ASPS Conference Proceedings 1: 1563-1568 (2022)

Proceedings of

12th Structural Engineering Convention-An International Event (SEC 2022)

Available at https://asps-journals.com/index.php/acp

Numerical Analysis of Behavior of Geo-Synthetically Reinforced Slopes Under Seismically Active Conditions

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Paper ID - 150353

Abstract

Slopes are the unsupported inclined soil mass. Stability of slopes has always been a governing factor for carrying out construction on slopes. Both static and dynamic loads can cause failure to a slope yet there are considerate methods to determine the bearing capacity and factor of safety for slopes under static loads while as dynamic loads specifically earthquake loads are generally unpredictable. This paper checks effect of installation of geogrid layers in soil slopes under seismic loads. This study has been carried out using Finite Element Based Software PLAXIS incorporating CD-ROM (SMC) file of WNW OF FERNDALE, CA on 10th March 2014.The model was scaled as 1x .5 x .5 m with slope angle of 32° and a model footing of 50 mm which was loaded suitably. During the study numerical results of deformation compared with experimental results. It was found that addition of geogrid layers enhanced the factor of safety upto appreciable extent. Optimum depth and optimum number of geogrid layers were also determined. The percentage increase in factor of safety at different levels of installation was also recorded.

Keywords: Seismic Slope Stability, Finite Element Model (FEM), Plaxis.

1. Introduction

In geotechnical engineering soil is classified as constitution of rocks or rock particles, water and air molecules. Rocks are formed due to adherence of mineral particles. Engineering properties of soils are mainly governed by properties like mineral particle constituents, size of constituent particles, and relative size distribution of particles and relative proportion of minerals, water and air present in soil matrix. Slopes are the unsupported inclined soil mass. Slopes can occur naturally or they are engineered by humans for various reasons like space constriction, economy etc. Gravity is principle force causing the movement of soil mass down the slope. As its effect is experienced all over Earth's surface, it tends to exhibit the force towards center of the Earth. Numerous factors have been known which have impact on the stability of slope like composition of soil, angle of slope, water pressure, and subjugation of static and dynamic loads. Various methodologies have been designated to appraise slope stability by means of analytical as well as experimental approaches. Evaluation of slope stability has received wide range of acceptance under the effect of static loads. Conventionally, Pseudo-static approach is adopted to assess the dynamic stability of slopes. Which employs displacement based methods (e.g. Newmark) or linear or equivalent linear methods. When the prime frequency of the input motion surpasses the natural frequency of the mass the sliding block procedure appears to be conservative [1,2].The performance of soils in association with slope response has been described comprehensively by experimental approaches. [3] suggested an energy balance method taking an inclined plane with rigid block supporting over it. Determination of bearing capacity of footings resting on slopes on application of dynamic and static loads was carried out. The tests were conducted on models in the laboratory. Sand in dry state was used to prepare the slope. The slope angle and relative density were maintained as 30^0 and 50% respectively. A model footing of size 10 cm was used. Hence load-settlement behavior was observed and the ultimate bearing capacity was inferred from the results. The results depicted that both the load-settlement behavior and ultimate bearing capacity were enhanced on enhancing the edge distance of the footing . one dimensional shaker was used to impart steady state vibrations in the slope model. Accelerations imparted on the slope surface and footing was recorded. Observations load-settlement behavior was carried out during the shaking. This in turn helped into the determination of dynamic bearing capacity and observation of failure surface [5].
Behavior of slope profile is studied when subjected to dynamic loading conditions. Shake table was used to carry out experimental investigation. Shake table with one dimensional steady state vibrations characteristic outputs was

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Proceedings of the 12th Structural Engineering Convention (SEC 2022), NCDMM, MNIT Jaipur, India| 19-22 December, 2022

Published online: December 19, 2022
doi:10.38208/acp.v1.689

used. Different dynamic characteristic parameters were used for study which included acceleration of shaking (% of g), frequency (Hz) and dynamic loading duration (cycles). Analysis of failure was carried out on the basis of crest subsidence in slope in comparison to initial slope profile. Constant frequency of 4 Hz was incorporated for conduction of tests. Acceleration was varied in different tests as 10%, 20%, and 30% of acceleration due to gravity. Soil mass displacement was also observed on variable duration of dynamic loading cycles of 10, 20 and 40 from start. It was also noted that the failure surface remained fairly shallow and was confined within the slope profile. Failure surface on observation was circular in the upper region of slope; while as translational movement and bulging were observed in bottom. A factor called as "Distortion Factor" was introduced to study the subsidence behavior of the slope when subjected to dynamic loading[6].Evaluation of behavior of reinforced soil structures under different seismic loads Stress and displacement of soilwere estimated and emphasis was laid on requirement of reinforcement for enhancing the strength of soil . Implementation of numerical model of finite difference of a soil slope and its behavior under different seismic loads was assessed. [7,8]. A non- recursive algorithm and nonlinear Hybrid Frequency Time Domain (HFTD) methods were followed to calculate the probabilistic amplification in the model. It was observed that with the use of non-recursive algorithm time period of analysis was reduced which formed the basis of analysis. Different parameters were studied during the analysis like velocity of shear waves, density of materials, damping characteristics and thickness. On analysis the results depicted that the damping ratio is the most important parameter in determination of peak ground acceleration of ground surface. The probabilistic PGA, response spectrum and amplification factor of ground surface were determined. Two approaches for four were employed with variable shear wave velocities in consideration. On Comparison of results from two different approaches non-linear HFTD depicted more accurate results than linear HFTD [9]. A comparison of results acquired from different softwares was carried out. It was observed that average factor of safety values generated by FLAC/Slope were about 8.33% higher than the other softwares. On considering the results statistically it was concluded that design with such difference can prove fatal at the time of hazards and can bring instability in the structure. Properties like Elastic Modulus (E) and Poisson's Ratio (ν) have not shown any considerable effect in calculation of factor of safety **[9]**,. A 3-dimensional dynamic loading analysis was carried out using vertical or torsional loads for calculation of displacement. It was observed that when geometry symmetrical to axis is subject to non-axis symmetrical loads displacement occurred can be representative of 3 $\hat{r}$, $\hat{z}$ and θ. It was concluded that modulus of elasticity and mass density vary as power functions of spatial directions **[10]** .

Effect of geo-synthetic materials particularly geo-grids was studied in a reinforced soil when dynamic loads are applied. The results established the fact that geo-synthetic materials

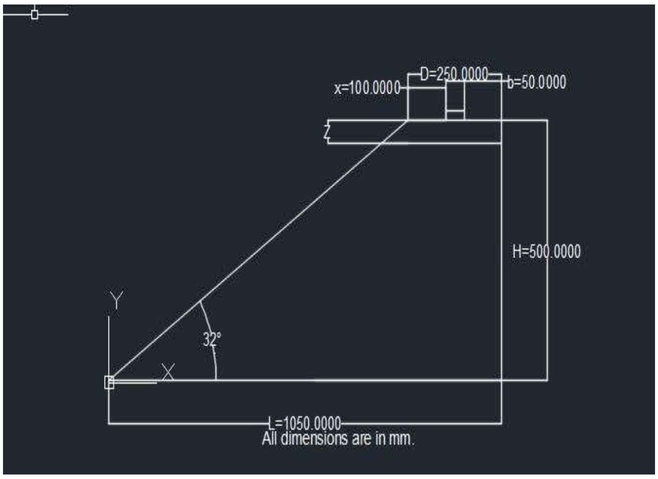

Figure 1 2-Dimensional Geometric Model of Slope

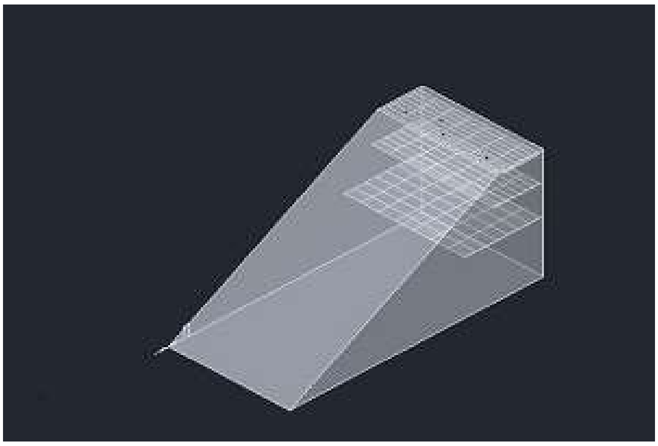

Figure 2 3-Dimensional Model of Slope With Installed Geogrid Layers

can be used for enhancement in properties of soils when subjected to dynamic loads also. Different tests were conducted on soil model with variable frequencies as 0.2, 0.4 and 1 hertz and displacement amplitude of 2mm on reinforced and un-reinforced soil models. It was concluded that different parameters laid considerate effect on has been observed that there is considerable effect on strength of soil on variance of number of reinforcement layer, size of reinforcement and spacing of reinforcement layers [12-16]. It was also observed that variance of frequency of loading effected the dynamic bearing capacity. Decrease in settlement of the reinforced subgrades was also observed. PLAXIS is a finite element method (FEM) based software package that has been programmed explicitly for the evaluation of deformation and stability in geo-tech based engineering assignments. With easy input technique used by Plaxis as in the form of graphical input the process of generation of complex finite element models has hastened, and the improved output facilities have been found of providing in depth exhibition of calculated results. Earthquakes are considered as natural source of vibration. Dynamic analysis is set to be carried out when the frequency of vibration exceeds the natural frequency of the system. Vibrations with lower frequency values are computed by

pseudo-static approach. While exhibiting the response of dynamic loads on a soil structure, the inertia and time dependence of load on sub-soil are also taken into consideration while carrying out the analysis [16-22].

2. Material Properties

The soil used for the analysis has been locally procured from the banks of river Solani region roorkee India and determined experimentally. The properties of used soil are enlisted in Table 1. Furthermore the propertes have been compared with [5] that have been observed in the same region and fund in good agreement.

Geogrid as a soil reinforcing material has improvised the strength of soil embankments and slopes significantly to aiding to an economical and durable construction of soil slopes Mechanical properties of geogrid material used in the study are given in Table 2

The model of concrete footing ha been used during the study and its values have been callibirated with numerical model. Properties of Model footing are enlisted in Table 3.The model was scaled as 1x .5 x .5 m with slope angle of 32° and a model footing of 50 x 50x 30 mm which was loaded suitably with primarily Geogrid layers Installed in it

Table 1 Properties of Soil

Model of Analysis	**Mohr-Coulomb**
Soil	SP
Unsaturated Unit Weight (Υ_{unsat})	14.55 kN/m^3
Saturated Unit Weight (Υ_{sat})	18.55 kN/m^3
Initial Void Ratio ($e_{int)}$)	0.670
Modulus of Elasticity	13000kN/m^2
Poisson's Ratio (ν)	0.3
Modulus of Rigidity (G)	5000kN/m^2
Internal Angle of Friction (ϕ)	36°.50°
Cohesion (c)	1.0 kN/m^2
Dialatancy Angle (ψ)	0.00°
Specific Gravity (G)	2.43
Grain Size mm (D_{50})	.27
Uniformity Coefficient	1.90
Maximum Void Ratio (e_{max})	.86
Minimum Void Ratio (e_{min})	.48

Table 2 Mechanical Properties of Geogrid Used

Mechanical Properties of Geogrid Material Used	
Property	Value
Peak Tensile Resistance	0.62 kN/m
Elastic Modulus	40 MPa
Tensile Strength	0.44 MPa
Percentage Elongation at Maximu load	1.4%
Yield Strength at 10% Strain	0.47 kN/m

Table 3 Properties of Model Footing

Properties of Footing Used	
Property	Value
Width (b)	50 mm
Height (h)	30 mm
Moment of Inertia (I)	1.125* 10^{-7} mm^4
Characteristic Strength (fck)	25kN/mm^2
Modulus of Elasticty (E_f)	23.5 *10^5 N/mm^2

The Strong motion file (SMC File) of earthquake used during the analysis was of **WNW of Ferndale, California** Earthquake that occurred on 10/03/2014, 05:18 UTC (09/03/2014, 21:18 PM PDT) [23]**.** Its magnitude was 6.80 recorded on Richter scale. Earthquake was recorded at 73.20 km from epicenter with maximum frequency of 200Hz. It recorded motion is given in 6- Noded Mesh model of the slope has been shown in Figure 4. The meshing of model has been done in 6 noded triangular elemets with fine meshing technique for better visualisation of results.

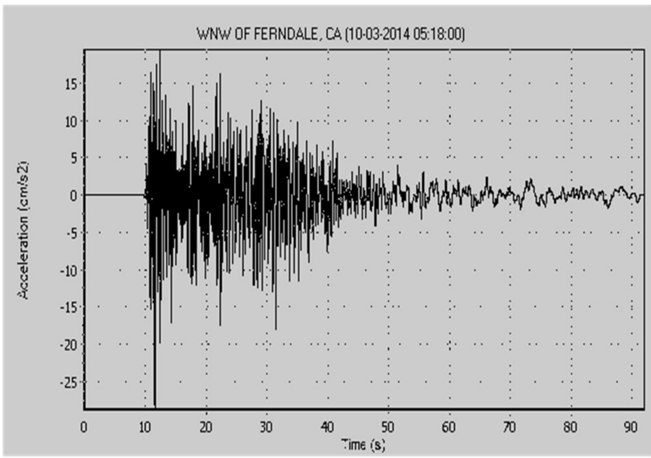

Figure 3 SMC File characteristics of Ferndale earthquake

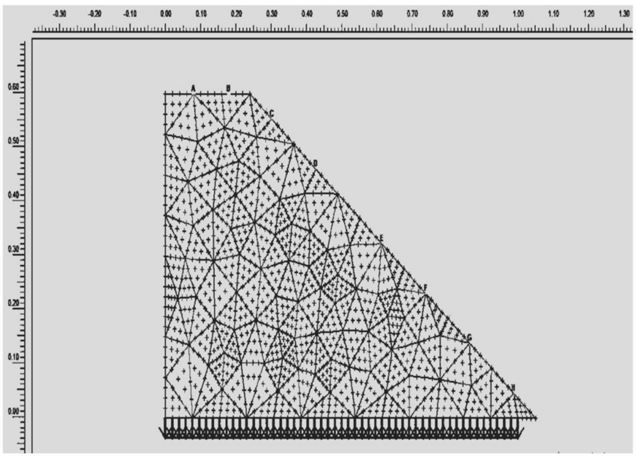

Figure 4 6 Noded mesh for the calculation of prescribed displacements

3. Numerical Study

The present study aims at determination of behavior of soil slopes under the effect of earthquake loads. Mohr-Coulomb model is the well-known model used as a first approximation of soil behavior in general. The model involves five parameters, namely Young's modulus, (E), Poisson's ratio (ν), cohesion (c), the friction angle (ϕ) and the dilatancy angle (ψ). This model is primarily opted for its simulation benefits which can be opted in lab as well. The Mohr–Coulomb criterion in point of fact performs as an elastic, perfectly-plastic constitutive model, it serves both as the yield surface and the failure surface. Subsequently the Mohr–Coulomb criterion is used for pressure-dependent materials.

$$\tau = c + \sigma \operatorname{Tan}(\phi) \qquad (1)$$

where (τ) is the shear strength, is the (σ) normal stress, c is the intercept of the failure envelope with the axis, and Tan(ϕ) is the slope of the failure envelope. The quantity (c) is often called the cohesion and Tan(ϕ) the angle is called the angle of internal friction.

Mohr–Coulomb criterion in three dimensions is often expressed as

$$\pm\frac{\sigma_1-\sigma_2}{2}=[\frac{\sigma_1+\sigma_2}{2}]\sin(\phi)+c\cos(\phi)$$
$$\pm\frac{\sigma_2-\sigma_3}{2}=[\frac{\sigma_2+\sigma_3}{2}]\sin(\phi)+c\cos(\phi) \qquad (2)$$
$$\pm\frac{\sigma_3-\sigma_1}{2}=[\frac{\sigma_3+\sigma_1}{2}]\sin(\phi)+c\cos(\phi)$$

where $\sigma_1, \sigma_2, \sigma_3$ are Normal stresses in principle directions. In this study slope was modeled in Plaxis Software and it was subjected to harmonic loading earlier and **WNW of Ferndale, California Earthquake**. The Slope was reinforced with varying number of geogrid layers and introduced to varying time intervals thus factor of safety was obtained. Optimum position and no. of reinforcement layers were determined .

Table 5 depicts the Comparison of Experimental Deformation Factor (DF) Vs Numerical Deformation Factor (DF). In the analysis slope profile was subjected to dynamic loading with constant frequency of 4HZ, varying time period and acceleration as (2.5, 5 and 10 s) and (.1g, .2g and .3g) respectively. On comparison of experimental and numerical results it was inferred that the error percentage in the results were restricted to less than 10%, which in turn suggests the usage for software for carrying out the stability analysis.

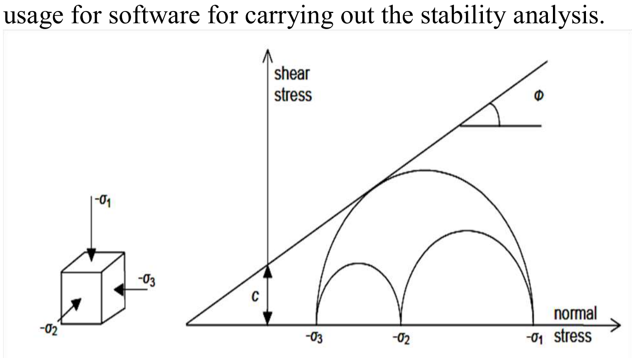

Figure 5 Mohr- Columb Failure Criterion

Table 4 Comparison Of Experimental deformation Factor vS Numerical Deformation Factor

Dynamic Load Duration		Acceleration of Dynamic Force 0.1g		
Cycle	Sec	DF Experimental	DF Plaxis	Error %
10	2.5	.109	.106	2.75
20	5	.134	.128	4.47
40	10	.161	.153	5
		Acceleration of Dynamic Force 0.2g		
10	2.5	.139	.134	3.73
20	5	.161	.153	4.96
40	10	.202	.201	.495
		Acceleration of Dynamic Force 0.3g		
10	2.5	.204	.201	1.47
20	5	.231	.249	7.79
40	10	.288	.309	7.29

Deformation factor (DF) Vs Loading cycle description is given in Figure 5.

Where, g= acceleration due to gravity, Sec = Seconds, H=Height of Slope, ΔH = Change in Height of Slope, DF= $\frac{\Delta \boldsymbol{H}}{\boldsymbol{H}}$ = Deformation Factor

Typical deformation of soil slope under seismic loads is given in figure 6.

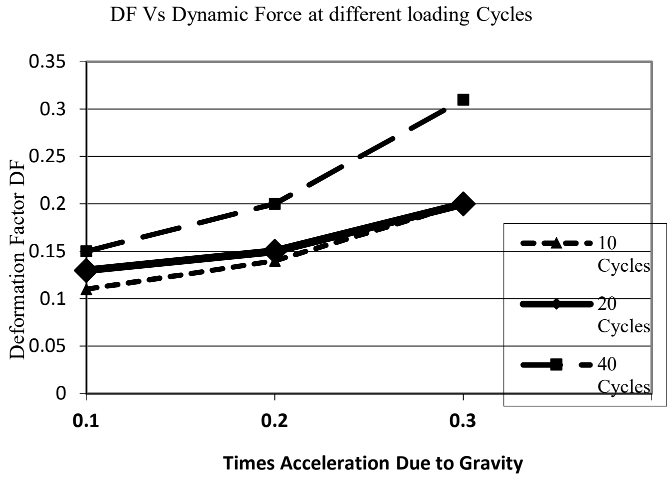

Figure 6 Graphical representation of numerical results

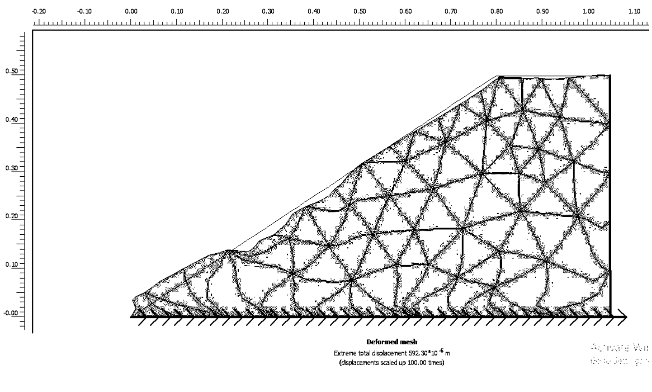

Figure 7 Representation of Deformed Soil Slope

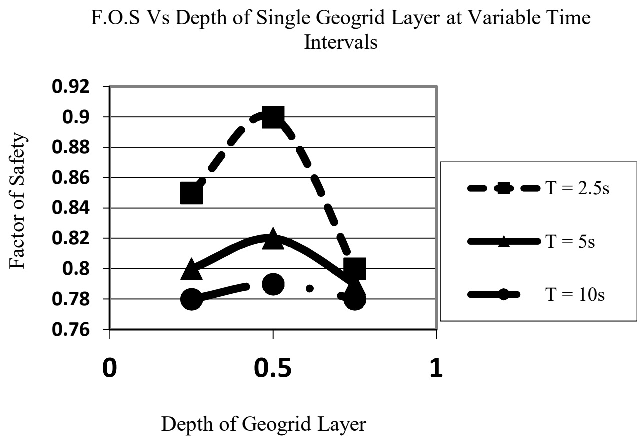

Figure 8 Factor of Safety Values for single layer of Geogrid

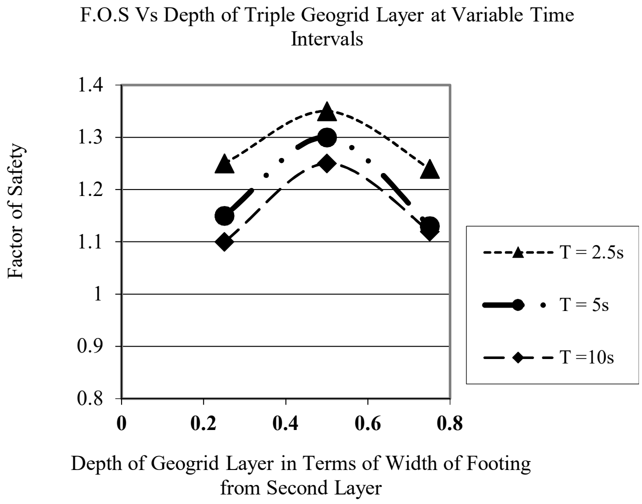

Figure 9 Factor of Safety for Three Layered Geogrid Slope

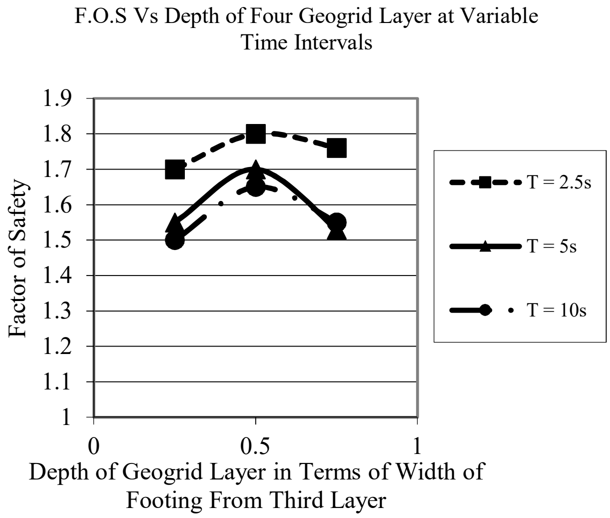

Figure 10 Factor of Safety Values for 4 layers of Geogrid

on application of Seismic loads it was observed that the slope profile failed miserably on application of seismic loads. it was recorded that peak factor of safety FS values were .7 for unreinforced slope. On Installation of geogrid layer the depth was preliminary varied from .25b (width of footing) to .75b. It was inferred from the results that due to application of seismic loads the factor of safety has still remained below 1 but it had certainly shown an increase which in other words is the indication of the slope being unstable or may lead to failure when dynamic loads are applied on it. Factor of safety Value for single layered geogrid reinforced slope are given in Figure 7.

It can be concluded from the results that the optimum depth for the installation of single layer geogrid is at .5b from the crest surface, after fixing of first layer optimum depth of 2nd layer is also determined. The maximum increase in factor of safety values was estimated to be 11.61% from the factor of safety values for slope without reinforcement for a Geogrid layer located at .5b from crest at time interval of 2.5s. It was also observed that the factor of safety is still below thus extra reinforcement that is required to make the slope safe against the designed loads. On installation of seecond and Third layer of geogrid material, optimum depth of subsequent layers is also determined. The maximum increase in factor of safety values was estimated to be 49.04% from the factor of safety values for slope without reinforcement . A considerable increase of about 36.2% from the factor of safety values at .5b from crest at which the first layer is located at time interval of 10s was also observed. Although Installation of second layer has greatly helped in development of factor of safety values. The desired results can be obtained by further adding the geogrid layers. This technique incorporates the FEM analysis to get results more realistic.

Calculation of factor of safety of three layer reinforced slope with varying embedment depth and varying time period is shown in figure 8. The maximum increase in factor of safety values was estimated to be 67.5% from the factor of safety values for slope without reinforcement and increased 36.2% from the factor of safety values at .5b from position of 2nd layer at 5 seconds. It is also noted there occurs the narrowing of difference in factor of safety values at different positions which indicates the uniform distribution of stress in the planes.

Calculation of factor of safety of four layer reinforced slope with varying embedment depth and varying time period. After installation of 4th layer sufficient factor of safety is recorded to support the construction which is above 1.5 in all the time interval changes. More Geo-grid layers can be installed although the chances of changes in strength parameters are low yet they can be used to control the superficial displacements. The maximum increase in factor of safety values was estimated to be 109.1% from the factor of safety values for slope without reinforcement and increased 25% from the factor of safety values at .5b from position of 3rd layer at 10 seconds. Factor of Safety values are given in Figure 9.

4. Conclusions

The results clearly depict that results obtained by Plaxis analysis are in accordance to the experimental results and the error percentage of results was restricted to less than 10%. It can be concluded from the results that due to variation of time period of loading cycles about 20% difference in safety factors was recorded with decrease in factor of safety values on increasing time duration of loading.The maximum increase in factor of safety values was estimated to be 109.1% from the factor of safety values for slope without reinforcement and increased 25% from the factor of safety values at .5b from position of 3rd layer at 10 seconds.It can also be concluded that optimum depth of installation of Geo-grid layers is uniform which indicates the symmetry in the distribution of stresses which extend upto 2b from the top or crest surface. It also ascertains the validation of fact that earthquakes trigger landslides

Disclosures

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