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Performance Study of Vertical Skirted Rectangular Combined Footing Subjected to Higher loads

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ABSTRACT: A typical case in combined footing is one, in which footing is subjected to load higher than actual load which it can carry from allowable safe bearing capacity consideration. It results in excessive settlement of the footing. In such situations skirted combined footing may proves to be an innovative and economical solution. Skirt is a vertical projection below the footing plane which helps in confining the under lying soil and thus improving its bearing capacity. Present study is focused on finding the effectiveness of vertical skirts, provided under a rectangular combined footing, to control the maximum settlement within the permissible limits and at the same time increasing the bearing capacity of the soil. For this purpose three footing sizes F1, F2, & F3 resting on two types of soil for five different cases based on location of skirts, have been analyzed by using FEM based software SAP2000 vs.18. These five cases along with locations also incorporate depth of skirt for analysis.

The study shows that rectangular combined footing with vertical skirt all around the four edges is most efficient way to increase bearing capacity of the soil and control excessive settlement of the footing.

Keywords: Rectangular combined footing, maximum settlement, location of skirt, depth of skirt, SAP2000vs.18.

I. INTRODUCTION:

A combined footing supports load of two or more adjacent columns. Combined footing is considered as a special case of isolated footing with number of columns placed on a common footing area. The area of the footing is provided in such a way that there is uniform pressure distribution under the footing. For this the c. g. of footing area x 0.55), (F2 = 3 x 7.5 x 0.60) & (F3 = 3 x 9 x 0.7) are considered.

As stated above, the footings F1, F2 & F3 are subjected to two equal column loads placed should coincide with the c. g. of the columns. Combined rectangular footing is common in field and is usually provided for two columns.

In the present study a special case of combined rectangular footings with two columns is considered in which the columns with equal loads are symmetrically placed on the footing. And at the same time the combined rectangular footing is subjected to load higher than actual load. The actual load is defined as the load carrying capacity of the footing worked out on the basis of safe allowable bearing capacity of the soil and footing area provided. Usually the area of a footing is worked out on the basis of safe bearing capacity of the soil; but many a times it's not possible to provide the required area due to various reasons. Such cases fall under the above category. For these higher load cases restricting the settlement within permissible limit is a great challenge.

It has been established for isolated footings, that the provision of vertical skirt below the footing is an innovative technique to reduce the maximum settlement and to ensure uniform soil pressure soil pressure below the footing. The skirt is a vertical wall projected below the footing area. The skirts may be provided at various locations and may be of different depths. These helps in confining the underlying soil below the footing and thus improve the bearing capacity of the soil and in turn restrict the settlement.

In present study combined rectangular footing with two equally loaded symmetrically placed columns with three different aspect ratios (L/B=2.0, L/B=2.5 & L/B=3.0) have been considered. Where, L indicates length and B width of combined rectangular footing. On the basis of aspect ratios three footing sizes (F1 = 3 x 6 equidistant from the shorter edge of the footing. The applied loads (higher loads considered) are calculated considering a value of the safe allowable bearing capacity of soil as 200 KN/m^2.

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For the combined rectangular footings F1, F2 & F3 five different locations of the skirts have been considered. All the five different locations of vertical skirt have been designated as five cases ranging from Case-I to Case-V for three footings. In first four Cases i.e. Case-I to IV the vertical skirts have been considered parallel to shorter edge of the footing, where in Fifth case i.e. Case-V the vertical skirts provided at all around the four edges of footing. The various cases considered are summarized as follows.

Case-I: Combined rectangular footings F1, F2 & F3 with vertical skirt parallel to shorter edge provided at the centre of gravity (c. g.) of the footing, shown in figure 2. The various depths of skirts provided are - 0mm, 250mm & 1000mm. The two types of soils considered are having bearing capacities of 80 KN/m^2 and 160KN/m^2, respectively.

Case-II: Combined rectangular footings F1, F2 & F3 with vertical skirt parallel to shorter edge provided equidistantly from both the shorter edges of the footings i.e. for F1 = 2.0m, F2 = 2.5m & F3 =3.0m, shown in figure 3. The various depths of skirts provided are - 0mm, 250mm & 1000mm. The two types of soils considered are having bearing capacities of 80 KN/m^2 and 160KN/m^2, respectively.

Case-III: Combined rectangular footings F1, F2 & F3 with vertical skirt parallel to shorter edge provided below two columns of the footing, shown in figure 4. The various depths of skirts provided are - 0mm, 250mm & 1000mm. The two types of soils considered are having bearing capacities of 80 KN/m^2 and 160KN/m^2, respectively.

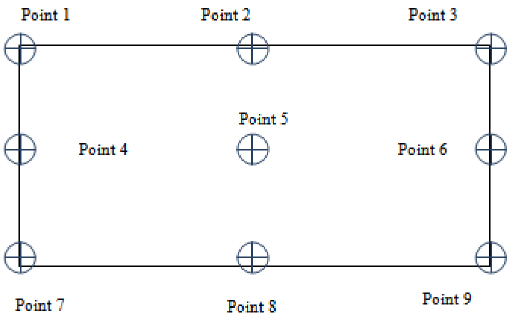
Case-IV: Combined rectangular footings F1, F2 & F3 with vertical skirt provided along two opposite parallel shorter edges of the footing, shown in figure 5. The various depths of skirts provided are - 0mm, 250mm & 1000mm. The two types of soils considered are having bearing capacities of 80 KN/m^2 and 160KN/m^2, respectively.

Case-V: Combined rectangular footings F1, F2 & F3 with vertical skirts all around the four edges of the footing, shown in figure 6. The various depths of skirts provided are - 0mm, 250mm & 1000mm. The two types of soils considered are having bearing capacities of 80 KN/m^2 and 160KN/m^2, respectively.

To study settlement and soil pressure below the three footings nine observation points located on footing area have been considered. The maximum values of settlement and soil pressure have been studied for both the values of bearing capacities of soil. The nine point observations are compared for all the five cases of the three footings F1, F2 & F3, for two types of soils. These observations for different five cases show the better performance of vertical skirt based on location and depth, to control the soil pressure and maximum settlement.

All the above mentioned cases indicate failure of case – (I to IV) with regards to control the settlement based on nine point observations, except case-V. This failure is clearly indicated with the bar chart for four cases respectively. The provision of vertical skirts reduces the maximum settlement within the permissible limit as in case-V.

Figure1. General Arrangement of observation points on Combined Footing



II. LITERATURE REVIEW

The research that conducted by

[1] Ortiz (2001) inserted a discontinuous vertical skirt dowels around existing foundation. A marked increase 20 % in the bearing capacity and a reduction of settlement were observed.

[2] Gourvenec (2002, 2003) applied two and three dimensional finite element analysis to assess the behaviour of strip and circular skirted foundations subjected to combined vertical, moment, and horizontal loading.

[3] Al-Aghbari and Zein (2004, 2006) was performed tests on strip and circular footing models resting on sand.

[4] Nighojkar S. and Mahiyar H.K. (2006) had studied experimentally Bi-angle shaped skirted footing subjected to two way eccentric load under mixed soil condition.

[5] Experimental study on the Performance of skirted strip footing subjected to eccentric inclined load was performed by Nasser M. saleh et.al (2008).

[6] EI WAKIL(2013) using 18 laboratory test of skirted circular footing that machined from steel, with the sand as the media of testing and concluded that the use of skirted footing is very effective on

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increasing the value of footing bearing capacity.

[10] Performance of vertical skirted strip footing on slope using finite element software PLAXIS 2D by Dr. S. PUSADKAR et.al (2016). A series of various numerical model were analyzed using PLAXIS 2D to evaluate the bearing capacity of strip footing with and without structural skirts resting on sand slopes.

[11] Thakare Et al (2016) studied the performance of rectangular skirted footing resting on sand bed subjected to lateral loads and concluded that as the D/B ratio increases from 0.5 to 2.0, the ability of skirted footing for resisting lateral load increases up to 300%. Mohammed Y.

[12] Al-Aghbari and A. Mohamedzeim (2018) investigate the use of skirts to improve the bearing capacity and to reduce the settlement of circular footing resting dune sand. The improvement in bearing capacity is upto about 470% for a surface footing with skirt of depth 1.25Band settlement reduces by 17%.

[14] B. Naik et. al (2020) studied the settlement of single skirt Isolated square footing for different skirt parameters and found that the effectiveness of skirted foundation be very significant when skirt is provided symmetrically or coaxial to the footing side. Whereas the effect of size of footing and value of net upward soil pressure does not affect the settlement of single skirted footing much as compared to the depth of skirt.

[15] S. Nighojkar et.al (2020) have conducted the performance study of skirt depth on settlement and net upward pressure characteristics of single skirted Isolated square footing and concluded that at near side on which skirt is provided, the average settlement is reduces by 40 to 60% of skirt depth 250 mm and by almost 60 to 70% for skirt depth of 1500 mm.

[16] S. Nighojkar et.al (2020) on finite element modelling of Bi-angle shape skirted footing resting on clayey soil using SAP2000 Vs.18 and concluded that skirted footing resting on clayey soil having low bearing capacity of 80 KN/m^2 is taking load which belongs to 1.87 times higher upward pressure of soil. Also for various skirt depths, settlement of footing comes within the assumed permissible limit of 25 mm. Though the initial settlement of the footings was already within the permissible limit for higher bearing capacity of 200 KN/m^2.

In this paper; the rectangular combined footing of three different sizes F1, F2 & F3 subjected to equally loaded columns studied for five different locations of vertical skirt. Analysis performed to get effectiveness of location of skirt. The study suggest better location of skirt to reduce maximum settlement and soil pressure of model footing F1, F2 & F3 using finite element software SAP 2000 vs.18.

III. MODELLING:

A series of finite element models for combined footings F1, F2 & F3 are prepared and analyzed by using software SAP2000 Vs.18. The material for footings and skirt is same and thickness of skirt is 200mm for all five cases. Thick shell element considered for footing models and skirt to perform linear static analysis. The thickness of skirt is considered as 200 mm. The material properties mentioned in Table 2, are applicable to combined footings as well as skirt.

The investigation on combined footings F1, F2 & F3 consists five different cases based on locations of skirt. The depths for skirt considered are 0mm (footing without skirt) 250mm and 1000mm (footing with skirt). The combined footings F1, F2 & F3 are considered to be resting on two different types of soils having safe bearing capacity of 80 KN/m^2 and 160KN/m^2.

The total load on footing is greater than the actual load from safe bearing capacity criteria. The load on the footings (higher load) has been worked out considering safe bearing capacity of the soil as 200KN/m^2. Thus for the footings higher loads considered are 3600.0KN, 4500.0KN and 5400.0KN for F1, F2 and F3 footings respectively. The higher actual load has been kept constant for the footings even when they are considered to be resting on two different types of soils. The two columns considered, are equally spaced from the shorter edge of combined footing F1, F2 & F3. The two columns are considered to be equally loaded for all the three footings. Thus, the columns in each footing F1, F2 and F3, shall be subjected to a higher load of 1800.0KN, 2250.0KN and 2700.0KN, respectively. When the footing is resting on soil with bearing capacity as 80KN/m^2 the actual load carrying capacities of the three types of footings shall be 1440KN, 1800KN and 2160KN, for the three footings F1, F2 and F3, respectively. Similarly for the soil with bearing capacity as 160KN/m^2 the actual load carrying capacity of the three types of footings are 2880KN, 3600KNand 4320KN, respectively.

Allowable maximum permissible settlement of model footing analysis in SAP2000 vs.18 is restricted to 25mm.

Table 2: Material properties for Model Footings

S. No.	Parameter	Value
1.	Material Name	M20
2.	Material type	Concrete
3.	Weight per unit volume	24.9926
4.	Mass per volume	2.5485
5.	Modulus of elasticity	22360680
6.	Poisson ratio	0.2
7.	Coefficient of thermal expansion A	5.500E-6
8.	Shear modulus G	9316950
9.	fck	20000

Figure 2: Case-I - Model of combined footing with skirt at c. g. of footing.

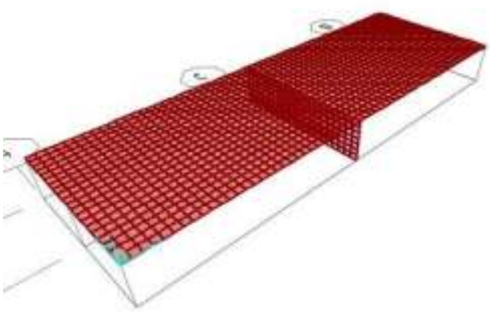

Figure 3: Case-II - Model of combined footing with two skirts equidistant from shorter edges.

Figure 4: Case-III - Model combined footing with two skirts below column load.

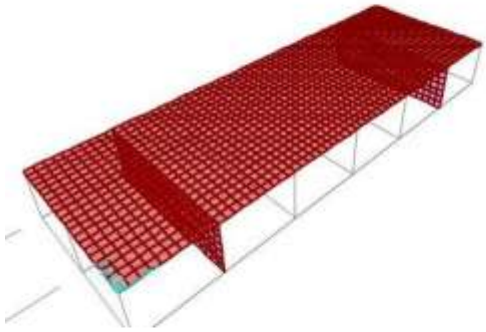

Figure 5: Case-IV - Model combined footing with two skirts on two opposite parallel shorter edges.

Figure 6: Case-V - Model combined footing with Four Skirts all around the edges

IV. RESULT & DISCUSSION:

In this study combined footings (F1, F2 & F3) resting on two types of soil having bearing capacity of 80 KN/m2 and 160KN/m2 have been analyzed. Five different cases based on locations and depth of skirt discussed. The footings are

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subjected to loads higher than the actual load from allowable safe bearing capacity criteria.

This results in excessive settlement and soil pressure below the footing. Results obtained from modelling and analysis clearly indicates the effectiveness of skirt in controlling the settlement and improving bearing capacity thus increasing soil pressure below the footing. Following bar charts between settlement V/S skirt depth and soil pressure V/S skirt depth presented below.

Figure 7-(A): Bar Chart for Max Settlement of Footing (F1)

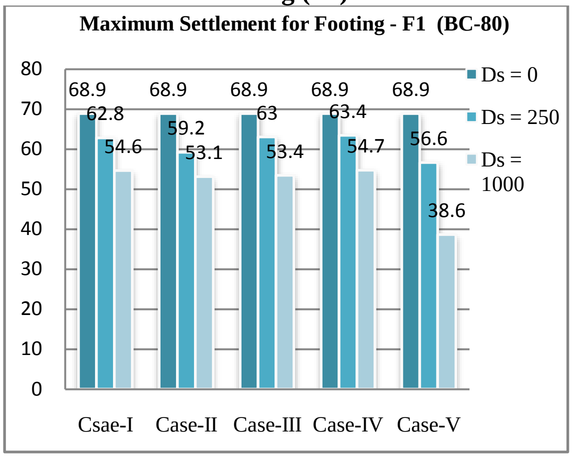

Figure 7-(B): Bar Chart for Max Soil pressure of Footing (F1)

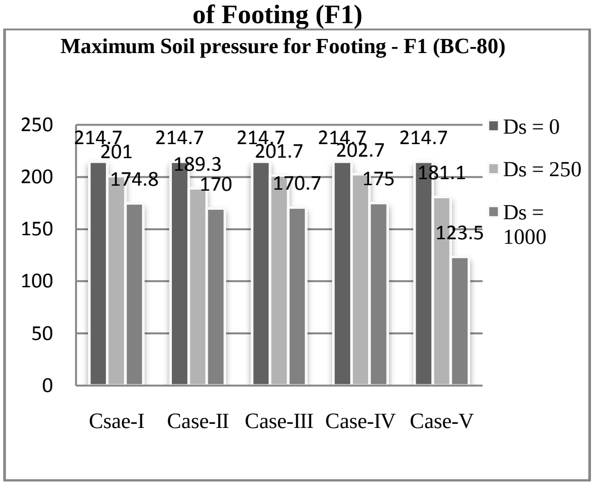

Figure 8-(A): Bar Chart for Max Settlement of Footing (F1)

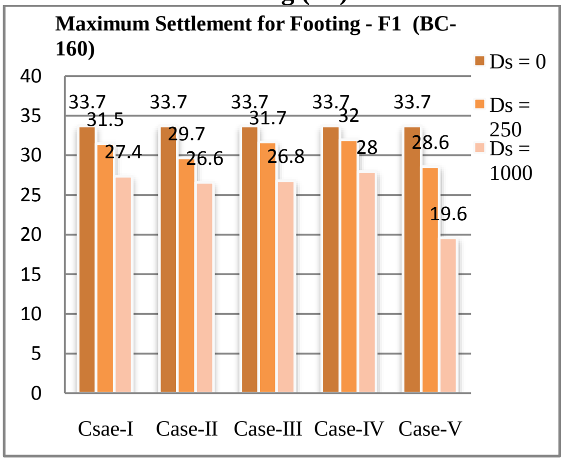

Figure 8-(B): Bar Chart for Max Soil pressure of Footing (F1)

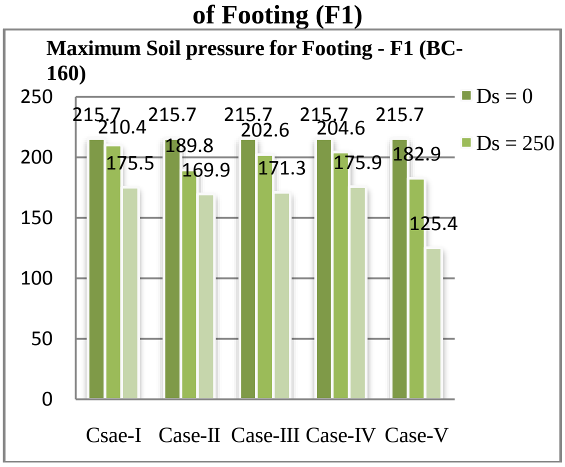

Figure 9-(A): Bar Chart for Max Settlement of Footing (F2)

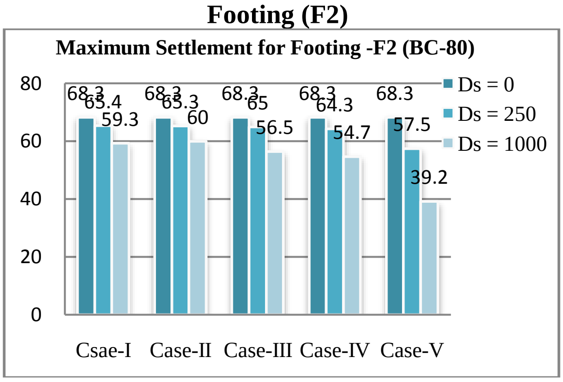

Figure 9-(B): Bar Chart for Max Soil pressure of Footing (F2)

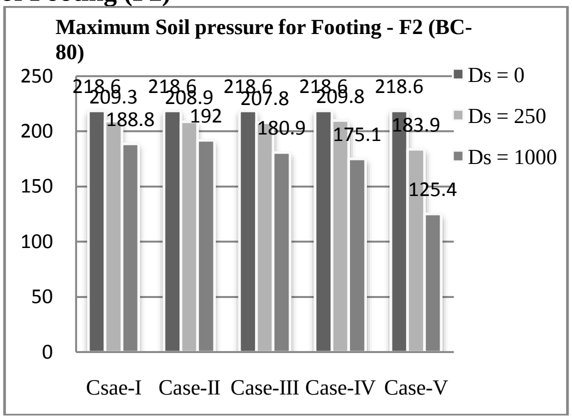

Figure 10-(A): Bar Chart for Max Settlement of Footing (F2)

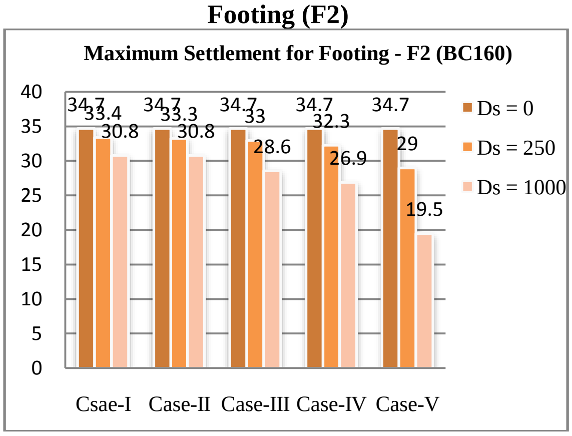

Figure 10-(B): Bar Chart for Max Soil pressure of Footing (F2)

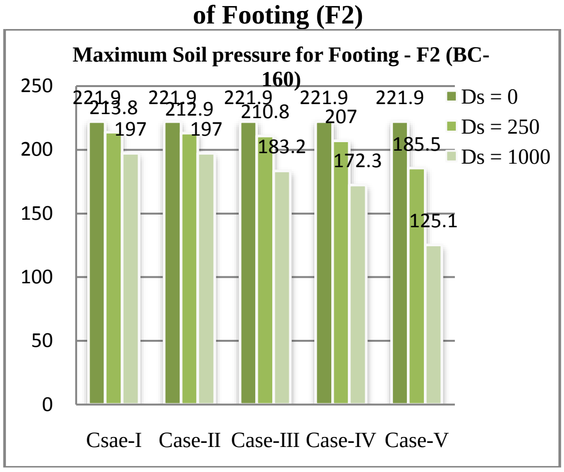

Figure 11-(A): Bar Chart for Max Settlement of Footing (F3)

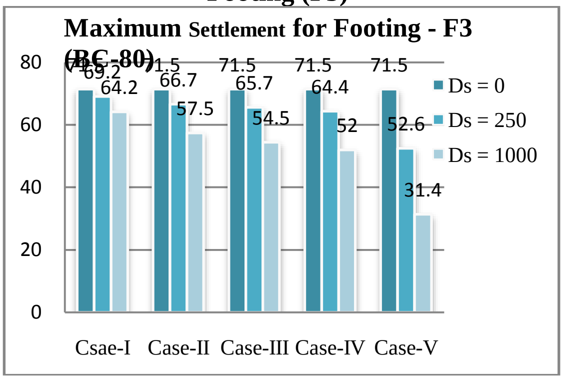

Figure 11-(B): Bar Chart for Max Soil pressure of Footing (F3)

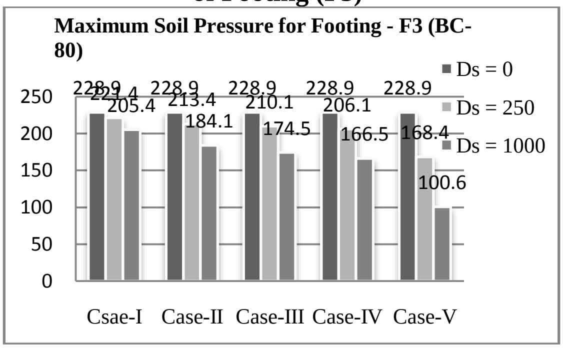

Figure 12-(A): Bar Chart for Max Settlement of Footing (F3)

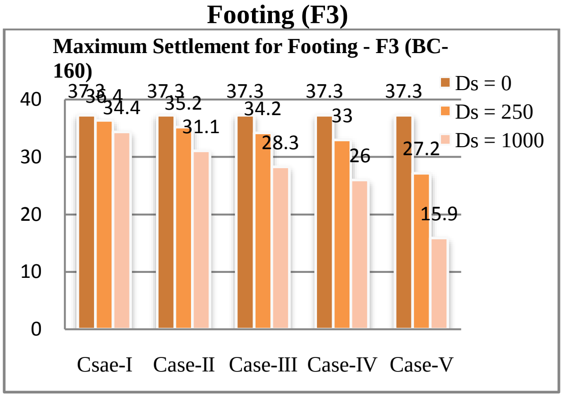

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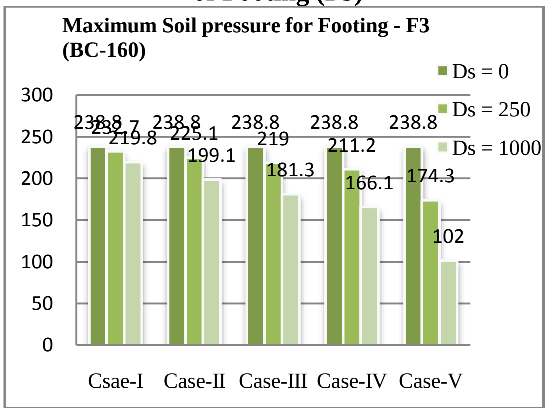
Figure 12-(B): Bar Chart for Max Soil pressure of Footing (F3)



V. DISCUSSION:

The results for the three footings F1, F2 and F3 with L/B ratio 2.0, 2.5 and 3.0 respectively has been presented independently in the following paragraphs.

FOOTING- F1 WITH (L/B=2.0)

For first four cases Case-I to IV following points are observed from Figures 7(A), 7(B) & 8(A), 8(B) -

As the depth of skirt increases maximum settlement reduces. The values of maximum settlement decreases by almost 50% when bearing capacity of soil increases from 80 KN/m^2 to 160 KN/m^2.

The settlement exceeds the maximum permissible value of 25mm considered.

The variation of maximum soil pressure for both the values of bearing capacity of soil is almost same. This shows that variation of maximum soil pressure below the footing is independent of bearing capacity of soil.

And for case-V the observations referring figure 7(A), 7(B) & 8(A), 8(B) are-

The maximum settlement value below footing resting on soil having bearing capacity 160KN/m^2 is found to be within restricted permissible limit 25mm, when the depth of skirt provided is ranging from 500mm to 1000mm.
The maximum settlement values exceeds than the restricted limit of 25mm. this shows failure of footing at low bearing capacity of soil i.e. 80KN/m^2. The value of maximum soil pressure exceeds allowable bearing capacity 80KN/m^2 showing higher confinement of soil below the footing.

FOOTING- F2 WITH (L/B=2.5)

Again for first four cases Case-I to IV following points are observed from Figures 9(A), 9(B) & 10(A), 10 (B) -

As the depth of skirt increases maximum settlement reduces. The values of maximum settlement decreases by almost 50% when bearing capacity of soil increases from 80 KN/m^2 to 160 KN/m^2.

Though the maximum settlement values are exceeding the restricted permissible limit of settlement 25mm, shows the failure hence not recommended.

Maximum soil pressure belongs to both the values of bearing capacity of soil are almost same. This shows that variation of maximum soil pressure below the footing is independent of bearing capacity of soil.

And for case-V the observations referring figure 9(A), 9(B) & 10(A), 10(B) are-

The maximum settlement value below footing resting on soil having bearing capacity 160KN/m^2 is found to be within restricted permissible limit 25mm, when the depth of skirt provided is ranging from 500mm to 1000mm.

The maximum settlement values exceeds than the restricted limit of 25mm. this shows failure of footing at low bearing capacity of soil i.e. 80KN/m^2.

FOOTING- F3 WITH (L/B=3.0)

For first four cases Case-I to IV following points are observed from Figures 11 (A), 11 (B) & 12 (A), 12 (B) -

As the depth of skirt increases maximum settlement reduces. The values of maximum settlement decreases by almost 50% when bearing capacity of soil increases from 80 KN/m^2 to 160 KN/m^2.

Though the maximum settlement values are exceeding the restricted permissible limit of settlement 25mm, shows the failure hence not recommended.

Maximum soil pressure belongs to both the values of bearing capacity of soil are almost same. This shows that variation of maximum soil pressure below the footing is independent of bearing capacity of soil.

And for case-V the observations referring figure 11(A), 11(B) & 12(A), 12(B) are-

The maximum settlement value below footing resting on soil having bearing capacity 160KN/m^2 is found to be within restricted permissible limit 25mm, when the depth of skirt provided is ranging from 500mm to 1000mm.

The maximum settlement values exceeds than the restricted limit of 25mm. this shows failure of footing at low bearing capacity of soil i.e. 80KN/m^2.

VI. CONCLUSIONS:

From the study of combined footing having various (L/B) ratios, with different skirt locations the bar chart of all the five cases show the value of settlement and soil pressure.

(i) For the bearing capacity 80KN/m^2 among all the five cases; the case V with skirt (Ds=1000mm) reduces the maximum settlement almost 50% in comparison to footing without skirt i.e. (Ds=0mm)

(ii) For the bearing capacity 160KN/m^2 among all the five cases; the case V with skirt (Ds=1000mm) restricted the value of maximum settlement within permissible limit.

(iii) For bearing capacity 80KN/m^2 & 160KN/m^2 all the cases of combined footing with skirt shows the almost same value that means the settlement of footing is independent from soil pressure.

(iv) The combined footing with skirt does not perform satisfactory for higher load than the actual load as observed for soil with bearing capacity of 80kN/m^2. Here the load applied on the footing is 2.5 times the actual load carrying capacity of the soil.

(v) The combined footing with skirt having performs satisfactory for higher load than actual load only when skirt provided all around the four edges but the actual load is not very high.

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