Design and construction of high mechanically stabilized earth wall in specific conditions

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ABSTRACT New elite suburb is in plan to construct in vicinity of Skopje, the capital city of R. Macedonia, on the south facing slopes of the mountain Vodno, just above the city. To obtain direct and fast transportation system from the Skopje center to the new suburb, access road has to be constructed. The route of the access road in its entire length is passing through mountain sloped region, which generates high excavation slopes, embankments, retaining structures etc. Particularly, this paper deals with mechanically stabilized earth (MSE) wall that is located on part of the access road where difficult morphological, geotechnical, geological and seismic conditions were encountered, and where, due to the previously defined route, change in the layout was not feasible. Namely, according to the morphological conditions, the actual terrain had denivelation of about 10 m, while from geological point of view it is a fault zone of two very distinctive rocks, which are highly grusified on the contact zone. Moreover, the Skopje area is known as seismic very active one, due to which many destructive earthquakes happened in the past: the last one in 1963. In order to overcome these problems, a specific project for this section was prepared. In the very beginning of the preparation of the design, several preliminary solutions were prepared concerning typical earthfill embankment, bridge construction, different kinds of retaining structures, deviation of the previously designed road etc. Generally, the designers’ main idea was to prepare cost effective solution by the use of excavated crushed stone material as construction material and to prepare a design that will make minor change of the morphology of the terrain due to the specific site conditions, as well as to take into consideration the fault and seismicity. Considering all these conditions, a MSE wall was decided to be designed with gabion facing and soil reinforcement by the use of steel wire mesh extending out of the gabions. The total height of the wall is 21.0 m, separated in three horizontal sections with berms between in order to incorporate with the road curvature. Reinforcement length depending of the cross section varies 6.0-10.0 m. Verification of the structure was carried out with software model in GEO 5 – MSE Wall developed according to the site survey data and ground profile established upon performed geotechnical field investigation works and laboratory testing. The construction works are in progress and it is expected to be completed very soon.

1 INTRODUCTION

The newly planned elite suburb is located in the vicinity of Skopje, on the south facing slopes of the mountain Vodno. In order to obtain direct and fast link to the capital’s center, a few limiting solutions for construction of access road were possible. From them, the route which satisfied most of the criteria was chosen, consciously knowing that there will be a couple of difficult geotechnical problems, under which it is understood that the access road is passing through mountain sloped region, which generates high excavation slopes, embankments, retaining structures etc. Moreover, one of the geotechnical problems stands apart: very difficult morphological, geotechnical, geological and seismic conditions were encountered on one section of the route.

From morphological point of view the natural terrain has denivelation of about 10 m. The reason is the fault that passes right through the route. From geological point of view, this fault separates the terrain into two distinctive rocks, which is the main reason of formation of such a phenomenon. The rock masses are very grusified on the contact zone due to the movements in the past, so that they have reduced strength and deformation parameters.
Moreover, the Skopje area is known as a seismic very active one, due to which many destructive earthquakes happened in the past: the last one in 1963. The seismic activity combined with the fault zone makes this problem more specific, because even though considered as stable zone, with change of the morphology of the terrain by the construction of the road and seismic activity in the future, slight movements along the fault might be possible and can be expected.

In order to overcome these problems, a specific project for this section was prepared in which the route of the access road and the retaining construction are treated.

2 GROUND PROFILE

Investigations were performed at project site for establishing of the ground geotechnical profile. This specific site is located on the mountain slopes, and most of the site is composed of rock.

2.1 Geological properties

The site of the access road and generally the whole area is composed of metamorphic rocks represented by marble and marbleized limestone, and metamorphic rocks represented by schist.

These two distinctive rocks are separated with the fault where the process of grusification took place. The marbleized limestone has relatively good quality and it is appropriate for construction works even though it is jointed rock. On other hand, the schist are highly weathered and jointed, additionally the foliation is unfavorable. Thereby they are very difficult and complex geotechnical media for construction activities.

On the surface of the terrain diluvium with maximum thickness of 1.50 m is recorded.

Based on the seismic map of the region it may be concluded that this site belongs to the Skopje’s seismic active zone, with seismic intensity of VIII and IX degrees according to MCS.
2.2 Geomechanical properties

Determining the parameters for the rock mass is one of the most challenging tasks in the process of designing. For that purpose in situ geological mapping and rock parameters were used, so the Mohr-Coulomb parameters for the rock mass were obtained by converting them using the software RocLab. Additionally soil parameters of crushed stone material from excavation – which would be used later as fill material – are obtained by laboratory testing.

The properties which are assigned to the soil materials in the calculation model are listed in below.

Table 1. Mohr-Coulomb parameters of rock mass

<table>
<thead>
<tr>
<th></th>
<th>Mm</th>
<th>Sab</th>
<th>Fill material</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma ) (kN/m(^3))</td>
<td>25.00</td>
<td>23.50</td>
<td>20.50</td>
</tr>
<tr>
<td>( \varphi ) ((^\circ))</td>
<td>35.00</td>
<td>30.00</td>
<td>38.00</td>
</tr>
<tr>
<td>( c ) (kN/m(^2))</td>
<td>100.00</td>
<td>75.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

3 TECHNICAL SOLUTION

Preparation of geotechnical designs is very challenging and creative task, where presence of many different materials, construction methods and constructions types make the task even more challenging for obtaining cost effective, on one side, solution and, on other hand, correct and suitable solution from technical point of view.

3.1 Considered variant solutions

In the very beginning of the preparation of the design, several preliminary solutions were considered, concerning techno-economic issues. During the process of brainstorming several constructions and changes of the route were established and later on they were analyzed in detail.

The feasible solutions that were considered were typical earthfill embankment, bridge construction, different kinds of retaining structures, deviation of the previously designed road etc.

Concerning the earthfill embankment, several issues came up. Steep slope of the natural terrain gives no possibility for formation of stable slopes of the embankment, as well as such heavy loading of the natural terrain may cause further instabilities.

Bridge construction may have been the most technically justified solution because of the little disturbance of the natural terrain, overpassing the fault and small additional loading, but it was not cost effective solution.

In order to overcome this problem a deviation of the road was analyzed, but in that case with conservation of the minimal geometrical elements of the road, high excavations were inevitable which may lead to further issues with the upper slope.

Several kinds of retaining structures were considered as concrete cascade retaining walls, high retaining wall with foundation on piles and anchoring system, flexible mechanically stabilized earth walls using different kinds of reinforcements etc., but they were all over passed by mechanically stabilized earth (MSE) wall.

3.2 Adopted solution

As it was mentioned, MSE wall was accepted as final, most suitable solution. Generally, the designers’ main idea was to prepare cost effective solution by the use of excavated crushed stone material as construction material and to prepare a design that will make minor change and disturbance of the morphology of the terrain due to the specific site conditions, as well as to take into consideration the fault and seismicity.

For designing of MSE wall many types of materials and construction types and methods are available. Due to the great height, complex geometry, face protection necessity, rocky environment etc. gabions with ties were chosen. Apart from the above listed advantages of the gabions with ties, the greatest advantage is their flexibility, which is the main reason for their use in this specific project.
It is clear that taking into consideration the seismicity of the region tectonic movements can occur along the fault. Flexible construction can respond to such reasonable deformation and adapt to the new conditions conserving its full retaining capacity, whereas rigid concrete construction will suffer considerable damage.

For this construction Maccaferi Terramesh System was used. This is modular system used for soil reinforcement applications such as mechanically stabilized earth walls and slopes. Terramesh System is fabricated soft tensile, heavily galvanized and PVC coated double twisted steel wire mesh. The lid, facing, base and tail are made from continuous mesh panel. The gabion unit is formed by connecting the back panel and diaphragms to the main unit’s lid, facing and base. This crates rectangular shaped cells used for stone confinement.

Since this units are prefabricated, the dimensions of the units used in this project are as follows, height 0,50 m, width 2,0 m and total length of 7,0 m and 11,0 m. Mesh tensile strength is 50,0 kN/m.

The MSE wall has total length of 60,0 m. Typical cross sections of the MSE wall with some basic geometrical characteristics are given in Figure 6 and Figure 7. The face of the embankment is formed by gabions, which form blocks 7,0 m in height and have 2,7:1 (~70°) face inclination. To achieve that inclination 0,20 m horizontal offset between each unit is performed.

At the highest cross section, the MSE wall has total height of 21,00 m, which is achieved by three individual 7,00 high blocks. These blocks are divided from each other by berms to reduce global inclination of the structure and to correct geometry during construction.
In layout, due to the curvature of the road in that section, the first block is foreseen to be constructed in straight line, while second and third have arc shape with different radii. From there the berms between the block are with different lengths varying from 1,80 m to 5,00 m, as well as the global inclination is varying from 1,15:1 (~49°) to 1,4:1 (~54,5°).

Each gabion row has an appropriate anchoring, which at the same time acts as soil reinforcement, so no additional geosynthetic reinforcement was used. The length of the anchoring is 6,0 and 10,0 m, dictated by the morphology of the terrain as well as the calculation analyses.

The base of the first block is adapting to the terrain itself and it is deeply embedded in to the terrain seeking firm bearing base for foundation. At the end of the construction process the first block is completely covered with soil in order to form the natural inclination of the terrain.

The top of each block as well as the top of the final third block is inclined to follow the difference in height between the beginning and the end of the route section. That is accomplished by varying the height of the embankment above the gabions and by adding rows of units along the structure.

To prove the stability of the construction and to adopt the most appropriate solution detailed stability analyses were conducted. In order to analyze the construction analytical approach was used by developing a model using FINE GEO 5 – MSE Wall software.

4.1 Load cases
All conducted analyses of the MSE wall were carried out considering the following load cases:
• Load case 1 – Dead load and earth pressures
• Load case 2 – Dead load, earth pressures and traffic loading
• Load case 3 – Dead load, earth pressures, traffic loading and seismic loading

4.2 Stability checks and minimum safety factors
In load case 1 the dead load of the construction itself is taken into account as well as the earth pressure of the backfill. The minimum factors of safety for global, local and internal stabilities are 1,50, while the obtained minimum one was 1,50.

In load case 2 additionally traffic loading is taken into account over whole paved area with a magnitude of 33,33 kPa. Due to the transient nature of this combination of loads, the minimum factors of safety of 1,30 are adopted. The calculated minimum one for this loading case was 1,46.

Finally in load case 3 a combination of loads same as load case 2 with additional seismic loading is taken into account. Seismic impact on the structure is implemented as pseudo-static loading. In accordance with the peak ground acceleration in the region, seismic coefficient of horizontal acceleration \( kh=0,15g \) and seismic coefficient of vertical acceleration \( kv=0,075g \) are adopted. Due to the accidental nature of this combination of loads, the minimum factors of safety of 1,10 are adopted, while the most critical obtained had value of 1,38.
From the above listed load cases it is obvious that the governing one for dimensioning of the construction is load case 3 because of the construction geometry and high seismicity of the region. Whereas load case 1 and load case 2 are not excluded from the analyses because of their higher factors of safety and loading specificity.

It is stated that for all of the cross sections stability checks are carried out as follows:

- Check for overturning stability
- Check for slip
- Bearing capacity of foundation base
- Eccentricity verification
- Verification of slip on georeinforcement
- Global stability

As mentioned above, from the performed analyses it can be concluded that the stability of the structure is ensured in different and demanding loading cases.

5  CONCLUSION

Designing process for MSE wall was a unique experience, having in mind the complexity of the morphology, geotechnical and geological condition as well as seismicity of the region. From technical point of view developing a correct and suitable retaining construction and bringing all concerns for the stability and serviceability at minimum was a challenging and time consuming job.

Even though the analyses has shown satisfactory outcome, the observation process shouldn’t stop when construction process ends. Further auscultation of the construction in its lifetime is necessary to be conducted in order to prevent any adverse effects.

Additionally further research should be carried out by developing and analyzing of numerical stress strain model. In order to analyze the affect of the fault and seismicity of the region and if plain strain model is used two separate models shall be developed from both sides of the fault and the results shall be compared. For more plausible seismic response a time history analysis shall be conducted.

At the moment, the construction works at the location are in progress and it is expected to be completed very soon.

REFERENCES

Geing Krebs & Kiefer. 2014. Project on access road to Sunny City, Geing Krebs & Kiefer, Skopje.