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STABILITY OF EARTH RETENTION SYSTEM IN DRY COHESIONLESS SOIL UNDER STATIC AND SEISMIC CONDITION

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Abstract. *The objective of this paper is to assess the stability of earth retention systems like supported excavation known as braced excavation (consisting of retaining wall and support members known as struts) under both static and seismic condition. A numerical analysis has been done considering the excavation in dry cohesionless soil with properties such as density, friction angle, dilatancy angle and Poisson's ratio as 2040 kg/m3, 35°, 0° and 0.3 respectively. The shear modulus of the soil depends on the mean effective stress below ground level. The bulk modulus also behaves similarly as shear modulus. The wall and the struts are modeled as beam elements. The soil structure interaction is modeled by introducing interface elements between wall and soil. It is concluded from the present study that there is a substantial increment in the values of maximum strut force, wall moment, wall deflection and the ground surface settlement under seismic condition as compared to static condition.*

1 INTRODUCTION

The construction of underground basement, pipeline network or transport system in congested urban area at a substantial depth below ground level is possible only when the earth can be excavated as a deep vertical cut. This vertical cut is supported on both sides by retaining wall (sheet pile wall or diaphragm wall) and support members (steel struts, wale, concrete slabs). The construction of braced excavation involves different stages such as installation of retaining wall, excavation of soil below strut level, installation of struts at the corresponding level. This sequence of soil excavation and strut installation continues till the final excavation level is reached. Thus, at different stages of the construction of the supported excavation, there will be different values of strut force, wall moment, wall deflection and the ground surface settlement. Out of all these values the maximum value of each of the above design parameters has been compared under both static and seismic conditions.

Numerical methods have been used for analysis of braced excavation under static condition ([1], [2], [3], [4], [5], [6]). The optimum values of the design parameters i.e. wall thickness, embedment depth of the wall, the stiffness of the struts and the depths of the struts below ground level have been obtained under static condition and a design guideline of braced excavation have been proposed under static condition [7]. However, very few studies have been done for analyzing the behavior of such type of excavation under seismic condition. Numerical analysis of embedded cantilever retaining walls in dry coarse-grained soil under seismic condition using Tolmezzo time acceleration history data has been analyzed in FLAC [8]. A number of studies has been done on other types of retaining walls such as gravity, cantilevered, anchored walls or mechanically stabilized earth retaining walls under seismic condition ([9], [10], [11], [12], [13], [14]).

In view of the previous works, an attempt has been made in the present study to assess the behavior of braced excavation under seismic condition. Based on the work [7], the depth of excavation (D_e), depth of embedment of the wall below the final excavation level (D_b), thickness of the wall (t_{wall}) and the stiffness of the struts are taken as 10m, 8m, 0.6m and $5x10^5$kN/m/m, respectively. The width of excavation is taken as 10m. Two levels of struts at 3m and 7m below ground level have been considered in the analysis. The effect of Tolmezzo earthquake which occurred in Italy is considered in the present study. The acceleration time history data has been taken from [8]. This history data is applied at the base of the model. The earthquake may occur at any stage of the braced excavation. So, in order to simúlate this uncertain condition, each stage of the excavation is analyzed under static condition and then under seismic condition.

2 NUMERICAL MODELLING

The numerical modeling, as shown in Figure 1, has been done using two dimensional plane strain finite difference code FLAC (Fast Lagrangian Analysis of Continua) [15]. In the seismic analysis, two diaphragm walls and the distance between the walls are taken as 10m. The horizontal boundary at the bottom of the model is located at a distance of 62m below the toe of the wall. The left and right vertical boundaries are located at 60m from the face of the diaphragm wall. The size of the zones are taken as square with 0.5m dimension. In the numerical model, the behavior of the soil under earthquake condition is described through a hysteretic model which updates the tangent shear modulus at each calculation step. The soil is assumed to behave as a linearly elastic-perfectly plastic material and fails according to Mohr-Coulomb criterion. The free-field conditions are applied along the vertical boundaries so that boundaries absorb outward propagating waves from the structure. Thus the lateral boundaries of the main grid are connected with the free field grid by viscous dashpots [16]. The bottom boundary is fixed from movement both in the vertical as well as horizontal directions.

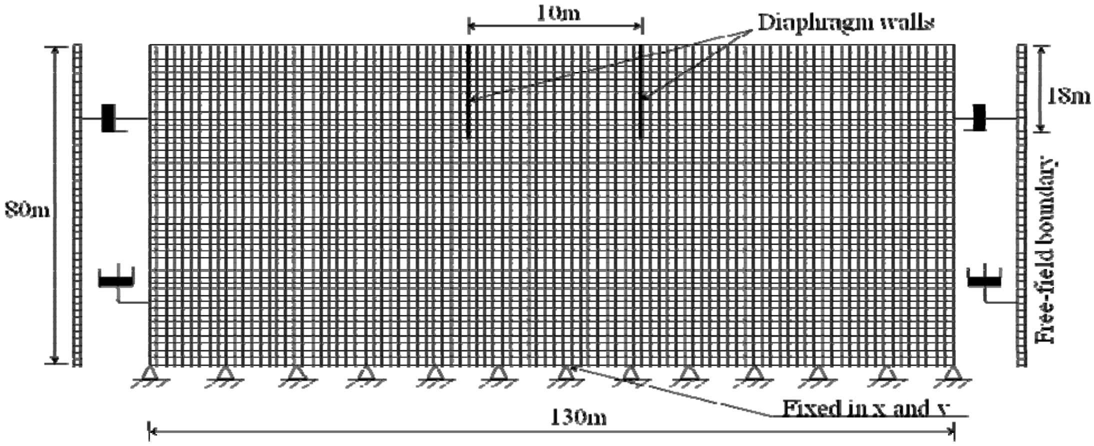

Figure 1: Numerical model in FLAC.

Earthquake may occur at any stage during the construction of braced excavation. Each stage of the excavation is analyzed simultaneously under static and seismic condition upto the final stage of excavation. The acceleration time history of Tolmezzo Earthquake as shown in Figure 3 has been applied at the nodes located along the base of the model.

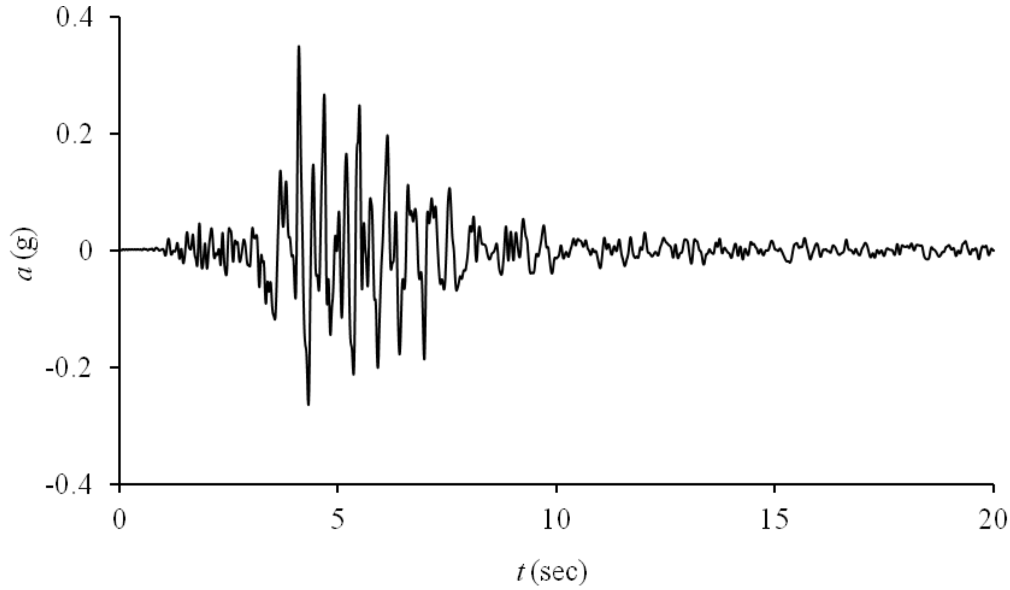

Figure 2: Input acceleration time history for Tolmezzo earthquake

As the dimension perpendicular to the plane of analysis is very large compared to other two dimensions, the problem is analyzed as a two-dimensional plane strain problem. The cross-sectional area (A_{wall}) and moment of inertia (I_{wall}) of the wall are given as input in the program. A typical cross-section of the excavation is shown in Figure 3.

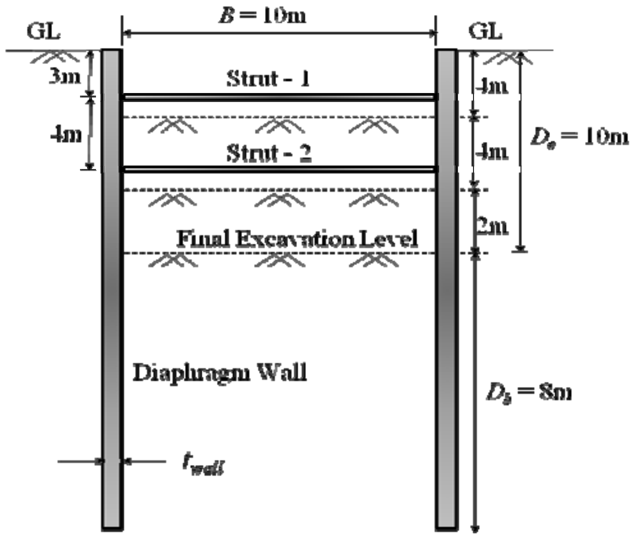

Figure 3: Cross-section of the braced excavation.

The soil properties namely, dry density, friction angle and initial shear modulus are taken from [8]. The coefficient of lateral earth pressure at rest (K_0) is taken as 0.426 (for ϕ equal to 35^o). A rigid rock layer has been considered at the bottom of the model, that is, at 62m below the bottom of the diaphragm walls. The wall friction angle (δ) and the Poisson's ratio (μ) of soil are taken as 20^o and 0.30 respectively. The small strain shear modulus (G_0) and mean effective stress (p') are related as [8]

$$\frac{G_0}{p_{ref}} = K_G \left(\frac{p'}{p_{ref}} \right)^{0.5} \tag{1}$$

where, p_{ref} is the reference pressure which is taken as 100 kPa, p' is the mean effective stress and K_G is the stiffness multiplier which is taken as 1000. The bulk modulus is calculated from shear modulus and Poisson's ratio. In the numerical modeling, the values of the shear modulus and bulk modulus has been given as input. The static analysis has been done considering the value of shear modulus as G_0. In the seismic analysis, the static simulation of each stage has been done with reduced value of small strain shear modulus, i.e. $0.3G_0$, because the model does not consider the reduction of soil stiffness with strain level [17]. The seismic stages are analyzed with shear modulus G_0.

3 RESULTS AND DISCUSSION

The values of the four design factors, i.e. strut force, wall moment, wall deflection and ground surface settlement as obtained from static and seismic are shown in Table 1.

Design factors	Static condition	Seismic condition
1st level Strut force (x10^3 kN/m)	1.2	2.8
2nd level Strut force (x10^3 kN/m)	1.1	3.9
Bending moment (x10^3 kN-m/m)	0.1	0.4
Wall deflection (mm)	3.2	55.2
Ground surface settlement (mm)	1.9	24.6

Table 1: Comparison of results obtained from static and seismic analysis

3.1 Effect on maximum strut force

The results between the maximum strut force obtained under static condition and seismic conditions are compared and shown in Table 1. From the above table, it is found that the maximum strut force at first and second levels under seismic conditions are around 2.3 and 3.5 times than that obtained under static condition.

3.2 Effect on maximum bending moment

The maximum bending moments developed in the wall during the two conditions are compared and it is found from Table 1 that the ratio of seismic moment to static moment comes out to be 4.

3.3 Effect on maximum wall deflection

The maximum deflections of the wall as obtained from static and seismic analysis are shown in Table 1. From the above table, it is found that the maximum wall deflection under seismic condition is 17.3 times than that obtained under static condition.

3.4 Effect on maximum ground surface settlement

The maximum ground surface settlement plays an important role in the stability analysis of the braced excavation and the adjacent structures. From the analysis, it is found that the maximum ground surface settlement during earthquake is 12.9 times the ground surface settlement obtained under static condition. Liquefaction of the soil during seismic event is not considered in the analysis.

4 CONCLUSION

From the present numerical analysis, it can be found that the values of maximum strut force, wall moment, wall deflection and the ground surface settlement are higher in seismic condition than that under static condition. The strut forces and the bending moment as obtained from the seismic analysis are (2 - 4) times higher than that obtained from static analysis. However, the effect of earthquake on the wall deflection and ground surface settlement are much higher and these are around (13 - 20) times than that obtained under static condition. Thus it can be concluded that there is significant influence of earthquake on wall deflection and ground surface settlement as compared to strut force and wall moment for this particular earthquake and the geometry of the problem selected.

5 ACKNOWLEDGEMENT

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