Numerical Model Study of Two-Tiered Reinforced Soil Retaining Wall Subjected To Dynamic Excitation

Sudipta Sikha Saikia[1] Arup Bhattacharjee [2]

[1] PG student, Jorhat Engineering College , Jorhat-785007
[2] Associate Professor, Jorhat Engineering College, Jorhat-785007
sudiptasikhasaikia@gmail.com , bhatta_arup@yahoo.com

Abstract. This paper emphasized on response of the multi-tiered geosynthetic reinforced soil wall subjected to seismic excitation. A 2.8 m high finite element model of modular block facing reinforced soil wall is simulated using finite element software PLAXIS 2D. The numerical model is subjected to dynamic excitations of 0.4g Kobe earthquake and results of the response of the numerical model are validated with shake table tests results available in literature. A 9 m high two tiered wall with different offset distances of 0.5m, 0.75 m and 1m is simulated with validated model parameters. The construction sequence is followed in numerical model simulation and model is brought to equilibrium condition after each stage of construction. The tiered wall is subjected to seismic excitation of 0.4g Kobe earthquake and the variation of horizontal displacements, maximum reinforcement loads, lateral stress of backfill and acceleration amplification factors of single tiered and two-tiered walls with various offset distances are compared. The results indicated that the deformation, maximum reinforcement load and acceleration amplification factor decreases with the increasing tier offset.

Keywords: Geosynthetic reinforced soil retaining wall, Numerical model, Seismic excitation.

1 Introduction

The applications of geosynthetic reinforced soil (GRS) walls are increasing due to appearance, durability, cost efficiency and their higher performance during earthquakes. It is observed from available literature and design considerations that the tensile stress in the reinforcement increases with increase in height of GRS walls. The GRS walls can be constructed in tiered fashion with facing discontinuity to reduce the tensile stresses. The study of multi-tiered GRS wall has not made much progress as compared to the single tiered GRS wall. Few guidelines available for the design of multi-tiered walls [1], [2], [3], [4], [5]. Numerical study on multi- tiered reinforced soil walls are reported by few researchers [6], [7], [8], [9].

The objective of this paper is to investigate the performance of two-tiered geosynthetic reinforced soil walls subjected to seismic excitation. The response of two-tiered wall is compared with vertical reinforced soil walls. The study envisaged to get insight on the behavior of two-tiered reinforced soil walls focusing mainly on variation of horizontal displacement of facing, lateral stress of backfill, maximum reinforcement load, acceleration amplification factor with tier height under dynamic loading conditions.

2 Development of reinforced soil wall model in PLAXIS 2D

2.1 Target Model

The large scale shaking table tests on modular block geosynthetic reinforced soil retaining wall subjected to Kobe earthquake motions [10] is considered as target model for validation purpose. The wall was 2.8m high, 4m long and 2m wide wall constructed on a 20 cm thick soil foundation. The facing blocks were 20 cm high, 30cm deep and 45 cm wide. The wall was backfilled with medium dense Tokachi port sand (D_r=55%) and reinforced with PET geogrid. Geogrids length of h=205cm were placed at vertical intervals of 60cm and its ultimate strength was 35KN/m. The foundation soil has the same properties as the backfill soil but at a relative density of 90%. To prevent waves reflecting from the steel walls during shaking, 10 cm thick expanded polystyrene (EPS) boards had been placed at the front and back ends of the steel container. The geometry of the wall is shown in fig1. The wall was subjected to horizontal shakings of Kobe earthquake (1995) scaled to a peak acceleration of 0.4g.

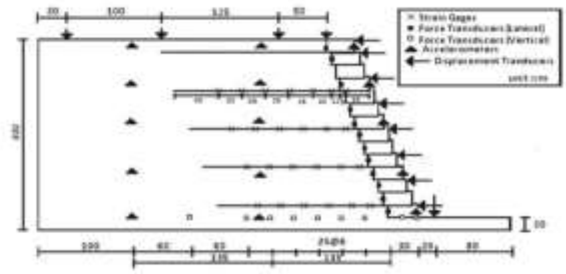


Fig 1. The geometry of the model used for validation [10]

2.2 Numerical Model in PLAXIS 2D

The components of shake table test as reported [10] is simulated using two-dimensional finite element program PLAXIS 2D. The wall and backfill soil is modeled using 15 nodded triangular elements. The geometry of the model is shown in Fig. 2. The input parameters of numerical model are given in Table 1. The bottom boundary of the numerical model is fixed in vertical direction and side boundary is fixed in horizontal directions. The absorbent boundary condition is applied to the far boundaries to absorb shear wave velocities. The wall is excited with maximum horizontal acceleration of 0.4g.

Table 1. Input model parameters used in PLAXIS 2D

Properties	Backfill	Foundation	Facing wall	Geogrid
Material model	Mohr Coulomb	Mohr Coulomb	Linear elastic	Linear elastic
Elastic modulus(kPa)	156E3	156E3	2E6	
Cohesion (kPa)	1	1		
Angle of friction(∘)	38	40		
Dilatancy angle (ψ)	8	8		
Mass density (kN/m^3)	14.30	14.30		
Poisson's ratio	0.33	0.33	0.2	

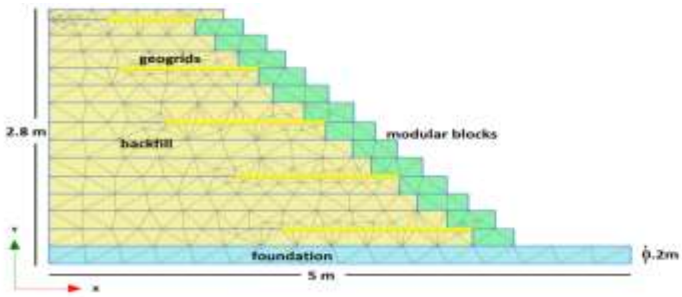


Fig 2. Numerical model used for validation

2.3 Validation analyses

The results in terms of horizontal displacements, lateral and vertical stresses of the shaking table test as reported [10] are compared with the results obtained from the finite element model.

Horizontal displacement of facing: The horizontal displacements of facing are compared with measured and predicted results and are shown in Fig 3. The maximum horizontal displacement at the top of the wall is found to be 72mm in numerical model and that of physical model [10] is 70 mm. The predicted and measured results show reasonably good agreement.

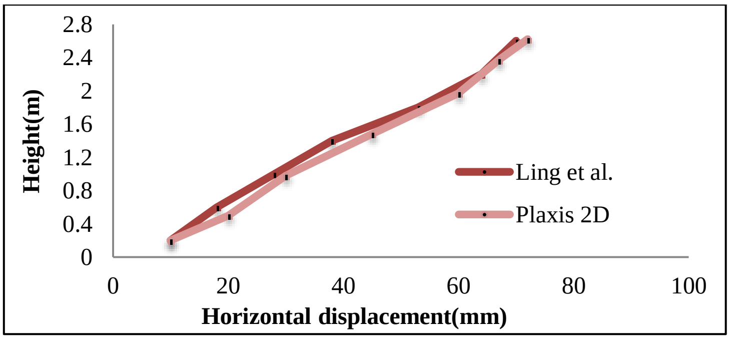


Fig 3. Horizontal displacement measured by Ling et. al.(2005) and FE analysis

Lateral stress of backfill: The comparison of lateral stress of soil acting at the wall face measured in the physical model and finite element model is shown in Fig 4. The maximum measured and predicted lateral stress is 8 kPa and 6 kPa respectively. The predicted and measured results show reasonably good agreement.

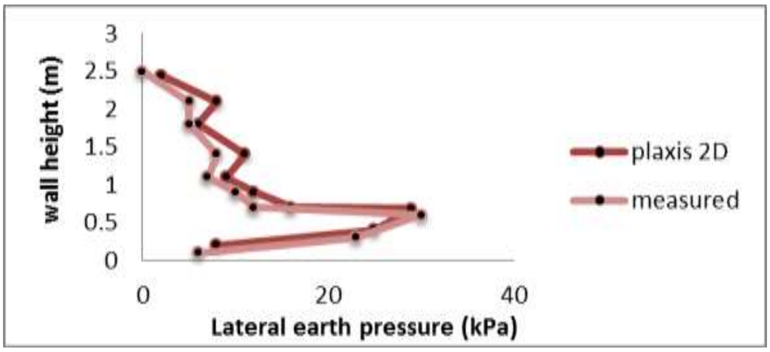


Fig 4. Predicted and measured lateral stresses of backfill at the wall face

Vertical stress of backfill: The measured and predicted value of vertical stresses is shown in Fig.5. The vertical stress is maximum near the facing wall where the measured value is slightly high than predicted value. The maximum predicted and measured vertical stress is 240 kPa and 250 kPa respectively. The finite element model was able to give satisfactory agreement with measured value.

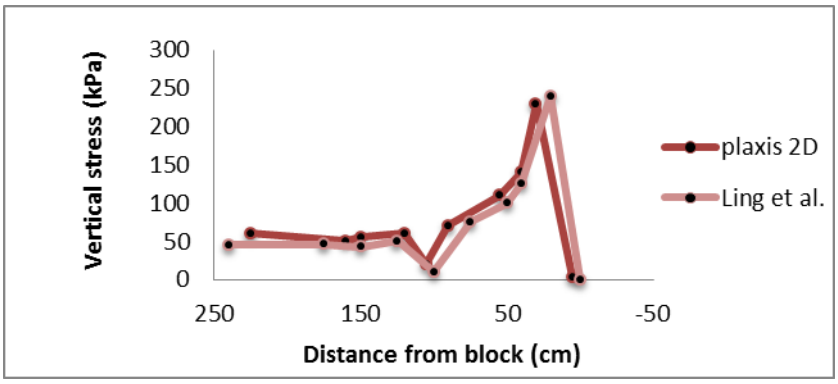


Fig 5. Predicted and measured vertical stresses at the wall base.

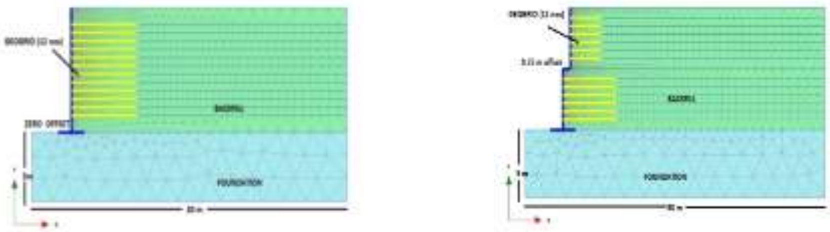
3 Numerical modeling of two-tiered reinforced soil walls

Using the validated model parameters, numerical model of 9 m high wall with tier height of 4.5 m is developed. Two-tiered walls with offset distances of 0.5 m, 0.75 m and 1.0 m are considered for the analysis and compared with reinforced soil wall without any offset termed as zero offset wall. Geometry of two tiered walls with (a) zero offset (b) 0.75 m offset distances is shown in Fig.6. The reinforcement lengths are calculated as per design guidelines [5] for different tiers and are shown in Table 2 below.

Table 2. Reinforcement lengths for different tiers as per FHWA (2010)

No. of tiers	Position of tier	Reinforcement length
Vertical wall(H=9m)		0.7H=6.3m
Two- tier	Upper tier	$0.7H_1$=3.15m
(H=9m, H_1=4.5m)	Lower tier	0.6H=5.4m

A total of 12 number of geogrid layers are laid in all different models of tiered reinforced soil walls at a spacing of 0.6 m. The boundary conditions considered for two tiered walls are same as that of the validated model. The acceleration histories of 1995 Kobe earthquake having PGA 0.4g is applied at the base of all the models. This dynamic loading is modeled by employing the prescribed displacement at the base of the foundation.



(a) (b)

Fig. 6. Geometry of two-tiered walls with (a) zero offset (b) 0.75 m offset distances.

3.1 Comparison of Results

Horizontal displacement of facing: The horizontal displacements of zero offset wall and tiered walls subjected to 1995 Kobe earthquake is shown in Fig.7. The wall displacements at the top of the wall is found to be 17.2mm,15.8 m, 15.5 m and 15.2 m for offset distances of 0m, 0.5m, 0.75m and 1m respectively .The maximum deformation reduces with increasing tier offset. The upper tier acts as a surcharge on the lower tier, which increases the deformation near the mid height of the wall. Due to uneven reinforcement length in the lower and upper tier, the deformation pattern is not linear.

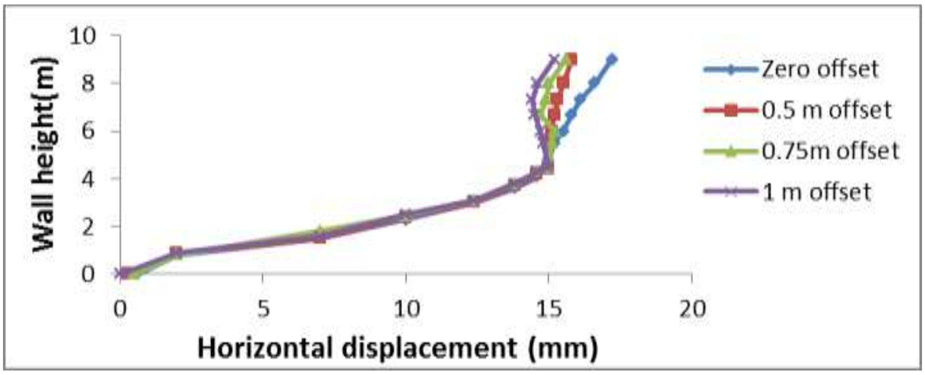


Fig 7. Wall deformation for different offsets of two-tiered walls subjected to Kobe earthquake excitations.

Maximum reinforcement load: Fig.8 shows the comparison of maximum reinforcement load at the end of shaking for two-tiered walls with different offset distances subjected to Kobe excitations. The maximum reinforcement load is almost similar to vertical wall in the lower tier, but the reinforcement load decreases significantly with offset distances in the upper tier. The maximum reinforcement load is lesser for tiered walls with different offset length than that of zero offset walls.

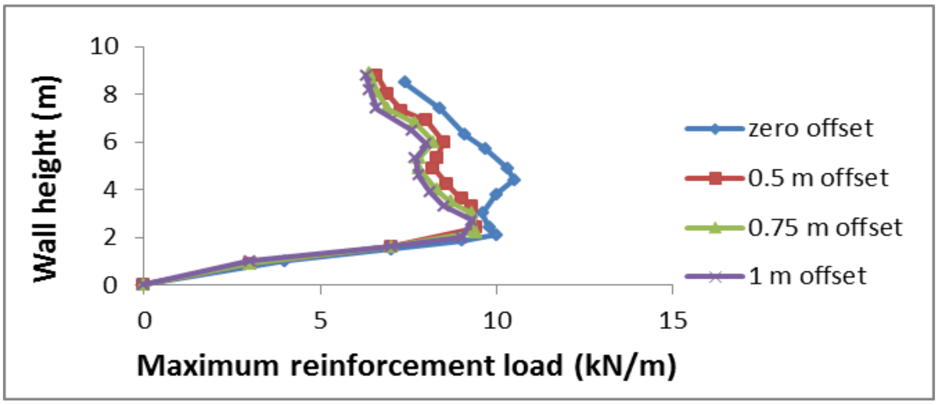


Fig 8. Maximum reinforcement load for different offsets of two-tiered walls subjected to Kobe earthquake excitations.

Acceleration amplification: The RMSA amplification factor is the ratio of RMS acceleration values at different elevations to the base RMS acceleration value. The acceleration amplifications at different elevations of the wall are quantified as root mean square acceleration (RMSA) amplification factor. The RMS acceleration can be calculated [11] as follows

$$\text{RMS} = [\frac{1}{t_d}\int_0^{t_d} a(t)^2\ dt]^{\frac{1}{2}}$$

where $a(t)$ is acceleration time history

t_d is duration of the acceleration record

dt is the time interval of the acceleration record

Fig 9 shows the RMS amplifications measured 10 m away from the toe for two-tiered walls. The acceleration amplification factor at the top of zero, 0.5 m, 0.75 m and 1.0 m offset wall are 0.9, 2.19, 2.11 and 2.05 respectively. Acceleration amplification factors for zero offset walls are less than 1. The acceleration amplification of tiered offset walls is more than 1 and increases with increase in height of wall. The acceleration amplification of tiered wall decreases with increase in offset distance. The acceleration amplifications are high in two-tiered walls due to facing effect and smaller length of reinforcement in the upper tier compared to lower tier for all the walls.

Lateral stress of backfill: Fig. 10 shows the variation of lateral soil pressure on the face of the wall for zero offset and tiered offset walls. The maximum lateral stresses are 130kPa, 100kPa, 92kPa and 88kPa near the bottom of the wall for zero, 0.5 m, 0.75 m and 1.0 m offset wall respectively. The lateral stresses decrease almost linearly with height of wall. The higher stresses in the tiered wall at the mid height are mainly due to the surcharge pressure from the upper tier.

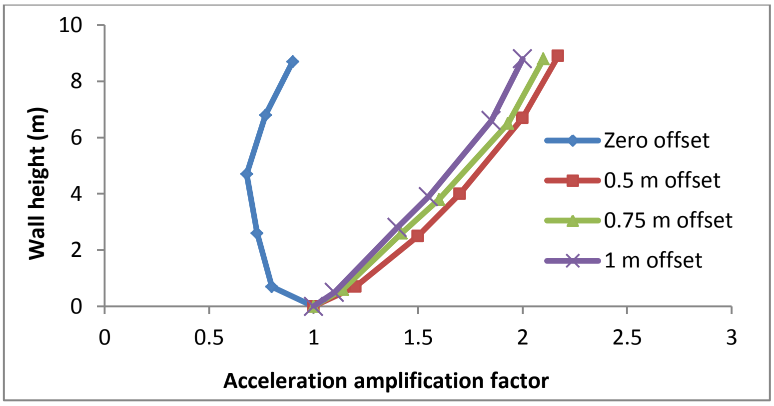


Fig.9. Horizontal acceleration amplifications in the backfill for two-tiered walls subjected to Kobe earthquake excitations.

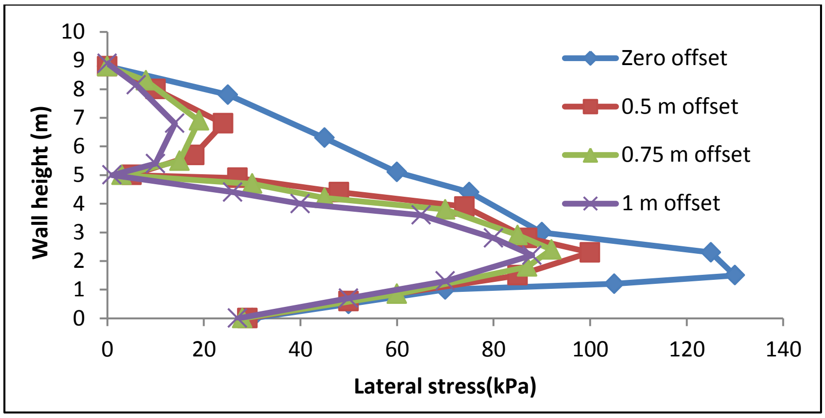


Fig.10. Lateral soil pressure on the face of the wall for different offset of two-tiered walls

4 CONCLUSIONS

A numerical model of shake table test was developed in finite element program PLAXIS 2D and verified by comparing numerical results with physical measurements taken from shake table test on reinforced soil wall reported in literature [10]. (2005).The following conclusions are drawn from the present research work.

- With an increase in the tier-offset, the facing lateral displacement decreased significantly, particularly in the upper tier.
- The maximum reinforcement load in tiered wall decreases with increase offset distance.

- The acceleration amplification factors for tiered walls are more than that of zero offset walls.
- The acceleration amplification factor decreases with increase in offset distance.

References

1. NCMA: Design Manual for Segmental Retaining Walls. *National Concrete Masonry Association*, Collin, J., Editor, Second Edition, Herndon, Virginia, USA(1997).
2. NCMA: Segmental Retaining Walls Seismic Design Manual. *National Concrete Masonry Association*, Bathurst, R.J., Editor, First Edition, Herndon, Virginia, USA (1998).
3. AASHTO : Standard specifications for highway bridges, *American Association of State Highway and Transportation Officials*, Washington, DC, USA (1998).
4. FHWA Publication.:"Geosynthetic Design and Construction Guideline", FHWA Publication No: FHWA-HI-95-038,(1995).
5. FHWA Publication.: "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines", Vol. I& II. Publication No. FHWA-NHI-10-024, US Department of Federal Highway Administration (FHWA),(2010).
6. Leshchinsky, D. and Han, J.: "Geosynthetic Reinforced Multitiered Walls", Journal of Geotechnical and Geoenvironmental Engineering, 130 (12) ASCE (2004).
7. Yoo, C. and Kim, S.: "Performance of two-tier geosynthetic reinforced segmental retaining wall under a surcharge load: Full scale load test and 3D finite element analysis". Geotextiles and Geomembranes, 26, pp. 460-472. (2008).
8. Liu, H., Yang, G. and Ling, H.I.: "Seismic response of multi-tiered reinforced soil retaining walls". Soil Dynamics and Earthquake Engineering, 61-62(2014)1–12, pp. 1-12. (2014).
9. Mohamed, S.B.A., Yang, K.-H. and Hung W.-Y.: "Finite element analyses of two tier geosynthetic-reinforced soil walls: Comparison involving centrifuge tests and limit equilibrium results". Computers and Geotechnics, 61 (2014) 67–84, pp. 67–84. (2014).
10. Ling et al.: "Large scale shaking table tests on modular block reinforced soil retaining walls". Journal of geotechnical and geoenvironmental engineering ASCE, April (2005)
11. Kramer, S.L.:Geotechnical Earthquake Engineering, Prentice Hall, Upper Saddle River, NJ,(1996).