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EXPERIMENTAL STUDIES OF BEARING CAPACITY OF SKIRTED FOOTINGS RESTING OVER SOILS

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ABSTRACT:

In conventional footing/foundations when the load is applied, the soil beneath the footing will spread laterally. If the lateral movement of the soil is restricted by providing vertical sections beneath the footing, the bearing capacity of the soil increases due to its confinement. The vertical sections attached along the outer perimeter of the footing is known as skirt and the footing is known as bucket/skirted/bounded/confined footing. These types of footings are commonly employed in offshore structures. Skirted foundations are alternative solutions for deep foundations. They are also economical when compared deep foundations. However, skirted foundations are yet to find its place in onshore structures. Recently skirted foundations have caught the attention of engineers. Although research works are ongoing, significant contribution is yet to come.

Pressure-settlement curve is drawn for different parameters to determine the bearing capacity of the skirted footing. To compare these test results with conventional footings, similar tests were repeated for footings without skirts and suitable recommendations are made for optimal design of skirted footings. A detailed numerical analysis is also done to validate the experimental test results.

INTRODUCTION

Bearing capacity problems are major challenges for civil engineers especially in difficult subsoil conditions. Civil engineers are continuously striving to find alternate solutions to improve soil conditions of substructures. This is essential particularly in the modern world where land scarcity is looming large due to exponential population growth.

Foundation design is becoming challenge for civil engineers for various reasons. Superstructures are becoming taller to cater to the needs of ever increasing population. The land availability in major cities is becoming scarce and construction on difficult soil condition is inevitable. Many coastal cities across the globe are opting for land reclamation for development. Many factors such as site topography, soil conditions, water table, frost depth, loading etc, are to be considered while designing a foundation

Foundations are designed to resist the load with an allowable settlement.

TYPES OF FOOTING

Footings are classified based on depth of the footing as shown in Fig.1.1. If the depth of the footing is less than the width of footing, then footings are termed as shallow footings. Spread footings, strap footings, strip/continuous footings, combined footings and mat or raft footings belongs to shallow foundations. On the other hand, if the depth of the footing is greater than width of footing, they are termed as deep foundations. Piles, Piers, Caissons/well foundation are grouped in this category.

When the subsoil has sufficient bearing capacity at shallow depth, spread or continuous footings are adopted. When the subsoil has insufficient bearing capacity, the size of footing may be

increased to reduce the intensity of load or the loads from superstructure may be transferred to deeper level through piles or pier. The type of foundation is decided on various factors such as the magnitude of the load from superstructure, importance of the project, subsoil condition, cost of the super structure and many other factors

When two columns are close to each other, the footings under individual columns overlap. Under such circumstances, individual footings may be joined together. Such footings are called as combined footings.

When peripheral column is combined with interior column, the load is uniformly distributed. When the magnitude of loads on the two columns vary significantly then Trapezoidal shape of footing is preferred instead of rectangular footing.

Strap footing is adopted when two isolated footings are placed at a large distance and a connecting beam called strap is provided to keep both the columns in equilibrium

position. The strap acts as a connecting beam and does not carry any load. A strap footing is preferred when the bearing capacity is high and the distance between the columns is large.

Strip footing is adopted for load bearing walls and also when a row of columns are closely spaced. In such cases strip footings are economical than spread footings.

Mat or Raft footings cover the entire area beneath the structure including all the columns and walls. A mat is adopted when the allowable soil pressure is low or isolated footings overlap each other. Mat foundations reduce the differential settlements in non-homogeneous soils or when there is large variation in the loads on individual columns. Mat foundations are further classified into conventional type and Buoyancy type.

used to anchor structures to resist uplift forces, lateral and overturning forces.

BEARING CAPACITY

Bearing capacity is the maximum pressure that the soil can resist without undergoing shear failure or excessive settlement. Foundation soil is that portion of ground which is subjected to stresses due to load from the foundation and the superstructure.

The bearing capacity of a soil is based on the stability requirement of a foundation. The two factors on which the bearing capacity of a soil depends on are shear strength and settlement. The first criterion is that the shear failure should not occur. The settlement criterion is that the foundation shall not settle more than the safe or tolerable magnitude of the settlement such that the anticipated settlement due to the applied pressure on the soil should not affect the stability of the foundation. Figure 1.2 explains bearing capacity theory.

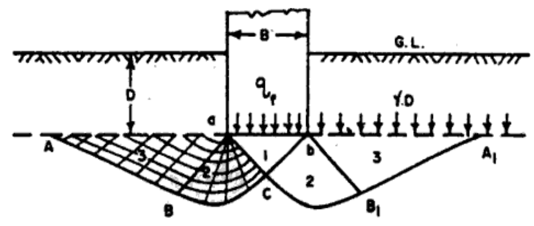


Fig. 1.2: Bearing Capacity Theory

(Source: Braja M Das**)**

Terzaghi's bearing capacity theory classifies foundation soil into three categories as shown in Fig.1.2. When the footing sinks under the load from the superstructure, the soil wedge 'abc' beneath the footing is prevented from undergoing any lateral movement due to the friction developed between the base of the footing and the soil. This wedge of the soil is called Zone I which remains in a static equilibrium at failure. The vertical downward movement of the footing and the soil wedge 'abc' pushes the soil on either side of the elastic wedge and transform it into a state of plastic equilibrium. The soil wedges 'aBC' and 'bCB$_1$' are called zones of radial shear or Zone II. The soil wedges 'ABa' and 'bB$_1$A$_1$' are called passive zones or Zone III.

TYPES OF BEARING CAPACITY

The bearing capacity of the soil is the maximum pressure the foundation soil,can resist without undergoing shear failure in the soil. Bearing capacity is further classified as ultimate bearing capacity, net ultimate bearing capacity, safe bearing capacity and allowable bearing pressure.

Ultimate bearing capacity is the maximum pressure that the foundation soil can resist without undergoing shear failure. It is the maximum gross pressure intensity at the base of the foundation at which the soil does not fail in shear.

Net ultimate bearing capacity is the maximum extra pressure that a foundation soil can resist without undergoing shear failure. It is the ultimate bearing capacity excluding the self-weight of the footing and initial overburden pressure due to soil above the base of the footing.

$$q_n = cN_c + \gamma D N_q + 0.5\gamma B N_\gamma - \gamma D$$

Safe bearing capacity is the safe additional pressure on the foundation soil in addition to initial overburden pressure.

$$q_s = \left[cN_c + \gamma D(N_q - 1) + 0.5\gamma B N_\gamma\right]\frac{1}{F} + \gamma D$$

Allowable bearing pressure is defined as the maximum pressure the soil can resist without undergoing shear failure and as well as excessive settlement.

PLATE LOAD TEST FOR DETERMINING BEARING CAPACITY:

Bearing capacity may be computed either by analytical or by field methods. One of the most popular method of computing the bearing capacity is Plate Load Test shown in Figure 1.3.

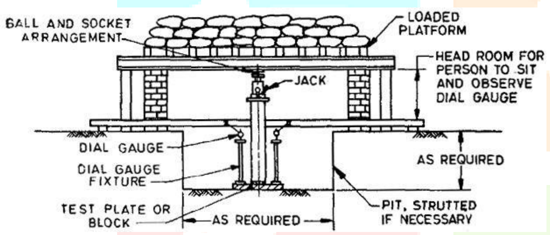


Plate load test is a field test for determining the bearing capacity and settlement characteristics at the foundation level. A test pit up to the foundation level is prepared. A rigid steel plate of size 300 mm to 750 mm and 25 mm thick is used for model footing. Settlement is measured with the help of two dial gauges as shown

in Fig.1.3. The load is applied either by gravity or through reaction. Sand bags may be used for smaller loads. A reaction truss is anchored to the ground in the case of reaction loading. A hydraulic jack is used for applying the load. Average settlement of the two dial gauges is recorded and pressure - settlement curve is plotted as shown in Figure 1.4. Ultimate bearing capacity is determined by drawing tangents from both ends of the curve.

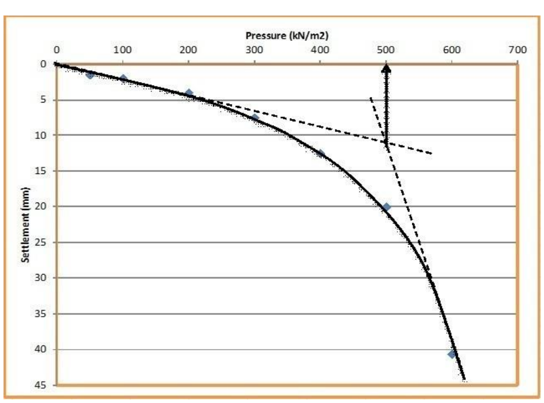


Fig. 1.4: Pressure-settlement curve for Plate Load Test

(Source: civilblogs)

where,

c	=	Cohesion, kN/m^2
γ	=	Unit weight of soil, kN/m^3
D	=	Depth of foundation, m
B	=	Width of foundation, m
N_c, N_q, N_γ	=	Bearing Capacity factors
F	=	Factor of safety

BEARING CAPACITY OF FOOTINGS SUBJECTED TO ECCENTRIC LOADING:

The bearing capacity equation is developed on the assumption that the load on the foundation is concentric. However, eccentricity of loads is bound to happen in field condition and be subjected to additional moment as shown in Figure 1.4. In such situations, the effective width of foundation will be reduced by twice the eccentricity. Thus, effective width of foundation will be calculated by, B' = B – 2e as shown in Figure 1.5.

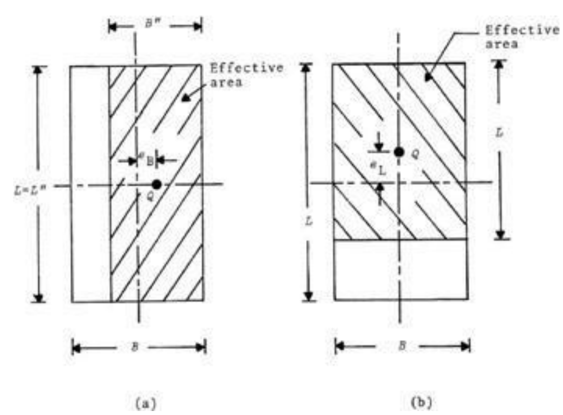


Fig. 1.5: Effect of Eccentricity on Bearing Capacity of Footing

(Source: Braja M Das)

EFFECT OF GROUND WATERTABLEON BEARING CAPACITY FOOTING:

The level of ground water table influences the bearing capacity of soil. If the ground water table is at greater depth, the bearing capacity is not affected. As the ground water level rises close to the footing the bearing capacity reduces. Hence, the reduction coefficients R_{W1} and R_{W2} are applied in bearing capacity equation to consider the effects of water table .

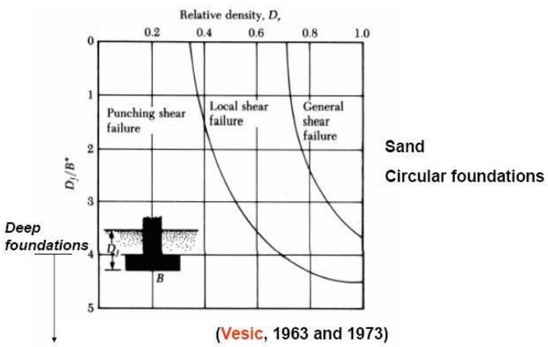


Fig. 1.8: Modes of Failure at Different Relative Densities and Depths of Foundations (Source: Vesic)

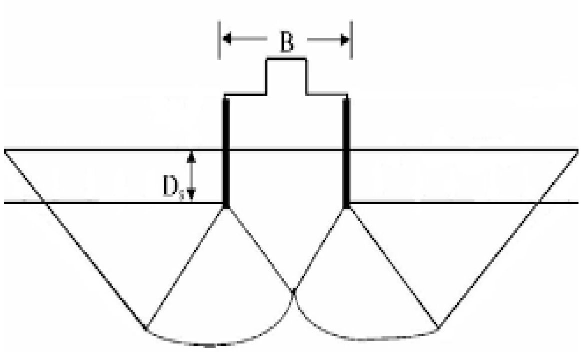
TYPES OF SOILS

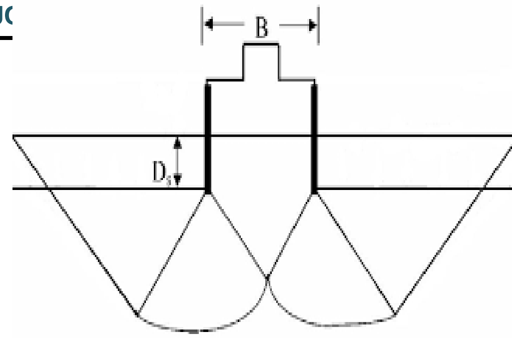
Soils are broadly classified into fine grain and coarse grain. If more than 50% of the soil retains on 75 μ sieve the soil is termed as coarse grain soil. On the other hand, if more than 50% of the soil pass through 75 μ sieve, the soil is classified as fine grain soil.

Fine grain soils are also called as cohesive soils or c-soils. In this type of soils, shear strength is derived from cohesive property. In purely coarse grain soils, shear strength is derived from angle of internal friction. In nature, the soils may contain both fine and coarse grains. Such soils are termed as c-Φ soils.

1.9SKIRTED FOUNDATION:

The difficulty of improving the bearing capacity of shallow





foundations has been broadly discussed in the geotechnical engineering. Several methods have been presented for determination of bearing capacity of foundations. Confinement of soil in shallow depths has a considerable effect in increasing the soil bearing capacity.

In skirted foundation, the principle of confinement is adopted to improve the bearing capacity of the soil. Rigid skirts are provided along the periphery of the footing to confine the soil below it. This type of foundation is called skirted foundation. These foundations are steel or concrete plated foundations with a circumferential skirt underneath the perimeter which penetrates the confined soil. Skirts restrain the soil laterally and acts as single unit to transfer the load from the superstructure to the soil at the level of skirt tip. The development of slip lines extend below the skirts as shown in Figure 1.10. This results in the reduction of the settlement and also increases the bearing capacity of the soil.

Fig. 1.10: Failure Mechanism of Skirted Foundation

(Source: S. Golmoghani-Ebrahimi, M.A. Rowshanzamir)

Structural skirts have been used for marine applications and other situations where water scour is a main problem. Skirted foundations do not require excavation of the soil and is not affected by high ground water table.

In addition to resisting downward loads, Skirted foundations also have capability to resist uplift due to suction created within the confined soil. Skirted foundations not only control the settlement of the structure but also mitigate the environmental hazard during installation at site. Skirts can be of any shape but generally it is kept same as that of footing

Skirted foundations are extensively used in offshore structures foundation as an alternative to deeper foundations due to easy installation, low cost, simpler and faster construction compared to deep foundations. Skirted foundations reduce the embedment depth, size of the foundation and satisfy bearing capacity requirement.

Vertical loading due to self-weight (e.g. Jacket structure, wind turbine) is enhanced as soft surface soils are confined inside the skirts and the foundation loads are transferred down to harder underlying layers. Horizontal load capacity is increased by vertical insertions. From the literature, it was found that a skirt improves the bearing capacity of soil between 3 to 8 times depending on the type of soil, relative density and skirt length.

1.9.1 SKIRTED FOOTINGS:

The major applications of skirted foundation is in offshore structures. Wind turbine foundation, oil and petrol gas plant, tension leg platforms and bridge foundation are some of the examples.

The concept of skirted foundations has evolved from offshore structures where they are adopted as a replacement for deep foundations to reduce the cost of construction. Recently researchers are showing interest in exploring suitability of skirted foundations for onshore site conditions. In this research, an attempt has been made to study the load settlement characteristics of skirt foundations on sand and c-Φ soils.

CONCLUSION

The concept of skirted foundations has evolved from offshore structures where they are adopted as a replacement for deep foundations to reduce the cost of construction. Recently researchers are showing interest in exploring suitability of skirted foundations for onshore site conditions. In this research, an attempt has been made to study the load settlement characteristics of skirt foundations on sand and c-Φ soils.

Skirted foundations are the clearest illustration of improving the bearing capacity of all types of soils for onshore conditions. Given its proven record in offshore structures, skirted foundations may be found to be useful where other types of foundations have limitations. This report is pivotal in comprehending the behavior of skirted foundations for different types of soils and hence could be immensely handy for field conditions and as well for future research works.

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