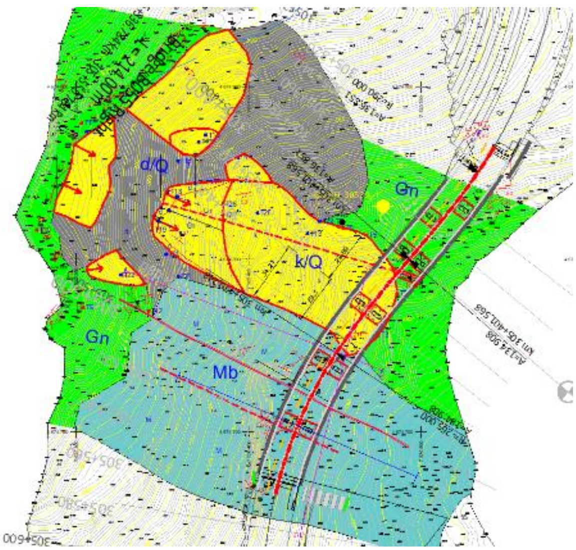

Figure 3. Geological Mapping following Landslide

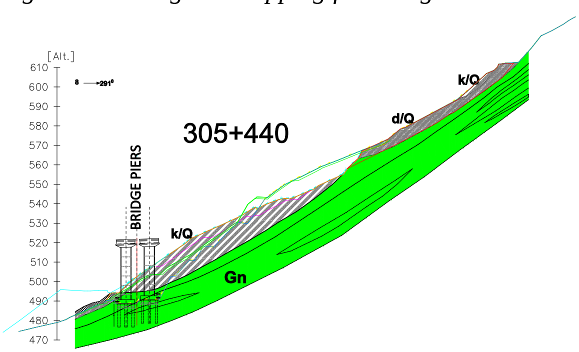

Figure 4. Geological Cross-section of landslide on S3 pier position

Dominant reason for the sliding is the increased saturation of deluvial sediments by intense precipitation and snow melting, as well as the lack of appropriate slope protection during excavation. Other factors that had impact on sliding are the morphology of the terrain (steep slope), the existence of unfavourable discontinuities (cracks), with a drop identical or close to the fall of the slope and the presence of decomposed gneiss to the north of the landslide (Milanovski, M. 2018).

1.2 Remediation variants

After site visit from the designer's team and desk study of the collected data several different approaches for remediation of the landslide and reconstruction of the viaduct‘s columns were considered.

Toe of the landslide rested on the damaged column S3R, which has tilted in the downhill direction, while the column S3L seemed to be unaffected. With respect to that it seems possible to cut the damaged column S3R and construct new one on existing foundation.

Variants have considered different approach to remediation, from permanent stabilization of the sliding mass and construction of the viaduct B055 as designed to leaving sliding mass in the current state and making changes on the design of viaduct B055 (relocating and adding columns etc.).

For all solution types, additional stabilization of the local road in the area above landslide had to be ensured as well as drainage/dewatering along the sliding mass and local road.

2 DESIGN SOLUTION

For construction and legal reasons, wish of the Client was to opt for solutions which would leave sliding mass in current state, with limited involvement and make changes to viaduct's design.

Initially, long span solution (80 m) between adjacent piers S2 and S4 spanning over damaged pier S3 was studied. However, 80 metres span solution resulted in significant increase in loading on existing foundation for piers. Therefore, the selected design solution for remediation included abandoning existing pier pairs S3 and construction of the new piers left and right of the sliding mass spanning the gap above landslide. Existing piers S3 were to be partially removed and shortened in order not to stand in a way of the bridge's top structure.

New piers were to be protected with protection wall / retaining structure (RC wall on piles) constructed at the side and above the piers in a semi-circular configuration. In that way sliding mass is left in the current (stable) state, while allowing any potential future slide to pass between the proposed new piers, without affecting them (see Figure 5)

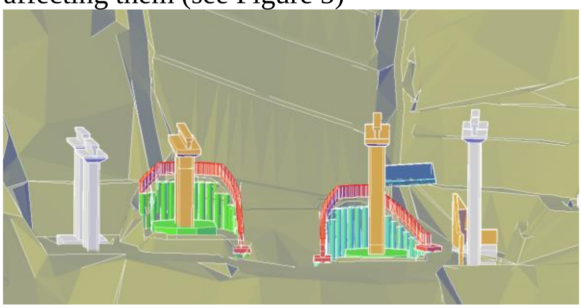

Figure 5. Protection walls R3_1 and R3_2 for new piers (3D View)

The final solution adopted re-profiling of slided debris with several drainage measures within and above the slide, mitigation measures for adjacent pier S2 and mitigation measures on local road above landslide (see Figure 6).

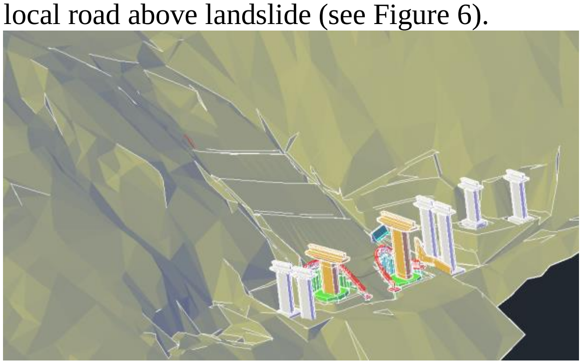

Figure 6. Re-profiling of slided mass (3D View)

Retaining structures R3_1 and R3_2 consist of vertical and inclined bored concrete piles in the diameter d=120 cm, placed in one and two rows on different heights to create retaining structure for excavation for new viaduct piers. Inclined piles (inclination 5° to vertical axis), positioned at the toe of the structure (arch), provide lateral stability. On the left side of retaining structure R3_2, where piles enter marble rock material, transfer of structure loads is ensured by concrete foundation block. Two rows of piles are placed at the crown of the arch in order to resist large bending moments. Face of the pile wall is to be lined with shotcrete in the thickness from 10-15 cm, in order to prevent fall off the material.

Piles are connected together by concrete capping beam. Capping beam follows the contour of the terrain and is providing the load transfer in the arch form towards toe of the arch.

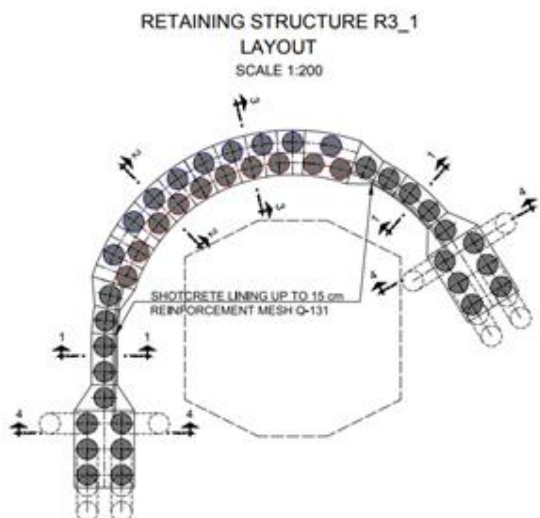

Figure 7. Protection Pile layout for S3_1 retaining structure

From the capping beam concrete wall is erected in a height of 3,5 m and in 1 m thickness. Concrete wall serves to accommodate future sliding mass coming towards the retaining structure.

3 DESIGN CALCULATIONS

Geometry of retaining structures for piers protection is complex. It is placed in an arch form ("horseshoe"), with changing height, respectful of slope geometry. Each retaining structure takes on the loads from surrounding soil and transfers it through the structure in an arch form, so no additional support (anchors, struts etc.) were used.

For design objectives three major types of calculation are conducted in the final design:

1. Stability 2D calculations (SLOPE),
2. Stress-strain 2D calculations (Plaxis),
3. 3D structural calculation (Tower).

Basic principle calculations methods for the retaining construction were iterations of these steps:

- Determine parameters of the soil based on survey data, and limit equilibrium analysis,
- Obtain forces which are acting on the retaining construction,
- Analyse behaviour of the retaining structure and obtain stresses in the retaining structure.

3.1 Limit equlibrium analysis

Stability calculation analysis where carried out in Geostudio/Slope 2D, on current landslide situation to check on global stability and establish strength parameters of sliding mass for further calculations (see Figure 8).

Design parameters for calculation were selected as careful estimate of calculated (survey data), suggested parameters (expert literature) and by several iteration on computer model.

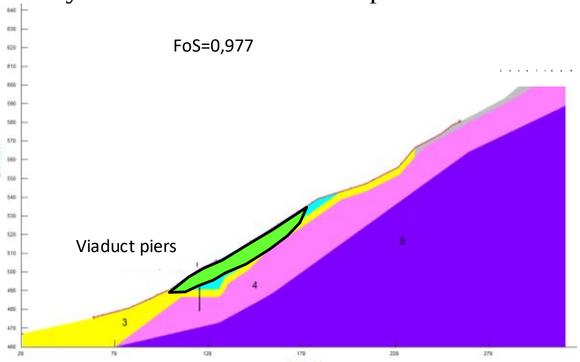

Figure 8. Establishing FoS ~1,0 for state after landslide

Pore pressures which appear as natural seepage process were not detected during investigation works and in the inconsistent rock/soil materials are difficult to determine. In the analysis Ru values were selected as Ru=0,1 ÷ 0,2 for deluvium and highly weathered and disturbed rock mass, and for deeper layers, more compacted and less disturbed rock mass as Ru=0 ÷ 0,1.

For design situation where retaining structure protects piers from sliding mass influence, satisfactory factors of safety were reached, both in static and pseudo-dynamic analyses (seismic).

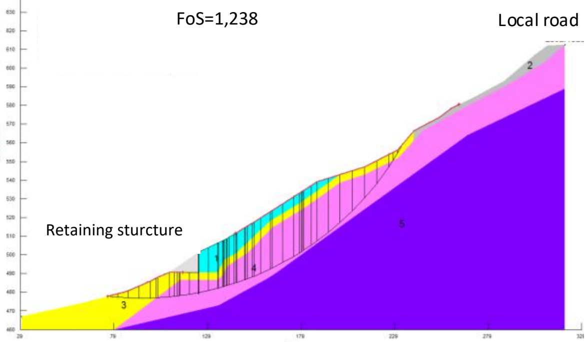

Figure 9. Global stability analyses for designed state

3.2 Stress-strain 2D analysis

The main objective in stress-strain 2D calculation Plaxis models was to obtain forces - total normal stress (earth pressures at failure state on c/fi reduction analyses), which act on retaining structure from the foundation level to the top of the wall. In the c/fi reduction analysis approach the cohesion and the tangent of the friction angle are reduced in a step-by-step procedure until failure occurs (non-convergence of calculation). The reduction of strength parameters is controlled by the total multiplier ΣMsf. The safety factor is then defined as the value of ΣMsf at failure (see Figure 10).

Maximum soil pressures acting on the structure from sliding mass, are present at the point of soil failure. Total normal stress was then input data for static 3D analyses in calculation program Tower 3D Model Builder, where structure's behaviour was analysed (movement, torsion, internal stresses, etc.) (see figure 11).

For calculation purposes, three calculation 2D models were made on each retaining structure, respectful of position in retaining structure (excavation height 14 m, 11 m and 8 m), as an input for 3D analyses.

Several calculation assumptions had to be made in order to reach viable solution:

1. Sliding mass has residual parameters and pore pressures are beneath sliding mass,
2. Modulus of elasticity of the retaining wall are highly overestimated,
3. Dynamics impact on retaining structure is added as horizontal pressure of debris flow (He and Wu, 2009) as:

$$\sigma = \lambda \frac{\gamma_c}{g} V_c^2 \sin \alpha \tag{1}$$

, where σ is the impact force of the debris flow due to the dynamic pressure (kg/m²); γc is the density of the debris flow (kg/m³); λ is the building shape coefficient, usually determined as 1.33 when the building is rectangular; Vc is velocity of debris flow (m/s); α is the angle between the buildings and the stress surface pressure direction, which is usually determined as 90°.

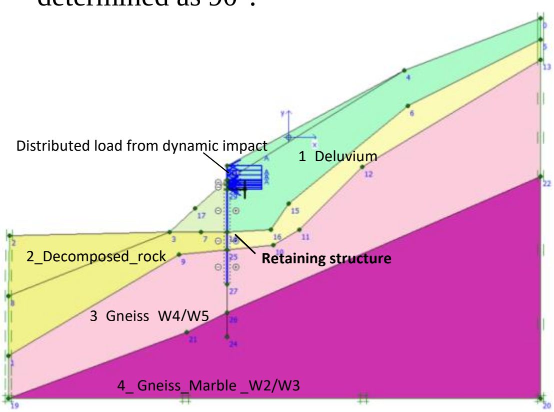

Figure 9. Plaxis model of retaining structure

In critical design situation (phi/c refuction) resulting pressures develop at failure state of soil pressing on the structure. Pressures acting on retaining structure, obtained in phi/c reduction, are bigger than the lateral earth pressure at rest k0 or active earth Rankine pressures kA and are getting closer to passive earth Rankine pressures kp.

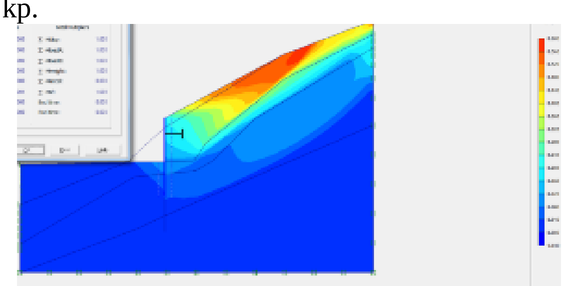

Figure 10. Plaxis model - deformation at critical state

For further structural analysis total normal pressures from design situations have been simplified and adjusted to fit load curve from Plaxis calculation (see figure 11).

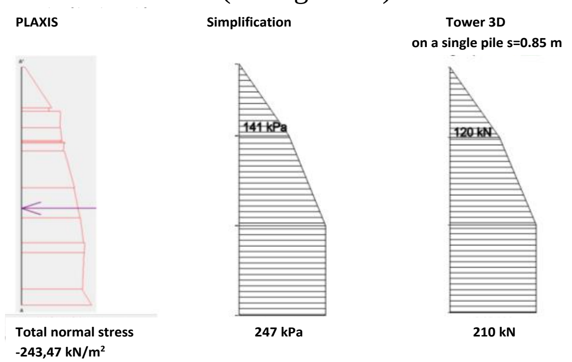

Figure 11. Example of pressure simplification for 3D model input

3.3 Structural 3D calculation

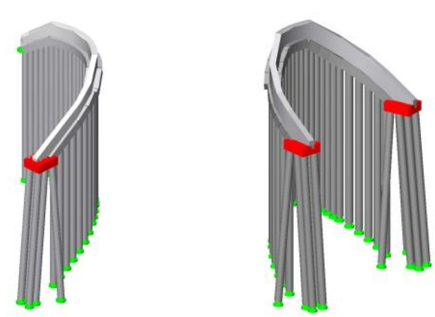

Figure 12. Structural 3D model of retaining structures

Retaining structures R3_1 and R3_2 were modelled in 3D structural program (see figure 12).

Total normal stresses are input data for static analysis. Behaviour of the structure is monitored through various load cases (see Table 1).

Table 1. Load cases list for structural analyses

LC	Name
1	G1 – Self weight (g)
2	G2/1 – Soil pressure on the left part
3	G2/2 – Soil pressure on the right part
4	Comb.: I+II+III
5	Comb.: I+II+0.7xIII
6	Comb.: I+1.35+1.35xIII
7	Comb.: I+1.35xII+III

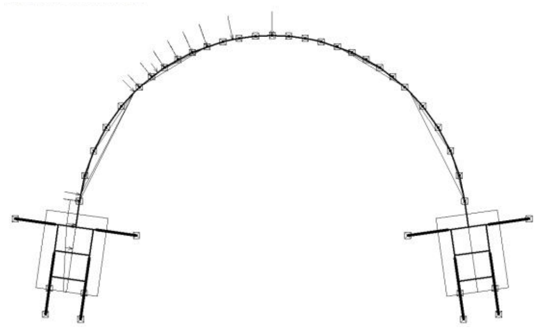

Figure 13. Asymmetrical loading scheme (LC2)

Different loading schemes enabled insight into deformations and internal forces, in cases when sliding mass acts on structure asymmetrically. Also, transfer of loads through arching effect was proven (see Figure 14).

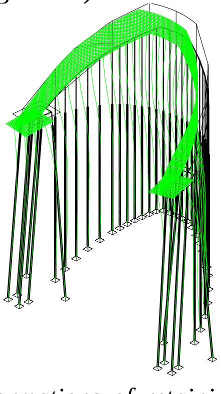

Figure 14. Deformations of retaining structure (3D view)

Finally, elements of retaining structure were dimensioned (reinforced) according to structural calculation, and in provisions with Eurocode 2.

4 REMEDIATION WORKS

Remediation works started in the autumn of 2017, with reshaping of sliding mass and installation of drainage channels (see Figure 15).

Figure 15. Reshaping and drainage works on landslide

After partial removing of damaged piers, piling of retaining structures proceeded. Capping beam on top of piles was constructed, connecting piles within the structure into arch form which can take soil pressures. At that point, excavation for new piers could be done.

Figure 16. Excavation under retaining structure for new pier construction

New piers for viaduct were successfully constructed and span was placed.

Figure 17. Viaduct B055 under reshaped landslide in final construction stage (November 2018)

5 CONCLUSION

Landslide, which happened during construction of viaduct on motorway Prishtina – Hani i Elezit in the Republic of Kosovo, damaged piers and caused suspension of works.

Design solution included construction of new piers, protected with arch-shaped retaining, pile structure, which had to enable excavation for pier construction, as well as to permanently protect viaduct's piers from the influence of landslide. Gap was left in between new piers to provide space for sliding mass movement (old and new).

Retaining structure's complex shape was analysed both in 2D geotechnical and 3D structural software. Soil pressures from sliding mass , that structure needs to withstand are higher than pressures at rest and rise towards Rankine passive earth pressures.

Construction has successfully finished in 2018, while long term monitoring continues.

6 ACKNOWLEDGEMENTS

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