# Performance Study of Skirt Depth on Settlement and Net Upward Pressure Distribution Characteristics of a Single Skirted Isolated Square Footing

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**Abstract:** ***Skirts in foundation are common feature in offshore structures. These plays an important role as a structural member in foundation and are generally being used underneath shallow foundations of offshore structures. They are being used over the years, due to their stability advantages. However, limited knowledge is available on the performance of the skirted footings, when it comes to their usages as conventional shallow foundations on routine structures in cohesive soils. In the present work study is being carried out to check the effectiveness of various Skirt depths (Ds) in improving the performance of Single Skirted Isolated Square Footing (SSISF) resting on cohesive soil, either by reducing the settlement or by minimizing the variation of Net Upward Soil Pressure (NUSP), average soil pressure, beneath the footing. Finite element modeling of SSISF has been done considering uniform soil pressure under the foundation. For the study nine observation points for three footing sizes with seven different skirt depths have been considered. The model is being prepared and analyzed by making use of software SAP2000 Vs.18. In the study two types of soils have been considered in which the Net Upward Soil Pressures are being restricted to 80KN/m$^2$and 150KN/m$^2$, respectively. A special case also has been considered in which the footing is crossing over the property line. One third length of footing is being resting on poor soil with maximum permissible net upward soil pressure as 80kN/m$^2$ while remaining two third length is resting on better soil with maximum permissible net upward soil pressure as 150kN/m$^2$. Results from the analysis shows that the increase in depth of skirt controls the average settlement of footing within permissible limit and minimizes variation of average soil pressure below the footing.***

**Keywords:** Cohesive soil, Skirt depth, NUSP, Average settlement, Average soil pressure, SAP200 Vs.18

## 1. Introduction

Availability of soil at any construction site is a natural phenomenon, which can not be control by foundation designer. In clayey soil regions the bearing capacity of soil varies with the location of site as well as the depth of excavation for foundation. In Malwa region of M.P. state where black cotton soil is available up to large extent of depth and below which naturally compacted yellow soil is there. The bearing capacity of yellow soil is comparatively greater than that of black cotton soil. Sometimes it could happens that a part of foundation is resting on black cotton soil whereas remaining part is founded on yellow soil or vice versa. That is when combination of soil is there at site having different bearing capacities. Differential settlement of foundation is one of the important issue to be deal by design engineers. Clayey soils are also known as cohesive soil where expansion or shrinkage is an controlling parameter. Due to this expansion or shrinkage of clayey soils foundation of structures are likely to be subjected to differential settlement or overall settlement. To control the differential settlement of foundation, some techniques are required to be applied on foundation for improving the performance of foundation.

In the present study an attempt is made to investigate the effect/role of skirted footing in improving the performance of foundation, either by reducing the settlement or restricting the settlement of foundation within the permissible limit. In skirted footing, a vertical projection below the footing is provided along one or more edges of footing known as skirt. According to findings of previous researchers these vertical skirts helps in confining the under lying soil beneath the footing, which results in improvement of bearing capacity of soil. This study is being carried out considering three different conditions of sites having clayey soil as under—

a) The foundation is subjected to low permissible net upward soil pressure of 80KN/m$^2$.
b) The foundation is subjected to better permissible net upward soil pressure of 150KN/m$^2$.
c) The foundation is crossing a property line and lying on two different soils with permissible net upward soil pressures of 80KN/m$^2$& 150KN/m$^2$, respectively.

For the iii) condition, when foundation is crossing property line about 1/3 the length of footing is considered lying on poor soil with permissible net upward soil pressure of 80KN/m$^2$and rest 2/3 portion of the footing is being considered resting on better soil with NUSP 150KN/m$^2$.In such cases usually the footing is designed with lower NUSP. It becomes mandatory that the differential settlement of foundation should be restricted to maximum permissible limit of settlement.

### 1.1 Skirt

Skirt is a plate or wall provided below the footing. The dimension of plate/wall perpendicular to the plane of footing is known as depth of the skirt (Ds) and dimension of the plate/wall parallel to the side or edge of the footing is known as length of skirt (L). The study is being carried out to investigate the effect of various depths of single skirt on the settlement of footing. The different depths of the skirt have been considered along the edge of the footing. The Single skirted isolated square footing has been studied with permissible Net Upward Soil Pressure being restricted to 80 $KN/m^2$ and 150 $KN/m^2$.

The side of the footing on which skirt has been provided is being designated as Near Side and opposite side of the footing is designated as Far Side. The other two sides of the footing are designated as sides. The side on the right side of the skirt shall be designated as Right Side and the side on the left side of the skirt is designated as Left Side. For the two net upward soil pressure cases, settlement of the Single Skirted Isolated Square footing along with different skirt depths at various points are observed. In this study Net Upward Soil Pressure (NUSP), and the depth of skirt has also been varied.

### 1.2 Study Point

For this purpose, 09 points on the different locations of footing area have been considered. The point of junction of left side and near end has been designated as Left Near End (LNE). Similarly, junction of right side and near side shall be designated as Right Near End (RNE). The junction of left side and far side shall be designated as Left Far End (LFE) and junction of right side and far side shall be designated as Right Far End (RFE), respectively. The centre points of all the four edges of the footing, i.e. near side, far side, left side and right side shall be designated as Near Mid-Point (NMP), Far Mid-Point (FMP), Left Mid-point (LMP) and Right Mid-point (RMP), respectively. Centroid of the footing area has been designated as Centre Point (CP).

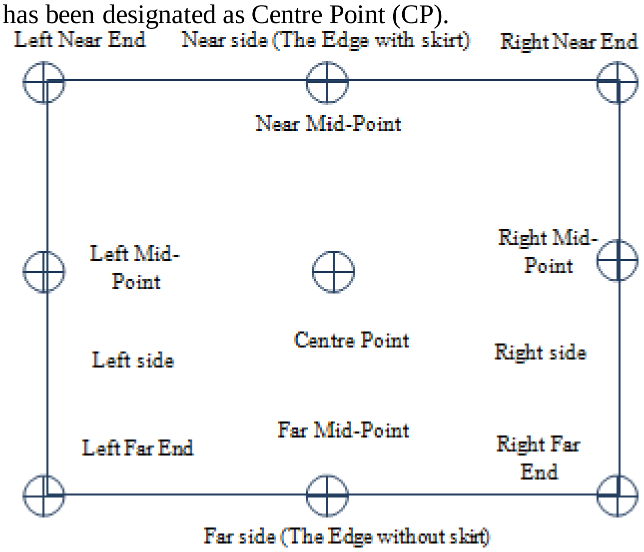


**Figure 1:** Nine observations points on footing

The study has been conducted to evaluate the effect of different skirt depths (Ds) along various isolated square footings subjected to different concentric loads from column. To understand the effect of skirt depth, on the settlement and soil pressure variation beneath the footing; 09 observation points are considered on footing area. Numerical model footings are analyzed by finite element-based software SAP 2000 Vs18.

## 2. Literature Review

The objective of literature review is to identify the contribution established by previous researchers on skirted foundations in terms of behavior, performance, analysis approaches by numerical and analytical study and to identify the gap in research for the present study. conducted 3D finite element analysis using ABAQUS Vs6.12 to evaluate performance of skirt foundations influence by vertical load, soil medium, aspect ratios and area ratios of skirted foundation. The increase in the aspect ratio (d/D) of skirted foundation will increase the vertical load carrying capacity significantly. Sushil Kumar B. Magade et. al (2019) present a simple approach for Tammineni Gnanandarao Et al(2020) conducted an investigation on the model unskirted /skirted footing (plus and double box) on sand. Skirt depth, sand relatively density, footing interface conditions and skirted footing type were varied parameters. Skirt depth (Ds) varied in this investigation was from 0.25B to 1.5B (B footing width). Finally for the settlement reduction factor an empirical equation was developed. C. Goutham et. al (2019) calculating the depth of footing to meet the rigid condition under rigid concentric loading. A simple procedure was developed for calculating the maximum moment using the diagonal strip method (DSM). DSM is a substitute of FEM. Keivan Esmaelli Et al (2018) studied semi-deep skirted foundations and numerical solution to evaluate bearing capacity where the soil beneath the foundation is loose to a great depth and there is no possible way to use any way of soil improvement and applying piles would not be a logical way considering their cost and time of enforcing. In addition the bearing capacity of a skirted foundation under combined loading V-H space has been analyzed by this approach and two dimensional failure envelope has been presented. Chandani Seth et. al (2017) carried out dynamic analysis of pile block foundation model using SAP:2000Vs18 of dynamic response of foundation was analysed. Results are compared and validated with mode shapes and frequencies. For block foundation resting on soil, piles and soil can be modeled by spring elements, the dynamic behavior can be represented accurately. It is recommended for block foundation to include the whole structure and replaced the soil/ piles by spring elements. 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%. Location of skirt with respect to load direction has significant effect on horizontal load carrying capacity of footing. Dr. S. PUSADKAR et.al (2016) a series of various numerical model were analyzed using finite element software PLAXIS 2D to evaluate the bearing capacity of strip footing with and without structural skirts resting on sand slopes. Entidhar AL- Taie et. al. (2014) tested three sites in Iraq for best type of foundation to be chosen. The average and worst values of bearing capacity were ($177 KN/m^2$-$77 KN/m^2$)for Mosul at North, ($125 KN/m^2$&

68KN/m$^2$ )for Bagdad at Middle and (84KN/m$^2$-24KN/m$^2$) Basrah at South. S. Golmoghani-Ebrahimi et. al (2013) investigated the effect of skirt stiffness and depth on the bearing capacity of skirted footing models. It was found using structural skirts may improve the footing bearing capacity up 3.68 times, depending on various parameters.

## 3. Numerical Modeling

In present study three footing sizes F1(2x2x0.5)m, F2(2.8x2.8x0.65)m and F3 (3.6x3.6x0.85)m are considered with seven skirt depths (Ds) i.e. 0, 250,500,750,1000,1250, and 1500 mm.

The thickness of skirt is 200 mm. Total 42 nos. Numerical model footings of single skirted Isolated Square footing subjected to concentric load from column are analyzed using SAP 2000Vs18. These three footing sizes F1, F2 and F3 are analyzed to get settlement and soil pressures at 09 observation points located on footing area. Spring stiffness based on two values of Net Upward Soil Pressure 80 KN/m$^2$ and 150 KN/m$^2$ are used to apply soil properties on model footings. A special case consider for numerical model of sample footing Fs (2x2x0.5m) with skirt depth Ds=1000mm. The 1/3 part of sample footing Fs is resting on soil having NUSP 80KN/m$^2$and 2/3 part on NUSP 150KN/m$^2$below it. Single skirt applied towards the edge of footing where the value of Net Upward Soil Pressure is lower i.e. 80KN/m$^2$ and the footing model is analyzed for settlement as well as soil pressure beneath the footing area.

Details of various geometrical parameters, load, skirt length and skirt depth are given in figures and tables below.

**Table 1:** 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 |

**Table 2:** Numerical model footing data

| *S. No* | *Size of Footing (in m)* | *Load in (KN)* | *Net Upward Soil Pressure (KN/m$^2$)* | *Depth of skirt (Ds)(mm)* | *Length of Skirt* |
|---|---|---|---|---|---|
| 1 | F1 | 265 | 80 | 0 | Without Skirt |
| 2 | F1 | 265 | 80 | 250 | 1.0L |
| 3 | F1 | 265 | 80 | 500 | 1.0L |
| 4 | F1 | 265 | 80 | 750 | 1.0L |
| 5 | F1 | 265 | 80 | 1000 | 1.0L |
| 6 | F1 | 265 | 80 | 1250 | 1.0L |
| 7 | F1 | 265 | 80 | 1500 | 1.0L |

**Table 3:** Numerical model footing data

| *S. No.* | *Size of Footing (in m)* | *Load in (KN)* | *Net Upward Soil Pressure (KN/m$^2$)* | *Depth of Skirt (Ds) (mm)* | *Length of Skirt* |
|---|---|---|---|---|---|
| 1 | F1 | 540 | 150 | 0 | Without Skirt |
| 2 | F1 | 540 | 150 | 250 | 1.0L |
| 3 | F1 | 540 | 150 | 500 | 1.0L |
| 4 | F1 | 540 | 150 | 750 | 1.0L |
| 5 | F1 | 540 | 150 | 1000 | 1.0L |
| 6 | F1 | 540 | 150 | 1250 | 1.0L |
| 7 | F1 | 540 | 150 | 1500 | 1.0L |

**Table 4:** Numerical model footing data

| *S. No* | *Size of Footing (in m)* | *Load in (KN)* | *Net Upward Soil Pressure (KN/m2)* | *Depth of Skirt (Ds) (mm)* | *Length of skirt* |
|---|---|---|---|---|---|
| 1 | F2 | 495 | 80 | 0 | Without Skirt |
| 2 | F2 | 495 | 80 | 250 | 1.0L |
| 3 | F2 | 495 | 80 | 500 | 1.0L |
| 4 | F2 | 495 | 80 | 750 | 1.0L |
| 5 | F2 | 495 | 80 | 1000 | 1.0L |
| 6 | F2 | 495 | 80 | 1250 | 1.0L |
| 7 | F2 | 495 | 80 | 1500 | 1.0L |

**Table 5:** Numerical model footing data

| *S. No.* | *Size of Footing (in m)* | *load in (KN)* | *Net Upward Soil pressure (KN/m$^2$)* | *Depth of Skirt (Ds) (mm)* | *Length of skirt* |
|---|---|---|---|---|---|
| 1 | F2 | 1040 | 150 | 0 | Without Skirt |
| 2 | F2 | 1040 | 150 | 250 | 1.0L |
| 3 | F2 | 1040 | 150 | 500 | 1.0L |
| 4 | F2 | 1040 | 150 | 750 | 1.0L |
| 5 | F2 | 1040 | 150 | 1000 | 1.0L |
| 6 | F2 | 1040 | 150 | 1250 | 1.0L |
| 7 | F2 | 1040 | 150 | 1500 | 1.0L |

**Table 6:** Numerical model footing data

| *S. No.* | *Size of Footing (in m)* | *load in (KN)* | *Net Upward Soil pressure (KN/m$^2$)* | *Depth of Skirt (Ds) (mm)* | *Length of skirt* |
|---|---|---|---|---|---|
| 1 | F3 | 745 | 80 | 0 | Without Skirt |
| 2 | F3 | 745 | 80 | 250 | 1.0L |
| 3 | F3 | 745 | 80 | 500 | 1.0L |
| 4 | F3 | 745 | 80 | 750 | 1.0L |
| 5 | F3 | 745 | 80 | 1000 | 1.0L |
| 6 | F3 | 745 | 80 | 1250 | 1.0L |
| 7 | F3 | 745 | 80 | 1500 | 1.0L |

**Table 7:** Numerical model footing data

| *S. No.* | *Size of Footing (in m)* | *Load in (KN)* | *Net Upward Soil pressure (KN/m$^2$)* | *Depth of Skirt (Ds)(mm)* | *Length of skirt* |
|---|---|---|---|---|---|
| 1 | F3 | 1640 | 150 | 0 | Without Skirt |
| 2 | F3 | 1640 | 150 | 250 | 1.0L |
| 3 | F3 | 1640 | 150 | 500 | 1.0L |
| 4 | F3 | 1640 | 150 | 750 | 1.0L |
| 5 | F3 | 1640 | 150 | 1000 | 1.0L |
| 6 | F3 | 1640 | 150 | 1250 | 1.0L |
| 7 | F3 | 1640 | 150 | 1500 | 1.0L |

**Table 8:** Numerical model of sample footing

| *S.No* | *Size of Sample Footing (in m)* | *Load in (KN)* | *Net Upward Soil Pressure (KN/m$^2$)* | *Depth of skirt (Ds) (mm)* | *Length of Skirt* |
|---|---|---|---|---|---|
| 1 | Fs | 450 | (1/3)L80<br>(2/3) L150 | 1000 | 1.0L |

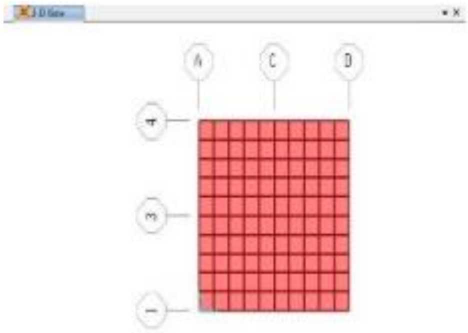

**Figure 2:** ISF model footing without skirt

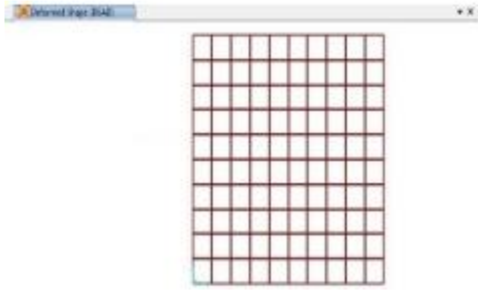

**Figure 3:** Deformed Shape of ISF model footing without skirt

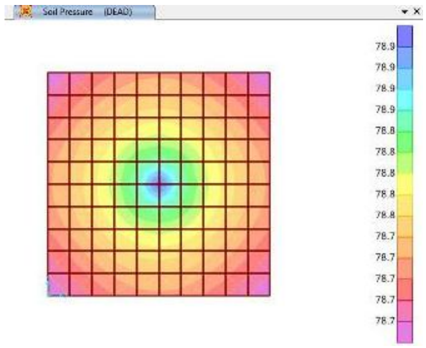


**Figure 4:** Soil pressure of ISF model footing without skirt

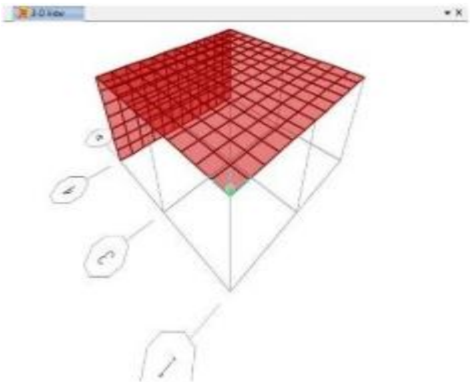

**Figure 5:** SSISF model footing with single skirt

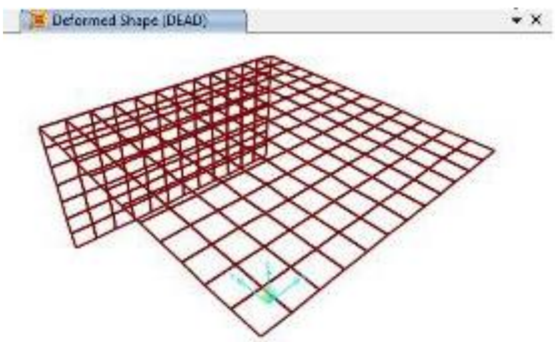


**Figure 6:** Deformed shape of SSISF model footing

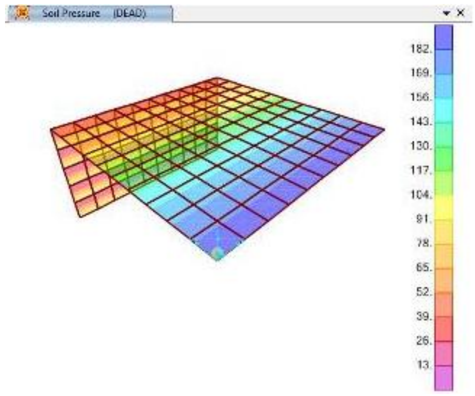


**Figure7:** Soil pressure variation of SSISF model footing

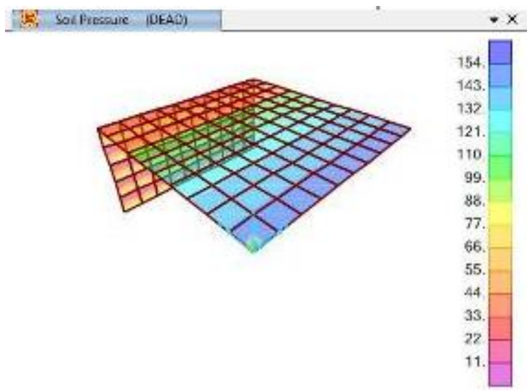


**Figure 8:** Soil pressure variation of (FS) model footing

## 4. Results and Discussion

On the basis of numerical modelling of SSISF for different NUSP and skirt depth ( Ds) due to Concentric loads from column, the various interpretation regarding average settlement of footing and average soil pressure have been obtained using SAP 2000 Vs18. Results from the comparative analysis are represented by various graphs as shown below.

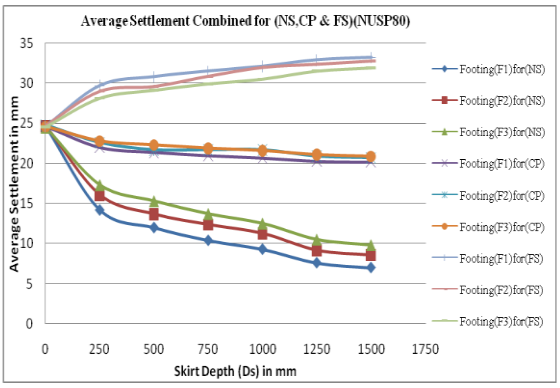


**Figure 9:** Average settlement for SSISF model footings

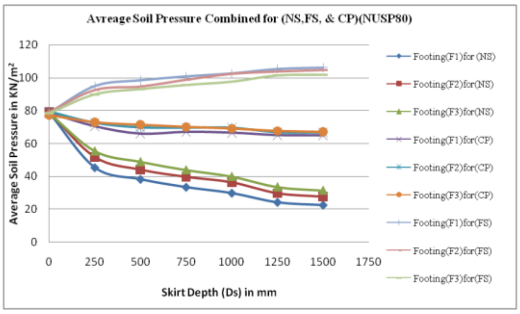


**Figure 10:** Average soil pressure for SSISF model footings

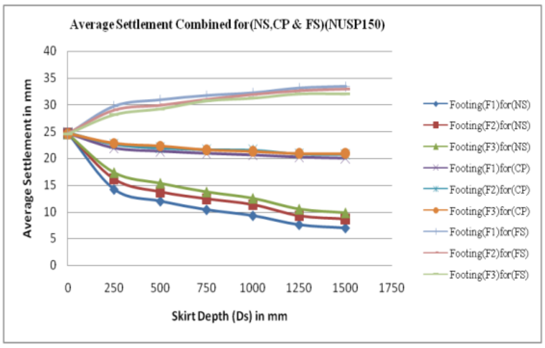


**Figure 11:** Average settlement for SSISF model footings

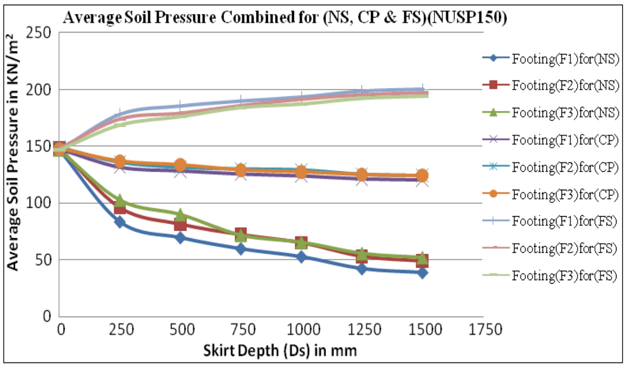


**Figure 12:** Average soil pressure for SSISF model footings

### 4.1 Discussion

As per I.S. codal provision for traditional Isolated footing without skirt the maximum single skirted isolated square footing with variable depth of skirt and net upward soil pressure acting below the footing; shows almost linear relationship between average settlement with skirt depths. At the same time graphical interpretation of skirt depth with variation of average soil pressure is also found to be almost linear with low gradient value. The study conducted on poor soil and better soil does not indicate any vulnerable changes in the performance of footing. The results are more appreciable for low depth of skirt ranging from 250mm to 1000mm, with regards to average settlement and average soil pressure below the footing. It is not always advisable to provide higher depth of skirt because it provides large confinement of soil below the footing. Resulting in higher differential settlement or tilt of the footing.

## 5. Conclusions

1) For both type of soil and any size of footing, the maximum settlement at the centre point under the column can be arrested by 20%.
2) At Near Side (NS) on which the skirt has been provided, the average settlement reduces by 40 to 60% for skirt depth of 250mm and by almost 60 to 70% for skirt depth of 1500mm.
3) Due to provision of skirt the Far Side (FS) of the footing gets lifted, causing differential settlement between the two opposite sides of the footing, which increases with the depth of skirt. No appreciable arrest in the settlement could be achieve but results in higher differential settlement, also known as tilt. Hence it is advisable to provide smaller skirt depth, until and unless it is very essential to adopt higher depth of skirt.
4) In case of soil with poor NUSP the average soil pressure reduces by maximum to 76% for the highest depth of skirt considered as 1500mm. Whereas for soil with better NUSP average soil pressure reduces to 66%. The average NUSP reduces by 15 to 20%.
5) NUSP for the Far side increases by 20 to 25%. In order to keep this NUSP within limits, it is advisable to design the footing for 25% higher load than actual design load. So that NUSP at the Far Side (FS) remains within the safe bearing capacity (SBC Limit).
6) Special case of Sample Footing (Fs) can resist 1.6 times more load with maximum permissible settlement of any portion or point on the footing not exceeding permissible limit of settlement 25 mm; when skirt is provided on poor soil side.

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