IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 1 Ver. VI (Jan- Feb. 2016), PP 68-71
www.iosrjournals.org

Designing an Isolated Footing in Cohesive and Non-Cohesive Soils

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Abstract : *The main aim of this project is to design the size of footing for cohesive and non-cohesive soils for a same type building, try to find which soil is more economical and the ways to reduce the cost of construction of building. Standard Penetration Tests were conducted at different locations in both cohesive and non cohesive soils to calculate the bearing capacity of the soil. In the design reinforced concrete rectangular footings subject to axial load and exude in two directions, different pressures in the four corners. In this paper, a mathematical model is developed to take into account the real pressure of soil acting on the contact surface of the footings and these pressures are presented in terms of the mechanical elements (axial load, around moment the (X) and (Y) axis, when applying the load that must support said structural member. The classical model takes into account only the maximum pressure of the soil for design of footings and is considered uniform at all points of contact area of footing, i.e., all the contact surface has the same pressure. The data show that the classical model is larger than the model proposed. Therefore, normal practice to use the classic model will not be a recommended solution. Then the proposed model is the most appropriate.*

Keywords: *Rectangular Footings, Real Pressures, Contact Surface, Resultant Force, Moments, Shear Force, Standard Penetration Test.*

I. Introduction

Footings are structural elements that transmit column or wall loads to the underlying soil below the structure. Footings are designed to transmit these loads to the soil without exceeding its safe bearing capacity, to prevent excessive settlement of the structure to a tolerable limit, to minimize differential settlement, and to prevent sliding and overturning. The settlement depends upon the intensity of the load, type of soil, and foundation level. Where possibility of differential settlement occurs, the different footings should be designed in such away to settle independently of each other. Foundation design involves a soil study to establish the most appropriate type of foundation and a structural design to determine footing dimensions and required amount of reinforcement. Because compressive strength of the soil is generally much weaker than that of the concrete, the contact area between the soil and the footing is much larger than that of the columns and walls. The foundation is part of the structure which transmits the loads to the soil. Each building demands the need to solve a problem of foundation. The foundations are classified into superficial and deep, which have important differences: in terms of geometry, the behavior of the soil, its structural functionality and its constructive systems. A superficial foundation is a structural member whose cross section is of large dimensions with respect to height and whose function is to transfer the loads of a building at depths relatively short, less than 4 m approximately with respect to the level of the surface of natural ground. Superficial foundations, whose constructive systems generally do not present major difficulties, Algin (2007), Practical formula for dimensioning a rectangular footing, Engineering Structures, may be of various types according to their function, isolated footing, combined footing, strip footing, or mat foundation. The structural design of foundations, by itself, represents the union and the frontier of structural design and soil mechanics. Luevanos-Rojas (2013) designed mathematical model for dimensioning of footings rectangular, shared the hypothesis and models of both disciplines, which do not always coincide, the high degree of specialization with which are being designed today makes that structural engineers and engineers of soil mechanics will have different approaches, which in some way affects the final product that will find in these two disciplines: foundation design. Bonet et al., (2006), did a comparative study of analytical and numerical algorithms for designing reinforced concrete sections under biaxial bending. Indeed, for normal working, structural analysis is usually done with the hypothesis that the building structure is embedment in the ground, i.e., it is supported by a undeformable material. On the other hand, the engineer of soil mechanics, for calculating the conditions of service by soil settlement, despises the structure, whose model are only forces as resulting from the reactions. The reality is that neither the soil is undeformable, neither the structure is as flexible as for that its effects are not interrelated. After all, the system soil-structure is a continuous element whose deformations of one depend on the other.

In the design of superficial foundations, the specific case of isolated footings is of three types in terms of the application of loads subject to concentric axial load; axial load and moment in one direction (unidirectional flexure) and footings subject to axial load and moment in two directions (bidirectional flexure).The hypothesis used in the classical model is to consider the pressures uniforms for the design, i.e., the same pressure at all points of contact in the foundation with the soil, the design pressure is the maximum that occurs of at the four corners the footings rectangular. The classical model for dimensioning of footings rectangular is developed by trial and error, i.e., it is proposed a dimension and using the expression of the bidirectional flexure to obtain the stresses acting on the four corners of the rectangular footing, which must meet with the following conditions: 1) The minimum stress should be equal to or greater than zero, because the soil is not capable of withstand tensile stresses; 2) The maximum stress must be equal or less than the allowable capacity that can withstand the soil. A direct method of proportioning a rectangular footing area subjected to biaxial flexure is proposed by R. Jarquio and Jarquio (1983), Design of footing area with biaxial bending as an alternative to the trial and error method of solution. Formulas for the dimensions of the footing area are derived using the ordinary flexure formula and the limiting conditions that the maximum and minimum pressures are developed at the critical corners which are diagonally opposite each other. In addition, the maximum pressure is equated to the allowable bearing capacity of the soil while the minimum pressure is equated to zero. The analysis yielded the basic relationship of the footing area dimensions as 12 times the eccentricities of the total vertical load about the centroidal axes while the minimum area is controlled by the allowable soil bearing capacity. A comparative study of different integration methods of stresses (both analytical and numerical) for concrete sections subjected to axial loads and biaxial flexure, such methods are applied to circular and rectangular sections. The comparison was performed with regard to the accuracy and the computational speed of each method. The objective of the paper is to determine which of the integration methods compared is more efficient in computing the interaction surfaces for rectangular and circular sections. A simple design chart is also provided to determine the minimum dimensions of a rigid rectangular footing resting on elastic mass subjected to the combination of biaxial flexure in both axes and vertical column load. Luevanos-Rojas (2013), developed a mathematical model to obtain the dimensions most economic for rectangular footings subjected to axial load and moment in two directions (Bidirectional exure), which must meet with the two conditions mentioned previously. Luevanos-Rojas developed a mathematical model to take into account the real pressure of soil acting on the contact surface of the rectangular footings when applying the load that must support said structural member, this model is presented in function of the pressures, for obtain the moments acting on the rectangular footings. Cohesive soil means soil with a high clay content, which has cohesive strength. Cohesive soil does not crumble, can significant cohesion when submerged. Cohesive soils include clayey silt, sandy clay, silty clay, clay and organic clay be excavated with vertical side slopes and is plastic when moist. Cohesive soil is hard to break up when dry and exhibit Composition, Cohesion and Consistence. In the present study various field penetration tests were conducted on cohesive and noncohesive soils and design the optimum size of the footing based on the field tests.

Standard Penetration Test (Field Test)

The standard penetration test is the most commonly used in-situ test, especially for non-cohesive soils which cannot be easily sampled. The test is extremely useful for determining the relative density and the angle of shearing resistance of non-cohesion soils. It can also be used to determine the unconfined compressive strength of cohesive soils. The standard penetration test is conducted in a bore hole using a standard split-spoon sampler. When the bore hole has been drilled to the described depth, the drilling tools are removed and the sampler is lowered to the bottom of the hole. The sampler is driven into the soil by a drop hammer of 63.5 kg mass falling through a height of 750 mm at the rate of 30 blows per minute (IS: 2131-1963). The number of hammer blows required to drive 150 mm of the sample is counted. The sampler is further driven by 150 mm and the number of blows recorded. Likewise, the sampler is once again further driven by 150 mm and the number of blows recorded. The number of blows recorded for the first 150 mm is disregarded. The number of blows recorded for the last two 150 mm intervals are added to give the standard penetration number (N). In other words, the standard penetration number is equal to the number of blows required for 300 mm of penetration beyond a seating drive of 150 mm. Terzaghi and Peck recommended the following correction in the case of silty fine sands when the observed value of N exceeds 15. The corrected penetration number, Nc = 15+ (NR-15)/2; Where NR is the recorded value, and Nc is the corrected value. If $N_R \leq 15$ and $Nc = N_R$.

Correlation Between N And Q_u

N	Consistency	Q_u kN/m^2
0 - 2	Very Soft	<25
2 - 4	Soft	25 - 50
4 - 8	Medium	50 - 100
8 - 15	Stiff	100 - 200
15 - 30	Very Stiff	200 - 400
> 30	Hard	>400

Standard Penetration Test

Cohesive Soil

Observed **N** = 11

Unit Weight of Soil = $17.0\ kN/m^3$

Submerged unit Weight = $7.2\ kN/m^3$

Assumed depth of foundation D = 2m

Assumed Width of foundation B = 2m

Cohesion = $41\ kN/m^2$

Using IS Code 6403 – 1981

$N_c = 5.14$, $N_{q'} = 1.0$, $N_{r'} = 0$

Net ult B.C = $1.3c'N_{c'} + r{\cdot}D(N_{q'}-1) + 0.4BN^{r'}$

= $273\ kN/m^2$

With a FS of 3, SBC = $91\ kN/m^2$

Recommended safe Bearing capacity is $80\ kN/m^2$

Non-Cohesive Soil

Observed **N** = 21

$N_c = 15+(N_R-15)/2$ = 18

Unit Weight of Soil = $18.9\ kN/m^3$

Submerged unit Weight = $10.19\ kN/m^3$

Assumed depth of foundation D = 2m

Assumed Width of foundation B = 2m

Cohesion = $41\ kN/m^2$

Using IS Code 6403 – 1981

$N_c = 8.89$, $N_{q'} = 1$, $N_{r'} = 0$

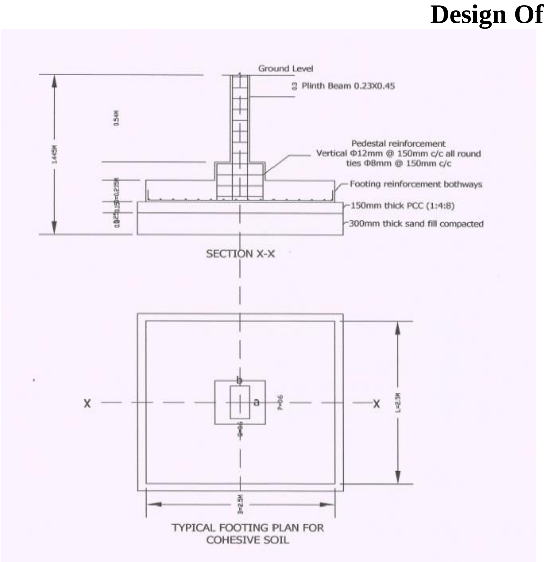
Net ult B.C = $1.3c'N_{c'} + r{\cdot}D(N_{q'}-1) + 0.4BNr'$

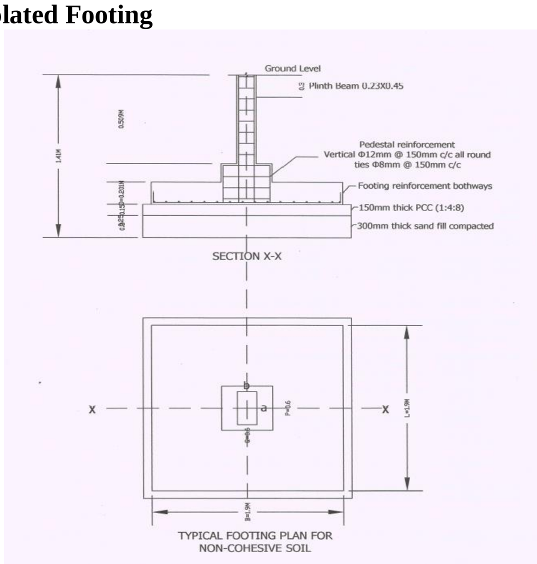
= $474\ kN/m^2$

With a FS of 3, SBC = $158\ kN/m^2$

Recommended safe Bearing capacity is $15\ kN/m^2$

Design Of Isolated Footing





Cohesive Soil

Load coming on each column = 500kN, Allowable soil pressure = $80kN/m^2$, Size of column = 0.23m × 0.45m.

Area of footing = $\frac{Q}{q} = \frac{500}{80} = 6.25\ mm^2$

$B = \sqrt{6.25} = 2.5$ m

$M = \frac{q*B*(B-b)2}{8} = \frac{80*2.5*(2.5-0.23)2}{8} = 128.83$ kN-m

Rectangle width $= b + \frac{(B-b)}{8}$

$= 0.23 + \frac{(2.5-0.23)}{8} = 0.51$ mm

$M_r = Rbd^2 = 128.82*1000 = 0.874*0.513*d^2$

d = 540 mm

$p_o = \frac{500}{2.5*2.5} = 80\ kN/mm^2$

$F = p_a(B^2-b^2)$

$b_0 = (b+d) = 0.23+0.54 = 0.77$mm

$F = 80*(2.5^2-0.77^2) = 452$kN

$\Gamma v = \frac{F}{4*bo*do} = \frac{452}{4*0.77*do}$

$\Gamma v = 0.16*\sqrt{20} = 0.715kN/mm^2$

$d_o = 205$mm

Size of Footing = 2.5m × 2.5m × 0.205m

Non-Cohesive Soil

Load coming on each column = 500kN, Allowable soil pressure = $150kN/m^2$, Size of column = 0.23m × 0.45m.

Area of footing = $\frac{Q}{q} = \frac{500}{150} = 3.3\ mm^2$

$B = \sqrt{3.3} = 1.9$ m

$M = \frac{q*B*(B-b)2}{8} = \frac{150*2.5*(2.5-0.23)2}{8} = 99.35$kNm

Rectangle width $= b + \frac{(B-b)}{8}$

$= 0.23 + \frac{(1.9-0.23)}{8} = 0.439$ mm

$M_r = Rbd^2 = 128.82*1000 = 0.874*0.439*d^2$

d = 509 mm

$p_o = \frac{500}{1.9*1.9} = 138.504kN/mm^2$

$F = p_a(B^2-b^2)$

$b_0 = (b+d) = 0.23+0.509 = 0.739$mm

$F = 138.504*(1.9^2-0.739^2) = 424.376$kN

$\Gamma v = \frac{F}{4*bo*do} = \frac{424.376}{4*0.739*do}$

$\Gamma v = 0.16*\sqrt{20} = 0.715kN/mm^2$

$d_o = 201$mm

Size of Footing = 1.9m × 1.9m × 0.201m

II. Conclusion

Based on the field tests and design considerations the following conclusions were drawn.
The size of footing in cohesive and noncohesive soils the dimensions are (2.5m × 2.5m × 0.205m) and (1.9m × 1.9m × 0.201m) respectively. The volume of footings are 1.28m^3 and 0.72m^3 for cohesive and noncohesive soils respectively with a % change in volumes is (0.72/1.28)*100 = 56.25. So the volume of foundation required in cohesive soil is 56.25% more than the volume required for non-cohesive soils. That shows that the construction cost of a foundation is 56.25% more in cohesive soils. The load coming on each column is same i.e., 500 KN. But the size of footing in Non-Cohesive soil is 2.5m × 2.5m × 0.205m and in case of Cohesive soil the size is 1.9m × 1.9m × 0.201m that shows us for same intensity of load the size of isolated footing in Cohesive soil is nearly two times more than that of Non-Cohesive soils. It shows that in case of Cohesive soils Isolated footing is not advisable as it is two times costlier than Non-Cohesive soils. So in Cohesive soils we have to go for another type of foundation like Pile grouping, Well foundation etc. If we are constructing a Commercial or Apartment building then we can go for a deep foundation in cohesive soils. Where as if we are laying a road then we should stabilize the existing ground below the proposed road using different stabilizing techniques to minimize the cost of construction and go for the construction. In case of foundations for bridges we should go for well foundation or group piling.

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