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Comparative Analysis of Single and Two-tiered Geo-Synthetic Reinforced Soil Walls subjected to Dynamic Excitation

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Abstract. Geo-synthetic reinforced soil (GRS) walls are the most common and effective soil retaining structures. This technique has been chosen more and more often due to its aesthetics, stability, cost-effectiveness and sound performance during earthquakes. From literature and current design guidelines, it is observed that tensile stresses in reinforcement increases with increase in height of GRS walls. The tensile stresses in reinforcement can be reduced by constructing the GRS walls in tiered fashion with facing discontinuity by an offset at facing. This paper presents a comparison of responses of single and two-tiered GRS walls with different offset distance subjected to dynamic excitation. The analysis is conducted by simulation of numerical models of 9 m height walls using finite element software PLAXIS 2D. A validation analysis is conducted and results are compared with experimental results reported by Ling et al. (2005). Validated parameters are used to simulate single and two-tiered walls where tiered offsets are considered as per FHWA (2010) guideline. The models are subjected to seismic excitation of 0.25g Loma Prieta (1989) earthquake. The dynamic behavior of walls in terms of lateral facing displacement, lateral earth pressure, reinforcement load and acceleration amplification are investigated and compared. The analysis shows that depending on offset distances multi-tiered walls offer better seismic performance in comparison to the single-tiered walls.

Keywords: Geo-synthetic reinforced soil (GRS) wall, Multi-tiered reinforced soil wall, Dynamic Excitation

1 Introduction

Geo-synthetic reinforced soil (GRS) retaining wall is one of the most common applications of reinforced soil where polymeric material geo-synthetic is used as reinforcement. It has gained wide spread acceptance in the engineering field as an economic and innovative alternative of earth retaining wall. This technique has been chosen more and more often due to its aesthetics, stability, cost-effectiveness and sound performance during earthquakes. In seismically active areas, GRS walls are constructed in the tiered configuration as it helps to reduce maximum lateral deformation of the wall caused by earthquake loading. Researchers suggested that tiered configuration in geo-synthetic reinforced soil (GRS) retaining wall is needed when considering tall walls since both internal and external stability of the retaining wall is affected by increasing wall height. The use of multi-tiered wall is applicable when the height is greater than 6m (Liu et al. 2011).In FHWA 2010 guideline, the tiered wall is termed as superimposed wall and suggests that GRS walls in tiered configuration with smaller wall height reduces vertical stress on the facing element as well as the lateral stress in the whole wall system. For multi-tiered walls, Liu et al. 2014 showed that depending upon the offset distance, tiered configurations could considerably reduce residual lateral facing displacement and average reinforcement load.

The objective of the present work is to study the dynamic behavior of single tiered and two tiered Geo-synthetic Reinforced soil (GRS) retaining wall through numerical simulation. The study is executed by comparing the dynamic behavior of the single-tiered and two-tiered wall with different offset distances under dynamic loading condition. In the present work, a set of numerical models has been developed using finite element program PLAXIS 2D which can describe the seismic behavior of tiered GRS retaining wall under dynamic condition. To assess the accuracy of the numerical procedure employed for this research work, a validation analysis is performed. After that, numerical analyses of multi-tiered GRS retaining walls are performed for different offset distances. Reinforcement and offset distance are considered as per FHWA (2010) guideline.

2 Modeling of Geo-synthetic Reinforced Soil (GRS) Retaining Wall

In this study, finite element software PLAXIS 2D is used for numerical modeling. Plane strain model of 15 nodded triangular elements is used to discretize the soil medium and other material clusters. The 15 nodded triangular elements are used as it gives high quality stress results. The geo-synthetic reinforcements are simulated using the 5 node geo-grid element and soil-structure interactions are simulated using the 5 node thin layer interface element. To simulate the effect of the real construction process of GRS retaining wall, stage construction procedure is implemented. In PLAXIS 2D, this procedure allows for a realistic determination of stresses and displacements. An experimental modular block reinforced soil wall reported by Ling et al. (2005) is selected for validation analysis. The experimental model is developed using finite element program PLAXIS 2D and results are compared with experimental results. The comparisons are carried out in terms of parameters such as horizontal displacement, lateral earth pressure and acceleration amplification factor.

2.1 Validation

Ling et al. (2005) conducted an experimental study by using large scale shake table test to observe the seismic performance of modular block reinforced soil retaining walls. The large-scale 2.8 m high modular-block geo synthetic-reinforced soil wall was subjected to significant shaking using the 0.8g Kobe earthquake motions. The wall was 2.8 m high, 5m long and 2m wide constructed on 20cm thick foundation. The facing blocks were 24 cm high, 30 cm deep and 45 cm wide by creating an angle 78 degree with foundation. The wall was backfilled with fine Tokachi sand with relative density 55% and polyester geogrid (PET) of length 205 cm were placed at a vertical distance of 60 cm. The foundation was constructed with the same type of sand as backfilled soil. To prevent the waves reflecting from the steel walls during shaking, 10 cm thick expanded polystyrene (EPS) boards were placed at the front and back ends of the steel container.

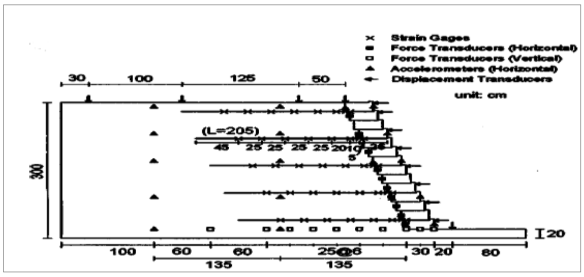

Fig.1. The geometry of the model used for validation (after Ling et al. 2005)

Backfill soil

The linear elastic perfectly plastic Mohr-Coulomb model is considered to represent the sand used in foundation and backfill in the physical model. Basic input parameters for Mohr-Coulomb models are elastic modulus (E), cohesion (c), frictional angle (ϕ), Poisson's ratio (v), and dilatancy angle (ψ).

Facing Block, Geo-grids and EPS board

The geo-grids are modeled using geo-grid element with modulus of axial stiffness (EA). The facing blocks are modeled as linear elastic material using plate element which consists of input parameters including elastic modulus (E), Poisson's ratio (ν), and unit weight (γ). The EPS boards are modeled as linear elastic and the input parameters are modulus of elasticity (E), Poisson's ratio (v) and density (γ).

Interface element

In order to properly simulate the soil structure interaction, interface elements are used between two different materials. The interface elements are modeled as linear elastic material using interface element. The roughness of the interaction is modeled by choosing a suitable value for strength reduction factor R_{inter} which is interlinked to the strength properties of the soil layer. The R_{inter} are chosen as 0.7, 0.65 and 0.5 for interface between soil-geogrid, soil-concrete and concrete-geogrid.

Dynamic boundary condition

In the numerical model, the side boundary nodes are fixed in the horizontal direction and bottom boundary nodes are fixed in both horizontal and vertical direction. In dynamic analysis, to reduce reflections of seismic waves reaching the model boundaries, special dynamic boundaries are provided. Earthquake load is defined by prescribe displacement and applied at the bottom boundary with a maximum horizontal acceleration of 0.8g Kobe Earthquake (1995). To simulate the damping of soil, damping ratio of 5% is taken for soil.

Table 1. Material properties of Finite element (FE) model

Backfill soil properties	
Elastic Modulus(kN/m^2)	159 x 10^3
Cohesion (kPa)	1
Mass density (kN/m^3)	14.30
Poisson's ratio	0.33
Angle of friction(°)	38
Dilatancy angle (°)	8
Facing wall	
Elastic Modulus(kN/m^2)	2 x 10^6
Mass density (kN/m^3)	23
Poisson's ratio	0.2
EPS Board	
Elastic Modulus(kN/m^2)	2 x 10^6
Mass density (kN/m^3)	1
Poisson's ratio	0.2
Geogrid	
Axial stiffness (kN/m)	680

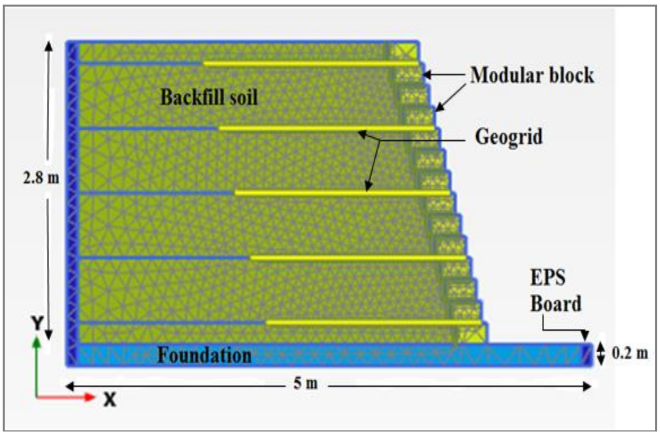

Fig. 2. Numerical mesh(FE model

Horizontal Displacement of facing

Figure 3 shows the maximum displacements measured on the experimental wall and the maximum displacements are calculated using the finite element (FE) Model. The maximum displacement of the FE model is found to be 75 mm at the top which is very close to the measured value 72 mm as discussed by Ling et al. (2005). Therefore, good agreement is shown in between the FE model and the experimental model.

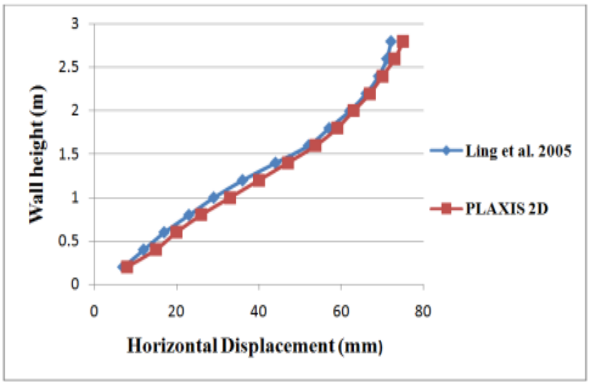

Fig. 3. Horizontal displacement measured by Ling et al. (2005) and FE Model

Lateral soil stress

Figure 4 illustrated the lateral stress obtained at facing during dynamic excitation from the experimental model and FE analysis. Both the wall has maximum lateral stress at the bottom and minimum at the top of the wall. The maximum lateral stresses are found to be 31 kPa and 28 kPa for PLAXIS 2D model and experimental model respectively

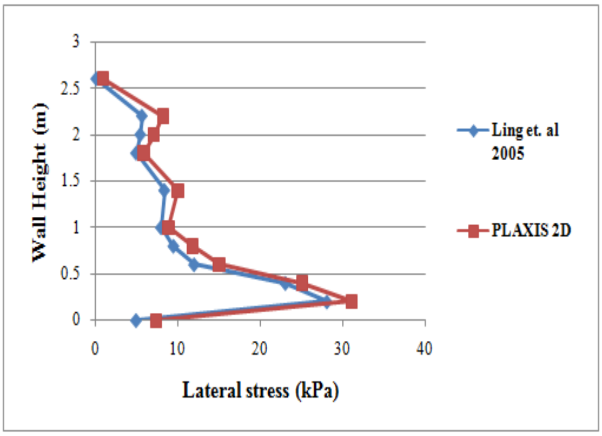

Fig. 4. Lateral stress measured by Ling et al. (2005) and FE model

Horizontal acceleration amplification

Horizontal acceleration amplification along the height of the wall obtained from numerical analysis and experimental analysis at the end of dynamic excitation is presented in Figure 5.The amplification factor is given for the ratio of maximum acceleration in the backfill, typically at the top of backfill, to the acceleration at the foundation level (Ling et al, 2005). It is observed from the figure that the measured and predicted acceleration amplification is in reasonable agreement. The peak acceleration computed by the FE model is 1.2 while the measured value suggested by Ling et al, 2005 is 1.1.

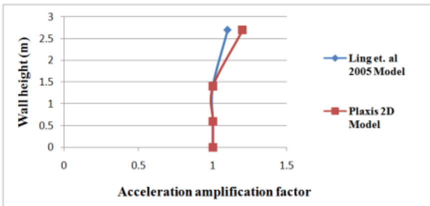

Fig. 5. Horizontal acceleration amplification factor measured by Ling et al. (2005) and FE model

The validation procedure adopted for the present work shows that numerical results are in good agreement with experimental results. Therefore it can be suggested that that the finite element method is capable of simulating the construction behavior of geo-synthetic reinforced soil retaining wall.

3 Numerical Modeling of Multi-Tiered GRS Wall with Offset Distances

In the present work, with the aim of investigating the seismic behavior of tiered geo-synthetic reinforced soil retaining wall under dynamic load, a 9 m height wall is selected for numerical analysis. Using the same model parameters from validate model, single-tiered and two-tiered walls are developed. Firstly, single-tiered wall with 12 geo-grid reinforcement of length 0.7 times of wall is considered for simulation. Further, two-tiered wall of each 4.5 m tier height with different offset distances of 0.5 m, 1.5m, 2m, 2.5m and 3m are considered for numerical simulations. The offset length and reinforcement length are calculated as per FHWA (2010). A record of the 1989 Loma Prieta with a peak acceleration of 0.25g is used as input and applied at the base of the walls. The dynamic behavior of walls are studied in terms of parameters such as horizontal displacement, lateral earth pressure, reinforcement load and acceleration amplification factor.

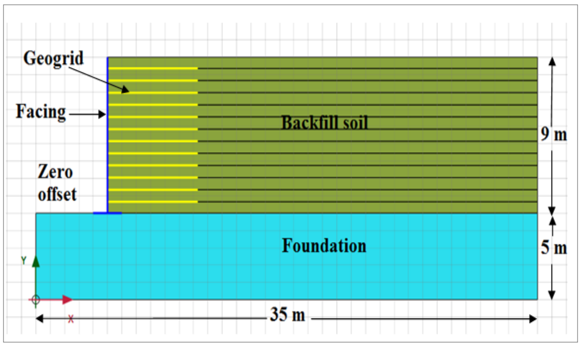

Fig. 6. FE model of Single-tiered GRS wall(Zero offset)

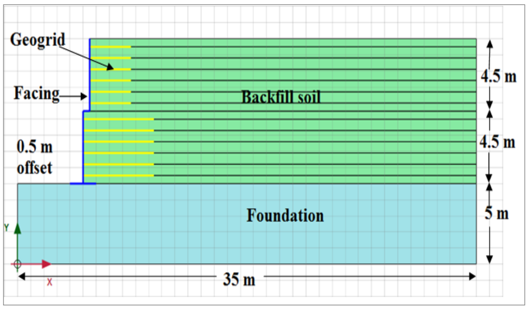

Fig. 7. FE model of Two-tiered GRS wall (0.5 m offset)

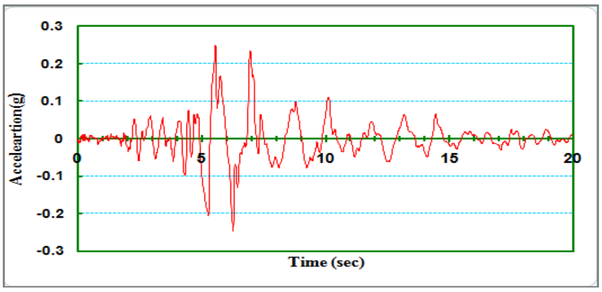

Fig. 8. Acceleration time-history for Loma Preita Earthqauke (1989)

3.1 Horizontal displacement of facing

Figure 9 shows the comparison of lateral displacement of the single-tiered wall and two-tiered wall with different offset lengths. The maximum displacement at the top of the walls are found to be 152 mm, 120 mm, 86 mm, 72mm, 66 mm and 52mm for zero offset, 0.5 m offset, 1.5 m offset,2m offset, 2.5m offset, and 3 m offset respectively. The results show that maximum displacement decreases with increase in tier offset length. During an earthquake retaining wall experienced an additional thrust behind it, which is known as dynamic earth pressure. Due to the effect of dynamic earth pressure, wall exhibit excessive horizontal deformation. But in retaining wall with tiered configuration shows smaller displacement, unlike vertical wall. The smaller displacement is the result of the smaller inertial force comes from the smaller mass in the upper tier. Hence it can be suggested that by providing adequate offset distances in vertical wall, notable displacement can be reduced.

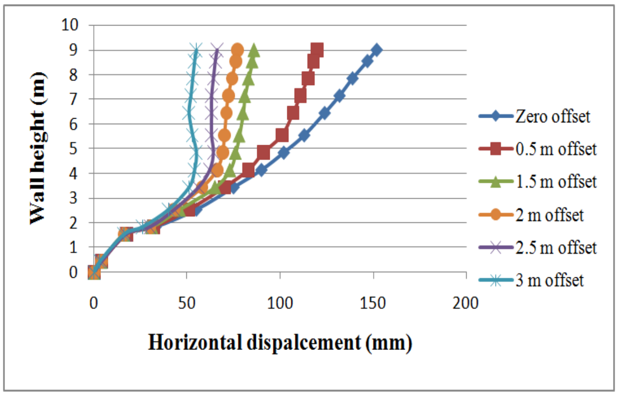

Fig. 9. Wall deformation for single-tiered and two-tiered wall with different offset distances

3.2 Reinforcement Load

The variation of reinforcement load distribution along the height of the wall of all cases is shown in Figure 10. As can be seen in figure, the occurrence of the maximum reinforcement load decreases significantly with an increase in tier offset. The maximum reinforcement loads are found to be 14.3 kN/m,12.89kN/m,10.9 kN/m, 9.6 kN/m, 8.4kN/m and 7.2kN/m for offset distances of zero offset, 0.5m offset, 1.5m offset, 2 m offset, 2.5 m offset and 3 m offset respectively. In reinforced soil retaining wall, internal stability depends on the reinforcement layer which is basically known as tension resisting component. The role of tensile reinforcement is to resist induced shear deformation due to dynamic force. Therefore, from the results presented in Figure 10, it can be concluded that by providing offset distance in single-tiered wall, reinforcement load can be significantly reduced.

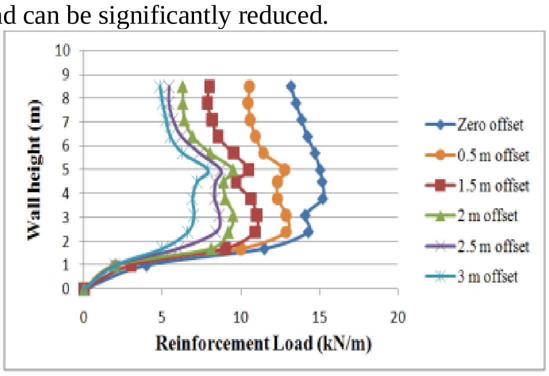

Fig. 10. Reinforcemnt laod for single-tiered and two-tiered wall with different offset distances

3.3 Lateral soil pressure at the face of the wall

Figure 11 compares the lateral soil pressure of single-tiered and two-tiered walls with offset distances. As can be seen from the figure, the maximum soil pressure occurs at near the base of the wall and decreases linearly towards the top, attained a very small value at the top of the wall for all cases. The maximum lateral soil stresses are found to be 189 kPa, 171 kPa, 160 kPa, 151 kPa, 148 kPa and 135 kPa for zero offset, 0.5 m offset, 1.5 m offset, 2m offset, 2.5 m offset and 3m offset respectively near the bottom of the walls. The lateral soil pressure at the mid height are found to be 30.3 kPa , 28.12 kPa, 26 kPa , 24.7 kPa and 24 kPa for 0.5 m offset, 1.5 m , 2m ,2.5 m offset and 3 m offset respectively. Thus, it can be observed that maximum lateral stress decrease with an increase in tier offset distance.

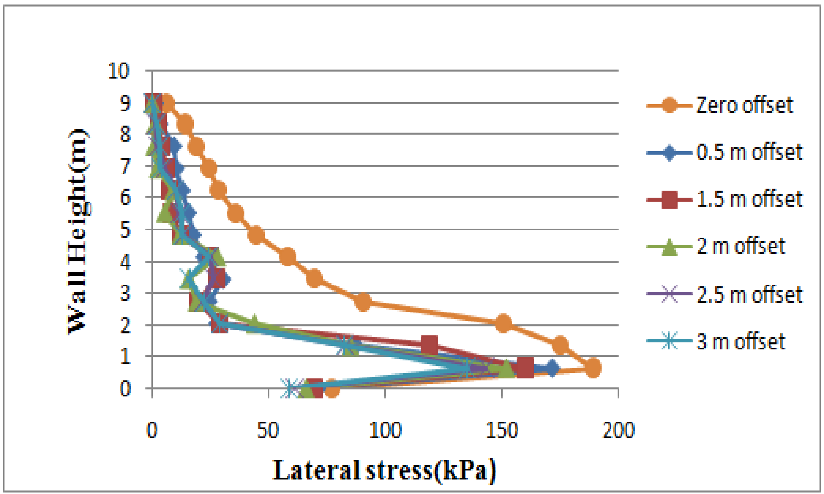

Fig. 11. Lateral soil pressure on the face of the wall for single-tiered and two-tiered wall with different offset distances.

3.4 Acceleration amplification factor

Figure 12 shows the horizontal acceleration amplification recorded at backfill soil for different tier offset lengths. The acceleration amplification factor is defined as the ratio of the maximum acceleration at that point to the acceleration applied at the foundation**.** The measuring points are selected at a distance of 15 m away from the toe. The acceleration amplification is minimum at the base of the wall and gradually increases along the height of the wall. The peak acceleration amplifications are observed at the top surface of the walls and are found to be 1.51, 1.49, 1.542, 1.56, 1.59 and 1.65 for offset lengths of 0 m, 0.5 m, 1.5m, 2m, 2.5m and 3m respectively. As can be seen in the Figure 12, acceleration amplifications are slightly higher in the multi-tiered walls due to the effect of wall facing.

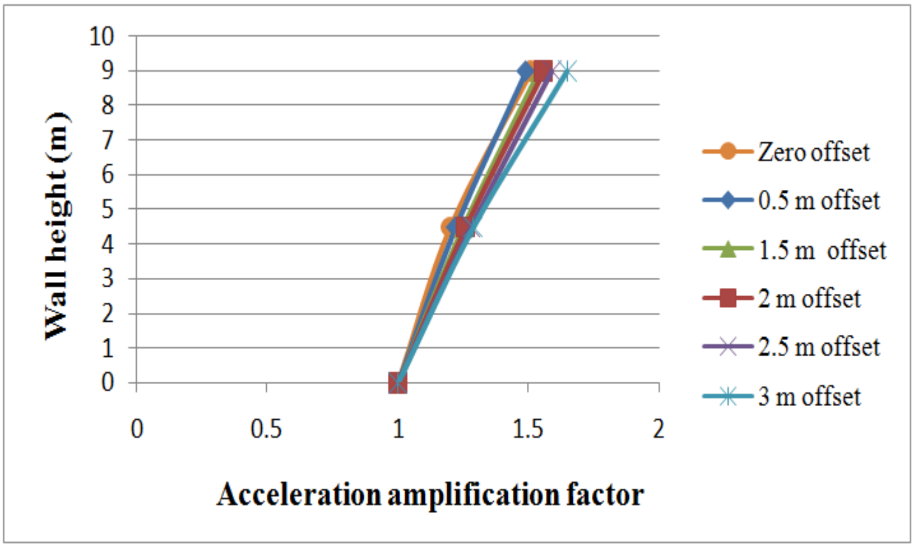

Fig. 12. Horizontal Accleration amplification factor recorded at backfill soil for different tier offest lengths.

4 Conclusions

In the present work, verified finite element models are used to conduct numerical analysis on the seismic performance of tiered GRS retaining wall. Finite element program PLAXIS2D is used to simulate the construction procedure of single tiered and two tiered wall. A record of the 1989 Loma Prieta is used as input earthquake for dynamic excitation. The seismic responses are studied in terms of horizontal displacement of facing, maximum reinforcement load, lateral soil pressure and acceleration amplification.

The following observations are made from the present study:

1. Two-tiered wall can significantly reduce the horizontal displacement and maximum reinforcement load in comparison to the wall with single-tiered configuration. The magnitude of smaller displacement and smaller reinforcement load is due to the effect of smaller soil mass in upper tiers.
2. Two-tiered wall also reduces the maximum lateral stress considerably compared to the single-tiered wall.
3. The acceleration amplifications are high in multi-tiered wall due to the influence of wall facing.

Therefore, it can be seen from the present study that multi-tiered configuration significantly improves the seismic performance of GRS wall.

References

1. FHWA Publication: Mechanically Stabilized Earth Walls and Reinforced Soil Slopes De sign and Construction Guidelines, Vol. I & II. Publication No. FHWA-NHI-10-024, US Department of Federal Highway Administration (FHWA), US (2010).
2. Ling, H. I., Mohri,Y., Leshchinsky, D., Burke, C., Matsushima, K. and Liu, H. : Large-Scale Shaking Table Tests on Modular-Block Reinforced Soil Retaining Walls. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 131, No. 4©ASCE, ISSN 1090-0241/2005/4 pp.465–476 (2005).
3. Ling, H.I., Yang, S., Leshchinsky, D., Liu, H. and Burke, C.: Finite-element simulations of full scale modular-block reinforced soil retaining walls under earthquake loading. Journal of Engineering Mechanics, ASCE, Vol.135, No. 5, pp. 653-661 (2010).
4. Liu, H.: Comparing the seismic responses of Single and multi-tiered Geo-synthetic rein-forced soil walls: Geo-Frontiers, ASCE (2011).
5. 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).
6. Reference Manual: PLAXIS 2D, Brinkgreve, R.B.J. (eds): Delft University of Technology & PLAXIS, The Netherlands (2016).
7. Tutorial Manual: PLAXIS 2D, Brinkfreve, R.B.J. (eds), Deft University of Technology & PLAXIS, Netherlands (2016).