International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. 06 Special Issue 01 | 2021

"Triangular Shell" An innovative foundation

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ABSTRACT

Individual footing or isolated footing, combined footing, strip footings, raft or mat foundation are the various type of foundations used to provide the stable, safe and efficient support to structures, and referred as shallow foundation. Their structural rigidity is obtained by the material used for their construction. Shells are used as foundation since 1950's in different parts of the world. Foundations in the form Shell are adopted as an alternative to the conventional flat shallow foundations. They can be geometrically shaped in elevation, triangular, cylindrical, parabolic, etc., for continuous footings, and conical, spherical, hyperbolic-parabolic, etc., for isolated footings. The evaluation of geotechnical behaviour of triangular shell foundations is studied and presented in this paper The experimental study on triangular shell footing models with various peak angles were carried. This paper presents experimental investigations of triangular shell strip footings on silty sand. The results of this study indicate that these footings provide higher bearing capacity and produce less settlement when compared to conventional flat foundations. Although there have been rapid advances in efficiency, reliability, and economy in the fields of construction technology and assembly of precast foundations however, concrete units the use of shell is still limited by their economics. There is potential for the use of shell foundations as an alternative to the conventional flat foundations in the future.

Keyword: - Triangular shell, Strip footing, Shell foundation, Peak angle, Ultimate bearing capacity, Membrane theory

1. INTRODUCTION

Foundations are inevitable part of any structure. Conventional foundations are individual footing or isolated footing, combined footing, strip footings, raft or mat foundation etc. Shell foundations have been used as an alternative to the conventional flat shallow foundations. They can be geometrically shaped in elevation, triangular, cylindrical, parabolic etc. for continuous footings and conical, spherical, hyperbolic-parabolic etc. for isolated footings. These footings provide higher bearing capacity and produce less settlement, when compared to conventional flat foundations. The classical bearing capacity theory for flat shallow foundations cab be extended for triangular shell strip footings. Although there have been rapid advances in efficiency, reliability and economy in the field of construction technology and assembly of precast concrete units. The use of shell foundations is still limited by their economics. However, the shell foundation proves its economy in bearing capacity as compared to flat foundation. Since the bearing capacity is higher than conventional flat foundation. However, there is potential for the use of shell foundations as an alternative to the conventional flat footing foundations in the future.

1.1 Bearing Capacity:

Bearing capacity or supporting power of any soil formation is intensity of pressure that a Foundation of finite loaded area can sustain before the underlying material fails in shear. In other words, it is the supporting power offered by soil formation or rock and is referred as its bearing capacity.The bearing capacity alone seldom used and prefixed with other words to distinguish the situations.

1.2 Ultimate Bearing Capacity:

The ultimate bearing capacity is defined as the minimum gross pressure intensity at the base of the foundation at which the soil fails in shear.

1.3 Net Ultimate Bearing Capacity (N) :

It is the minimum net pressure intensity causing shear failure of soil. The ultimate bearing capacity and net ultimate bearing capacity are evidently connected by the following relations:

$$q_f = q_{nf} + \overline{\sigma}$$
$$q_{nf} = q_f - \overline{\sigma}$$

Where $(\overline{\sigma})$ is the effective surcharge at the base level of the foundation.

1.4 Net Safe Bearing Capacity (q_{ns}):

The net safe bearing capacity is the net ultimate bearing capacity divided by a factor of safety F

$$q_{ns} = \frac{q_{nf}}{F}$$

1.5 Safe Bearing Capacity (q_s):

The maximum pressure which the soil can carry safely without risk of shear failure is called the safe bearing capacity. It is equal to net capacity plus original overburden pressure safe bearing

$$q_s = q_{ns} + \gamma D = q_{nf}/F + \gamma D$$

Sometimes, the safe bearing capacity is also referred to as the ultimate bearing capacity q_f divided by a factor of safety F.

2. HISTORICAL DEVELOPMENT

2.1 Shells as Foundation:

Shells used as foundation engineering in 1950's in the different parts of world. In the mid 1950's shells were first employed as foundation by Felix Candela in Mexico City, and they have also been used in India, West Germany, China, the Soviet Union and the United States. However, there is no study available in literature regarding the determination of the ultimate bearing capacity and settlement of these foundations. Nevertheless, since then, the use of shells in foundation engineering has drawn considerable interest around the world, particularly in situations involving heavy loads transmitted to weak soils, or towers subjected to high lateral forces due to wind or earthquake loads. Their use was based on practical experiences and the engineering judgement of the designers. Telecommunication towers, silos and chimneys are the examples of structures where shell foundations are used as support for structure. The design of shell foundation is currently based on the membrane theory in which the soil contact pressure is assumed to be uniform.

2.2 Membrane Analysis of Shells:

Let the figure. (3) shows the plan and c/s of a shell roof. Consider O the mid-point of shell, as the centre of co-ordinates, taken positive along OX and OY, Z is another axis of co-ordinates which is normal to the surface at any point. The Y axis is tangential at any point.If the load on the shell is continuous, it is possible to support this loads by means of membrane forces only. These membrane forces will vary from point to point in the shell which will also undergo deformations due to these forces. If the edges of shell are so supported that the membrane forces acting at edges are balanced by support reactions and that the supports allow the necessary displacements of the shell, the shell will not develop any bending stresses and the calculated membrane forces will be correct.

2.3 Shells as economical foundation

Shell foundations are potentially economic under conditions of heavy loads to be transmitted to weaker soils. Since their economy is mainly the results of the savings in materials they offer, it is obvious that overall economy with them should be more pronounced in countries where material costs are high compared to labour costs. This is a situation typically prevalent in many of the developing countries, which should speak for the popularity of foundations this type in those countries. Shell foundations are used in various countries including India.

3. BEARING CAPACITY EQUATIONS:

3.1 Terzaghi's Bearing classical theories

Terzaghi (1943) gave a general theory for the bearing capacity of soils under a strip footing, making the following assumptions:

i) The base of the footing is rough.
ii) The footing is laid at a shallow depth i.e., DEB.
iii) The shear strength of the soil above the base of the footing is neglected. The soil above the base is replaced by a uniform surcharge D.
iv) The load on the footing is vertical and is uniformly distributed.
v) The shear strength of the soil is governed by the Mohr coulomb equation.
As the base of the footing is rough, the soil in the wedge ABC immediately beneath the footing is prevented from undergoing any lateral yield. The soil in this wedge (zone I) remains in equilibrium. It behaves as if it were state of elastic a part of the footing itself. It is assumed that the angles CAB and CBA are equal to the angle of shearing resistance of the soil.
The sloping edges AC and BC of the soil wedge CBA beat against the radial shear zones CBD and CAF (zones II). The curves CD and CF are arcs of a logarithmic spiral.
Two triangular zones BDE and AFG are the Rankine passive zones (Zones III). An overburden pressure q = γD_facts as a surcharge on the Rankine zones.
The failure zones do not extend above the horizontal planes passing through the base AB of the footing. In other words the shearing resistance of the soil located above the base of the footing is neglected, and the effect of soil is taken equivalent to a surcharge ofD_f. Because of this assumption, Terzaghi's theory is valid only for shallow foundation ($D_f \leq B$), in which the term isγD_frelatively small.

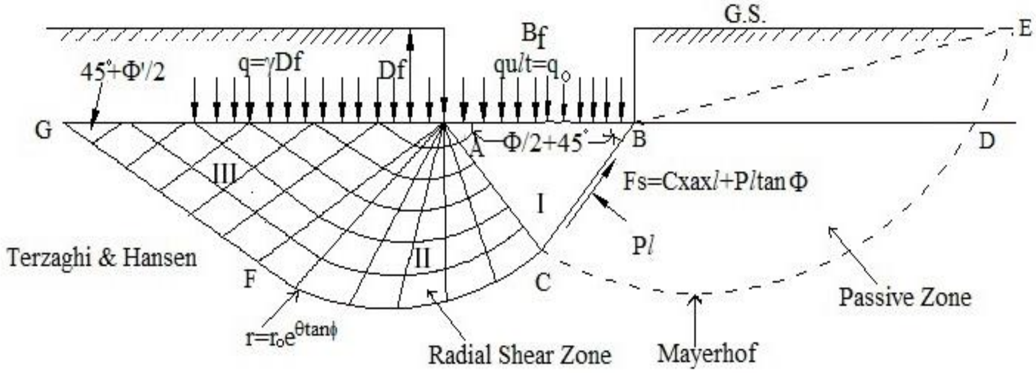

Figure (3.1) -Boundaries of Failure

Bearing Capacity Equation by Terzaghi

Where,
C = cohesion

Type of footing	Bearing Capacity Equation	Constants
Continuous	$q_{ult} = CN_c + qN_q + 0.5\gamma BN\gamma$	$N_q = a^2/2\cos^2(45 + \emptyset/2)$
Square	$q_{ult} = 1.3CN_c + qN_q + 0.4\gamma BN_\gamma$	$a = e^{(0.75\pi - \emptyset\frac{1}{2})\tan}$
Round	$q_{ult} = 1.3CN_c + qN_q + 0.3\gamma BN_\gamma$	$N_c = (N_q - 1)\cot\emptyset$ $N = \tan\emptyset/2\ (K_{p\gamma}/\cos^2\emptyset\text{-}1)$

q= load intensity
B = width of footing.
γ = unit weight of soil.
$\emptyset$ =Angle of shearing friction.
$K_{p\gamma}$= It is obtained by a curve fitting process and back computing two valueof N_γ given by Terzaghi.

3.2 Bearing Capacity Equation by Meyerhofs

Type of loading	Bearing Capacity Equations	Constants
Vertical load	$q_{ult} = CN_cS_cd_c + qN_qS_qd_q + 0.5BN_\gamma S_\gamma d_\gamma$	$N_q = e^{\pi\tan\emptyset}\tan^2(45 + \emptyset\frac{1}{2})$ $N_c = (N_q - 1)\cot\emptyset$ $N_\gamma = (N_q - 1)\tan(1.45)$
Inclined load	$q_{ult} = CN_ci_cd_c + N_qi_qd_qq + 0.5BN_\gamma i_\gamma d_\gamma$	

Where,
C = Cohesion
q = Intensity of load.
B = width of footing
γ = Unit weight of soil.
$\emptyset$ =Angle of shearing friction.

3.3 Bearing Capacity Equation by Hansen

	Bearing Capacity Equations	Constants
General	$q_{ult} = CN_cS_cd_ci_cg_cb_c + q$ $N_qS_qi_qd_qg_qb_q + 0.5BN_\gamma S_\gamma d_\gamma i_\gamma g_\gamma b_\gamma$	N_q =same as given by Meyerhof N_c =same as given by Meyerhof N= $1.5(N_q - 1)\tan\emptyset$
When $\emptyset = 0$	$q_{ult} = 5.14S\left(1 + S'_c + d'_c - i'_c - g'_c - b'_c\right) + \bar{q}$	

d-factors(for B$\geq$ D):- $d_c = 1 + \frac{0.2D_f\sqrt{N_\emptyset}}{B} N_\emptyset = \tan^2(45 + \emptyset\frac{1}{2})$

$d_q = d_\gamma = 1$ for$\emptyset \leq 10°$

$d_q = d_\gamma = 1 + 0.1D_f\sqrt{N_\emptyset}/Bfor\emptyset > 10°$

i-Factors:-

$i_c = i_q = (1 - \frac{\alpha}{90})^2$

$i\ = (1 - \frac{\alpha}{\emptyset})^2$

Where α = inclination with vertical.

3.5 General Observations:

General observations about the bearing capacity equations may be made as follows -

i) The cohesion terms predominates in cohesive soil.

ii) The depth term (qN_q) predominates in cohesionless soil.

iii) The base width term 0.5$\gamma N_\gamma B$, provides some increase in bearing capacity for both cohesive and cohesion less soils. In cases where B <3 to 4 m. this term could be neglected with little error.

iv) No one would place a footing on the ground surface of a cohesion less soil mass.

v) It is highly unlikely that one would place a footing on a cohesion less soil with a D_r less than 0.5. If the soil is loose, it would be compacted in some manner to a higher density prior to placing footing in it.

vi)Where the soil beneath the footing is not homogeneous or is stratified, some judgement must be applied to deterring the bearing capacity. In the case of stratification, later sections will consider several cases.

4. Contact Pressure:

The normal stress at the plane of contact between the loaded base and the foundation bed is known as "contact pressure", the contact pressure distribution depends on several factors, such as flexural rigidity of base, load distribution type of soil and confinement.

4.1 Rigid Base:

A rigid base on sandy soil induces parabolic pressure distribution, with zero intensity at the edges and maximum at the centre.

On clayey soils induces minimum pressure at the centre and maximum at the edges. As a real soil cannot take infinite pressure, the pressure distribution in clay reaches a finite intensity of pressure at the edges.

4.2 Flexible Base:

Uniform loading on a flexible base induces uniform contact pressure on any type of soil while a rigid base induces non-uniform pressure.

5. Experimental Investigation

Tests were conducted on five models of triangular strip footings. All model footings have the same width B of 10 cm, length L of 11.0 cm and the peak angle varied from 60° to 180° (flat footing). The length of each model was essentially equal to the width of the testing tank to simulate the case of strip footing. The models were fabricated of mild steel, and the bearing area was covered by sand paper to provide rough base.

The testing tank was made of a steel base and acrylic sheet side to allow observation of the development of the failure mechanise in the sand in the vicinity of the footing. The inner dimensions of the tank were 10 cm, 60 cm, and 50 cm, in width, length and height respectively.

To assure the plane strain condition, the displacements of the longitudinal sides of the testing tank were measured during testing using dial gauges mounted on both sides of the tank. The measured lateral displacements were found to be negligible.

The silt sand used in the present experimental investigation is used in all construction work of college and brought from PUS River near PUSAD TOWN. Grain size analysis and visual inspection allow this sand to be classified as a clean, angular and quartz with silt fraction. The sand has uniformity coefficient of 1.82 and an average value of specific gravity G= 2.67. To ensure the reproducibility of sand in the testing tank, a spreading technique was developed by dropping the sand from a predetermined height. In the present investigation, the sand was prepared in the dense state by having a minimum height of drop of 50cm. The corresponding unit weight of the sand was 15.61367 KN/m^3 and the angle of shearing resistance was found to be $\emptyset$= 37° as deduced from direct box shear tests.

5.1 Engineering Properties of Sand

After the sand was placed into the testing tank up to the founding level, the footing was mounted, and the volume inside the footing was entirely filled sand through three holes each 25mm in diameter, located at top of the foundation models. The sand was compacted through these holes by means of small hammer to reach the same unit weight of the sand inside the testing tank. The procedure was calibrated before testing and found to be successful.

The model footing was subjected to vertical compression load acting on the centre by means of a compression machine. Two dial gauges were mounted on the top surface of the footing during testing to assure that no tilting would occur. The load acting on the footing and the corresponding settlements were recorded regularly until failure took place.

The experimental load-settlement curves plotted the ultimate load, which is represented by thick line, was defined at the point where the slope of the load-settlement curve first reaches a steady minimum value. This concept was employed for all models tested in the present investigation for the purpose of comparison and revealed a unique value for the ultimate load for each load settlement curve.

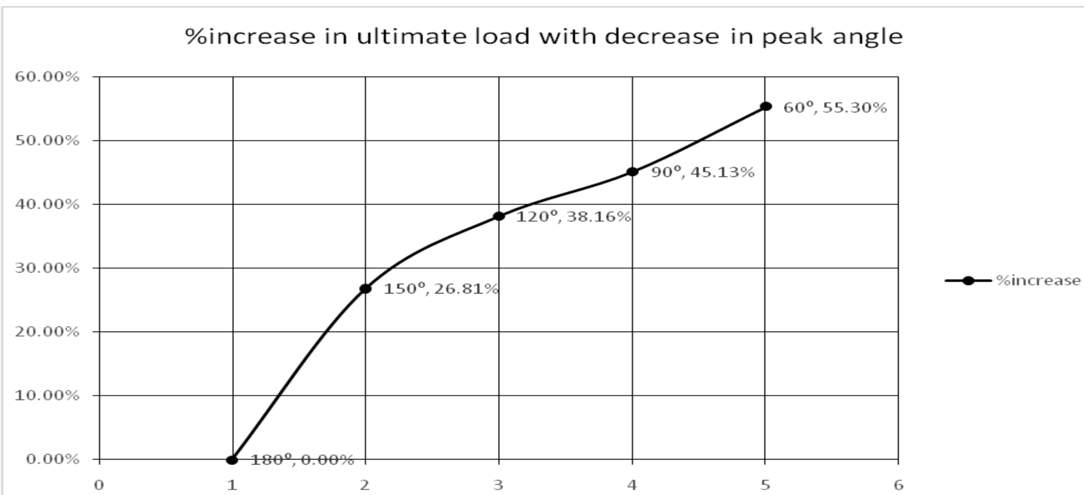

Figure 5: Percentage increase in ultimate load with decrease in peak angle

Result and discussion:

Experimental investigation s on the triangular shell strip footing models were conducted for determination of gross pressure intensity at failure. Five model footings were tested. The peak angle of model footings were 180^0, 150^0, 120^0 , 90^0, and 60^0 . The foundation models were tested for the buried condition for a D/B ratio of 0.5 on silt sand. The sand spreading technique and test procedure were developed and calibrated before testing. The experimental results showed that triangular strip footing, in general have a higher bearing capacity and a better settlement characteristic than the flat foundation with equivalent width. It can be reported that at a certain load level the smaller the peak angle of the foundation, the higher will be the ultimate bearing capacity lower will be the settlement.

Limitations:

Although shell foundations are more difficult and costly to construct than flat footings, there are situations where they are technically and economically be more feasible. With new advances in construction techniques and assembly of prefabricated concrete units, the use of shell foundations will become more competitive with flat foundations in the future.