Comparison of Different Soil Models for Excavation using Retaining Walls

Arjun Gaur[1], Ankit Sahay[2]
[1]Department of Civil Engineering, Delhi Technical Campus, Guru Gobind Singh Indraprastha University, Delhi
[2]Assistant Professor, Civil Engineering Department, Delhi Technical Campus, GGSIPU, Delhi, India.

Abstract

This research work is carried out various effects of different soil models for excavation, using retaining wall. There are two types of material models namely Mohr-Coulomb model (MC) and Hardening Soil (HS) model are used. For both these models Plaxis software is being used for analysis. This paper describes the study of dry excavation & retaining wall using tie back wall. We know there is risk to human life,natural resources and also on infrastructure due to landslide. These slope failures causes huge loss of life and property along with many inconveniences and problems such as disturbances, deviation of traffic along highways and damage to the roads. This study involves the comparasion between dry construction of an excavation with retaining wall by using MC model and HS model. PLAXIS allows for a complete modelling of this given type of problem. It explains modelling of anchoed retaining wall and pre-stressing condition. More over, the dry excavation also involves the calculation of groundwater flow, displacements, stresses and phi-c reduction etc. which finds the new water pressure distribution, deformations, and obtained new forces. A fully comparison between the results from Mohr-Couloumb and Hardening Soil cases yields some important differences which are presented in this paper.

Keywords — *Excavation, Retaining wall, Tie back wall, Plaxis, Hardening soil model, Mohr coulomb model.*

I. INTRODUCTION

In (Géotechnique) tunnel works explained the study of excavation. This research work provides the modelling of the excavation and retaining wall using tie back wall with the MC model and HS model, both are finite element methods. (W. Allen Marr et al.) explained that the design is now becoming more complex and challenging due to more requirements of equipments, deeper excavations on non suitable sites, which has restricted the limits on allowable displacements for a closed adjacent structures.

(Rafał F. Obroad et.al) explained that engineers who are looking for reliable and very realistic predictions of the engineering system than response should be aware that linear-elastic, perfectly plastic models in the finite element (FE) analysis should be done. Soil ground movements are computed for supporting structural elements which may be underestimated and may influence the magnitude of the forces.

(Daniel deb. Richter et al.) explained that soil science and its engineering is seriously challenged by new economic and environmental demands and also by changing the model of soil that brings with it different needs for new data.

Therefore, firstly different soil parameters as an input in both of these models are being used. In Mohr Coulomb model, parameters like Young's modulus, Poisson's ratio, Friction angle, Cohesion, Dilatancy angle, etc. are used. In Hardening Soil model, basic Mohr Coulomb model parameters are used in similar way, but some extra parameters are also used such as Secant Modulus 50% Strength, Oedometric Modulus, Unloading-Reloading Modulus, Unloading-Reloading Poisson's Ratio, Exponent of the stress-stiffness function etc.

After the modelling of excavation with tie back wall using both models i.e. Mohr Coulomb and Hardening Soil model respectively, we obtained some interesting results as total deformation, total stress, active pore pressure, axial force, bending moment etc. We found that there are differences in the results of both models. Due to extra addition of parameters in Hardening Soil model, it gives more precise or accurate results. Finite element analysis require values of soil stiffness to make reasonable predictions of displacement.The excavation is supported by concrete diaphragm walls like retaining wall shown in fig.1. The walls are tied back by pre-stressed ground anchors.

(Z. Cap et al in 2003) also explained the cuttings, fillings, and excavation methods of the FE analysis.

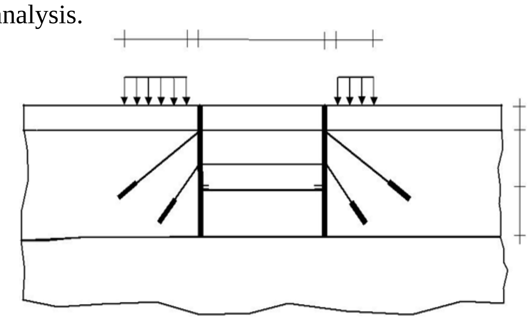


Fig 1: Excavation Diagram With tie Back Walls

II. LITERATURE REVIEW

A. *The Mohr-Coulomb model*

(V. Józsa) explained that it is used as the first method of approximation. Due to its constant stiffness, the calculation is very fast. The model is ideally correct for stability test, but the displacements and forces obtained are not real. Parameters of (MC) model are given below:

1. (E) Young's modulus [kN/m2]
2. (ν) Poisson's ratio [-]
3. (φ) Friction angle [°]
4. (c) Cohesion [kN/m2]
5. (ψ) Dilatancy angle [°]

B. Mohr-Coulomb failure

(Joseph F.Labuz et al.in 2012) also explained the failure criteria. To understand the relationships and comparisons between stress, deformation, and change in other parameters, we used this relationship to predict the soil behavior.

1) Explanation of Principal Stresses and Introduction of Shear Stress and Normal Stress.

1. Stress is resolved into 3 main principal vectors at right angles to each other σ_1, σ_2, and σ_3 where $\sigma_1 \geq \sigma_2 \geq \sigma_3$
2. σ_1 is the maximum principal stress, σ_2 is the intermediate principal stress, and σ_3 is the minimum principal stress.
3. For any plane which is parallel with σ_2, stress is resolved into 2 given components:
   a. Shear stress (σ_s), in the direction parallel to the plane, and
   b. Normal stress (σ_n), in the direction perpendicular to the given plane.
4. The given stress components are related to each other by:
   $\sigma_s = ½(\sigma_1-\sigma_3)\sin(2\theta)$ eq. (1)
   $\sigma_n = ½(\sigma_1+ \sigma_3) - ½(\sigma_1 - \sigma_3)\cos(2\theta)$ eq. (2)
   Where θ is the angle between the plane and σ_1

2) Coulomb failure criterion

1. On a Mohr coulomb diagram, each homogeneous material has a different characteristic failure envelope for the fracture of brittle shear.
2. Combinations of σ_s and σ_n which may plot outside of the envelope will result in form of fracture. Those plots inside the envelope are stable.
3. For parabolic behavior, failure envelopes are in the form of tensile stress and for straight lines, it should be in form of compressive stress.
4. Under the compressive stress, failure envelope at any given point is defined by the Coulomb law of failure,
   $\sigma_c = \sigma_0 + \tan(\varphi)\sigma_n$ eq. (3)
   Where:
   σ_c = critical shear stress
   σ_0 = cohesive strength, or σ_s value of the given failure envelope where σ_n = 0 (where failure envelope intersects the y-axis)
   φ = angle of internal friction. $\varphi = 90-2\theta$
   Tan (φ) is known as the coefficient of internal friction
5. Most rocks and soil have an internal friction angle ≈ 30°. Therefore, θ at failure is also ≈ 30°, even though σs is maximum when θ = 45°.
6. Pore-fluid or active/extreme water pressure (P_f) effectively minimize the stress equally in all directions.
7. The effective stresses (σ_{1eff}, σ_{2eff}, and σ_{3eff}) are defined as:
   $\sigma_{1\,eff} = \sigma_1 - P_f$ eq. (4)
   $\sigma_{2\,eff} = \sigma_2 - P_f$ eq. (5)
   $\sigma_{3\,eff} = \sigma_3 - P_f$ eq. (6)
8. Note that $\sigma_{1eff} - \sigma_{3eff} = \sigma_1 - \sigma_3$ so that pore fluid pressure does not change the differential stress, it only lowers down the confining pressure
9. Increase of pore fluid pressure slightly moves the Mohr circle to the right, which is closer to the failure envelopes.

C. The Hardening Soil (HS) model

(Schanz.T et al. in 1999) discussed about the verification and formulation of this model. It is an advanced and latest model for the simulation and modelling of soil behaviour.

As for the Mohr-Coulomb method, the limiting state value of stress is explained by these parameters given as an angle of friction friction (phi), cohesion (c) and angle of dilatancy (psi). But in HS model, soil stiffness is explained much more correctly by using of extra three different input stiffnesses: triaxial stiffness (E_{50}), triaxial unloading stiffness (Eur), oedometer loading stiffness (Eoed) and also used an extra cap shown in figure 2 related to Mohr-Coulomb model.

The HS model is also known for stress-dependency of stiffness moduli. This explains that all stiffnesses increases with the pressure. Hence, all three input stiffness parameters relate to a reference stress, usually taken as 100 kPa (1 Bar) whenever we have to assume. Besides the different model parameters discussed above, initial soil conditions, such as preconsolidation plays an important role in most of soil deformation problems. This can be modern phenomena taken into account in the initial stress generation. Thr primary load which creates the both elastic (recoverable by unloading) and plastic (irrecoverable by unloading) deformations has been explained in this model which uses the important unloading-reloading modulus and also the compression modulus. The given relationship is hyperbolic between the vertical strain, ε_1, and the deviatoric stress.

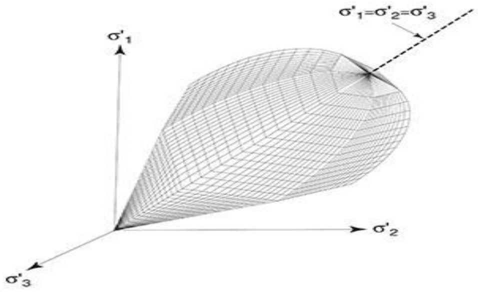


Fig 2: Hardening Soil Model Having Extra Cap

D. Features of HS model

The Hardening Soil model, also called as HS-Standard was explained by (Addenbrooke et al.), (Schanz et al in 1999) & (Rafał F. Obrzud) in order to modify the important phenomena which is exhibited by soils such as:

1. Densification, defines as decrease of the voids volume in soil due to plastic deformations, which also decreases the void ratio,
2. Stress dependent stiffness, is basically an observed technique of increasing the stiffness modules with the increasing of confining stress,
3. Soil stress history, explains the accounting for preconsolidation process and its effects,
4. Plastic yielding, is very important which accounts for the development of irreversible strains with reaching a yield criteria,
5. Dilatancy, explains as the uses for an occurrence of negative volumetric strains during shearing.

(Truty A. in 2008) explained about this model which known to be one of the simplest and important in the class of latest models designed to handle the small strain stiffness. It has two plastic mechanisms, shear and volumetric. Different to the other material models such as the Cap model or the Modified Cam Clay model, the magnitude of soil deformations, stresses, forces, etc. can be modelled more accurately by using three different input stiffness parameters which is related to triaxial loading stiffness (E50), triaxial unloading-reloading stiffness (Eur), and oedometer loading modulus (Eoed).

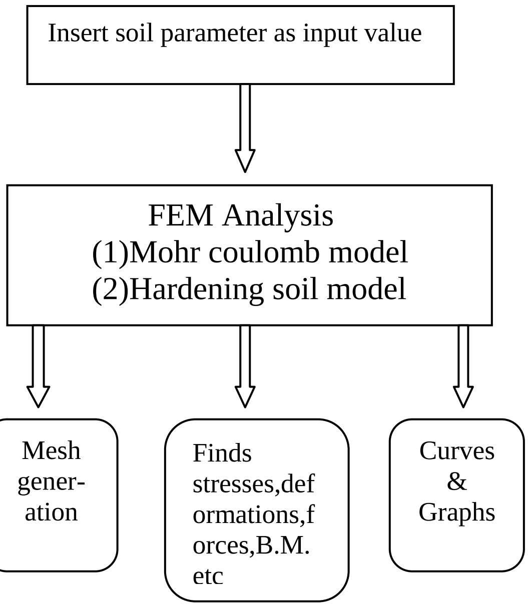
There are five parameters in the hardening soil model differ than the MC model is:

1. ($E50_{ref}$) secant modulus 50% strength[kN/m^2]
2. ($Eoed_{ref}$) Oedometric modulus [kN/m^2]
3. (Eur_{ref}) Unloading-reloading modulu[kN/m^2]
4. (ν_{ur}) Unloading-reloading Poisson's ratio [-]
5. (m) Exponent of the stress-stiffness function

Parameters previously used in MC model:

1. (Φ) Friction angle [°]
2. (c) Cohesion [kN/m^2]
3. (Ψ) Dilatancy angle [°]

III.METHODOLOGY ADOPTED



IV. MODELLING BY MOHR-COULOMB MODEL

Table 1. Soil Parameters and Interface Properties

Parameter	Name	Fill	Sand	Loam	Unit
Material model	*Model*	MC	MC	MC	-
Type of material behaviour	*Type*	Drained	Drained	Drained	-
Soil unit weight above p.l.	$\gamma unsat$	16	17	17	kN/m^3
Soil unit weight below p.l.	γsat	20	20	19	kN/m^3
Horizontal permeability	k_x	1.0	0.5	0.1	m/day
Vertical permeability	k_y	1.0	0.5	0.1	m/day
Friction angle	*Φ*	30	34	29	°
Dilatancy angle	*Ψ*	0.0	4.0	0.0	°
Cohesion strength	c_{ref}	1.0	1.0	8.0	
Interface reduction factor	*Rinter*	0.65	0.70	Rigid	-
Void ratio	v_{nu}	0.350	0.300	0.330	
Young's modulus	E_{ref}	500.000	3.000E+04	2.000E+04	kN/m^2

Put the soil parameters in the Mohr coulomb model of Plaxis. The dimension of excavation is 80 m wide and 20 m deep. 15 m long, concrete diaphragm walls or retaining walls of 0.35 m thickness are used to retain the adjacent soil. Two ground anchors are used at each wall to support the walls at different locations. The upper anchor has a length of 14.5 m and inclined at 33.7°. The lower anchor has a length of 10 m and is inclined at 45°. In the given modelling, a surface load of 10 kN/m^2 is applied on the left side and on the right side a surface load of 5 kN/m^2 is applied.

A. Output

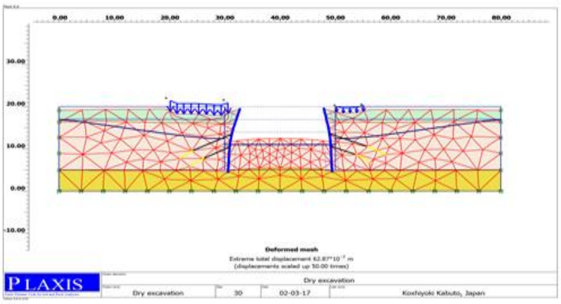


Fig 3: Deformed mesh final stage.

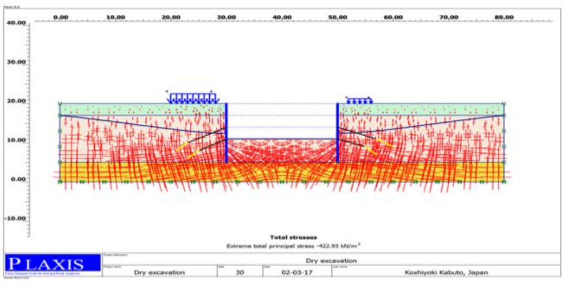


Fig 4: Total stress

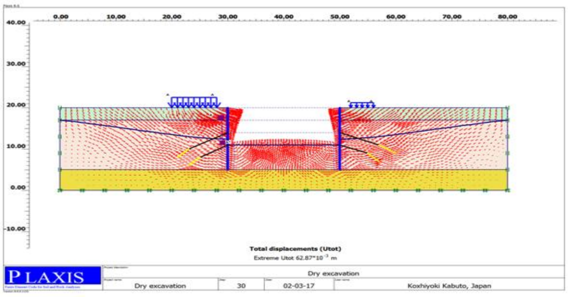


Fig 5: Total displacement

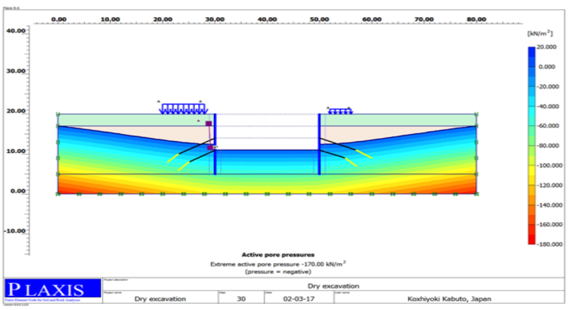


Fig 6: Active Pore Pressure

V. MODELLING BY HARDENING SOIL MODEL

Table 2. Soil Paramters And Its Properties

Parameter	Name	Fill	Sand	Loam	Unit
Material model	*Model*	HS	HS	HS	-
Type of material behaviour	*Type*	Drained	Drained	Drained	-
Soil unit weight above p.l.	$\gamma unsat$	16	17	17	kN/m^3
Soil unit weight below p.l.	γsat	20	20	19	kN/m^3
Horizontal permeability	k_x	1.0	0.5	0.1	m/day
Vertical permeability	k_y	1.0	0.5	0.1	m/day
Secant stiffness for CD triax.	E_{50}^{ref}	22000	43000	20000	kN/m^2
Tangent oedometer stiffness	E_{oed}^{ref}	22000	43000	20000	kN/m^2
Unloading/reloading stiffness	E_{ur}^{ref}	66000	129000	60000	kN/m^2
Power for stress depend. stiffn.	m	0.5	0.5	0.6	-
Reference stress	$pref$	100	100	100	kN/m^2
Poisson's ratio	vur	0.20	0.20	0.20	-
Lateral stress coefficient	K_0^{NC}	0.5	0.44	0.52	-
Cohesion	$cref$	1.0	1.0	8.0	kN/m^2
Friction angle	ϕ	30	34	29	°
Dilatancy angle	ψ	0.0	4.0	0.0	°
Interface reduction factor	*Rinter*	0.65	0.70	Rigid	-

In previous example the model of Mohr-Coulomb was used to analyze the soil behavior although the Mohr-Coulomb technique uses the particular form of soil behaviour such as the difference in stiffness parameters between virgin-loading and unloading-reloading. (Obrzud R.F et al.) discussed that such problems are easly solved in more advanced model like Hardening Soil model. In the modelling of the excavation, the soil which is at the bottom part of the excavation is exactly allowed for unloading and it shows a relatively stiff behaviour. The soil next to the wall is mainly subject to shear stresses and comparatively shows a less stiff behaviour. Though this soil behavior could be obtained by the formation of different clusters, nodes, stress points and different soil parameters below and next to the excavation pit. It is easier and more reliable to use Hardening Soil model. Therefore, the same topic has now been modified so that all soil layers are modelled using the Hardening Soil model instead of Mohr-Coulomb model.

A. Output

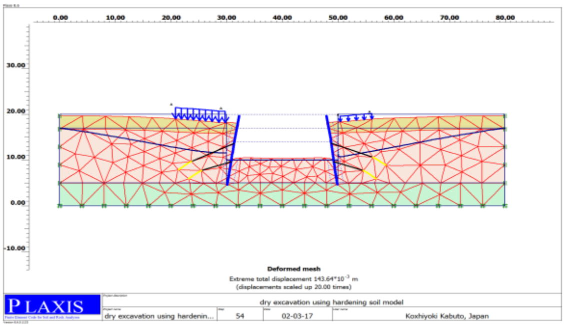


Fig 7: Deformed mesh final stage

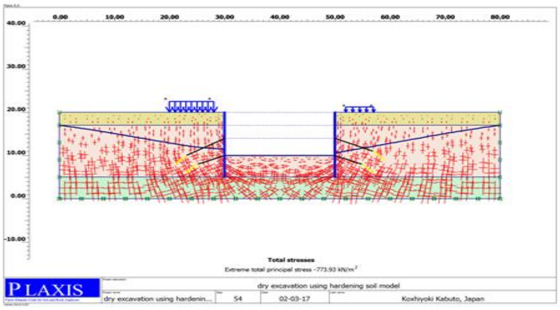


Fig 8: Total stress

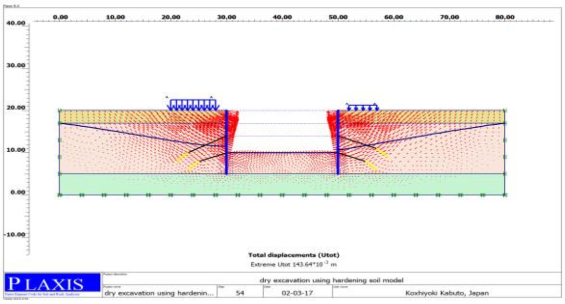


Fig 9: Total displacement

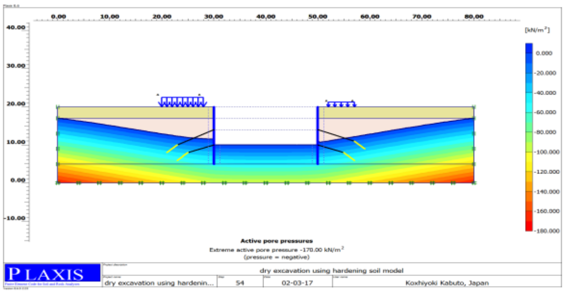


Fig 10: Active pore pressure

VI. RESULTS AND DISCUSSION

We can see that there are lots of differences in both models. In Mohr Coulomb model, deformed mesh or extreme displacement is 62.87×10^{-3}m which is shown in fig.3. and in Hardening Soil model, deformed mesh displacement is 143.64×10^{-3} m which shown in fig.7. So we conclude that mesh deformation or extreme displacement is less in Hardening Soil model, which is due to more stiff behaviour of HS model. Similarly, total stress is -422.93 kN/m^2 shown in fig.4 and -773.93 kN/m^2 shown in fig.8 in Mohr Coulomb And Hardening Soil Model respectively. Negative sign shows the direction. We obtained more stress value in the HS model than MC model. Active pore pressure is same in both models -170.00 kN/m^2(- sign shows the direction) shown in fig. 6 & 10 separately. We also finds some more results as Bending moment is 118.66 kNm/m and 124.36 kNm/m in MC model and HS model respectively. Axial forces obtained in HS and MC models are -310.75 kN/m and -403.44 kN/m respectively(-ive sign shows the direction). All these values are plotted on graphs which shows the more real comparison between both of the models.

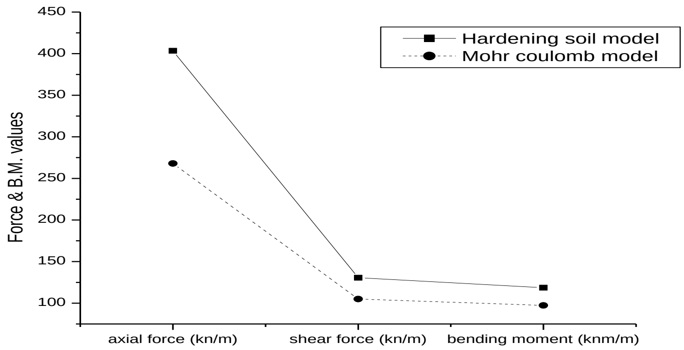


Fig 11: S.F, B.M, & Axial Force Comparasion Between Both Models.

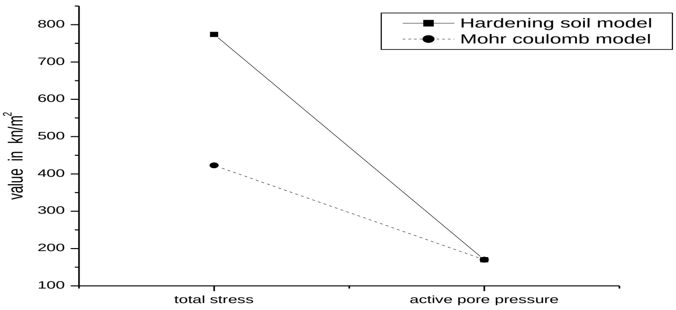


Fig 12: Total Stress & Active Pore Pressure Comparasion Between Both Models.

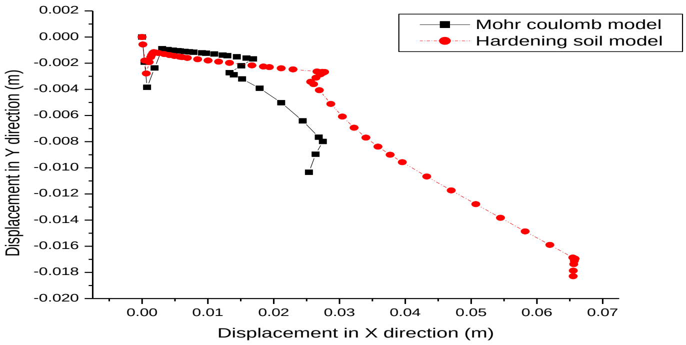


Fig 13: Displacement in X & Y Direction.

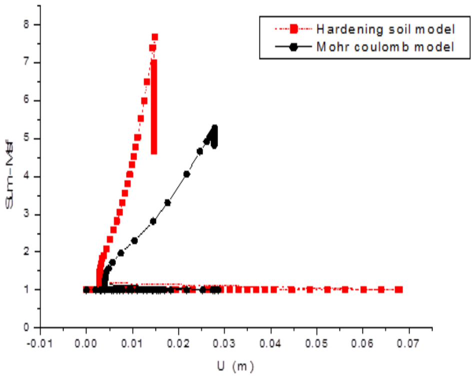


Fig 14: Graph Of Factor of Safety (Sum – Msf V/S Distance)

VII. CONCLUSION

The complete comparison between the results from the Mohr-Coulomb and the Hardening Soil methods, produces some important differences:

1. In the mesh formation the bottom part of the excavation rises less in the HS model than in the MC model, the reason behind this is unloading factor of the HS model which explains the difference clearly. The behavior of HS model is much stiffer in unloading than MC model shows, the reason that the MC model has only a single stiffness parameter which minimize its deformation.
2. The inward movement of both the sides (left & right) retaining walls are less on the HS model than in the MC model, reason behind this is the difference of unloading behavior of both models.
3. The settlement surface arises more in the HS model than in the MC model. This is due to the reason of difference in the vertical movement of the walls for both cases. For MC model the bottom part of the excavation rises more due to the softer or weaker unloading behaviour and which is the reason to push up the walls, so that it influences the settlement trough. While in HS model the bottom rises less in the excavation due to stiffness and its loading-reloading behaivour.
4. The structural forces as axial and shear forces in the walls are higher in the HS case than in the MC case. Similarly the stress value is more in the HS model than MC model. And the factor of safety value in HS model is also more than MC model.

Practical cases have proven that for different types of excavations, where the unloading behaviour of the soil is very important, the Hardening Soil (HS) model gives more realistic and accurate results than the Mohr-Coulomb (MC) model.

REFERENCES

[1] Effects of rarely analyzed soil parameters for FEM analysis of embedded retaining structures - V. Józsa1
[2] Plaxis V.9 Material Models Manual, 2010
[3] Addenbrooke, T., Potts, D., and Puzrin, A. The influence of pre-failure soil stiffness.
[4] The numerical analysis of the tunnel construction. Géotechnique, 47(3):693–712, 1997.
[5] Obrzud R.F, The Hardening Soil model – a practical guidebook. Technical report
[6] "The Changing Model of Soil" Revisited - Daniel deB. Richter
[7] R. Szepesházi, Modern Soil models (web note) p.4-6
[8] Displacement-Based Design for Deep Excavations W. Allen Marr and Martin Hawkes
[9] Z. Czap, G. Varga, Cuttings and fillings, Methods of the FE analysis, MTM (2003/5. okt.)
[10] Schanz, T., Vermeer, P., and Bonier, P. (1999). Formulation and verification of the Hardening Soil model. In Beyond 2000 in Computational Geotechnics. Balkema, Rotterdam, 1999.
[11] Truty A. Hardening soil model with small strain stiffness. Technical Report 080901, Zace Services Ltd., Lausanne, 2008.
[12] Schweiger H.F. Benchmarking in geotechnics. part i: Results of benchmarking. part ii: Ref-erence solution and parametric study.
[13] Brinkgreve R.B.J., Vermeer P.A. On the use of Cam-Clay models. Proc. 4th Int Symp on Num Mod in Geomech – NUMOG IV, Swansea, UK, 24-27 August, 1992.
[14] On the use of the Hardening Soil Small Strain model in geotechnical practice - Rafał F. Obrzud
[15] Mohr–Coulomb Failure Criterion -Joseph F. Labuz and Arno Zang
[16] The Analysis of Geotechnical Properties of Soils improved by Different Nanomaterials (SSRG-IJCE) – volume 4 Issue 2 – February 2017, Dr. Zaid Hmaeed Majeed, Mrs Zahraa Jabbar Hussein.