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Modelling Study on the Geotextile, Geogrid and Steel Strip Reinforced Slopes

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Changing the natural conditions of soil creates unexpected stress increments in slope stability projects, which are required high amount of soil excavation near the highways and railways or braced cut systems. Some safety problems can occur during this application under different loading cases. In addition, slope stability design requires economical solutions. Slope-supporting structures should be designed with most effective solution according to these signified requirements. A slope stability problem considering deep excavations in front of the reinforced soils are studied within this study in all its parts, after an extensive review of the literature. Geotextile (GT), geogrid (GG) and steel strip (SS) reinforcements are used to increase the stability conditions of slope during both experimental procedure and modelling process with Plaxis software. Each reinforcement type provided the bearing capacity enhancement and showed that unique displacement behavior. Therefore, most effective reinforcement member can be chosen in design procedure and construction phase in the site according to the bearing capacity and displacement requirements according to presented values.

Keywords: Slope stability, Reinforced slope, Geotextile, Geogrid, Steel strip

Geotekstil, Geogrid ve Çelik Şerit Donatılı Şevlerde Modelleme Çalışması

Öz

Zeminin doğal koşullarının değişmesi, yüksek miktarda hafriyat gerektiren otoyol ve demiryolu kenarları veya destekli kazılardaki şev stabilitesi projelerinde beklenmedik gerilme artışlarına neden olmaktadır. Bu işlem sırasında farklı yükleme durumlarında bazı güvenlik sorunları oluşabilmektedir. Ek olarak, şev stabilitesi tasarımı ekonomik çözüm gerektirmektedir. Şev destek yapıları için bu önemli gereksinimler göz önünde bulundurularak en efektif tasarım yapılmalıdır. Bu çalışmada; kapsamlı bir literatür taramasının ardından, donatılı zemin yapısının ön kısmında yer alan derin kazılar dikkate alınarak şev stabilitesi problemi tüm yönleriyle incelenmiştir. Geotekstil (GT), geogrid (GG) ve çelik şerit (SS) donatılar, hem deney sürecinde hem de Plaxis yazılımı ile modelleme aşamasında şevin stabilite koşullarının arttırılması işleminde kullanılmıştır. Her donatı tipi zemin taşıma kapasitesi artışı sağlamış ve kendine has yer değiştirme davranışı göstermiştir. Dolayısıyla, sunulan değerlere göre taşıma kapasitesi ve yer değiştirme gereklilikleri doğrultusunda, tasarım işlemi ve sahadaki inşa sürecinde en efektif donatı elemanı seçilebilecektir.

Anahtar Kelimeler: Şev stabilitesi, Donatılı şev, Geotekstil, Geogrid, Çelik şerit

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1. INTRODUCTION

Retaining structures are used to support for vertical or close to vertical and inclined slopes of soil along the highway, road and railway structures. They are also used for bridge abutments and stability of miscellaneous slopes as well. They are made of reinforced concrete named as cantilever retaining walls and stone masonry named as gravity retaining walls, generally. If the height of retaining walls exceed about 8 m-10 m, counterfort retaining walls can be constructed within the purpose of reducing the shear and bending moments. On the other hand, reinforced earth structures are used to design foundation and earth retaining buildings. Reinforced earth is created with the combination of soil and geosynthetics such as geotextile, geogrid and geonet type of materials. Reinforced earth structures are preferred due to the fast construction, high resistance to earthquake, relatively high tensile strength, economic feasibility and aesthetic appearance too.

The first reinforced earth-retaining wall for the roads was constructed in 1972 in the United States according to Das [1]. Vidal [2] presented the concept of systematic analysis and design of reinforced earth structures. Several reinforced earth retaining walls were constructed in France soon after his work. Moreover, geosynthetic reinforced walls was gaining demand in Northern America in time due to its specific advantages according to Bathurst and Simac [3]. Miyata and Bathurst [4] mentioned that more than 30,000 steel strip reinforced soil walls have been constructed in Japan from 1970s to 2012s. These approaches showed that reinforced soils have been widely used around the world.

Geosynthetic is defined as a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure, or system as stated by ASTM D4439-15a [5]. Geotextile is a permeable geosynthetic made of textiles that is generally woven product with different filament properties and dimensions, too. Geotextile is used with soil and any other earth like materials within the purpose of separation, reinforcement, filtration and drainage applications. While soil is good in compression, geotextile is good in tension. Therefore, geotextiles are used in the case of low strength fine-grained silt and clay type of soils to eliminate the risk of local tearing under load. Geotextile has rapid, economical and eco-friendly usage in many geotechnical areas with vegetation and extra steel reinforcement, recently. In addition to this, geogrid is a mesh like material produced from polymeric materials with variable space and rib properties according to standards. Besides, steel strip utilization in soil layers creates a strong composite matrix against active forces. All of these reinforcements are used with respect to both increasing of soil bearing capacity and decreasing both horizontal and vertical deformations against failures such as settlement, sliding, overturning, pullout failure and local or general failures.

2. PREVIOUS STUDIES

The most common study approaches of reinforced soils are experimental evaluations in the literature. Juran and Christopher [6] determined the behavior and failure mechanisms of reinforced soil retaining walls with geotextile and geogrid materials. Three different failure mechanisms were observed caused by sliding or breakage of reinforcement and excessive facing displacement. DeMerchant et al. [7] realized experimental plate load tests on geogrid reinforced lightweight aggregate bed for the case of underlying foundation area. Subgrade modulus was presented depending on soil density, width and location of geogrid reinforcements, tensile strength of geogrid and number of reinforced layer. Yıldız [8] realized that the experimental and analytical study at shallow foundation which is constructed on geogrid reinforced soil according to distance between foundation and slope with 30º angle, number of reinforcement layers and depth of reinforcement tests. Bathurst et al. [9] predicted that full-scaled instrumented soil walls reinforced with bar mat, welded wire and steel strips depending on the evaluation of AASHTO simplified method accuracy. Granular backfills have less than 45º internal friction angle showed reasonably precision for steel strip reinforced soil wall design according to related study. Palmeira [10] conducted that the testing techniques are still rough approximations about the behavior of geosynthetic type of materials in the field. Lin et al. [11] proved the effectiveness of grid-rib type of geometry in geosynthetic reinforcements according to experimental pull out performances. Indraratna et al. [12] discussed the beneficial effects of geogrids on the strength characteristics were evaluated using large-scale direct shear tests. Latha and Santhanakumar [13] examined the stronger and weaker polypropylene biaxial geogrid reinforcements with rigid and modular concrete block facing systems on shaking table. Nearly 60% of vertical deformation decrement was reported with using 3 layers of geogrid usage. Gonzalez-Torre et al. [14] evaluated those six different geosynthetics within the purpose of anti-cracking agent utilization. It is also effective between soil layers in terms of interlocking effect that consists of voids between grid strips and thickness. Suzuki et al. [15] studied the effect of cement treated soil as a backfill material behind the reinforced soil walls under different seismic conditions. Costa et al. [16] investigated the time dependent deformations in geotextile reinforced soil walls. Deformations of geogrid reinforced soil walls through centrifuge model tests at constant gravity under the effects of molding water content and stiffness of the geogrid were presented by Balakrishnan and Viswanadham [17]. Provision of stiffer geogrid reinforced soil walls reduced problems due to the marginal backfills as stated in study. Xiao et al. [18] studied about some model tests to understand the effects of the offset distance and width of footing, the length of geogrid reinforcement, and connection mode between geogrid and facing, on the maximum capacity of strip footings that is located on the reinforced soil walls. Load - settlement characteristics of coir geotextiles in various forms were studied by Lal et al. [19], which were subjected to plate load test. Al-Rkaby et al. [20] realized the monotonic drained tests within the aim of determination the effect of principle stress direction on reinforced soil samples.

The other important research area of reinforced soils is in-situ applications. Richardson [21] presented the detailed information about initial facing failure of geotextile-reinforced retaining wall constructed in 1987 in North Carolina, USA. Kim and Won [22] studied long-term behavior of geosynthetic reinforced walls (GRS) which are constructed on weak ground. The maximum horizontal displacement and shear strain at soil mass without reinforcement were observed about 2.5 times and 1.4 times greater than GRS walls, within the results of in-situ application and finite element modelling, respectively. Stuedlein et al. [23] studied that 46 m tall steel strip reinforced earth wall technology near the runways of Seattle - Tacoma International Airport via real time geotechnical instrumentations. Yonezawa et al. [24] described the design and construction of GRS according to satisfying very high-performance requirements, a high stability for earthquakes and a high cost effectiveness, which is higher than the conventional type soil structures. Liu et al. [25] observed the pressure and displacement changes of expansive soil/rock channel slope reinforced with soil bags under moisture effect within 60 m long full-scaled project. Soil bags practically eliminated the water content change of underlying soil influenced by rainfall or channel flow. In addition, swelling pressure of expansive soil can be prevented with overburden pressure of soil bag.

Furthermore, various studies can be found in the literature about new method proposals, finite element modelling or economic analysis within the aim of enhancement of the effectiveness. Saving money within retaining wall projects may be possible up to 25% and 85% in 5 m tall and 20 m tall retaining structures with using reinforced soil walls, respectively consistent with Jones [26]. Yılmaz and Aklık [27] indicated that the reinforced concrete retaining wall was more expensive than both geotextile and geogrid reinforced walls at the rate of 71% and 24%, respectively. Allen et al. [28] developed that steel reinforced soil walls in new design methodology that is called as K-stiffness method. It is utilizing about prediction of reinforcement loads more accurately. Hatami and Bathurst [29] presented the simulation of full-scaled reinforced soil segmental retaining walls with different reinforcement types such as polypropylene, polyester, welded wire mesh in FLAC model. Lin et al. [30] developed a new version of reinforcement mechanism for slopes. Pseudo-static approach was used to reduction of reinforcements. Gu [31] evaluated the benefits of geogrids in two types of steel wire mesh and steel bar mesh geogrid reinforced soil underlying flexible pavements in Abaqus software. The use of geogrid reinforcement decreases the deformations within the base and subgrade layers as well as reduces the vertical deformations on top of subgrade layer. Damians et al. [32] reported that compressible bearing pads could be effective in reducing vertical compression loads in reinforced soil wall structures with limited to a 16.7 m wall height and 1.5 m depth of embedment. Yu and Pradhan [33] realized the numerical study on the mechanism of geogrid reinforcements with respect to various parameters. Loading rate and particle shape were founded as leading factors for geogrid - soil interaction in discrete element method. Hou et al. [34] compared the friction, stress distribution and displacement behaviors of strip and H-V reinforced soils due to finite element modelling under vertical loads. H-V reinforcement can be defined as horizontal strip reinforcement strengthened with vertical partial plates to improve of its load bearing capacity. Yu et al. [35] defined the effects of interface stiffness, soil modulus and foundation modulus parameters on the steel strip reinforced earth walls due to linear elastic Mohr Coulomb constitutive model. Carbone et al. [36] proposed a new inclined plane test procedure both static and dynamic conditions for interaction between soil and geosynthetic reinforcements. Allen and Bathurst [37] developed existing K-stiffness method to improve the accuracy of simplified method. Reinforcement stiffness, facing stiffness, facing batter, and cohesion of backfill soil were defined as key variables. Liu [38] proposed an analytical method to analyze the reinforcement load and compression of reinforced soil mass subjected to surcharge load. Analytical method considered soil nonlinearity, soil dilatancy, soil reinforcement interaction and end restrictions of reinforced soil mass. Damians et al. [39] depicted that Plaxis software could be safely used for the analysis and design of reinforced soil structures according to both numerical results and physical measurements. Gao et al. [40] used the limit analysis approach to determine the required strength and length of reinforcement. Three-dimensional analysis for reinforced soil slopes gave more conservative results than two-dimensional analysis.

In this study, slope stability conditions in deep excavation constructions in front of the retaining structure were evaluated. Slope models were set up in the laboratory by considering behavior of reinforced slopes with geotextile, geogrid and steel strip reinforcements. Vertical static load is applied up to the failure for each case. In addition, analytical model of reinforced slopes was modelled with Plaxis software under 0.50 kg/cm^2 vertical stresses within the scope of slope simulation under light road load located on the top corner. Displacement values and failure mechanisms were determined and compared.

3. THEORETICAL CALCULATIONS

Main design criteria of reinforced soil walls are to compensate the active forces caused by external effects or soil in itself. Passive forces are the first solution of this problem. However, if passive forces remain incapable during this conflict, extra retaining structures become a part of activity to provide safety. The material strength of each reinforcement members distinguishes during the design process, unlike the system requirements in bracing systems such as reinforced concrete retaining walls, lateral piles, sheet piles, etc. Soil reinforcements must have enough strength against tension forces, bending moments or tearing with respect to related standards for geogrid [41], geotextile [42] and steel strips [43] as well. Friction behavior is the most important design criteria to define the interaction performance between reinforcement and the soil layers. Main failure mechanisms must be ensured against overturning, sliding and bearing capacity. In addition, long-term stability conditions must be checked both slope reinforcements and facing behavior in spite of the fact that negative possibilities may be caused by natural conditions, unexpected load parameters and harmful effects on materials. Common standard and regulations involve the design methods, construction and maintenance about mechanically stabilized earth walls (MSEW) and reinforced soil slopes (RSS), and the monitoring of their long-term performance. MSEW is a generic term that includes reinforced soil. Reinforced earth indicates a specific reinforced soil system. Reinforced soil walls having nearly or almost vertical face inclination which has 70° to 90° and horizontal rows of the same length and type of reinforcement that retain a homogeneous backfill, generally [44]. A minimum reinforcement length of 0.6 to 0.7H (H = height of wall at wall face) has been used in most designs of geosynthetic reinforced soil (GRS) and geosynthetic mechanically stabilized earth walls (GMSE) [45].

Sun and Graves [46] listed the design checks as follows; strength limit states, service limit states and global stability according to LRFD (Load and Resistance Factor Design) methodology. Strength limit states are inclusive of external stability (limiting eccentricity, sliding, bearing resistance) and internal stability (tensile and pullout resistance of reinforcement, structural resistance of face element and face element connections) checks. In addition, vertical and horizontal wall movements are defined as service limit states. In order to check that global stability, overall and compound stability must be provided as well. Miyata and Bathurst [47] compared the reliability of geogrids pullout models used in Japan in terms of ultimate limit state.

Reinforced earth walls are generally used for construction of retaining walls, bridge abutments, waterfront walls, and so forth. There are three basic ways to design ties that resist the lateral earth pressure such as Rankine method, Coulomb force method and Coulomb moment method. Rankine method was used in this study related illustration is shown in Figure 1 [1].

Some deformation limits are defined in the literature by researchers and standards for reinforced soil walls or retaining walls. Displacement limits are generally defined as a function of height of retaining wall (H). Wu and Prakash [48] suggested that 0.02 H and 0.1 H displacement limits for permissible horizontal displacement and failure horizontal displacement criteria, respectively. Japan Road Association [49] proposed that permissible differential settlement values should be between 0.1 - 0.2 m. On the other hand, if settlement value is greater than 0.2 m that is called as severe differential settlement, damage is required for long term retrofitting measurements are required. Facing deformations of reinforced walls are limited at the range from 0.1% to 0.3% vertically [50]. This limit can reach up to the 3.0% according to PWRC [51] for all walls and maximum limit is defined as 3.5% for segmental walls [52]. Minimum factor of safety found from slice method during the analysis as 1.57 that is greater than allowable value of 1.50.

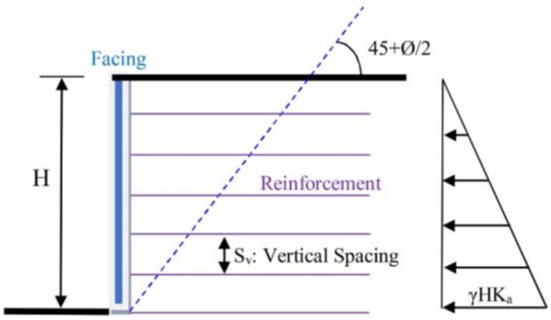


Figure 1. Analysis of a reinforced earth retaining wall

4. EXPERIMENTAL STUDY

In this study, model box was developed for reinforced slope simulation according to the theoretical calculations. A slope model, which has 20 cm in height, 50 cm in width and 90º angle of facing, was prepared in the box cell. Different type of slopes was established without reinforcement (WR) and with reinforcements such as geotextile (GT), geogrids (GG) and steel strips (SS). After placing the reinforcements at required positions, the soil was compacted by using compaction energy, which has proper magnification factor obtained from standard proctor test. Concrete facing of the slope was constructed within the scope of tighten the reinforcements properly. The facing member that both provides the movement of reinforcements together and spreads over the load, which concentrated on connection points. Only experimental part consists of the partially elaborated study of existing works have been evaluated by Özdemir et al. [53] and Onur et al. [54], partially.

4.1. Soil Properties

Clayey sand type of granular fill material was used as a backfill that has 77.6% sand, 17.8% silt and 4.6% clay. Specific gravity of fill material is 2.67 and the optimum water content is 6.0% obtained from compaction test. Undrained cohesion and internal friction angle values were determined as 5.7 kN/m^2 and 33.3º, respectively according to the triaxial test results.

4.2. Reinforcement Properties

Geotextile, geogrid and steel strip reinforcements are given in Figure 2. 40 mm x 40 mm in square mesh opening 1.6 mm thick geogrid material has 200 g/m^2 planar density. 0.7 mm thick and 8.10^6 g/m^3 density possessed galvanized steels have 240 mm in length and 10 mm in width. In addition, geotextile material has 1.2 mm thickness and 200 g/m^2 planar density values. Reinforcements were placed 20 mm intervals in the horizontal direction. All of these dimensions were calculated by considering real sizes, after the theoretical calculations within the experimental frame limits. The average tensile strength values of reinforcements are taken from manufacturers as follows; 9.25 kPa, 45 kPa and 515 MPa for GT, GG and SS, respectively.

Figure 2. Geotextile, geogrid and galvanized steel from left to right

4.3. Test Setup

The loading frame was generated with a cubic cell that has 500 mm unit width and metal braces (Figure 3). Hydraulic jack was assembled on the top of the frame to create vertical load. Data acquisition system consists of 10 tons capacity load cell and four linear variable differential transducers (lvdt). 50 mm capacity of two lvdts were used to collect data of vertical displacement from soil surface and this value indicates the settlement of soil. 25 mm capacity of lvdts were placed to measure the horizontal displacement of facing. Data collection was provided from instrumentations simultaneously.

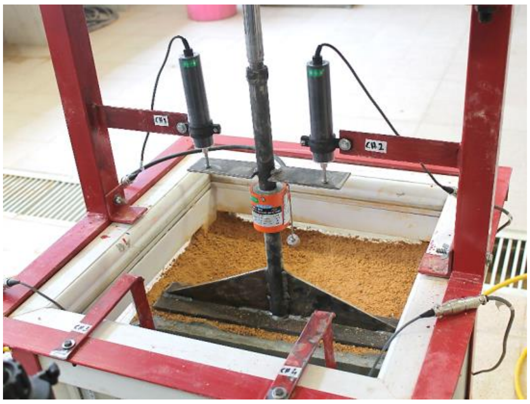


Figure 3. Experimental test setup

5. RESULTS

Slope without reinforcement (WR) and with reinforcements (GT, GG and SS) were subjected to vertical static loading case to simulate site behavior, after implementation of facing. When slopes have been subjected to external loading up to the ultimate point, each cases collapsed with their unique behaviors. Although, slope without reinforcement showed toe circle type of failure mechanism under the low stress level and ultimate load is observed as 320 kg. Test process of unreinforced slope is given in Figure 4. Maximum applied stress of slope without reinforcement is found as 0.86 kg/cm^2 at ultimate condition. Vertical and horizontal displacements of the slope just before the collapse down are detected as 6.2 mm and 4.2 mm, respectively.

Figure 4. Slope without reinforcement (WR), before, pending and after test

Construction and loading steps of geotextile-reinforced slope are given in Figure 5. Geotextile products were placed on the required coordinate before compaction of granular materials. The bundling of slope surface was provided layer by layer within the scope of facing structure generation. Maximum vertical and horizontal deformations are observed around 28.0 mm and 9.0 mm respectively, under 2.6 tons of vertical load that are corresponding to 6.6 kg/cm^2 stress value at collapse status. Partially rigid deviations were observed on the excavation surface with respect to the vertical axis. Geotextile layers also deflected from horizontal direction because of local collapsing.

Figure 5. Geotextile reinforced slope (GT), before, pending and after test

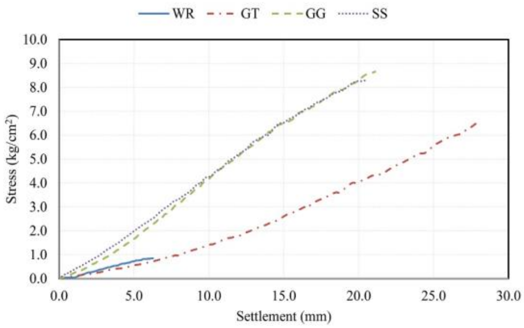
The placement of geogrid members, construction of rigid concrete facing and final deformed state are presented in Figure 6. The exiting ribs along the horizontal direction were anchored to the wire mesh located at slope surface. Then, water cement mixture was poured inside the formwork in order to create rigid facing wall. Maximum stress is calculated about 8.6 kg/cm^2 under 3.3 tons applied load. It also indicates the extreme loading condition for slope loading near the slope surface. 22.0 mm and 7.0 mm displacement values are noted as maximum readings in vertical and horizontal directions, respectively.

Figure 6. Geogrid reinforced slope (GG), before, pending and after test

Steel strip reinforcements were placed on the predefined locations according to theoretical calculations (Figure 7). Strips were fixed to the wire mesh before construction of facing member. Maximum applied stress is calculated as 8.3 kg/cm^2 after 3.2 tons vertical static load application. It simulates the extreme loading case. Vertical and horizontal displacements are observed as 19.0 mm and 5.0 mm, respectively.

Figure 7. Steel strip reinforced slope (SS), before, pending and after test

The obtained stress-displacement curves are presented in Figure 8 for each case. Vertical displacement values represent the settlement of top soil level with respect to soil surface elevation at the beginning of test. Facing displacement values indicate the horizontal translation of slope surface at the measurement point, which may be defined as three out of four parts from the bottom of slope. Unreinforced slope collapsed at low state of load and displacement performance. Geotextile reinforced slopes present the highest displacement both horizontal and vertical directions under reasonable level of stress. On the other hand, steel strip reinforced and geogrid-reinforced slopes demonstrate similar settlement behavior under same loading steps. However, steel strips and geogrid members have seriously increment influence on the bearing capacity of slope according to their high modulus of elasticity and tensile strength capacity. They increase the bearing capacity of soil about 10.0 times greater than unreinforced slope. This range remains relatively low in geotextile-reinforced case around 7.5 times increasing. Facing of steel reinforced slope behaves much more rigid deflection comparing to the others. Maximum horizontal deflection action on facing can be seen on the geotextile-reinforced slope associated with partially rigid deviations.



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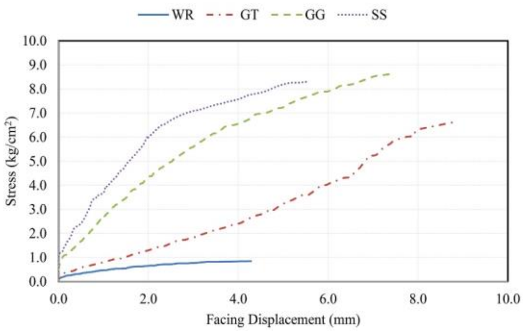
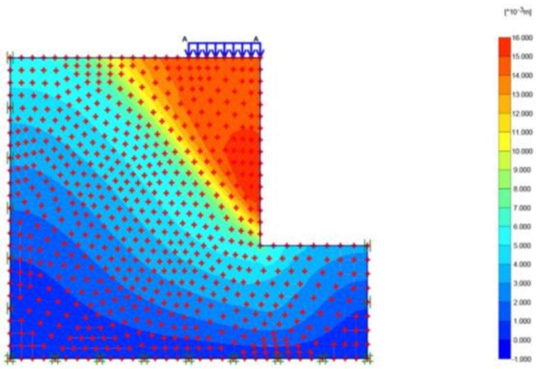


b.

Figure 8. a. Stress-settlement graph of slopes and b. Stress-horizontal facing displacement graph of slopes

6. ANALYTICAL STUDY

Analytical study of reinforced slopes is modelled with Plaxis software under vertical stress of 0.50 kg/cm^2 within the simulating of light level vehicle load on the top corner of slope. Real scaled slope construction is modelled in 5.0 m height of wall with 90º angle. Soil properties are defined as same as soil characteristics acquired from geotechnical experiments. Unit weight of unsaturated and saturated soils is considered as 18.5 kN/m^3 and 19.0 kN/m^3, respectively. The young modulus is calculated as 12000 kN/m^2 with respect to the uniaxial compression test results. The other stiffness parameter, Poisson's ratio, is taken as 0.35. Mohr-Coulomb material model and undrained material type are used during modelling process. Each reinforced case have facing element within the aim of observation of the changes in shear force and bending moment along the wall height. Extreme total displacement outputs of slopes are given in Figure 9.



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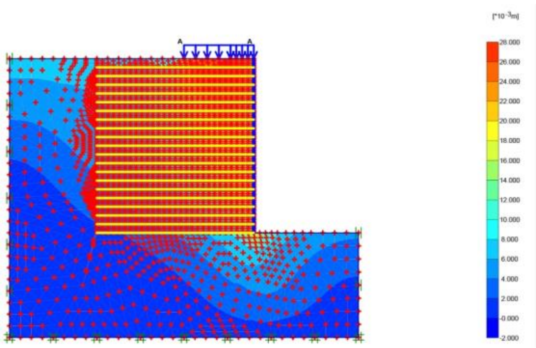

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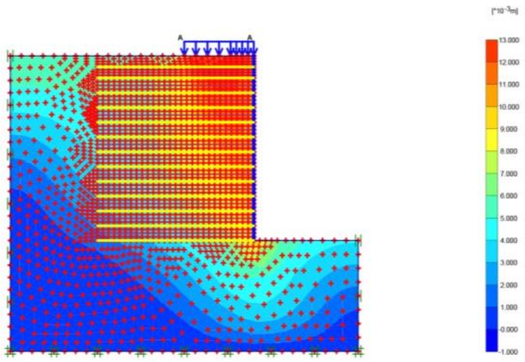

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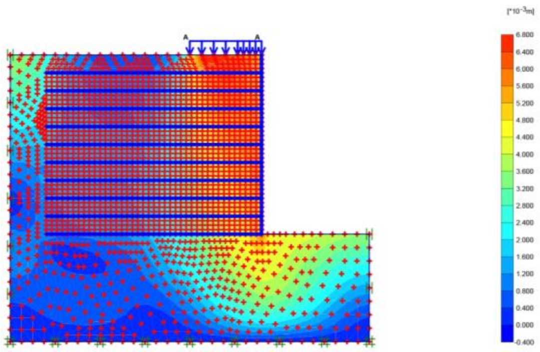

d.

Figure 9. Total displacement shades of slopes, a. WR, b. GT, c. GG and d. SS

The comparative displacement values of reinforced slopes are given in Figure 10 with respect to the whole soil structure. Geotextile reinforced slope has 2.1 times greater total displacement than geogrid reinforced slope as well as 4.0 times more displaces if compared with steel strip reinforced slope. In other saying, geotextile reinforced soil has more displacement for each component.

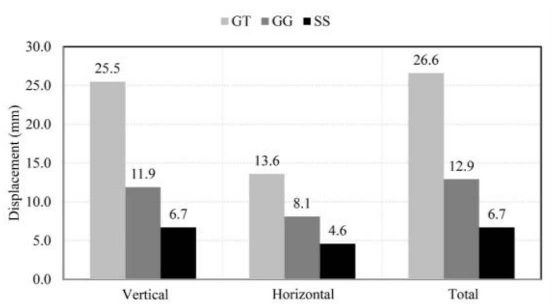

Figure 10. General displacement values of reinforced slopes

The other required query is an identification of the location defined as the translation point, which has maximum deformation along horizontal direction. Horizontal displacement values of top reinforcement, top point of facing and whole facing surface, are given in Figure 11. It can be clearly seen from the figure that top point of facing has not always represents the maximum displacement location in reinforced slope structures.

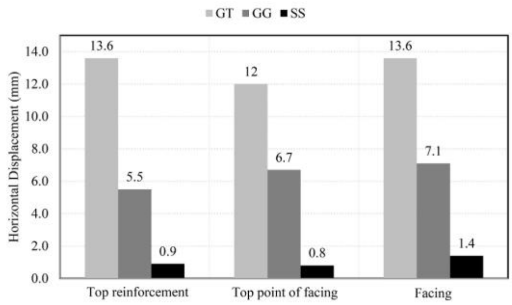

Figure 11. Horizontal displacement behavior of slope surface

Shear force has a vital role on the connection points between reinforcement and facing member. Material properties and number of reinforcement layers affect both distribution and magnitude of resultant shear force on the facing members according to its rigid, semi rigid or modular construction method. Obtained values showed that facing member of steel strip reinforced slope has 2.3 times greater shear force than geotextile-reinforced slope. This multiplier was attained about 1.9 times for geogrid reinforced one as given in Figure 12.

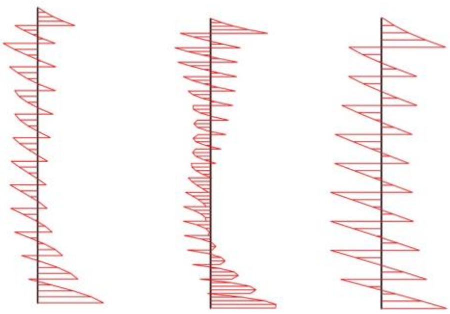

Figure 12. Resultant shear force on the facing, a. GT, b. GG and c. SS

Figure 13 represents the bending moment envelopes of reinforced slopes created at the facing member. Bending moment is directly affected from rigidity of facing caused by construction materials and methods. On the other hand, reinforcement locations and mechanical properties also affect the peak nodes of envelopes. Resultant bending moment created on the facing member of geogrid reinforced slope at existing maximum load levels are acquired as 1.7 times greater value than geotextile reinforced soil, contrary to expectations coming from shear forces. This value reaches to the just 1.4 times greater than geotextile reinforced slope that is valid for steel reinforced one.

Figure 13. Resultant bending moment on the facing, a. GT, b. GG and c. SS

Obtained internal force values for facing and top reinforcement at the end of the modelling are given in Table 1.

Table 1. Ultimate forces obtained on top reinforcement and facing according to Plaxis software results

Internal Force	Reinforcement		
	GT	GG	SS
Axial Force on Top Reinforcement (kN/m)	12.6	15.6	31.8
Shear Force on Facing (kN/m)	9.1	17.0	21.2
Bending Moment on Facing (kNm/m)	3.6	6.1	5.2

7. CONCLUSIONS

In this study, geotextile, geogrid and steel strip types of reinforcements are used to improve the soil properties and stability of slope by using both experimental and finite element modelling. Following remarks can be concluded according to results obtained from this study.

Slope without reinforcement collapsed with toe circle type of failure mechanism under the 0.86 kg/cm^2 low state of stress. Related stress level is seriously increased about 10.0 times with using steel strips and geogrid members. This range remains in relatively low due to geotextile reinforcement implementation around 7.5 times. Main reasons of high increment ratio can be indicated as the mechanical properties of reinforcements and their application styles.

Vertical and horizontal displacement values of the slope without reinforcement just before the collapse down are detected as 6.2 mm and 4.2 mm. Vertical displacement values are increased around 4.5, 3.5 and 3.1 times greater values for geotextile, geogrid and steel strip reinforced slopes respectively, if compared with unreinforced slope. On the other hand, the increment coefficient of extreme horizontal displacement values is noticed as 2.1, 1.7 and 1.2 for same reinforcement arrangement. These high amounts of displacement enhancements are provided under heavy loads up to the failure. Most enormous displacement values are observed in the case of geotextile reinforced slope according to lack of facing requirement as well as common usage at site. Moreover, approximately 4.0 and 2.0 times greater extreme total displacement values are obtained than geotextile reinforced one in geogrid and steel strip reinforced slopes in Plaxis software modelling.

Each of the reinforced slopes have unique failure mechanisms. Geotextile reinforced slope is collapsed with extremely high amount of displacement at local bundled layers located at middle portions. However, steel and geogrid reinforced slopes are failed within the results of deformation on the reinforcements located at upper part. Therefore, horizontal displacement can be seen on the different portions of facing member. Number of reinforcements, mechanical properties of reinforcement materials and interlocking-frictional behavior between soil and reinforcement members directly affects the behavior.

This study presents the comparison between most common soil reinforcing members within the experimental and modelling results related to accepted theoretical calculations. Presented parameters may be use in design process or application at site confidently.

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