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A Comparative Study of Two Soil Models of Tower Settlement under Eccentric Loading Nearby Slope

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ABSTRACT

Evaluation of settlement of structures constructed on flat ground is an important criterion, that importance increased when these structures available near slope which increase the settlement at certain distance over than its value on flat ground. This study evaluated maximum settlement of Communication Tower foundation using finite element method, this foundation presented near sand slope with constant height and angle, and subjected to eccentric load with constant ratio of eccentricity to foundation width (e/B) equal (0.15), the eccentricity of loading caused by moment, two constitutive models adopted in the study for (Loose, Medium and Dense) sand, the study examined effect of embedment depth, relative density of sand and constitutive model on the relation between maximum settlement and ratio of distance from crest of slope to foundation width (b/B). The results showed which of the two models is more appropriate to represent the problem of study, and showed that at the distance equal and more than half of width of foundation (b/B≥0.5), the effect of the slope on the values of the maximum settlement of foundation begin to disappear, loose sand has the greatest values of maximum settlement, medium and dense sand have a convergence results from each to other. In addition, the results showed the effect of embedment depth in reducing the maximum settlement rate by an approximate range of (32.6 – 42.6) %.

1. Introduction

Many of structures especially the high ones are subjected to eccentric load. These structures available on flat ground or near slope. When they located near a slope, there are more attention must be taken about the settlement of foundation of these structures.

Communication Tower is one of these structures which is characterized by its light weight, foundation of this tower subjected to an overturning moment resulting from wind load, which is calculated according to the basic wind speed in the construction area and according to specialized codes.

Most of studies dealt with a shallow foundation under eccentric or/and inclined loads on flat ground [1,2].

There are also many studies on a shallow foundation near a slope, part of which exhibits concentric loads [3-7] and the other part exhibits eccentric or/and inclined loads [8-11].

There are studies dealt with shallow foundation near reinforced slope and subjected to eccentric loads [12,13].

The aforementioned studies, part of them are experimental work [1,10-13], part numerical [2-6], and the other part is experimental and numerical [7-9].

Numerical studies used finite element method with constitutive models to represent the soil and its behavior in programs such as Plaxis.

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These models include the Hardening Soil Model [7,8] and Mohr-Coulomb Model [2-6,9].

[2] examined models of square foundation subjected to eccentric inclined loading in sandy (loose, medium, and dense) soil, parameters in the study are (depth to width ratio (D_f/B), eccentricity to width ratio (e/B), angle of inclined load to vertical, relative density), the results of this study were presented in curves between settlement and pressure, horizontal displacement and pressure, tilt and pressure. When the inclination and eccentricity of load were increased the ultimate bearing, capacity decreased and settlement increased, also the horizontal displacement increased too. Correlation of tilt of foundation and its settlement depend on: soil density, load inclination and eccentricity of it, while it was un-depended on: width of foundation, embedment to width ratio (D_f/B) and factor of safety.

[9] studied numerically and experimentally strip footing in sand (unreinforced and reinforced by geogrid) slope subjected to eccentric load, parameters of study are:(eccentricity to width ratio, numbers of geogrid layers and depth of layers), the distance between foundation and crest of sand slope was constant, they found that the eccentricity in slope side has a great effect on behavior of strip footing.

[11] studied square foundation subjected to eccentric loading in (loose, medium and dense) sand slope, the study examined the settlement of the foundation depend on parameters: relative density, the effect of eccentricity with level of applied load, distance between foundation and crest of slope. They found that the bearing of soil increased and the settlement was decreased, with increasing relative density of soil, also settlement of square surface foundation depends on applied load level and its eccentricity.

Studies that dealt with a shallow foundation on flat ground or near slope and subjected to eccentric loads were based on the fact that the nature of eccentricity caused from a vertical or inclined load acting on a distance from the center of gravity of the foundation, few studies focusing on moment as a reason for the eccentricity.

From here the aim of this study came to investigate the effect of the overturning moment resulting from the wind load on the foundation of the communication tower, taking into account the exposure area of the tower that subjected to the wind load, according to certain codes.

The study examined the relation between maximum settlement under the communication tower foundation and the distance from the crest of slope, according to the variables of relative density of sand soil and embedment depth of the foundation, models of study simulated in Plaxis 3D V20 with two models; Hardening Soil Model and Mohr Coulomb Model, and examined the effect of each of these models on the other parameters of the study.

2. Methodology

Present study was taken mat foundation of self - supporting communication tower with 4 - legs and 50-meter height, dimensions of that foundation was (8*8*1) m and constructed near sandy slope with height of slope (H) equal (10) m and slope angle (β) equal (30 ˚) using finite element method in Plaxis 3D v20. The variables are (constitutive models, soil density (loose, medium, dense), embedment depth of foundation to its width ratio (D_f/B), distance between foundation and crest of slope (b/B)) and constant value of eccentricity (e) equal (0.15) from foundation width (e < B/6).

Properties of Sand soil which taken as (loose, medium and dense) soil obtained from average of typical values [14]. The study examined these parameters on maximum settlement of tower foundation. Eccentricity in loading caused by moment which caused by wind load (F), that moment effecting on tower foundation is calculated from the design wind load which effect horizontally on each section of tower. Wind load calculated at the value of basic wind speed equal (44 m/sec) by Equation 1 from (communication standards)[15]:

$$F = qz * GH * CF * AE \ (F \text{ in N}) \tag{1}$$

where:

F = horizontal wind load
qz = Velocity pressure
GH = Gust response factors
CF = Structure force coefficient

AE = Effective exposure area of structural component section.

Wind direction taken in slope direction and effect perpendicular on exposure face of tower, and neglected the appurtenances (antennas, mounts, lines, etc.) of tower in the calculation.

Here, the weight of the mat foundation with the four anchor columns, in addition to the weight of the tower; will all resist the overturning moment, according to Equation 2 from [16]:

$$e = \frac{M}{V+W_f} \quad (2)$$

where:

e = eccentricity

M = overturning moment (represented overturning moment resulting from wind load)

V = Vertical load (represented tower weight and its anchor columns)

W_f = weight of mat foundation

Figure 1 explained the sketch of tower and slope:

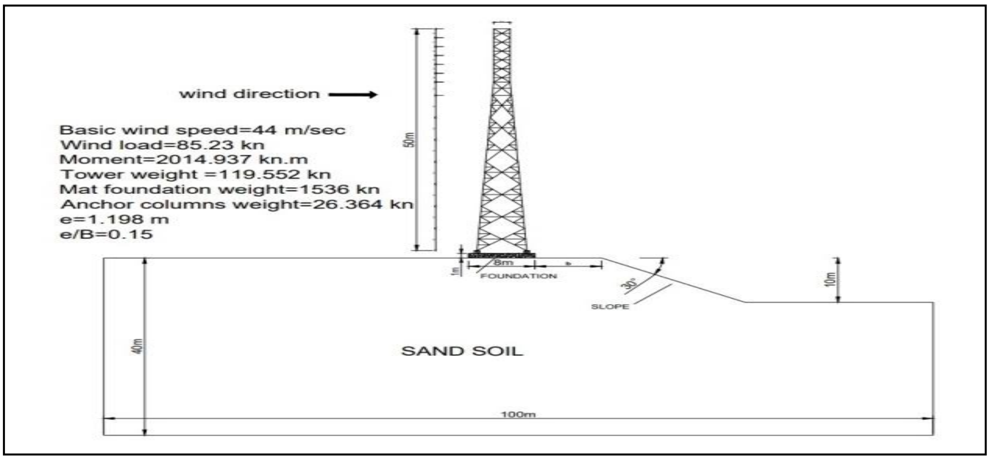


Figure 1. Sketch of tower and slope

2.1 Finite element analysis

The geometry of models was (100, 80, 40) m in dimensions as (x, y and z) axes respectively, standard fixity was adopted for all models. Elements of soil and concrete in Plaxis 3D presented by tetrahedral elements with 10 nodes, each element has three degrees of freedom at each node from its nodes; (Ux, Uy and Uz), also interface element used in the contact area between soil and foundation. Eccentric load presented as an increment surface load applied on the top of foundation. Automatic medium meshing was chosen after construction of models.

Figure 2 & Figure 3 show section of connectivity plot of geometry and fixities of model, respectively:

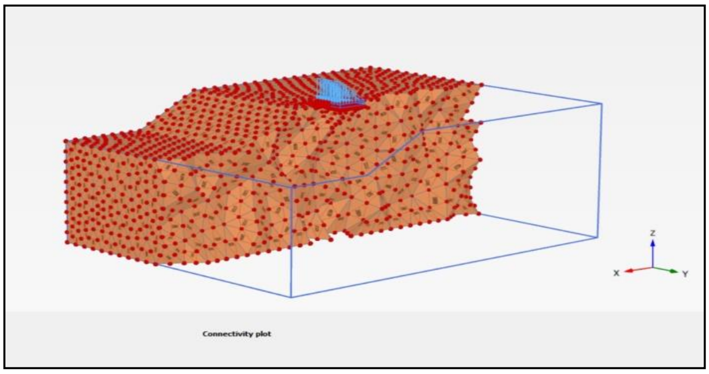


Figure 2. Section of connectivity plot of geometry

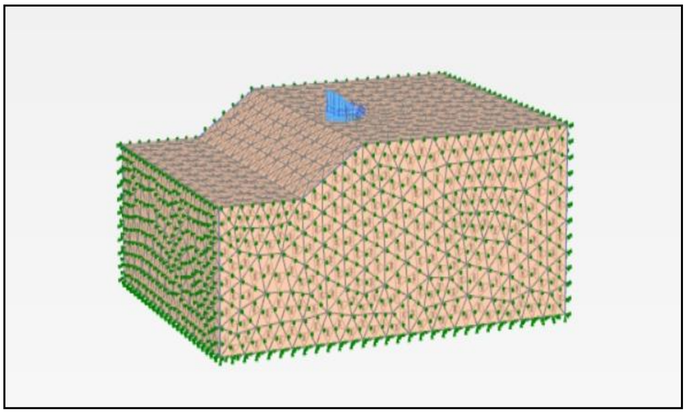


Figure 3. Fixities of model

2.2 Material models and verification

Mohr Coulomb Model (MCM) is the common model used in problems and it gives acceptable results. There are cases where it is necessary to use an advanced model; Hardening Soil Model (HSM) is one of these advanced models, it is used to represent the nature of the soil and its nonlinear behavior represented by the strain and resulting from applied stresses.

Figure 4 explained the ccomparison between real response of soil with the two constitutive models [17]:

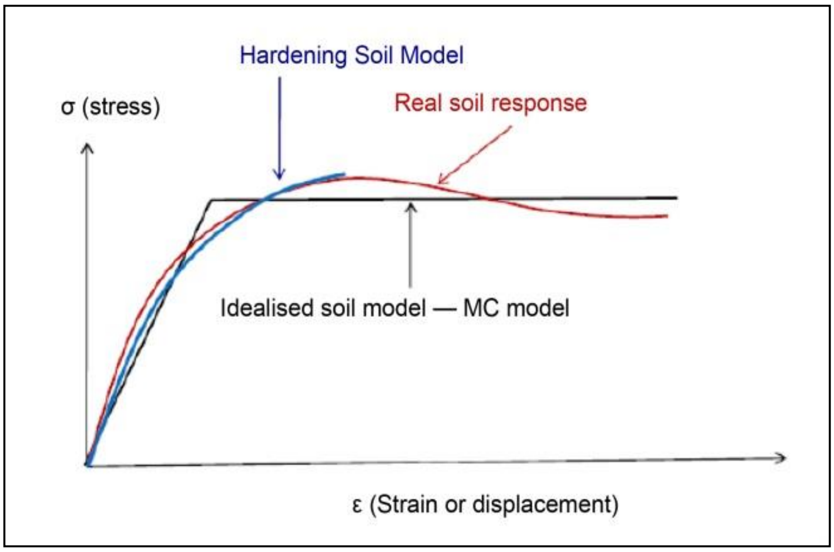


Figure 4. Comparison between HSM, MCM and real soil response [17]

Both of constitutive models: Hardening Soil Model (HSM) and Mohr Coulomb Model (MCM) adopted to simulate the soil, while the model of foundation was linear elastic. The behavior of soil was drained and for foundation was non - porous.

These constitutive models of soil verified with experimental results of strip footing near sand slope which conducted by pervious study [12], which was about bearing capacity of a strip footing with width (75) mm constructed in various distances from crest of slope with angle (34 ˚), this verification taken the distance from crest of slope to width footing as (b/B) equal (4).

Table 1 & Table 2 illustrated the properties of soil and footing respectively, while Figure 5 explained the comparison of experimental result and numerical one.

Table 3 illustrated the properties of sand soil (Loose, Medium and Dense) and mat foundation in present study respectively.

Table1: Properties of soil [12]

Property	Unit	Sand Soil		
		Experiment	Numerical	
Constitutive Model	-	-	MC	HS
Material behavior	-	-	Drained	
Angle of internal friction (Φ')	°	36	36	
Dilatancy angle (Ψ)	°	-	6	
Cohesion (c')	kN/m^2	0	1	
Unsaturated unit weight (γ_{un})	kN/m^3	16.3	16.3	
Saturated unit weight (γ_{sat})	kN/m^3	-	19	
Young's modulus (E'$_{oed}$)	kN/m^2	-	4000	-
Poisson's ratio (V)	kN/m^2	-	0.15	-
Secant stiffness (E_{50}^{ref})	kN/m^2	-	-	4000
Tangent stiffness (E_{oed}^{ref})	kN/m^2	-	-	4000
Unloading/ reloading stiffness(E_{ur}^{ref})	kN/m^2	-	-	12000
Poisson's ratio (V_{ur})	-	-	-	0.25
Power (m)	-	-	-	0.5
Interface strength (R_{inter})	-	Rigid	Rigid	Rigid

Table 2: Numerical Properties of foundation [12]

Property	Unit	Values
Young's Modulus (E)	(kN/m^2)	150000000
Unit Weight (γ)	(kN/m^3)	78
Poisson's ratio (V)	(-)	0.30
Dimensions (L*B)	(m)	(0.075*0.45)
Thickness (D)	(m)	0.01

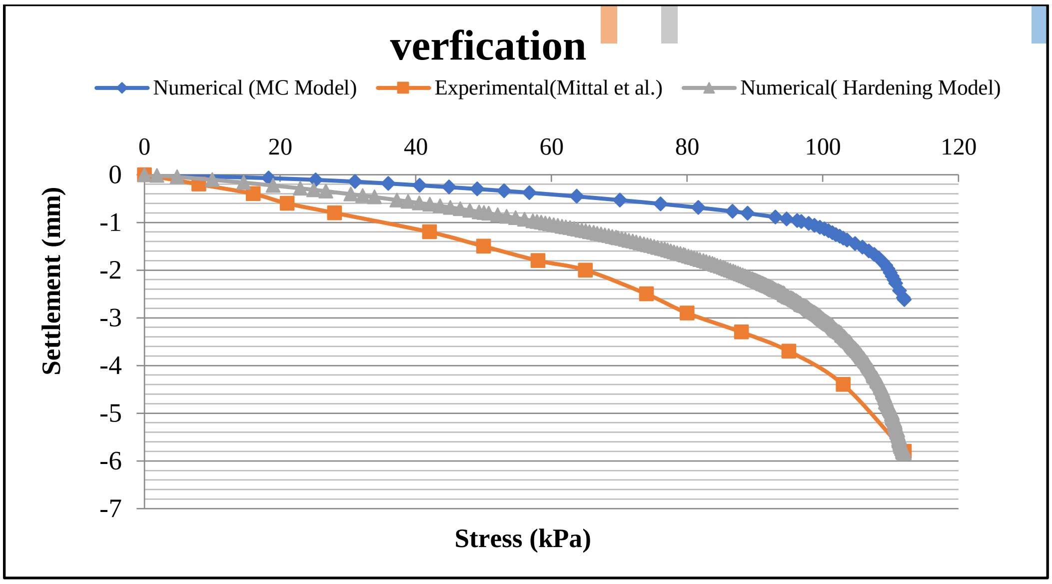


Figure 5. Comparison between experimental result and numerical models for footing on top of slope [12]

Table 3: Properties of soil and foundation of present study

Parameter	Unit	Soil						Mat Foundation
		Loose		Medium		Dense		
Constitutive Model	-	Mohr Coulomb	Hardening Soil	Mohr Coulomb	Hardening Soil	Mohr Coulomb	Hardening Soil	Linear elastic
Material behaviour	-	Drained	Drained	Drained	Drained	Drained	Drained	Non porous
Angle of internal friction (Φ')	°	32	32	35	35	38	38	-
Dilatancy angle (Ψ)	°	2	2	5	5	8	8	-
Cohesion (c')	kN/m^2	1	1	1	1	1	1	-
Unsaturated unit weight (γ)	kN/m^3	15	15	17	17	18	18	24
Young's modulus (E'_{oed})	kN/m^2	10000	-	30000	-	50000	-	23500000
Poisson's ratio (V)	-	0.3	-	0.33	-	0.35	-	0.15
Secant stiffness (E_{50}^{ref})	kN/m^2	-	10000	-	30000	-	50000	-
Tangent stiffness (E_{oed}^{ref})	kN/m^2	-	10000	-	30000	-	50000	-
Unloading/ reloading stiffness (E_{ur}^{ref})	kN/m^2	-	30000	-	90000	-	150000	-
Poisson's ratio (V_{ur})	-	-	0.2	-	0.2	-	0.2	
Power (m)	-	-	0.5	-	0.5	-	0.5	-
Interface strength (R_{inter})	-	0.8	0.8	0.8	0.8	0.8	0.8	-

2.3 Parametric study

Loading, ratio of eccentricity to width of foundation (e/B), dimensions of foundation, angle and height of slope, all these parameters were constant in models, the variable parameters were constitutive model, soil type, the ratio of distance from crest of slope to width of foundation (b/B) and the ratio of embedment of foundation to its width (D_f/B), these parameters presented in Table 4.

Table 4: Parameters of models in the study

β (˚)	e / B	Model	D_f/B	Sand	b / B
30˚	0.15	HSM	0	Loose	0
		MCM	0.125	Medium	0.5
				Dense	1
					1.5
					2

3. Results and discussion

From parametric study which includes (60) models constructed in Plaxis 3D as shown in pervious Table 4, the relation between maximum settlement and ratio of distance of foundation from Crest of slope (b/B) was examined in this study; also, the effect of (Constitutive Model, relative density of sand soil, embedment depth to foundation width ratio) on this relation was examined.

3.1 Effect of constitutive model

Figure 6 explained the effect of constitutive model on maximum settlement of foundation with critical value of (b/B) equal (0.5) where the effect of the slope on the values of the maximum settlement of foundation begin to disappear from crest of slope.

Hardening Soil Model has values of maximum settlement greater than results with Mohr Coulomb Model, that belong to stiffness consideration of hardening soil model, it has three parameters of stiffness (E_{50}^{ref}, E_{oed}^{ref}, E_{ur}^{ref}) while Mohr Coulomb Model depend on Young's modulus from odometer (E'_{oed}) only, also the results are agree with verification experimental results of pervious study [12] which examined here.

Nature of loading is increment surface load which consist of tension and compression in contact area between soil and Foundation showed a good agreement with Hardening Soil Model.

Verification showed that (HSM) had acceptable simulation for experimental results and that had a good agreement with previous study [18].

3.2 Effect of relative density of sand soil

From Figure 7 (a and b), it is shown that loose sand has the greatest values of maximum settlement, medium and dense sand have a convergence results from each to other, their results less than results of loose sand. It is noticed that the results of medium soil with (D_f/B=0.125) converge with the results of dense soil with (D_f/B=0).

The settlement of the foundation with the embedment depth ((D_f/B=0.125) in the medium sand is similar to the settlement of the same foundation, but it is placed on the surface of the dense sand, which indicates the similarity of the effect of embedment depth with the effect of increasing the relative density of sandy soil within the limits (medium to dense).

Increasing in the relative density of sand soil and angle of internal friction leads to increase strength of soil due to increase in the friction between the soil and foundation, which causes increasing in the stiffness of soil and reduces the settlement [7].

3.3 Effect of distance from crest of a slope

From results shown in Figure 7 & Figure 8 it is found that when the foundation located very close to crest of slope exactly at ratio (b/B) less than (0.5) the maximum settlement increased, because the soil under foundation tends to move towards slope side which has shear resistance less than the other side [7].

In addition, in this study increment of surface load was along slope direction which caused increasing in settlement.

Settlement decreased and effect of slope disappear when the foundation located away from crest of slope at distance equal or more than half of its width (b/B ≥ 0.5).

3.4 Effect of embedment depth

Figure 9 showed the effect of ratio of embedment depth to foundation width (D_f/B) on the maximum settlement of foundation with critical value of (b/B) equal (0.5) where the effect of the slope on the values of the maximum settlement of foundation begin to disappear from crest of slope.

Two cases taken of embedment ratio; first was surface foundation with (D_f/B) equal (0), Increasing in embedment depth of foundation caused decreasing in maximum settlement in all models of parametric study at range (32.6 -42.6) %, increase in embedment depth caused overburden pressure which caused increasing in stiffness of soil and thus decreased the settlement. Also, that caused increasing in bearing capacity when the applied loading reached to failure as mentioned in [2].

In sloping ground increasing the embedment depth leads to increase soil constraint to the foundation and thus reduce settlement [6].

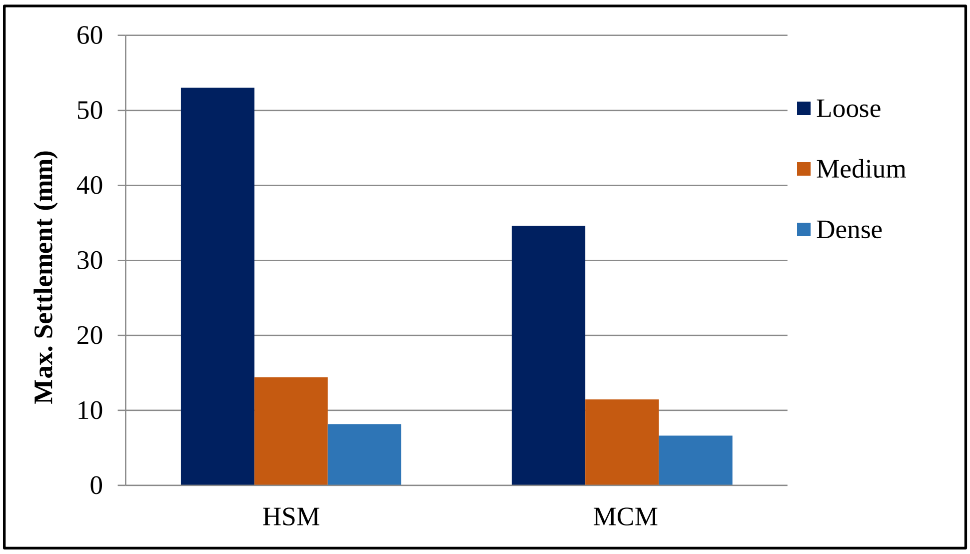
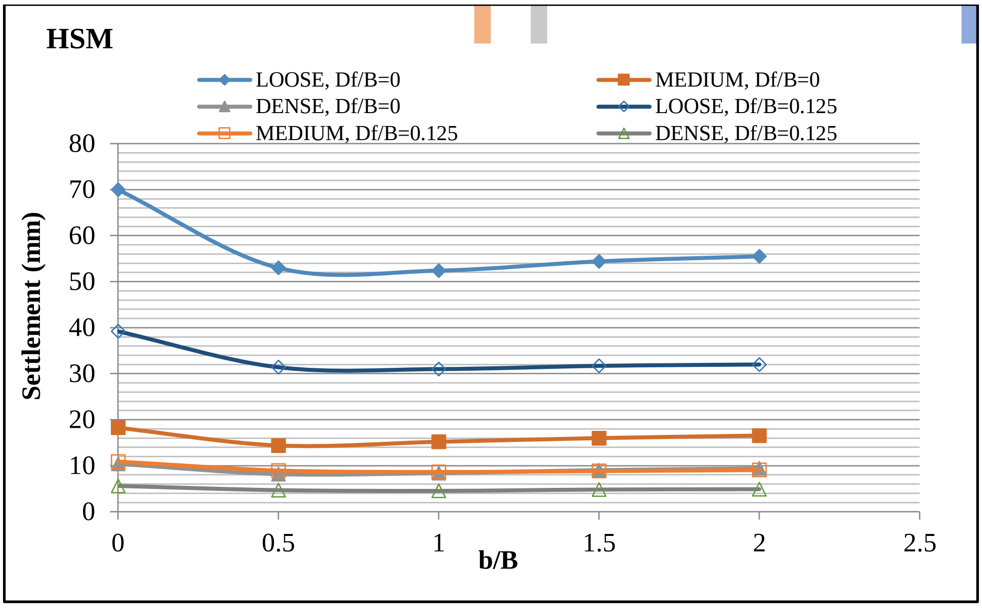
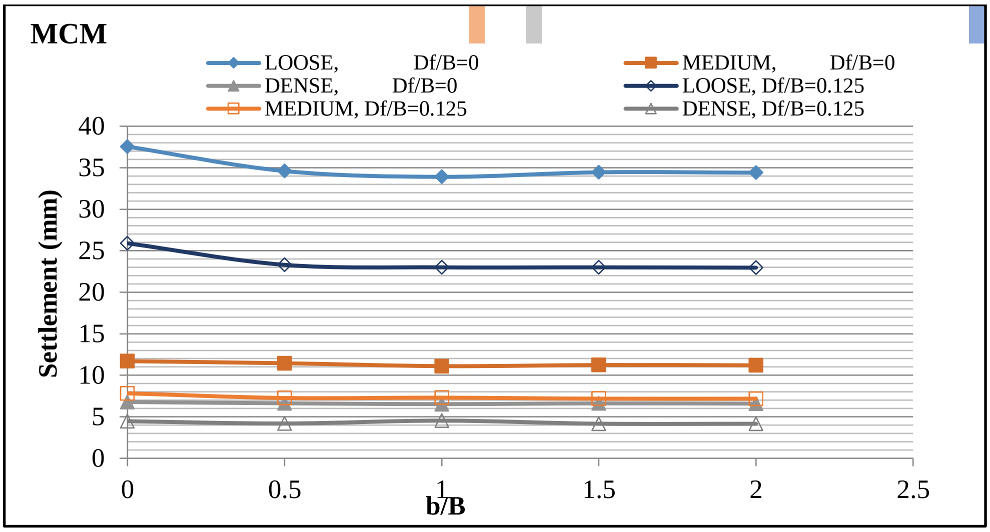


Figure 6. Effect of constitutive model on maximum settlement at (b/B=0.5) and (D_f/B = 0)

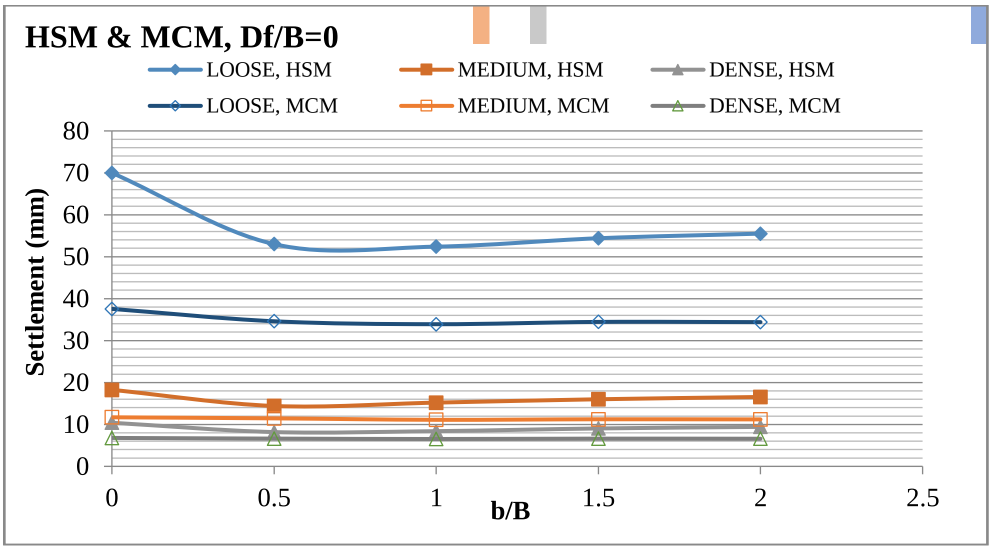


a. HSM

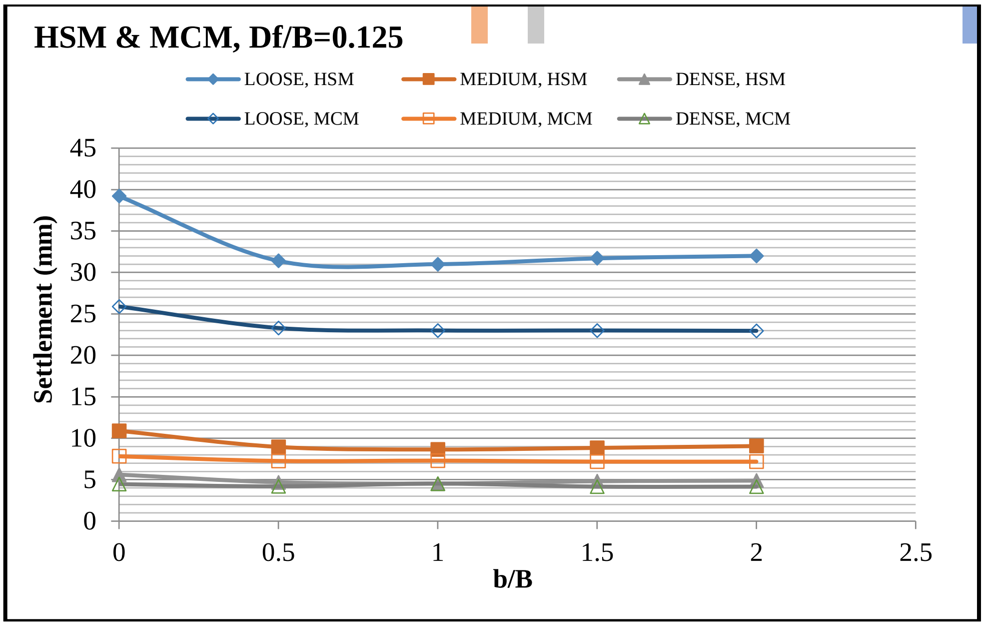


b. MCM

Figure 8. Maximum settlement in sand slope (30˚) with different (b/B) ratio at different relative density of soil



a. $D_f/B = 0$



b. $D_f/B = 0.125$

Figure 8. Maximum settlement in sand slope (30˚) with different (b/B) ratio at different relative density of soil

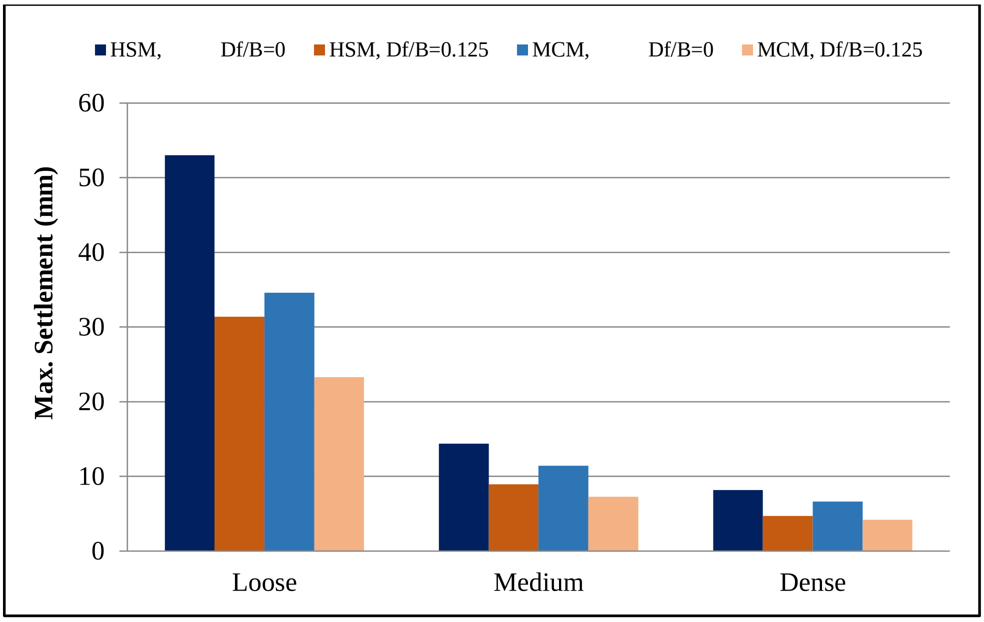


Figure 9. Effect of embedment depth to foundation width (D_f/B) on maximum settlement at (b/B=0.5)

4. Conclusions

The conclusions obtained from this study summarized as following:

1. Based on both of: verification of constitutive models with experimental results of pervious literature of foundation near slope and results of present study; Hardening Soil Model was the more acceptable model in case of problems with slope and eccentric loading.
2. Hardening Soil Model gave convergence results with Mohr Coulomb Model in case of medium and dense sand.
3. Maximum settlement of foundation near sand slope with constant angle and height depend significantly on (relative density of soil, embedment depth to foundation width ratio (D_f/B) and

distance from crest of slope to foundation width ratio (b/B)).

4. Loose sand has the greatest values of maximum settlement, medium and dense sand have a convergence results from each to other.
5. The acceptable distance of foundation from crest of slope is equal or more than half of foundation width, the effect of slope on settlement begins to disappear at this distance.
6. Increasing in ratio of embedment depth of foundation to its width (D_f/B) from (0) to (0.125) caused decreasing in maximum settlement at range (32.6 - 42.6) %.

References

[1] B. Sethy, C. Patra, R. Sahu, " Ultimate Bearing Capacity of Square Foundation on Homogeneous Sand under Eccentric Loading," Sixth IndianYoung Geotechnical Engineers Conference 6IYGEC2017, 10-11March 2017, NITTrichy, India: 2017. pp. 48-53.

[2] A. J. Zedan and H. J. Maulood, "Pressure-Settlement Characteristics of Shallow Foundations using Finite Element Method," Tikrit Journal of Engineering Sciences, vol. 24, no. 1, pp. 25-37, 2017.

[3] M. Qarmout, F. Ghrairi, A. Lavasan, D. König,T. Wichtmann, "Bearing Capacity of Embedded Strip Footing Placed Adjacent to Sandy Soil Slopes," in Modern Applications of Geotechnical Engineering and Construction: Springer, 2021, pp. 109-117.

[4] F. Jawad and M. Fattah, "Finite Element Analysis of the Bearing Capacity of Footings Nearby Slopes," International Review of Civil Engineering (I.RE.C.E.), vol. 10, n. 1, pp. 1-7, 2019.

[5] B. J. Abbas, H. Y. Aziz, B. H. Maula, R. T. Alkateeb, "Finite element analysis of spread footing near slops," in IOP Conference Series: Materials Science and Engineering, 2019, vol. 518, no. 2, p. 022055: IOP Publishing.

[6] R. Acharyya and A. Dey, "Square footings on unreinforced sandy slopes: numerical modelling using Plaxis 3D," Indian Geotechnical Society, Kolkata Chapter Geotechnics For Infrastructure Development, 11th – 12th March 2016,Kolkata, West Bengal, India, 2016.

[7] M. Salih Keskin and M. Laman, "Model studies of bearing capacity of strip footing on sand slope," KSCE Journal of Civil Engineering, vol. 17, no. 4, pp. 699-711, 2013.

[8] M. Alkahtani and M. H. El Naggar, "Bearing capacity of power transmission tower footings near cohesionless slopes," Innovative Infrastructure Solutions, vol. 6, no. 4, pp. 1-23, 2021.

[9] A. Abdi, K. Abbeche, R. Boufarh, B. Mazouz, "Experimental and Numerical Investigation of an Eccentrically Loaded Strip Footing on Reinforced Sand Slope," Electronic Journal of Structural Engineering, vol. 18, no. 2, pp. 7-15, 2018.

[10] B. Mazouz, K. Abbeche, A. Abdi, M. Baazouzi, "Model experiments to assess effect of eccentric loading on the ultimate bearing capacity of a strip footing near a dry sand slope," International Journal of Geotechnical Engineering, vol. 15, no. 10, pp. 1241-1251, 2021.

[11] T. Mansouri and K. Abbeche, "Experimental bearing capacity of eccentrically loaded foundation near a slope," Studia Geotechnica et Mechanica, vol. 41, no. 1, pp. 33-41, 2019.

[12] S. Mittal, M. Shah, N. Verma, "Experimental study of footings on reinforced earth slopes," International Journal of Geotechnical Engineering, vol. 3, no. 2, pp. 251-260, 2009.

[13] E. Turker, E. Sadoglu, E. Cure, B. A. Uzuner, "Bearing capacity of eccentrically loaded strip footings close to geotextile-reinforced sand slope," Canadian Geotechnical Journal, vol. 51, no. 8, pp. 884-895, 2014.

[14] J. E. Bowles, "Foundation analysis and design," 5th Ed., McGraw-Hill, New York, 1996.

[15] T. I. Association and A. N. S. Institute, "Structural standards for steel antenna towers and antenna supporting structures," Telecommunications Industry Association, 1996.

[16] T. M. Baban, "Shallow foundations: discussions and problem solving," John Wiley & Sons, 2016.

[17] R. Ehsan, "A Study of Geotechnical Constitutive Models Used in PLAXIS 2D," ICE G&S Papers Competition," ed, 2013.

[18] H. O. Abbase, "Evaluation of Sand Constitutive Models for Analysis of Piled Raft Foundation," Diyala Journal of Engineering Sciences, vol. 11, no. 1, pp. 28–32, 2018.