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Skirted Foundation on Sandy Soil - A Review

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***Abstract*:- Many methods were recently adopted by geotechnical engineers to promote the function of foundations. They always try to create procedures to improve the vertical and lateral load capacity (i.e. reduce the riskiness of sliding, overturning and on the other hand the settlement of whole structure). Some of these procedures include grouting, soil reinforcing, deep compaction, etc. However, these methods may be restricted by the cost and applicability. One of the promising innovative alternatives is using skirts to create a confinement for the loaded soil. This confinement improves the behavior of foundation and the features mentioned above (soil capacity, settlement, sliding and overturning, as well as the uplift capacity). In view of these features, it was found that the skirted foundation could be a strong competitor to traditional types of foundation for offshore structures. Moreover, the cost effective of skirted foundation made it an acceptable alternative to deep foundation in the case of low bearing capacity of the top soil**

Key Words: Skirted Foundation , Off shore , Sand Soil, deep foundation

1.1 INTRODUCTION

In last few decades, geotechnical engineers created many manners to develop the behavior of soil foundation system in order to increase soil bearing capacity as well as reduce the total settlement of foundation. One of these manners is using skirted foundation which is used when the supporting soil is weak or when the superstructures are subjected to combined loads (i.e. vertical, inclined and horizontal). Therefore, the foundation of such structures must be safe under all loading conditions.

A lot of studies using laboratory and field approaches were carried out to examine the behavior of skirted foundation. A survey of main studies which deal with this type of foundation is made in this chapter.

1.2 APPLICATIONS OF SKIRTED FOUNDATION

Skirted foundations are common foundation system used for offshore structures to support or anchor fix or float structures for oil and gas industries. The main offshore applications of skirted foundation are listed below; (Tripathy, 2013)

1- Gravity based structures
2- Jacket unit structure
3- Tension leg platforms
4- Foundation for wind turbine
5- Foundation for bridges
6- Petrol gas and oil plant

A selection of applications of skirted foundations offshore are shown in Figures (1), (2), and (3).

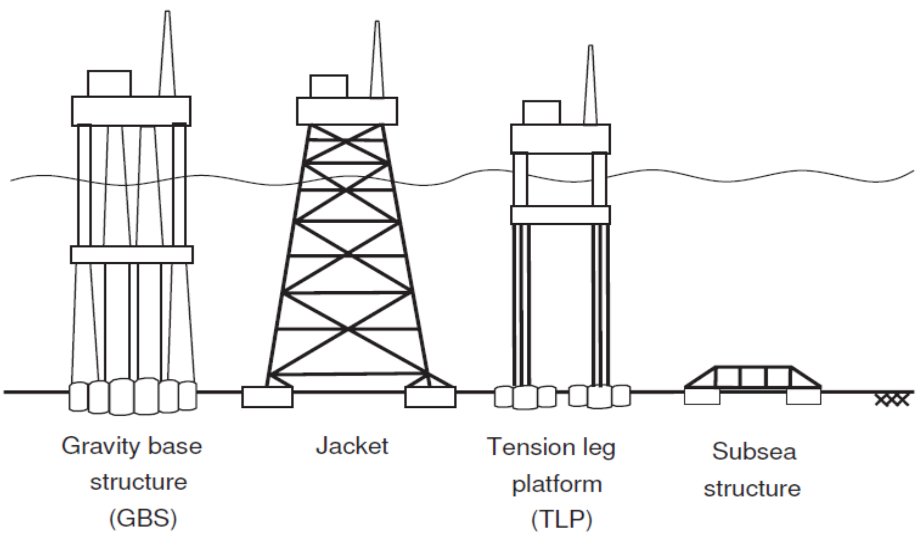

Figure 1: Applications of skirted foundations offshore. (Gourvenec and Randolph, 2010)

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Figure 1: Draupner E jacket with skirted foundations.(Andersen et. al., 2008)

Figure 2: View of offshore concrete structure with skirt foundation just before skirt penetration. (Saito et. al., 2003)

1.3 FAILURE MODES AND BEARING CAPACITY OF SHALLOW FOUNDATION

Reviewing the failure pattern and bearing capacity of classical shallow foundation is a good starting line to understand the behavior of skirted foundation. It is knowing that the failure mechanisms occur in shallow foundation are always soil shear failure. Based on the shape of slip line, three types of failure modes can be identified, general, local and punching shear failure. Compressibility and depth to width ratio (d/B) are the most important factors that determine the modes of failure (Terzaghi, 1943; Vesic, 1963). General shear failure is usually taking place in dense cohesion soils (Dr > 70 %) or stiff cohesive soils. Figure 4 shows general shear failure mode.

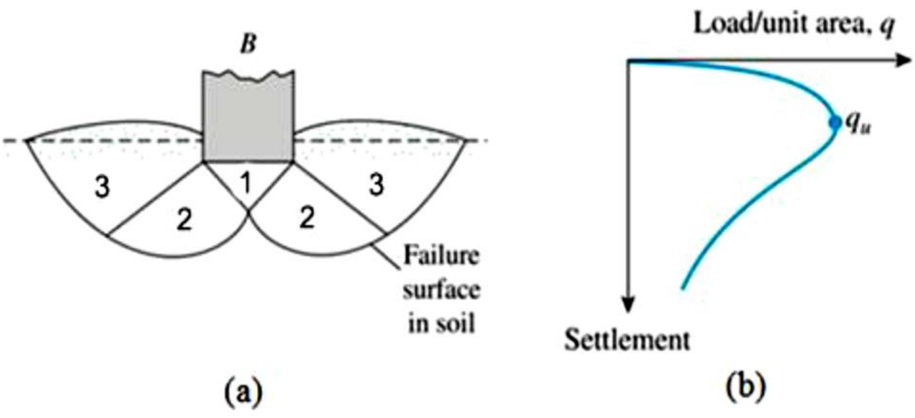

Figure 3: General shear failure mode (Vesic, 1973)

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The local shear failure is developed beneath the footing supported by medium dense sand with Dr ranged between 35% - 70%. Figure 5 illustrates the slip line of such failure mode and pressure- settlement relationship. It can be seen that there is no peak point can be identified (Vesic, 1973).

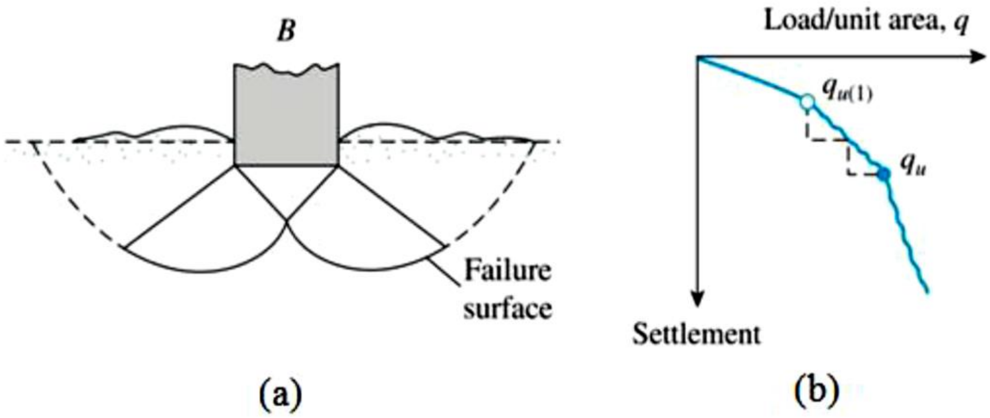

Figure 4: Local shear failure (Vesic, 1973)

Punching shear failure occurs in soft clay or loose sand soil with Dr of less than 35%. Linear steeped curve can be observed for pressure- settlement relationship as shown in Figure 6. ***(Vesic, 1973).***

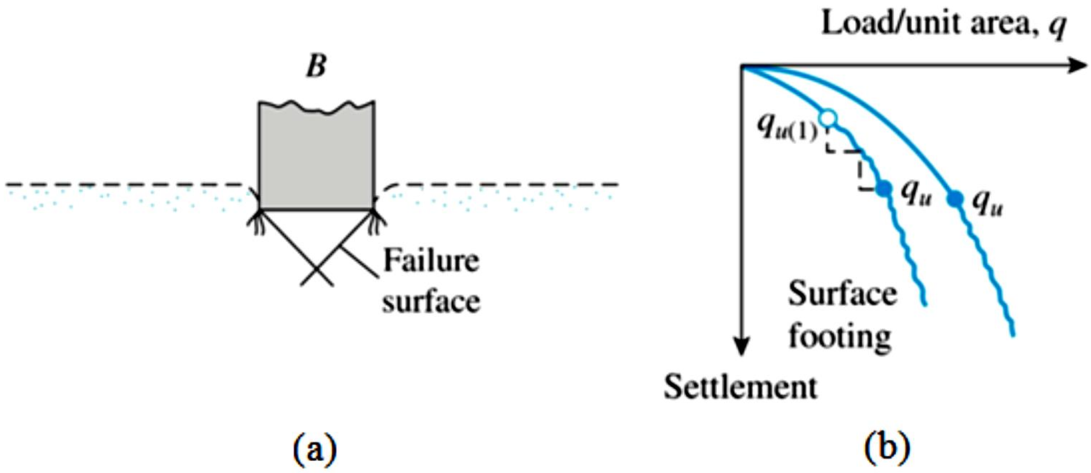

Figure 5: Punching shear failure (Vesic, 1973)

All failure patterns mentioned above were accompanied the shallow foundation. The foundation behaves as shallow when the ratio of d/B ≤ (1-4) (Meyerhof, 1963 and Vesic, 1973), where d is the foundation depth and B is the diameter or width of foundation. One of the first equations used to determine the bearing capacity was derived by Terzaghi in 1943. He derived the equation for strip footing placed on sandy soil and subjected to vertical load at centre as shown in Figure 7. The equation is:

$$q_{ult} = \gamma D_f N_q + 0.5 \gamma B N_\gamma \qquad (1)$$

Where;
q_{ult}= the ultimate bearing capacity;
γ = soil unit weight;
D_f = depth of footing;
B = width of footing;
N_q and N_γ are factors of the bearing capacity given by Terzaghi (1943)
The above equation was modified to be suitable for shallow circular foundation as follows (Terzaghi, 1943) : -

$$q_{ult} = \gamma D_f N_q + 0.3 \gamma B N_\gamma \qquad (2)$$

Where; B in this equation is footing diameter.

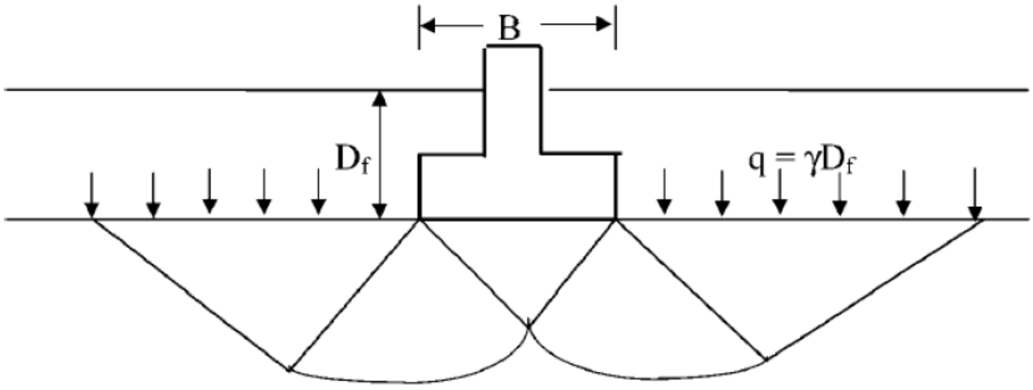

Figure 6: Mechanism of failure for soil under a rigid continuous foundation subjected to central vertical load (Terzaghi, 1943)

1.4 Bearing Capacity and Failure Modes of Skirted Foundation

Based on the equations of section 2-3, the vertical bearing capacity of skirted footing can be estimated. Al-Aghbari and Mohamedzein, 2004 proposed an equation for skirt strip footing placed on sand as shown in Figure 8. The equation is:

$q_u = \gamma\ (D_f + D_s)\ N_q + 0.5\ B'\ \gamma\ N_\gamma\ F_\gamma$ (3)

Where;

F_γ = Skirt factor

D_f = Foundation base depth below the ground level

D_s = Depth of the skirt below the base of foundation

B' = Total width of the foundation equals to $(B + 2t_s)$

t_s = Thickness of the skirt

They found that the skirt factor can be determined from the following formula:

$$F_\gamma = 1.15\left[0.4 + 0.6\left(\frac{tan\emptyset'}{tan\delta_f}\right)\right]\left[0.57 + 0.1(D_s B') + 0.37\left(\frac{tan\delta_s}{tan\delta_f}\right)\right][1.2 - 0.002D_r] \quad (4)$$

Where;

Ø'= Effective angle of internal friction

δ_f = Friction angle at foundation base

δ_s = Friction angle at sides of skirt

D_r = Relative density in percent

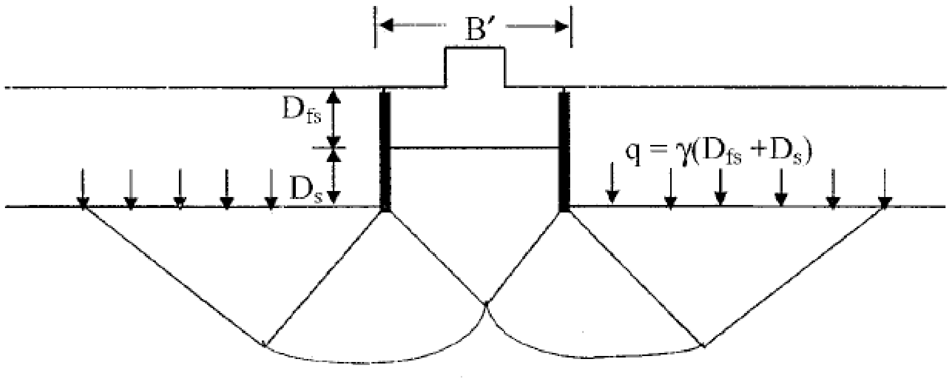

Figure 7: Mechanism of failure for soil under a rigid continuous foundation with skirts subjected to central vertical load. (Al-Aghbari, and Mohamedzein, 2004)

Based on their results, the deviation between measured and predicted ultimate bearing capacity was about 5 % or less as shown in Figure 2-9.

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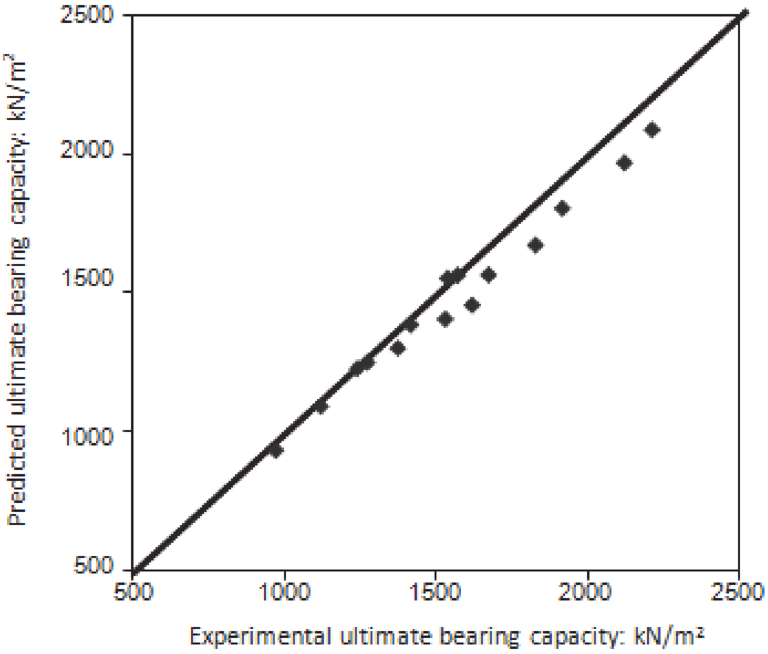


Figure 8: Comparison between the predicted and measured bearing capacity (AL-Aghbari and Mohamedzein, 2004).

In 2020, same authors conducted a new study and suggested a modified skirt factor as follow;

$F_\gamma = F_{\gamma f}\, F_{\gamma d}$ (5)

Where;

$F_{\gamma f}$ = Surface friction factor of the skirt,
$F_{\gamma d}$ = Depth factor of the skirt

The authors determined the components of the skirt factor that used in Eq. (5) experimentally as shown below.

$F_{\gamma d} = 1.1$ (6)

$F_{\gamma f} = 0.97 \frac{tan\delta_s}{tan\delta_{si}}$ (7)

Where; δ_s is the friction angle between the sand and the skirt, and δ_{si} is the initial angle of friction between the sand and the skirt. The values of δ_s vary from 28° to 38°, with a reference value of δ_{si} = 28°. According to that, the skirt factor (F_γ) as defined in Eq. (2-5) can be written as:

$F_\gamma = 1.06 \frac{tan\delta_s}{tan\delta_{si}}$ (8)

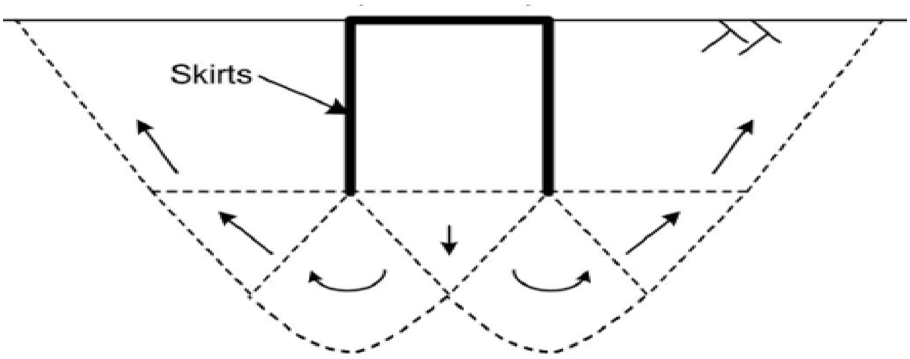
Based on the above, the general equation of ultimate bearing capacity for skirted foundation resting on sand soil is as follows:

$q_{ult} = \gamma(D_f + D_s)\, N_q\, s_q\, d_q + 0.5\, \gamma B'\, N_\gamma\, s_\gamma\, d_\gamma\, F_\gamma$ (9)

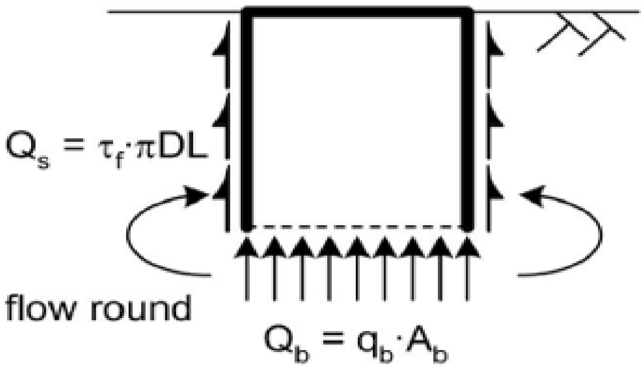
On the other hand, some other studies investigated the failure mechanism of skirted foundations. Three failure modes were presented by Schneider and Senders, 2010. Figure 2-10 shows these three modes of failure. The first mode is similar to shallow failure mechanism. However, the addition of skirts moves the shallow foundation failure mechanism to deeper soil layers, and possible stronger soils (Figure 10a).

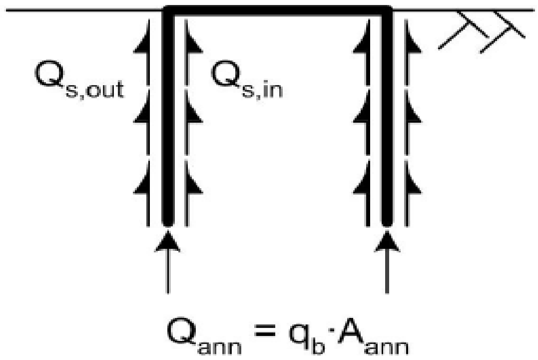
Another failure mechanism was observed for deep skirt. Figure 10b illustrated a flow round mechanism at the base of skirt foundation. There are two sources for the bearing capacity of skirted foundation in this failure type, base resistance ($Q_b = q_{b*}A_b$) and resistance due to friction along the side of skirt ($Q_s = \tau_f \pi DL$, where τ_f is the unit shaft friction along the side of the skirted foundation).

A third possible mechanism was predicted when there is a gap between internal soil and top plate of the skirted foundation as shown in figure 10c in such case, the end bearing is developed on skirt annulus only in addition to internal and external friction along the skin of skirt.



a. Shallow failure mechanism



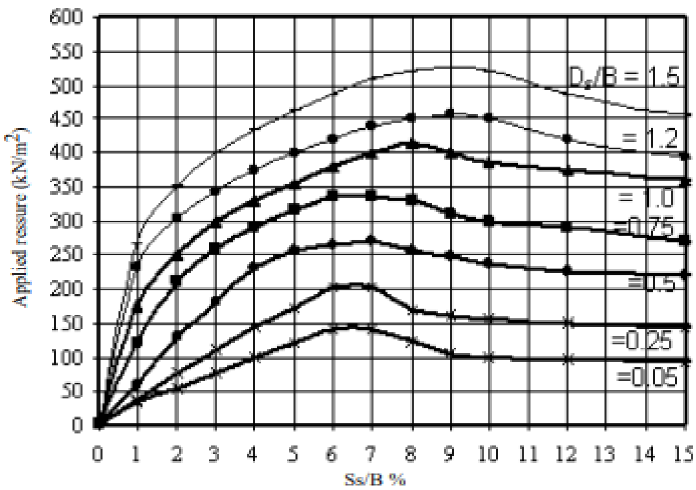


b- Plugged deep failure mechanism

c- coring deep failure mechanism

Figure 9: Failure mechanisms for skirted foundations. (Schneider, and Senders 2010)

Al-Aghbari and Mohamedzein (2006) carried out a study to explore the behavior of circular footing with and without skirt placed on sand soil. They found that using skirts increase the bearing capacity and reduce the settlement of footing. Same results were found by Al-Aghbari (2007), he found that the skirts have a significant influence on the reduction of footing settlement. The reduction of settlements depends mainly on the skirt depth (for constant applied load). The results of this study are shown in Figure 11.



(a) footimg with skirts

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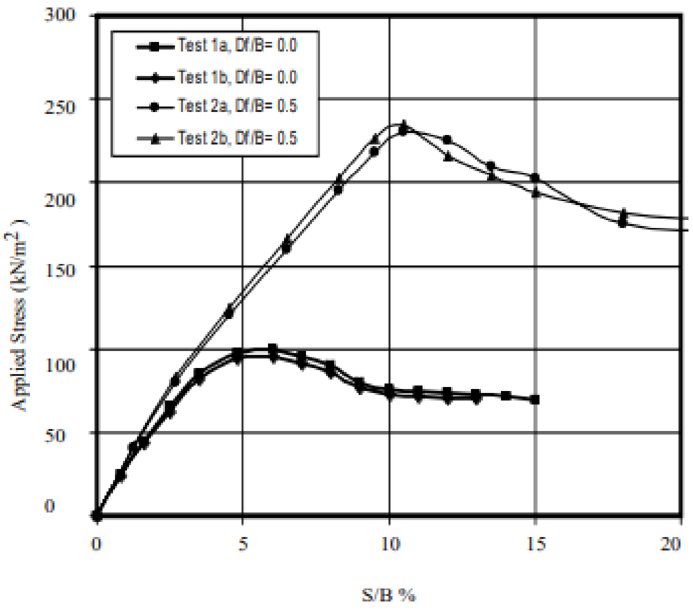

(b) footing without skirts

Figure 10: Relation between pressure-displacement for footings (Al-Aghbari, 2007)

Mohammed (2012) studied a model of foundation bounded by wall. The soil under the foundation was sand, depth and distance of wall are the main variables in the study. In addition, the relative density of the sand was changed by 33%, 56% and 75%. Strip, square and rectangular were the shapes of foundation used by the author. The results indicated that an appreciated growth in bearing capacity was achieved. It increased by 37%, 43% and 34% for strip, square and rectangular footing, respectively when using loose sand. For medium dense sand the growth was 25%, 56% and 33% while in dense sand it was in the order of 59%, 67% and 52%. Moreover, the study showed that the maximum effect of wall depth on bearing capacity was in the range of (1.5B-2B) for all shapes.

The above study was confirmed by Wakil, 2013, he examined the effect of a circular Steel footing with skirt on bearing capacity. Footing diameter, death of skirt and relative density of soil where the studied variables. The study concluded that the sand relative density and the ratio of the skirt depth to the footing diameter are the main factors that the performance of skirted footing depends on.

PLAXIS 2D finite element software was employed by Pusadkar and Bhatkar (2013) to study the performance of one and two side skirted foundation resting on sandy soil as shown in Figure 12. Different footing dimensions and skirt depths were studied.

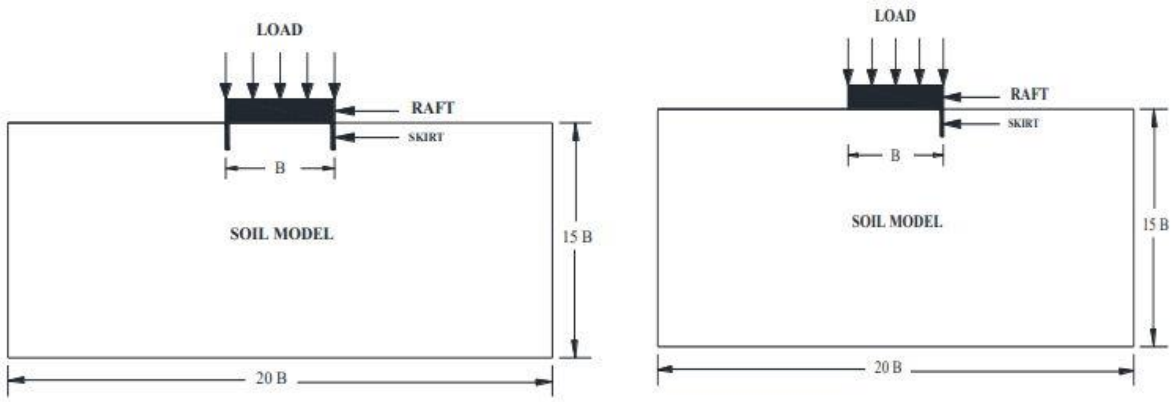

Figure 11: : Model geometry of raft foundation with one and two sides skirt.

The obtained results showed decreasing in settlement and increasing in bearing capacity for two side skirted footing. On the other hand, one side skirted footing showed increasing in settlement due to sliding.

The bearing capacity of square and rectangular (L=2B) skirted footing over sand soil was investigated by Khatri et, al. (2017). Four different relative densities for sand were chosen furthermore, the skirt depth varies by (0.25B - 1.0B). The results

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disclosed considerable improvement in bearing capacity. The improvement ranged between 33.3% and 262% depending on skirt depth and soil relative density. Moreover, it was found that the skirted footing had effect in law relative density (30% and 50%) more than in high relative density (70% and 87%).

1.5 CONCLUSION

The following summary can be drawn from the studies mentioned above: -

1- The soil bearing capacity has increased with using skirted foundation compared to that without skirt.

2- Decreasing in the settlement was obtained by adding skirt to foundation.

3- The improvement in bearing capacity depends on skirt depth to footing width ratio, soil relative density and shape of footing.

4- Sandy soil was used as supporting soil in all studies previously mentioned.

5- Angle of internal friction (particle to particle friction angle) and friction angle between soil and skirt material affected the results as well.

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