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Numerical analysis for asymmetric side supporting systems in sandy soil

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ABSTRACT: This study aims to study the effect of the asymmetry conditions surrounding strutted side support systems such as the change in loads acting on the retained soil on the systems' behavior. The study considers two types of strutted side supporting system; the first type is the single strutted system, and the second type is the multi strutted system. The two types will be studied for a dense sand soil. The studied retaining types will be analyzed at the symmetric and asymmetric conditions using two different soil models, the first soil model was the constitutive Mohr-Coulomb (MC) model while the second model is the constitutive Hardening Soil (HS) model. The analysis is performed using finite element software like Plaxis 8.2. The comparison between results will be from points of horizontal displacement, bending moments, and force in strut.

1 INTRODUCTION

Strutted side support system is one of the most common side support systems in many sites of the world. So, it is imperative to discuss everything related to this kind of support systems. One of the most important related things for this kind of side support system is how to make the analysis models for the system. It was observed that most of the designers are studying one half of the system assuming that the system is completely symmetrical and considering this as a kind of simplification. However, this supposed symmetry in analysis models is actually not happened in the real conditions of the system. Really, there are many factors may cause asymmetric condition for the side support systems. Without studying the changes might happened to the behavior of the system under the effect of asymmetric conditions, the acceptance of these models' results is doubtful. The study of the asymmetrical side support systems will be helpful for many purposes in the civil engineering fields.

The scope of study is to know the impact of the asymmetry loading conditions on the system behavior. A comparative study is implemented in this study to find out the difference between the results of the symmetric model and asymmetric model analysis.

2 LITERATURE REVIEW

It is necessary for design considerations of an excavation system that the wall deformation is restricted to an acceptable limit, especially the long-term behaviour as a result of the consolidation of the surrounding soil. Currently, the approaches in excavation support design are confined mainly to empirical and semi-empirical methods. This could be accelerated using computer programs in the last decades.

Lambe et al. (1972) reported that the lateral movements near the sheet pile are 5 to 7 times as large as those near the diaphragm wall.

Lee et al. (1986) reported that the rate of lateral wall movement during excavation ranges from 1.5 to 3.0 mm/day. Yong et al. (1989) reported the rate of increase in maximum displacement is about 1 to 3 mm/day during excavation and 0.4 to 0.7 mm/day after excavation.

Prior to installing the first level of struts, a cantilever condition exists in the wall. With the installation and pre-loading of the first strut, lateral movement at the top of the wall is reduced and maintained at a fairly constant magnitude. However, excessively large movement can develop if excavation is allowed to proceed too far before a strut is installed. Insertion and pre-loading of struts serve to restrict movement of the wall until the start of the next stage of excavation (Lee et al. 1986).

Generally, the maximum lateral wall movement increases when excavation proceeds until the next level of struts has been installed (Lee et al. 1986, Tan et al. 1995). Once the struts are installed, the lateral movement is generally restricted or reduced (Lee et al. 1986).

Lambe (1970) concluded that the state of the art for the design and the analysis of braced excavation was far from satisfactory, since support system loads and ground movement could not be predicted with confidence. He suggested that the finite element method (FEM) and the experience shared through published case histories, were the two most promising ways to understand the deep excavation performance.

Jardine et al (1986) concluded that non-linear behavior of soils must be accounted to properly study soil structure interaction problems. They concluded that non-linear stress-strain characteristics have a significant influence on the magnitude of wall deflections and the pattern of ground settlement.

Vermeer (2001) investigated the results of the analysis of single strut retaining wall. When considering a stiff wall in a stiff soil, a classical active earth pressures will occur, at least below the anchor. The stiff soil transfers a large part of the active pressure by arching. He concluded that bending moments are in general not significantly reduced by increasing wall penetrations.

Steiner and Werder (1991) found that surcharges on ground surface strongly influenced tie back anchor loads, and the lateral movement of the wall was about 0.1 % of excavation depth for final excavation. Reinfurt et al. (1994) found that maximum movements were essentially less than 0.2% of excavation depth. Patel and Castelli (1992) found that max. lateral wall movements were about 0.06 % of excavation depth.

3 STUDY PARAMETERS

3.1 *General*

The purpose of this study is to investigate the effect of asymmetric loading conditions on the behaviour of single and multi-strutted earth retaining structure for dense sand soil by using two constitutive soil models. The analysis results shall be investigated in lieu of wall deflection, wall bending moment (B.M), and force in propping system.

3.2 *Soil data*

The selected soil is dense to medium sand. The soil formation is a homogenous layer extends from ground top level to 30.0 m depth with the following parameters: range of N_{SPT} = 10 to 50 blows, and water level is far away from ground top level (more than 30 m depth). The following parameters will be used:

Saturated unit weight (γ_{sat}), drained angle of shearing resistance (ϕ\`), at rest horizontal soil pressure coefficient (K_o), drained elastic modulus (E_d), stress level dependency power (m), drained triaxial stiffness modulus reference (E_{50}^{ref}), reference drained constrained modulus (E_{oed}^{ref}) and reference drained unloading reloading modulus (E_{ur}^{ref}).

3.3 *Geometry data*

The plain strain 2D model is the suitable model to be used in the analysis of straight retaining structure. The rigid boundary shall be chosen upon literatures which discussed deep excavation. Figure 1 shows a suggestion for minimum requirements for boundary condition for deep excavation problems.

The drained analysis is considered in this study. The minimum requirements of boundary condition can cover this case of analysis.

The 15-noded triangular elements will be used in the setup of these models and five stress points are used for a 10-node interface element whereas three stress points are used for a 6-node interface element.

3.4 *Soil modelling data*

The soil models used in this study will be Mohr-Coulomb (MC) and Hardening Soil (HS) models. Both models will be used for symmetric and asymmetric wall loading conditions.

For modelling both soil models, a finite element computer software program *Plaxis* is used. This program can simulate the construction stages and implement the calculation for each stage.

4 SINGLE & MULTI STRUTTED SYSTEM (MODELS M1 & M2)

4.1 *General*

The analysis of strutted retaining system requires a set of data to be identified. The data required for the analysis includes soil properties, wall properties, struts properties, excavation depth and construction stages.

4.2 *Soil properties*

The dense sand layer is considered in the analysis for single and multi-strutted systems with a thickness of 30.0 m. The following soil properties are used.

Table 1. Soil Data

Soil Parameters	Mohr-Coulomb (MC) Model	Hardening Soil (HS) Model
γ_{sat} (kN/m^3)	19	19
Ko	0.426	0.426
ϕ\`	35	35
c\` (kPa)	0.0	0.0
Interface strength ratio	0.7	0.7
E\` (kPa)	30000	N.A
ν	0.3	N.A
E_{50}^{ref} (kPa)	N.A	29700
E_{oed}^{ref} (kPa)	N.A	26200
E_{ur}^{ref} (kPa)	N.A	89100
ν_{ur}	N.A	0.2
m	N.A	0.5

4.3 *Wall properties*

The wall system is a reinforced concrete wall of 0.6 m thick with the following properties of wall are used.

Table 2. Wall Data

System designation	Bending stiffness (*EI*) kPa/m'	Normal Stiffness (*EA*) kPa/m'
0.6 m RC wall	3.6×10^5	1.2×10^7

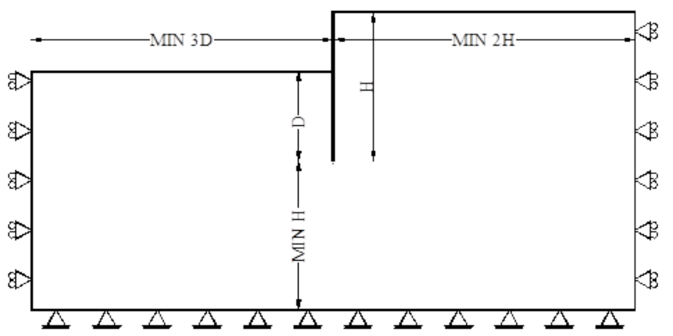


Figure 1. Minimum requirements for deep excavation problems (K.J. Bakker)

4.4 *Strut properties*

In the first retaining system, a single strut is used as a lateral support and located at 2.0 m depth from the ground level. In the multi strutted system, a group of 3 struts is considered as a lateral support with depths of 3.0, 6.0 and 9.0 m from the ground level. The used struts are chosen to be pipes (80 mm inner diameter and 10 mm thickness) with the following properties:

E (Elastic Modulus) = 2.0×10^8 kPa, A (Area) = 0.0254 m^2 and spacing between struts = 5.0 m.

4.5 *Excavation*

Trial analyses had been conducted on the both retaining systems to ensure the stability of the retaining structure with suitable safety factor.

For single strutted system, 7.0 m excavation is safe for 11.0 m depth retaining wall propped at depth 2.0 m from ground level. For multi strutted system, an excavation depth of 12.0 m was considered. The stability analysis shows that for excavation depth 12.0 m with 3 struts, the safe penetration depth shall be 3.0 m which gives a total depth of the wall of 15.0 m.

4.6 *Effect of asymmetrical surcharge loading on the behavior of strutted systems.*

The behavior of strutted systems under the effect of asymmetric surcharge loading is investigated. The static surcharge loading values varies from 20 to 60 kPa. The analysis results are presented for the symmetric case and for each wall in the asymmetric case. The wall near by the surcharge load will be named Wall-1 while the other one will be Wall-2.

4.7 *Effect of asymmetric condition on deflection*

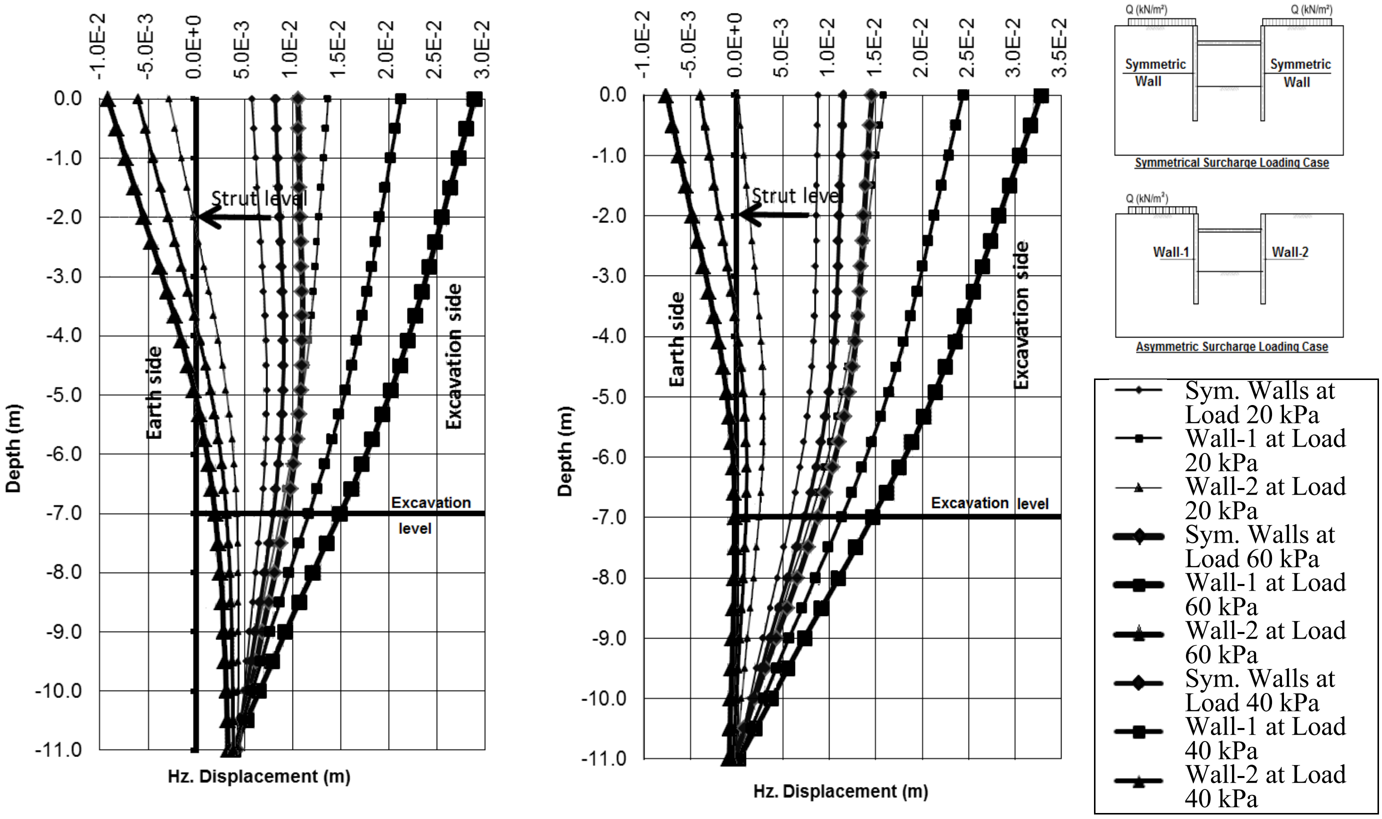
The horizontal displacement using soil models at different values of symmetric and asymmetric surcharge loading cases had been plotted as shown in figures 2 and 3 for model M1 and model M2 respectively.

4.8 *Effect of asymmetric condition on Bending Moment*

The Bending Moments using soil models at different values of symmetric and asymmetric surcharge loading cases are plotted in figures 4 and 5.

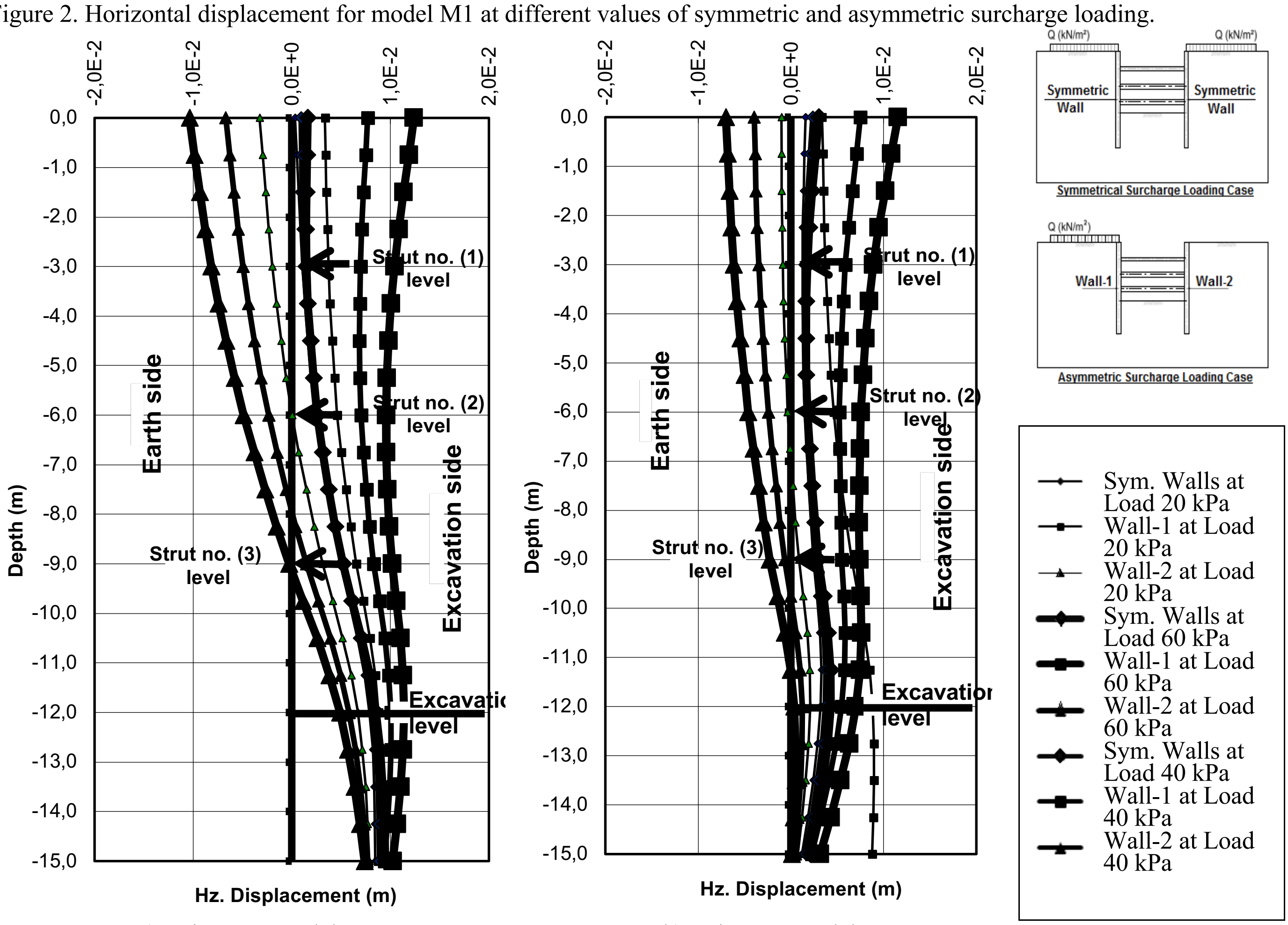
4.9 *Effect of asymmetric condition on strut(s) force*

The force in strut(s) for both symmetric and asymmetric surcharge loading cases using different soil models is investigated for both strutted retaining systems. The force in strut per surcharge load ratio versus surcharge load ratio is plotted in figures 6 and 7 for model M1 and model M2 respectively.



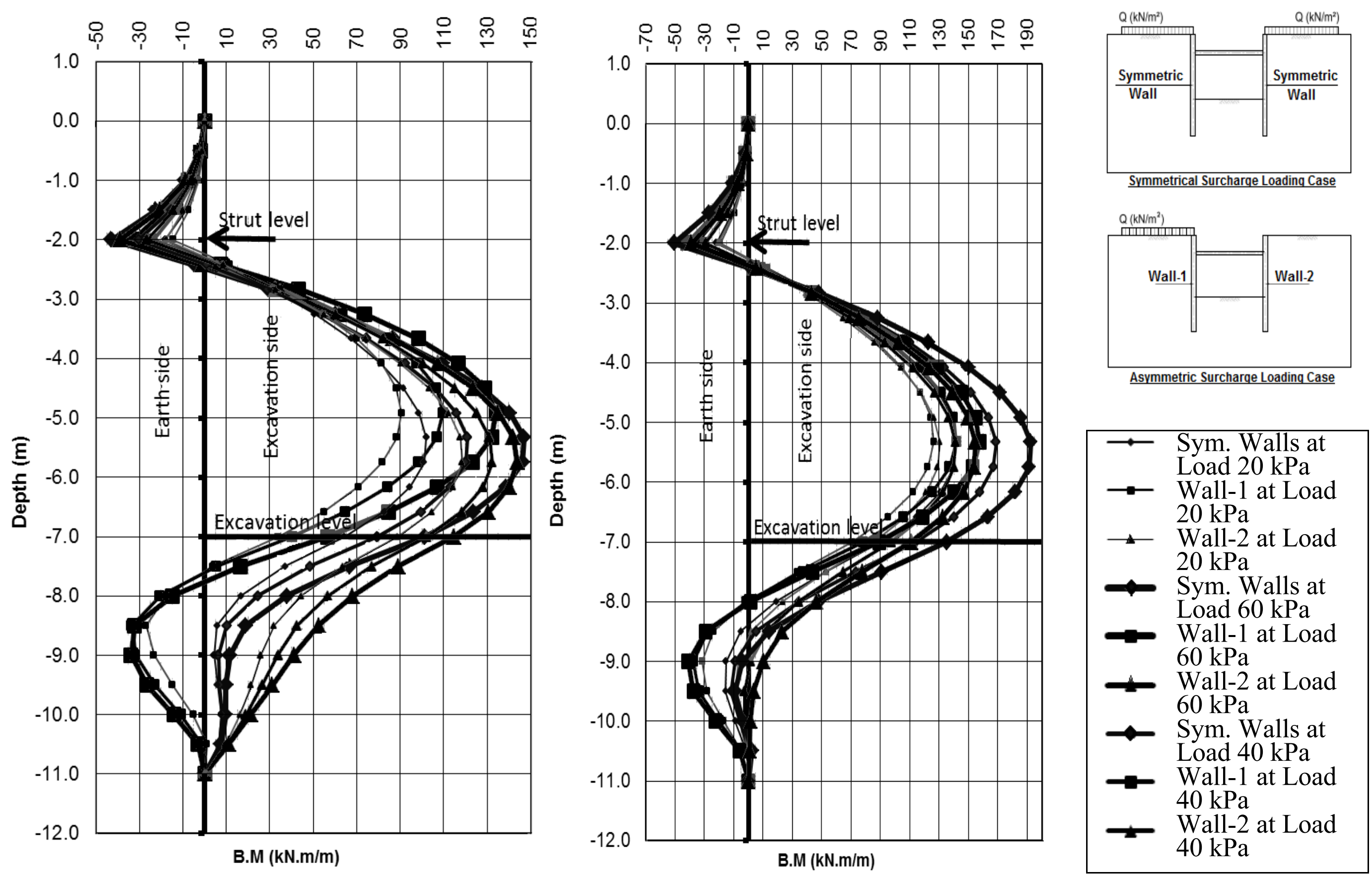
a) Using MC model. b) Using HS model.

Figure 2. Horizontal displacement for model M1 at different values of symmetric and asymmetric surcharge loading.



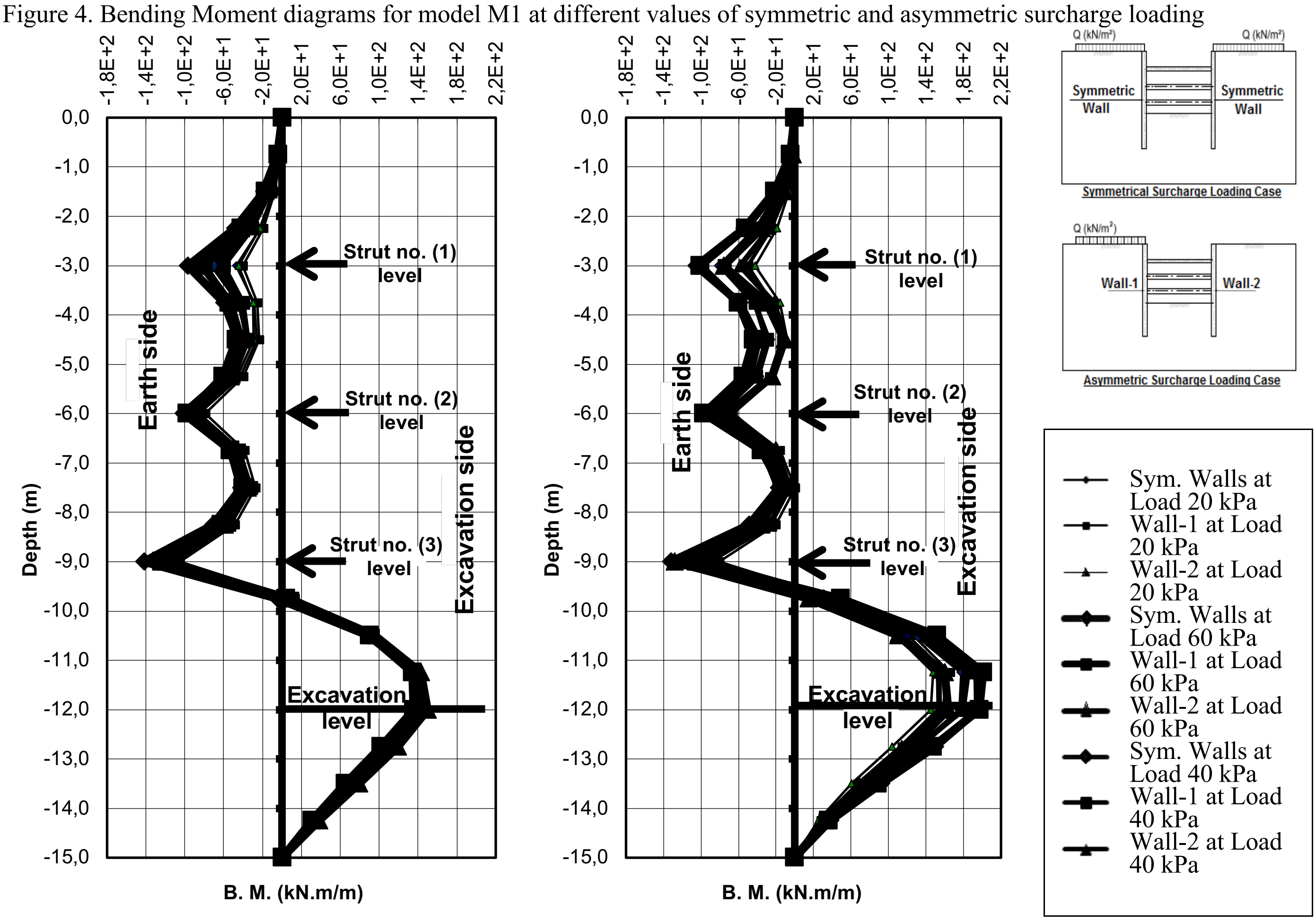
a) Using MC model. b) Using HS model.

Figure 3. Horizontal displacement for model M2 at different values of symmetric and asymmetric surcharge loading.



a) Using MC model. b) Using HS model.

Figure 4. Bending Moment diagrams for model M1 at different values of symmetric and asymmetric surcharge loading



a) Using MC model. b) Using HS model.

Figure 5. Bending Moment diagrams for model M2 at different values of symmetric and asymmetric surcharge loading

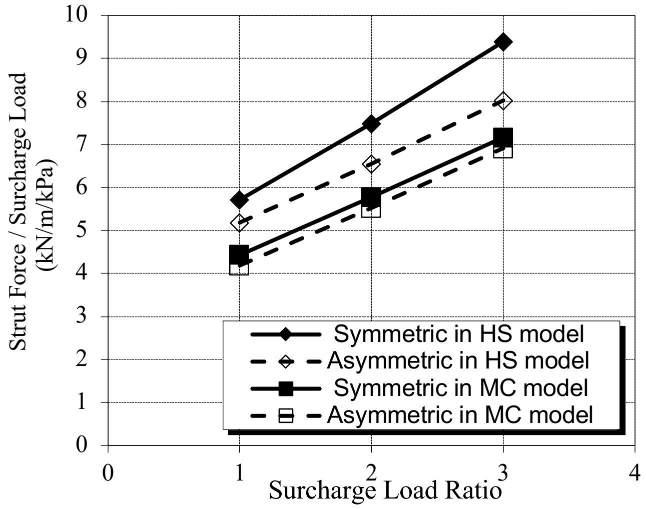


Figure 6. Strut force / surcharge load vs surcharge load ratio for model M1

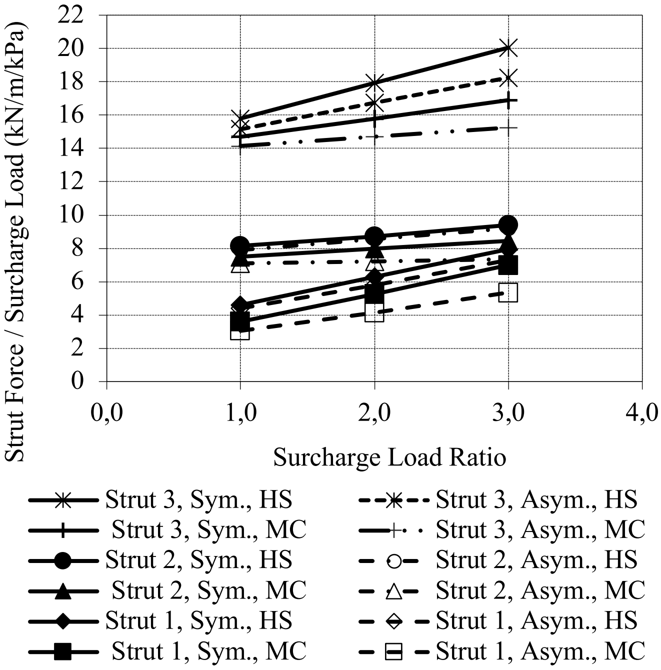


Figure 7. Strut force / Surcharge load vs Surcharge load ratio for model M2

5 SUMMARY

The main objective of this study was to study numerically the effect of the asymmetry loading conditions on strutted retaining systems in dense sand soil with focusing on the effect of soil modelling on the wall design parameters. The study considered two types of side supporting system, the first model is the single strutted system, and the second model is the multi strutted system. Both types are studied for relatively rigid retaining structure. The studied types were analyzed using two different soil models; the constitutive Mohr-Coulomb (MC) model and the constitutive hardening soil (HS) model. The analysis is done using the finite element software Plaxis 8.2.

6 CONCLUSIONS

The conclusion from the present study is limited to the studied cases of the analysis of the retaining system as well as the studied soil and the concluded parameters. The conclusions from the study shall be divided according to the case of the analysis and the points of the interest.

- The maximum B.M obtained from HS model is higher than that obtained from MC model for both symmetric and asymmetric cases.
- For both soil models and strutted systems, the asymmetric loading case causes increase in wall-1 maximum deflection, while the maximum deflection for wall-2 had decreased compared to symmetric wall maximum deflection.
- For both soil models and strutted systems, the strut force of symmetric case is higher than that of asymmetric case.
- For both soil models and both systems, the rate of increase of wall displacement with increasing the acting surcharge load is much higher for asymmetric case than symmetric case.
- For both strutted systems, the rate of increase of wall displacement with increasing the acting surcharge load is much higher for asymmetric case than symmetric case.
- For single strutted system, the asymmetric loading case causes decrease in value of maximum B.M for both wall-2 and wall-1 compared to symmetric wall maximum B.M, while in the excepted case value of maximum B.M of wall-2 only is increased compared to symmetric wall maximum B.M. For HS model of multi strutted system, the asymmetric loading case causes a neglected variation in value of maximum B.M of wall-1 and wall-2 compared to symmetric wall maximum B.M. For multi strutted system, the percentage of change in strut force due to asymmetric loading case is more significant for MC model than that obtained from HS model especially for the upper two struts.

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