EVALUATION OF STRENGTH PARAMETER FOR A DEEP EXCAVATION PROBLEM AND PREDICTION OF THE BEHAVIOUR OF EXACAVATION USING DIFFERENT SOIL MODELS

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Deep excavations are often required for infrastructure projects, power plant structures and underground transport systems. In the recent urban development, due to lack of space, it is required to carry out deep excavations very near to adjacent structures. For sites with limited space, it is always required to carry out deep excavations near existing structures. These excavations need to be analyzed and designed in such a way that the damage to the existing structure is minimal. In case of Nuclear Power Plant structures, the damage needs to be controlled to prevent the release of radioactivity to the environment. Such an analysis was carried out for a nuclear facility site located along east coast of India. In this case, for locating its foundation deep, open excavation was carried out. Various laboratory investigation results available from geotechnical investigation programme were analyzed and strength and stiffness parameters for the soil profile were arrived at. The excavation was idealized as a plain strain model and numerical analysis was carried out by commercially available software PLAXIS. Appropriate material models, namely Mohr-Coulomb model and HS model were adopted for predicting the displacement due to deep excavation.
KEY WORDS: Deep excavation, Numerical analysis, Soil Models, settlements

1. INTRODUCTION

Terzaghi (1943) defined excavations with depths smaller than their widths as shallow excavations, while depth larger than their width as deep excavations. While as per definition of Peck (1977), excavation whose depth less than 6m is shallow excavation and depth more than 6m is deep excavation. Deep Excavations are often required for infrastructure projects, power plant structures and underground transport systems. Nuclear reactors and facilities are being constructed in countries like India for achieving energy security. Generally, nuclear reactor structures are founded on competent rock strata which are available at deep depths, requiring deep excavations. Moreover, these structures are often planned with future expansion requirements, which also need deep excavations near to adjacent operating facilities.

These excavation needs to be analyzed and designed in such a way that the damage to the existing structures is minimum. In the case of Nuclear Power Plant structures, the damage needs to be controlled to prevent the release of radioactivity to environment. Deep excavation analysis is typically a soil-structure interaction problem. Various empirical and semi empirical approaches are available for the analysis of excavation system. However, more advanced techniques involving numerical methods are widely adopted nowadays for analysis of deep excavation and its support systems. The accuracy of these analysis and designs depends on the proper evaluation of sub soil properties and mathematical modeling of sub soil to evaluate the behavior of soil under the unloading problems like excavation. In this paper, the behavior of a deep open excavation of a nuclear facility site is studied using different constitutive models using finite element software PLAXIS. These analyses provided a frame work for selection of appropriate soil model for analyzing the future excavation problems within in the site.

2. REVIEW OF CONSTITUITIVE MODELS

Mathematical behavior of soil can be modeled using stress-strain relations which are generally defined through various constitutive models. Linear elastic perfectly plastic Mohr-Coulomb model (MC) and Hardening Soil Model (HS) are the commonly used constitutive models to define soil behavior. Various researchers Usmani .A. et al. (2010), Mohammad S.Parkbaz etal. (2013), Xingyu Pan & Hongyun Fu (2012), Chungsik Yoo & Dongyeob Lee (2008), and Bin_Chen Benson Hsiung(2009) studied excavation behavior and predicted ground surface settlements, wall displacements, earthpressure and bending moment distributions using Mohr-Coloumb model and HS Model. However all these numerical analyses only include one type of soil model for the entire analysis. Moreover, these analyses were carried out for supported deep excavations. From the literature, it is observed that Mohr-Coloumb model in general predicts the behavior of deep excavation in sandy soil. However, to predict the behavior of silty sand/clayey sand, different models like Hardening soil model need to be used. As the present site consists of loose to dense sand at top, followed by silty sand and residual soil, a combination of Mohr-Coulomb model for top sand layer and HS model for silty sand layer was adopted to predict the behavior of excavation.

3. GEOLOGY OF SITE

The site is located on the coastal plains comprising of beach deposits. The sediments are made up of sand, yellowish brown silty sands more oxidized owing to relative age. There exists a minor topographical break between this unit and the younger geomorphic unit indicating receding of the sea in geological time. The older beach is made up of fine to medium grained sand. Geologically the area is occupied by crystalline rocks of Archaean to late Proterozoic age mainly composed of Charnockite rocks.

4. CHARACTERIZATION OF SITE

Geotechnical investigation carried out at the site indicates that the site consists of loose to medium sand followed by dense sand. This sand layer is followed by Silty sand and residual soil. Competent

Table 1: Idealized Thickness of layer and Standard Penetration Test N Values

Layer	Thickness of layer in (m)	Range of SPT N values	Design SPT N values
Loose Sand	0.7	8-10	9
Medium Sand	3.3	14-30	27
Dense Sand	3.4	31-64	48
Silty/clayey Sand	5.6	18-25	22
Residual Soil	5.4	19-38	29

rock is available at a depth of 15m to 20m below the existing ground level. The thickness of each layer and average Standard Penetration Test N values observed are given in Table 1.

4.1 STRENGTH PARAMETERS

SPT N values are generally correlated with strength properties of soil material. Various empirical relations are available correlating SPT N values and angle of internal friction. However, Unconsolidated Undrained direct shear test(UU) and Consolidated Drained direct Shear test (CD) were carried out for sand, silty/clayey sand and residual soil, as a part of site characterization. The results of these direct shear tests were analyzed to establish site specific correlations between corrected SPT N values and strength parameters namely cohesion and angle of internal friction.The strength properties for various soil layers are given in Table 2.

Table 2: Strength properties for analysis

Layer	Drained Cohesion (kPa)	Drained Angle of internal friction
Loose Sand	0	32
Medium Sand	0	40
Dense Sand	0	45
Silty/Clayey Sand	29	32
Residual soil	31.63	31

4.2 STIFNESS PARAMETERS

Young’s Modulus is the commonly used stiffness parameter for analysis of excavation. Existing empirical relations of Young’s Modulus with SPT N values were considered for determination of Young’s Modulus required for this excavation analysis. Various empirical relations available were used for estimation of Young’s Modulus. These empirical relations provided a wide range of Young’s Modulus for the estimated value of N. Stiffness parameter provided by Bowles (1997) is a lower bound value and hence used for excavation analysis. Range of Young’s Modulus and Design Young’s Modulus are given in Table 3.

Table 3: Estimation of Young’s Modulus of Sandy Soil

Layer	**Range of E (kPa)**	**Design E (kPa)**
Loose sand	12000-48300	25300
Medium Sand	21000-78300	44000
Dense sand	31500-139200	59200
Silty Sand	8400-11840	10450
Residual soil	39750-70450	51400

Stress dependent stiffness according to a power law (*m*), plastic straining due to primary deviatoric loading (E^{ref} 50), plastic straining due to primary compression E(E^{ref} *oed*), elastic unloading/reloading input parameters (E^{ref} *ur* , υur) were considered for HS model in addition to the failure criterion according to the Mohr-Coulomb model(*c*, $\phi$and ψ)

5.0 ANALYSIS OF IDEALIZED EXCAVATION PROFILE

Excavation profile for the site was idealized from the geotechnical investigation results and the profile used for excavation analysis is indicated in Table 1. A typical idealized soil profile is shown in Fig 1. The excavation is carried out as open type excavation. The excavation is carried out in the form of benches. A 2.0m wide berm is also provided between the benches. A slope of 1V:2H is provided in soil and 1V:1H is provided for residual soil. The total width of the excavation is 49m and the depth of the excavation is 18.4m. Initial water table was considered at 2.0m below the ground level. The effect of dewatering was considered by carrying out a drained analysis.

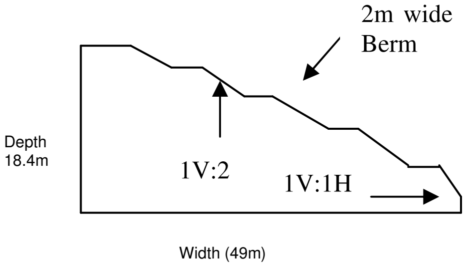

Fig1: Idealized Excavation Profile

From the estimated strength and stiffness parameters obtained from site investigations, an analysis was carried out using FE Software PLAXIS. The idealized excavation is carried out through eight phases. Eight Phases of excavation is defined as (i) excavation of top loose sand layer up to 0.7m (ii) excavation up to 3.5m (iii) excavation up to 4.0m and creation of first berm (iv) excavation up to 7.0m (v) excavation up to 7.3m and creation of second berm (vi) excavation up to 10.5m (vii) excavation upto 12.9m and creation of third berm (viii) excavation upto 18.4m. Basically two soil models as explained in previous sections namely, Mohr-Coulomb model and HS model were used to predict the excavation behavior. In the first case, Mohr-Coulomb model was considered for all the soil layers and in the second analysis for top sand layers, Mohr-Coulomb Model was considered and for silty sand and residual soil, HS Model was considered.

5.1 ANALYSIS USING MOHR-COLOUMB MODEL

The excavation was idealized into eight phases and drained analysis was carried out. Total displacement, horizontal displacement and vertical displacement were obtained using at the end of each stage of the excavation. Typical plots of vertical displacement and horizontal displacement at the end of excavation are given in Figs2 and 3 respectively. Analysis of the results indicates that the maximum vertical displacement occur at fifth phase which is 48.69mm. At the end of excavation, the vertical displacement is 43.19mm. The +ve sign indicates heave and –ve sign indicates settlement. At the excavation surface, heave was observed and behind the excavation face, settlement was observed during all the phases.

5.2 ANALYSIS USING HS MODEL

Stress–strain properties for Silty sand and residual layer encountered at site were modeled using HS model. Maximum vertical displacement is noted at the end of 5th phase of excavation which is 26.17mm. At the end of excavation, the vertical displacement is 21.31mm.

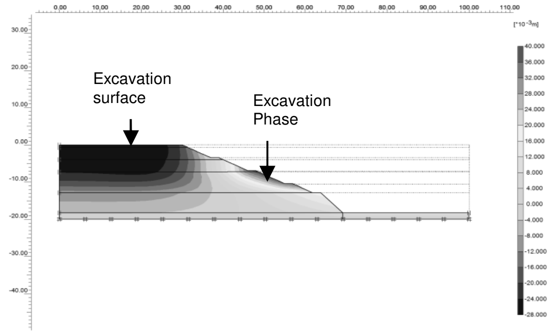

Fig 2: Vertical Displacement Profile at the end of excavation

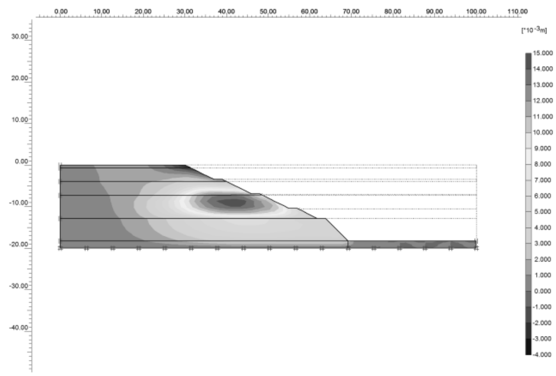

Fig 3 : Horizontal displacement Profile at the end of excavation

6.0 DISCUSSION OF RESULTS

Comparison of results indicates that the maximum displacement predicted by Mohr-Coloumb model is higher than that predicted using HS model which is attributable due to consideration of unloading stiffness properties of soil in HS Model. As a few strcutres will be located behind the excavation face, the settlement behind excavation line is required and accordingly the vertical settlement behind the excavation face is plotted from the face of excavation for 5th Phase of excavation.

The maximum vertical settlement is 26mm at a distance of 9.0m from face of excavation from Mohr-Coloumb Model. For HS Model, the predicted settlement was 18.5mm at a distance of 13m from the face of excavation. The settlement profile behind the face of excavation is given in Fig 4.

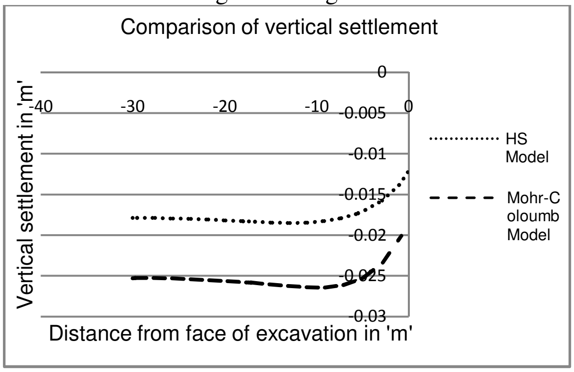

Fig4: Settlement Profile behind face of excavation

Horizontal displacement along the depth of excavation at 10.m away from the face of excavation also presented in Figs. 5 . At 10.0m away from the face of excavation, the maximum horizontal displacement is 2mm at a depth of 17m for Mohr-Coulomb model while HS Model predicts a displacement of 1.8mm at a depth of 15m.

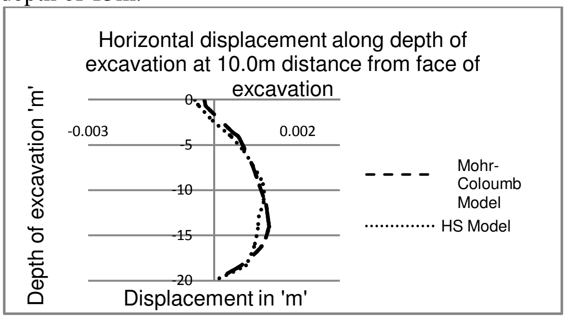

Fig 5: Horizontal displacement along depth of excavation at 10.0 distance from the face of excavation

7.0 CONCLUSIONS

A deep excavation carried out in a nuclear facility site was analyzed using Mohr-Coulomb model and HS Model in finite element software PLAXIS. The surface settlements and horizontal displacements obtained from HS Model are lower than those obtained using Mohr-Coulomb model due to accounting of non linear stress-strain properties of soil in HS Model. Even though open excavations are in general designed for stability as the depth of excavation increases, to predict the settlement of adjacent areas numerical analysis needs to be carried out using suitable soil models. The present analysis of open excavation provided a frame work for selection of appropriate soil models for prediction of behavior of future supported excavation system. The present study also predicted the settlement zones behind the excavation face which can be used for design of structures located in these zones after accounting the predicted settlements. However the predicted settlements need to be validated using the field observed data. .

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