ISET Journal of Earthquake Technology, Paper No. 543, Vol. 56, No. 2, June 2019, pp. 39-55

DYNAMIC RESPONSE OF GEOTEXTILE WRAP-FACED LIME TREATED REINFORCED CLAYEY SOIL WALLS

Bisrat Gidday* and Satyendra Mittal**
*Research Scholar, Civil Engineering Department, Indian Institute of Technology Roorkee, India
E-mail: *bisratgissila@gmail.com*
**Professor, Civil Engineering Department, Indian Institute of Technology Roorkee, India
E-mail: *satyendramittal@gmail.com*, Corresponding author

ABSTRACT

This paper describes model studies conducted on geotextile wrap-faced reinforced soil walls mounted on a shake table. Untreated and lime treated clay was used as backfill soils. The base motion parameters, surcharge pressure and number of reinforcing layers are varied in different model tests. It is inferred from these tests result that the response of the wrap-faced soil-retaining wall is extensively affected by the base acceleration levels, number of reinforcement and magnitude of surcharge pressure on the crest. The effects of these different parameters on acceleration response at different elevations of the retaining wall, settlement at crest and face deformations are presented in this paper. Numerical modeling has been done by computer program PLAXIS.

KEYWORDS: Geosynthetics, Retaining Wall, Shake Table Tests, Dynamic Analysis, Numerical Models, Lime

NOMENCLATURE

LVDTs: linear variable displacement transducers
Sv: vertical spacing between reinforcement
U1: displacement sensor one
U2: displacement sensor two
U3: displacement sensor three
Vp: primary wave velocity of soil
Vs: shear wave velocity of soil
WRSW: wrap faced reinforced soil retaining wall

INTRODUCTION

Reinforcement of soil to increase the stability of slopes and decreasing its deformations has now been a workable solution for geotechnical engineers to construct walls even in less space Mittal [1]. But, limited studies are available on the seismic response of reinforced soil slopes, (Perez [2], Perez and Holtz [3], Lo Grasso et al. [4], Nova-Roessig and Sitar [5] and Huang et al. [6]). GRS (Geosynthetic Reinforced soil) structures have also been examined with respect to enhancing the seismic stability of bridge abutments supporting bridge decks. Aoki et al. [7] carried out shaking table tests with 1 g acceleration on conventional and GRS bridge abutment models using cement treated backfill.

Krishna and Latha [8] investigated the seismic response of geotextile wrap-faced reinforced soil wall by conducting shaking table tests on model walls. They concluded that the seismic response of the retaining walls is extensively affected by the variations in base motion parameters, reinforcement configuration and surcharge pressure. Each model wall was subjected to 20 cycles of sinusoidal shaking. Saito et al. [9] carried out series of shaking table tests with cement treated sandy backfill soils in combination with geosynthetic reinforcement. The current AASHTO [10] technique in the USA limits pseudo-static methods to peak horizontal ground accelerations < 0.3 g.

Koseki et al. [11] conducted displacement-based analyses which is significant as engineers concentrate on performance-based (serviceability-based) design. Authors concluded that reinforced soil walls can out-perform conventional unreinforced soil retaining wall structures with respect to displacement performance.

Nevertheless, direct relationship of the displacement-time response of these two different classes of structures under nominally identical conditions using the same computational methods remains to be done. In addition, reinforced-soil walls are generally more flexible than conventional walls. Thus, they may be used in areas where large uneven displacements due to surface faulting during earthquake events are expected.

Suzuki et al. [12] examined the effects of the overburden pressure, the cement treatment, the pretension load, and the acceleration on the shaking behavior of the reinforced soil wall separately through a series of tests. Based on the test results, they discussed the characteristics of shaking pullout behavior of the strip and instantaneous displacement of the retaining wall. Finally they concluded that the displacement of the facing wall was smaller with increasing overburden pressure during the test and the use of cement -treated soil can critically enhance the stability of a reinforced soil wall, even if a big acceleration happens during an earthquake. Increasing functions of geosynthetics in permanent and main structures need design procedures that may ensure strength or acceptable displacement under seismic loading (Ling et al. [13]).

Srilatha et al. [14] observed the effect of frequency of base shaking on the dynamic response of unreinforced and reinforced soil slopes via a series of shaking table tests. Slopes were built using clayey sand and geogrids were used for reinforcing the slopes. Two different slope angles 45^0 and 60^0 were used in tests and the quantity, location of reinforcement were varied in different tests.

This paper aims at understanding the performance of wrap-faced reinforced soil retaining wall by using untreated and lime treated clay soil as a backfill material under seismic conditions through laboratory shaking table tests and simulate them in numerical model.

WRAP-FACED REINFORCED WALLS AND THEIR DYNAMIC BEHAVIOUR

Wrap-around structures are constructed by folding an extended reinforcing element (geotextile or geogrid) through 180^0 to form the face and anchoring it back into the fill or to another element at a higher elevation (Koerner [15]). A flexible soft facing is formed by wrapping each layer of reinforcement around individual lifts or pillows of fill which is shown in Figure 1. The reinforcement is anchored back into the fill either by pinning or by partial burial of the inner end by a sub layer of the encapsulated fill. Fill is usually placed and compacted against external, temporary framework. The face permits free movement of the reinforcing inclusion, thus allowing it to follow any settlement of the reinforced soil block (BS 8006 [16]).

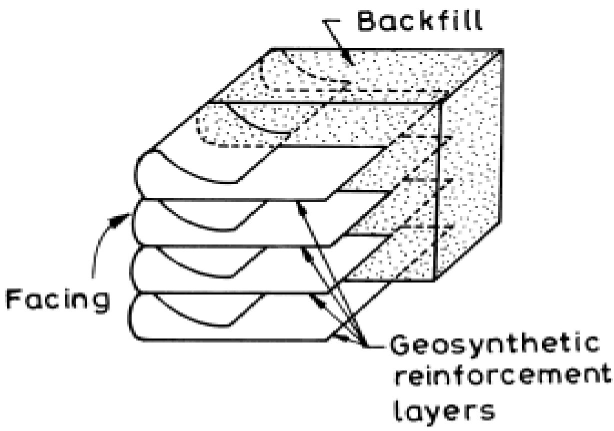

Fig. 1 Schematic diagram of a geosynthetic-reinforced soil retaining wall (Koerner, 1999)

Juran and Christopher [17] explained the results of a laboratory model study on the strength, behavior and failure mechanisms of reinforced soil-retaining walls using different reinforcing materials: woven polyester geotextile strips, plastic grids, and nonwoven geotextile strips. Palmeira and Gomes [18] described comparisons of predicted stability analyses with measured and investigated results of model reinforced soil walls using theoretical design methods. Sakaguchi et al. [19] and Sakaguchi [20] explained centrifuge tests conducted on model walls 150 mm high using 0.3 g acceleration, which corresponds to a 4.5 m high prototype wall, with geotextile reinforcement and lightweight rigid facing.

Koga et al. [21] tested retaining wall models of 1.0 to 1.8 m high with vertical and inclined slopes at one seventh scales, and investigated that deformations decreased with increasing reinforcement stiffness and density and decreasing face slope angle.

Therefore, the main aim of this research was to deal with the aspect of both reduction in deformation at the wall face and settlement at the crest adjacent to the wall face by increasing reinforcing layer for both untreated and lime treated local clay soil as a backfill material on WRSW.

EQUIPMENT AND MATERIALS USED IN THE EXPERIMENTS

1. Shaking Table

The test bin is a rectangular tank 600 mm wide, 1060 mm long and 600 mm high as shown in Figure 2. The sides of the tank consist of rigid mild steel frame with 5 mm thick steel panels. The tank is build up on a horizontal shake table. The platform with wheels rests on four knife edges being firmly fitted on two pairs of rails anchored to the foundation. This is driven in horizontal direction by a 3 H.P. A.C. motor through crank mechanism, for shifting rotary motion into translatory motion. The amplitude of motion can be changed through two eccentric shafts. By changing the relative position of two shafts, the amplitude can be fixed as desired. The hand brake assembly is used for discontinue the shake table. The maximum amplitude of horizontal acceleration which can be generated in the shake table was up to 0.3 g. The shake table could be shaked at 4, 8 and 12 Hz frequencies. For present study work acceleration of shaking was 0.1 g, 0.2 g and 0.3 g in all the tests to maximize the response and the frequency of shaking was kept the same in all tests as 4 Hz.

Fig. 2 View of shake table and surcharge weights

2. Test Material

Locally available soft clay was used as the backfill material and it was classified as CH according to the Unified Soil Classification System (Mittal and Shukla [22]). The properties of untreated and lime treated clay used are given in the Table 1 and Table 2.

Table 1: Properties of untreated backfill clay

Parameter	Value
Specific gravity	2.75
Liquid limit (%)	67.88
Plastic limit (%)	34.69
Shrinkage limit	19.5
Plasticity index (%)	33.19
Optimum moisture content, (%)	26
Maximum dry density, (kN/m^3)	15.33

Table 2: Properties of lime treated backfill clay

Parameter	Value
Specific gravity	2.62
Liquid limit (%)	60.59
Plastic limit (%)	43.86
Shrinkage limit	15.18
Plasticity index (%)	16.73
Optimum moisture content, (%)	21
Maximum dry density, (kN/m^3)	16

3. Lime

Soft clay deposits are broadly located in various coastal areas and they show poor strength and compressibility. Use of various improvement techniques for soft soil particularly soft clay is used in a wide range. These methods were based on using lime, cement and fly ash stabilization as examined by earlier studies presented by Ali et al. [23], Balasubramaniam et al. [24]. The optimum lime content required for efficient stabilization of clay soil was found to be between 3 to 7 percent (Sivapullaiah et al. [25]). For present study 7 % of lime content was used to blend the clay that used as a backfill material on wrap-faced reinforced soil walls.

4. Multichannel Analysis of Surface Waves (MASW)

Surface waves travel along the interface between two different media, i.e. near the surface of the Earth, and are the results of interfering P-waves and/or S-waves (Xia et al. [26]).There are two major kinds of surface waves; Rayleigh waves and Love waves (Evrett, [27]). For the present study, a comprehensive seismic dataset is acquired nearby the place where such soils are available, with the goal of determining Vs and Vp as an input parameter for PLAXIS software which are equal to 234 m/s and 487.11 m/s respectively with 0.35 Poisson ratio (used for present study). To determine Vp and Vs the geophones (Data receivers) are laid along the surface of the soil within 1 m difference, the seismic source (Strike plate) is placed at 2 m away from the last geophone, after connecting the multi channel seismograph (ACQ device) with data line and controller (Portable computer), the source is triggered to produce surface wave, finally analyzing the data acquisition with software set up were done. Figure 3 shows exploitation of surface wave (SW) propagation for retrieving Vs profiles.

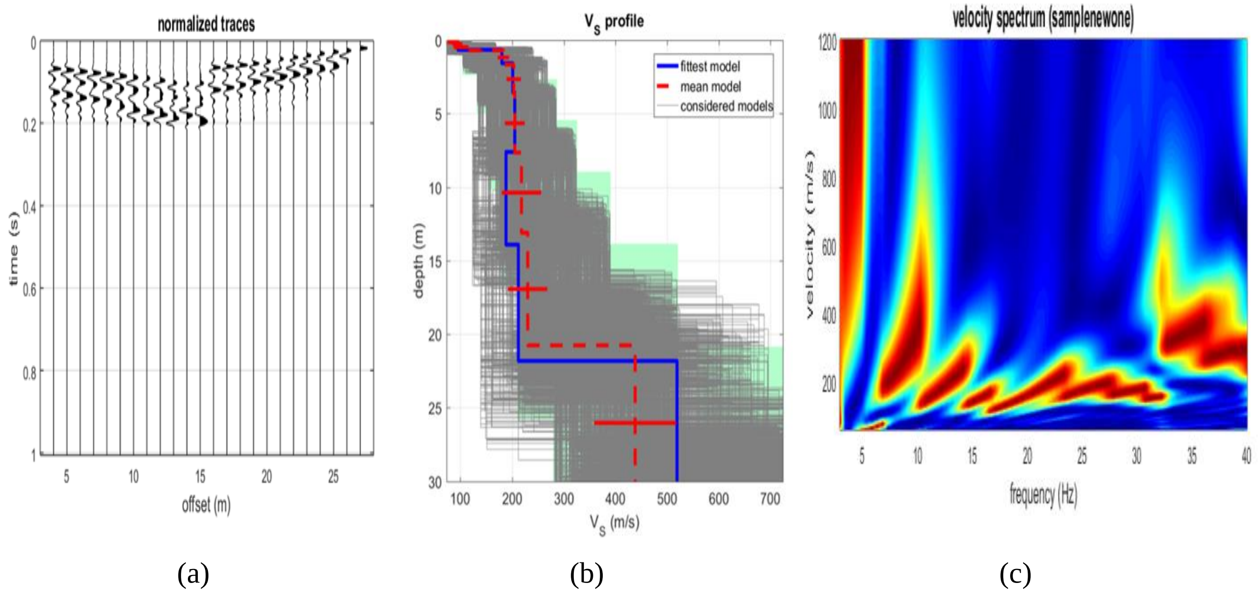

Fig. 3 a) synthetic traces (vertical component); b) Vs model; c) phase velocity spectrum

5. Reinforcement

A non woven polypropylene multifilament geotextile was used for reinforcing the untreated and lime treated clay in the tests. The properties of the geotextile are shown in Table 3. The tensile strength of the geotextile, obtained by the wide-width strip method (ASTM [28]) was 20.5 kN/m. The load–elongation response of the geotextile is determined from the wide-width tensile strength test performed in the weft direction is presented in Figure 4.

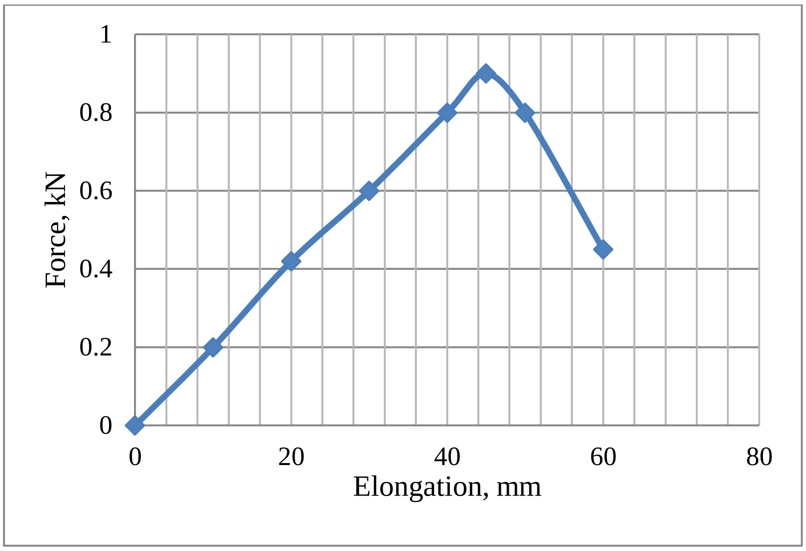

Fig. 4 Force (kN) Vs Elongation (mm)

Table 3: Properties of geotextile

Property	Value
Tensile strength (kN/m)	
Warp/Machine direction Weft/Cross direction	10.5 20.5
Elongation at break (%)	
Warp/Machine direction Weft/Cross direction	41.63 51.65
Secant stiffness (kN/m)	
Warp/Machine direction Weft/Cross direction	24.28 28.6
Thickness (mm)	1.5
Mass per unit area (GSM)	334

MODEL CONSTRUCTION AND TESTING PROCEDURE

The model of retaining walls will be built in a rectangular box to a size of 1060 mm × 600 mm in plan area and 600 mm deep. The model was built in lifts of equal height while reinforcing every lift with a layer of non woven geotextile. Each geotextile layer was wrapped at the facing for a length of 125 mm (4 layer), 100 mm (5 layer) and 83.33 mm (6 layer). The backfill clay soil was placed in the rectangular box to attain the desired unit weight and maximum dry unit weight that was obtained by Modified Proctor test during preparation of the retaining wall model. However, the maximum dry unit weight attained in each test was monitored by collecting samples in small cups of known volume placed at different locations and levels during preparation of the retaining wall model. The retaining wall was built using wooden plank formwork for every lift. After the completion of all lifts up to full height of the wall (500 mm), a surcharge of 1.62 kPa in the form of metal plate (53.5 kg with size 0.6 m x 0.55 m) and 3 kPa in the form of concrete slab (180 kg with size 0.6 m x 1.0 m), was applied to anchor the top wrapped geotextile. The facing formwork was removed carefully in sequential lifts from bottom to top after the backfill layers and surcharge were completed. Figure 5 shows the finished wrap faces, for five-layer and six-layer configurations after shaking with acceleration 0.2 g and a frequency of 4 Hz.

(a)

(b)

Fig. 5 Finished wrap-faced wall profiles: (a) five-layer configuration; (b) six-layer configuration

To measure horizontal displacement, three displacement sensors (LVDTs), U1, U2 and U3, were located at elevations 150, 300 and 450 mm respectively, along the facing for the tests with different layer configurations. LVDTs are positioned in place using a T-shaped bracket made up of angle sections that is firmly connected to the shaking table box frame and base, as shown in Figure 6. The locations of LVDTs are adjusted slightly to match the layer height in the tests with different layer configurations.

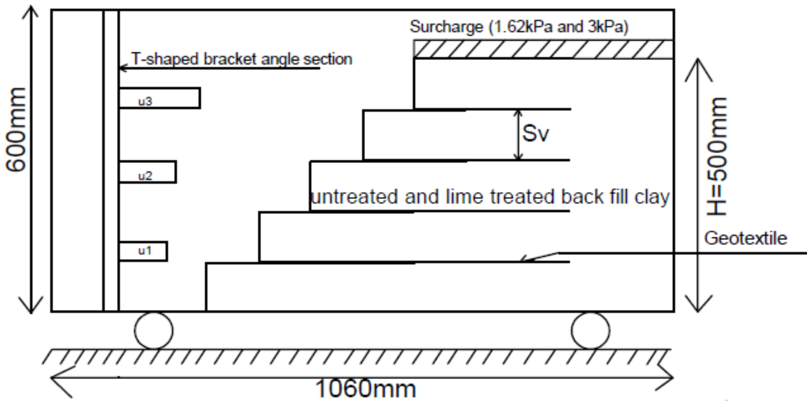

Fig. 6 Schematic illustration of typical test wall configuration and instrumentation

RESULTS AND DISCUSSION

Results investigated from different shaking table tests on wrap-faced reinforced soil-retaining wall models and numerical analysis by finite element using PLAXIS 2D model with and without lime as a back fill materials on wrap-faced reinforced soil-retaining wall models are presented in this paper. The parameters varied in model tests are base acceleration, number of layers and surcharge pressure on the crest. These parameters for different model tests are given in Table 4 and coded from M1 to M12. The surcharge pressure was kept 1.62 and 3 kPa. The base acceleration was kept as 0.1 g, 0.2 g and 0.3 g in different tests. The frequency was kept constant as 4 Hz. The number of layers were varied as 4, 5 and 6, giving Sv/H ratios of 0.25, 0.20 and 0.17 (where Sv is the vertical spacing of the reinforcement layers). Each model was built using clay in equal lifts (Sv) of 125 mm, 100 mm and 83.33 mm height for four, five and six layer configurations respectively, to achieve a total wall height (H) of 500 mm. The length (L) of the geotextile reinforcement at the interface of the untreated and treated clay layers was kept the same in all tests as 600 mm. The gap between the successive layers is 2 mm, each model wall was subjected to 20 cycles of sinusoidal shaking and angle of the slope kept the same in all test as 45^0 for present study.

Table 4: Test parameters

Test code	Frequency (Hz)	Base acceleration (g)	Surcharge (kPa)	No. of layers
M1	4	0.1	1.62	4
M2	4	0.1	3	4
M3	4	0.2	1.62	4
M4	4	0.2	3	4
M5	4	0.3	3	4
M6	4	0.1	1.62	5
M7	4	0.1	3	5
M8	4	0.2	1.62	5
M9	4	0.2	3	5
M10	4	0.3	3	5
M11	4	0.1	1.62	6
M12	4	0.1	3	6
M13	4	0.2	1.62	6
M14	4	0.2	3	6
M15	4	0.3	3	6

1. Effect of Acceleration on Horizontal Face Displacement

Horizontal face displacements along the height of the wall were examined using three LVDTs (represented by U1, U2 and U3) positioned as shown in Figure 6. Acceleration–displacement histories of the model test M4, M9 and M14, with 3kPa surcharge, 0.2 g base acceleration, 4 Hz frequency of base sinusoidal motion and 4, 5 and 6 layers of reinforcement placed at different elevations with untreated and lime treated clay as a backfill material on WRSW are shown in Figures 7 and 8. These figures show the effect of base acceleration on the face displacement response along the height of the wall. It is examined that the face displacement decreases as reinforcing layers increase. In addition, the lime treated clay backfill material shows still lower face displacement as compared to untreated backfill for all layers. The higher displacement is recorded with four layer reinforcement on untreated backfill clay at 450 mm elevation which is 30.5 mm. The same is reduced to 26 mm when the clay backfill is reinforced with lime. Maximum acceleration amplification is observed at the top of the wall in all the tests. This observation is in concurrence with the results of physical tests reported by Telekes et al. [29], Murata et al. [30] and El-Emam & Bathurst [31].

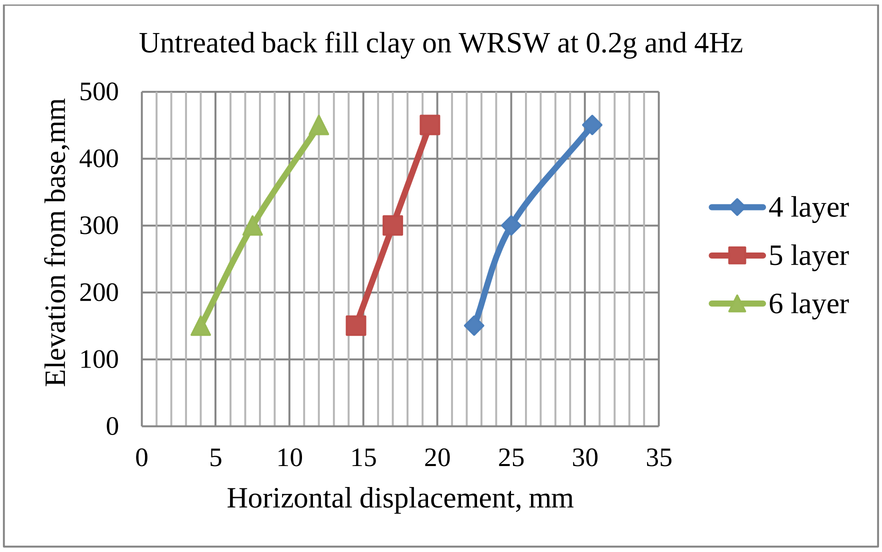

Fig. 7 Effect of base acceleration on reinforcement layers (Untreated backfill)

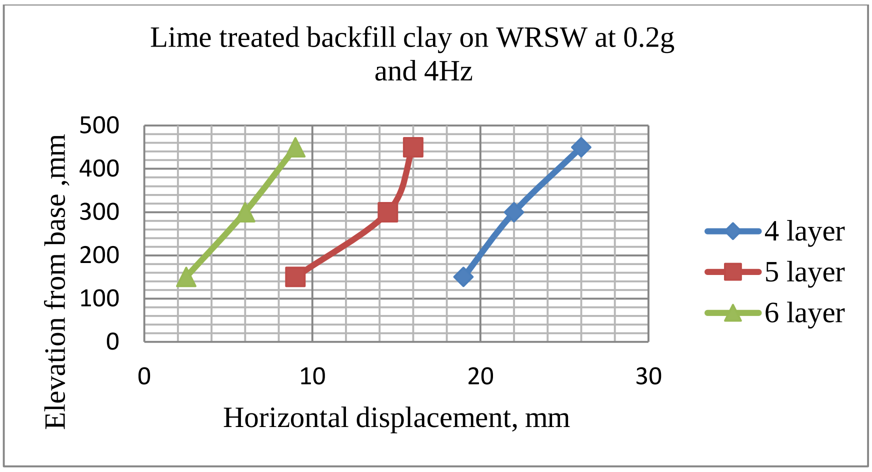

Fig. 8 Effect of base acceleration on reinforcement layers (Treated backfill)

Figures 9 and 10 describe the effect of base acceleration and surcharge on horizontal face displacement along the height of the wall for tests M1, M2, M3 and M5 with different base acceleration of 0.1 g, 0.2 g and 0.3 g. As shown in Table 4, these four tests are conducted with frequency of 4 Hz and 1.62 kPa and 3 kPa surcharges on the test wall with four layers of reinforcement (Sv/H = 0.25). From the figure it is observed that acceleration response against face displacement variation is directly proportional for both untreated and lime treated backfill clay. Horizontal face displacement is decreased by 11.07% when treated backfill on WRSW is used at 450 mm height with 0.3 g acceleration. Within the range of tests parameters, higher displacements are observed at the top of the wall for base accelerations and surcharge pressures.

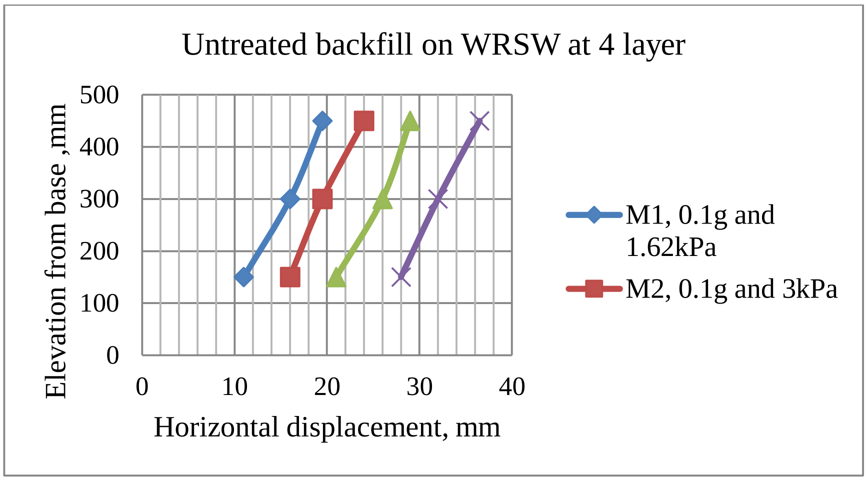

Fig. 9 Effect of acceleration and surcharges on horizontal displacement (Untreated)

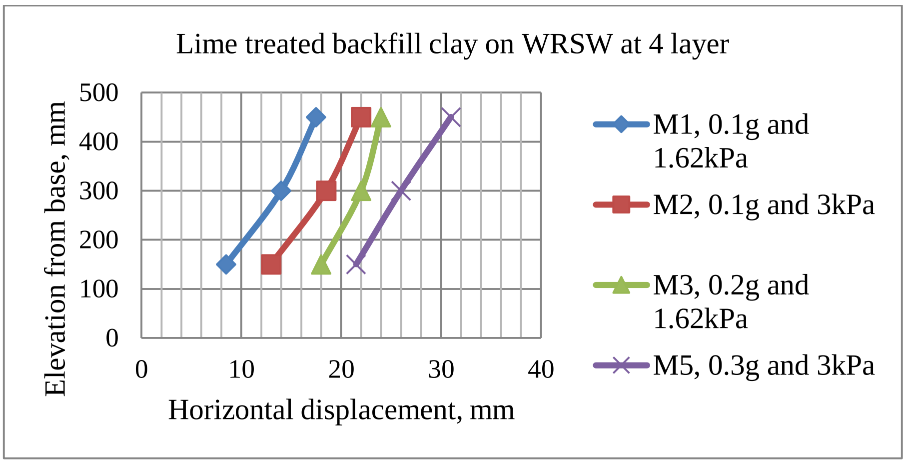

Fig. 10 Effect of acceleration and surcharges on horizontal displacement (Treated)

2. Effect of Acceleration on Crest Settlement

Vertical settlements on the top of the wall were measured after the test. Acceleration– settlement histories of different models with 1.62 kPa and 3 kPa surcharges, 0.1, 0.2 g and 0.3 g base acceleration, 4 Hz frequency of base sinusoidal motion and 4, 5 and 6 layers of reinforcement, with untreated and lime treated clay as a backfill material on wrap-faced reinforced soil retaining wall are shown in Figures 11 and 12. These figures describe the effect of base acceleration on the crest settlement response on the top of the wall. It is observed that the crest settlement decreases with increase in reinforcing layer, as simultaneously a decrease in surcharge pressures and accelerations of the wall occurs with all layers for both untreated and lime treated backfill material on WRSW. In addition lime treated clay backfill material shows lower crest settlement as compared to untreated backfill for all layers. Crest settlement is decreased by 14.28% and 13.64% when treated backfill on WRSW is used at 4 layers and 5 layers respectively with 0.3 g acceleration. The higher crest settlements recorded with four layer and reinforcement untreated backfill clay at 0.3 g base acceleration which was 0.98mm. Higher crest settlement is observed at higher acceleration in all the tests.

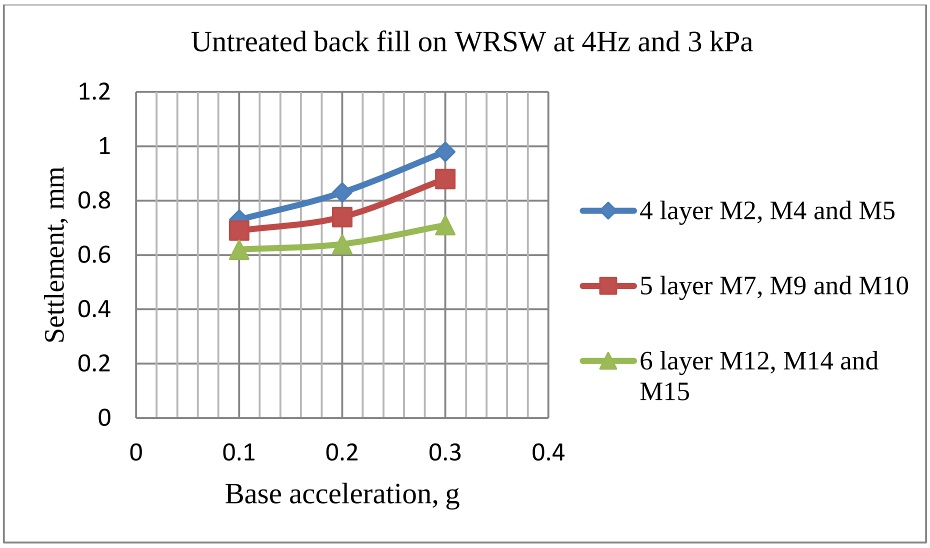

Fig. 11 Effect of acceleration with untreated backfill on crest settlement

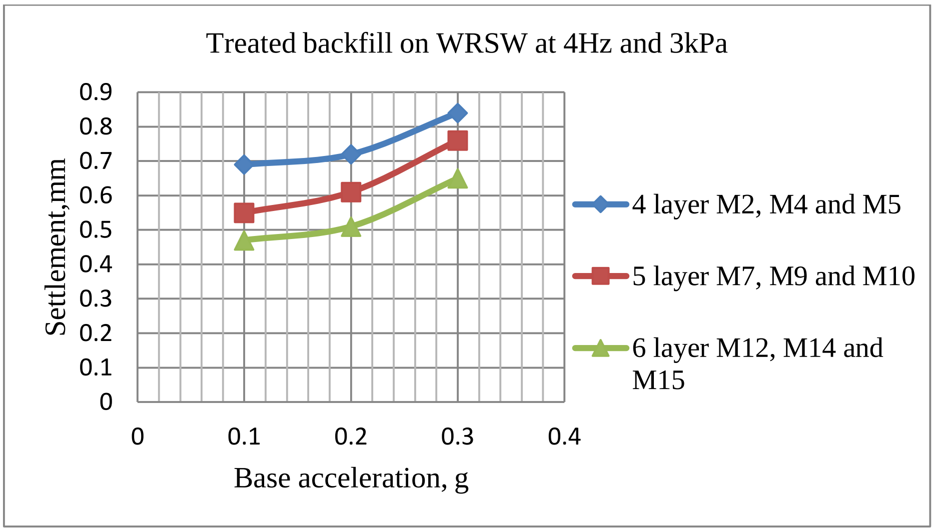

Fig. 12 Effect of acceleration with treated backfill on crest settlement

3. Numerical Modeling

Numerical models to simulate rectangular model box tests on wrap-faced geotextile reinforced soil retaining wall by applying surcharge pressure on the top of wall were developed using the computer program PLAXIS Version 8.2. PLAXIS is a finite element program for geotechnical application in which soil models are used to simulate the soil behavior. Numerical modeling methods are influential tools that have been used to study the static and dynamic behavior of reinforced soil structures (Bathurst and Hatami [32], El-Emam et al. [33]).

3.1. Numerical Grid and Material Properties

The numerical grid for the geometry is chosen to signify the physical model that was tested on rectangular box. Figures 13, 14 and 15 show the typical total displacement and deviatoric stresses of the numerical model at the end of construction with 4, 5 and 6 layers respectively to simulate the wrap- faced reinforced untreated soil retaining wall model. Construction sequence in the numerical model is followed as that of the physical model, i.e. building up the wall in stage wise with front lateral support, applying surcharge and removal of supports from top to bottom after building up to the full height. Numerical grid is solved for the equilibrium at each stage of construction process. Untreated and lime treated backfill material properties are shown in the Table 5 and 6 respectively. Some of the coefficients for the models were adopted from triaxial test.

Table 5: Material properties of untreated clay soil

Parameter	**Name**	**Value**	**Unit**
Material model	Model	Mohr-Coulomb	-
Type of material behaviour	Type	Undrained	-
Unit weight	γ	19.80	kN/m^3
Poisson's ratio	μ	0.35	-
Primary velocity	Vp	487.11	m/s
Secondary velocity	Vs	234.00	m/s

Table 6: Material properties of the lime treated clay soil

Parameter	Name	Value	Unit
Material model	Model	Mohr-Coulomb	-
Type of material behaviour	Type	Undrained	-
Unit weight	γ	19.40	kN/m^3
Poisson's ratio	μ	0.30	-
Young modulus	E	25000	kN/m^2
Primary velocity	Vp	139.30	m/s
Secondary velocity	Vs	74.45	m/s

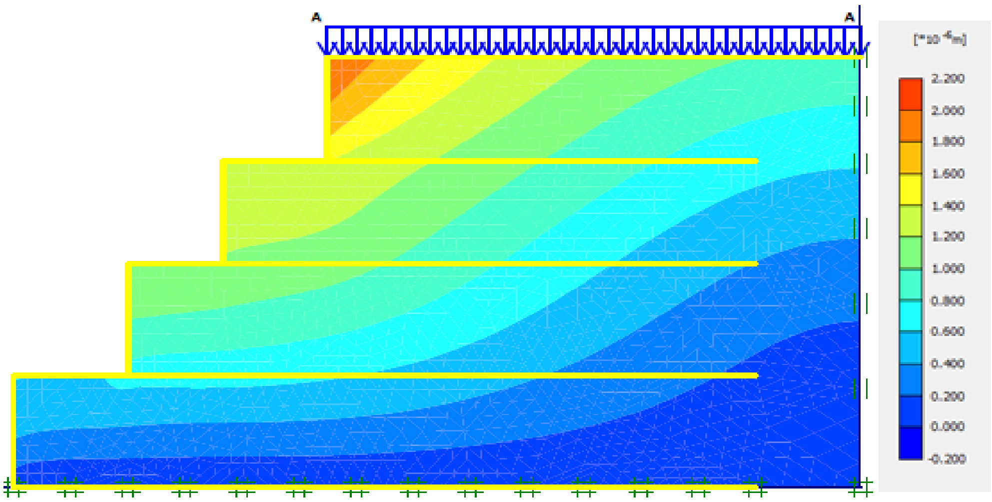

Fig. 13 Distribution of total displacement model wall with four layers of reinforcement

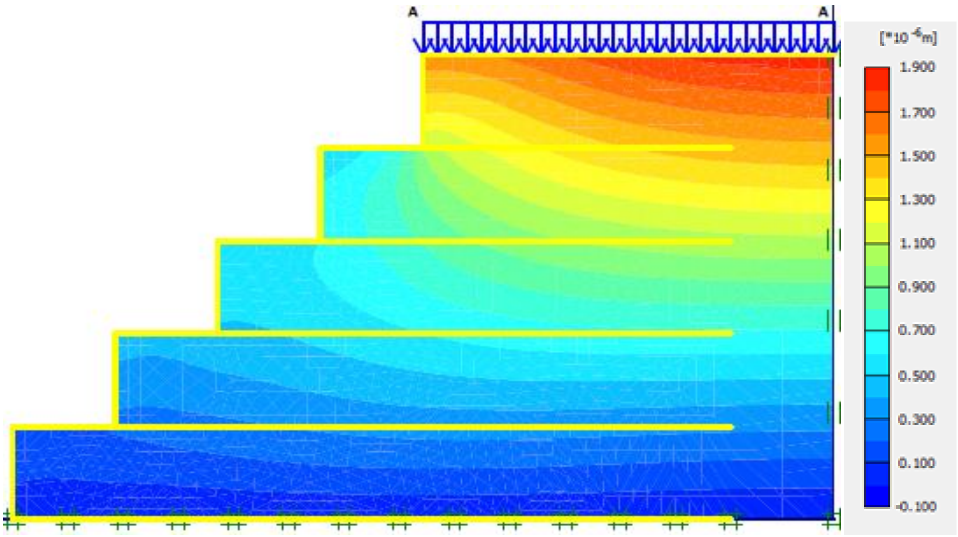

Fig. 14 Distribution of total displacement model wall with five layers of reinforcement

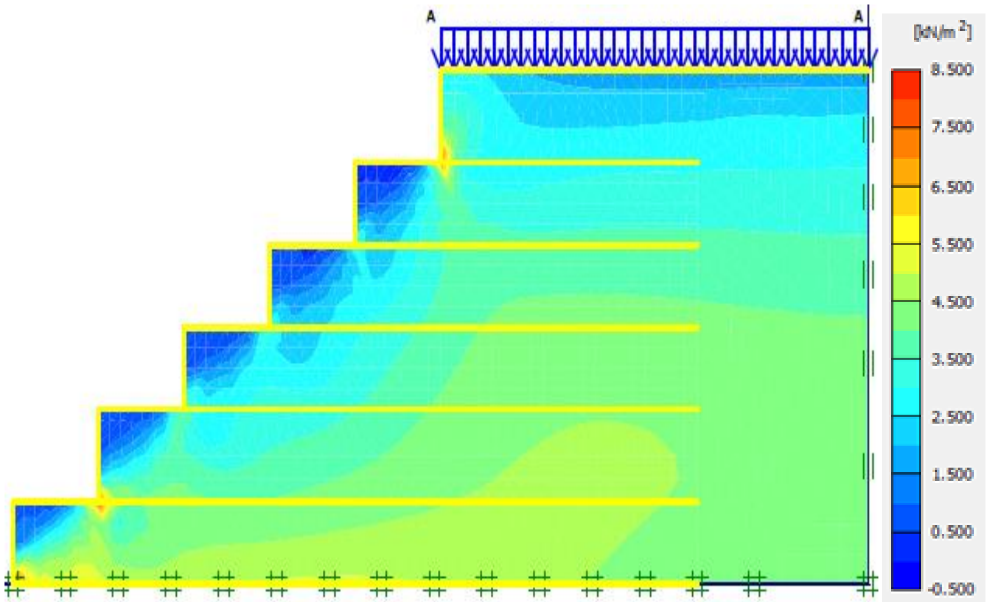

Fig. 15 Deviatoric stresses on six layer (Extreme deviatoric stress = 8.49 kN/m^2)

4. Acceleration on Horizontal Face Displacement

Horizontal face displacements along the height of the wall were observed by pin pointing the area in wrap-reinforced soil retaining wall shown in the Figure 5 (represented and positioned by U1, U2 and U3). Figure 16 and 17 describe numerical results on acceleration– displacement histories of the model test M4, M9 and M14, with 3 kPa surcharge, 0.2 g base acceleration, 4 Hz frequency of base sinusoidal motion and 4,5 and 6 layers of reinforcement, at different elevations with untreated and lime treated clay as a backfill material on WRSW. These figures show the effect of base acceleration on the face displacement response along the height of the wall. It was observed that the face displacement decreases as reinforcing layers increase. In addition lime treated clay backfill material shows lower face displacement as compared to untreated backfill for all layers. The higher displacement was recorded with four layer reinforcement with untreated backfill clay at 450 mm elevation which was 35.5 mm.

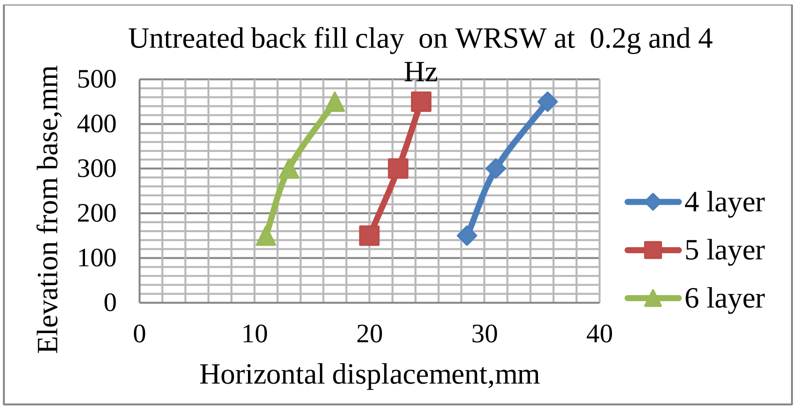

Fig. 16 Effect of base acceleration with untreated backfill on reinforcement layers

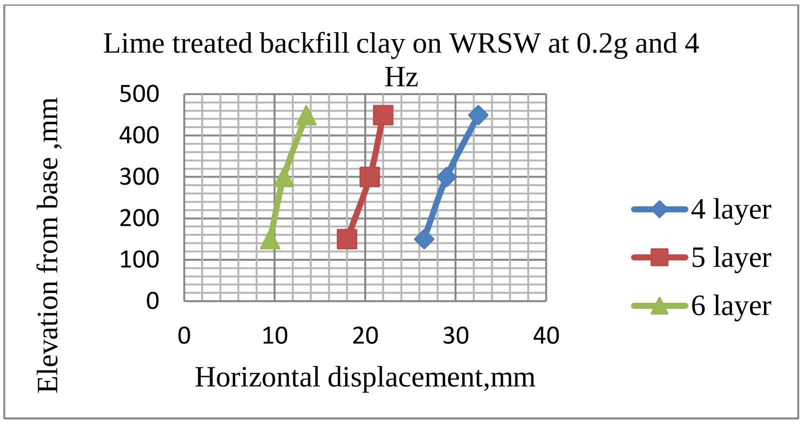

Fig. 17 Effect of base acceleration with treated backfill on reinforcement layers

Figures 18 and 19 shows the effect of base acceleration and surcharge on horizontal face displacement along the height of the wall for tests M1, M2, M3 and M5 with different base accelerations of 0.1 g , 0.2 g and 0.3 g. As shown in Table 4, these four tests are conducted with frequency of 4Hz with surcharge as 1.62 kPa and 3kPa on the test wall. The reinforcement was done through four layers of geotextile which were laid at Sv/H = 0.25. From the figure it was observed that acceleration response against face displacement variation is directly proportional for both untreated and lime treated backfill clay. Horizontal face displacement was increased with increasing surcharge pressure. However, within the range of tests conducted, higher displacement was observed at the top of the wall, for base accelerations and surcharge pressures.

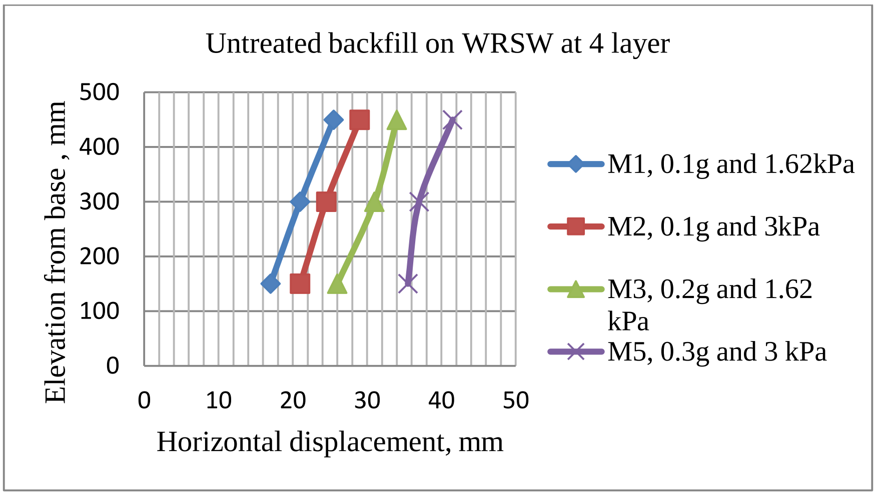

Fig. 18 Effect of acceleration and surcharges with untreated backfill on horizontal displacement

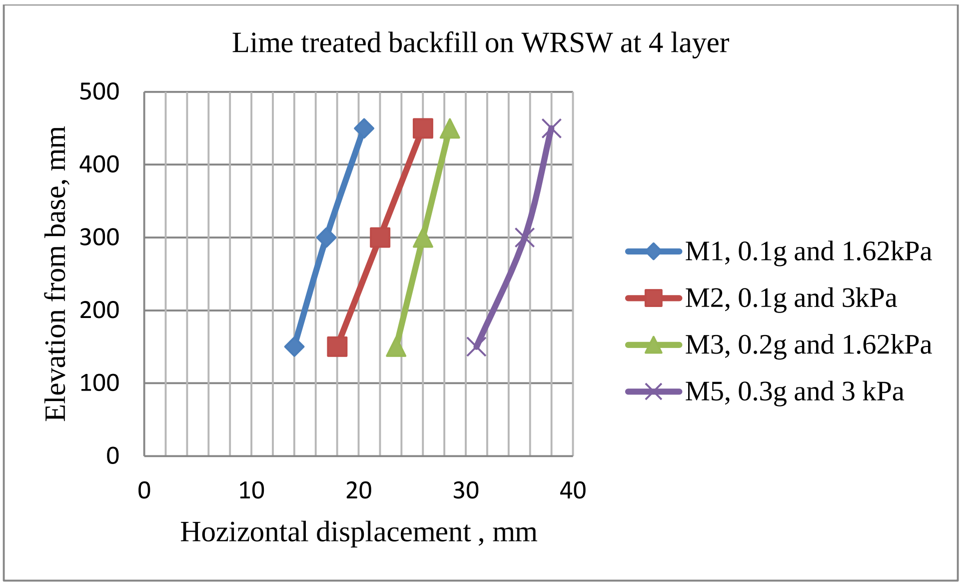

Fig. 19 Effect of acceleration and surcharges with treated back fill on horizontal displacement

Figure 20 shows the typical horizontal displacement numerical models with 4 layers, base acceleration of 0.2 g and 3 kPa surcharge pressure to simulate the wrap-faced reinforced by using lime treated backfill clay soil.

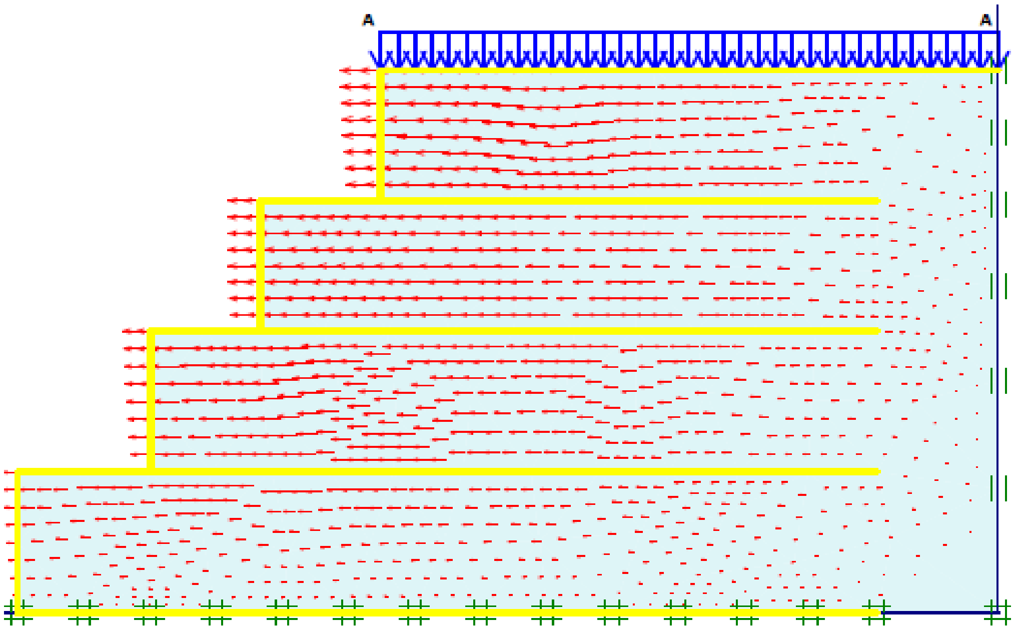

Fig. 20 Distribution of horizontal displacement model wall with four layers of reinforcement

5. Acceleration on Crest Settlement

Numerical analysis was done to simulate the vertical settlements on the top of the wall. acceleration–settlement histories of different model with 3 kPa surcharge, 0.1 g, 0.2 g and 0.3 g base accelerations, 4 Hz frequency of base sinusoidal motion and 4, 5 and 6 layers of reinforcement, with untreated and lime treated clay as a backfill material on wrap-faced reinforced soil retaining walls are shown in Figures 21 and 22. These Figures show the effect of base acceleration and surcharge on the crest settlement. It is observed that the crest settlement decreases as the number of reinforcing layers decrease with all layers of reinforcement for both untreated and lime treated backfill material on wrap-faced reinforced soil retaining wall. In addition, the lime treated clay backfill material shows lower crest settlement as compared to untreated backfill for all layers. The higher crest settlements recorded with four layer of reinforcement in case of untreated backfill clay at 0.3 g base acceleration is 1.33 mm. Higher crest settlement is observed at higher acceleration and surcharge of the wall in all tests.

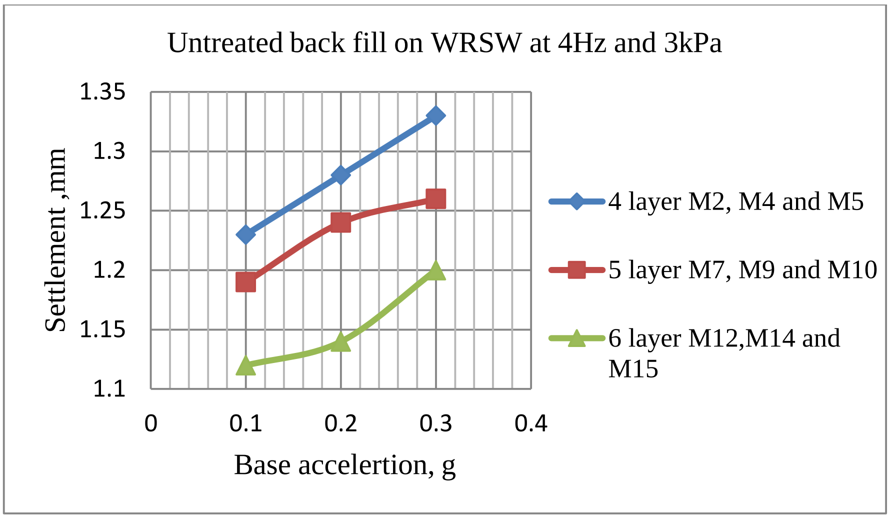

Fig. 21 Effect of acceleration and surcharges on crest settlement(Untreated backfill)

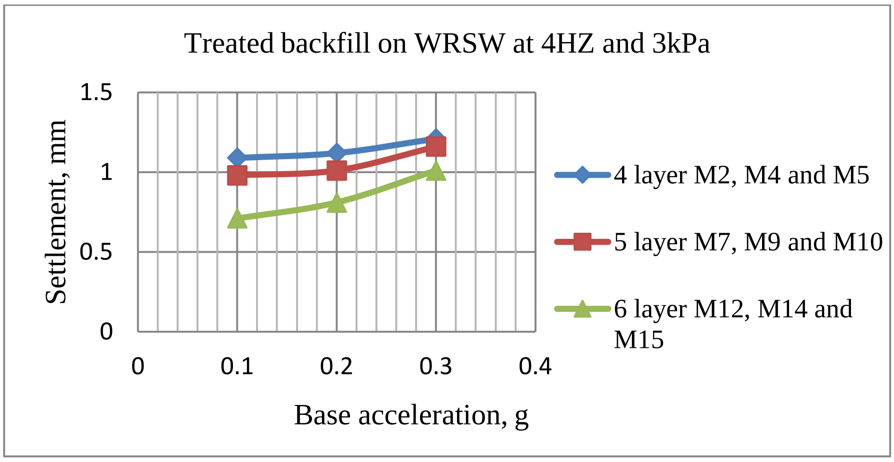

Fig. 22 Effect of acceleration and surchages on crest settlement (Treated backfill)

Figure 23 shows the typical vertical displacement observed from numerical models with 6 layers of reinforcement, base acceleration of 0.2 g and 3 kPa surcharge pressure to simulate the wrap-faced reinforced by using lime treated backfill clay soil.

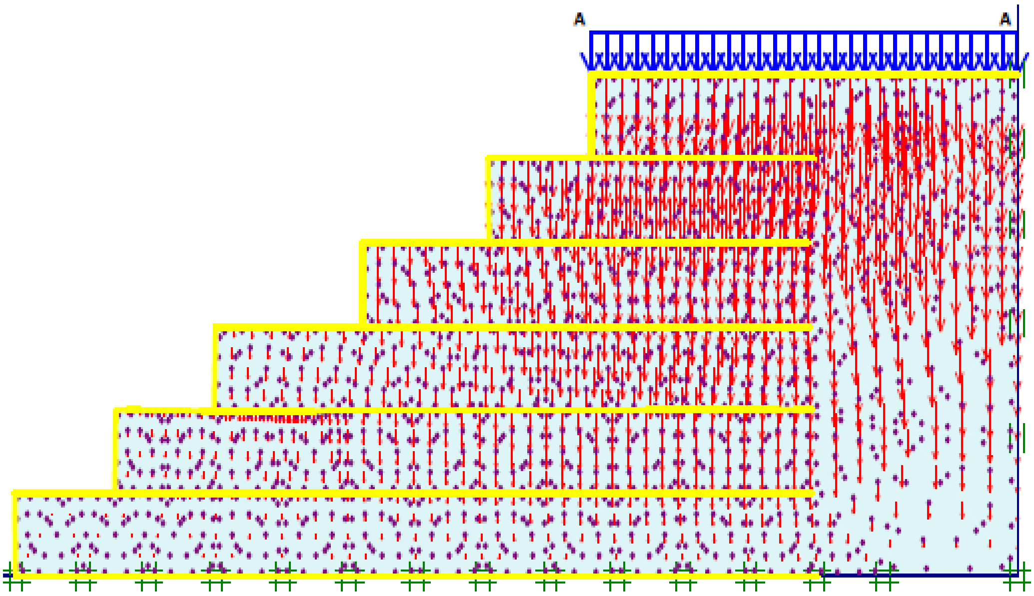

Fig. 23 Distribution of vertical displacement model wall with six layers reinforcement

CONCLUSIONS

The following major conclusions are drawn from the results presented from the shaking table studies carried out on untreated and lime treated backfill clay walls with physical and numerical modeling.

1. Displacement of the retaining wall during base shaking increases with the elevation of the wall for both untreated and lime treated backfill clay walls.
2. Increase in the reinforcement layers reduces the deformations significantly for both untreated and lime treated backfill clay walls. The lime treated reinforced soil retaining wall performed better than the untreated reinforced soil retaining wall in seismic condition. Hence on those locations where only clayey soils are available, the retaining wall may be constructed using them as a backfill soils but with wrap around geotextile reinforcement.
3. At any specific height of the wall, untreated reinforced soil retaining walls deformed more as compared to the lime treated reinforced soil retaining walls.
4. In case of wrap-faced reinforced soil retaining wall, the crest settlement and horizontal face displacement decreases with increases the reinforcing layer for physical and numerical model tests.
5. The higher face displacement and crest settlement were observed at higher acceleration (0.3 g).
6. Reinforced retaining walls exhibited increase in crest settlement and horizontal face displacement with an increase in base acceleration and surcharge pressure.
7. Results from the numerical model closely match with the results from the physical model tests for both cement treated and untreated soil back fill on WRSW.
8. The design and the construction of a reinforced soil retaining wall should ensure a treated backfill that results in better soil-reinforcement interaction for effective seismic performance.

REFERENCES

1. Mittal, S. (2014). "An Introduction to Ground Improvement Engineering", *SIPL Publication, New Delhi, India.*
2. Perez, A. (1999). "Seismic Response of Geosynthetic Reinforced Steep Slopes", *MS Thesis, University of Washington, Seattle, USA.*
3. Perez, A. and Holtz, R.D. (2004). "Seismic Response of Reinforced Steep Soil Slopes: Results of Shaking Table Study", *Geotechnical Engineering for Transportation Projects, in Proceedings of Geo Trans, (eds. M. K. Yegian and E. Kavazanjian), ASCE, GSP, Los Angeles, CA, USA, Vol. 126, pp. 1664-1672.*
4. Lo Grasso, A.S., Maugeri, M. and Recalcati, P. (2005). "Seismic Behavior of Geosynthetic-Reinforced Slopes with Overload by Shaking Table Tests: Slopes and Retaining structures under Static and Seismic Conditions", *in Proceedings of GeoFrontiers, (eds. M.A. Gabr, J.J.).*
5. Nova-Roessig, L. and Sitar, N. (2006). "Centrifuge Model Studies of the Seismic Response of Reinforced Soil Slopes", *J. Geotech. Geoenviron. Eng., Vol. 132, No. 3, pp. 380–400.*
6. Huang, C.C., Horng, J.C. and Charng, J.J. (2008). "Seismic Stability of Reinforced Slopes", *Failure Mechanism and Displacements, Geosynth. Int., Vol. 15, No. 5, pp. 333-349.*
7. Aoki, H., Watanabe, K., Tateyama, M. and Yonezawa, T. (2003). "Shaking Table Tests on Earthquake Resistant Bridge Abutment", *Proc. of 12th Asian Regional Conf. on Soil Mechanics and Geotechnical Engineering, Vol. 1, pp. 267-270.*
8. Krishna, A.M. and Latha, G.M. (2007). "Seismic Response of Wrap-Faced Reinforced-Soil Retaining Wall Models Using Shaking Table Tests", *Geosynth. Int., Vol. 14, No. 6, pp. 355–364.*
9. Saito, T., Ito, H., Izawa, J. and Kuwano, J. (2006). "Seismic Stability of the Geogrid-Reinforced Soil Wall Combined with Soil Cement", *this conference.*
10. AASHTO, (2002). "Standard Specifications for Highway Bridges, (17th Edition 2002), American Association of State Highway and Transportation Officials", *Washington, DC, USA.*

11. Koseki, J., Bathurst, R.J., Guler, E., Kuwano, J.A. and Maugeri, M. (2006). "Seismic Stability of Reinforced Soil Walls", *Invited Keynote Paper, 8th International Conference of Geosynthetics, Yokohama, Japan, pp. 28.*
12. Motoyuki Suzuki, Naoki Shimura, Takuto Fukumura, Osamu Yoneda and Yukio Tasaka, (2015). "Seismic Performance of Reinforced Soil Wall with Untreated and Cement-Treated Soils as Backfill Using a1-g Shaking Table", *Soils and Foundations, Vol. 55, pp. 626-636.*
13. Ling, H.I., Leshchinsky, D. and Perry, E.B. (1997). "Seismic Design and Performance of Geosynthetic Reinforced Soil Structures", *Geotechnique, Vol. 47, No. 5, pp. 933-952.*
14. Srilatha, N., Latha, G.M. and Puttappa, C.G. (2012). "Effect of Frequency on Seismic Response of Reinforced Soil Slopes in Shaking Table Tests", *Geotextiles and Geomembranes, Vol. 36, pp. 27-32.*
15. Koerner, R.M. (1999). "Designing with Geosynthetics", *4th Edition, Prentice Hall, NJ, pp. 761.*
16. BS, (8006). "Code of Practice for Strengthened/Reinforced Soils and Other Fills", *British Standards Institution, Milton Keynes.*
17. Juran, I. and Christopher, B. (1989). "Laboratory Model Study on Geosynthetic Reinforced Soil Retaining Walls", *Journal of Geotechnical Engineering, ASCE, Vol. 115, No. 7, pp. 905-926.*
18. Palmeira, E.M. and Gomes, R.C. (1996). "Comparisons of Predicted and Observed Failure Mechanisms in Model Reinforced Soil Walls", *Geosynthetics International, Vol. 3, No. 3, pp. 329-347.*
19. Sakaguchi, M., Yamada, K. and Tanaka, M. (1994). "Prediction of Deformation of Geotextile Reinforced Walls Subjected to Earthquakes", *Proceedings of the 5th International Conference on Geotextiles, Geomembranes and Related Products, Singapore, Vol. 1, pp. 521-524.*
20. Sakaguchi, M. (1996). "A Study of the Seismic Behavior of Geosynthetic Reinforced Walls in Japan", *Geosynthetics International, Vol. 3, No. 1, pp. 13-30.*
21. Koga, Y., Ito, Y., Washida, S. and Shimazu, T. (1988). "Seismic Resistance of Reinforced Embankment by Model Shaking Table Tests", *Proceedings of the International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Japan, pp. 413-418.*
22. Mittal, S. and Shukla, J.P. (2013). "Soil Testing for Engineers", *Khanna Publishers, New Delhi, India.*
23. Ali, F.H., Adnan, A. and Choy, C.K. (1992). "Geotechnical Properties of a Chemically Stabilised Soil from Malaysia with Rice Husk Ash as an Additive", *Geotechnical and Geological Engineering, Vol. 10, pp. 117-134.*
24. Balasubramaniam, A.S., Acharya, D.G., Lin, Kamruzzaman, S.S.S.A.H.M. (1999). "Behaviour of Soft Bangkok Clay Treated with Additives", *in the 11th Asian Regional Conference on Soil Mechanic and Geotechnical Engineering, Seoul, Vol. 1, pp. 11-22.*
25. Sivapullaiah, P.V., Sridharan, A. and Ramesh, H.N. (2000). "Strength Behavior of Lime- Treated Soils in the Presence of Sulphate", *Proceedings of Canadian Geotechnical Journal, Vol. 37, pp. 1358-1367.*
26. Xia, J., Miller, R.D., Park, C.B. and Ivanov, J. (2000). "Construction of 2-D Vertical Shear-Wave Velocity Field by the Multichannel Analysis of Surface Waves Technique", *Proceeding of the Symposium of the Application of Geophysics to Engineering Environmental Problems (SAGEEP 2000) Arlington, VA., pp. 1197-1206.*
27. Evrett, M.E. (2013). "Near-Surface Applied Geophysics", *Cambridge: Cambridge University Press.*
28. ASTM, (D4595). "Standard Test Method for Tensile Properties of Geotextiles by the Wide Width Strip Method", *ASTM, International, West Conshohocken, PA, USA.*
29. Telekes, G., Sugimoto, M. and Agawa, S. (1994). "Shaking Table Tests on Reinforced Embankment Models", *Proceedings of the 13th International Conference on Soil Mechanics and Foundation Engineering, New Delhi, India, Vol. 2, pp. 649-654.*

30. Murata, O., Tateyama, M. and Tatsuoka, F. (1994). "Shaking Table Tests on a Large Geosynthetic-Reinforced Soil Retaining Wall Model", *Recent Case Histories of Permanent Geosynthetic Reinforced Soil Retaining Walls, Tatsuoka, F., & Leshchinsky, D., Editors, Balkema, Rotterdam, The Netherlands, pp. 259-264.*

31. El-Emam, M. and Bathurst, R.J. (2005). "Facing Contribution to Seismic Response of Reduced-Scale Reinforced Soil Walls", *Geosynthetics International, Vol. 12, No. 5, pp. 215–238.*

32. Bathurst, R.J. and Hatami, K. (1998). "Seismic Response Analysis of a Geosynthetic-Reinforced Soil Retaining Wall", *Geosynthetics International, Vol. 5, No. 1-2, pp. 127-166.*

33. El-Emam, M., Bathurst, R.J. and Hatami, K. (2004). "Numerical Modeling of Reinforced Soil Retaining Walls Subjected to Base Acceleration", *Proc. 13th World Conf. on Earthquake Engg., Vancouver, Canada (CD-ROM).*