Geosynthetics: Leading the Way to a Resilient Planet – Biondi et al (eds)

Numerical analysis using FEM on the behavior of reinforced fill structure having geogrid and steel wire mesh as a reinforcing element

Ahsan Rehman Khan & Gemmina Di Emidio
Laboratory of Geotechnics, Department of Civil Engineering, Ghent University, Belgium

ABSTRACT: Nowadays, installation of geosynthetics is an effective and economical way to cater soil stability problems. It also helps in designing reliable, constructible, eco-friendly, cost-effective geotechnical structures. Numerous infrastructures resting on these stabilized soil structures is prone to failure due to collapse which result in financial loss, loss of life and disturbance in the services which may take few years to rebuilt. The aim of this paper is to highlight the importance of geogrid and wire mesh as a reinforcement method in reinforced fill structure. To assess the performance of this soil reinforcement, finite element method analysis was adopted. The geometry model of this reinforced fill structure has dimensions as 10 m height, 20 m wide. The type of geogrid used consist of high tenacity polyester fibers coated with a polyethylene sheath. This research paper explores the use of reinforced fill structures incorporating geogrids and wire mesh as an economical, eco-friendly, and adaptable alternative to conventional methods. These structures offer advantages in terms of minimal labor, low manufacturing costs and easy to install that can be customized to fit the specific requirement of any project. The study concludes that reinforced fill structures using geogrids and wire mesh represent a promising alternative solution for construction projects.

Keywords: Geogrids, Wire mesh, Reinforced fill structure, Soil, Eco-friendly

1 INTRODUCTION

The parameter that effects the tensile loads in MSE walls is the stiffness of a reinforcement (Allen & Bathurst 2019) . By inserting the reinforcing elements in the soil, the stiffness of the soil can be enhanced (Sulovska & Stacho 2021). The effect of soil reinforcement on horizontal and vertical deformation is shown in Figure 1. The behavior of retaining structures is influenced by the various factors that affect their construction, such as the type of compaction, and the degree to which it is applied. In order to avoid failure, proper guidelines are established during the construction process (Koerner & Koerner 2013, 2018). Different case studies have shown that poor or inconsistent compaction can lead to the failure of MSE walls (Mahmood 2009; Tarawneh & Siddiqi 2014).

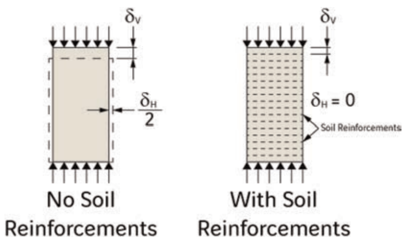

Figure 1. Effect of reinforcement on soil deformation.

DOI: 10.1201/9781003386889-121

Gabion walls, due to their weight, show dominating strength against hydraulic and active soil pressure. The gabions with wire mesh boxes are built by welding or twisting wires and the boxes are filled with course soils (Lin *et al.* 2010). The Gabion walls considered the best stabilization method having 50% less cost (Chikute & Sonar 2019). The reinforced fill structures are also more cost-effective when compared to traditional walls (Uray 2022). Wire mesh has been widely used as a secondary reinforcement for stabilizing earth structures in combination with units that can provide a stone-facing surface for the past few years (Lelli *et al.* 2015). These rectangular boxes are usually manufactured from a combination of steel mesh and stones at the worksite. These materials are commonly used in various infrastructure projects such as airports and roads. Besides stabilization, they can also be utilized for the construction of riverbanks, erosion control measures, and landslide mitigation. Compared to gravity-type retaining structures, reinforced fill boxes offer various economic advantages. They can be used as the wall's height increases (Rimoldi & Scotto 2012). A reinforced fill structure can be constructed using a combination of wire mesh and geogrids, which are commonly used as primary and secondary reinforcement materials respectively. Geogrids, as primary reinforcements, help to prevent the structure from experiencing any potential rupture surfaces. While wire mesh acts as a secondary reinforcement to offer the strength at the facing.

This paper contains the initial part of author's research work. In general, the whole research work is structured around three phases. The initial phase assesses the effectiveness of geogrid and welded wire mesh in terms of stability. The step-by-step procedure of how to model a reinforced fill structure in a simplified way is elaborated. In the second phase of the research, the author aims to predict the long-term performance (creep) of geogrids using finite element method and validate these values with the monitored field data. In the third phase of the research, the author will investigate the long-term pullout test (sustained loading) to predict the performance of geogrid under confined loading based on its design life.

2 METHODOLOGY

Finite element software Plaxis 2D was used here. The model with 15 node elements with plain strain condition was used for the analysis. The stratigraphic feature of the soil can be defined by using the borehole feature. The water table and the location of the soil layers can also be determined by using boreholes. A geogrid was used as a primary reinforcement as it is a slender structure with axial stiffness and axial force and can withstand tension. The gabions with wire mesh were used as a secondary reinforcement to provide erosion control and retention of earth. Also, double twisted wire mesh configuration guarantees the minimum occurrence of strength reduction. The typical steps involved in the analysis of the reinforced fill structure (Edition 2020) are as follows:

- Representation of a Conceptual model
- Specifying boundary, initial, and loading conditions
- Defining geometry
- Specifying the soil, reinforcement, and backfill properties
- Designate specific material model and parameters
- Generation of mesh
- Staged construction development
- Running & verification of the model
- Evaluation of the findings with engineering judgement

2.1 *Constitutive model and material properties*

For the analysis and design of complex geometries, finite element analysis software Plaxis 2D is frequently used nowadays. The tool has the power for the detailed soil response towards construction procedures, boundary conditions & simulating primary loading stiffness, initial stiffness, and unloading/reloading stiffness as per model requirement.

The material properties of the foundation soil & backfill are shown in Table 1, while for geogrid, gabion & wire mesh are listed in Tables 2, 3 and 4 respectively. The model was made using a highly refined mesh.

Table 1. Properties of soil.

Properties	Units	Foundation soil	Backfill soil
Saturated unit weight	kN/m^3	18	18
Unsaturated unit weight	kN/m^3	18	18
Angle of internal friction	Degree	30	35
Cohesion	kN/m^2	1	1
Poisson's ratio	–	0.3	0.3
Reference elastic modulus			
$Eref_{50}$	MPa	60	30
$Eref_{oed}$	MPa	60	30
$Eref_{ur}$	MPa	180	90

Table 2. Properties of geogrid.

Properties	Units	Value
Axial Stiffness (EA)	kN/m^2	3000
Maximum Axial force N_p	kN/m	300
Material Type	–	Elastoplastic

Table 3. Properties of gabion.

Properties	Units	Value
Unit weight	kN/m^3	18
Angle of internal friction	Degree	40
Cohesion	kN/m^2	27
Poisson's ratio	–	0.3
Elastic modulus	MPa	40
Material model	–	Mohr-Coulomb

Table 4. Properties of wire-mesh.

Properties	Symbols	Units	Value
Axial stiffness	EA	kN/m	62832
Flexural Rigidity	EI	$kN/m^2/m$	0.251
Weight	W	kN/m/m	0.023
Poisson's ratio	V	–	0.3
Maximum bending moment	M_p	kN/m/m	0.23
Maximum axial force	N_p	kN/m	135
Cohesion	C	kN/m^2	27

2.2 *Model geometry in Plaxis-3D*

The reinforced fill structure modelled in this study has the height of 10 m and base of 20 m as shown in Figure 2, comprises of the following materials components:

- Gabions modelled as soil clusters as shown in Figure 2a
- Welded wire mesh panels modelled as plate elements as shown in Figure 2b
- Geogrids modelled as Elastoplastic (N-ε) geogrid elements as shown in Figure 2c

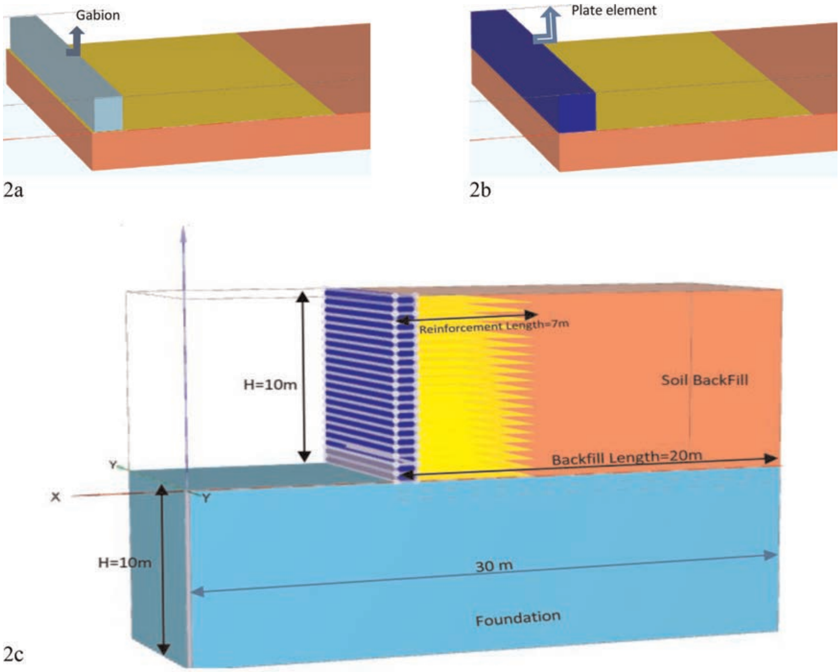

Figure 2. (a and b) Plaxis-3D geometry model and MSE wall components. (c). Plaxis-3D Geometry model and MSE wall components.

2.3 *Interface modeling*

One of the features of Plaxis 2D is the use of interfaces for modelling soil-structure interaction. Without an interface the soil & structure are tied together having no relative displacement between them. By using an interface, node pairs are introduced at the interface of soil & structure as shown in Figure 3. The interaction is modeled by the various interface elements that are used in the construction process. Here, Table 5 represents the coefficients of friction between the soil & wire mesh and soil & geogrid.

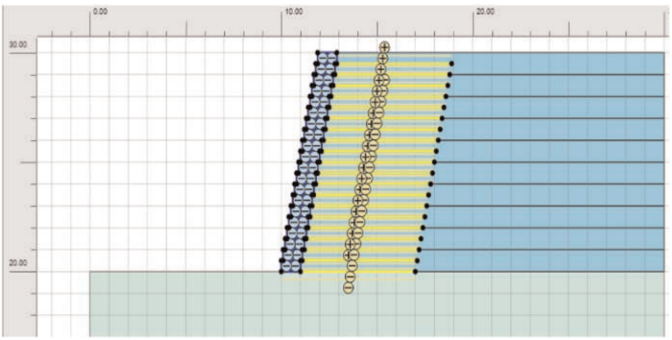

Figure 3. Interaction between soil and reinforcing elements.

Table 5. tan δ / tan φ friction coefficients for wire mesh & geogrid.

Soil	tan δ / tan φ (Wire mesh)	tan δ / tan φ (geogrid)
Clay	0.3	0.4
Silt	0.4	0.7
Sand	0.65	0.9
Gravel	0.9	0.9

3 RESULTS AND ANALYSIS

Modeling & analysis was executed using the software known as Plaxis 2D. For the stability assessment of the reinforced fill structure, the base soil and the embankment soil was generalized to be homogeneous with the physical properties. The maximum wall displacement is computed to be around 23 cm as shown in Figure 4. Horizontal and vertical displacement was obtained as 6.3 cm & 23 cm respectively as shown in Figures 5 & 6.

The phi/c reduction method was used for estimating the factor of safety. Both the strength parameters phi (φ) and c are gradually reduced until a failure occurs in the soil. The FOS was determined as 1.2 as shown in Figure 7. The required length and spacing of the geogrids used were 7m and 0.5m respectively.

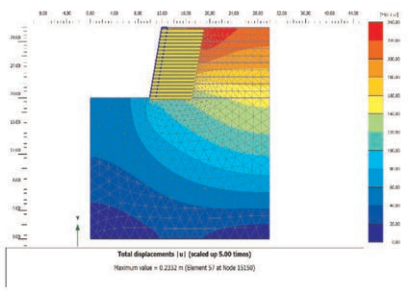

Figure 4. Total displacement.

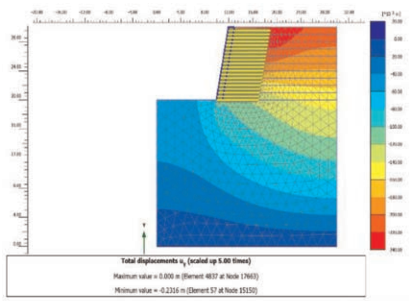

Figure 5. Horizontal displacement.

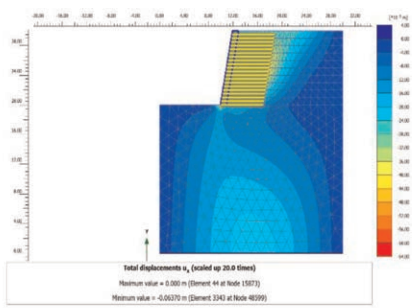

Figure 6. Vertical displacement.

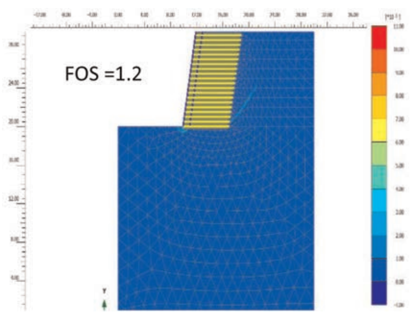

Figure 7. Factor of safety.

4 CONCLUSION

This study is a preliminary research based on first year PhD, about the stability of a reinforced fill structure with geogrids and wire mesh as a reinforcing unit. The reinforcement layer helps spreading the load over a wider area and provides the necessary tensile strength to the surrounding soils. It can be concluded that the use of geogrid and wire mesh can reduce horizontal movement and increase stability in slopes. These reinforcing materials distribute stresses evenly, mitigating the risk of failure. A reinforced fill structure with geogrids and wire mesh are an alternative and economic solution as compared to other conventional solutions as they are easily buildable, adaptive with nature, durable, ecofriendly, and flexible structure.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Higher Education Commission, Pakistan and Pollux Consulting bvba, Belgium for their financial support.

REFERENCES

Allen, T.M. and Bathurst, R.J. 2019. 'Geosynthetic Reinforcement Stiffness Characterization for MSE Wall Design', *Geosynthetics International*, 26(6), pp. 592–610.

Manual of Plaxis 2D. 2020. 'Plaxis 2D Reference Manual CONNECT Edition V20.02', pp. 1–23.

Koerner, R.M. and Koerner, G.R. 2013. 'A Data Base, Statistics and Recommendations Regarding 171 Failed Geosynthetic Reinforced Mechanically Stabilized Earth (MSE) Walls', *Geotextiles and Geomembranes*, 40, pp. 20–27.

Koerner, R.M. and Koerner, G.R. 2018. 'An Extended Data Base and Recommendations Regarding 320 Failed Geosynthetic Reinforced Mechanically Stabilized Earth (MSE) Walls', *Geotextiles and Geomembranes*, 46(6), pp. 904–912.

Lelli, M., Laneri, R. and Rimoldi, P. 2015. 'Innovative Reinforced Soil Structures for High Walls and Slopes Combining Polymeric and Metallic Reinforcements', *Procedia Engineering*, 125, pp. 397–405.

Lin, Der-guey, *et al.* 2010. "Deformation Analyses of Gabion Structures." *Proceedings of the interpraevent Conference*, 2010, pp. 512–526.

Mahmood, T. 2009. '*Failure Analysis of a Mechanically Stabilized Earth (MSE) Wall Using Finite Element Program Plaxis*', Ph.D. Thesis. The University of Texas at Arlington. Available at : http://hdl.handle.net/10106/1705

Rimoldi, P. and Scotto, M. 2012. 'Hybrid Reinforced Soil Structures for High Walls and Slopes', in *Second Pan American Geosynthetics Conference & Exhibition, GeoAmericas*.

Sulovska, M. and Stacho, J. 2021. 'Analysis of Geogrid Reinforced Structures with a Passive Facing System Using Different Computational Methods', *Civil and Environmental Engineering*, 17(2), pp. 500–512.

Tarawneh, B. and Siddiqi, J. 2014. 'Performance Issues of Mechanically Stabilized Earth Wall Supporting Bridge Abutment', in *Proceedings of 8th international conference on engineering and technology research, Dubai, UAE*, pp. 1–20.

Uray, E. 2022. 'Gabion Structures and Retaining Walls Design Criteria', *Advanced Engineering Science*, 2, pp. 127–134.

Walls, R., Chikute, G.C. and Sonar, I.P. 2019. 'Techno-Economical Analysis of Gabion Retaining Wall Against Conventional Techno-Economical Analysis of Gabion Retaining Wall Against Conventional Retaining Walls', *International Research Journal of Engineering and Technology*, 6(8), pp. 450–457