Analysis of Bearing Traits of Shallow Foundation

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Abstract

This chapter presents an overview on bearing capacity of shallow foundation. Bearing capacity of soil is the most important criteria for strength of a structure. It is of utmost importance to have sound strata of soil underneath a structure. Any settlement caused due to insufficient strength of soil can be harmful to any structure.This paper gives modes of failures of foundation soil, review of previous work of bearing capacity investigation and brief note on plate load test which is a field test to determine bearing capacity of soil.

Introduction

Bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. It is the power of foundation soil to hold the forces from the

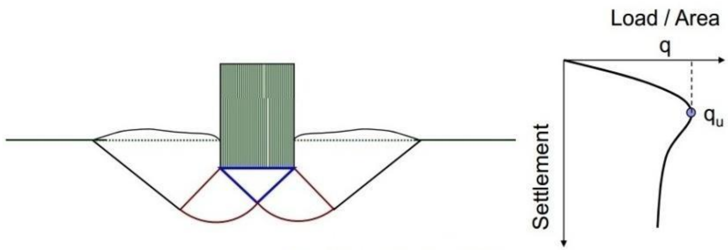

Fig 1 General shear failure

superstructure without undergoing excessive settlement or shear failure. Foundation soil is that portion of ground which is subjected to additional stresses when foundation and superstructure are constructed on the ground. The following are a few important terminologies related to bearing capacity of soil:

Ultimate Bearing Capacity (q_f)

It is defined as the minimum gross pressure intensity at the base of the foundation at which the soil fails in shear.

Net ultimate Bearing Capacity (q_n)

It is the maximum extra pressure (in addition to initial overburden pressure) that a foundation soil can withstand without undergoing shear failure.

$q_n = q_f - q_o$ ……………………… (Eq. 1)

Here, $q_o$represents the overburden pressure at foundation level and is equal to γD for level ground without surcharge where γ is the unit weight of soil and D is the depth to foundation bottom from Ground Level.

Safe Bearing Capacity (q_s)

It is the safe extra load the foundation soil is subjected to in addition to initial overburden pressure.

$q_s = q_n / F + q_o$ ……………........… (Eq. 2)

where F is factor of safety.

Allowable Bearing Pressure (q_a)

It is the maximum pressure the foundation soil is subjected to considering both shear failure and settlement.

Bearing Capacity Failures

Depending on the stiffness of foundation soil and depth of foundation, the following are the modes of shear failure experienced by the foundation soil:

A. General shear failure (Fig 1)
B. Local shear failure (Fig 2)
C. Punching shear failure (Fig 3).

General Shear Failure

This type of failure is seen in dense and stiff soil.

The following are some characteristics of general shear failure.

1. Continuous, well defined and distinct failure surface develops between the edge of footing and ground surface.
2. Dense or stiff soil that undergoes low compressibility experiences this failure.
3. Continuous bulging of shear mass adjacent to footing is visible.
4. Failure is accompanied by tilting of footing.

5. Failure is sudden and catastrophic with pronounced peak in force-settlement curve.
6. The length of disturbance beyond the edge of footing is large.
7. State of plastic equilibrium is reached initially at the footing edge and spreads gradually downwards and outwards.
8. General shear failure is accompanied by low strain (<5%) in a soil with large penetration number N (N > 30) having high relative density(I_D> 70%).

Local Shear Failure

This type of failure is seen in relatively loose and soft soil.

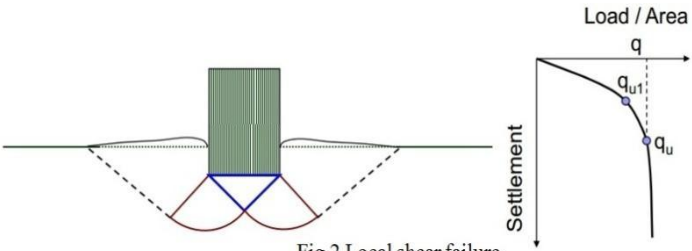

Fig 2 Local shear failure

The following are some characteristics of local shear failure.

1. A significant compression of soil below the footing and partial development of plastic equilibrium is observed.
2. Failure is not sudden and there is no tilting of footing.
3. Failure surface does not reach the ground surface and slight bulging of soil around the footing is observed.

4. Failure surface is not well defined.
5. Failure is characterized by considerable settlement.
6. Well defined peak is absent in load- settlement curve.
7. Local shear failure is accompanied by large strain (> 10 to 20%) in a soilwith low penetration number N (N < 5) having low relative density (I_D> 20%).

Punching Shear Failure

This type of failure is seen in loose and soft soil and at deeper elevations.

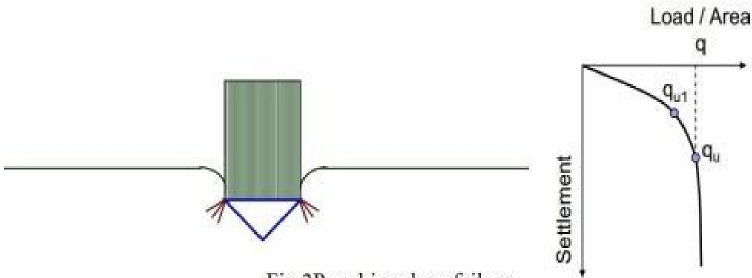

Fig 3Punching shear failure

The following are some characteristics of punching shear failure.

1. This type of failure occurs in a soil of very high compressibility.
2. Failure pattern is not observed.
3. Bulging of soil around the footing is absent.
4. Failure is characterized by very large settlement.
5. Continuous settlement with no increase in load value is observed in load- settlement curve.

Bearing Capacity of Shallow Foundation

Determination of bearing capacity of soil has undergone through a long process from old times through analytical and experimental studies by a number of research works. A brief review of significant bearing capacity investigations and contribution of different investigators have been presented briefly in Table 1. Terzaghi's method has been used widely. Meyerhof's values (used principally in England) tend to swing widely between conservative and non conservative.Meyerhof's theory does not provide reliable agreement with the full scale footing tests because he developed his theory using very small model footings. Hansen's equations show a good agreement with measured values for both cohesive and cohesionless soil. Hansen's method does not provide both static and kinetic equilibrium. IS: 6403- 1981 recommends that for the computation of ultimate bearing capacity of a shallow foundation in general shear failure, followingequations may be used:

$$q_f = c\, N_c s_c\, d_c i_c + q\,(N_q - 1)\, s_q d_q i_q + 0.5\, B\, \gamma\, N_\gamma\, s_\gamma\, d_\gamma i_\gamma\, W' \quad \text{.......................... (Eq. 3)}$$

where q_f is the ultimate bearing capacity. Nc, Nq and Ny are bearing capacity factors, recommended by Vesic (1973) in terms of Eq. 4,5 and 6

$$N_c = (N_q - 1) \cot \varphi \quad \text{............ (Eq. 4)}$$

$$N_q = e^{\pi \tan\varphi} \tan^2 (45° + \varphi/2) \quad \text{............ (Eq. 5)}$$

$$N_\gamma = 2\,(N_q + 1) \tan \varphi \quad \text{............ (Eq. 6)}$$

Where s, d and *i*are shape, depth and inclination factors given by IS code. Also c is cohesion, q is effective surcharge, B is width of footing and W' is correction factor for location of water table.

For local shear failure the shear strength parameters C_m and φ_m should be used in bearing capacity equations instead of C and φ.

$C_m = 2/3\ C$ .... (Eq. 7)

$\tan\varphi_m = 2/3 \tan \varphi$ .... (Eq. 8)

Table 1

Brief Review of Bearing Capacity Investigations

S No	Name of the author	Significant contribution
1	Shilpa Prakash (An orissan treatise on architecture)	Depth of foundation of a temple or an important building should be equal to one third of its height above ground level
2	Rankine (1885)	Bearing capacity of shallow foundation on loose, dry granular sandy soil $q_f = \gamma D \left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$ $q_f = \gamma D \left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$

		$q_f = \gamma_z \left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$ $q_f = \gamma_z \left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$ $\left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$ $\left[\frac{1+\sin\varphi}{1-\sin\varphi}\right]^2$
3	Pauker (1889)	Proposed the expression for bearing capacity $q_f = \gamma D \tan^2 (45° + \varphi /2)$
4	Bell (1915)	Modified the Rankine- Pauker expression to make it applicable for c-φ soils on the basis of theory of plasticity
5	Prandtl (1920)	Developed equations for bearing capacity of c-φ soils by assuming that the soil is weightless and considering the equilibrium of plastic sectors
6	Hogentogler and Terzaghi (1920)	Derive an expression by assuming the plane failure surface
7	Terzaghi and Hogentogler (1928)	Assumed triaxial type shear failure under uniform strip footing
8	Housel (1929)	Total load carried by a footing of area A and perimeter P can be given by: $Q = Aq + Ps$

		where q is compression stress below footing and s is unit shear stress at the perimeter
9	Newmark (1935)	Developed chart to determine vertical stress at a point under uniformly loaded area
10	Mindlin (1936)	Considered the soil stress for different loading condition
11	Westergaurd (1938)	Developed expression for pressure distribution in soil under point load, assuming the soil to be an elastic medium of semi-infinite extent
12	Terzaghi (1943)	Developed the bearing capacity expression for strip footing $q_{ult} = c\ N_c + q\ N_q + 0.5\ \gamma\ B\ N_\gamma$
13	Burmister (1947)	Gave semi- empirical expression of Housel to theory of plasticity
14	Terzaghi and Peck (1948)	Gave empirical formula to compare the settlement of model square footing (30 cm x 30 cm)

15	Skempton (1951)	Proposed the following expression for bearing capacity for cohesive soils $q_f = c\ N_c$ He gave different value of factor N_c in different conditions.
16	Meyerhof (1951, 1953, 1955 and 1963)	Derived an expression for bearing capacity by taking into account for shear resistance of soil mass above the foundation level for both shallow and deep foundations
17	Janbu (1964)	Used method of slices to determine bearing capacity of soil
18	Ohri (1971)	Studied the effect of interference of two adjacent smooth and rough square footings subjected to vertical load on cohesionless soil

19	Binquet and Lee (1975)	Reported study on reinforced soil beds. Proposed hypothesis on failure mechanism on reinforced earth. Evolved various dimensionless parameters which influence the bearing capacity of reinforced soil beds.
20	IS 6403- 1981	Equation 3
21	Akinmsuru and Akinbolade (1981)	Reported that bearing capacity ratio is highest at depth ratio(i.e. the ratio of depth of first layer of reinforcing strip to width of footing) of about 0.5
22	Guido et. Al. (1986, 1987)	For geogrid reinforced soil, the bearing capacity ratio is decreased with increase of depth ratio
23	Singh (1988)	Reported that effect of depth ratio on bearing capacity ratio was independent of the number of reinforcing layers. Optimum depth ratio for single and multilayer reinforced sand was reported as 0.15 and 0.25 times the width of footing

24	Yetimoglu et. Al. (1994)	Reported that optimum vertical spacing between reinforcing layers is about 0.2 times the width of footing
25	Michalowski and Shi (1995)	Used the kinematics approach of limit analysis to calculate the average limit pressure under footings in order to find the bearing capacity of footings resting on two-layer soil.
26	Kumar and Walia (2006)	An approximate method has been suggested to calculate the ultimate bearing capacity of a square footing resting on reinforced layered soil.
27	Ghasemzadeh and Akbari (2019)	A simple method is proposed to predict the bearing capacity of footings placed on unsaturated soil, using the limit equilibrium concept

SETTLEMENT OF SHALLOW FOUNDATION

One of basic criteria governing the design of foundation is that the settlement must not exceed the permissible value. Foundation loads can produce three types of settlements as follows:

(1) Immediate or elastic settlement (δ_i), which takes place immediately or a short time after the load is placed, is due to change in the shape of the soil without a change in volume or water content.

(2) Primary consolidation settlement (δ_c), which is due to gradual expulsion of pore water from the voids.

(3) Secondary compression settlement (δ_s), which occurs at constant effective stress, with volume change occurring due to rearrangement of soil particles.

The total settlement $\delta_t = \delta_i + \delta_c + \delta_s$........… (Eq. 9)

Table 2 provides the brief review of settlement findings. For proper function of any structure, the foundation settlement must be restricted to allowable limits. IS: 1904 – 1978 gives the limits of total, differential settlements and angular distortion.

Table 2

Brief Review of Foundation Settlement Investigations

S No	Name of investigators	Significant contribution
1	Terzaghi (1943)	Proposed equations for immediate settlement
2	Terzaghi and Peck (1948)	Recommended that settlement of a footing on a cohesionless soil can be extrapolated from settlement experienced by a test plate at same load intensity

3	Burmister (1947)	Developed a semi- empirical expression, based on theory of elasticity
4	Fox (1948)	Proposed depth correction factor, to take into account for embedment effect, in computation of settlement
5	De Beer and Martens (1957)	Proposed equation based on cone penetration resistance values
6	Schmertmann (1970)	Proposed equation to calculate the settlement, based on static cone test data
7	Barata (1973)	Derived equation for settlement in terms of plate load test data (from Housel- Burmister equation)
8	IS: 1888-1982	Recommends the use of Terzaghi-Peck (1948) equation to determine the settlement

Determination of Bearing Capacity In Field

The most prevalent method to determine the bearing capacity on field is Plate Load Test (conforms to IS 1888-1982). It is a field test to determine the ultimate bearing capacity of soil and the probable settlement under a given loading. The test essentially consists in loading a rigid plate at the foundation level, and determining the settlements corresponding to each load increment. The ultimate bearing capacity is then taken as the load at which the plate starts sinking at a rapid rate. The method assumes that down to the depth of influence of stresses, the soil strata are reasonably uniform. The bearing plate used in the test can be either circular or rectangular, made of mild steel of not less than 25 mm in thickness and varying in size from 300 to 750 mm with chequered or grooved bottom. The plate is provided with handles for convenient setting and centre marked. The test pit, usually at the foundation level, having in general normally of width equal to five times the test plate width, shall have a carefully levelled and cleaned bottom at the foundation level, protected against disturbances or changes in natural formation. The loading of test plates may be applied with the help of a hydraulic jack. The test plate shall be placed over a fine sand layer of maximum thickness 5 mm, so that the centre of the plate coincides with the centre of the reaction girder. The load is applied to soil in cumulative equal increments up to one fifth of the estimated ultimate bearing capacity. Settlements are observed for each increment of load at a specified interval of time. A load settlement curve is plotted out to arithmetic scale and ultimate bearing capacity is determined.

Conclusions

Determination of bearing capacity of soil is the first work to be done for construction of any structure. Different criteria are given by different works done on it and specific processes are used depending upon the condition of soil and the site.

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