Experimental and Numerical Studies of Three Layered Reinforced Soil Slope under Dynamic Loading Condition

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Abstract. In this study, three layered soil slopes consisting of two c- ϕ soil at top and bottom and one sandy soil at middle reinforced with Geogrid and Geotextile are evaluated under dynamic loading condition experimentally by shake table test and numerically by Plaxis 2D software to assess different soil stability parameters like maximum horizontal deformation, maximum RMSA amplification and crest deformation. Base shaking acceleration, frequency and quantity of reinforcement are varied in different tests and results obtained from experimental study are compared with the results of numerical analysis. Test results revealed that inclusion of reinforcement in layered soil reduces all above parameters but more effective in reduction of maximum RMSA amplification and crest deformation. With the increase of quantity reinforcement, reduction of RMSA amplification is more in comparison to other parameters. Geogrid reinforcement is slightly better in reducing soil stability parameters

Keywords: Shake Table, RMSA Amplification factor, PLAXIS 2D

1 Introduction

Slopes are the exposed ground surface which stands at an angle with the horizontal. The stability of slope is one of the major concerned and trending research topic in geotechnical engineering for designing highway embankments, earth dams etc. Slopes may be in stable condition under static loading but under seismic loading condition it collapses due to generation of inertia force which causes reduction of strength of soil mass. In such a distress situation, soil should have enough strength to negotiate seismic force. Inclusion of reinforcement may provide required stability by absorbing seismic energy and it can transmit small amount of seismic wave to the overlying structure to mitigate earthquake related hazards. Therefore, soil should provide enough strength and desired factor of safety during and after earthquake shock. The study of slope under static loading condition is done by several researchers [1-4]. But to understand the response under seismic loading, Clough and Pirtz [5] first performed a shaking table test on model rock fill dams and concluded that earth fill dams are very much resistant to earthquake due to its flexible nature. Seed and Clough [6] studied the earthquake resistant dams and concluded that catastrophic failure is not caused by earthquake; the major effect is there is a settlement in the upper section of slope and sliding in the base of the slope. Hazari et al. [7] performed a small scale shaking table test with the variation of water content and the obtained results are verified by the numerical analysis.

2 Objective

This study is preferred to show the effect of non homogeneity of soil mass by introducing three layered soil consisting of two c-ϕ soil and one sandy soil. Stability of layered soil slopes are improved by introduction of geogrid and geotextile reinforcement in single, two and three layer separately. To measure the stability of slopes under seismic loading, model tests are conducted on shake table by varying base frequency, base shaking acceleration, quantity and type of reinforcement. The numerical analysis has been performed by PLAXIS 2D [8] using parameters obtained from laboratory investigations so that the output results can be compared with those obtained from the experimental investigations.

3 Equipment and Materials

3.1 Shake Table

A computer controlled uniaxial shaking table has been used to simulate seismic condition or any other vibrating conditions during tests. The shaking table has a 1 m × 1 m square loading platform of capacity 100 kg fitted with symmetrically placed four (4) numbers ball bearings below the platform in such a way that it can run through the base channels which are firmly fixed with the foundation through nuts and bolts. One end of the crank shaft is fitted with the shake table and the other end is fitted with 7.5 H.P. reciprocating motor whose design speed is about 1400 rpm. The shake table can be operated within the acceleration range of 0.05–0.5 g and frequency range of 1 to 7 Hz with the amplitude of ± 100 mm.Model slopes are constructed in a 12mm thick glass perspex box having inside dimension 60 cm × 40 cm × 40 cm (l × b × h) for conducting shake table test. The set up of the shake table instrument used in the present study is shown in Fig.1.

Fig. 1. Arrangement of the shake table Instrument

3.1 Soil

Three types of locally available soils are used for model slopes. Soil 1 and soil 2 are typical c-ϕ soils which are classified as silty sand and sandy clay according to IS classification. Sand is another one which is classified as poorly graded (SP) as per IS classification. The properties of each soil are tabulated in Table 1.

Table 1. Properties of soil used in the experiment

Parameters	Soil 1	Sand	Soil 2
Zone	Nil	IV	Nil
Specific Gravity	2.59	2.66	2.61
D_{60},D_{30},D_{10} (mm)	0.125,0.25 and 0.32	0.35, 0.2 and 0.28	0.25,0.30 and 0.40
C_u and C_c	1.56,2.56	1.12,1.75	1.68,2.62
Maximum dry density(kN/m3)	20.6	Nil	19.3
Classification	Silty Sand	Poorly graded sand	Sandy Clay

3.2 Reinforcement

A bi-axial geogrid having aperture size 10mm x 10mm and a geotextile are used to reinforce the model slopes. Ultimate strength of geogrid is determined as per ASTM D6637 [10]. Ultimate strength of geotextile is determined as per ASTM D4595 [9]. Properties of reinforcements are given in Table 2.

Table 2. Properties of reinforcements

Parameters	Geogrid	Geotextile
Material type	Polypropylene	Polyethylene
Ultimate tensile strength(kN/m)	25	19
Elongation at specified tensile strength	16.60	19.57 -
Aperture shape	Square	-
Thickness (mm)	3	1
Secant modulus at 2% strain (kN/m^2)	219	162
Secant modulus at 5% strain (kN/m^2)	169	155.8
Mass per unit area (kg/m^2)	0.22	0.21

3.3 Model construction and methodology

A rainfall falling system is used for uniform filling of soils in perspex box. Each model is constructed by using three types of soil (soil 1 at top, sand at middle and soil 2 at bottom of equal height). Approximately, 45 kg of soil is used for model slope consisting of 15 kg each. Uniform weight of soil in each layer in each case is achieved by providing fixed number of blows with a hammer of 4.9 kg weight. Base accelerations are varied at 0.1g, 0.2 g and 0.3g with frequencies 1 Hz, 2 Hz and 3 Hz for each base acceleration for duration of 10 seconds. In this study, total thirty five numbers of different shaking table tests are performed on un-reinforced and reinforced slope model. Schematic diagramme of a typical three layer slope with instrumentation is shown in fig 2. Law of similitude is applied in order to simulate the prototype slope and model slope with a scaling factor of 10 (λ). Accordingly the scaling parameters between model and prototype are derived inTable 3.

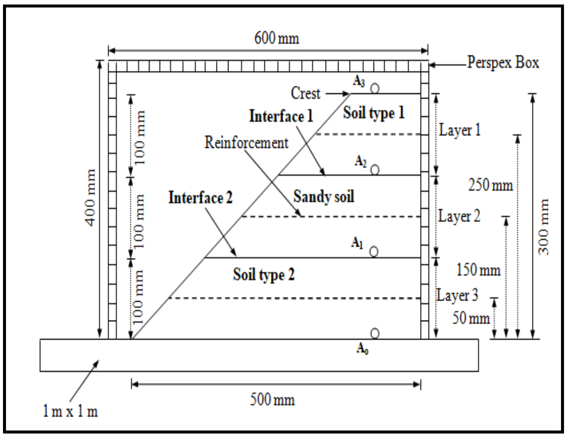

Fig. 2. Schematic diagramme of three layered soil slope

Table 3. Relationship between prototype and model

Parameters	Value of model parameters	Equation for scaling factor	Scal-ing factor	Prototype parameters
Unit weight of soil (kN/m3)	14.5, 16, 14	1	1	14.5, 16, 14
Dimension (L x B x H)	0.50 x 0.40 x 0.3	λ	10	5 x 4 x 3
Acceleration (g)	0.1, 0.2, 0.3	1	1	0.1, 0.2, 0.3
Frequency (Hz)	1, 2, 3	$1/(\lambda^{3/4})$	0.17	0.17, .34, .51
Time (s)	t	$\lambda^{3/4}$	5.623	5.623 x t
Displacement (m)	u	λ	10	10 x u

4 Results and Discussions

4.1 Effect of different frequencies

It is observed from Fig 3(a-c) that horizontal deformation decreases with increase of base frequency but RMSA amplification and crest deformation go on increasing with increase of frequency level. Inclusion of reinforcement in the slope has no significant effect on reducing horizontal and crest deformation but it has substantial effect in reducing RMSA amplification factor. Fig 3(b) reflects that at low frequency of 1Hz, reinforced slopes are de-amplified up to 0.33 normalized heights and further amplified up to a maximum value of 1. But unreinforced slopes are amplified throughout the full height of the slope .

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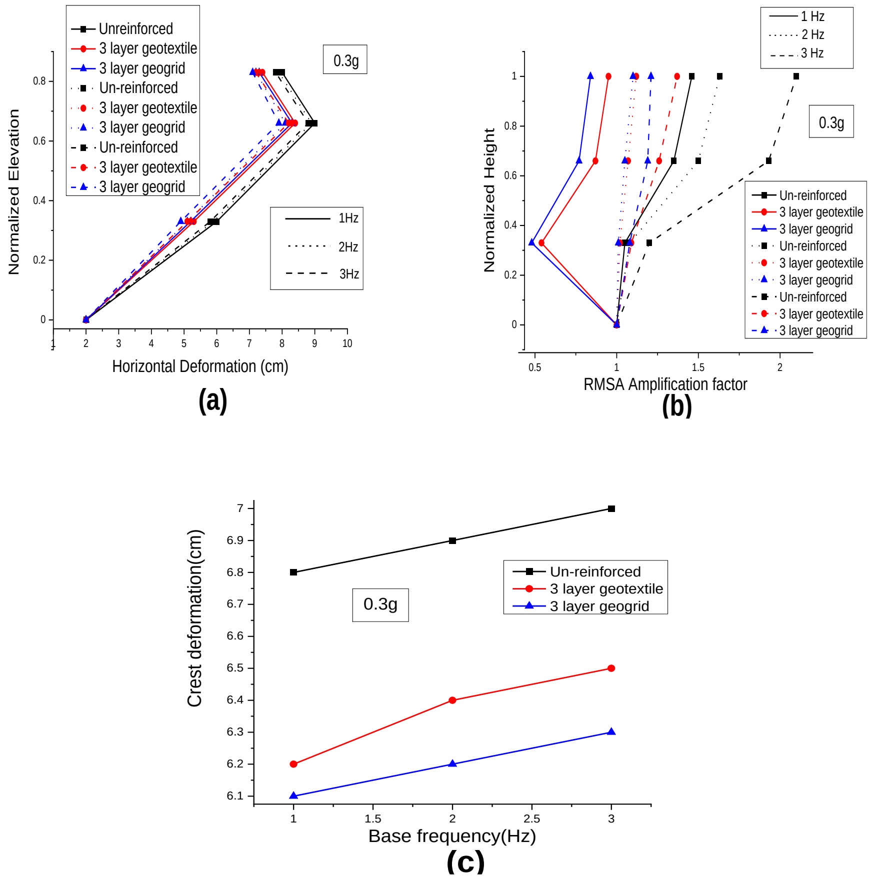

Fig. 3. Variation with frequency (a) Horizontal deformation (b) RMSA amplification factor (c) Crest deformation

4.2 Effect of different base shaking acceleration

Fig 4(a-c) shows the variation of horizontal deformation, RMSA amplification factor and crest deformation along with normalized height at different base shaking acceleration of 0.1g, 0.2g and 0.3g for a constant frequency of 3 Hz. It is seen from the plots that all above parameters are increased with increase of base shaking accelerations. Inclusion of reinforcements reduces RMSA amplification factor drastically than other two parameters. Slopes with three layer geogrid reinforcement are found to be better performing than slopes with three layer geotextile reinforcement.

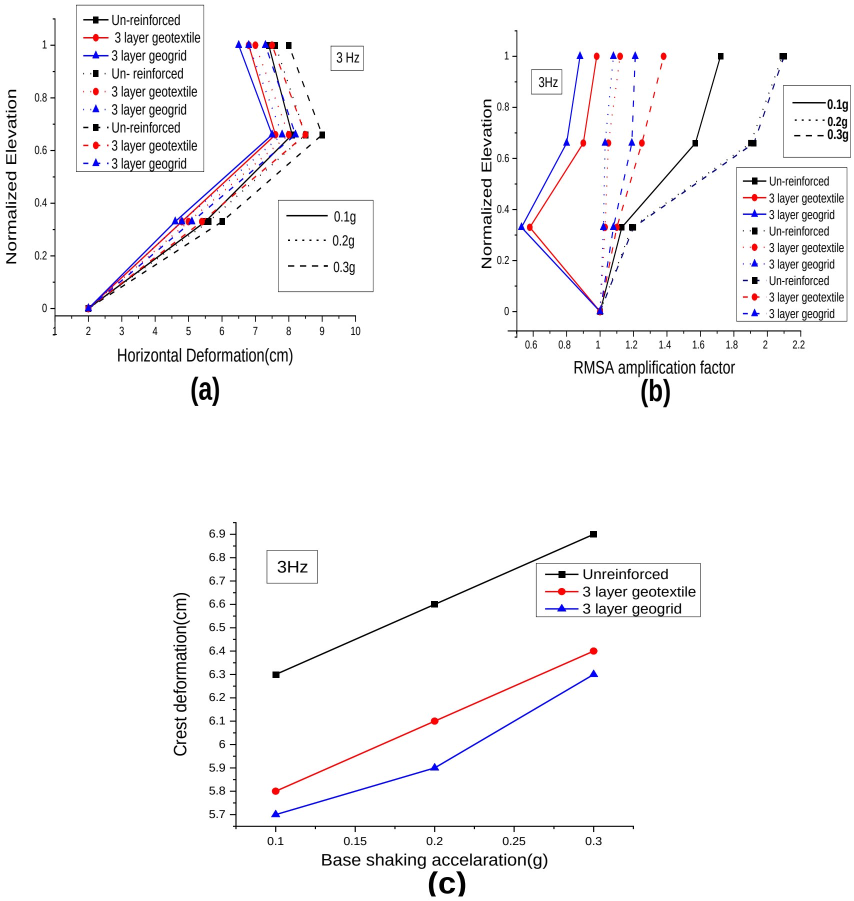

Fig. 4. Variation with base acceleration (a) Horizontal deformation (b) RMSA amplification factor (c) Crest deformation

4.3 Effect of type and quantity of reinforcement

Fig. 5(a) shows the response of horizontal deformation w.r.t. the normalized height of the slope reinforced with single, two layer and three layer geogrid/geotextile subjected to 0.3g base shaking acceleration and 3Hz frequency. Maximum horizontal deformation decreases with the increase of reinforcement quantity. Horizontal deformations are reduced to 2.2%, 4.4% and 6.6% with single, two and three layer geotextile reinforcement respectively as compared to unreinforced slope. The corresponding percentage of reduction is 4.4%., 5.5% and 10% for slopes with geogrid reinforcement.

Fig. 5(b) presents the response of RMSA amplification factor w.r.t. the normalized height of the slopes. Recorded response of acceleration amplification factors reflect the reduction up to 4.7% , 24.8% and 34.7% for single, two and three layer geotextile reinforced slopes respectively. The corresponding percentage of reduction is 6.2%., 28.5% and 42.3 % for slopes with geogrid reinforcement. Both geogrid and geotextile are effective in reduction of RMSA amplification factor but the reduction is significant for geogrid reinforced slope.

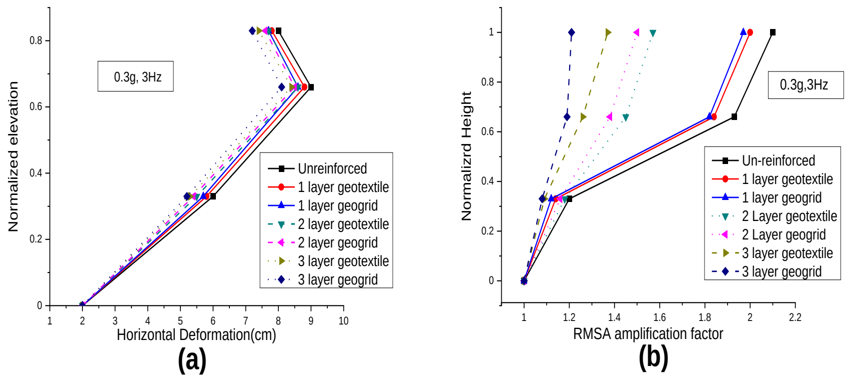

Fig. 5. Effect of type and quantity of reinforcement (a) Horizontal deformation (b) RMSA amplification factor

4.4 Comparison between homogeneous (single layered of soil 1) and layered soil slope

Fig. 6 (a, b) shows the comparison of horizontal deformation between homogeneous and three layered slopes. It is observed that in case of three layered soil slope, the horizontal deformation is maximum at normalized height 0.66, after that the horizontal deformation decreases. But in case of homogeneous soil slope, horizontal deformation is increased with elevation and gets maximum at top of the slope. On the other hand, Fig 7(a, b) shows the comparison of the RMSA amplification factor between homogeneous and three layered slopes. It is seen that in case of three layered soil slope, the rate of increase in RMSA amplification factor is different at different soil layers and it is maximum in sand layer. But in case of homogeneous soil slope, the RMSA amplification factor is not changed significantly throughout the height of the slope. The variations of the horizontal deformation and RMSA amplification factor in case of layered slope are due to the influence of the interfaces between the soils.

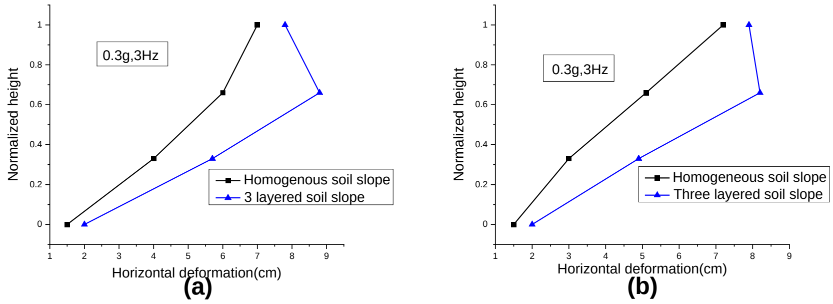

Fig 6 Comparison of horizontal deformation between homogeneous soil slope and three layered soil slopes (a) unreinforced slope (b) reinforced slope

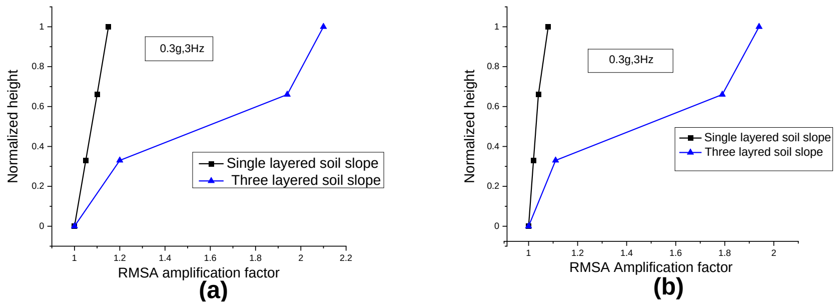

Fig. 7. Comparison of RMSA amplification factor between single layered soil slope and three layered soil slopes (a) unreinforced slope (b) reinforced slope

5 Numerical Modeling

In the present study, a two-dimensional finite element model of the experimental slope model during dynamic loading condition is developed and analyzed using PLAXIS 2D. To verify the model, the results as obtained from the experimental observation are compared with those obtained from the numerical analysis.

5.1 Geometry and boundary condition

Fig. 8 presents the geometry of the numerical model with slope angle 35°. The boundary of the model slope is considered at the base at a depth 300 mm below the top level of slope and roller at the two vertical sides; one vertical side passes through the center line of slope and another at a distance of 550mm away from the toe of the slope. A full fixed boundary condition is considered at the outer boundary of the slope. The boundaries are extended from the model to avoid the disturbances due to the possible reflections. Therefore, absorbent boundaries are adopted to avoid the reflections of the waves at left, right and bottom of the slope.

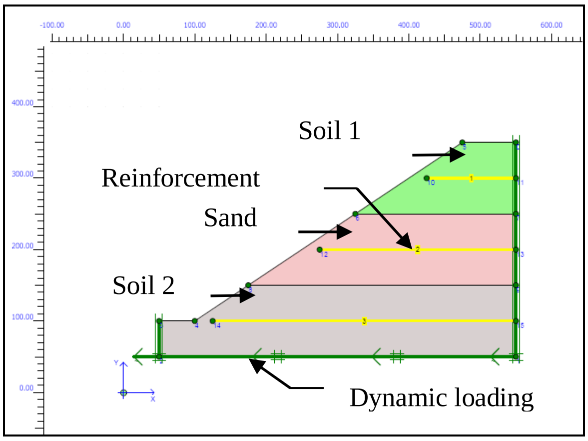

Fig. 8. Numerical model of slope at PLAXIS 2D

5.2 Mesh Generation

The slope model is divided into a number of 15-noded triangular elements having three degree of freedom in each node i.e. vertical displacement, horizontal displacement and rotation. Fig 9(a, b) shows the mesh structure of numerical model for unreinforced and reinforced slopes respectively.

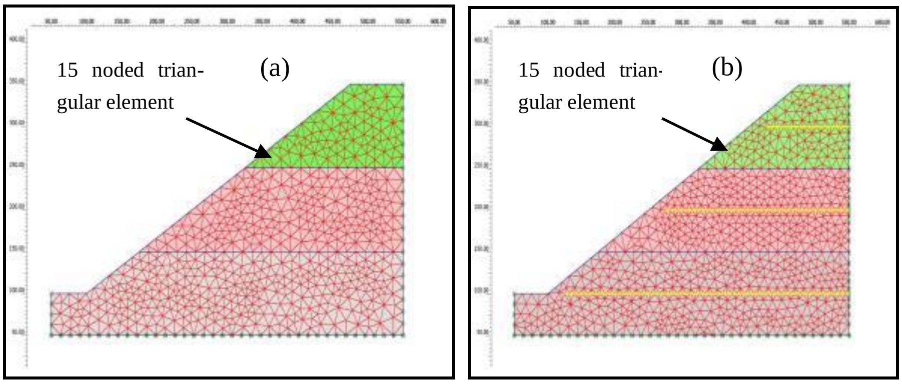

Fig. 9. Mesh structure of numerical model slope (a) Un-reinforced (b) Reinforced

5.3 Numerical results and discussions

Fig. 10(a, b) shows the deformed mesh of unreinforced and reinforced slopes due to application of the dynamic loading. Top layer of the slope goes down significantly due to presence of weak sand layer in the middle. However, subsidence of third layer is negligible. In case of reinforced slope, the top reinforcement deforms significantly. The middle and bottom reinforcements also distort after the application of dynamic loading but it is very nominal. It is also observed that meshes are deformed in the horizontal direction at the middle part of the slope for both un-reinforced and reinforced slopes but application of the reinforcement reduces deformation.

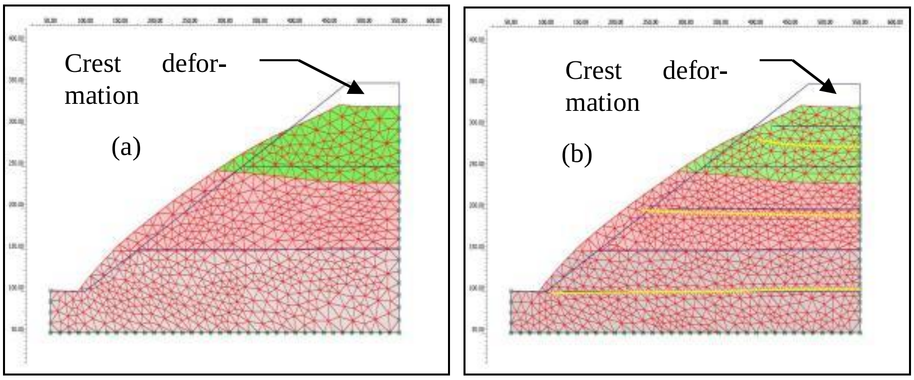

Fig. 10. Deformed mesh of model slope (a) Un-reinforced (b) Reinforced

Fig. 11 (a, b) shows the shaded horizontal deformation of un-reinforced and reinforced slopes. It is observed that horizontal deformations are appeared at the inclined face of slopes indicating rotational failures. But middle layer of the slope i.e. sand deforms more due to its cohesion less property. Fig 11(b) reveals that the provision of reinforcement reduces horizontal deformation.

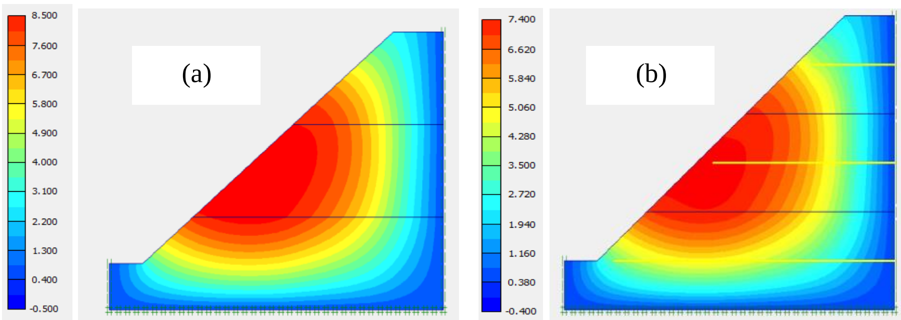

Fig. 11. Horizontal shaded deformation (a) Un-reinforced (b) Reinforced

Fig. 12 (a, b) shows the shaded vertical deformation of un-reinforced and reinforced slopes. From the plots, it is seen that the vertical deformation is very less or negligible at the base of the slope which is increased gradually with the height of the slope and at the top it is maximum. Fig. 12(b) reflects that the vertical deformation of reinforced slope is lesser in magnitudes in comparison to un- reinforced slope.

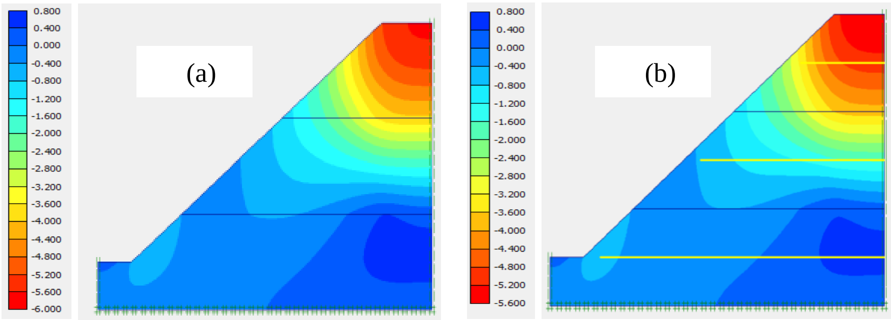

Fig. 12. Vertical shaded deformation (a) Un-reinforced (b) Reinforced

6 Comparison of Experimental and Numerical Results

The results obtained from the experimental study performed by shake table tests are compared with the results obtained from two-dimensional numerical analysis. Table 4 compares soil stability parameters on horizontal and crest deformation. From comparisons, it is concluded that results of experimental and numerical studies have good agreement with each other.

Table 4. Comparison of deformation values obtained from experimental and numerical studies at 0.3 g base shaking

		Experimental study		Numerical Study	
Reinforcement type	Frequency(Hz)	Maximum Horizontal deformation(cm)	Crest deformation(cm)	Maximum Horizontal deformation(cm)	Crest deformation(cm)
Un - reinforced	1	9.0	6.7	8.5	6.0
	2	8.9	6.9	8.0	6.4
	3	8.8	7.0	7.5	6.5
3 layer Geotextile	1	8.4	6.2	7.4	5.8
	2	8.3	6.4	7.3	6.0
	3	8.2	6.5	7.2	6.2
3 layer geogrid	1	8.3	6.0	7.3	5.7
	2	8.2	6.3	7.2	5.9
	3	8.0	6.4	7.1	6.0

7 Conclusions

The following major conclusions are drawn from the present study.

1. Inclusion of reinforcement in layered soil slope is very effective for reducing the soil stability parameters like maximum horizontal deformation, maximum RMSA amplification and crest deformation for all base accelerations and frequencies but more effective in reducing RMSA amplification.
2. It is observed that at low frequency of 1 Hz, acceleration response de- amplified up to 0.33 normalized height and amplified further up to 1.0 for reinforced slopes. But un-reinforced slopes do not show the same response.
3. Soil interfaces influence the accelerations and deformations of the slope.
4. The rate of increase of RMSA amplification factor in the middle layered soil (sand) is more than other two soil layer(c-ϕ) indicating that sand layer is the weakest layer than other two c-ϕ soil layer in mitigating stability of slopes.
5. Layered soil slope is less stable in mitigating stability parameters than slopes made up of single layered soil (homogeneous soil).
6. Experimental and numerical studies have good agreement with each other

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