DESIGN AND PRACTICE OF REINFORCED EARTH WALLS ALONG THE HIGHWAY IN THE CROATIAN KARST REGION

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Abstract

This paper presents a brief summary of the earth reinforcement technology, its applicability for various types of transportation projects and foundation soil conditions. Stressed is that use of this technology in addressing soil stabilization needs of transportation project can result in effective design solutions and achieve cost savings on large scale projects.
The paper reports case study that illustrates the concept of design and construction issues related to this type of construction. Presented are design and practice of reinforced earth walls in karst region along the highway Split – Ploče. In the paper it is discussed that reinforced earth structures also serve for protection of environment, because they may play roll as storage for a great amount of crushed stone that is produced by cutting way through rocks. On the other hand, crushed stone is very suitable for this type of structures because of its high frictional resistance characteristics. In the paper, shortly is presented a stability calculation for the reinforced earth wall Strikići, the highest from until now built reinforced earth wall along the Split – Ploče highway. Special consideration is given to performance of reinforced earth walls during earthquakes.
Finally, authors conclude that reinforced earth technology is a relatively straightforward and cost-effective construction process. Coupled with historically good performance under both static and seismic conditions makes earth reinforcement a valuable method in soil stabilization.

1 Introduction

In recent years, with increasing car and train speeds, railway and highway routes get more and more a form of a straight line. Consequently, more than previously there are more bridges, tunnels, and above all, retaining structures along the routes. Therefore, costs of these structures plays important role in the price of a whole project. Still nowdays, retaining structures are mostly made of reinforced concrete, like gravity or cantilever walls. These types of structures are essentially rigid and are not capable to accommodate significant absolute or differential settlements, when founded on a soft or similar soil. Their behavior is more than questionable when exposed to dynamic forces in regions with high earthquake activities. Additionally, the cost of concrete retaining walls increases rapidly with increasing height of soil to be retained and poor subsoil conditions.
Unlike concrete walls, mechanically stabilized earth walls (MSEWS) are cost effective soil-retaining structures, mainly for using local soil as construction material. The only restriction for selection is that the soil does not contain too much clay and that it has a sufficiently high internal friction angle.
Considering reinforcements, satisfying are all kinds of inexpensive materials with a little deformability, with long durability of the material itself and good frictional characteristics at contact with soil materials. At the beginnings of soil reinforcements preferably ribbed metal

strips were used. The choice of material for strips depends mainly on its behavior under environmental conditions, assuming that durability of strip in soil is quite different from its behavior in open air.
Facings are made mostly of reinforced concrete plates but also in some type of compact or hollow blocks. They are prefabricated elements, which means produced under controlled conditions, rather than other kinds of retaining walls which are mostly cast in place and because of that with questionable concrete characteristics. As facing panels are the only visible part of MSEW, their shape and surface may be formed in various ways to accommodate to environmental shapes and colors.

2 MSEWs in karst region of Croatia

In the last five years more than ten MSEWs are built in southern Croatia along the highway Split-Ploče, where now under way are numerous earthworks and construction activities for highways which will connect northern and southern parts of the country (along the coast). Great deal of construction activities refers to building of retaining structures. These structures should satisfy several criteria: firstly, they should satisfy the criteria for serviceability and stability, and secondly, they have to comply with karst environment, functionally and visually. Among several types of retaining structures (massive or reinforced concrete retaining walls, gabions, etc.), authors recommend MSEW as the most suitable type. Considering MSEW in karst, one has to recall to traditional means of building the retaining structures in the area which are dry-stone-walls. More easily than other technologies of retaining structures, MSEW may be constructed in the shape of cascades and recall to dry-stone-walls accordingly. MSEW-panels on the facing resemble to rocks, which is quite opposite from facings of other type of concrete retaining walls, for example gabions which, when built in rocky environment, recall to unstable slopes, like breccias.

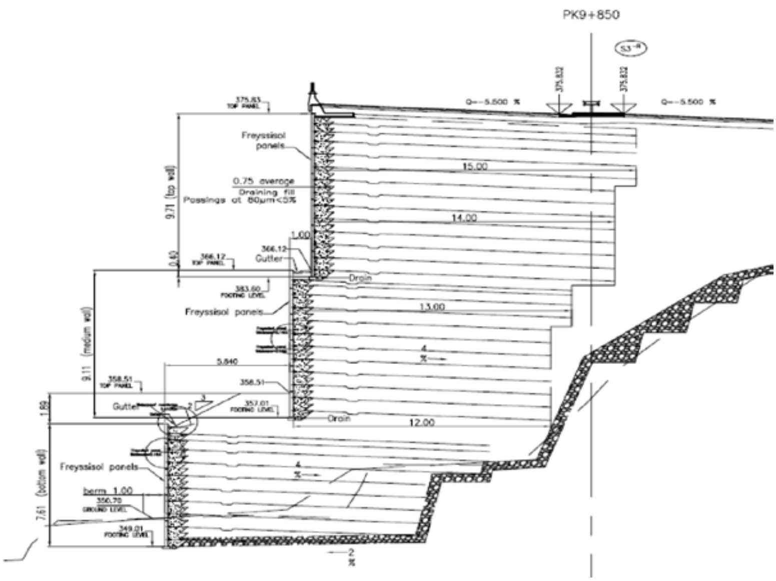

Figure 1 Cascades of RE Strikići.

Another advantage of using MSEW in karst is that it may serve as storage for the surplus crushed stone from tunnels or high cuttings in rock. Alternatively, if there were no MESWs or embankments, crushed stone should be deposited somewhere. For this purpose, adequate

land area should be occupied which causes additional expenses and waste of time, set aside the expenses of depositing itself. On the other hand, crushed stone is excellent construction material for MSEW. Depositing of crushed stone in embankments is not always possible especially in the case of steep slopes.
Another important issue is a height of MSEW which, in the case of (in karst common) a rock-type ground and slopes, may be appreciably higher than for a soil-type ground, which is mainly between 5m and 15m. In the case of favorably oriented discontinuities, contact pressures at foundation level may be much higher than in ground (soil) therefore, the height of walls may be much higher than for MSEW founded on soil.

3 MSEW Strikići

Among until now built MSEWs along the highway Split – Ploče, most outstanding is MSEW Strikići, Fig. 1. (named according to the neighboring village). It is among the greatest MSEWs in the world and, because of that, will be described here. Strikići is a vertical multitiered MSEW, 27m in height and 600m in length. Its facing is made of prefabricated concrete panels, stabilized by paraweb strips stretched behind them in zigzag pattern and fixed to steel bars in the fill. The paraweb reinforcement is made up of polyester fibers coated with high density polyethylene and shaped like a belt. The use of this reinforcement provides a structure of high-grade and safety.

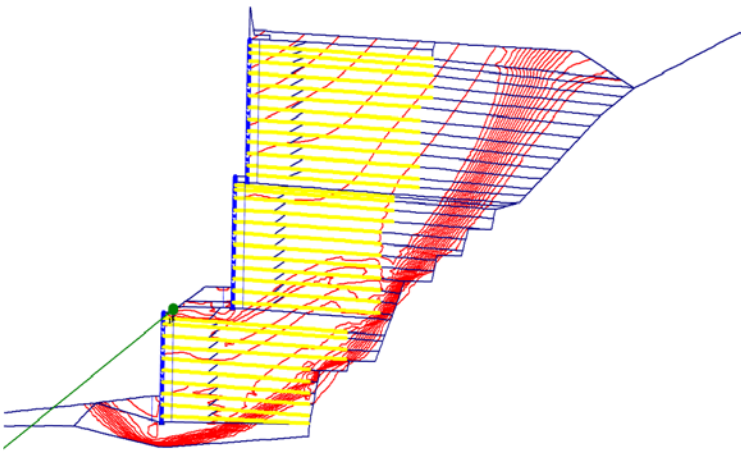

Figure 2 Stability analysis with PLAXIS for RE Strikići.

The foundation ground at the location of Strikići, [5] and [6], is constituted of well stratified rudist upper cretaceous limestones which are the only lithologic element. Rock mass has been characterized by a system of joints with relatively large gaps, from 1 to 5mm, rarely larger than 10mm. Gaps are partially filled with clay and debris. In the fault layers, rock varies from extremely crushed to completely monolithic. Parallelepiped and thetraedron blocks, mainly meter-sized, are bounded by systems of joints.
The authors think that the proposed type of retaining structure, MSEW, is particularly suitable for the type of rock at location Strikići since, for the purpose of foundation, the surface soil and rock material had to be excavated in horizontal direction to the depth approx. 12,0m, what included complete section of poor surface material. The slope inclination varies between 20 and 30°, while the slope of joints varies around 33° in the rock mass in the same direction.

4 Stability of MSEW Strikići against static and dynamic forces

Considering that the discontinuities are inclined downhill (unfavorably) in stability analysis, rock mass was treated as discontinuum and quasicontinuum. It was expected that in the phase of cutting the slope, failure plain would be formed along discontinuities but, after the construction of MSEW, failure might occur along the geometrically complex slip surface. The first type of analysis was carried out by plain surface method [3] and the second type with circular surface method (limit state analysis) by Spencer and Morgenstern-Price. Shear strength parameters for discontinuities were calculated according to Barton [1], c = 10 kN/m², and φ = 47°. With given rock characteristics, shear strength parameters for the rock mass were determined according to [4]. Taking into account relatively small amount of investigations, minimum values were chosen (for every rock layer). For plane surface analysis, calculated overall factors of safety (OFS) varied between 1,09 and 1,19, but, for circular slip surfaces, OFS varied between 2,83 and 4,43 [6], which showed that planar failures, before reinforced earth wall installation, could be critical. As a remediation measure, it was decided to fix the slope with anchor bolts (25mm diameter and 6m length) in two rows, at 2m distance. Assuming that the pullout force of a single anchor was 100 kN, OFS increased over 1,3, what was considered satisfactory for a temporary construction (slope before MSEW installation). The stability analysis was carried out with the engineering software SLOPE/W (Calgary, Canada) supposing a surface temporary load of 33,0 kN/m². Analyses for circular and polygonaly shaped slip surface resulted with factors of safety for dry slope of OFS=1,52 and for the slope with groundwater with OFS=1,48, that was considered satisfactory.

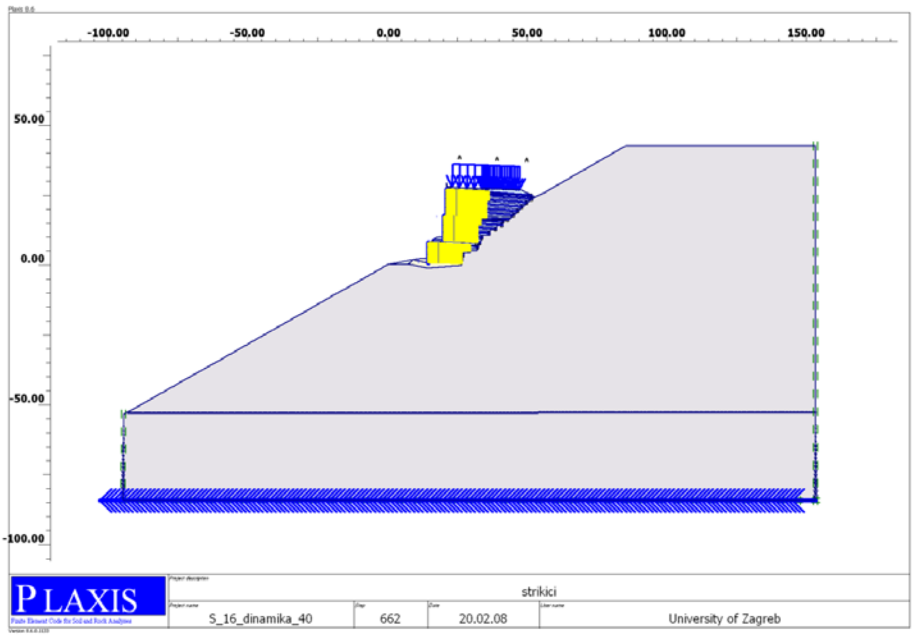

Figure 3 PLAXIS for dynamic analysis.

These calculations were checked with another type of analysis, by using engineering software PLAXIS V8 (Plaxis b.v., Delft, The Netherlands). The rock mass was modeled with so called *jointed rock model* which took into account a reduced stiffness of discontinuities [7]. In calculations, according to site investigations, two families of discontinuities were assumed, down the slope of 33°, and oppositely inclined, with angle of 66°. The first step was calculation of initial state of stresses and deformations, and the next step was so called phi-c reduction method that, by gradually reducing shear strength parameters in discontinuities, automatically finds out potentially critical slip surface.Figure 2. represents the FE-model and the critical slip surface determined with PLAXIS which resembles to one found with SLOPE/W. The OFS was 1,75 which was considered satisfactorily. For MSEW Strikići, seismic analysis was carried out by using software Plaxis V8 dynamic module which include absorbent boundaries; an absorbent boundary is aimed to absorb the increments of stresses on the boundaries caused by dynamic loading, that otherwise would be reflected inside the soil-body. The problem was modeled as plain strain and dynamic loading source was applied along the bottom of the model resulting to shear waves that propagate upwards (Fig. 3.). As a plain-strain model in Plaxis does not include geometric damping, in attempt to get realistic results, material – Rayleigh damping was included. Dynamic stability of MESW Strikići was checked in two separate analyses, with two accelerograms of earthquakes "Gilroy" (M=4,9) and "El Salvador" (M=7,6), recorded by USGS. The expected magnitude of earthquake for the Strikići location was somewhere between these two earthquakes (a_{max}=2,9*g*) The behavior of the wall was checked by comparing the tension forces in reinforcement (strips) to maximum allowable tension forces (Fig. 4.) and through calculated facing displacements (Figure 5.). It may be concluded that, even for the stronger earthquake, tension forces are below the allowable limits and facing displacements are below one foot (30 cm) which is considered acceptable.

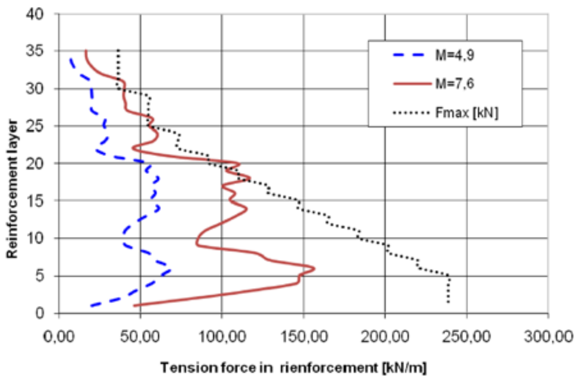

Figure 4 PLAXIS dynamic analysis – tension forces in reinforcements.

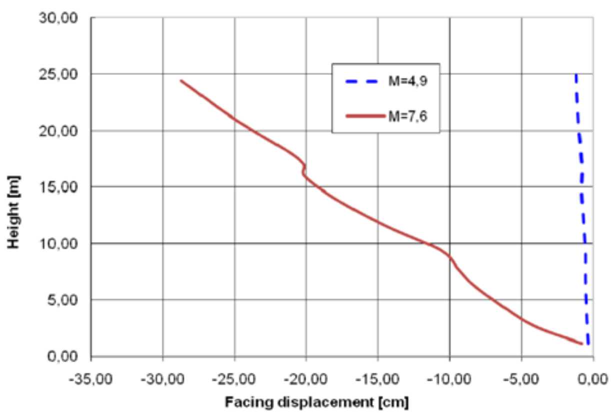

Figure 5 PLAXIS dynamic analysis – facing displacemens.

This result is not surprising! For example, according to report from the recent Californian 1994 Northridge-earthquake, M=6,7, which caused severe structural damage to buildings and freeways, there were no remarkable damages to MSEWs. The earthquake generated the highest vertical ground accelerations ever recorded in California. Ground accelerations were recorded as high as 1,82*g* horizontal and 1,18*g* vertical 5km from the epicenter. The extensive structural damage included the collapse of 6 major freeway bridges, 18 parking buildings with garages and carports on the first floor [2]. After earthquake review encompassed a total of 23 MSEWs located within the affected area. The distance of MSEWs ranged from 10 to 70km from the quake epicenter and ground accelerations ranged from 0,46*g* to 0,66*g* horizontal and from 0,18*g* to 0,29*g* vertical. Regardless of wall locations, all walls remained structurally sound and intact, except only one wall that suffered only superficial damage.

5 Conclusion

MSEWs are suitable type of retaining structure for karst region, because they satisfy the criteria for serviceability and stability. They comply with karst environment, visually because they recall to traditional types of retaining constructions in the area which are dry-stone-walls.
In the case of great amount of crushed stone, that is produced by cutting way through rocky environment and should be deposited somewhere, MSEWs may serve as a storage for this material. In the paper, shortly is presented stability calculation for MSEW Strikići, the highest from until now built MSEW along the Split – Ploče highway. Discussed is also a behavior of MSEWs under earthquake loading which was found satisfactory because of strength and flexibility inherent to MSEWs. Good performance of MSEWs in seismic events can be attributed to fact that it is flexible, allowing significant differential movement to occur within the reinforced mass without risking the integrity of the wall or its supporting structure. Granular backfill serves as an excellent damping medium. Panel joints are open allowing pore pressures (if any) to dissipate. It is only for its high strength characteristics that karst type of ground may sustain heavy loads from large MSEWs. Therefore, if in ground there are no phenomenons such as weak layers or caves (not uncommon in karst), extremely high MSEWs could be built.

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