Numerical Investigation into the effect of various surcharge loadings on propped wall excavations and embankments

***Oluwaseun Ogunyemi, Alireza Ahangar Asr**

School of Science, Engineering and Environment (SEE), University of Salford, Manchester. M54WT
O.F.Ogunyemi@edu.salford.ac.uk, A.AhangerAsr@salford.ac.uk

ABSTRACT

Several guidance and formulation have been developed in the literature to account for the analysis of external surcharges adjacent to a propped excavation but less attention has been paid to the presence of sloping ground or embankments. However, CIRIA C760 states that the actual ground profile should be modelled and analysed as a series of surcharge loading over the extent of the active side of the wall. In this research, two braced excavation models were analysed of which one was the actual ground profile and the second with a series of surcharge loading representing the embankment adjacent to the excavation. The accuracy, efficiency, and conservation of the proposed approaches were examined on a propped cantilever wall excavation using a finite element geotechnical analysis software PLAXIS 2D. The models were analysed and examined in terms of the bending moment and deflection of the diaphragm wall and the prop load, the model with the actual ground profile was also investigated for any thrust load on the support system should the embankment or sloping ground fail in shear. The results were presented, and comparisons were made. Merits and advantages of the proposed numerical approach were discussed.

Keywords: embankments, propped excavations, finite element analysis.

1. Introduction

The design and construction of deep excavation often interact with its surroundings in terms of adjacent structures like buildings, roads, nearby slopes, embankments and stacked construction materials such that if not duly given required consideration it can lead to the damage of these structures and loss of life [3]. It can also lead to failure of the excavation support system due to the changes in stresses or force exerted on the support system.

Several types of researches have been carried out in the past to investigate the interaction of these external surcharges for instance [5][2] investigating the impact of an excavation adjacent to a tunnel in terms of settlement while [6], investigating the damages caused due to an existing building adjacent to a deep excavation.

Guidelines have been provided for analysing the external structures mentioned above in [7] CIRIA C760 page 67 guidance on embedded retaining wall design however limited guidance was provided in the case of a sloping ground or embankment adjacent to an excavation particularly if the slope is steep or has a weak shear strength such that it will fail the instability check. This research aims to observe the difference between these two approaches and observe the possibility of the horizontal force to be generated due to shear failure of the slope.

2. Modelling

To investigate the difference in the analysis method, an actual slope (5m high) profile was analysed and replaced with a series of incremental surcharge from 10kN/m^2 using the equation γz (20kN/m^3 x 0.5m) to a maximum of 100kN/m^2, where "z" is the slope height as it increases equivalent to the stress from the soil slope adjacent to a propped (prop located 1.0m below ground level) cantilever excavation support system 5m deep with 7m embedment and 30m wide because the excavation is symmetrical one side of the excavation is analysed as shown in

Figure 1. The 2D plane strain finite element analysis (PLAXIS 2D 2018) method was adopted in this study. All soil was modeled using 15- node elements. The finite element model and the mesh generated are shown in Figures 1. A "very fine" mesh was adopted to increase accuracy. The soil is considered as an ideal elastic-plastic material satisfying the Mohr-Coulomb (MC) yield criterion. The drained analysis was then carried out. The calculation stage includes Phase 1(Initial stress calculation), Phase 2 (first stage of excavation), Phase 3 (installation of a fixed anchor) and Phase 4 (final excavation). The physical properties of the soil and the supporting structure for the excavation and that of the slope profile are listed in Tables 1, 2 and 3. The analysis was carried out on two different soil cases from previous research [1]. Note: The stability of the soil slope was not taken into account to observe the effect of shear failure on the excavation support system.

Table 1: Soil Parameters for the MC model.

Soil Type	Slope angle θ	Elastic Modulus (MPa)	γ (kN/m^3)	Poisson's ratio (μ)	Cohesion c (KPa)	Frictional angle (φ)
Cohesive Soil	26.57^o	14	20	0.3	20	5

Table 2: Diaphragm wall properties [4].

Support Structure	Normal Stiffness EA (kN/m)	Flexural rigidity EI (kNm^2/m)	Poisson's ratio (μ)	Unit weight (kN/m/m)
Diaphragm wall (Plate)	7.5 x 10^6	1.0 x 10^6	0.0	10.0

Table 3: Material properties of the strut (anchor) [4].

Support Structure	Normal Stiffness EA (kN)	Type of Behaviour	$L_{spacing}$ (m) Spacing out of plane
Strut (Anchor)	2 x 10^6	Elastic	5.0

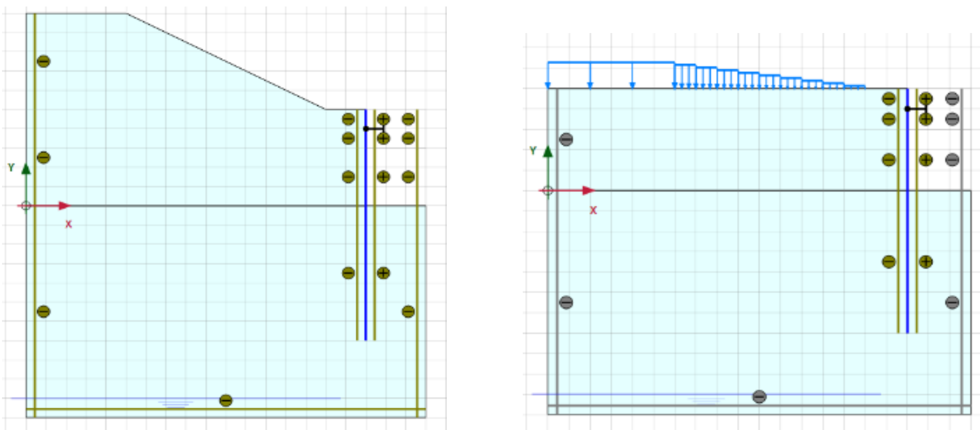


Figure 1: Slope, surcharge and excavation geometries implemented in the modeling and analysis stages.

3. Result and Analysis

From the analysis of the propped cantilever wall above, the tables below show the results from the two cases.

Table 4: Result from the analysis of the model in Figure 1 above.

Surcharge				Actual ground profile with slope			
Deflection (m)	Bending moment (kNm/m)	Shear Force (kN)	Strut (anchor) (kN)	Deflection (m)	Bending moment (kNm/m)	Shear Force (kN/m)	Strut (kN)
0.023	576	221	1169	0.052	611	275	1532

Below is the graphical representation of diaphragm wall behaviour along the length of the two analysis approaches.

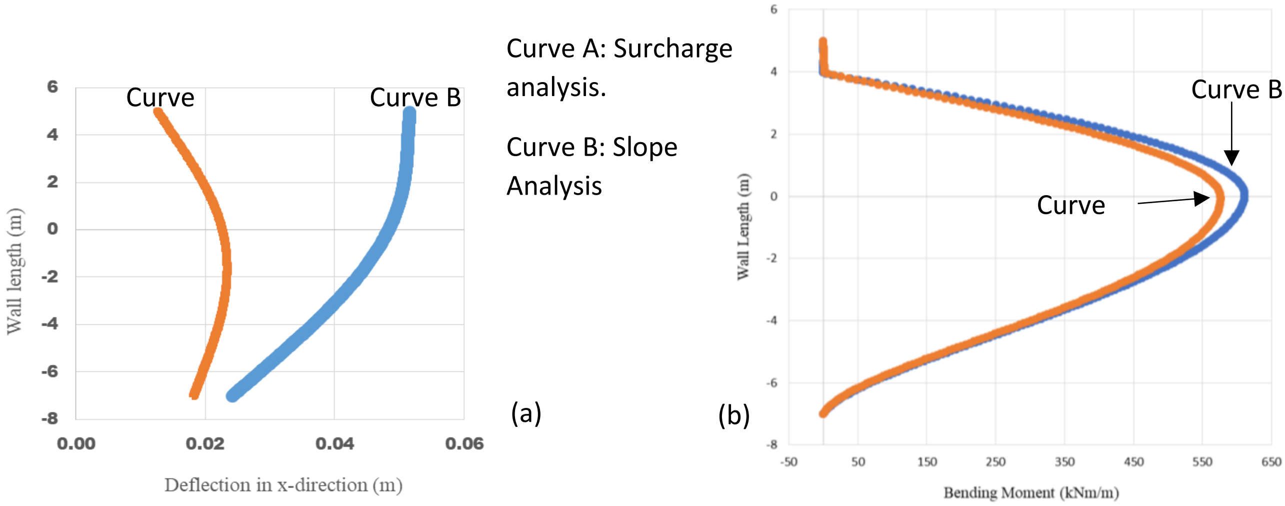
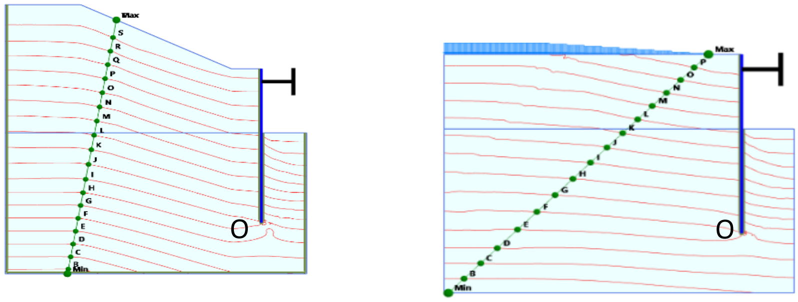


Figure 2: The deflection (a) and bending moment (b) of the diaphragm wall due to slope loading and surcharge loading analysis.

From the result produced as a result of the analysis carried out using PLAXIS, from Table 4 it was found that for all the parameters of comparison the values obtained from actual sloping ground analysis were greater than that of equivalent surcharge. It was observed that the forces exerted on the strut or anchor under surcharge analysis experience a 25% increase under the slope profile analysis because the slope was unstable, which is as expected. This sharp increase was traced back to the location of the critical slip surface of the slope which happens to pass through the location of the strut; it can be said that the support system experienced an additional horizontal force; with this response it can be said that the wall experiences a thrust load due to the sliding mass of soil. Also, Figure 2a Curve B shows that the wall and the strut moved out of position, thereby moving the maximum deflection position to the point of critical slip surface of the slope which contradicts the general knowledge of negligible or zero deflection at supports, which is observed in the case of surcharge analysis as illustrated by Curve A.

From Figure 2b, the difference in bending moment from the two methods of analyses was 6% although it might be expected that there should be a great margin between the two analyses. It was found that the bending moment is governed by the vertical stress which is converted to lateral earth pressure from the soil, the surcharge applied is the total stress due to the soil slope above the commencing level of excavation. In Figure 3 below, the stress points extend to the surface of the slope with both analyses giving a maximum stress value of 240kN/m^2 at the final level of the diaphragm wall (point marked O). There is a possibility for an increase in bending moment if the critical slip surfaces extend past the strut level which implies that when slope profile analysis is to be conducted it is essential to know the location of the critical slip surface. Positioning the strut or prop at this location controls the possibility of a large bending moment on the diaphragm wall due to sliding soil mass as the prop takes the thrust or horizontal load generated.



(a) (b)

Figure 3: Stress profile of the slope model analysis (a) and surcharge model of analysis (b).

4. Conclusion

Finite element method was used to analyse and investigate the accuracy of the two approaches for analysing sloping ground adjacent to deep excavation support systems and the following conclusions were drawn from the analysis:

- The surcharge analysis approach should only be used under a stable slope condition.
- The prop or strut experiences a load increase under unstable slope condition which implies the presence of a thrust load on the wall and the estimation of this load appears to be the horizontal component of the sliding soil mass. This load appears to be the required force to keep the slope stable or minimise failure.
- These research results advise that the slope should be analysed for stability before the design of the excavation support system.
- To control excessive bending moment on the wall, struts could be positioned at the location of the critical slip surface in the case of a multi-propped excavation.

References

[1]. Cheng, Y. C., & Jiang, P. (2012). Sensitive Analysis of Factors Affecting Soil Slope Stability. Applied Mechanics and Materials, 170-173, 1072-1075. doi:10.4028/www.scientific.net/AMM.170-173.1072

[2]. Chen, R., Meng, F., Li, Z., Ye, Y., & Ye, J. (2016). Investigation of response of metro tunnels due to adjacent large excavation and protective measures in soft soils. Tunnelling and Underground Space Technology, 58, 224-235.

[3]. Ou, X., Zhang, X., Fu, J., Zhang, C., Zhou, X., & Feng, H. (2020). Cause investigation of large deformation of a deep excavation support system subjected to unsymmetrical surface loading. Engineering Failure Analysis, 107, 104202. doi:https://doi.org/10.1016/j.engfailanal.2019.104202.

[4]. PLAXIS. (2018). Material Models Manual.

[5]. Sharma, J. S., Hefny, A. M., Zhao, J., & Chan, C. W. (2001). Effect of large excavation on deformation of adjacent MRT tunnels. Tunnelling and Underground Space Technology, 16(2), 93-98. doi:https://doi.org/10.1016/S0886-7798(01)00033-5

[6]. Zhang, X., Yang, J., Zhang, Y., & Gao, Y. (2018). Cause investigation of damages in existing building adjacent to foundation pit in construction. Engineering Failure Analysis, 83, 117-124. doi:https://doi.org/10.1016/j.engfailanal.2017.09.016

[7]. Asim Gaba, Stuart Hardy, Lauren Doughty, William Powrie, Dimitrios Selemetas. (2017). Guidance on embedded retaining wall design (Vol. C760). London: CIRIA.