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Experimental Studies of Strip Footing on Model Wrap-Around Reinforced Soil Walls

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ABSTRACT

The paper presents the results of experimental studies with regard to the response of small scale model strip footings resting on the surface of wrap-around reinforced soil retaining walls constructed using locally available sand as backfill and geotextile as reinforcing elements. Number of reinforcing layers and footing size were varied to find their influence on the bearing capacity and load deformation (both vertical and lateral) characteristics of the walls. It is found that the ultimate bearing capacity of the footings and initial tangent modulus increases with increase in the number of reinforcing layers but the initial tangent modulus decreases with increase in footing size.

KEYWORDS: Geotextile; reinforced soil wall; strip footing; warp-around facing.

INTRODUCTION

Geosynthetic reinforced earth/soil walls (GRE/GRS walls) are increasingly being preferred over conventional rigid retaining walls due to its cost effectiveness, ability to withstand differential settlements and better performance to withstand severe earthquakes. Because of the flexible nature of the construction, such walls can undergo larger differential movements without failure. It is possible to construct even vertical soil wall/embankments with geosynthetic reinforcements. Such double or single faced vertical walls are very often constructed in elevated highways and bridge abutments. GRE/GRS walls can be rapidly constructed and do not require skilled labor or specialized equipment. As the backfill soil of such walls are generally subjected to repeated vertical traffic loads of high intensity, they should be adequately designed for safety against bearing capacity failure and unwanted vertical and lateral displacements. Geosynthetic reinforcement provides a cost effective solution for improving the supporting capacity of the underlying soil and the backfill. A detailed review of application of geosynthetics in reinforced soil structures was presented by Palmeira (2008).

Anticipated deflection of the wall face (both lateral and vertical) and aesthetics are the major factors for deciding the type of facing system for reinforced earth walls. A wide range of facings such as Full height precast concrete panels, interlocking precast concrete blocks, welded wire panels, gabion baskets, treated timber facings and geosynthetic face wraps can be used. Geosynthetic warp around facing is having the advantages of low cost, ease of installation and faster construction especially in temporary constructions. Such temporary GRE walls are very often used for diversion of roads. It is necessary to understand the performance of such walls when subjected to static and dynamic loading for developing better design criterion.

Experimental studies on the bearing capacity of strip footings resting on embankments reinforced with geosynthetics were reported by Bathurst et al. (2003), Huang et al. (1994), Lee & Manjunath (2000), Sawwaf (2007), Selvadurai and Gnanendran (1989), Yoo (2001). Similar studies for bearing capacity of footings resting on reinforced soil walls have been reported by Kennedy et al. (1980), Krieger and Thamm (1991), Sawicki & Lesniewska (1987), Tatsuoka et al. (1992), Thamm et al. (1990), Yoo & Kim (2008), Sahu et al. (2011). Out of these studies only few studies are available on wrap-around geotextile reinforced walls.

Therefore, in present study an attempt has been made to investigate the behavior of footings resting on the surface of vertical wrap-around GRS walls under vertical loading by conducting small-scale laboratory model tests. Effects of number of reinforcement layers and footing size on load deformation behaviour, ultimate bearing capacity and initial tangent modulus been studied. However, it should be noted that small scale model tests has its inherent limitations (scale effect) and to use the data obtained for theoretical prediction of the wall movements using values of modulus of elasticity and Poisson ratio from conventional triaxial test leads to erroneous results. Therefore, either these properties should be determined at very low confining pressures or suitably adjusted, as proposed by Hatami and Bathurst (2005), Anubhav and Basudhar (2011), for simulation of model behavior.

EXPERIMENTAL SETUP

Schematic diagram and photograph of the test setup are shown in Fig. 1 & Fig. 2 respectively. Model wrap-around reinforced soil walls were conducted in a steel tank 1.5 m long, 0.72 m wide and 0.9 m deep. A 15mm thick Perspex sheet was fitted on the front of the steel tank so that visual examination of the displaced GRS walls and deformation of the backfill soil could be made. Possible friction between the inside walls of the test box reinforced soil wall was minimized by attaching thin transparency films onto the inside walls. The walls of the box were made sufficiently rigid to maintain plane strain conditions. All walls were 450 mm high with varying number of reinforcement layers and overlap length. The footings were modeled with mild steel plates of sizes 100 mm×710 mm and 150 mm×710 mm. For 100 mm wide footing 15 mm thick plate was used and 150 mm wide footing was made by welding two 12 mm plates to avoid any bending of plates during loading. In order to create plane strain conditions within the test arrangement, the length of the footings were kept almost equal to the tank width. On each side a gap of 5 mm was given to prevent contact between footing and side walls. The load was applied at the centre of the footing through a loading frame fitted with proving ring.

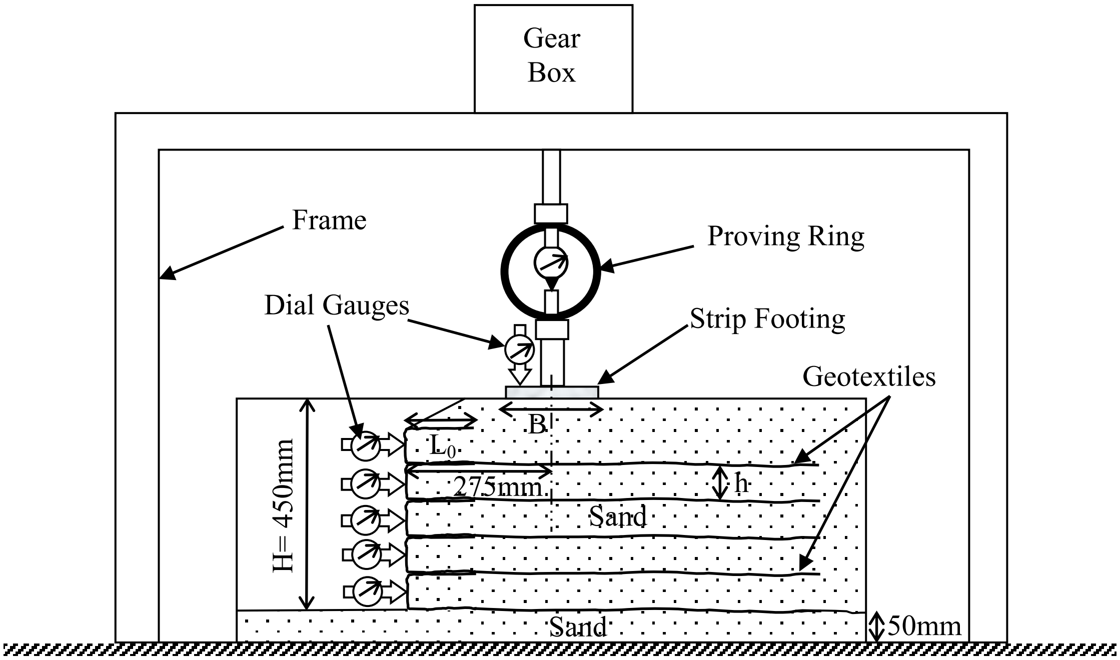

Figure 1: Schematic Diagram for Test Setup

Figure 2: Test setup for wrap-around reinforced soil wall

The settlement of the model footing was measured by placing two dial gauges equidistant from the point of application of the load along the central axis of the footing. The horizontal deformations of the double-faced vertical wall were measured by placing dial gauges at the mid height of each reinforcement layers. Readings were taken at regular intervals for the vertical load, vertical settlement and lateral deformation of the vertical reinforced soil wall.

MATERIALS USED

Natural river sand locally known as Kalpi sand (collected from the Kalpi region of Yamuna river basin situated in northern part of India) was used as backfill and bottom sand cushion for constructing the double faced wrap up vertical GRS walls. The minimum and maximum unit weights of backfill sand were obtained as $\gamma_{d\min} = 14.8$ kN/m^3 ($e_{\max}$ = 0.78) and $\gamma_{d\max} = 17.2$ kN/m^3 ($e_{\min}$ =0.54). The experiments were conducted at a relative density of D_r =70% i.e. with dry density of $\gamma_{d70} = 16.5$ kN/m^3. At D_r =70%, the peak friction angle (ϕ_p) and residual friction angle (ϕ_{cv}) were obtained using direct shear test as 46° and 36° respectively.

Multifilament woven geotextile was used as the reinforcing elements in the experiments. The specimen has average thickness of 0.65 mm and mass per unit area of 228 g/m^2. The static puncture strength was obtained as 0.9 kN using a 50 mm probe. These properties have been determined as per relevant ASTM standards. Tensile strength of the geotextile was determined from wide-width tensile test as per ASTM D4595. The ultimate tensile strength in machine and cross machine direction obtained as 45 and 48 kN/m respectively.

CONSTRUCTION PROCEDURE OF WRAP-AROUND GRS WALLS

The model wall was constructed by initially placing wooden plank on facing side of the wall and removing it after the wall was fully prepared. The backfill was built up by the constant volume technique. For this purpose, the height of wall was divided into number of small thickness layers according to the spacing of geotextile layers. In each layer, according to their volume and the relative density ($D_r = 70\%$) the known weight of air dried Kalpi sand was poured from a hopper moving over the model box from zero height. The top surface was leveled with a scale and level was checked by sprit level at many places. After leveling, a wooden board of approximately the plan size of the wall was placed on top of it and then tamping was done on the top of wooden board so that the specified height of the layer was achieved. By this procedure homogeneous sand embankment having relative density in the range of about 70% was obtained. To avoid any lateral deformation or bending of the formwork during compaction, the space between the formwork and wall of the tank was tightly filled with bricks.

At each prescribed depth, the filling was temporarily stopped, the lower geotextile layer was wrapped around and a new layer of geotextile was placed on top of it. The procedure was repeated till the top layer of geotextile reinforcement was placed at the desired height and sand filling was continued till the wall attained a height of 400 mm. The last layer of geosynthetic was wrapped around and 50 mm thick sand layer was placed on the top of it. After that the formworks (wooden planks) were gently removed. As, it was not possible to place any dial gauge or LVDT at the wraparound face of the wall during the construction due to the placement of the formwork, the construction deformations could not be measured.

RESULTS AND DISCUSSIONS

The behavior of reinforced soil wall subjected to strip loading has been studied by comparing load-deformation behavior, ultimate bearing pressure, initial tangent modulus and deformation of warp-around face. The overlap length of the wrap-around (L_0) was kept constant as 150mm. The reinforcement spacing (h) was varied as: 80 mm (5 layers), 67 mm (6 layers) and 57 mm (7 layers). Two different footing sizes (150mm and 100mm) were used to investigate the effect of width of footing. Summary of the model tests performed with different configuration of walls and footing width are given in Table 1.

Table 1: Details of Model Tests

Width of Footing, B (mm)	**Overlap Length, L_0 (mm)**	**No. of Layers, N**
100	150	5*, 6* & 7*
150		5, 6* & 7

The overlap length could have been varied during the test and such a study was not undertaken. It is well anticipated that increased overlap length of the geotextile would manifest in increased bearing capacity and lesser vertical settlement and lateral deformation. Such a study for double faced vertical wall was earlier conducted by Sahu et al. (2008)

Pressure-Settlement Behavior

Pressure-settlement response of 100 mm wide footings on surface of wrap-around reinforced soil walls, with varying number of reinforcement layers and overlap length of 150mm, are shown in Fig. 3 (a). To study the effect of width of footing on the load settlement response, the width of strip footing has been varied from 100 mm to 150 mm with no changes in any other parameters. The pressure-settlement curves for 150 mm wide footing with different number of reinforcement layers and overlap length of 150 mm are presented in Fig. 3 (b). All the pressure settlement curves (for B=100 mm and 150 mm) are linear over the most of the applied pressure ranges showing nonlinearity a little before failure.

The ultimate bearing pressures (q_{ult}) for various cases were estimated from these plots. The pressure-settlement response of 100 mm wide footing is similar to general shear failure for the walls with different number of reinforcement layers under consideration. For 150 mm wide footing with 5 and 6 numbers of reinforcement layers the responses are similar as in the case of 100 mm wide footing. However, for the curve not exhibiting any explicit failure point (B=100 mm & N=7), the ultimate load was taken as the point at which the slope of the load-settlement curve reaches a minimum or attains a steady value. In case of 100 mm wide footings the failure load reaches approximately at 4 to 4.2 mm vertical settlement of the footing with increase in number of reinforcement layers. For 150 mm wide footing, the failure reaches about at 5.2 to 6.4 mm vertical settlement.

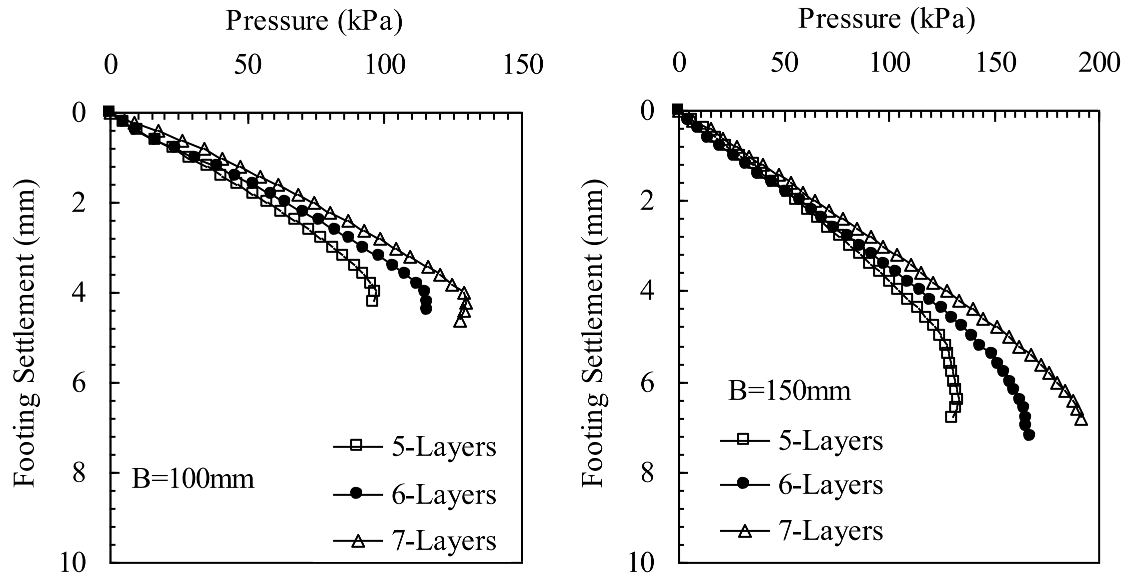

Figure 3: Pressure-Settlement Relationship of Strip Footing on Wrap-Around Reinforced Soil Walls (a) 100 mm wide footing (b) 150 mm wide footing

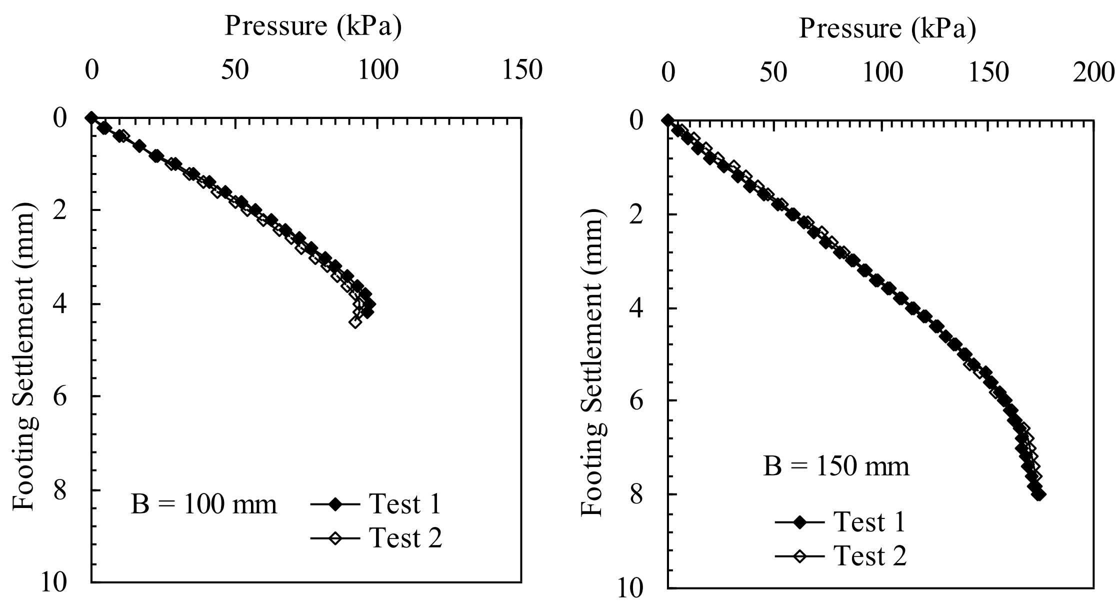

Figure 4: Pressure-Settlement Relationship of Strip Footing on Reinforced Soil Wall - Repeated Tests (a) B= 100mm & N=5 (b) B= 150mm & N=6

Some of the tests were also repeated carefully to examine the repeatability of the system, reliability and consistency of the results (Table-1). During the repeated tests if the differential settlement of the footing exceeded 10% of the settlement of footing at failure, the tests were discarded and were not considered as repeat test. Fig. 4 (a) and (b) show the comparison of results of the repeated tests for 100 mm wide footing on 5 layered reinforced soil wall and for 150 mm wide footing on 6 layered reinforced soil wall respectively. These figures show that the repeatability of tests can be ensured with the procedure adopted in the present study.

Effect of Number of Reinforcement Layers on Ultimate Bearing Pressure and Initial Tangent Modulus

Fig. 5 (a) shows the relationship between the ultimate bearing pressure of 100 mm and 150 mm wide footings with varying number of reinforcement layer. Variation of initial tangent modulus for footing on reinforced soil walls with number of reinforcement layers for both footing sizes are plotted in Fig. 5 (b). The ultimate bearing pressure and initial tangent modulus values for 100 mm & 150 mm wide footings for different configurations geotextile reinforced walls are shown in Table 2 & 3, respectively.

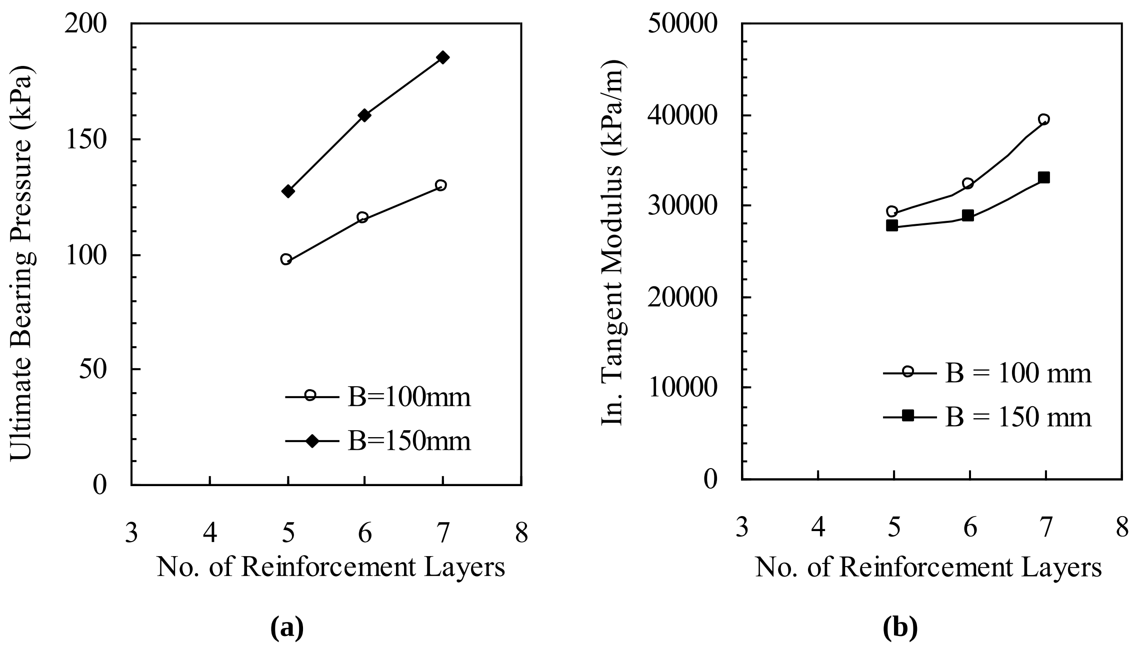

Figure 5: Variation of Ultimate bearing Pressure and Initial Tangent Modulus with Number of Reinforcement Layers for Footings on Reinforced Soil Wall

Table 2: Ultimate bearing pressure of footings on reinforced soil walls

Width of Footing, B (mm) \ **No. of Layers**	**5**	**6**	**7**
	Ultimate Bearing Pressure, q_{ult} (kPa)		
100	97	115.4	129.4
150	127.6	160	185
% Variation	31.5	38.6	43

As expected, ultimate bearing pressure and initial tangent modulus increases with increase in number of reinforcement layers. The ultimate bearing pressure value is the least for five layers of reinforcement and increases significantly with number of reinforcement layers (6 and 7). In case of 100 mm footing the ultimate bearing pressure increases by 19% when the reinforcement layers increased from 5 to 6 and this increase become 12.1% for increase in reinforcement layers from 6 to 7. The initial tangent modulus increases by 10.6% and 21.6% when the number of reinforcement layers increased from 5 to 6 and 6 to 7.

Table 3: Initial tangent modulus of footings on reinforced soil walls

No. of Layers / Width of Footing, B (mm)	5	6	7
	Initial Tangent Modulus (kPa/m)		
100	29154.5	32258.1	39215.7
150	27700.8	28653.3	33003.3
% Variation	- 5.0	- 11.2	- 15.8

For 150 mm wide strip footing the ultimate bearing pressure increases by 25.5% and 15.6% with increase in reinforcement layers from 5 to 6 and 6 to 7. The initial tangent modulus increases by 7.1%, and 19.2% when the number of reinforcement layers increased from 5 to 6 and 6 to 7, respectively, for 150 mm wide footing on reinforced soil wall. It is seen that with all other parameters remaining constant as the number of reinforcing layers increase (i.e. with corresponding decrease in spacing of the reinforcement layers), the stiffer responses of load-settlement were observed. It is due to the fact that as the number of reinforcing layer increases, the resulting composite becomes stiffer and stiffer supporting larger loads for both 100 mm and 150 mm wide footings.

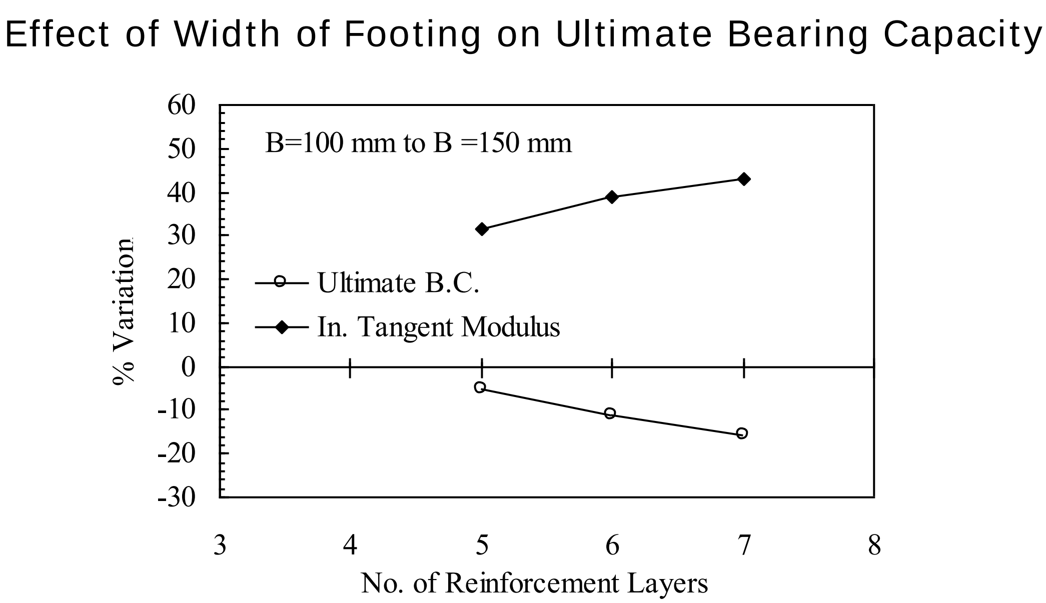

Figure 7*a*: Percentage Variation of Ultimate Bearing Pressure and Initial Tangent Modulus for Footings on Reinforced Soil Walls - Effect of Width of Footing

The percentage variation of ultimate bearing pressure and initial tangent modulus with increase in width of strip footing are plotted with number of reinforcement layers and are shown in Fig. 7*a*. It shows that ultimate bearing pressure increases with increase in footing size. It is also observed that with increase in number of reinforcement layers, effect of width of footing on q_{ult}

becomes more significant. For 5 layered wall 31.5% increases in q_{ult} is observed with increase in width of footing from 100 mm to 150 mm. However, with the increase in footing width the increase in q_{ult} gradually increased to 38.6% and 43% respectively for 6 and 7 reinforcement layers (Table 2). From the Table 3 and Fig. 6 it is observed that initial tangent modulus decreases almost linearly with increase in width of strip footing from 100 mm to 150 mm. For 5 layered reinforced soil wall, variation in initial tangent modulus was observed to be (-) 5% with increase in footing width from 100 mm to 150 mm. However, the variation in initial tangent modulus with increase in footing width for 6 & 7 reinforcement layers are observed to be (-)11.8% &(-)15.2% respectively.

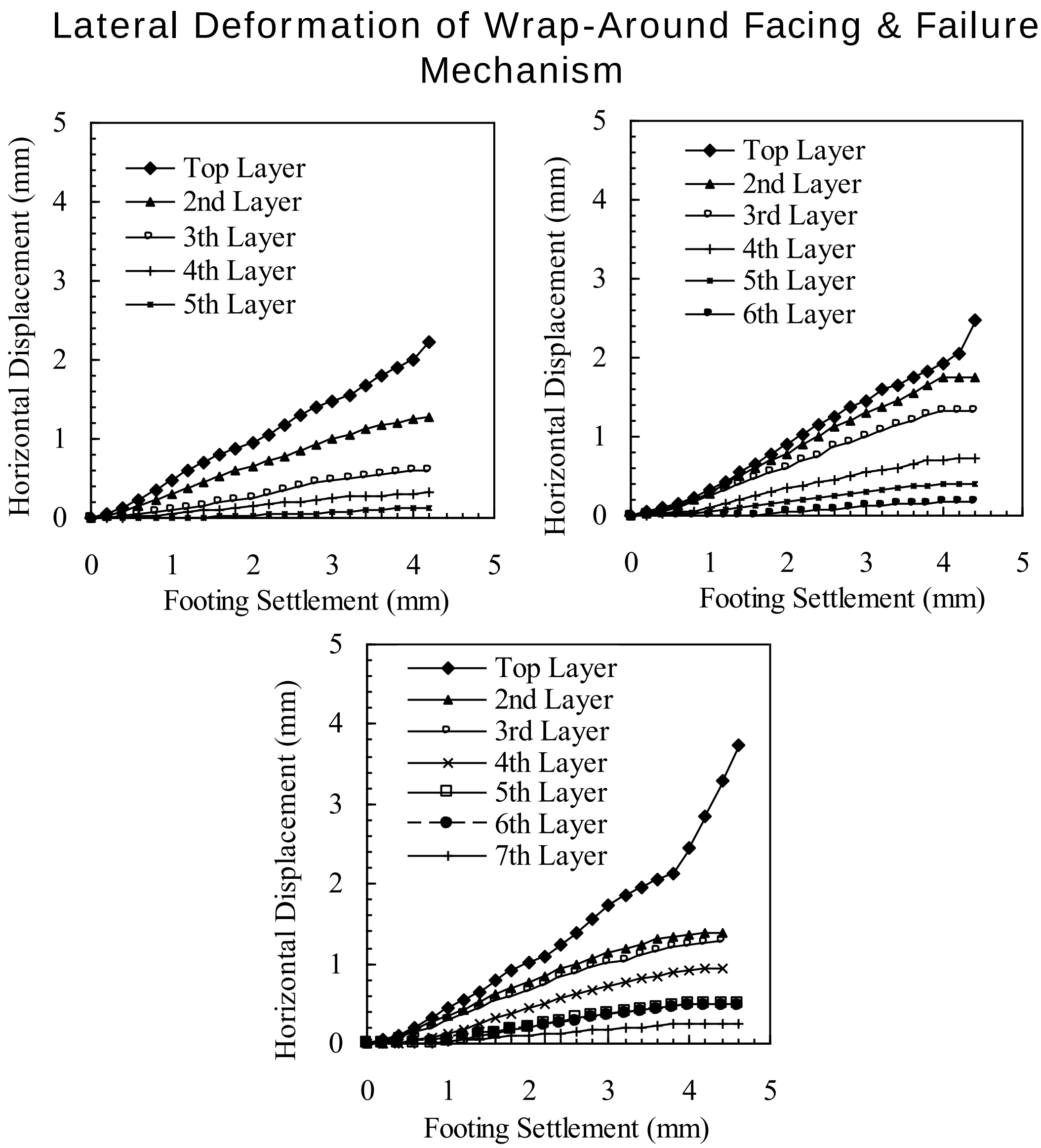

Figure 7*b*: Lateral Deformations of Wrap-around facing of Reinforced Soil Wall with Vertical Settlement of the 100 mm Wide Footing

Lateral deformation of the wrap-around reinforced soil walls were measured with vertical settlement of the footing. The lateral deformations were measured using horizontal dial gauges placed at the center of each layer. Horizontal displacements of different layers with vertical settlement of 100mm wide footing are shown in Fig. 7*b*. It is observed that in all types of reinforced soil walls (5, 6 & 7 layered) the top most layers deformed most. In general, the lateral deformation of facing increases with the height of wall. In all the cases failure of the footing is accompanied with sudden increase in rate of lateral deformation of top layer. It was also observed that the horizontal deformation of other layers almost stops after failure for 6 and 7 layered walls. In case of 5-layerd wall, a small drop in the deformation rate of 2nd layer was observed, but, for bottom 3 layers, post failure deformation as observed was not appreciable.

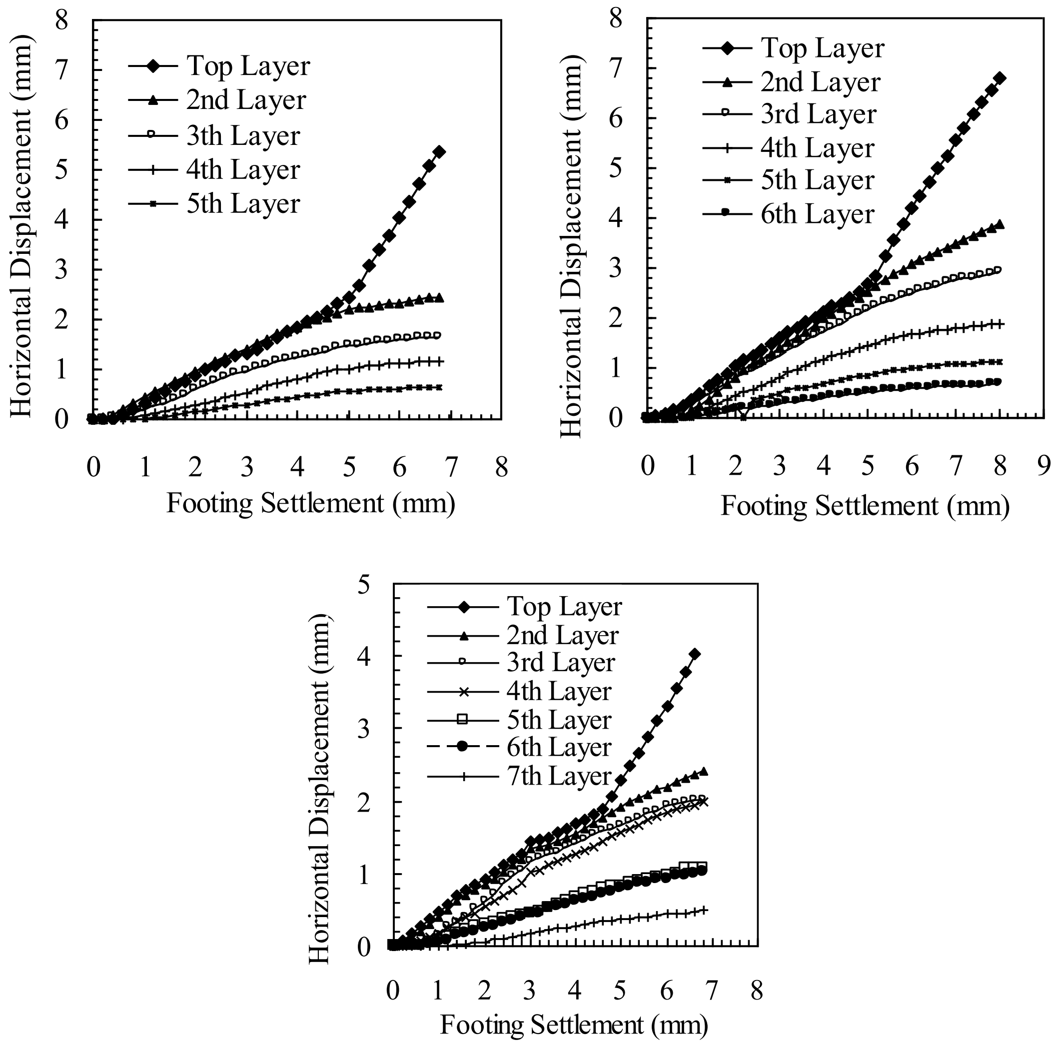

Figure 8: Lateral Deformations of Wrap-around facing of Reinforced Soil Wall with Vertical Settlement of the 150 mm Wide Footing

Horizontal displacements of different layers with vertical settlement of 150mm wide footing are shown in Fig. 8. The observations here are also similar to that of the 100 mm wide footing. However, in this case the deformations of top and 2nd layers were observed to be same till failure occurred and after the failure the deformation of top layer increases rapidly as compared to 2nd layer. This implies that with increase in footing size the failure zone penetrates deeper inside the wall.

In all the cases, failure of the footing was observed with very rapid lateral deformation of the top most layer of reinforcement, which suggests that, the failure is due to excessive deformation of the wrap-around facing of the top layer of reinforcement. During the experiments, subsequent to the footing failure, sudden slipping of top layers of reinforcement was also observed on further loading.

RESULTS AND DISCUSSIONS

Based on the experimental model studies on the behavior of strip footings resting on the surface of GRE walls as reported above, the following conclusions are drawn:

The ultimate bearing pressure of the footings increases linearly with increase in number of reinforcement layers. With increase in width of strip footing from 100 mm to 150 mm, the ultimate bearing pressure increases and the effect of increase in footing size on ultimate bearing pressure becomes more significant with increase in number of layers (from 5 to 6 & 6 to 7).

The initial tangent modulus increases with increase in number of reinforcing layers however, it decreases with the increase in the size of strip footing from 100 mm to 150 mm. The effect of increase in footing size on initial tangent modulus increases with increase in number of reinforcement layers.

In all the model tests failure is associated with large deformation of the top layer of the reinforcement in wrap-around zone. The slippage of top layer is followed by the failure of footing. With increase in footing size, the failure zone penetrates deep inside the wall and deformation of second layer was observed to be same as top layer before failure.

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REFERENCES

1. ASTM D 4595-05. "Standard Test Method for Tensile Properties of Geotextiles by Wide-Width Strip Method", American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA.
2. Anubhav, S. and Basudhar, P.K. (2011) "Numerical Modeling of Surface Strip Footings Resting on Double Faced Wrap-Around Vertical Reinforced Soil Walls", Geosynthetics International, 18 (1), 21-34.
3. Bathurst, R.J. Blatz, J.A. and Burger, M.H. (2003) "Performance of Full-Scale Reinforced Embankments Loaded to Failure", Canadian Geotechnical Journal, 40 (6), 1067-1083.

4. Hatami, K. and Bathurst, R.J. (2005) "Development and Verification of A Numerical Model for the Analysis of Geosynthetic-Reinforced Soil Segmental Walls under Working Stress Conditions", Canadian Geotechnical Journal, 42, 1066-1085.
5. Huang, C.-C. Tatsuoka, F. and Sato, Y. (1994) "Failure Mechanisms of Reinforced Sand Slopes Loaded with A Footing" Soils and Foundations, 34 (2), 27-40.
6. Kennedy, J.B. Laba, J.T. and Mossaad, M.A. (1980) "Reinforced Earth Retaining Walls under Strip Load", Canadian Geotechnical Journal, 17, 382-394.
7. Krieger, J. and Thamm, B.R. (1991) "Studies of Failure Mechanism and Design Method for Geotextile-Reinforced Soil Walls", Geotextiles and Geomembranes, 10 (1), 53-63.
8. Lee, K.M. and Manjunath, V.K. (2000) "Experimental and Numerical Studies of A Geosynthetic-Reinforced Sand Slopes Loaded with A Footing", Canadian Geotechnical Journal, 37, 828-842.
9. Palmeira, E.M. Tatsuoka, F. Bathurst, R.J. Stevenson, P.E. and Zornberg, J.G. (2008) "Advances in Geosynthetics Material and Applications for Soil Reinforcement and Environmental Protection Works" Electronic J. of Geotechnical Engineering, Special Volume.
10. Sahu, T. Anubhav, Madhav, M.R. and Basudhar, P.K. (2008) "Studies of Footings on Double Faced Wrap-Around Reinforced Soil Model Walls", Indian Geotechnical Conference, 2, 559-562.
11. Sawicki, A. and Lesniewska, D. (1987) "Failure Modes and Bearing Capacity of Reinforced Soil Retaining Walls", Geotextiles and Geomembranes, 5 (1), 29-44.
12. Sawwaf, M.A.El (2007) "Behavior of Strip Footing on Geogrid-Reinforced Sand over A Soft Clay Slope", Geotextiles and Geomembranes, 25 (1), 50–60.
13. Selvadurai, A.P.S. and Gnanendran, C.T. (1989) "An Experimental Study of A Footing Located on A Sloped Fill: Influence of A Soil Reinforcement Layer", Canadian Geotechnical Journal, 26 (3), 467-473.
14. Tatsuoka, F. Murata, O. and Tateyama, M. (1992) "Permanent Geosynthetic-Reinforced Soil Retaining Walls used for Railway Embankments in Japan" Geosynthetic-Reinforced Soil Retaining Walls, Wu, J.T.H, Editor , A.A. Balkema, Rotterdam, 101-130.
15. Thamm, B.R. Krieger, B. and Krieger, J. (1990) "Full-Scale Test on A Geotextile Reinforced Retaining Structure", Proc. of the 4th Int. Conf. on Geotextile, Geomembrane and Related Products, Hoedt, D., Editor, A.A. Balkema, Rotterdam, 1, 3-8.
16. Yoo, C. (2001) "Laboratory Investigation of Bearing Capacity Behavior of Strip Footing on Geogrid-Reinforced Sand Slope", Geotextiles and Geomembranes, 19 (5), 279-298.
17. Yoo, C. and Kim, S.-B. (2008) "Performance of A Two-Tier Geosynthetic Reinforced Segmental Retaining Wall under A Surcharge Load: Full-Scale Load Test and 3D Finite Element Analysis", Geotextiles and Geomembranes, 26 (6), 460-472.