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Effect of groundwater and various parameters on bearing capacity of shallow Foundations using finite element method

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Abstract - ***Settlement calculation is an important part in the design of shallow foundations resting on granular soils. Rise of ground water level is believed to increase the settlement significantly and had been a topic of research for many years. Terzaghi (1943) suggested that the submergence of soil mass reduces the soil stiffness to half, which in turn doubles the settlement. Since then, various researchers proposed correction factors to account for the additional settlement due to water table fluctuation. In this paper was to evaluate the effect of water table rise on settlement of footing. Two-dimensional model of Coarse-grained soil and shallow foundation in soft PLAXIS software was created. The analysis has been done using Mohr-Coulomb constitutive model. Also the effect of soil elasto-plastic parameters include the effect of changes in modulus of elasticity, cohesion, internal friction angle and dilation angle of soil on the bearing capacity and settlement efficiency was calculated. The results obtained will be valuable in verifying Terzaghi's intuitive reasoning and explaining the observed additional settlement of footings found in the literature.***

Key Words: *shallow foundations, finite element method, ground water level, Settlement, bearing capacity.*

1. Introduction:

The variation of moisture content stored in the ground and earth structures under varying environmental conditions is an important aspect closely related to the mechanical behavior of partially saturated soils. Change in the degree of saturation can cause significant changes in volume, shear strength and hydraulic properties, consequently bearing capacity. Eventually the soil may get submerged and bearing capacity will get reduced.

The bearing capacity is the most important soil property, which governs the design of foundation. Bearing capacity and the settlement are the two important parameters in the field of geotechnical engineering. Civil engineering projects such as buildings, bridges, dams and roadways require detailed subsurface information as part of the design process. Bearing capacity is affected by various factors like change in level of water table, eccentric loads, inclined loads, dimensions of the footings, etc. Water table at the site remains at great depth so as to create unsaturated state of foundation soil. In unsaturated case the ultimate bearing capacity of shallow foundation is analytically estimated by using any of the available bearing capacity equations. However the water table eventually rises up and reaches the foundation level and the soil becomes submerged. In submerged case soil foundation system exhibits reduced bearing capacity. Bearing capacity of shallow foundation is often reduced during the spring thaw, partly because.

This aspect of effect of degree of saturation on reduction in the bearing capacity of shallow foundation is comparatively the most neglected aspect with respect to both analytical treatment and actual experimentation. Theoretically this aspect has been covered to a limited extent by only few investigators (Krishnamurthy, S. and Kameshwara Rao (1925), Ausilio and Conte (2005), De Simone and Zurlo (1987), Vanapalli et. al. 2013, Hansen et. al. 1987). Experimental investigations and observation on this aspect are still very limited (Murtaza et. Al .1995). Ernesto Ausilo and Enrico Conte(2005) studied Influence of groundwater on the bearing capacity of shallow foundation by using kinematic approach of limit analysis. S.Y.Oloo and D.G.Fredlund (1998) proposed a solution which quantify the reduction in bearing capacity arising from a static water table at any depth in any kind of soil. Booking and Fredlund (1980) concluded that for a degree of saturation above of 85% the air permeability was effectively zero.

Most of the rainfall-induced slope failures are shallow and occur at high degree of saturation (low matric suction). It has been recognized that an unsaturated soil behaves differently at wetting and drying. Therefore, studies of the effect of wetting and drying on the unsaturated residual behavior of soils under different net normal stresses are recommended. The method available for calculating ultimate bearing capacity of shallow foundation under submergence of soil is different from each other. Some empirical coefficients are given to multiply to third term of Terzaghi bearing capacity equation, while calculating the ultimate bearing capacity of submerged soil. As not much practical test data is available regarding the ultimate bearing capacity of shallow foundation with respect to submergence of soil. By keeping the concept of unsaturated soil mechanics nobody consider the degree of saturation while calculating ultimate bearing capacity of shallow foundation either in unsaturated condition or in submerged condition. The present work has been undertaken to know the same basic aspects in this respect. As a first attempt in evaluating the effect degree of saturation on reduction in ultimate bearing Capacity of shallow footing foundation (qu) the following soil-foundation system is considered.

2. Soil Water Characteristic Curve (SWCC)

Figure 1 shows the SWCC (drying curve) for the tested sand plotted as a relationship between the degrees of saturation, *S* and the matric suction, *(ua - uw)* using two different methods. The air-entry value for the sand was found to be between 2.5 kPa and 3 kPa.

In the first method, the SWCC is directly measured from the test box. In the second method, a Tempe Cell apparatus was used in the laboratory for measuring the SWCC. The procedures used in the determination of the SWCC are available in Mohamed FMO study in 2006.

Figure 1 shows that there is a good agreement between the SWCC's using both the methods. The objective of the determination of the SWCC was to understand its relationship with the bearing capacity of unsaturated soils and propose a simple method for its prediction.

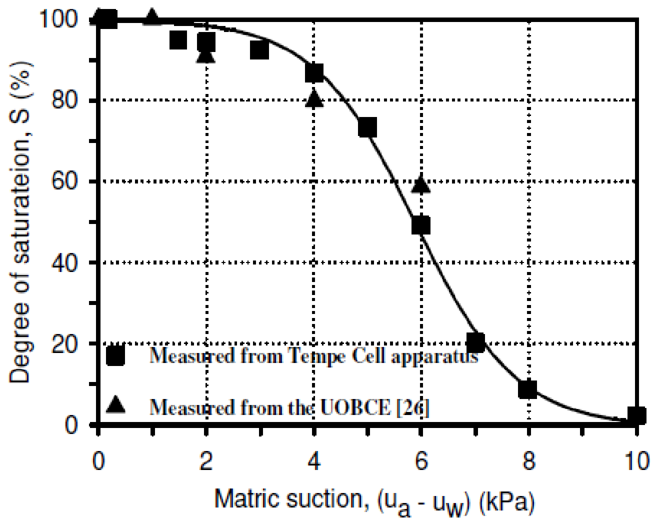

Fig. 1- Measured SWCC from the Tempe Cell apparatus and the test box of the UOBCE.

3-BEARING CAPACITY OF UNSATURATED SOILS

Terzaghi suggested Eq. (1) to estimate the ultimate bearing capacity, *qu* for strip footings (i.e., plain strain condition) in saturated soils assuming general shear failure conditions:

$$q_u = c' Nc + \gamma\, D_f\, Nq + 0.5\gamma\, B\, N\gamma \qquad (1)$$

where: q_u = ultimate bearing capacity (kN/m^2),
c' = effective cohesion(kPa),
γ = unit weight, (kN/m^3),
D_f=footing base level (m),
B = footing width, (m),
Nc ,Nq , $N\gamma$ = bearing capacity factors which are function of effective friction angle, Φ'.

Extending Eq. [1], a semi-empirical equation (i.e., Eq. (2)) was suggested by Vanapalli et al to predict the variation of bearing capacity with respect to matric suction for surface square footings (using shape factors suggested by Vesic in 1973) for unsaturated soils using the effective shear strength parameters (i.e., *c'* and Φ') and the SWCC as below:

$$\begin{aligned} q_u = {} & [c' + (u_a - u_w)_b (\tan\phi' - S^{\psi_{BC}} \tan\phi') \\ & + (u_a - u_w)_{AVR}\, S^{\psi} \tan\phi'] N_c\, \zeta_c + 0.5\gamma B\, N_\gamma\, \zeta_\gamma \end{aligned} \qquad (2)$$

where: $(u_a - u_w)b$ = air entry value from SWCC (kPa),
$(u_a - u_w)AVR$ = average matric suction (kPa),
Φ' = effective friction angle (º),
S = degree of saturation (%),
ψ_{BC} = bearing capacity fitting parameter,
ξ_c , ξ_γ = shape factors (from [27]).

There is a smooth transition between the bearing capacity equation proposed by Vanapalli et al in 2007 for unsaturated soils and the conventional Terzaghi's bearing capacity equation for saturated soils. In other words, the equation (i.e., Eq. (2) proposed by Vanapalli et al in 2007) will be the same as Terzaghi's bearing capacity equation when the matric suction value is set equal to zero.

The general form of Eq. (2) to estimate the bearing capacity of square footings in unsaturated soils is shown in Eq. (3). This equation takes into account of the influence of overburden stress and the shape factors as follows:

$$\begin{aligned} q_u = {} & [c' + (u_a - u_w)_b (\tan\phi' - S^{\psi_{BC}} \tan\phi') \\ & + (u_a - u_w)_{AVR}\, S^{\psi_{BC}} \tan\phi'] N_c\, \zeta_c\, F_c \\ & + \gamma D_f\, N_q\, \zeta_q\, F_q + 0.5\gamma B\, N_\gamma\, \zeta_\gamma\, F_\gamma \end{aligned} \qquad (3)$$

where: ξq = shape factor; Fc , Fq , $F\gamma$ = depth factors

The bearing capacity fitting parameter, ψ_{BC} along with the effective shear strength parameters (*c'* and Φ') and the SWCC are required for predicting the variation of bearing capacity with respect to matric suction assuming drained loading conditions. The bearing capacity fitting parameter,

ψ_{BC} can be estimated from relationship provided by researchers in Eq. (4) given below:

$$\psi_{BC} = 1.0 + 0.34(I_p) - 0.0031\,(I_p^{\,2}) \tag{4}$$

Several investigators provided bearing capacity factors for cohesion, *Nc*; surcharge, *Nq* and unit weight, *Ng* (Terzaghi, 1943; Meyerhof, 1951; Kumbhokjar, 1993). The values for bearing capacity factors of *Nc* and *Nq* provided by various investigators are approximately the same. For this reason, the bearing capacity factors, *Nc* and *Nq* originally proposed by Terzaghi were used in the analysis. The values *Ng* suggested by Kumbhokjar in 1993 have been widely used in recent years. For this reason, In this paper a numerical simulation carried out on Influence of groundwater on bearing capacity of shallow Foundations were investigated. Mohr–Coulomb failure criterion and drained behaviour was considered for all the materials. Material properties that have been adopted in this study are presented in table 1.

Table1- properties of soil

Φ (degree)	C (KN/m^2)	v	E (KN/m^2)	γ_{wet} (KN/m^3)	γ_{sat} (KN/m^3)	parameter
33	10	0.35	60 000	17	18.5	value

In the present study, finite element analyses of the shallow foundations resting on Granular beds are carried out using the program PLAXIS (version 8) which is a finite element software package. In the present investigation the footing is assumed as rigid; since only the stresses and deformations occurring in soil are studied. The selected elements were 15-node triangular finite elements under plane strain. The modeling based on underground water level of 0.5 meters above ground level has done. That in Figure 2 to 4, respectively deformed mesh; total displacement and effective stress is given.

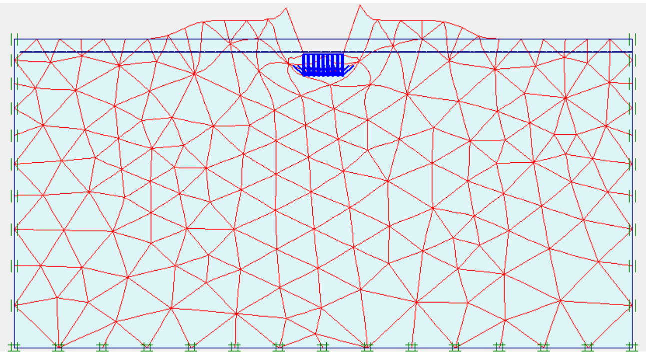

Fig. 2- deformed mesh of geometry of modeling

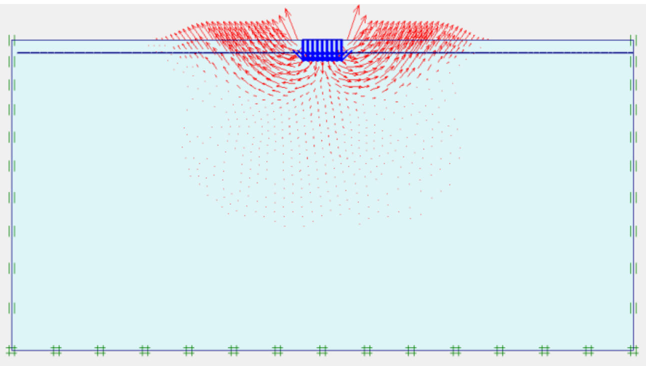

Fig. 3- total displacement of modeling

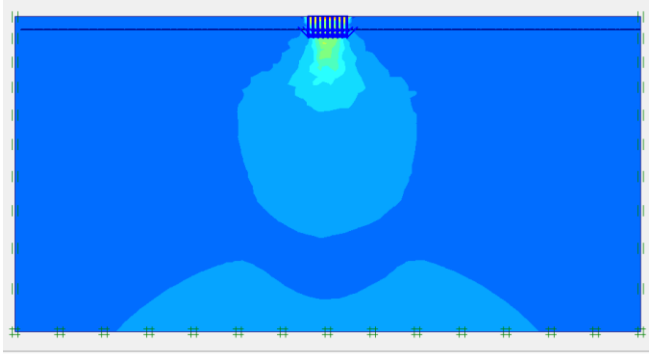

Fig. 4- effective stress of modeling

In this section examines the impact of various parameters including the level of groundwater and soil elastoplastic parameters on the load-settlement curves. Therefore, the load-settlement curve for different levels of water are given in Figure 5.

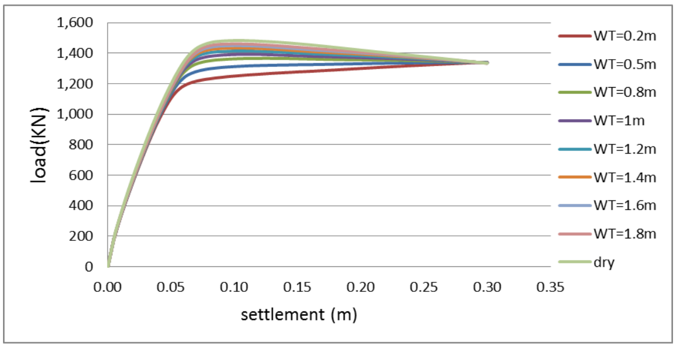

Fig 5- Effect of underground water level on bearing capacity

Then, to evaluate the effects of soil elasto-plastic parameters, the effect of changes in modulus of elasticity, cohesion, internal friction angle and dilation angle of soil in W_T = 0.5 m are shown in Figures 6 to 9.

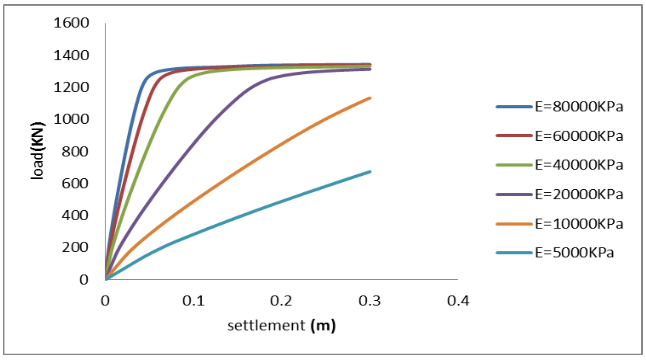

Fig 6- The effect of changes in the modulus of elasticity on bearing capacity

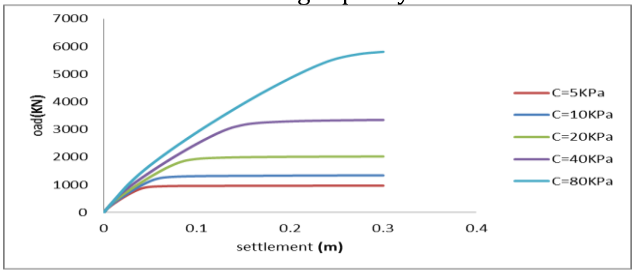

Fig 7- The effect of changes in the cohesion on bearing capacity

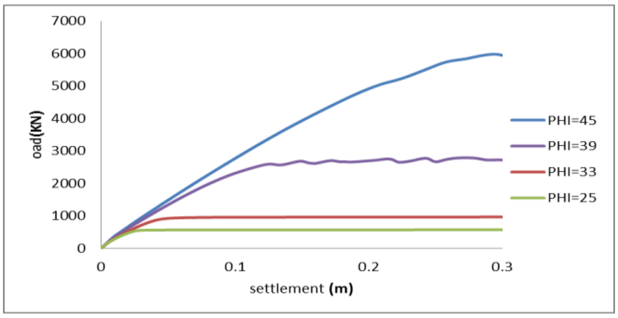

Fig 8- The effect of changes in the internal friction angle on bearing capacity

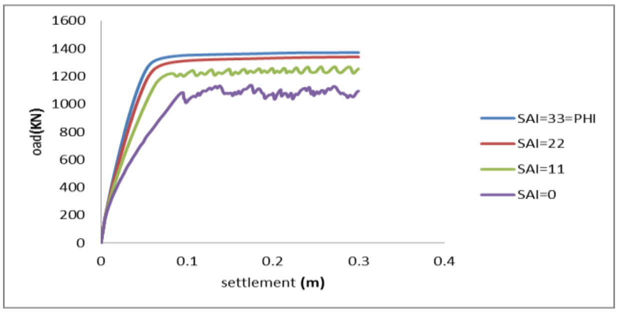

Fig 9- The effect of changes in the dilation angle on bearing capacity

4. CONCLUSIONS

Based on the studies carried out following conclusions are drawn:

1. With falling groundwater levels, the bearing capacity is reduced.
2. With falling groundwater level over 1 meter (2/3 B); the effect of water level on bearing capacity is reduced.
3. With increasing E, the slope of the curve increases.
4. for Modulus of elasticity more than 60000KPa, the effect of increasing the modulus on the gradient of the curve is reduced.
5. By reducing cohesion, the bearing capacity is reduced.
6. for cohesion less than 10KPa, the effect of these parameters on the bearing capacity is reduced.
7. With reduced internal friction angle of the soil, bearing capacity is reduced.
8. For amounts of soil internal friction angle less than 33°, the effect of these parameters on the bearing capacity is reduced.
9. By increasing the angle of dilation of the soil, bearing capacity increases.
10. for Soil dilation angle values more than 22°, the effect of the increase in this parameter to change the bearing capacity is reduced.

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