Design solutions for road widening and stabilization in complex geotechnical conditions

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Abstract

This paper presents two solutions for reconstruction, widening and stabilization of the state road R1202, section to Bigorski Monastery of St. Jovan Krstitel, municipality of Mavrovo and Rostushe. The main goal of the widening is to ensure a safe construction because it is located in a cut on a very steep slope, without the possibility of cutting in the terrain, which is talus slope made from deposited material. Therefore, two solutions have been proposed to ensure the stability of the widened road, the first with a shallow foundation retaining wall stabilized by anchors in the base, tension beams in the road body ending in wells. The second solution provide a system consisting of columns founded on piles, tension beams in the body on the road that end with wells and a concrete slab on which the upper structure is constructed. From the conducted analysis of the two solutions, the second solution is more optimal from an economic and construction point of view and is recommended for construction.

Key words

Piles, retaining wall, road widening, slope, stabilization.

1 INTRODUCTION

During the design of new and reconstructing existing roads, the engineers are often faced with problems related to complex geotechnical conditions. Namely, the subject of this paper is the widening of the State Road R1202 section: "Section to Bigorski Monastery of St. Jovan Krstitel", municipality of Mavrovo and Rostushe, which is built in a cut on a very steep slope, without the possibility of cutting in the terrain. The terrain is built from naturally deposited scree material. The main objective of the widening is not only to ensure a safe and stable construction, but also to ensure the stability of the terrain around and along with the construction.

The Bigorski Monastery of St. Jovan Krstitel is located on the western slope of the Bistra mountain, on the left side of the Radika river, close to the regional road R1201 Mavrovo - Debar. Due to the increased number of visitors, vehicles and traffic to the monastery, it is necessary to widen the existing local road, and thus to improve its traffic characteristics (speed, comfort, safety). The local road is mostly loaded with light vehicles and trucks.

The biggest engineering challenge in adopting a solution and its implementation is the configuration of the terrain and the location of the existing route. The terrain through which the route of the local road passes is mountainous with a height difference of 25m. The section starts at an elevation of 736.57 m.a.s.l and ends in front of the parking in front of the monastery at an elevation of 761.57 m.a.s.l.

The reconstruction of the local road includes extension to 6.0m in length of 253.0m. The route is guided according to the existing one. The existing roadway has a width of 3.7m - 4.8m and on both sides in certain places according to the terrain conditions there are shoulders with a variable width of 0.3m - 0.5m and a gutter of 0.5m, as well as retaining walls.

Figure 1. Location and road dimensions Source: www.google.mk/maps

2 GEOLOGICAL – GEOTECHNICAL CHARACTERISTICS OF THE LOCATION

Analyzing the regional circumstances and the knowledge from the performed investigations, a reliable geotechnical assessment of the state of the site can be given.

The base of the site is built from ophiolitic rock mass, specifically serpentinite, to fully serpentinized diabase, with inclusions (enclaves) of marble, limestone, in places quartz masses. The rock mass is very cracked to crushed, in places also worn, twisted and folded into micro folds ("dm") in which the limestone enclaves are embedded. The crack surfaces in the serpentinite mass are smooth "opalized", with traces of striae that clearly indicate movements (tension zone). Their color is greenish to pale greenish, with greyish to dark gray in the marbled limestones.

The described geological and engineering-geological characteristics of these materials indicate a geotechnical environment with relatively unfavorable properties. The physical-mechanical parameters important for the necessary analyzes are: γ=25 kN/m^3, φ=32° and c=80 kPa.

Above this basic rock mass extends a zone of completely physico-chemically decomposed clasts to clayey ophiolites (completely serpentinized diabases), pale-greenish with inclusions (enclaves) of gray to dark-gray marbleized limestones.

There is also dark brown, humus interlayers and lenses with "dm" sizes, which can be interpreted by the proximity of the scree deposit or by processes of movement, washing, etc. in the geological past. The thickness of this zone is about 3.0 – 4.0m' with γ=18kN/m^3, φ=20° and c=35kPa. In fact, this zone represents a zone of decomposition of the basic rock mass, which in the upper parts is mixed with the scree deposit.

The ophiolitic formation is overlain by slope material represented by scree deposit, i.e. unrounded gravel, Ø mostly 5-10 cm, and rare blocks with Ø up to 0.30 m, somewhere up to 1.0 m, from limestones, carbonate schists and ophiolites less often. The thickness of this slope creep material is variable. The physical-mechanical parameters of these zones are: γ=21kN/m^3, φ=35° и c=8-14kPa.

There is also a very porous to cavernous rock, with a pale yellowish color. It occurs in the form of a plate above the limestones with a thickness of several to about 10, maximum 15m. It belongs to quite young-contemporary geological creations, which was created by exposure from cold spring waters enriched with calcium-hydrocarbonate [1].

For the purposes of the analysis, the following parameters of the represented materials given in the following table have been adopted:

Table 1. Adopted geomechanical parameters for analysis

Parameter	γ (kN/m^3)	φ (°)	c (kPa)
Bedrock	21	35	40
Scree deposit (talus)	18	30	0

There are public fountains that represent spring waters. According to the stories, under the monastery complex, at a depth of 1-3m, there is underground water everywhere, which is logical when there are sedimentary formations. The origin of this underground water may be related to the fault zone rich in carbonate component (the sources would be of the exit type), or in the limestone deposits that prevail in the building of the region (the sources would be of gravitational type splenic type) and are distinguished by significant karstification (caverns, canals, caves) in which they may contain accumulated underground water. Over time, scale was deposited in the zone of and around the springs. The ascertained ground water level is in a relatively dry period, so in a wet period it can be higher, that is, the regime is variable and dependent on precipitation.

3 DESIGN SOLUTIONS FOR ROAD WIDENING AND STABILIZATION

The decision to widen the road was made based on analyzes of the existing condition of the road as well as the new traffic requirements. Cutting on the left side is not possible, so it is necessary to extend it towards the slope. Hence, two solutions have been proposed to ensure the stability of the widened road, the first with a supporting structure further stabilized by anchors in the base and tension beams in the road body and the second with a system consisting of pillars founded on piles, tension beams in the road body ending with short piles and a concrete slab on which the upper structure is constructed.

3.1 RETAINING WALL STABILIZED WITH ANCHORS, BEAMS AND PILES

The first alternative for slope stabilization and road widening provides construction of a retaining wall with shallow strip footing, and due to the presence of scree deposit, an additional stabilization measure with self-drilling anchors [2] was adopted, see Figure 2.

The cross-section shape of the retaining wall is non-standard cantilever wall. It is a reinforced concrete cantilever retaining wall, connected via tension beams to short piles on the active side. Cross-sections with different stem heights of 3.0m - 4.0m were analyzed. The stem has a width of 30 cm, the dimensions of the foundation are (100-120)/50 cm. The tension beams have a length of 3.0m and end in a vertical short piles with a diameter of 80cm. The dimensions of the tension beams in cross section are b/h=30/40cm.

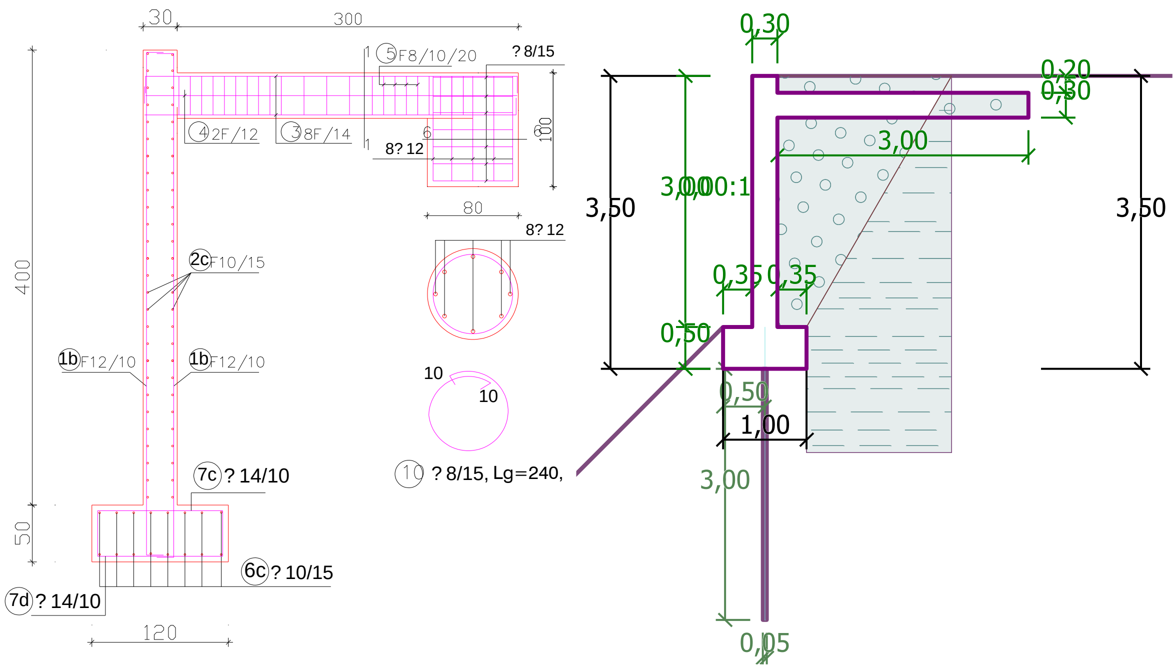

Figure 2. Characteristic cross-section of a technical solution (reinforcement details and numerical model)

The tension beams are placed at a distance of 5.0m in the longitudinal direction, and the connection with the RC wall is formed by hidden columns, i.e. in the stem itself there are also RC pillars at the same center distance. The beams on the other side penetrate piles Ø800 mm In diameter and 1.0m in length.

In order to increase the sliding resistance (stability), anchors are adopted for the foundation of the wall. They are placed in the middle of the foundation (in one row), every 2.5 m in length. Their depth is 3.0 m. They are performed as self-drilling anchors R38 8.2 made of standard steel, nominal diameter of 38.0 mm and thickness of 8.2 mm. The anchors are made in 76 mm holes which is dictated by the diameter of the crown. They are performed by rotary drilling and injection of a cement-based mixture until the borehole is finally filled. During construction, part of the anchor is connected to the reinforcement from the foundation, ie. it penetrates the foundation, which enables joint work of the entire construction.

The space between the beams and the excavated material is filled with crushed material over which the BNS22 d=5.0 cm and AB11 d=5.0 cm asphalt layers come [3].

The stability analysis of the retaining wall in static and seismic conditions is done in the program GEO5, Cantilever Wall module, which determines the geometry of the structure that meets the design requirements. The dimensioning of the elements is carried out according to Eurocode 2.

Table 2. Results of the performed analysis

Verification	Citeria	Safety factor
Sliding	>1.50	1.87
Overturning	>1.50	2.48
Eccentricity	<0.333	0.049
Contact pressure	<300kPa	116.80

3.2 SYSTEM OF RC FOUNDATION PILES, PILARS, SLAB AND PILES

The second alternative for slope stabilization and road widening provides for the construction of a system consisting of reinforced concrete columns founded on RC piles, beams in the longitudinal direction to connect the columns, beams in the transverse direction that end in RC short piles, and on this construction is also performed RC slab (Figure 3).

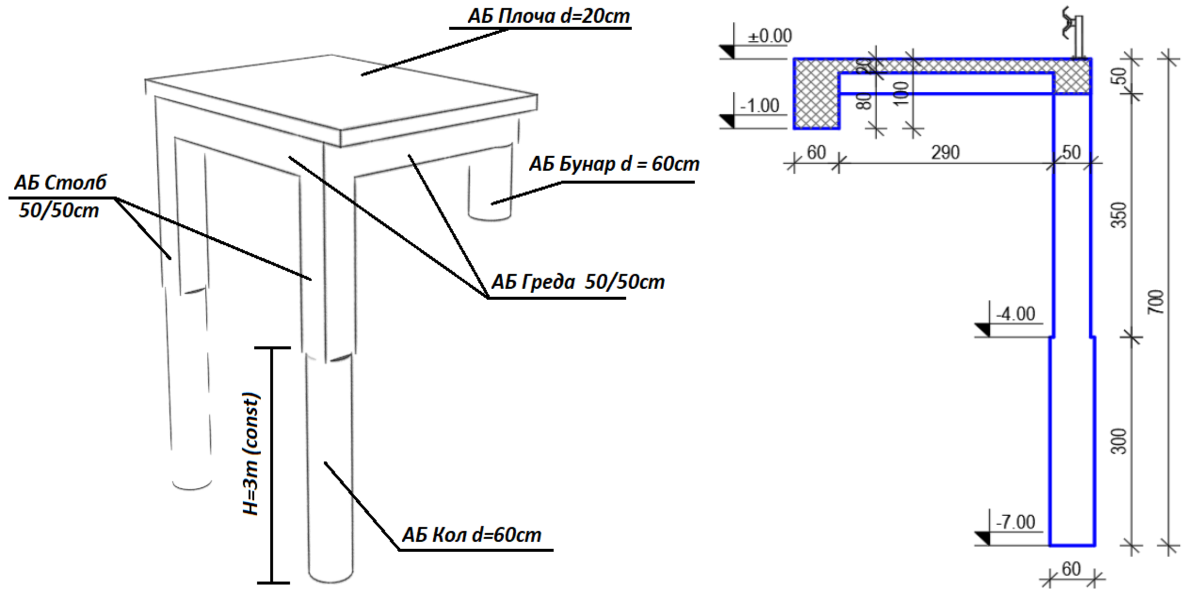

Figure 3. 3D view and cross-section of a technical solution

First of all, piles with a circular shape 60 cm in diameter and 3.0m in length are made. Where the terrain configuration allows, piles are interconnected by a pile connection beam. The pillars have a square shape in cross-section and dimensions 50/50cm. Their length depends on the terrain configuration, but is not less than 3.5m. In the longitudinal direction, they are placed at 3.0m. Reinforced concrete beams with dimensions' b/h=50/50cm are connected to the reinforced concrete column in the transverse and longitudinal direction. The columns are connected to the longitudinal beam, while the transverse RC beam ends with a short pile located in the middle of the existing road. This piles have a diameter of 60 cm and a length of 1.0 m. Above this construction rests an RC slab with a thickness of 20 cm.

Since it is a construction with changes in both directions, the analysis and dimensioning were carried out in the TOWER 6 software for different load combinations, including the reference vehicle load V600 (Figure 4).

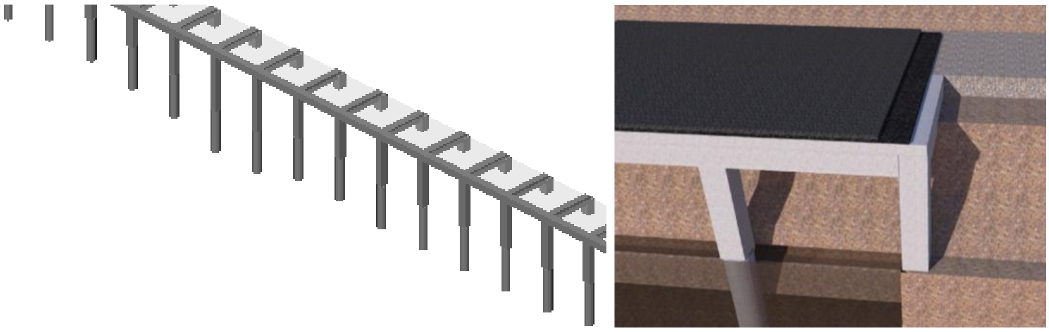

Figure 4. 3D representation of the numerical model

The road construction is composed of asphalt AB 11 with d=4cm and a layer of asphalt BNS 22 with d=7cm placed on separated crushed stone with d=30cm on the part where no slab is provided. The banks are made of crushed stone, and the gutters are made of asphalt AB 11 with d=6cm and concrete curbs 18/24cm placed on a concrete base.

4 SELECTION OF SOLUTION AND CONSTRUCTION

According to the analyzes of the two alternatives, including a technical-economic analysis, recommendations for choosing a more favorable alternative emerge. In the first case, the terrain configuration has a particularly negative impact due to the difficult access and the use of specific equipment. There is also a high risk of the slope sliding if an excavation is carried out for the foundation of the retaining wall. For the second variant solution, local excavation is carried out only for the piles, and plating is carried out only for the pillars. The total amount of excavation is less and the risk of sliding is minimized. From a financial point of view, the estimated design value in both cases is approximate. Hence, the second alternative is recommended for construction. The next few photos show several stages of the construction.

Figure 5. Construction photos

Figure 6. Photos of the final construction (October, 2022)

5 CONCLUSIONS

During the design of new and reconstructing existing roads, the engineers are often faced with problems related to complex geotechnical conditions. This paper presents alternatives for the reconstruction, widening and stabilization of a part of the local road to the monastery of St. Jovan Bigorski, municipality of Mavrovo and Rostushe, which is built in a cut on a very steep slope, without the possibility of cutting in the terrain. It is built from naturally deposited scree material. The main objective of the widening is not only to ensure a safe and stable construction, but also to ensure the stability of the whole terrain.

For this purpose, two alternatives were developed: the first with a supporting structure further stabilized by anchors in the base and tension beams in the road body and the second with a system consisting of pillars founded on piles, tension beams in the road body ending with short piles and a concrete slab on which the upper structure is constructed.

In the first case, the terrain configuration has a particularly negative impact due to the difficult access and the use of specific equipment. There is also a high risk of the slope sliding if an excavation is carried out for the foundation of the retaining wall. For the second variant solution, local excavation is carried out only for the piles, and plating is carried out only for the pillars. The total amount of excavation is less and the risk of sliding is minimized. From a financial point of view, the estimated design value in both cases is approximate.

From the conducted analysis of the two alternatives, it was concluded that the second solution is more optimal from an economic and construction point of view and is recommended for execution.

6 REFERENCES

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