Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 5, Issue 4; April-June, 2018, pp. 272-277

http://www.krishisanskriti.org/Publication.html

# Numerical Simulation of Multi-Tiered MSE Walls

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**Abstract—***This paper presents a numerical modelling of MSE walls for comparative study of behaviour of multi-tiered MSE walls with single tiered MSE wall. The reinforcements used were uniaxial (HDPE) geogrids. A Finite element model of MSE wall is developed using PLAXIS 2D and the model is validated with the response of a full scale physical model (Ling et al. 1995). The validated model parameters of model are used to simulate tiered MSE walls. It is found from the analysis that the multi-tiered wall can considerably reduce the lateral facing displacements, lateral soil pressure at the face of the wall and vertical soil pressure at the base of the backfill.*

## 1. INTRODUCTION

MSE walls are coherent gravity structure, customed-engineered to project-specific requirements including foundation condition and aesthetics. These walls normally include a facing element and soil reinforcing strips embedded in the backfill behind the facing.MSE walls are often used to support fills for roadways and bridges and when substantial total and differential settlement are anticipated. To take advantages of both the aesthetics and the economics of MSE (geo-synthetic) walls while considering high heights, multi-tiered walls are considered where an offset is provided between adjacent walls. FHWA (2010) also suggested design methods of multi-tiered reinforced soil wall. In most cases finite element analysis necessitates that its results are validated by physical tests. Therefore it is logical to validate finite element models with actual test data and use the validated models to understand the behaviour of similar structures. The physical tests that are conducted by Ling et. al. (1995) is modeled by means of FE analysis and in turn the validated model is used to understand the behaviour of walls with various geometries. A geo-synthetic- reinforced soil retaining wall constructed at the PWRI in Japan is studied to simulate in the PLAXIS 2D. The results obtained from analysis in PLAXIS 2D is compared with the full scale model and then validated model parameters are used to simulate multi-tiered MSE walls to compare the response of multi-tiered walls.

## 2. VALIDATION OF PLAXIS 2D

A brief summary of the PWRI wall and geometry is shown in Figure 1. It is 6 m high and 5 m wide and was constructed in a concrete test pit with a concrete floor consist of different concrete facing blocks and discrete panels. It consisted of six primary geogrids of length 3.5m and five secondary geogrids of length 1m. A total of 12 facing blocks are used to construct the wall face.

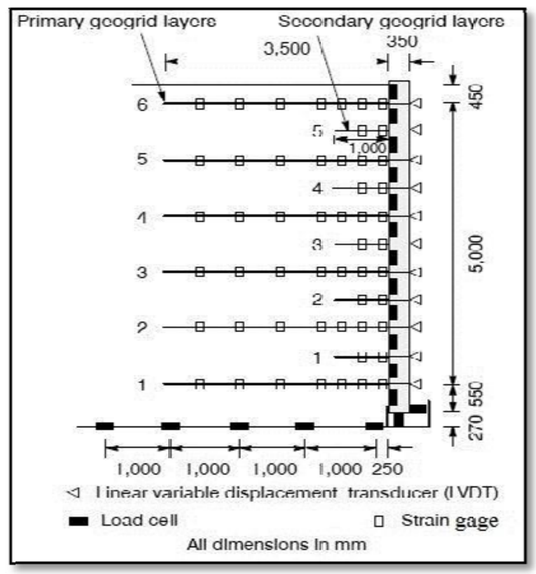



**Figure 1: PWRI Wall geometry, Japan**

### 2.1. VALIDATED MODEL IN PLAXIS 2D

A Plane strain model of 15 nodded triangular elements was used for discretisation. The properties used in PLAXIS for the backfill soil, foundation soil, retaining wall and geogrids are taken from table 1, table 2, table 3, and table 4 respectively. The soil layers were modeled as Mohr-Coulomb material and retaining wall as linear elastic material. The wall is modeled as plate bending member which gives both geotechnical and structural design parameters. Mesh type is chosen as Coarse. After defining the geometry of the model and determining the boundary conditions and properties of the material, the software generates the initial stress condition, and after this, the finite element model is completed.

**Table 1: Properties of backfill soil.**

| Parameter | Name | Value |
|---|---|---|
| Material Model | Model | Mohr-Coulomb |
| Type of Material Behavior | Type | Drained |
| Dry Unit Weight | $\gamma$unsat | 16.31kN/m3 |
| Saturated Unit Weight | $\gamma$sat | 20 kN/m3 |
| Young’s Modulus | $E_{ref}$ | 10E3 kN/m2 |
| Poisson’s Ratio | μ | 0.4 |
| Cohesion | C | 1 kN/m2 |
| Friction Angle | Φ | 38 |

**Table 2: Properties of foundation soil.**

| Parameter | Name | Value |
|---|---|---|
| Material Model | Model | Linear-elastic |
| Type of Material Behavior | Type | Non-porous |
| Dry Unit Weight | $\gamma$unsat | 24 kN/m3 |
| Saturated Unit Weight | $\gamma$sat | 24 kN/m3 |
| Young’s Modulus | $E_{ref}$ | 2E6 kN/m2 |
| Poisson’s Ratio | μ | 0.17 |

**Table 3: Properties of facing.**

| Parameter | Name | Value |
|---|---|---|
| Material Model | Model | Linear-elastic |
| Axial stiffness | EA | 700E3 kN/m2 |
| Inertial stiffness | EI | 7146 kN/m2 |
| Poisson’s Ratio | μ | 0.17 |

**Table 4. Properties of Geogrid.**

| Parameter | Name | Value |
|---|---|---|
| Axial stiffness | EA | 826.5 kN/m2 |

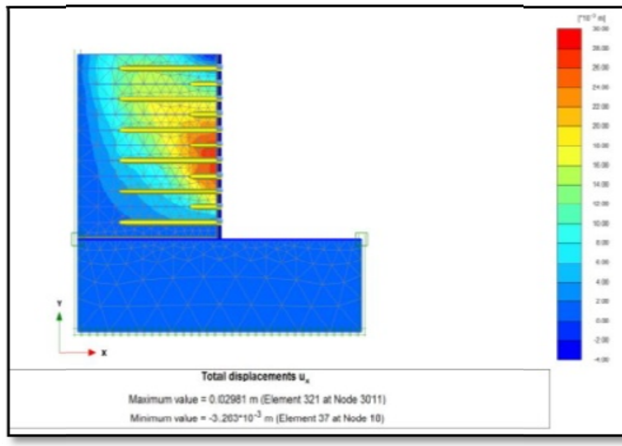



**Figure 2: Wall deformation from FE analysis**

## 2.2. RESULTS AND DISCUSSIONS

The results obtained from analysis in PLAXIS 2D are compared with the measured results. Figure 3 shows the comparison between the predicted and measured results for the horizontal displacement of the wall facing. The maximum horizontal displacement is found to be 29.81 mm at the mid height of the wall which is similar to the measured value (approximately 30 mm) as shown in Fig. 2.

The results obtained from analysis in PLAXIS are compared with the measured results. Fig. 3 shows the measured and predicted wall displacement.

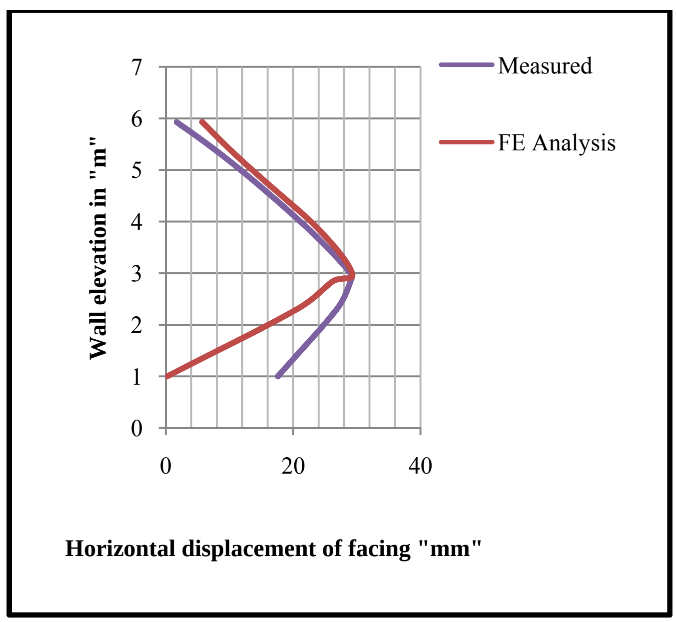



**Figure 3: Wall deformation from FE analysis**

The lateral stress acting at the wall face is shown in Fig. 4. The lateral pressure distribution shows a typical earth pressure distribution on retaining wall. The results shows that the lateral stress decreases with increasing height, almost linearly and prediction improves towards the top of the wall. The vertical stress distribution of 6 m high wall at the base of the backfill is shown in the Fig. 5. The measured and predicted values show similar trends of stress distribution. The results show that presence of the geogrid reinforcement near the facing wall reduces the vertical stress at the base of the backfill.

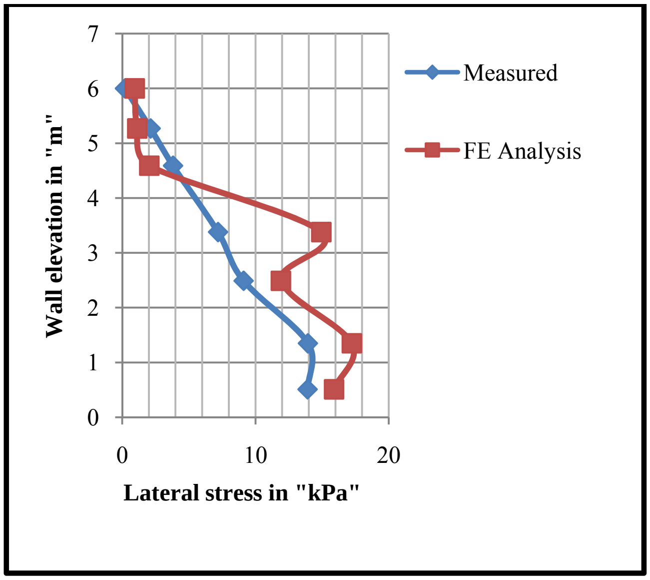



**Figure 4. Lateral stresses of backfill at wall face**

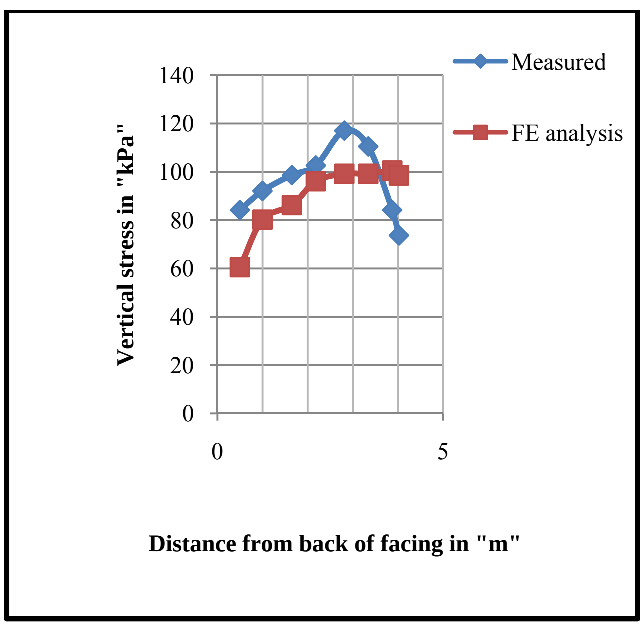



**Figure 5. Vertical stresses at the wall base**

The strain in geogrids decreases with increasing height and the predicted results shows similar trend of distribution with the measured results as shown in Fig. 6. For all cases the higher strain occurs on primary geogrid layer near the mid-height of the wall, though maximum stress is predicted at reinforcement layers near bottom of wall as per FHWA (2001). This shows that a greater preventive measure upto the mid-height of the wall from bottom needs to be taken to avoid excessive wall deformation. The reinforcement layers with higher stiffness and lesser spacing of layers upto the mid-height of the wall will serve the purpose.

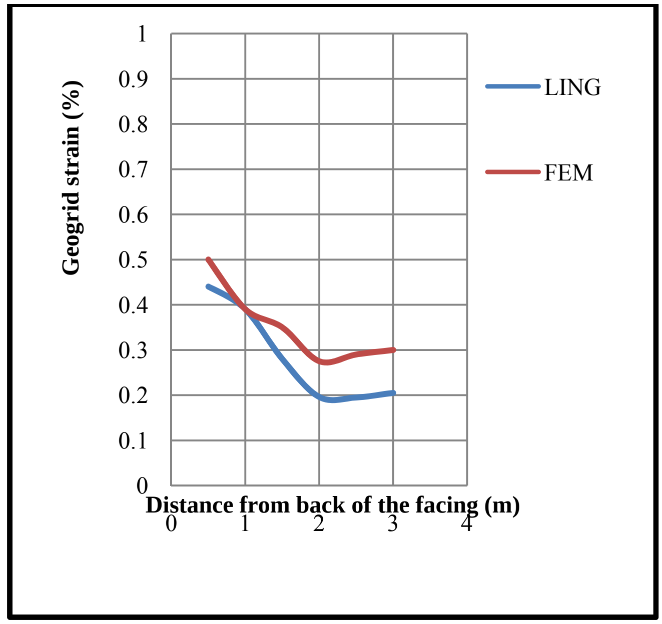
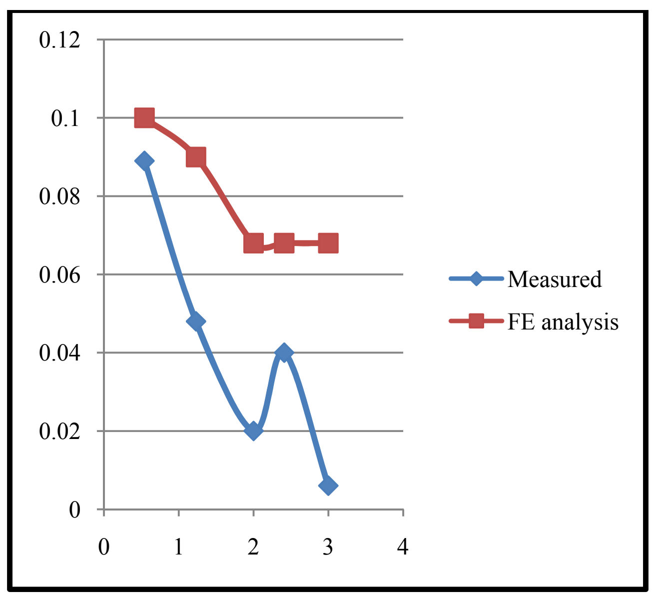



**Figure 6. Strain in primary geogrid layer 1**

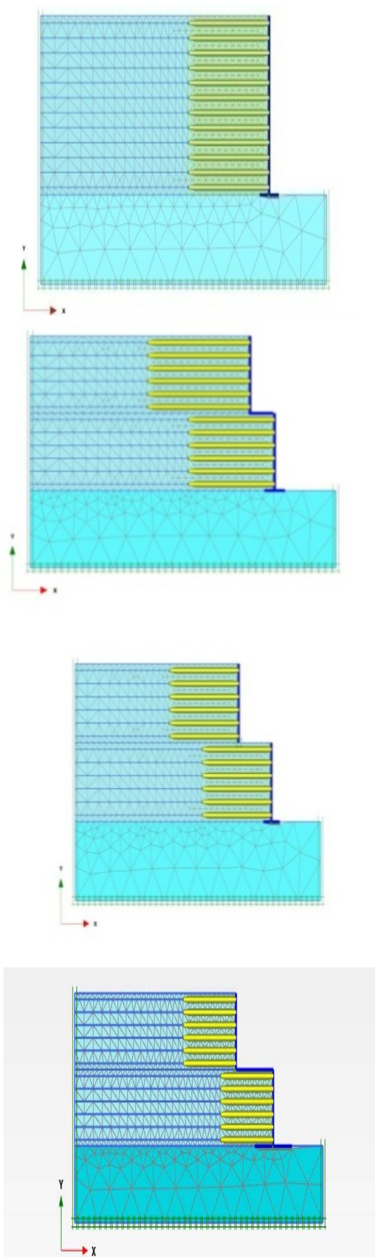



**Figures 7. Strain in primary geogrid layer 6**

This comparative study of numerical and measured experimental results indicated that the PLAXIS 2D is capable of simulating the construction behaviour of MSE wall.

## 3. NUMERICAL MODEL OF TWO-TIERED MSE WALL

The validated 6.0 m high model is modified to two-tiered 9 m high wall to study the different response of the tiered reinforced soil wall. In the development of numerical models of tiered reinforced soil walls, four different conditions are considered as shown in Fig. 8.

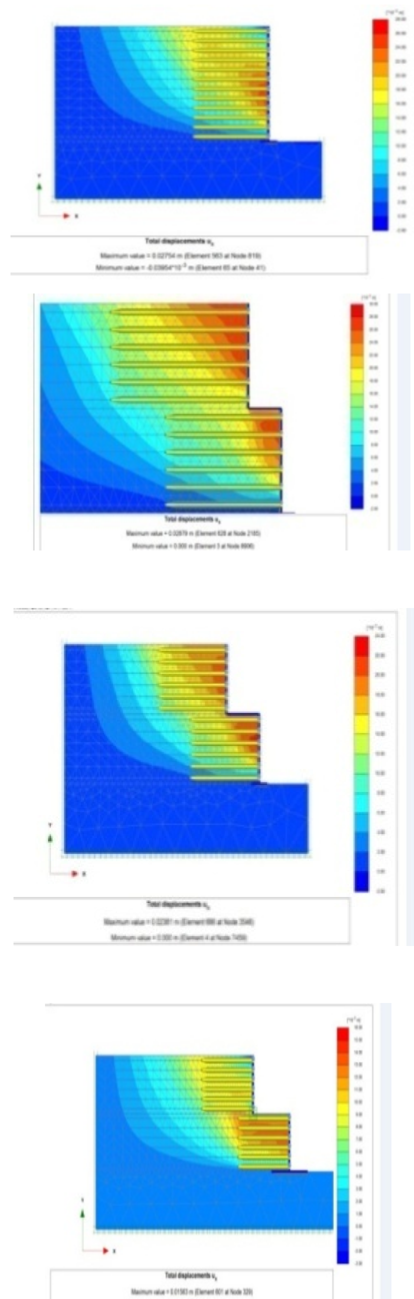


**Figures 8: FE models of tiered GRS wall for (a) zero offset (b) 1.2 m offset (c) 2.0 m offset and (d) 3.0 m offset**

## 3.1 RESULTS AND DISCUSSIONS

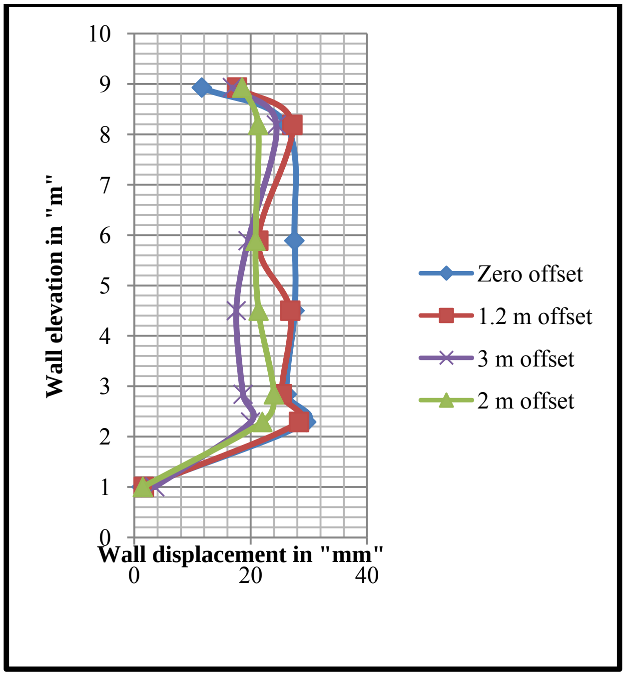
### 3.1.1 Horizontal Displacement

The tiered walls are studied for horizontal displacement of facing and different responses are observed from each of the wall model. Fig. 8 shows the contour of horizontal displacement of the wall for different tier offset. The contours show that the backfill soil particle moves towards the mid height of the walls and exerts high earth pressure at the mid height of the wall.



**Figures 9: Contour showing deformed shapes of GRS wall for (a) zero offset (b) 1.2 m offset (c) 2 m offset and (d) 3 m offset**

The maximum displacements are found to be 27.54 mm, 26.79 mm, 21.36 mm and 17.52 mm at mid height of wall with zero offset, 1.2 m offset, 2.0 m offset and 3.0 m offset respectively. The maximum deformation reduces with the increasing tier offset. Thus by providing some offset to the wall the deformation can be reduced. It is observed that at the mid-height of the wall, near the junction of two tiers the deformation suddenly increases excessively .The upper wall act as a surcharge on the lower tier, which increases the deformation near the mid height of the wall.




**Figures 10. Wall deformation for different tier offset**

### 3.1.2 Lateral Soil Pressure and Vertical Soil Pressure

The maximum lateral stresses are found to be 73.12 kPa, 72.2 kPa, 70.4 kPa and 66.6 kPa for zero offset, 1.2 m offset, 2.0 m offset and 3.0 m offset respectively near bottom of wall. The lateral stresses at the mid height are found 29.46 kPa, 34.796 kPa, 36.85 kPa and 40.184 kPa for zero offset, 1.2 m offset, 2.0 m offset and 3.0 m offset of the wall respectively. The higher stresses in the tiered wall at the mid height are mainly due to the surcharge pressure from the upper tier. Although the overall stresses decrease with the increasing tier offset as shown in the figs, but the stresses at mid height almost remain same for wall with the increasing tier offset.

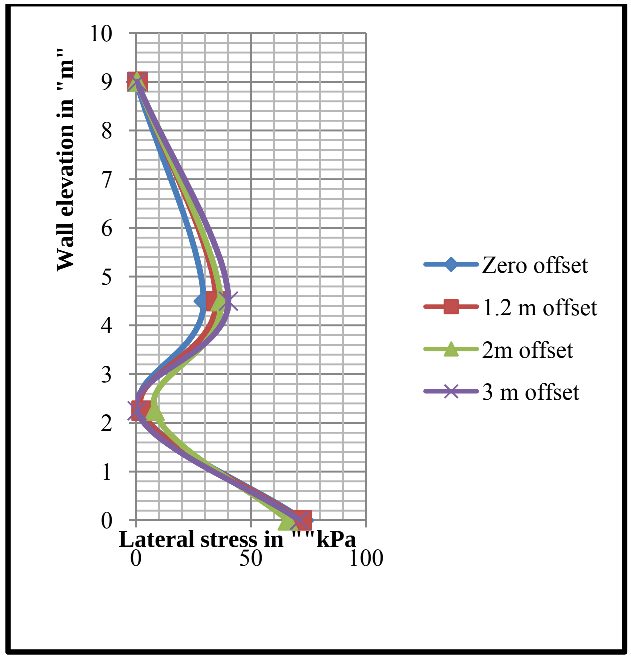



**Figure 11. Lateral soil pressure on the wall face for different tier offset**

The minimum vertical stresses are found to be 44.48 kPa, 36.702 kPa, 37.66 kPa and 34.837 kPa for zero offset, 1.2 m offset, 2.0 m offset and 3.0 m offset respectively near the facing wall. The geogrids connected to the wall reduces the vertical soil pressure at the base of the wall. Increase in tier offset reduces the amount of soil masses in the upper tier, which greatly reduces the vertical stress to the underlying soil mass and finally at the base.

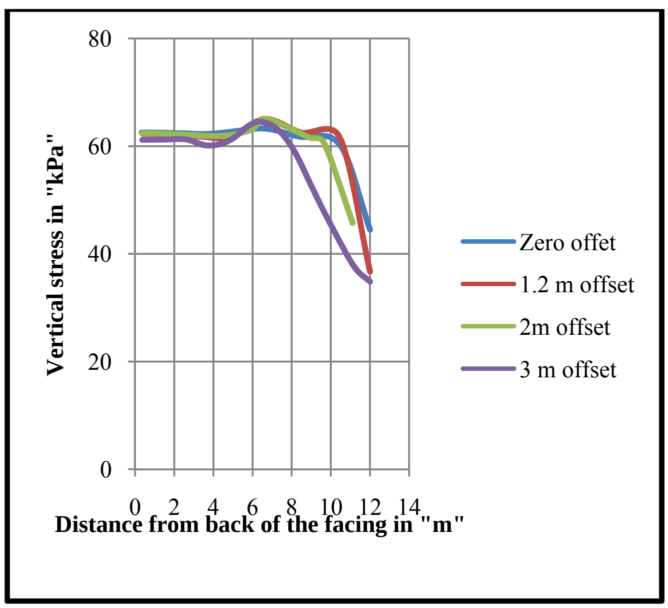



**Figure 12. Vertical stresses of soil on the base of backfill for different tier offset**

## 4. CONCLUSIONS

It is found from the finite element analysis that the multi-tiered wall considerably reduces the lateral facing displacement. The displacement decreases with the increasing tier offset. The upper walls act as a surcharge on the lower tier, which increases the deformation near the mid height of the wall. The maximum lateral soil pressure on the facing wall is near the base of the wall and decreases with the increasing height. The lateral stress decreases almost linearly with the height except at the junction of two tier, i.e. at the mid-height of the wall where the stress is little higher. The vertical stress of backfill soil is very less at the top and much higher at the bottom. The vertical stress at the reinforced soil is less than the unreinforced soil. The wall connected geogrids holds the surrounding soil masses and transfer the loads partially to the facing wall and the reaming to the underlying layers. As the tier offset increases the vertical soil pressure decreases, particularly near the facing wall where the tier offset exists.

## 5. ACKNOWLEDGEMENT

I thank NEQIP for assistance with PLAXIS 2D and Dr Arup Bhattaacharjee, Associate Professor of JEC for guidance that greatly improved the manuscript.

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