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Design and construction of soil reinforced structures using composite reinforcement systems: modern and cost effective alternatives for high walls and slopes

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ABSTRACT: The innovative concept discussed deals with the possibility to combine geogrids and steel mesh together to build high Mechanically Stabilized Earth (MSE) walls or slopes. The study stems from the need to analyze when a more efficient use of the reinforcements will work in favor of the overall project's economy, which is often looked at as a function of the material cost only. Results on existing structures indicate that, as structures achieve relevant heights (above 10 m), there is a large potential for cost effectiveness in using wire mesh and grids combined, in place of a 100% geogrids or a 100% steel mesh reinforcement solution only. In high MSE walls or slopes the steel higher flexural rigidity makes it suitable to work as the preformed facing component of the reinforcement system. Additionally, the steel shorter tail can provide the function of secondary reinforcement. The benefit of the geogrid system as the primary reinforcement is evident, achieving the material a higher strength at moderately low cost with relatively simple installation requirements. However, the interaction of the steel mesh and geogrids when used for soil reinforcement needs to be looked at, since these materials are characterized by a different structural response under load. Geogrids are mostly characterized by a time-load sensitive response (creep), and by elongations at break higher than those obtained for the steel mesh which, on the contrary, is primarily characterized by a constant rigid elasto-plastic response. Research has shown that some combined reinforcement configurations have the benefit to be only minimally affected by the different structural response, therefore a simplified design model can be used for a realistic failure prediction. Some numerical methods (Bishop, Janbu, working stress "displacement" method) for slope stability analysis, were implemented in a computer software to provide a simplified numerical model. The software allows to enter any type of soil and reinforcement mixed geometry. The numerical examples presented show how different geometries can provide a different degree of reinforcement effectiveness.

1 INTRODUCTION

Reinforced soil walls offer economic advantages over conventional mass gravity wall systems as the wall increases with height. This work will present the experience on two recently constructed high walls in Europe where the combined use of different types of reinforcement provided a further reduction in the overall project costs.

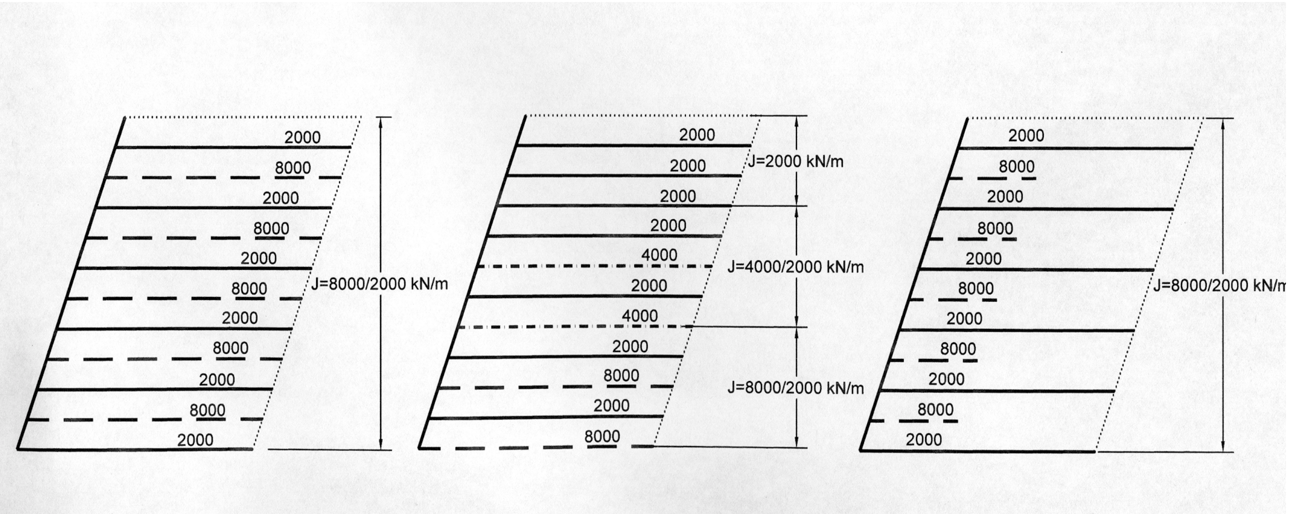
From a general point of view, in high retaining structures reinforcement loads can widely vary with depth, and this may often require more than one reinforcement type or spacing pattern along the wall height. However, from a general point of view, the placement of a stiffer reinforcement will attract more load to the stiffer region of the reinforced zone. The potential for exceeding the tensile strength of the stiffer reinforcement layer will have to be addressed.

There are currently no guidelines that directly consider the influence of different stiffness reinforcement layers on the distribution of the tensile load in reinforced soil wall systems. Results from a numerical study (Bathurst, Hatami and Di Pietro [1]), indicate that the analysis on some reinforcement geometries using the stress-strain numerical approach in a high reinforced soil wall system may provide a static response similar to the one achievable using a less rigorous data interpretation model, like the conventional limit-equilibrium approach.

1.1 1.1 *Background research study*

The numerical simulations, carried out with the assumption of plane-strain conditions, show that an alternating reinforcement scheme appears to be a more effective reinforcement arrangement, than grouped schemes with different stiffness combined together. The J values reported in Fig. 1 represent the stiffness values associated with the reinforcement used in the numerical model. The mixed reinforcement configurations with reduced stiffness toward the wall top did not result in

Fig. 1 – Effective mixed reinforcement arrangements



significantly larger lateral wall displacements compared with walls with uniform reinforcement using the stiffest reinforcement type. Another interesting aspect for economic reinforced soil wall design is to reduce the length of every other reinforcement layer by 50% while maintaining the same stiffness value. This approach was found to be the best method to reduce the reinforcement supply requirement while maintaining wall serviceability and performance.

This initial research highlighted that using a realistic failure prediction numerical model (finite differences), some of the mixed reinforcement configurations provide a response under load similar to a theoretical uniform reinforcement pattern. This finding may also be interpreted in the design practice as that a more simplified numerical approach may be used when a structure with mixed reinforcement layers has a geometry as illustrated in Fig.1. A software computer program was specifically developed to allow mixed reinforcement geometries to be calculated using the simplified approach.

2 DESIGN ISSUES

2.1 *MAC.ST.A.R.S. 2000 software*

Macstars 2000 is a software developed to perform slope stability analysis using different types of reinforcement and complex design scenarios. The software uses conventional limit equilibrium approach (Bishop, Janbu, and “Displacement Method”). The Displacement Method, recently become more popular in literature, has the ability to check the reinforcement effectiveness through the analysis of their stiffness at the intersection with the predicted failure surface.

The software was extensively used in the design of two recent project studies of high walls constructed in Portugal and in Italy, where the use of combined reinforcement geometries provided an interesting cost saving benefit compared to the more conventional uniform reinforcement solution.

The first project in Italy is located in Loreto Aprutino (near Pescara). The second is in a Retail Park in Leiria, Portugal. Both reinforced soil structures are characterized by relevant heights (from 15 to 30m). They were designed using mixed reinforcement configurations with high strength geogrids as primary reinforcement and steel mesh as secondary reinforcement and facing unit.

2.2 *The Loreto Aprutino Project*

The project consisted in the construction of an embankment along SS151, as part of the main roadway rehabilitation project connecting the city of Pescara and Loreto Aprutino, Italy. Due to the morphology of the territory, hilly and mountainous in this area, the original design included the construction of a viaduct to provide a better roadway alignment. The engineers at the Road Authority (ANAS) looked at other alternative designs, and eventually decided for a solution that could permit vegetation on the facing: a 70º sloped reinforced soil embankment. The cross section in the highest point of the structure reached a height of 19 m from bottom to the top elevation. Soil parameters used in the design are reported in Table 1.

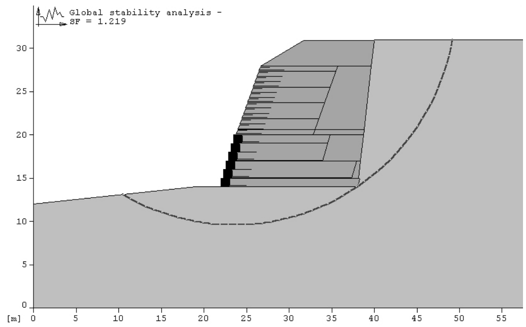
Table 1. Loreto Aprutino project – Soil parameters used in design

	γ (kN/m^3)	φ (deg)	c (kN/m^2)
Backfill	18	32	0
Foundation	20	24	10
Retained fill	20	24	10

The heaviest loading condition was assumed with a horizontal seismic coefficient of 0.07 and no surcharge load acting concurrently.

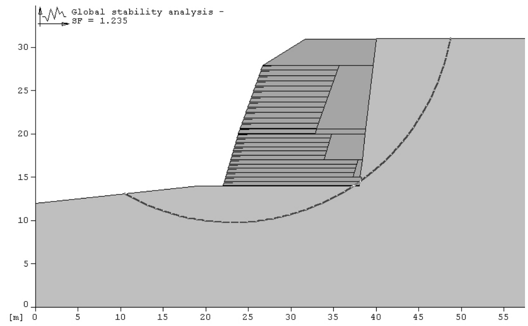
The design solution adopted (Fig.2) in the design was a reinforced soil slope using combined primary geogrids widely spaced between secondary shorter layers of steel mesh reinforcements, also used to provide a modular facing system.

Fig. 2 – Loreto Aprutino – Solution used (geogrids and steel mesh)



Concurrently, a comparative design was made using a conventional approach using the same type of geogrid reinforcements with variable grades of strength and uniformly spaced. The geogrid reinforcements were chosen to provide internal and global safety factors comparable to the solution combining primary and secondary reinforcements. The alternative design section is reported in Fig.3.

Fig. 3 – Loreto Aprutino – Uniform reinforcement type



Based on the field experience, the installed cost of the design section using combined reinforcements, assuming the material supply and installation costs (labor, equipment and backfill compaction) was estimated approximately 10 to 12% lower than the equivalent section designed with geogrids reinforcements only.

2.3 *The Retail Park Project in Leiria (Portugal)*

Another reinforced soil wall was constructed to extend the parking space in the Retail Park in Leiria, Portugal. The wall in this case reached a maximum height of 29.2 m. The combination of MSE (mechanically stabilized earth) wall (semi-vertical) and a reinforced soil slope were considered in the design, due to the relevant heights and the limited space available at the toe. Soil parameters used in the design are reported in Table 2.

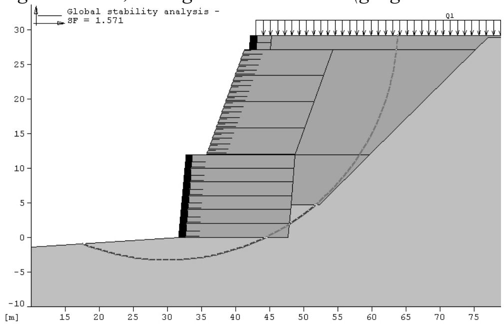
Table 2. Leiria project – Soil parameters used in design

	γ (kN/m^3)	φ (deg)	c (kN/m^2)
Backfill	19	35	0
Foundation	19	33	20
Retained fill	19	33	20

Same as in the previously described project, a reinforced soil slope (tiered wall) using combined primary geogrids widely spaced between secondary shorter layers of steel mesh reinforcements was the solution adopted in the final design (Fig.4).

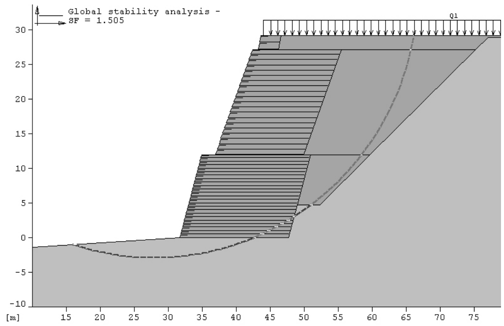
The same type of comparison as the project in Loreto Aprutino, that is checking for an alternative design using only geogrid reinforcements with lower grade and uniformly spaced, was

Fig. 4 – Leiria, Portugal – Solution used (geogrids and steel mesh)



made for the same comparison purpose. The alternative design is reported in Fig. 5.

Fig. 5 – Leiria, Portugal – Uniform reinforcement type



Based on the field experience, the estimated cost of the designed section using combined reinforcements, assuming the material supply and the installation costs (labor, equipment and backfill compaction) was estimated approximately 15 % lower than the equivalent section designed with geogrids reinforcements only.

3 INSTALLATION

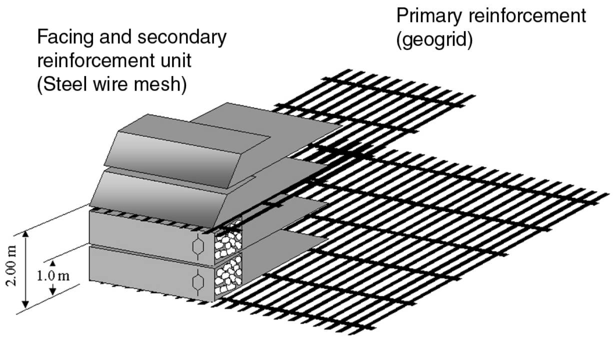
The construction of the reinforced embankments in both projects proceeded on schedule. The Loreto Aprutino project was designed in October 1998. The structure, consisting of 1,800 m^2 of wall face, was built between June and September 2000. Fig.6 illustrates the connection detail between the geogrid and the steel reinforcement at the wall face. Fig.7 shows a view of the wall upon construction completion. In May 2001 a hydro-seeding treatment was made. The project in Leiria was designed in April 2001. The wall construction (3,300 m^2 of wall face) started in May 2001 and ended in August 2001. The hydro-seeding treatment was made in October 2001. Fig.8 shows a detail of the geogrid and steel mesh overlap near the wall face. The lower portion of the walls required a free-draining facing

Fig. 6 – Loreto Aprutino, – Geogrids and steel mesh overlap at the face

Fig. 7 – Loreto Aprutino, Italy – View of the completed structure

system. This was achieved by using steel mesh secondary reinforcements "gabion-like" shaped on the outer side. Fig.9 shows a detail of the compaction operation operation on the Leiria jobsite. Fig. 10 shows an overall view of the wall. Both

Fig. 8 – Leiria, Portugal – Geogrids and steel mesh overlap at the face



projects, according to the project's general contractors confirmed the preliminary expectation, which is that the overall project construction time was lower than what had been experienced with conventional MSE systems. The gain in construction time also permitted the hydro-seeding to be performed not too long after the completion of the works, in a season favorable to a more effective vegetation growth.

From the contractor's perspective, the possibility to combine a modular ready-to-use facing and secondary reinforcement system (steel mesh) able to allow vegetation growth, with the "easy-to-handle" geogrid material to simply roll out and cut to the required length, was a very effective and innovative concept. This was found to hold true for wall sections of relevant height (above 10m). In these circumstances, in fact, a solution with a uniform geogrid reinforcement system using the wrapped-around face would require frameworks and care to ensure a proper shaping of the outer slope. Along the same line, in high walls or slopes (10m and above) a uniform steel mesh reinforcement solution may require a length for each layer that could not result cost effective when supplied pre-cut to the required sizes. Another interesting feature highlighted on both jobsites was about the easier handling operations and quality control during the construction, due to the lesser number of different reinforcement sizes (rolls of one or two grades of high strength geogrid and one-size standard steel mesh reinforcements supplied in bundles).

4 CONCLUSIONS AND RECOMMENDATIONS

The experience on the two existing projects has shown that there is a potential for cost effectiveness that may be further exploited in high reinforced soil walls. This may only be considered the first step towards an innovative construction system. Still further work shall be done before consistency with the field data can finally be achieved. The numerical analysis has shown that some mixed reinforcement configurations develop strains in the same pattern as an equivalent uniform reinforcement configuration. Further research should investigate more in detail over the actual stress-strain relationship developed by each reinforcement using realistic design scenarios. Furthermore, the ability to provide an anchoring effect in relationship with the vertical spacing of the primary reinforcement system should be better analyzed. All of the above recommendations would require to develop some more numerical analysis. The numerical interpretations of this further research should then be correlated with the field data collected from existing monitored structures, in order to build a consistent data interpretation model.

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Fig. 9 – Leiria, Portugal – Fill compaction

Fig. 10 – Leiria, Portugal – View of the completed structure