# SEISMIC RESPONSE OF MECHANICALLY STABILIZED EARTH WALL FOR WIDENED EMBANKMENT

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**ABSTRACT:** Earth retaining structures, principally mechanically stabilized earth (MSE) walls, have grown in popularity over the last few decades. MSE walls are more resilient and cost-effective than conventional retaining walls. The facing, reinforced backfill soil and geogrid reinforcement are the integral elements of the MSE wall. In this study, numerical modeling of an existing embankment augmented with geogrid and soil nailing is used to broaden its width in order to ensure the smooth movement of an increased flow of traffic while also providing seismic load protection. The numerical modeling in this paper follows the federal highway administration's (FHWA) requirements (FHW2001). The seismic response of a mechanically stabilized earth retaining wall is described and compared to that of a conventional retaining wall. Then after, the findings of the pseudo-dynamic analysis are compared to the results of the pseudo-static analysis and are validated with the available methods.

**Keywords:** Conventional retaining wall, Mononobe-Okabe, MSE wall, Plaxis-2D, Seismic loading.

## 1. Introduction

Because of its overall superior seismic performance compared to conventional earth retaining walls, mechanically stabilised earth (MSE) walls are being built in significant numbers in earthquake-prone areas. Several research on the seismic function of MSE walls have been published in recent years, including Whitman (1983), Yogendrakumar (1992), Rajagopal et al. (1995), Hatami (2000), Bourgeois (2011).

Multiple approaches were discussed by Siddharth et al. (2015), who determined that the pseudostatic approach is an efficient method for improving reinforced earth walls. For different seismic excitation coefficients, the critical failure angle and internal angle of soil friction were compared. Curves for load, elevation, and displacement were drawn. In order to resist an earthquake load, it is necessary to investigate the effect of soil structure interaction in the analysis of reinforced earth walls. Vadavadagi et al. (2016) conducted a parametric study on the MSE wall employing C-Ø soil as backfill and geogrids as reinforcement, altering the spacing and stiffness of the geogrids. The results of reinforced and unreinforced retaining walls are compared under static and dynamic conditions.

When the tire-chip sand combination is employed instead of C-soil, displacements are modest in both pseudo-static and pseudo-dynamic instances. In FLAC 7.0 software, Joseph et al. (2021) designed and assessed an MSE wall with cohesionless soil as backfill. To investigate permanent wall displacements, axial forces in geogrid, and backfill settlements at various heights of MSE wall, the peak ground acceleration and frequency of ground motion are altered from low to high. The anchors are linked to the reinforcement and aid in the dispersal of any residual tensile stresses created at the rear of the geogrid reinforcement into the surrounding soil. In this work, an affordable and stable strategy for enlarging an embankment under seismic load was presented.

## 2. Objective

To design the mechanically stabilized earth (MSE) wall for widened embankment under seismic loads.

## 3. Soil parameters

Both foundation soil and backfill are comprised of soil with an interface friction angle and cohesion of 34° and 3 kN/m$^2$, respectively. The modulus of elasticity and poisson ratio of soil were taken as 35 MPa and 0.3, respectively. The Mohr-Coulomb failure criterion was adopted to simulate foundation soil and backfill (12). An exceptionally small mesh has been used in the design. The anchors are connected to the geogrid in the model to comprehend the geogrid's increased tension to the surrounding rigid soil through anchors.

## 4. Reinforcement and Facing Panel properties

An MSE wall of 6m height is evaluated, with geogrid axial stiffness of 2500 kN/m, 0.6m spacing, and anchors of 4m length at a $10^0$ inclination. Anchors with a rigidity of $2*10^5$ kN/m and a spacing of 0.5 m are considered in this study. A total of five concrete facing panels with a length of 1.2 m and a width of 0.2 m are installed as shown in Fig.01.

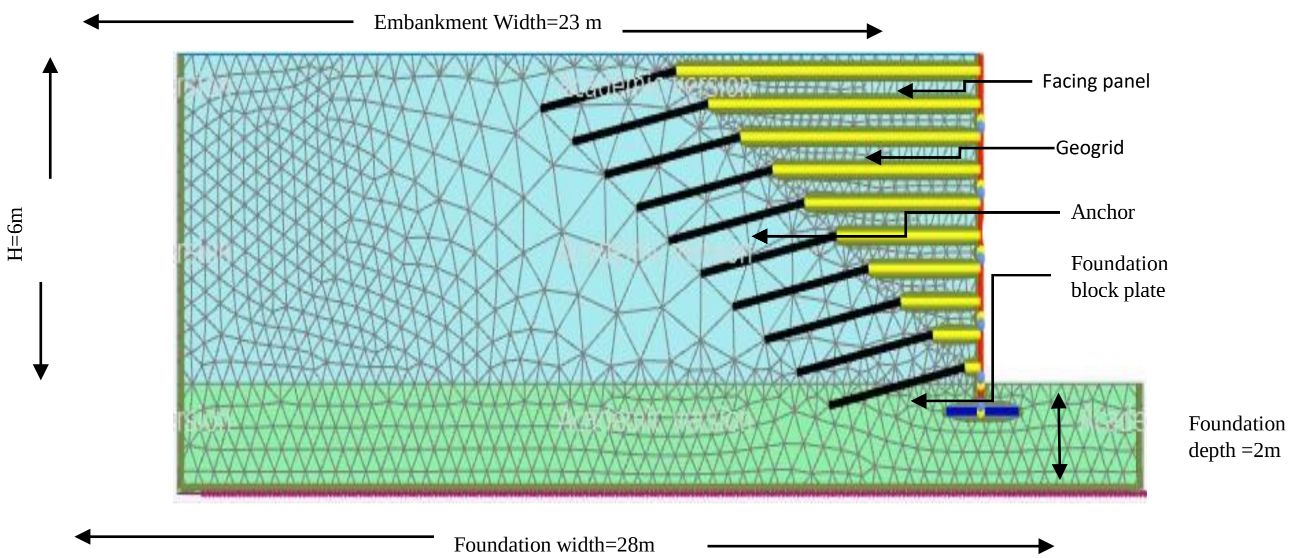



**Fig.01** Typical view of embankment modeled in Plaxis 2D

On top of the embankment, a surcharge load of 30 kPa is envisaged based on the design specifications given by AASHTO (7). The backfill is placed in layers, and the reinforcing and facing pieces are positioned in a sequential order. The approach is continued for each layer until the wall reaches a height of 6 meter. The properties of the facing panels are given it Table 01. Overturning, bearing capacity, and sliding are all assessed in the MSE wall's stability.

## 5. Methodology

Plaxis 2D programme includes a two-dimensional plane strain model with twelve nodes triangular parts. Clusters are separated into triangle components by the algorithm during automated mesh construction. Prior to the investigation, an MSE wall was designed in Plaxis 2D software that met all of the stability check criteria.

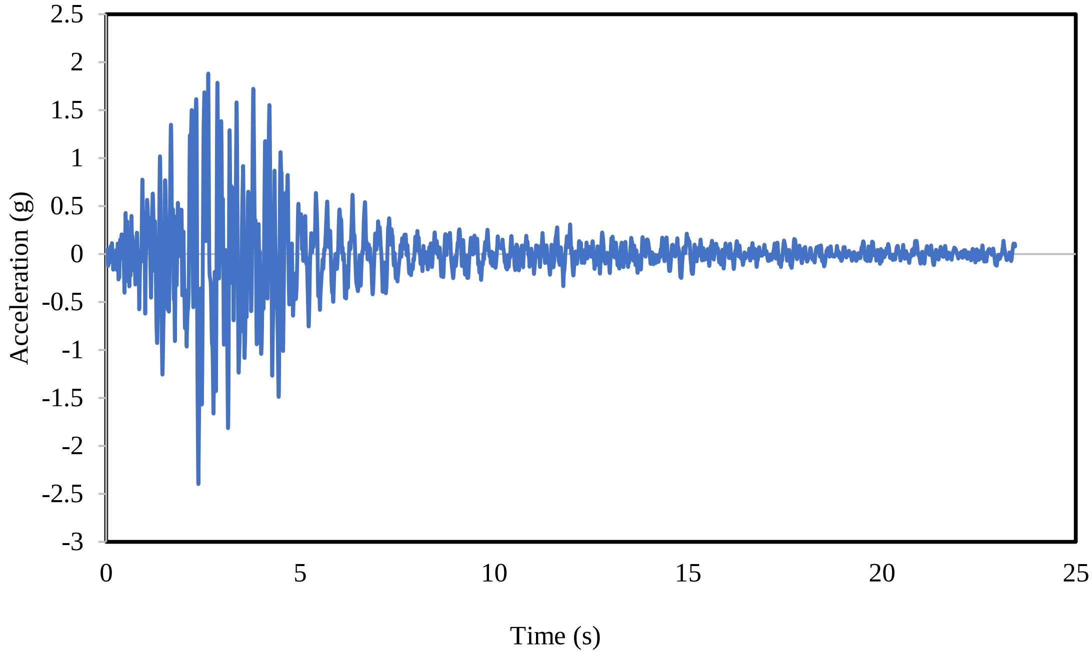



**Fig.02** Shows the Seismic exciations of 5.4 magnitude earthquake

Modeling of the MSE wall in Plaxis 2D by applying an amplitude of 0.1m as shown in Fig.02. After applying the seismic excitations (9), testing for wall stability, determining lateral and vertical forces on the wall, and lateral wall deformation was carried. The deformations and lateral pressures are examined and compared to the Mononobe-Okabe method's results.

**Table 01.** Properties of facing panels considered in this study

| Properties of Facing panel | Magnitude |
|---|---|
| Flexural rigidity (EI) kNm$^2$/m | 1.8*10$^4$ |
| Axial stiffness (EA) kN/m | 5.48*10$^6$ |
| Poisson's ratio (μ) | 0.1 |
| Thickness (D) m | 0.2 |

**5.1 Mononobe- Okabe Method**

The Mononobe-Okabe (M-O) approach is still used by geotechnical engineers to evaluate lateral ground pressures during earthquakes. M-O solves the equations of equilibrium using a closed form method and suggests seismic active and passive lateral earth pressures (1) based on a few fundamental assumptions. For an active wedge leaning on a retaining wall, the idea achieves global force equilibrium. The location of the resultant force must be inferred when assessing the stability of the wall because it is not part of the force equilibrium formulation. The M–O formulation is a Coulomb formulation that includes ground acceleration-induced pseudostatic inertia force components. Mononobe and Okabe predicted that the total pressure calculated using their mathematical method would operate on the wall at the same height as the initial static pressure, i.e., H/3 above the base. For practical reasons, the vertical acceleration components of many earthquakes are lower than their horizontal components. Therefore, it looks reasonable to presume that the effect of vertical components $k_v$ may be considered in less in magnitude. The following are the equations on which M-O method is based:

$$K_{ae} = \frac{\cos^2(\phi-\psi-\theta)}{\cos\psi\cos^2\theta\cos(\psi+\theta+\delta)}\frac{1}{(1+\sqrt{\frac{\sin(\emptyset+\delta)\sin(\emptyset-\psi-\beta)}{\cos(\delta+\psi+\theta)\cos(\beta-\theta)}})^2} \quad (1)$$

$$\psi = \tan^{-1}\left(\frac{K_h}{1-K_v}\right) \quad (2)$$

$$K_h = \alpha_m = (1.45 - \alpha) \quad (3)$$

$$\alpha = \frac{Z*I}{2R} * \left(\frac{S_a}{g}\right) \quad (4)$$

$$P_{ae} = 0.5 * K_{ae} * (1 - K_v) * \gamma * H^2 + K_{ae} * (DL + LL) * H + LL \quad (5)$$

Where

Z = zone factor; I = importance factor; R = reduction factor

$P_{ae}$ = lateral earth pressure on wall

$K_h$ = horizontal seismic coefficient; $K_v$ = vertical seismic coefficent

$\theta$ = inclination of wall; $\delta$ = internal friction angle; $\beta$ = slope angle

$\gamma$ = unit weight of soil; H = height of wall; $\psi$ = seismic inertia angle

DL = dead load; LL = live load

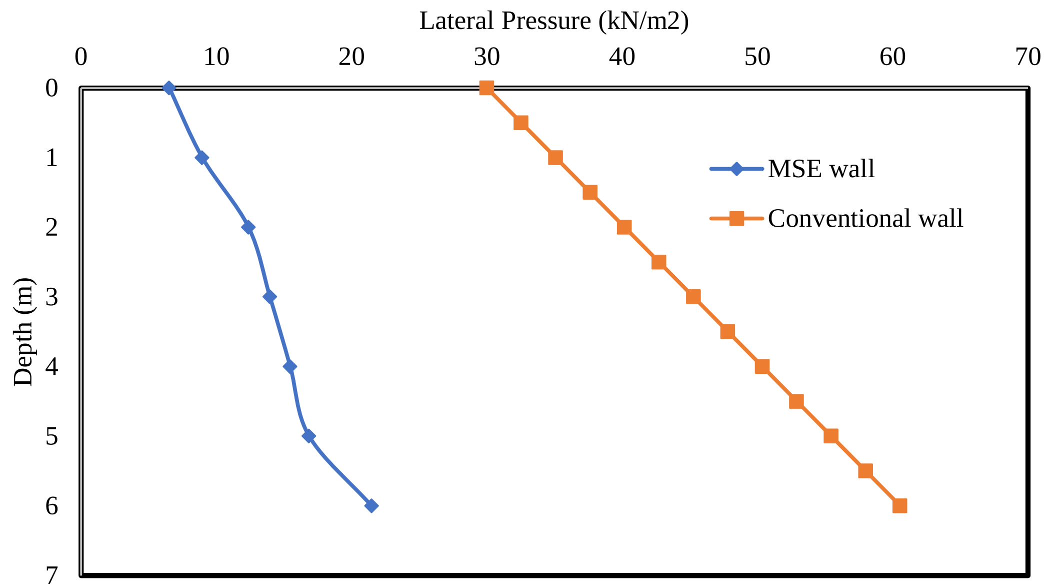
**6. Numerical Modeling**

Plaxis 2D software was used to analyze the MSE wall. The existing embankment was built by employing 2 m of granular material as the foundation soil and 6 m of granular soil as the embankment fill, with a top width of 14 m. A diaphragm concrete wall has been used as a face panel, as well as a foundation blocks plate, to increase (13) the width to 23m. Hinges integrate the facing panels, allowing them to reduce the moment due to rotation. To enhance the soil's stiffness and load-carrying prowess, geogrids with an axial stiffness of 2500 kN/m are positioned 0.6m apart along the depth. Anchors with a length of 4m and a spacing of 0.5m are hammered into the existing embankment at a 10 degree angle and connected (18) with geogrids. The top of the embankment retrieves a 30 kPa surcharge (11) load, while the bottom experiences a seismic load during the analysis.

**7. Results and Discussion**

The lateral earth pressures, vertical pressures, and displacements are calculated at various heights of the wall using the above Mononobe-Okabe equation for seismic loads, and the results are plotted in a graph and compared to the results obtained using the Plaxis 2D software.

Under normal loading conditions and without adding any reinforcement (i.e., the conventional retaining wall), the lateral earth pressure is mobilized at a pressure of 60.5 kN/m$^2$. Similar to lateral pressure, vertical pressure is also mobilized at a pressure of 140 kN/m$^2$. When the conventional wall is modeled as an MSE wall, the stresses mobilize to 21.5 kN/m$^2$ of lateral and vertical pressures, respectively.



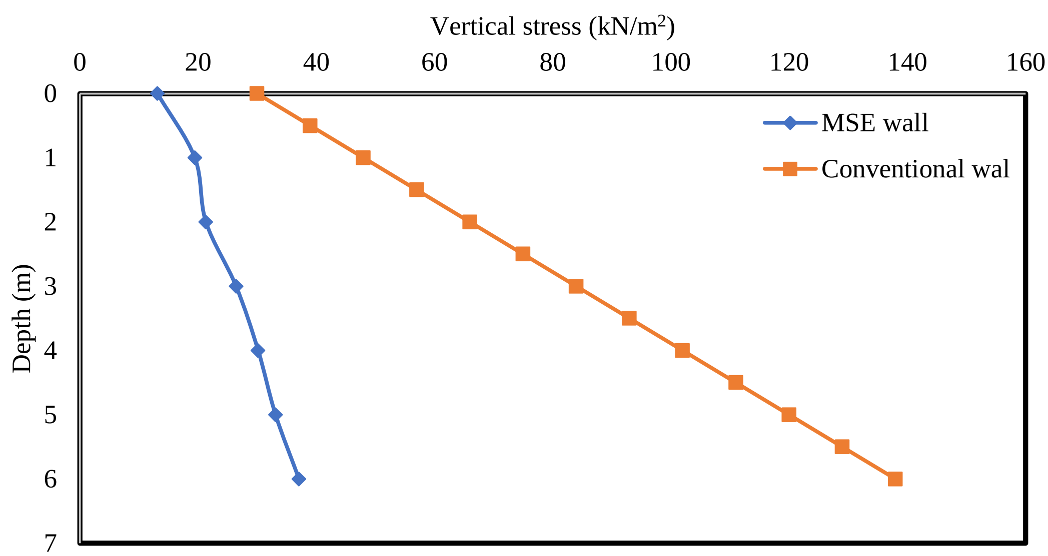




**Fig.03 (a)** Lateral pressure distribution in Conventional retaining wall and MSE wall under normal loading conditons. **Fig.03 (b)** Vertical pressure distribution in Conventional retaining wall and MSE wall under normal loading conditons.

In seismic contingencies, the wall that is modeled in this research indicated reduced lateral stress at the top of the retaining wall as compared to the existing approach in previous studies, namely the Mononobe-Okabe method, which is available in the literature.

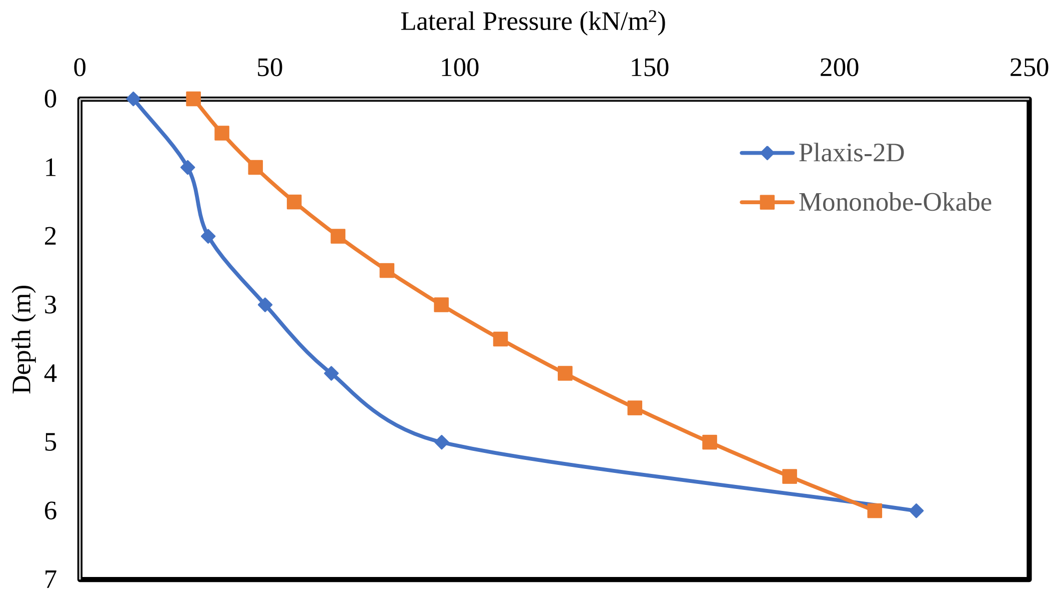



**Fig.04 (a)** Lateral pressure distribution in Conventional retaining wall and MSE wall under seismic loading conditons.

The stress at the top of the retaining wall is determined to be 18 kN/m², although the stress obtained using the Mononobe-Okabe approach was slightly greater than the stress observed in this analysis as shown in Fig.4 (a)

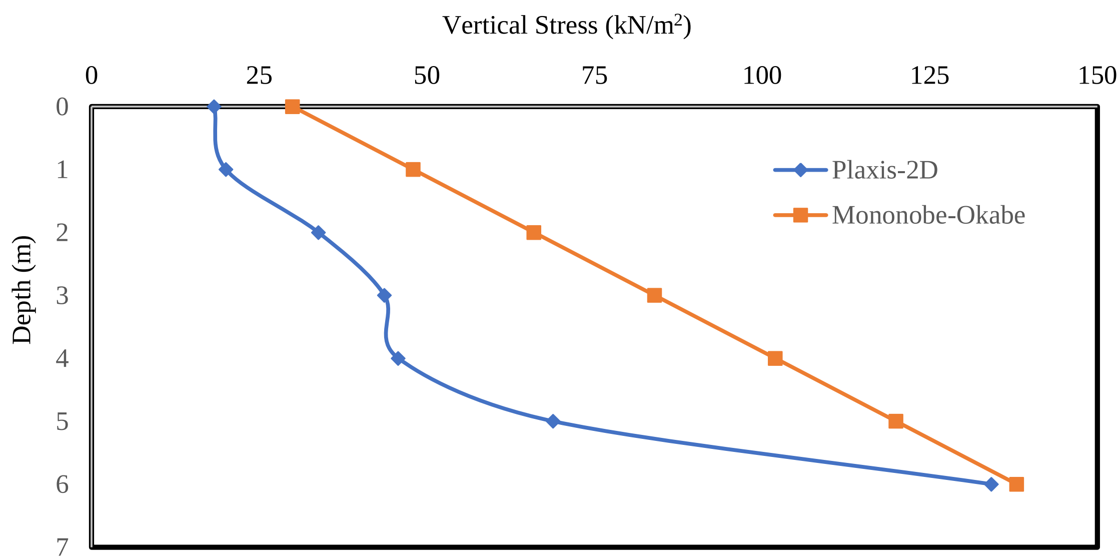



**Fig.04 (b)** Vertical pressure distribution in Conventional retaining wall and MSE wall under seismic loading conditons.

. As a result, it may be concluded that this embankment is stable in the case of lateral pressure. In case of vertical stresses, the results from Fig.04 (b) portray the same scenario as seen in the case of lateral pressure. As a result, regardless of the approach used in this study or the way accessible in the literature, the stresses mobilized at the bottom of the retaining wall.

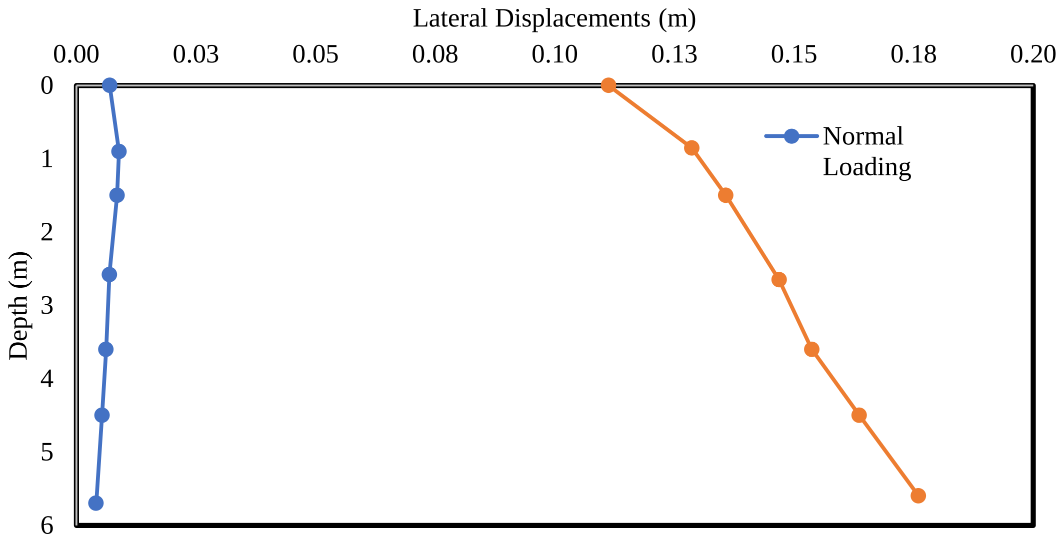



**Fig.05** Shows the lateral displacements based on different loading conditions.

As all the stresses that were obtained after modeling the existing embankment were less than the stresses that were obtained from the Mononobe-Okabe method, therefore it can be concluded that all the stresses are in the permissible limits. Before finalizing the modeled retaining wall, there should be a check against the displacements in the

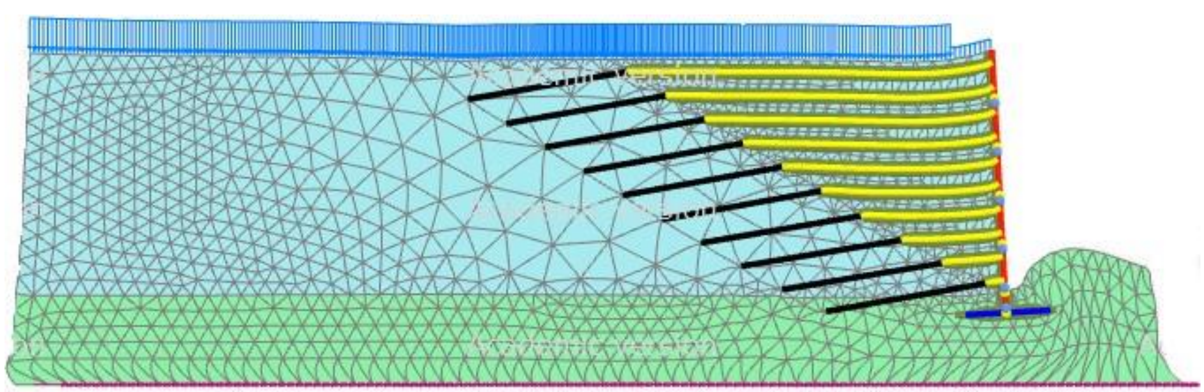


**Fig.06** Typical view of lateral displacements based on different loading conditions.

retaining wall. Fig.(05) and Fig.(06) shows the displacements based on the loading conditions. As the displacements were not in greater magnitude, therefore it can be said that the modeled retaining wall can be suggested to meet the increased flow and requirements of the traffic.

## 8. Conclusions

To accommodate the increasing traffic flow, an attempt was made to expand an existing embankment. As a result, the proportions of the embankment and the conventional wall were modeled in Plaxis-2D to meet the traffic requirements. The behavior of the retaining wall and embankment under various loading circumstances was investigated. The following findings were drawn from this research:

1. When the retaining wall was strengthened with geogrids and anchors under typical loading conditions, the lateral and vertical earth pressures were lowered by 3 and 5.5 times, respectively.

2. The earth pressures of the MSE wall were validated and compared with the Mononobe-Okabe approach in the instance of seismic loading conditions. The earth pressures obtained by the seismic analysis in Plaxis-2D were lower than those determined by Mononobe-Okabe method.
3. Since the retaining wall and embankment were stable at the amount of displacements, the displacements were seen to be smaller under seismic loading conditions after modeling the conventional retaining wall as MSE wall.

There the modeled embankment can be replaced in place of the existing embankment considering all the safety precautions while placing the reinforcement, facing panels and anchoring.

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