Settlement Response of a Multi-Story Building

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Abstract-**The settlement calculation of a multi-story building is a challenging task due to the variation of soil properties and the use of an appropriate constitutive model for the reliable representation of soils' stress-strain behaviors. In this study, the settlement response of a multi-story building was calculated with the simple Mohr-Coulomb Model (MCM) and the Hardening Soil Model (HSM). The effect of soil modulus of elasticity using both models was investigated on the overall settlement response of the building. Results indicated that MCM overestimated immediate settlement in a range of 50 to 65% compared to HSM. The settlement response of the building calculated with both models was within the allowable range. The results of this study can be helpful for geotechnical engineers working on reliable predictions of the settlement of multi-story buildings.**

Keywords-immediate settlement; finite element method; consolidation process; raft foundation; Mohr-Coulomb model; hardening soil model

I. Introduction

The reliable prediction of a multi-story building's settlement is a great challenge for geotechnical engineers [1-3]. Several factors affect the settlement of a building, such as the type of soil, the degree of compactness, soil stratigraphy, and the location of water table [4-5]. Modulus of elasticity is a main parameter that controls the settlement, as higher values result in lower settlement [6]. In modern geotechnical engineering, soils are considered as elastoplastic materials. This indicates that a part of the settlement is elastic and the remaining is plastic. With the advancement of low-cost computing in geotechnical applications, software programs are used for the calculation of settlement in various geotechnical structures. Such programs utilize various constitutive models for calculating stress strain response of soils. Thus, it is very important to choose the appropriate constitutive model that could realistically simulate the stress strain response of soils. Several constitutive models for stress strain of soils are available in commercial software, e.g., Plaxis2D/3D, Geostudio, Z-soil etc. However, choosing a constitutive model to run a settlement analysis is not easy task, as a thorough understanding of its main features and parameters is required. In general, the use of advanced constitutive models requires several input parameters. Due to the lack of availability of laboratory tests, advanced constitutive models are not used for routine calculations.

Although the Mohr-Coulomb Model (MCM) has several limitations, it is used in various applications due to its simple and easily obtained parameters. On the other hand, the Hardening Soil Model (HSM) is a suitable constitutive model for predicting the settlement response of geotechnical structures. In [7], it was found that the settlement of the shallow foundation calculated with MCM was greater than the Cam Clay model. This showed that MCM overestimates the settlement of buildings. There are very few case studies on the settlement of geotechnical structures where the results from MCM are compared with HSM [8-9]. Therefore, there is a necessity for more studies, in which the suitability of both MCM and HSM should be evaluated for a multi-story building's settlement calculation. This paper presents the

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numerical analysis for calculating the settlement of a building using both MCM and HSM. Moreover, the foundation soil profile and the material properties are presented. Finally, the settlement is evaluated with both MCM and HSM, and the results are compared.

II. MATERIALS AND METHODS

A. Finite Element Model

Numerical analysis of the multi-story building settlement was performed using Finite Element Program PLAXIS 2D [10] for a 10-story residential building with a floor area of 25m×20m. The building's geometry is shown in Figure 1 and its finite element model is presented in Figure 2. The model was extended 100m horizontally on both sides to consider the influence of deformations due to building loads. The bottom of the finite element model was fixed in both horizontal and vertical directions. The vertical boundaries of the model were fixed in horizontal direction and free in vertical. Fifteen node triangular elements were adopted. The mesh was sufficiently refined in order to minimize the influence of coarseness on the results. The left and right vertical boundaries and the bottom of the finite element model were closed to prevent the dissipation of excess pore pressures. Coupled deformation and consolidation analysis was performed in order to study the settlement behavior and the development and dissipation of excess pore pressures under the building's loads [11].

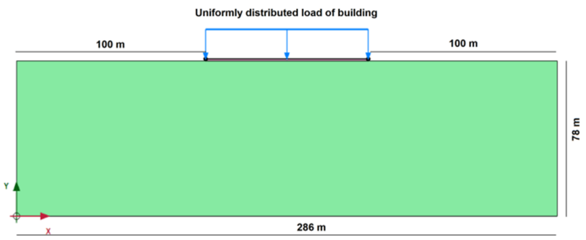

Fig. 1. Foundation of soil profile along with load.

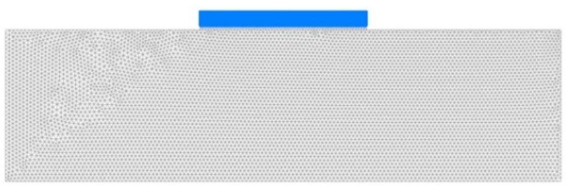

Fig. 2. Finite element mesh of the building.

B. Loading Condition

The load of the building was calculated by considering live and dead loads. Reinforced Cement Concrete (RCC) and steel are the major construction materials for raft foundation. The total load for each floor was calculated at 7kN/m^2.

C. Soil Properties

Three boreholes were conducted to determine the geotechnical properties of the soil. Soil's average moisture content was about 60%. The soil was classified as silty sand according to the unified classification system [12]. Stress strain behavior of the soil was simulated with both MCM and HSM. The input parameters of HSM are presented in Table I. The values of cohesion, unit weight, permeability, modulus of elasticity, and Poisson's ratio of the soil were obtained from laboratory tests. The remaining parameters were taken from [13-14]. MCM has five input parameters: cohesion, friction angle, dilatancy angle, Poisson's ratio, and modulus of elasticity. These parameters are shown in Table I. Soil's Modulus Of Elasticity (MOE) varied from 1000 to 40000kPa to observe how the settlement of the building was reduced with increasing density of the foundation soil. Water table was located 1m below the surface. In this study, 1m thick reinforced cement concrete raft was placed as building's foundation. The material properties of the raft were adopted from literature [13] and are presented in Table II.

TABLE I. INPUT PARAMETERS OF HARDENING SOIL MODEL

Parameter	Value
Saturated unit weight	17.5 kN/m^3
Unsaturated unit weight	13 kN/m^3
Permeability in horizontal direction	$0.75 \times 10^{-3}\ m/day$
Permeability in vertical direction	$0.75 \times 10^{-3}\ m/day$
Tangent stiffness modulus (E_{oed})	10000kN/m^2
Secant stiffness (E_{50}^{ref})	10000kN/m^2
Reference modulus for unloading and reloading (E_{ur}^{ref})	30000kN/m^2
Power (m)	0.5
Poisson's ratio	0.3
Cohesion	10kN/m^2
Angle of internal friction	30°
Dilatancy angle	0°

TABLE II. MATERIAL PROPERTIES OF CONCRETE

Parameter	Value
Unsaturated unit weight	24 kN/m^3
Modulus of elasticity	20×106kN/m^2
Thickness of raft	1m
Poisson's ratio	0.15

III. RESULTS AND DISCUSSION

The construction of the proposed ten-story building was assumed to be carried out in stages. The sequence of construction of the building is listed in Table III. The calculations were performed for various construction activities.

TABLE III. CALCULATION DETAILS FOR STAGED CONSTRUCTION OF 10-STORY BUILDING

Phases	Duration (days)	Type of analysis
Raft foundation	30	Consolidation
Ground floor	365	Consolidation
First floor	270	Consolidation
Second floor	270	Consolidation
Third floor	240	Consolidation
Fourth floor	240	Consolidation
Fifth floor	240	Consolidation
Sixth floor	240	Consolidation
Seventh floor	240	Consolidation
Eighth floor	240	Consolidation
Ninth floor	240	Consolidation
Tenth floor	240	Consolidation

Vertical settlement of the multi-story building was calculated using both MCM and HSM. Settlement was calculated for each floor starting from floor 1 to 10. The effect of soil's MOE was examined. Settlement response of the multi-story building computed with MCM and HSM is presented in Tables IV and V respectively. As it can be observed, the maximum settlement of the building up to the 10th floor calculated with MCM was 52mm and 14mm when the values of soil's MOE were adopted as 10000kPa and 40000kPa respectively.

TABLE IV. MCM CALCULATIONS OF SETTLEMENT

	Soil modulus of elasticity (kPa)						
	10000	15000	20000	25000	30000	35000	40000
Floor	**Settlement of building (mm)**						
1	48	30	24	20	16	14	12
2	48	32	24	20	16	14	13
3	48	32	24	20	17	15	13
4	48	34	26	20	17	15	13
5	48	34	26	22	18	15	14
6	52	34	26	22	18	16	14
7	52	34	26	22	18	16	14
8	52	36	28	22	18	16	14
9	52	36	28	22	18	16	14
10	52	36	28	22	18	16	14

TABLE V. HSM CALCULATIONS OF SETTLEMENT

	Modulus of elasticity of soil (kPa)						
	10000	15000	20000	25000	30000	35000	40000
Floor	**Settlement of building (mm)**						
1st	17	12	9	8.5	7.2	6.4	5.6
2	17	12	9.5	9	7.6	6.8	6
3	18	13	10	9	7.6	6.8	6
4	19	13	10	9.5	8	7.2	6.4
5	19	13	11	9.5	8	7.2	6.4
6	20	14	11	9.5	8	7.2	6.4
7	20	14	11	10	8	7.2	6.4
8	20	14	11	10	8.5	7.2	6.4
9	22	14	11	10	8.5	7.2	6.4
10	22	14	11	10	8.5	7.2	6.4

Fig. 3. Comparison of settlement calculated with MCM and HSM.

The settlement response of the building using MCM and HSM were compared. Table V shows that there was comparatively less settlement predicted with HSM than with MCM. The maximum settlement of the building up to the 10th floor was 22mm and 6.4mm when the MOE of the soil was 10000kPa and 40000kPa respectively. The comparison of building's settlement calculated with MCM and HSM is presented in Figure 3. As it can be observed for various loading conditions, the settlement predicted with MCM was about 50 to 65% higher than the one predicted by HSM. According to [15], the allowable settlement for a raft foundation is about 100mm. Hence, the settlements of the building up to the 10th floor computed with MCM and HSM are within the allowable range. It has to be emphasized that the settlement response of the building is investigated after the end of the construction. This settlement does not involve long term settlement response. For this purpose, detailed numerical analysis is required to find the long term response of the building under sustained loading conditions.

IV. CONCLUSION

This paper compared the calculated immediate settlement of a multi-story building using two soil constitutive models, i.e. MCM and HSM. MCM overestimated the settlement of the building in a range of 50 to 65% compared to HSM. Overall, the magnitude of the settlement calculated with both models is within the permissible limits. Future studies are needed to investigate the settlement response of such buildings under sustained long-term loads. The compared results of the settlement calculations can be beneficial for the geotechnical engineering community.

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