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Design Of Skirted Rectangular Combined Footing With Vertical Skirt All Around The Four Edges

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Abstract:

Skirted foundation is finding its way as an advance foundation technique for non offshore structures. It is one of the latest foundation improvement techniques. So far skirted footings have been studied for isolated footings. The studies done for skirted rectangular combined footing shows that it is one of the effective techniques of foundation improvement, for combined footing. The combined rectangular footing with vertical skirts all around the edges has been found to be most efficient technique amongst the various skirt locations. The depth of skirt also plays an important role in improving the performance of the footing. Assessing the depth of skirt for a combined footing is a challenging job. The Studied presented helps in arriving at the depth of skirt to arrest the foundation settlement and pressure even at higher load than normal.

Index Terms: **Combined footing, depth of skirt, higher load, settlement, soil pressure, vertical skirt.**

INTRODUCTION

The study carried out earlier shows that provision of skirts with combined footing can be a better foundation improvement technique. It has been reported in the literature that combined rectangular footing with skirts all around the edges of footing is the best alternative. It can arrest the settlement and soil pressure under the footing within permissible limit, even if the footing is subjected to load(actual load on footing) higher than load (Normal load)carrying capacity of the combined footing calculated on the basis of safe bearing capacity of the soil and area of footing. The ratio of actual load i.e. load on the footing to normal load, i.e. load carrying capacity of the footing, is defined as Load Ratio.

Usually, in combined footing Length (L) to Breadth (B) ratio is usually greater than 2. When footing area is such that L/B ratio is likely to exceed 3, in such cases usually strap beam footings are provided. Combined footing has been sufficiently thick to ensure rigid body or thick plate function. In deciding the type of footing and size of footing bearing capacity of the soil plays an important role. In the present work two types of soils with bearing capacities of $80kN/m^2$ and $160kN/m^2$ have been considered.

The skirts provided under the footing are usually of the same material as that of the footing. For modelling the footing and skirts are considered to be of concrete. Thickness of skirts considered is 200mm. It can easily be worked up to a depth of 1500mm with modern digging equipment's or even manually. In this study, different skirt depths considered, ranges from 0mm (i.e. No skirt condition) to 1250mm.

For present study a combined footing F with L/ B ratio as 3 has been considered. Usually maximum width of footing is restricted to 3.0m which commonly is spacing of columns in a normal building with regular layout. Thus, a combined footing "F", of size3m x9m x0.7m, with two symmetrically placed columns with equal loads and skirts all around the edges of footing has been considered.

The variation of maximum settlement of combined rectangular skirted footing F (3m x 9m x 0.7m) with various load ratios ranging from LR 1.00 to 1.75 has been studied. Similarly, the effect of skirt depth on maximum soil pressure under the footing is also studied for the two types of soil with bearing capacities as stated above.

Earlier studies have shown that the maximum settlement and pressure under the combined rectangular footings is independent of size of footing. Hence it could be concluded that making use of the graphs prepared on the basis of above studies, the maximum settlement and pressure under of any combined rectangular skirted footing can be obtained.

To ascertain this, further work is carried out to predict the depth of skirt for a combined rectangular footing with two symmetrically placed columns with equal loads. In this work the soil with different bearing capacity than considered in the above studies has been considered. For this a new combined rectangular footing F1 and F2, with all parameters different than the considered in the study of combined footing F, is considered. The models of the two footings are prepared with the software and results of the settlement and pressure under the footings are compared with the results obtained from the graphs obtained based on earlier study.

The main objective of this study to obtain design parameter of the vertical skirt for a rectangular combined footing subjected to symmetrically placed two equal column loads. For this purpose two types of soil having low bearing capacity 80KN/m^2 and higher bearing capacity 160KN/m^2 are considered. The results obtained from numerical study of footing on these soils will be validated for other values of bearing capacity of soils as 100KN/m^2 and 200KN/m^2.

LITERATURE REVIEW

The research that conducted by 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. 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. Al-Aghbari and Zein (2004, 2006) was performed tests on strip and circular footing models resting on sand.

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

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 increasing the value of footing bearing capacity. 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. 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. 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%.

B. Naiket. 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.

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.

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/m2 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.

B. Naiket. al (2020) studied the effect of location of vertical skirt on three different (L/B) ratios of rectangular combined footing subjected to higher load on two different soil bearing capacities of 80 KN/m^2 & 160 KN/m^2. Five different cases based on location of vertical skirt have been studied to control the maximum settlement and soil pressure below the combined footing. Among all the vertical skirt all around the four edges performed better.

B. Naik et. al(2020) studied the rectangular combined footing with (L/B) ratio 1:3 resting on two types of bearing capacities of soil for various location of vertical skirt for at various depth of skirt and the study extended for a particular case of vertical skirt all around the four edges of footing at different load ratios. On various load ratios and depth of vertical skirt the maximum settlement and soil pressure have been investigated.

In this paper; design parameters to ascertain the depth of skirt for rectangular combined footing of different sizes subjected to different load ratios on various types of soil. Analysis performed to get effectiveness of provision of skirts all around the edges of the combined footing. The study suggest appropriate depth of skirt to arrest maximum settlement and soil pressure within permissible limit, using finite element software SAP 2000 vs.18.

1. MODELING AND OBSERVATION

The rectangular combined footing, “F” (3m x 9m x 0.7m), modelled and analyzed using finite element modelling based software SAP2000 Vs.18. The analysis is performed to get the values of maximum settlement and soil pressure beneath the footing F. Applied load on the footing F are higher than the actual load from safe bearing capacity criteria. Thick shell element considered for rectangular combined footing F and skirt to perform linear static analysis. The material properties mentioned in Table 1 are applicable to combined footing F as well as skirt.

Table 1: Material Properties for Model of Footing and Skirt

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

Table no. 2 shows the applied load on each column calculated on the basis of different load ratios (LR). The different skirt depths and various load ratios on footing F considered for analysis as tabulated below in Table no. 3 & 4 for bearing capacity 80KN/m^2 and 160KN/m^2 respectively. Figure 1 shows the geometry of rectangular combined footing F with skirts all around the edges.

Table No. 2 Load Ratios (LR) and Load on Each Column

S. No.	Load Ratio (LR)	Load (KN)
1	1.00	2160
2	1.25	2700
3	1.50	3240
4	1.75	3780

Table No. 3: Maximum Settlement for various Load Ratios (LR) and Skirt Depths

S. No.	BC (KN/m^2)	Skirt Depth (mm)	Maximum Settlement (mm)			
			LR - 1.00	LR - 1.25	LR - 1.50	LR - 1.75
1	***80***	***0***	***31.9***	***38.5***	***45.1***	***51.7***
2	80	250	23.6	28.4	33.3	38.1
3	80	500	18.7	22.5	26.3	30.1
4	80	750	17.0	20.4	23.8	27.3
5	80	1000	15.2	17.2	20.1	22.9
6	80	1250	12.5	14.9	17.4	19.8
7	***160***	***0***	***30.4***	***37.5***	***44.2***	***51.2***
8	160	250	22.2	27.2	32.3	37.3
9	160	500	17.4	21.3	25.3	29.2
10	160	750	15.6	19.1	22.6	26.1
11	160	1000	13.1	15.9	18.8	21.7
12	160	1250	11.2	13.7	16.2	18.6

Table No. 4 Maximum Soil Pressure for Various Load Ratios (LR)

S. No.	BC (KN/m^2)	Skirt Depth (mm)	Maximum Pressure (KN/m^2)			
			LR - 1.00	LR - 1.25	LR - 1.50	LR - 1.75
1	80	0	102.0	123.2	144.3	165.4
2	80	250	75.5	90.9	106.4	121.9
3	80	500	59.9	72.1	84.2	96.4
4	80	750	54.4	65.3	76.3	87.2
5	80	1000	45.1	55.1	64.2	73.3
6	80	1250	39.9	47.7	55.5	63.3
7	160	0	194.6	238.8	283.1	327.4
8	160	250	142.1	174.3	206.5	238.7
9	160	500	111.4	136.5	161.6	186.7
10	160	750	100.0	122.4	144.8	167.1
11	160	1000	83.5	102.0	120.6	139.1
12	160	1250	71.8	87.6	103.5	119.3

Results obtained from the modelling and analysis of footing F (3x9x0.7m) is presented in tabular form and in terms of graphs, for maximum settlement and soil pressure. The variation of maximum settlement when plotted against skirt depth for two different bearing capacities of the soil considered shows that it is independent of bearing capacity of the soil. Similarly, the variation of maximum pressure under the footing with different depths of skirt is identical for the two types of soils. Or it can be said that variation in maximum pressure is independent of the bearing capacity of the soil.

The different skirt depths (Ds) ranging from 0 to 1250mm and two types of soil with bearing capacity 80KN/m^2 and 160KN/m^2 are considered. The graphs for settlement and soil pressure for the skirted combined footing subjected to various load ratios 1.00, 1.25, 1.50 to 1.75 have been plotted. Results shows that with increasing depth of skirt settlement and soil pressure below the footing decreases even with increase in load ratios.

Table No.5: Parameters for Modeling of Footing F - (3 m x 9 m x 0.7m)

S. No.	**B.C. of Soil (KN/m^2)**	**Load Ratio**	**Depth of skirt Provided (mm)**
1	80	1.00	**0**, 250, **500,**750, **1000**&1250
2	80	1.25	**0**, 250, **500,**750, **1000**& 1250
3	80	1.50	**0**, 250, **500,**750, **1000**&1250
4	80	1.75	**0**, 250, **500,**750, **1000**&1250
5	160	1.00	**0**, 250, **500,**750, **1000**&1250
6	160	1.25	**0**, 250, **500,**750, **1000**&1250
6	160	1.50	**0**, 250, **500,**750, **1000**&1250
8	160	1.75	**0**, 250, **500,**750,**1000**&1250

The variation of maximum settlement and maximum soil pressure under the footing has been tabulated in the Table No. 3 and 4 and the variation has been represented graphically in the Figures 3(a), 3(b) & 4(a), 4(b), respectively.

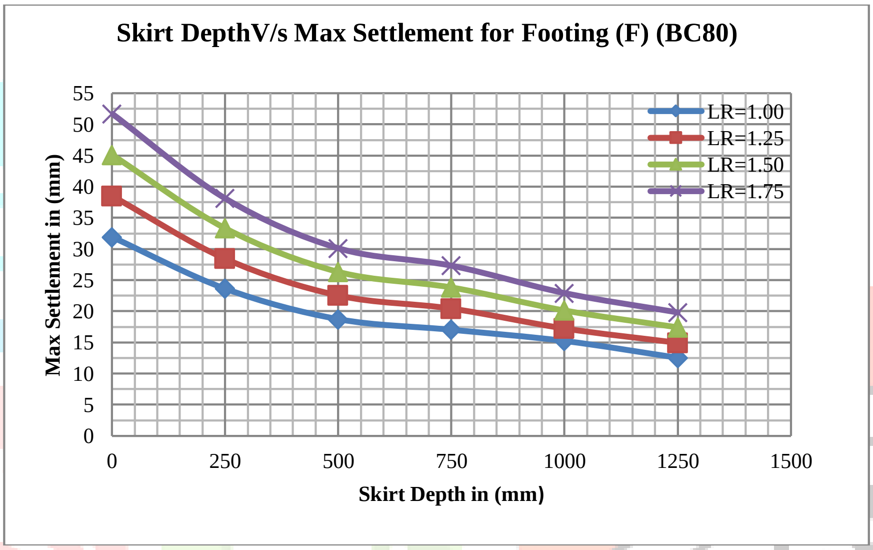

Figure 3(a): Graph Skirt depth V/s Maximum Settlement for Combined Footing F with Soil BC 80KN/m^2

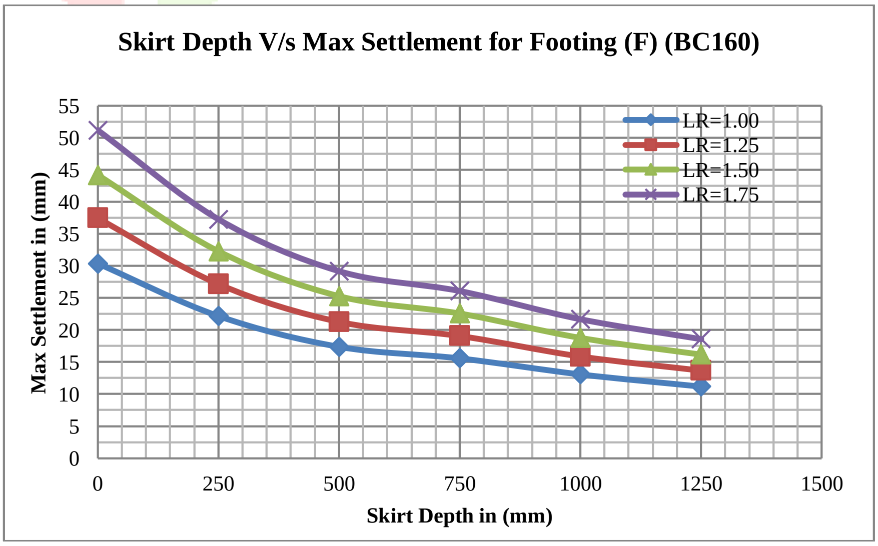

Figure 3(b): Graph Skirt depth V/s Maximum Settlement for Combined Footing F with Soil BC 160KN/m^2

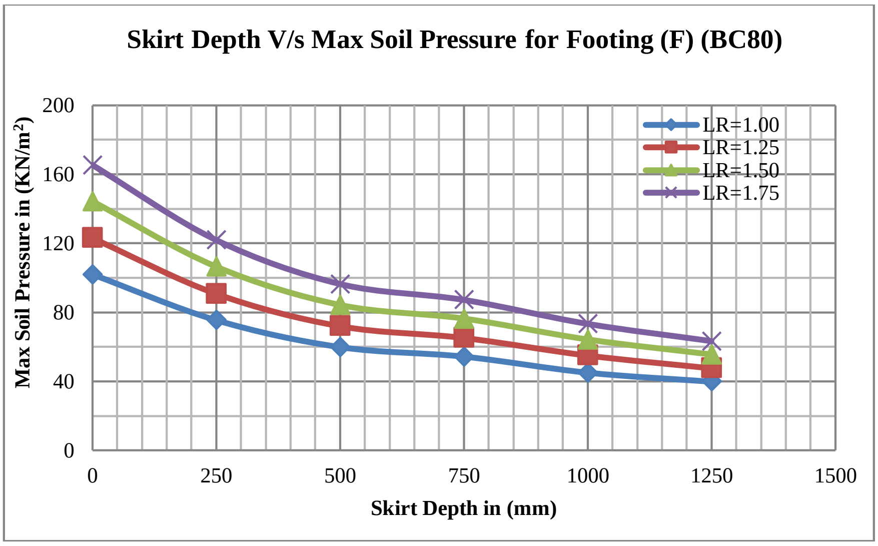

Figure 4(a): Graph Skirt depth V/s Maximum Soil Pressure for Combined Footing F with Soil BC 80KN/m^2

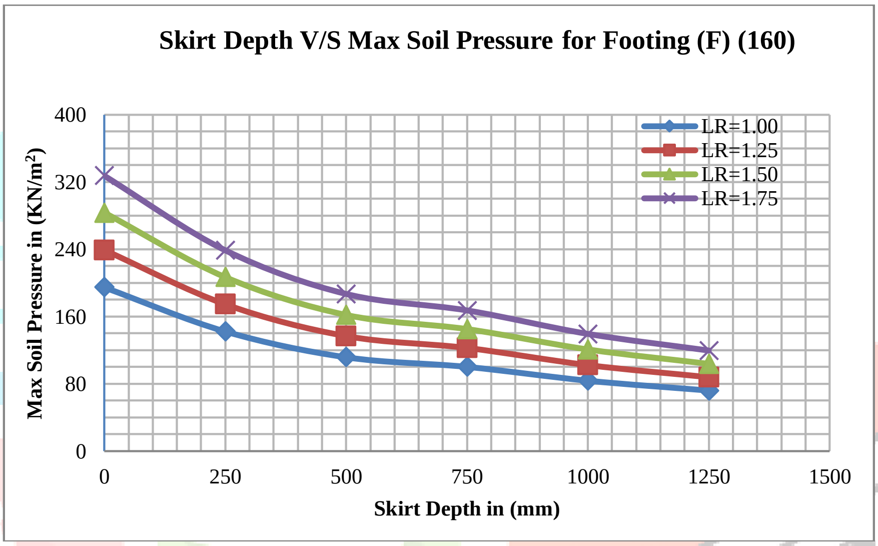

Figure 4(b): Graph Skirt depth V/s Maximum Soil Pressure for Combined Footing F with Soil BC 160KN/m^2

From the graph it's very clear that percentage reduction in settlement for the two types of soil is same. The settlement decreases by almost same percentage with increase in depth of skirt for the two types of soils. It has already been reported in the literature (B. Naik et.al.) that size of footing has no significant effect on performance of the skirted footing. Thus it could be concluded that these graphs can be used for evaluating the depth of skirt for arresting the settlement of any sized combined footing with symmetrically placed and identically loaded two columns; within permissible limits.

As stated in above paragraph for settlement similar observations can be made for maximum soil pressure under the combined footing. The two graphs above show that percentage reduction in maximum soil pressure for the two types of soil is same. Like settlement, maximum soil pressure decreases by almost same percentage with increase in depth of skirt for the two types of soils. Thus, again, it could be concluded that these graphs can be used for evaluating the depth of skirt for ascertaining the maximum soil pressure under any sized combined footing with symmetrically placed and identically loaded two columns.

2. Validation

In order to validate the above two observations modelling of two combined rectangular footing has been done. The two footings considered have the sizes (2.5mx6.0mx0.55m) & (3.0mx7.0mx0.7m) with two symmetrically placed equally loaded column. For the study load ratios considered are 1.35 and 1.60 respectively.

The first footing F_1' (2.5mx6.0mx0.55m) has got L/B ratio as 2.4 and is modelled with the soil having bearing capacity of 120KN/m^2.The load radio taken for the footing is 1.35.Thus total load on the footing considered is 2430 KN (2.5x6x120x1.35=2430). The depth of skirt has been taken as 350mm. The load is considered to be equally shared by the two columns. The footing has been modelled with the material parameters shown in Table no.1 except the soil parameter.

Similarly, the second footing F_2' (3.0mx7.0mx0.7m) has got L/B ratio as 2.33 and is modelled with the soil having bearing capacity of 160KN/m^2. The load radio taken for the footing is 1.6. Thus total load on the footing considered is 6048KN (3.0x7.0x160x1.60=6048).The depth of skirt has been taken as 550mm. The load is considered to be equally shared by the two columns. Here also the footing has been modelled with the material parameters shown in Table no.1 except the soil parameter.

The parameters considered for the two footings are shown in Table No.5.

Table No.6: Parameters Considered for Combined Footings F_1' and F_2'

S. No.	Footing Type	Size (m)	B.C. of Soil (KN/m²)	Load Ratio	Total Load (KN)	Depth of skirt (mm)
1	F_1'	2.5 x 6.0 x 0.55	120	1.35	2430	350
2	F_2'	3.0 x 7.0 x 0.70	180	1.6	6048	550

The values of Maximum settlement and Maximum soil pressure for the two modelled footingsF_1' and F_2' are tabulated in Table No.6.

Table No.7: Maximum Settlement & Maximum Soil Pressure for Combined Footings F_1' and F_2'

S. No.	Footing Type	Size (m)	Depth of skirt (mm)	Max Settlement (mm)	Max Soil pressure (KN/m²)
1	F_1'	2.5 x 6.0 x 0.55	350	26	124.9
2	F_2'	3.0 x 7.0 x 0.70	550	27.5	198.1

The first footing F_1' is being loaded with load so as to have the load ratio as 1.35. The soil on which the footing is resting has got bearing capacity of 120KN/m². Referring the graph in Figure No. 3 (a), the maximum settlement for a skirt having depth of 350mm and Load ratio 1.25 comes out to be around 25mm. And for load ratio 1.50 it comes out to be 30mm. Thus by linear interpolation the value of maximum settlement for depth of skirt as 350mm comes out to be 27mm for soil with bearing capacity of 80KN/m².Referring the graph in Figure No. 3 (b), the maximum settlement for a skirt having depth of 350mm and Load ratio 1.25 comes out to be around 24mm. And for load ratio 1.50 it comes out to be 28mm. Thus by linear interpolation the value of maximum settlement for depth of skirt as 350mm comes out to be 25.6mm for soil with bearing capacity of 160KN/m². By interpolating the two values of settlement for skirt depth of 350mm for bearing capacity of soil as 120KN/m² comes out to be 26.3mm. The actual settlement comes out to be 26mm which is nearly equal to the value evaluated from the graph. The difference in the two values is just 1.15% of actual values. Thus the settlement calculated from the graph is quit in agreement with the actual values.

Similarly for the footing F_1' the maximum soil pressure worked out from the graph shown in Figure No.4 (a) by interpolation for the depth of skirt as 350mm comes out to be 86KN/m².Maximum soil pressure worked out for skirt depth of 350mm from Figure 4(b) comes out to be 164KN/m².The maximum soil pressure for the soil with bearing capacity of 120KN/m² for skirt depth of 350mm comes out to be 125KN/m².The actual maximum pressure worked out under the footing is 124.9KN/m²which equal to the actual value. Thus, the graphs can very well be used to evaluate maximum soil pressure under the footing.

Similarly for the footing F_2', with depth of skirt 550mm and bearing capacity of the soil as 180KN/m²referring the graphs shown in Figure No. 3(a) & 3(b) for settlement and Figure No. 4(b) & 4(b) for maximum soil pressure; extrapolating the values, maximum settlement and maximum soil pressure can be worked out the maximum settlement and maximum soil pressure for the footing comes out to be 26.4mm and 184KN/m²respectively. The evaluated values are nearly equal to the actual values. The percentage error in evaluating the settlement is just 4% of actual value. Similarly, for maximum pressure the percentage error is just 7.11% of actual values. Thus with the help of graph maximum settlement and maximum soil pressure for a combined footing with skirts can be worked with reasonable accuracy.

3. CONCLUSIONS

Thus it can be concluded form the above study for a skirted footing that the graphs can very well be used for either evaluating the maximum settlement and maximum soil pressure under the footing or can be used to work out the depth of skirt in order to bring the settlement and pressure under the footing within permissible limit with reasonable accuracy.

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