Analysis of sheet pile walls under surcharge loading at different distances using FLAC2D

Akshay Pratap Singh[1] and K. Chatterjee[2]

[1] Ph.D. Research Scholar, Department of Civil Engineering, IIT Roorkee, Roorkee 247667, India.
[2]Assistant Professor, Department of Civil Engineering, IIT Roorkee, Roorkee 247667, India.

ABSTRACT

Cantilever sheet pile walls, which are generally used to retain a certain height of excavation, experiences the surcharge load in the field. In the present study, a numerical analysis is carried out based on the finite difference based approach to analyze the influence of uniform surcharge load located at varying distances from the top of the wall in cohesionless medium sand using pseudo static approach. From the results, it is observed that increase in seismic inertia forces increases the bending moment and earth pressures along the depth. Also, shifting of uniform surcharge load away from the top of the wall decreases the influence of surcharge on the cantilever sheet pile walls significantly and beyond a certain distance, no influence is observed. Numerical model is also validated to available literature having no surcharge.

Keywords: bending moment; FLAC2D; uniform surcharge; earth pressure; sheet pile wall; pseudo-static approach

1 INTRODUCTION

Failure of retaining walls due to sliding, overturning or bearing capacity have been observed during various past earthquakes. Although, failure mechanisms of rigid retaining walls have been analyzed significantly (Fang et al. 2003; Koseki et al. 2012), however due to complex nature of dynamic soil-structure interaction an accurate study on flexible cantilever sheet pile wall is still lacking in literature. Flexible cantilever sheet pile walls are generally used to support moderate height of excavation in both cohesive as well as cohesionless soil as a temporary or permanent structure. It derives its stability mainly from the passive resistance of soil near its toe. Though, in practice, surcharges are present on the backfill, instead literatures containing cantilever sheet pile walls with surcharge are limited. Georgiadis and Anagnostopoulos (1998) and Steenfelt and Hansen (1984) have analyzed cantilever sheet pile walls with surcharge having finite widths. Therefore, in the present study, the cantilever sheet pile walls are analyzed with uniform surcharge placed at different distances on backfill using Fast Lagrangian Analysis of Continua in 2 Dimensions, a numerical software, through pseudo static approach.

2 NUMERICAL MODELLING

Finite difference based computer program FLAC2D is used to study the influence of uniform surcharge on cantilever sheet pile walls by considering plain strain problems. The mesh size, domain and boundary condition of the model are as shown in Fig. 1. The cohesionless soil and sheet pile walls are modelled using Mohr Coulomb model and beam elements having properties tabulated in Table 1 and Table 2 respectively. Standard boundary conditions are used for analysis. The sufficient domain size i.e. width of backfill = 8(H+D) and depth below dredge level 5(H+D) with mesh size of dimension 0.5m x 0.5m is used. Normal stiffness and shear stiffness are used to represent the interaction of soil and wall having magnitude 2000 MPa/m.

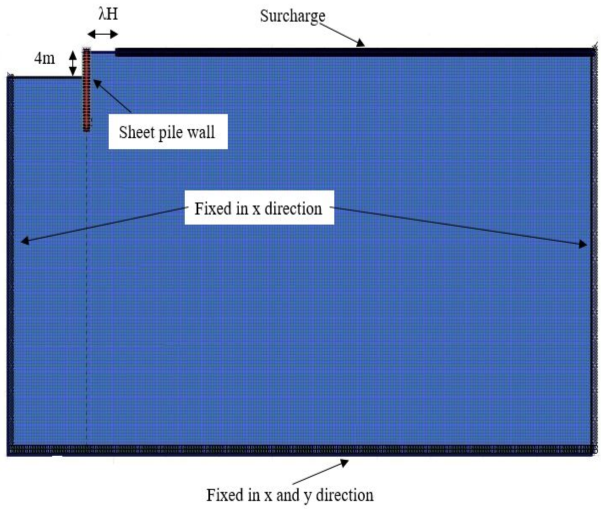

Fig. 1. Numerical model used in present study

2.1 Validation of the present model

The present numerical model without surcharge has been validated with the centrifuge results of King (1995) and numerical analysis results of Conte et al. (2017). A 11m long cantilever sheet pile walls (H=6m, D=5m) is installed in a loose sand soil stratum having γ=14.2kN/m^3, ϕ=40^0, δ=15.8^0 [King (1995)]. The variation of bending moment in the sheet pile walls along depth is plotted and the present numerical results are compared with King (1995) and Conte et al. (2017). It is observed from Fig. 2 that a good conformity exists among the numerical results obtained from the present study with that of King (1995) and Conte at al. (2017).

Table 1. Properties of Cohesionless soil.

Properties	Values
Density (kg/m^3)	1.8
Young's Modulus (MPa)	65
Angle of internal friction	34º
Poisson's ratio	0.34
Bulk Modulus	67.7
Shear Modulus	24.3

Table 2. Properties of Sheet pile walls.

Properties	Values
Type	SKZ 38
Cross-section area (m^2/m)	0.023442
Section Modulus (m^3/m)	3.35 x 10^{-3}
Moment of Inertia (m^4/m)	0.00076588

3 RESULT AND DISCUSSIONS

After validation of numerical model under no surcharge loading conditions, the present study investigates the seismic response of a cantilever sheet pile walls under the influence of surcharge loading and at varying distance from the top of the wall using finite difference program FLAC2D. For all parametric studies, the width of excavation is kept constant as 15m. The ground water table is considered at a depth of 2m from ground surface and the same is simulated in the numerical model. The magnitude of surcharge load considered in the present study is q=50kPa and the total length of cantilever sheet pile wall is d=12m. The excavation height (H) is 4m. The distance between cantilever sheet pile wall and uniform surcharge (b) considered in the present study are 1m, 2m, 3m, 4m, 5m, 6m, 8m and 12m. The results obtained from the study are represented in terms of normalized bending moment ($M/\gamma H^3$), earth pressure ($p/\gamma H$), distance ($\lambda=b/H$) and depth (z/d).

Fig. 3 shows the normalized bending moment variation along the normalized depth of the wall for different k_h=0, 0.05, 0.1, 0.15, 0.2 and 0.25 in medium sand when uniform surcharge (q=50kPa) is placed at the top of the wall (λ=0). It is observed that the variation of bending moment for all seismic conditions are same. However, there is an increase in the normalized maximum bending moment with increase in seismic action of inertia forces. The maximum normalized bending moment for static condition is 32.1 % and as the k_h increases to 0.05, 0.1, 0.15, 0.2 and 0.25, the increase in maximum normalized bending moment are 16.4%, 18.87%, 27.7%, 44.8% and 54.2% respectively. The increase in maximum bending moment observed are due to increase in lateral stresses due to inertia forces.

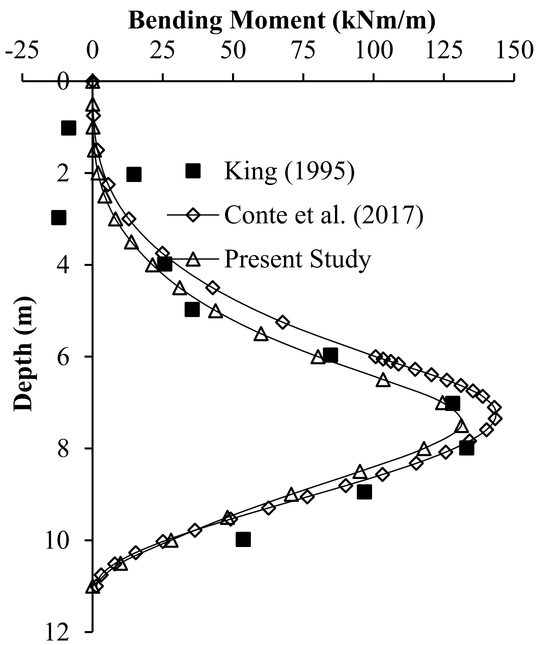

Fig. 2. Comparison of bending moment along depth obtained in the present study with that of King (1995) and Conte et al. (2017).

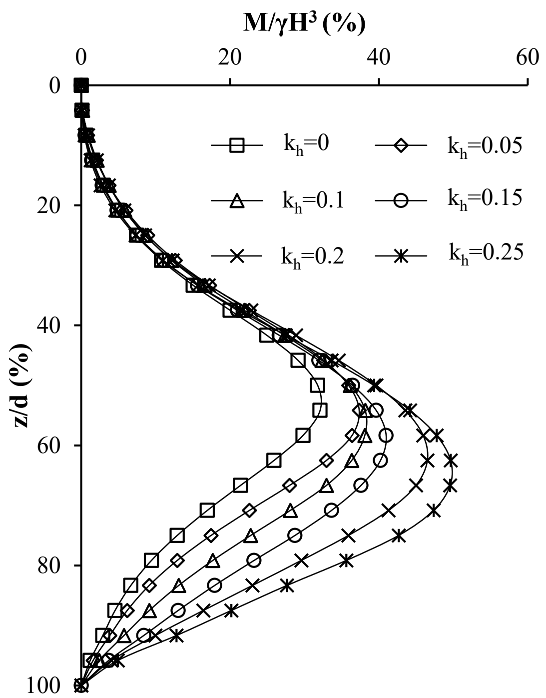

Fig. 3. Normalized bending moment variation of cantilever sheet pile walls along the depth for k_h=0, 0.05, 0.1, 0.15 at λ=0.

The influence of location of surcharge on the backfill of cantilever sheet pile walls at a uniform surcharge q=50kPa is highlighted in Fig. 4 for different coefficient of horizontal seismic acceleration. The maximum normalized bending moments are observed when the uniform surcharge is placed at the top of the wall and as the distance of uniform surcharge shifts away from the

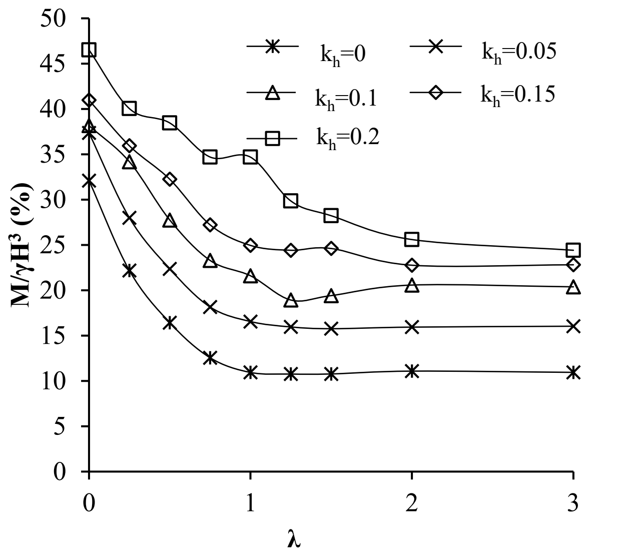

Fig. 4. Variation of maximum normalized bending moment with respect to λ for k_h=0, 0.05, 0.1, 0.15 and 0.2.

wall, a decrease in normalized bending moment of cantilever sheet pile wall is observed. The decrease in normalized bending moment for λ=0.25, 0.5, 0.75, 1, 1.25, 1.5, 2 and 3 are 26.6%, 41.4%, 52.4%, 56.6%, 58.2%, 58.7%, 58.2% and 58% respectively from a condition when surcharge is placed at the top of the cantilever sheet pile walls for k_h=0.05. It is clearly seen that beyond λ=1, the influence of surcharge is negligible. This is because the increase in vertical stress caused by uniform surcharge placed beyond λ=1, does not increase the lateral stress on cantilever sheet pile walls. Also, at high seismic inertia forces, the variation is not smooth as compared to low seismic inertia forces.

On the other hand, the influence of coefficient of horizontal seismic acceleration on the earth pressures developed around the cantilever sheet pile wall is shown in Fig. 5. It clearly shows that the horizontal earth pressures on both sides of cantilever sheet pile walls increases with increase in coefficient of horizontal seismic acceleration. On observing the behavior of earth pressures closely, it is seen that the earth pressure curves change at a lesser height for low seismic inertia forces and at a greater depth for higher seismic inertia forces. This type of behavior is observed due to more mobilization of earth pressure at high seismic forces.

The increase in lateral earth pressures can also be understood by observing the displacement vectors of soil in the numerical model. The displacement vectors of numerical model as shown in Fig. 6 shows that the application of seismic inertia forces try to move the displacement vectors towards the excavation and downwards, thus trying to increase the lateral earth pressure on the cantilever sheet pile walls and hence bending moment.

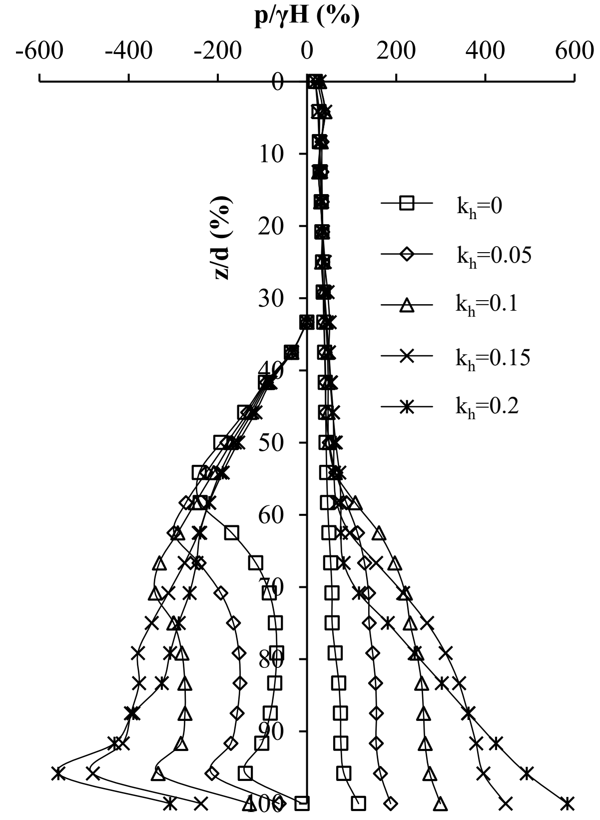

Fig. 5. Variation of earth pressure distribution on both sides of cantilever sheet pile walls along the depth for different k_h=0, 0.05, 0.1, 0.15 and 0.2 at λ=0.

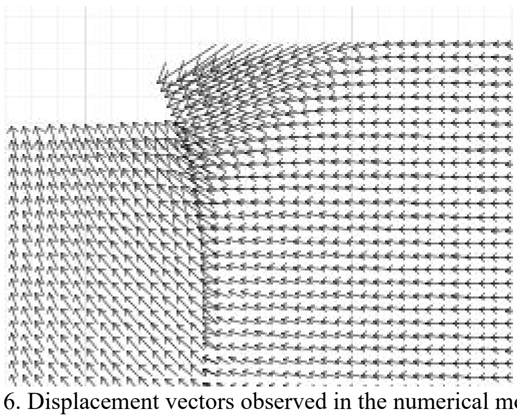

Fig. 6. Displacement vectors observed in the numerical model for k_h=0.1.

The mobilization of earth pressures can also be understood with the help of Mohr-Coulomb strength / stress ratios shown in Figs. 7, 8 and 9. Fig. 7 highlights the strength / stress ratio for a uniform surcharge placed at the top of the cantilever sheet pile walls. It is observed

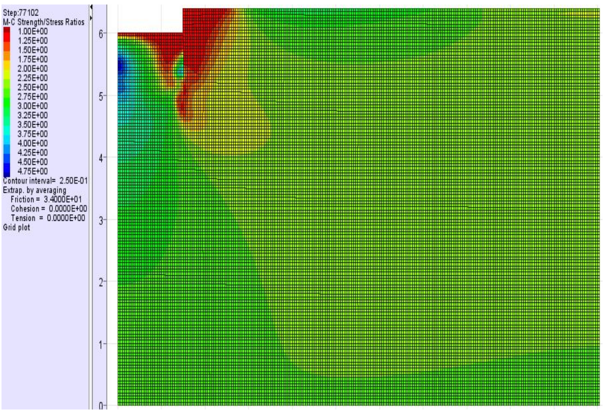

Fig. 7. Mohr-Coulomb strength / stress ratio for q=50kPa and k_h=0.

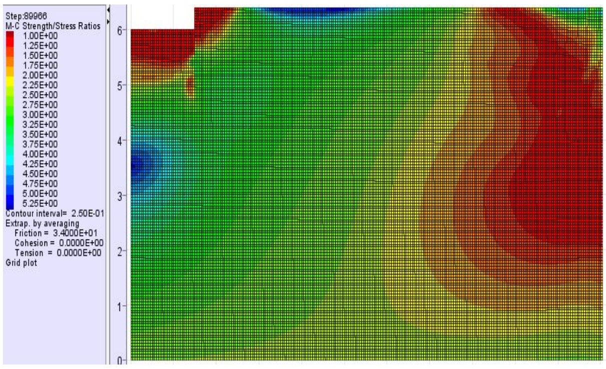

Fig. 8. Mohr-Coulomb strength/stress ratio for q=50kPa and k_h=0.1

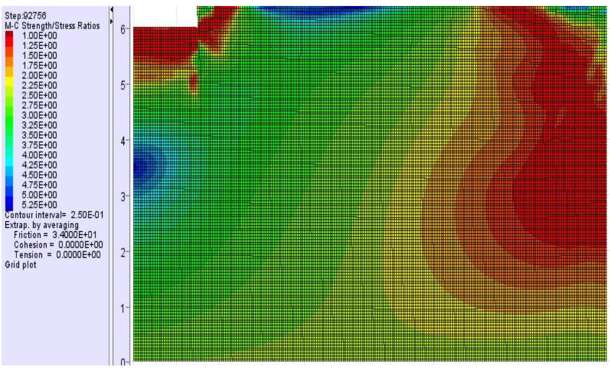

Fig. 9. Mohr-Coulomb strength/stress ratio for q=50kPa, k_h=0.1 and λ=1

that by placing the surcharge at the top of the cantilever sheet pile walls, the Mohr-Coulomb strength of material is same as that of stress near the sheet pile walls. The active earth pressure is mobilized fully above the dredge level in Fig. 7 and 8. The earth pressure on the right side of the wall for k_h=0 is mobilized to a greater depth than k_h=0.1 due to occurrence of active earth pressure while on the left side, as the passive earth pressure increases, the mobilization takes place to a greater depth when k_h=0.1 than k_h=0. The placement of surcharge at a normalized distance λ=1, reduces this mobilization as shown in Fig. 9 where on the right side of the sheet pile wall Mohr-Coulomb strength / stress reduces near the top of the cantilever sheet pile wall. Also, the influence of seismic inertia force is also seen in the numerical model near the right side boundaries of the model where full mobilization takes place.

4 CONCLUSION

In the present study, a numerical analysis using FLAC2D on finite difference based technique is implemented to study the influence of surcharge load at varying distances from the wall under pseudo-static condition. Based on the results obtained, following conclusion can be drawn:

- The seismic forces influence the behavior of cantilever sheet pile wall significantly because under the action of seismic forces, lateral stresses are increased resulting in increase in the bending moment experienced of the cantilever sheet pile walls.
- Uniform surcharge load placed at the top of the wall gives maximum value of bending moment and earth pressure. The influence of surcharge gets nullified at larger distance from the cantilever sheet pile wall.

REFERENCES

Conte, E., Troncone, A. and Vena, M. (2017). A method for the design of embedded cantilever retaining walls under static and seismic loading. Géotechnique, 67(12), 1081-1089.

Fang, Y. S., Yang, Y. C. and Chen, T. J. (2003). Retaining walls damaged in the Chi-Chi earthquake. Canadian Geotechnical Journal, 40(6), 1142–1153.

FLAC2D (2016). Fast Lagrangian Analysis of Continua. Version 8.0, Itasca Consulting Group, Minneapolis, Minnesota, U.S.A.

Georgiadis, M. and Anagnostopoulos, C. (1998). Lateral pressure on sheet pile walls due to strip load. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 124(1), 95-98.

King, G. J. W. (1995). Analysis of cantilever sheet-pile walls in cohesionless soil. Journal of Geotechnical Engineering, ASCE, 121(9), 629–635.

Koseki, J., Koda, M., Matsuo, S., Takasaki, H. and Fujiwara, T. (2012). Damage to railway earth structures and foundations caused by the 2011 off the Pacific Coast of Tohoku Earthquake. Soils and Foundations, 52(5), 872–889.

Steenfelt, J. S., and Hansen, B. (1984). Sheet pile design earth pressure for strip load. Journal of Geotechnical Engineering, ASCE, 110(7), 976-986.