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Effectiveness of Skirt in Rectangular Combined Footing for Two Symmetric Columns

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Abstract:
Effectiveness of skirts has been well propagated for offshore structures. It has also been widely studied for isolated footings. But study of skirts for combined footings is still unreported. An attempt has been made to study the effectiveness of skirts in combined footing. For the study different locations of skirts and skirt depths have been considered for a particular footing. The combined footing considered has length to breadth ratio as 1:3 with symmetrically placed columns having equal loads. Two types of soils with safe bearing capacities, as 80KN/m2 and 160KN/m2 have been considered. Four different load ratios, which is defined as ratio of total load on footing to actual load carrying capacity of footing based on safe bearing capacity of soil; have been considered. The load ratios considered are 1.0, 1.25, 1.50, & 1.75. The study is carried out considering maximum allowable settlement of footing being restricted to 25mm. The study concludes that the skirts all around the footing with different depths for different load ratios are the best alternative amongst all locations. The analysis has been carried out using finite element based software using SAP2000Vs.18.

Key words: *Rectangular Combined footing, Vertical skirts, Skirt location, Skirts depth, Load Ratio, Bearing Capacity, SAP2000vs.18.*

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I. Introduction

A combined footing is required to be provided when footing area overlaps each other, either because of poor bearing capacity of soil or columns are very near to each other. The columns may or may not be carrying equal loads. For any footing it is desirable that the pressure distribution under the footing should preferably uniform so as to have uniform settlement and minimum angular rotation of the footing. To get uniform pressure distribution under the combined footing, the prerequisite is that c. g. of footing area should coincide with the c.g. of the column loads. The factors which affect the settlement of combined footing on a given soil are load and footing area. The settlement is affected in direct proportion to these parameters. But due to practical problems and local site conditions, sometimes it becomes difficult to maintain uniform soil pressure and settlement beneath the combined footing. In weak soils the differential settlement is the major concern for the engineers and hence at such places where soil properties are not obvious; different alternatives have to be thought off.

In such critical situations the provision of vertical skirts below the combined footing may be a innovative and economical solution. Skirts i.e. vertical walls at the base of footing, helps in confining the under lying soil, generating a soil resistance on skirt sides which helps the footing to resists the settlement. To study the effectiveness of skirt, a rectangular combined footing (F) having size (3 x 9 x 0.7) m with two column carrying equal load and are at equal distance from the edges; is modeled in FEM software SAP 2000. For this two models of the combined footing (F) are considered with two different types of soil strata having safe allowable bearing capacity of 80KN/m2 and 160KN/m2, respectively. The combined footing is considered to be subjected to loads higher than actual load carrying capacity from safe soil bearing capacity criteria. Load ratio has been defined as ratio of acting load on the footing to the actual load carrying capacity of the footing calculated using safe bearing capacity of the soil. Initially two load ratios as LR=2.50 and LR=1.25 have been considered for model for maximum settlement and soil pressure. Five different locations of the skirts under the combined footing have been considered for the two types of soils with three different depths of the skirts.

In the combined footing (F) five different locations of the skirts have been considered. The footing with these five locations has been designated as five cases ranging from Case-I to Case-V. In first four Cases i.e. Case-I to IV the skirts have been considered parallel to short edge of the footing, where in Fifth case i.e. Case-V the skirts all-around the footing has been considered. The various cases considered are summarized as follows.

Case-I: Combined footing (F) with vertical skirt parallel to shorter edge provided at the centre of gravity (c. g.) of the footing (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/m2 and 160KN/m2, respectively.

Case-II: Combined footing (F) with vertical skirt parallel to shorter edge provided equidistantly at 3.0 m from both the shorter edges of the footings (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/m2 and 160KN/m2, respectively.

Case-III: Combined footing (F) with vertical skirt parallel to shorter edge provided below two columns of the footing (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/m2 and 160KN/m2, respectively.

Case-IV: Combined footing (F) with vertical skirt provided along two opposite parallel shorter edges of the footing (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/m2 and 160KN/m2, respectively.

Case-V: Combined footing (F) with vertical skirts all around the four edges of the footing (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/m2 and 160KN/m2, respectively.

For the detailed study of maximum settlement nine observation points have been considered on the combined footing (F). The nine observations show the better performance of Case-V i.e. when skirts are provided all around the four edges of combined footing (F).

The preliminary investigation of all the above mentioned cases indicates failure with regards to the settlement based on nine point observations, except Case-V. This failure is clearly indicated in tables 3-A, 3-B, 4-A, 4-B, 5-A, 5-B, 6-A & 6-B for four cases respectively.

The provision of skirts as in Case-V reduces the settlement within the permissible limit (refer table 7-A and 7-B). For the final investigation Case-V is further analyzed in detail.

Based on preliminary investigation of all the five cases the Case – V has been considered for final investigation. In this study of combined footing (F) four load ratios and six skirt depths are considered. As stated earlier, the location of skirts all around the four edges of the footing has been considered. For detailed study of Case-V, the different depths of skirt considered are 0 mm (footing without skirt) 250mm, 500mm, 750mm, 1000mm & 1250mm (footing with skirt) and the load ratios considered are (LR=1.00, 1.25, 1.50 & 1.75). The maximum settlement and maximum soil pressure for the case has been observed for the combined footing (F).

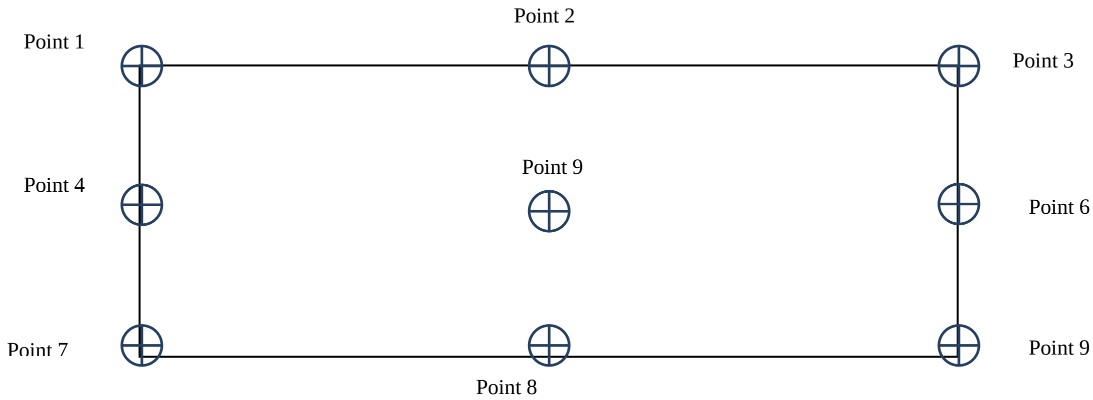

Fig.1 General Arrangement of observation points on Combined Footing (F)

II. 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.

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

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. 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.

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/m2.

In this paper; the rectangular combined footing (F) with equally loaded and symmetrically placed columns studied for five cases based on 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 combined footing (F), using finite element software SAP 2000 vs.18.

MODELLING:

The Combined footing (F) modeled and analyzed using finite element modeling based software SAP2000 Vs.18. The material for footing and skirt is same and thickness of skirt is 200mm for all five cases. Thick shell element considered for combined footing (F) and skirt to perform linear static analysis. The thickness of skirt is considered 200mm for both the investigations. The material properties mentioned in Table 2 are applicable to combined footing (F) as well as skirt.

The preliminary investigation on Rectangular combined footing (F) consists five cases based on different locations of skirt. The depths for skirt considered 0mm (without skirt) and 250mm and 1000mm (with skirt). The combined footing (F) is considered to be resting on two different types of soils having safe bearing capacity of 80 KN/m^2 and 160KN/m^2. In this way total 30 models are being prepared and studied for preliminary investigation.

The acting load (P) on footing is greater than the actual load from safe bearing capacity criteria. The acting load on the footings (higher load) has been worked out considering safe bearing capacity of the soil as 200KN/m^2 and it worked out to be 5400kN (200x 3 x 9 = 5400). The actual load on combined footing (F) considering bearing capacity 80KN/m^2 and 160KN/m^2 comes out to be 2160KN and 4320 KN, respectively. Both the columns are equally spaced from the shorter edge of combined footing (F). The acting load (P) equally shared by both columns of the combined footing (F). All the details for different five cases with nine point observations tabulated below in table no.-3 to 7.

The preliminary investigation shows that the Case-V in some cases results in settlement within the permissible limit. Hence the detailed studies for various load ratio and skirt depth has been carried out for this case. The study has been conducted for maximum settlement and maximum soil pressure beneath the combined footing (F). The material properties and dimensions of combined footing (F) for Case-V for detailed study considered are same as taken in preliminary investigation.

For detailed study of Case-V the load ratios considered are 1.0, 1.25, 1.50 and 1.75, respectively. For each load ratio, acting load has been considered as 1.00, 1.25, 1.50 and 1.75 times the actual load on the footing. Thus for Case-V with load ratio as 1.00, the acting load and actual load for soil with bearing capacity of 80kN/m^2 comes out to be 2160KN (1.00 x 3 x 9 x 80 = 2160) and 2160KN (3 x 9 x 80 = 2160). Similarly, for L/R 1.25, 1.5 and 1.75 for soil with bearing capacity as 80kN/m^2 the actual load shall be 2160 KN and acting loads comes out to be 2700KN, 3240KN, 3780KN, respectively. And, for L/R 1.25, 1.5 and 1.75 for soil with

bearing capacity as 160KN/m^2 the actual load shall be 4320 and acting loads comes out to be 5400KN, 6480KN, 7560KN, respectively.
The combined footing (F) studied with six Depths of skirts (Ds) i.e. 0mm (footing without skirt), 250mm, 500mm, 750mm, 1000mm & 1250 mm (footing with skirt). The skirts with different depths (Ds) ranging from 0mm to 1250 mm, are provided all around the four edges of combined footing (F).

Allowable maximum permissible settlement has been restricted to 25mm for the footing analysis in SAP2000 vs.18.The modulus of sub-grade reaction, a conceptual relationship between soil pressure and deflection, is widely used in structural engineering for foundation analysis. It is used for continuous footing, Mat and various types of piling, this ratio is defined as Ks=q /δ.

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

CASE-I Combined footing (F) with vertical skirt parallel to shorter edge provided at the centre of gravity (c. g.) of the footing.
The Table 3-A, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 80KN/m^2.
The Table 3-B, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 160KN/m^2.

Table 3-A for Case-I: Settlement at Nine points for different Depth of skirts for soil with –**BC 80KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	71.3	65.3	71.3	71.5	66.5	71.5	71.3	65.3	71.3
2	F	5400	250	69.0	62.2	69.0	69.2	62.5	69.2	69.0	62.3	69.0
3	F	5400	1000	64.0	55.9	64.0	64.2	56.1	64.2	64.0	55.9	64.0

Table 3-B for Case-I: Settlement at Nine points for different Depth of skirts for soil with –**BC 160KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	37.1	31.5	37.5	37.3	31.7	37.3	37.1	31.5	37.1
2	F	5400	250	36.1	29.9	36.1	36.4	30.1	36.4	36.1	29.9	36.1
3	F	5400	1000	34.1	26.6	34.1	34.4	26.8	34.4	34.1	26.6	34.1

CASE-II Combined footing (F) with vertical skirt parallel to shorter edge provided equidistantly at 3.0 m from both the shorter edges of the footings.
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.
The Table 4-A, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 80KN/m^2.
The Table 4-B, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 160KN/m^2.

Table 4-A for Case-II: Settlement at Nine points for different Depth of skirts for soil with –**BC 80KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	71.3	65.3	71.3	71.5	66.5	71.5	71.3	65.3	71.3
2	F	5400	250	66.5	59.7	66.5	66.7	59.7	66.7	66.5	59.7	66.5
3	F	5400	1000	57.3	49.1	57.3	57.5	49.3	57.5	57.3	49.1	57.3

Table 4-B: Settlement at Nine points for different Depth of skirts for soil with –**BC 160KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	37.1	31.5	37.5	37.3	31.7	37.3	37.1	31.5	37.1
2	F	5400	250	34.9	28.6	34.9	35.2	28.8	35.2	34.9	28.6	34.9
3	F	5400	1000	30.9	23.2	30.9	31.1	23.4	31.1	30.9	23.2	30.9

CASE-III Combined footing (F) with vertical skirt parallel to shorter edge provided below two columns of the footing.

The Table 5-A, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 80KN/m^2.

The Table 5-B, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 160KN/m^2.

Table 5-A for Case-III: Settlement at Nine points for different Depth of skirts for soil with –**BC 80KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	71.3	65.3	71.3	71.5	66.5	71.5	71.3	65.3	71.3
2	F	5400	250	65.5	60.0	65.5	65.7	60.2	65.7	65.5	60.0	65.5
3	F	5400	1000	54.4	49.9	54.4	54.5	50.1	54.5	54.4	49.9	54.4

Table 5-B for Case-III: Settlement at Nine points for different Depth of skirts for soil with –**BC 160KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	37.1	31.5	37.5	37.3	31.7	37.3	37.1	31.5	37.1
2	F	5400	250	34.0	28.9	34.0	34.2	29.1	34.2	34.0	28.9	34.0
3	F	5400	1000	28.2	24.0	28.2	28.3	24.2	28.3	28.2	24.0	28.2

CASE-IV Combined footing (F) with vertical skirt provided along two opposite parallel shorter edges of the footing.

The Table 6-A, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 80KN/m^2.

The Table 6-B, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 160KN/m^2.

Table 6-A: Settlement at Nine points for different Depth of skirts for soil with –**BC 80KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	71.3	65.3	71.3	71.5	66.5	71.5	71.3	65.3	71.3
2	F	5400	250	64.2	60.5	64.2	64.4	60.7	64.4	64.2	60.5	64.2
3	F	5400	1000	51.6	52.0	51.6	51.7	52.0	51.7	51.6	52.0	51.6

Table 6-B: Settlement at Nine points for different Depth of skirts for soil with –**BC 160KN/m^2**

S.No.	Footing	Acting Load (KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	37.1	31.5	37.5	37.3	31.7	37.3	37.1	31.5	37.1
2	F	5400	250	32.8	29.4	32.8	33.0	29.6	33.0	32.8	29.4	32.8
3	F	5400	1000	25.6	25.9	25.6	25.7	26.0	25.7	25.6	25.9	25.6

CASE-V Combined footing (F) with vertical skirts all around the four edges of the footing.

The Table 7-A, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 80KN/m^2.

The Table 7-B, shows the settlement values in mm obtained at nine observation points for the footing having three different depth of skirts for soil having bearing capacity as 160KN/m^2.

Table 7-A for Case-V: Settlement at Nine points for different Depth of skirts for soil with –**BC 80KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	71.3	65.3	71.3	71.5	66.5	71.5	71.3	65.3	71.3
2	F	5400	250	52.4	48.3	52.4	52.6	48.6	52.6	52.4	48.3	52.4
3	F	5400	1000	31.3	30.2	31.3	31.4	30.4	31.4	31.3	30.2	31.3

Table 7-B for Case-V: Settlement at Nine points for different Depth of skirts for soil with –**BC 160KN/m^2**

S.No.	Footing	Acting Load(KN)	Depth of Skirt (Ds) in mm	Settlement Below Nine Observation Points of Footing (F)								
				1	2	3	4	5	6	7	8	9
1	F	5400	0	37.1	31.5	37.5	37.3	31.7	37.3	37.1	31.5	37.1
2	F	5400	250	27.0	23.3	27.0	27.2	23.5	27.2	27.0	23.3	27.0
3	F	5400	1000	15.8	14.8	15.8	15.9	14.9	15.9	15.8	14.8	15.8

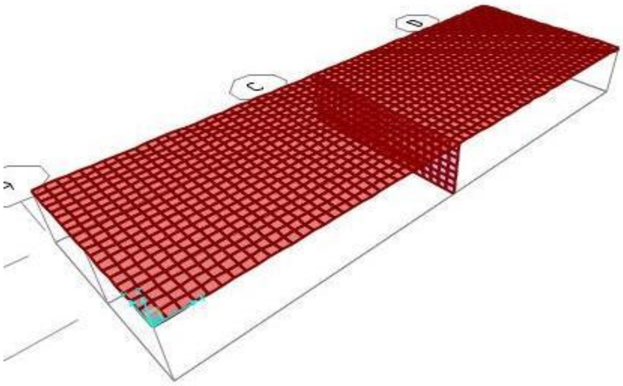

Figure 2: Case-I - Model of combined footing (F) with skirt at c. g. of footing.

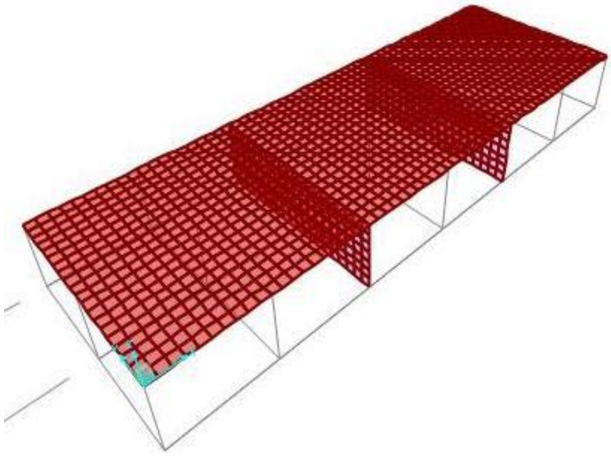

Figure 3: Case-II - Model of combined footing (F) with two skirts equidistant from shorter edges.

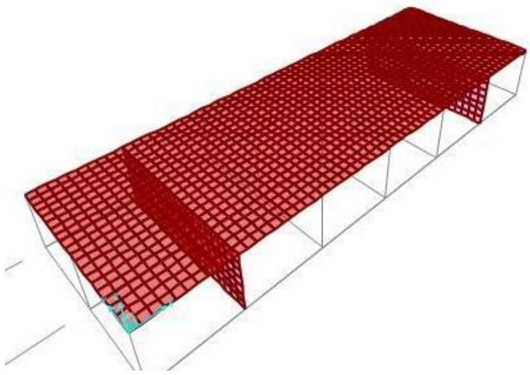

Figure 4: Case-III - Model combined footing (F) with two skirts below column load.

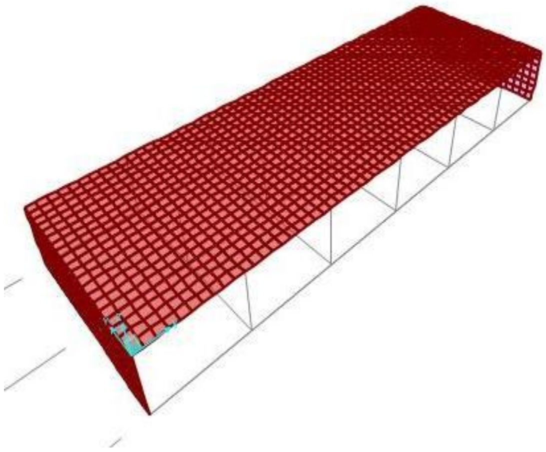

Figure 5: Case-IV - Model combined footing (F) with two skirts on two opposite parallel shorter edges.

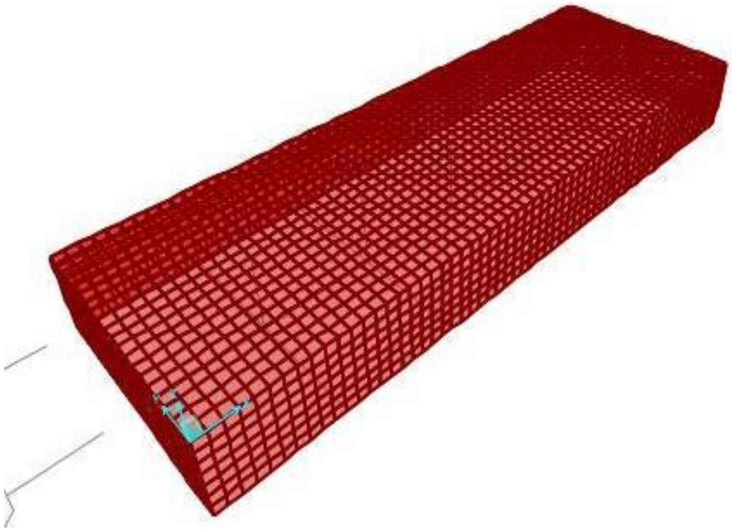

Figure 6: Case-V - Model combined footing (F) with Four Skirts all around the edges

III. Result & Discussion

For preliminary study of combined footing, F (3 x 9 x 0.7m) resting on two types of soil having bearing capacity of 80 KN/m^2 and $160KN/m^2$ the two columns considered are equally loaded with axial loads for all five cases of different locations of skirt. The columns are considered to be symmetrically placed on the footing. Various skirt depths considered in the analysis of combined footing (F) for the different five cases are – Ds = 0mm (without skirt), Ds = 250 &1000 mm (with skirt). The combined footing (F) subjected to load corresponding to load ratios (LR = 2.50 & 1.25) for bearing capacity $80KN/m^2$ and $160KN/m^2$ respectively for all the five cases.

The extended study for Case-V, model of combined footing (F) with skirts all around the four edges of the footing, has been carried out. The various load ratios i.e. 1, 1.25, 1.5 & 1.75 have been considered for the study. The study is being carried out by model analysis of combined footing (F) using FEM based software SAP2000 Vs.18. Combined footing (F) has been analyzed for different skirt depths ranging from 0 to 1250mm, i.e. (0, 250, 500, 750, 1000, 1250)mm provided at all around the edges. The result from various graphs in figure (7 to 10) and bar charts in figure (11 to 14) have been discussed below.

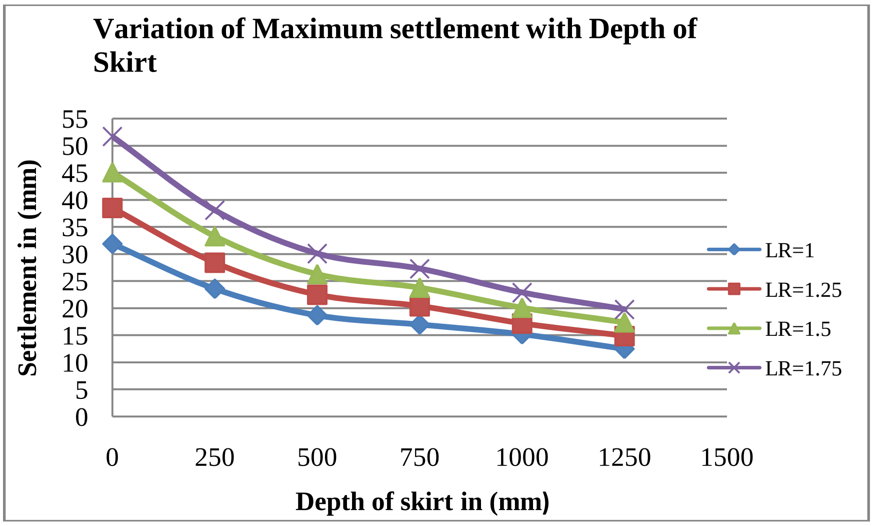

Figure 7: Variation of Maximum settlement with Depth of skirt for Combined Footing (F) for soil with BC 80KN/m^2

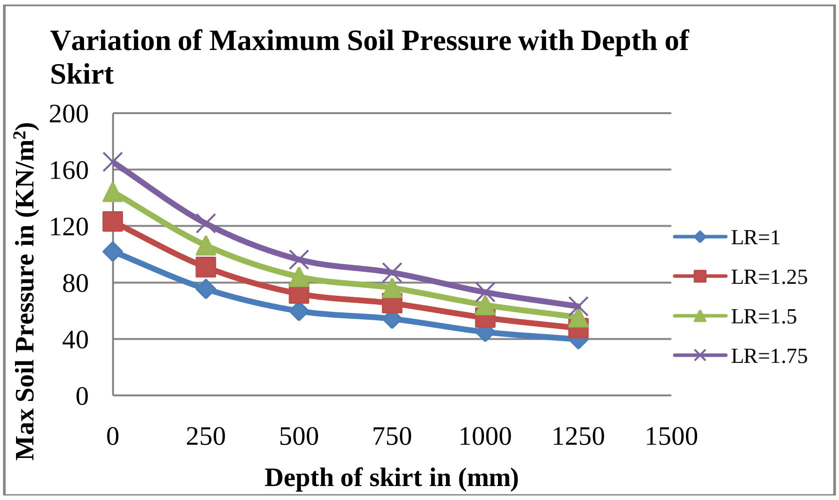

Figure 8: Variation of Maximum soil pressure with Depth of skirt for Combined Footing (F) for soil with BC 80KN/m^2

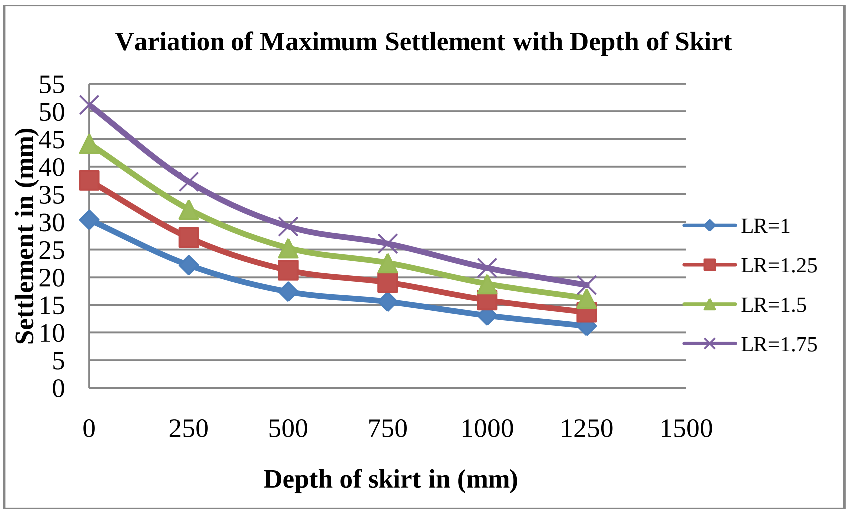

Figure 9: Variation of Maximum settlement with Depth of skirt for Combined Footing (F) for soil with BC 160KN/m^2

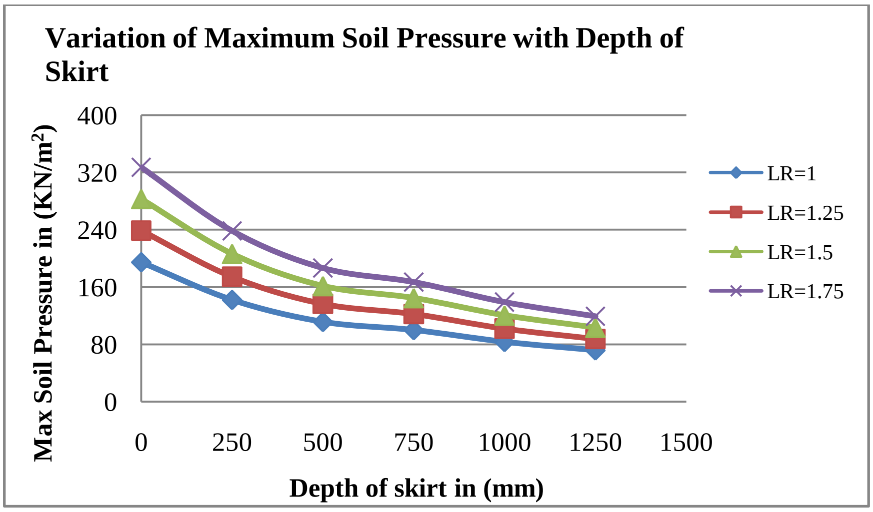

Figure 10: Variation of Maximum soil pressure with Depth of skirt for Combined Footing (F) for soil with BC 160KN/m^2

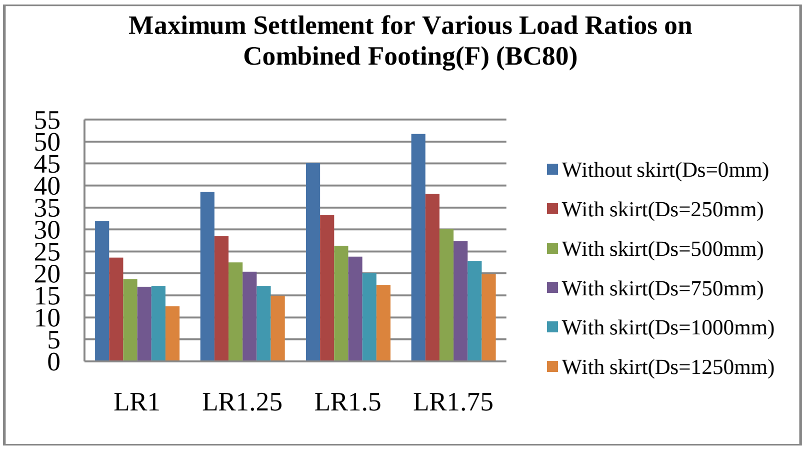

Figure 11: Bar-Chart for Maximum Settlement with various Load Ratios

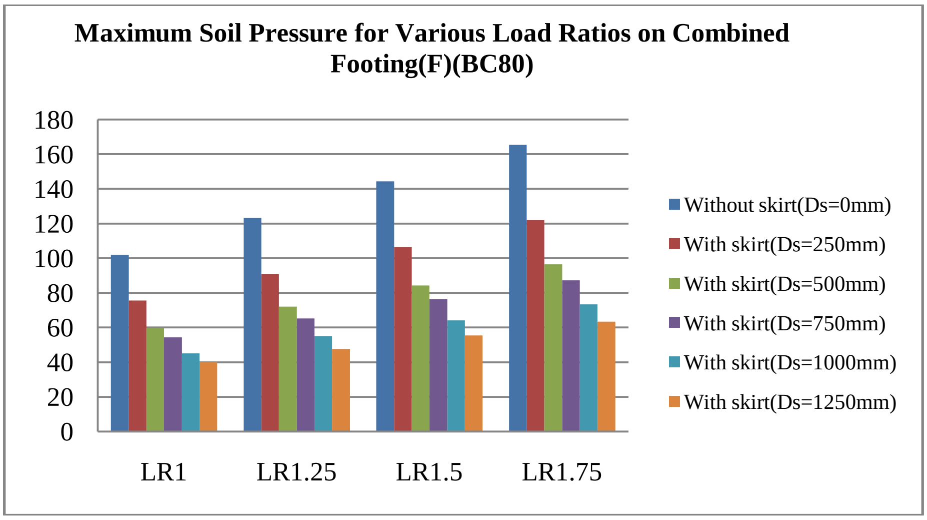

Figure 12: Bar-Chart for Maximum Soil Pressure with various Load Ratios

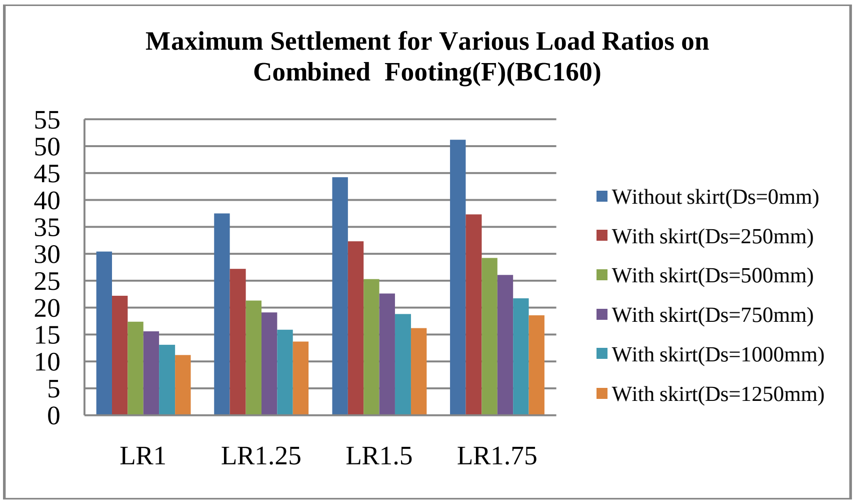

Figure 13: Bar-Chart for Maximum Settlement with various Load Ratios

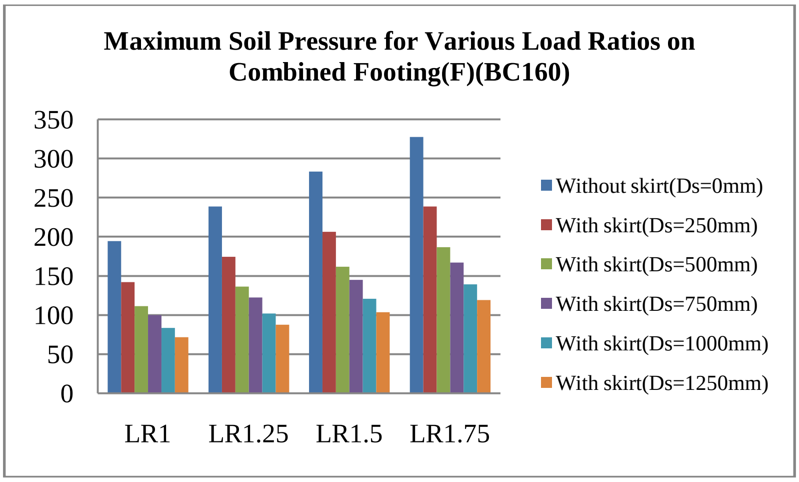

Figure 14: Bar-Chart for Maximum Soil Pressure with various Load Ratios.

IV. Discussions

This study has been conducted for combined footing (F), based on location of skirts with depth (Ds= 0, 250 & 1000mm). Initially considered four different cases shows failure due to excessive settlement values, except Case-V, in some cases.

Finally Case-V is further analyzed for four different load ratios (LR = 1, 1.25, 1.5, 1.75) and six skirt depths (Ds = 0, 250, 500, 750, 1000 & 1250) mm to check the effectiveness of vertical skirt in combined footing (F).

Combined footing (F) of size (3 x 9 x 0.7) m resting on soil having low bearing capacity of 80KN/m^2 and subjected to loads belongs to load ratios 1, 1.25, 1.5 and 1.75.

The preliminary investigation carried out for five cases at nine study points for two types of soil and three depths of skirt have been reported in tables from table 3(A) to 7(B).

The table 3(A) shows the settlement at nine observation points for Case-I for soil with bearing capacity 80KN/m2. From table it is clear that at all the nine observation points the excessive settlement occurs. This excessive settlement is because of very heavy higher load that the acting load considered is 5400KN and load ratio for the footing comes out to be 2.5 and 1.25 for two bearing capacities of 80KN/m^2 and 160KN/m^2 respectively.

The table 3(B) shows the settlement at the nine observation points for the footing when bearing capacity is 160KN/m^2. The settlement at all the nine observation points reduces to almost 50% of the settlements for all the combinations of depth of skirt reported in table 3(A) for soil with bearing capacity of 80KN/m^2.

In this case also settlement of all the points exceed than the permissible limit. Hence it can be stated that Case-I may not be an effective alternative of foundation improvement technique.

From both the table 3(A) & 3(B) it is very clear that the variation in settlement at all the nine observation points for both the types of soils is very small even when skirt of depth 1000mm is provided. This reduction in settlement from no skirt depth to a skirt depth of 1000mm varies between 5% to 20% of settlement in no skirt condition.

Table 4(A) & 4(B) shows the variation of settlement at nine observation points for the footing resting on the soils with bearing capacity 80KN/m^2 and 160KN/m^2 respectively for Case-II. Almost same variation has been observed for Case-II as seen in Case-I.

In this case only at three points of the footing with depth of skirt as 1000mm and bearing capacity of soil as 160KN/m^2 the settlement comes within the limit. For different depths of skirt & types of soil considered the values exceed than the permissible values.

The variation of settlement at nine different points for two types of soil and three depths of skirt for Case-III has been shown in table 5(A) & 5(B) respectively. The variation observed is in close agreement with variation seen for Case-II.

The variation in settlement observation points for the soils 80KN/m^2 & 160KN/m^2 and for depth of skirt for Case-IV has been shown in table 6(A) & 6(B). no significant improvement in settlement has been seen in Case-IV for the two types of soil except the model in which the depth of skirt has been taken as 1000mm for soil having bearing capacity of 160KN/m^2. For this model the settlement arrived is just closer to permissible limit.

The table 7(A) & 7(B) shows the variation of settlement at all the nine observation points for two types of soil. In this case the variation of settlement at all the observation points for the two types of soil is significant with respect to increase in depth of skirt. For both types of soil the settlement reduces by more than 50% when depth of skirt changes from no skirt condition to a depth of 1000mm.

It has been observed for all the nine observation points moreover the settlement at all the nine observation points are almost equal it ensures uniform pressure distribution under the footing.

The preliminary investigation suggest as Case-V is most effective enhance the detailed studies are being carried out for the Case-V for two types of soil. In this study the four load ratios i.e. LR= 1.0, 1.25, 1.5 & 1.75 considered to further investigate the effect of depth of skirt on the settlement of the footing in Case-V six different depths of skirt have been considered. The observations of detailed study of Case-V has been shown by graphs in figure 7 to 10.

From the graphs in figure 7 to 10 it is clear that the settlement & soil pressure decreases with increase in depth of skirt. It has been observed for all the four load ratios considered. The % reduction in settlement & soil pressure is almost independent of bearing capacity of soil for the different load ratios considered.

Figure 11 to 14 shows the variation of maximum settlement and soil pressure with depth of skirt for various load ratios for the two types of soil.

For all the five cases studied for average settlement of a combined footing (F) resting on soils having bearing capacities 80KN/m^2 and 160KN/m^2 respectively, is exceeding the assumed max permissible settlement 25mm except in the Case-V for bearing capacity 160KN/m^2.

In Case-V when skirts are provided all around the four edges of footing resting on soil having bearing capacity of 160KN/m^2; the values of settlement are found within the assumed permissible limit of settlement 25mm at all nine observation points located on footing.

So this particular Case-V further considered for detailed analysis to get controlled soil pressure and maximum settlement of combined footing (F) resting on two types of soil having bearing capacity 80 KN/m^2 and 160KN/m^2; subjected to load at different load ratios.

V. Conclusions

On the basis of present study of combined footing (F) for different five cases regarding the location of skirt and the various load ratios having two values of bearing capacities of soil 80KN/m^2 & 160 KN/m^2, following conclusions have been.

(i) The preliminary investigation carried out for all the five cases shows that Case-V i.e. the skirt all around the footing is the best choice.

(ii) The preliminary investigation also suggest that first four cases with increase in depth of skirt the settlement reduces significantly but fails to reduce the settlement effectively. So as to bring it within assumed permissible limit.

(iii) For soil with bearing capacity 80KN/m^2 the settlement exceeds the assumed permissible limits even for load ratio LR=1.0. At LR=1.0 depth of skirt of 250mm satisfies the settlement criteria at all the nine observation points. For every 25% increase in load ratio the 250mm increase in depth of skirt has been found to be satisfying the settlement criteria.

(iv) From figure 7 & 9 it is concluded that for load ratios from 1.0 to 1.75, settlement is independent of bearing capacity of soil. From figure 8 & 10 it is clear that the maximum soil pressure is independent of bearing capacity of soil with same % reduction.

(v) In Case-V since settlement and % reduction in soil pressure is independent of bearing capacity of soil the graphs 7 to 10 can be used to work out the depth of skirt required for a combined footing with known load ratios. So as to keep the settlement and soil pressure within permissible limit.

For (BC80)

For all load ratios (LR=1, 1.25, 1.5 & 1.75) combined footing (F) with skirt depth (Ds=1000 & 1250mm) shows maximum settlement within assumed allowable permissible limit of 25mm and soil pressure is less than allowable bearing capacity as 80KN/m^2.

For load ratios (LR=1,1.25 & 1.5) combined footing (F) with skirt depth (Ds=750mm) results in maximum settlement within assumed allowable permissible limit 25mm and soil pressure also restricted within safe allowable bearing capacity of soil 80KN/m^2.

For load ratios (LR=1 & 1.25) combined footing (F) with skirt depth (Ds=500mm) shows maximum settlement within assumed allowable permissible limit of 25mm and soil pressure within the limit of safe allowable bearing capacity of 80KN/m^2. Combined footing (F) with skirt depth (Ds=250mm) shows the maximum settlement within assumed allowable permissible limit of 25mm and soil pressure within safe allowable bearing capacity of soil 80KN/m^2; for load ratio (LR=1) only.

Combined footing (F) without skirt (Ds=0mm) shows maximum settlement higher than assumed permissible limit of 25mm for all ratios. Maximum settlement ranges from almost 30mm to 50mm. Maximum soil pressure is also shows values higher than the safe allowable bearing capacity of soil 80KN/m^2.

(A) For (BC160)

For all load ratios (LR=1,1.25,1.5 &1.75) combined footing (F) with skirt depth (Ds= 750,1000 & 1250mm) are showing maximum settlement within assumed permissible limit of 25mm and maximum soil pressure also restricted within safe allowable bearing capacity 160KN/m^2.

For load ratios (LR= 1,1.25 & 1.5) combined footing (F) with skirt depth (Ds=500mm) results in maximum settlement within assumed allowable permissible limit of 25mm and maximum soil pressure restricted within the limit of safe allowable bearing capacity of soil 160KN/m^2. For load ratios (LR=1.75) combined footing (F) is not advisable.

Combined footing (F) with skirt depth (Ds=250mm) shows maximum settlement within assumed allowable permissible limit 25mm and soil pressure restricted within safe allowable bearing capacity of soil 160KN/m^2 for load ratio (LR=1) only. Thus model footing (F) with skirt depth of (Ds=250mm) not found suitable for load ratio higher than one.

Combined footing (F) without skirt shows maximum settlement higher than the assumed allowable permissible limit 25mm for all load ratios. Maximum settlement values ranging from 30mm to 50mm, maximum soil pressure values are also beyond the safe allowable bearing capacity of soil 160KN/m^2, for all load ratios.

© For various load ratios maximum value of settlement and soil pressure beneath the footing is found to be independent of value of bearing capacity of soil. Depth of skirt is having great impact on controlling the maximum settlement and soil pressure within permissible limit. As depth of skirt increases in the range from 250mm to 1250mm; the percentage value of maximum soil pressure and maximum settlement arrested increases in the range from 30% to 60% respectively.

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