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Numerical Analysis of Skirted Strip Footing Behavior Nearby Unsupported Slope

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Abstract

The soil around foundation plays a very critical role during its behavior. The skirts form an enclosure in which soil is confined and works as a unit with the overlie foundation to transfer superstructure load to soil essentially at the level of skirt tip resulting increase in the bearing capacity and lowering in the settlement of the structure. The present research focused on the analysis of skirted strip footing adjacent to unreinforced slope using a finite element software PLAXIS 2D. The variables which are considered in the current study are depth of embedment of the footing (De) in terms of height of slope (H), the ratio of distance of strip footing from crest to the width of the footing (b/B), and the ratio of depth of skirt to width of the footing (ds/B). The skirt configuration is provided on one side vertical skirt, both sides equal vertical skirt and unequal vertical skirt. The numerical study shows that the using of structural skirts with adequate depth in the conjunction of strip footing to slope crest has a substantial increase in the ultimate load bearing capacity of strip footing. The enhancement in ultimate load bearing capacity of skirted strip footing increases with increasing skirt depth, embedment depth of footing and crest distance of unsupported slope. The two sides equal vertical skirted strip foundation shows significant increase in ultimate load bearing capacity and decrease in settlement.

Keywords: *skirt, ultimate load bearing capacity, unsupported slope, skirted strip footing, & PLAXIS 2D.*

1. Introduction

The skirted foundation had been extensively used for offshore structures like wind turbine oil, gas industry due to easy installation compared to deep foundation. The skirt foundation serves variety of functions such as control settlement during service life, less impact to environments during operation at installation site. The skirted foundations satisfy bearing capacity requirement and minimizes the embedment depth and dimensions of the foundation. Therefore, it may become an alternative approach for improving the bearing capacity of footing adjacent to slope. The performance of skirted strip footing subjected to eccentric inclined load studied by laboratory work and numerical analysis using PLAXIS. [9]. It was concluded that the rate of improvement of settlement with skirt depth increases with the increase of both load eccentricity and load inclination angle and reached its maximum value at skirt length equal to half the footing width. The ultimate bearing capacity increases and settlement decreases with increase in load inclination angle and skirt angle. The performance of bi-angle shape skirted footing in clayey soil subjected to eccentric load on square footing shown that the tilt of diagonally opposite corners of the footing was affected considerably due to presence of skirts [7]. The skirt had been found to be helpful in reducing tilt due to eccentric loading. The result of experimental and numerical analysis skirted square footing on sand revealed that skirted foundation exhibit bearing capacity and settlement values that are close, but not equal, to those of pier foundation of the same width and depth [5]. The enhancement in bearing capacity of shallow foundation increase with increasing skirt depth and decrease relative density of sand. The laboratory model tests and numerical study shows that stabilizing the earth slope using structural skirts with adequate depth in the conjunction of strip footing adjacent to slope crest has a significant effect in improving the soil bearing capacity [3].

To investigate the performance of skirted strip footing constructed on an unsupported slope, a numerical study had been carried out considering various parameters such as embedment depth of footing De, distance of footing from slope crest b, skirt depth d_s and compare the ultimate load bearing capacity of skirted strip footing with the strip footing without skirt, In order to give an optimum location of skirted strip footing constructed nearby unreinforced slope with the use of various skirts configurations with several parametrical aspect were considered in the running study. The performance of skirted strip footing with and without skirt adjacent to slope with angle of 26.56°is studied using PLAXIS 2D software. The footing is placed at different location from the crest of the slope (b/B= 0, 1, 2, 3, & 4.), and embedment depth of the footing (De= 0, 0.2H, 0.4H, 0,6H, & 0.8H).The analysis is carried out with skirt depth of (ds/B= 0.5, 1, &1.5) for several skirt configuration of one side vertical skirt, both side equal vertical skirt, both side unequal vertical skirt.

2. Conceptualization of PLAXIS Modeling System

For each new 2D project to be analyzed it is important to create a geometry model first. A geometry model is a representation of a real two dimensional problem and is defined either by a plane strain or an symmetric model. A geometry model should include a representative division of the subsoil into distinct soil layers, structural objects construction stage and loadings. The model must be sufficiently large so that the boundaries do not influence the results of the problem to be studied. The analysis was carried out during the entire study by using skirts to improve the ultimate load carrying capacity of strip footing $P_{(ult)}$ and settlement behavior in similar way for three skirts types, skirt depth, crest distance and embedment depth of the footing. The ultimate load carrying capacity $P_{(ult)}$ for the footing-soil systems obtained from load settlement curve plotted in each run analysis. The ultimate load obtained from each run analysis was used for the investigation and finding efficiency factor (ζ) which is defined as ratio of ultimate load bearing capacity of skirted strip footing $P_{(ult)S}$ to the ultimate load bearing capacity of strip footing without skirt $P_{(ult)}$ at the same embedment depth and distance of footing from the crest.

3. Methodology of Numerical Modeling

The geometry of the finite element soil model in PLAXIS 2D is adopted as 10B X 20B with the width of strip footing B=2m as shown in Figure. 1. The analysis is run out using PLAXIS 2D software for strip footing without skirt and then with three types of skirts placed adjacent to unreinforced slope of 26.56°, and then mesh is generated during the analysis. Atypical case modeled in PLAXIS 2D is as shown in Figure. 2. The footing was placed at different location from crest (b/B= 0, 1, 2, 3, & 4.) and footing embedment depth (De= 0, 0.2H, 0.4H, 0,6H, & 0.8H). The details of parameters that used in this study are as shown in table.1.

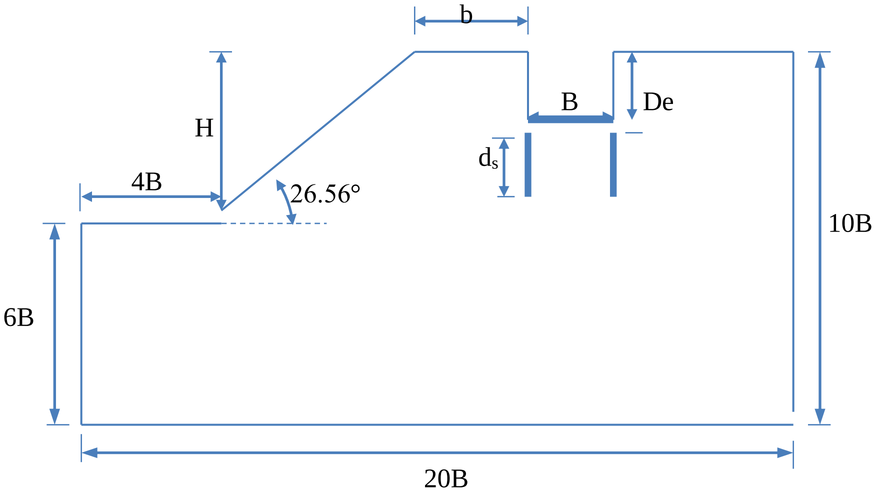


Figure 1: Geometry Model of Skirted Strip Footing adjacent to Unsupported Slope

The analysis is calculated for three types of skirts configurations of one side vertical skirt, both side equal vertical skirts, both side unequal vertical skirts (long side = 2× short side) as shown in figure. 2. The analysis is done with skirt depth of (ds/B= 0.5, 1, &1.5) for the several skirt configuration.

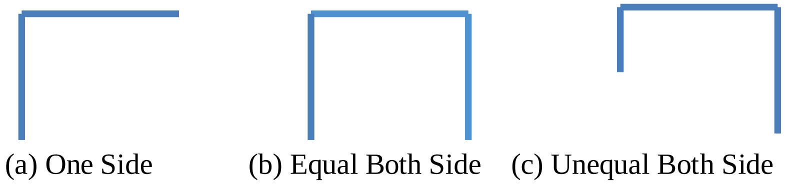
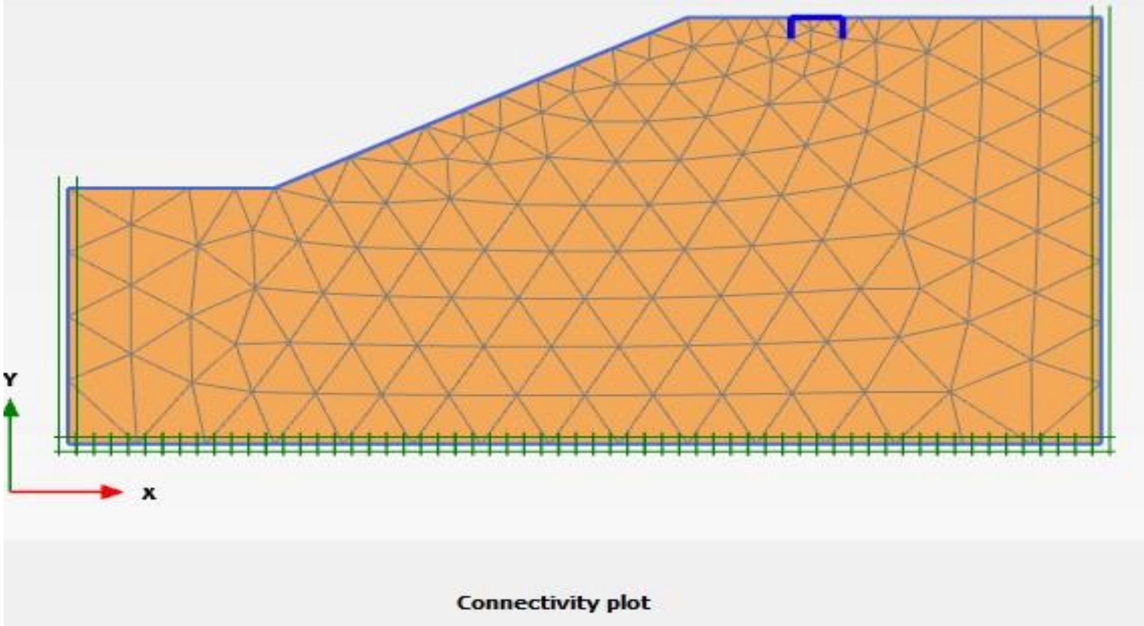


Figure 2: Configuration Types of Skirts

When the geometry model is fully defined and material properties are assigned to all clusters and structural objects, the geometry has to be divided into finite element (FE) calculation. A compassion of finite element is called mesh. The basic type of element in a mesh is the 15-node triangular element (used in the present study) or the 6-node triangular element. For this modeling an automatic generation of 15 node triangle plane strain elements for the soil, 5 node beam elements for the footing, and 5 node elastic elements for the geogrid were used. PLAXIS provides automated mesh generation system, in which the model is discredited into standard elements. Medium and fine element distributions were conducted to determine a suitable mesh density. In medium mesh, 213 elements are generated in skirted strip footing case and 267 elements for fine mesh the difference was less than 1%. In this study, a fine mesh density was adopted for skirted and unskirted strip footing analyses. An example of the FE mesh of soil, foundation, and skirts elements illustrated in figure.3. The mesh generation takes full account of position of points and lines in the geometry model so that the exact position of loads and structures are accounted for the finite element mesh. The model of skirted strip footing collapse point with deformation of the soil beneath it is shown in figure (4).



Stress point 3204   Element 267   Node 2247

Figure 3: Fine element mesh distributions of the model created by PLAXIS 2D

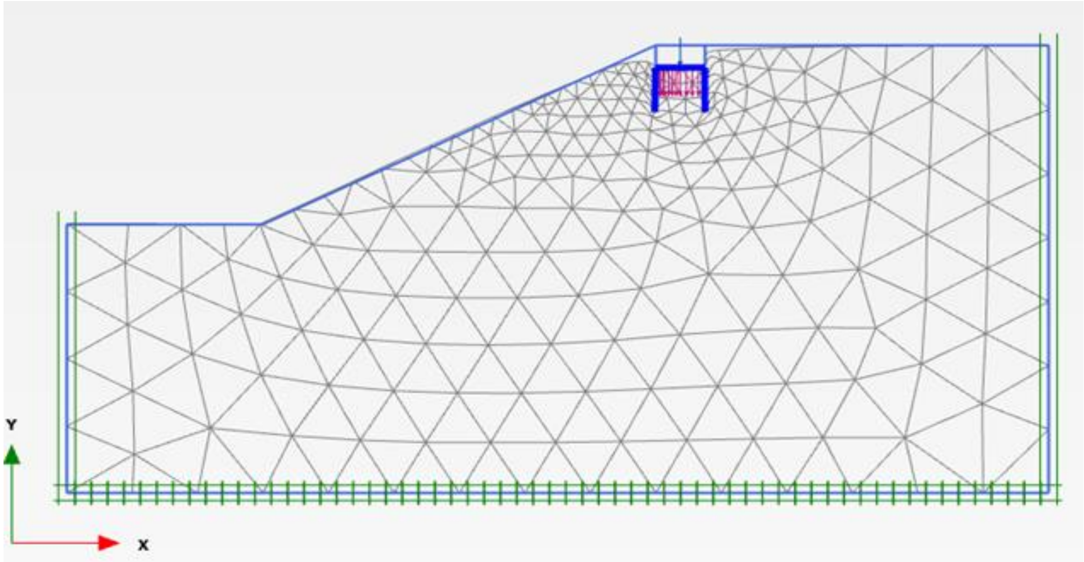


Figure 4: Model failure pattern with soil deformation by PLAXIS 2D

Table 1: Details of Parametric study

No	parameters	Details of parameters
1	Slope angle (β)	26.56°
2	Type of footing	Strip footing (width B= 2m)
3	Type of load	vertical
4	Depth of embedment of footing (De)	0.2H, 0.4H, 0.6H, & 0.8H
5	The ration of distance of footing from crest to the width of footing(b/B)	0,1, 2, 3, & 4
6	The ratio of the depth of skirt to width of the footing (ds/B)	0.5, 1, & 1.5
7	Skirt Configuration	- One side vertical skirt - Both side equal vertical skirt -Unequal both vertical skirt

Soil and Strip Footing Properties

While analyzing the model in PLAIXS 2D, the material properties of the soil and the footing are required. The soil is considered as sand while strip footing was considered as concrete for the analysis. The properties of soil used in the analysis are as in table 3 while for strip footing are given in table 2.

Table 2: Properties of Strip Footing

No.	Parameter	Value
1	Type of material	Elastic-plastic
2	Normal stiffness, EA(kn/m)	8944000
3	Flexural rigidity, EI(kn/m)	119253.33
4	Poisson's ratio	0.15

Table 3: Properties of Soil

No.	Parameter	Value
1	Material type	sand
2	Material model	Mohr-Coulomb
3	Young's modulus of sand (ken[m2)	50000
4	Cohesion (kn/m3)	1
5	Passion's ratio	0.3
6	Friction angle (Φ)	36°
7	Dilatancy angle	5°
8	Interface reduction factor (R inter)	0.67
9	Dry density (kn/m3)	18

4. Results Analysis and Discussion

This section contains all results that obtained from analysis of vertical skirted strip footing by PLAXIS 2D.

Table(4) Ultimate Load Carrying Capacity Values $P_{(ult)}$ of Strip Footing With & Without Skirts

Skirt Type	**(ds/B)**	**(b/B)** **(De)**	**0**	**1**	**2**	**3**	**4**
(A) Strip Footing with One Side Vertical Skirt	**0.5**	**Surface**	232	487	714	822	860
		0.2H	636	949	1330	1695	2036
		0.4H	1180	1647	2015	2469	3020
		0.6H	1902	2407	2863	3458	4021
		0.8H	2857	3472	4015	4685	5166
	1	**Surface**	244	516	734	902	953
		0.2H	744	1088	2214	1703	2181
		0.4H	1295	1777	2196	2729	3219
		0.6H	2049	2543	3038	3634	4275
		0.8H	3185	3724	4124	5088	5732
	1.5	**Surface**	323	550	791	1051	1094
		0.2H	784	1178	1564	1948	4236
		0.4H	1369	1825	2325	2845	3428
		0.6H	2422	2735	3244	3900	4556
		0.8H	3550	3975	4544	5160	5740
(B) Strip Footing with Two Sides Vertical Equal Skirts	**0.5**	**surface**	399	702	1033	1286	1651
		0.2H	881	1256	1663	2109	2538
		0.4H	1531	1970	2423	2919	3636
		0.6H	2426	2908	3468	4145	4644
		0.8H	3541	4097	4668	5299	5800
	1	**surface**	577	959	1355	1773	1975
		0.2H	1452	1637	2116	2657	3045
		0.4H	1940	2411	13051	0.6H	4140
		0.6H	2903	3510	4331	5001	5604
		0.8H	4455	4965	5644	6245	6950
	1.5	**surface**	885	1285	1716	2249	2659
		0.2H	1452	2081	2549	2827	3732
		0.4H	2919	2889	3583	4195	4654
		0.6H	3713	4366	5019	5870	6036

		0.8H	5265	6254	6644	7181	7799
(C) Strip Footing with Two Sides Vertical Unequal Skirts	**0.5**	**surface**	334	634	931	1161	1326
		0.2H	760	1137	1587	1887	2324
		0.4H	1342	1812	2200	2870	3355
		0.6H	2071	2667	3300	4076	4400
		0.8H	3191	3906	4524	5008	5506
	1	**surface**	427	754	1026	1410	1689
		0.2H	937	1272	1744	2135	2559
		0.4H	1558	2025	2655	3052	3554
		0.6H	2470	2946	3624	4130	4667
		0.8H	3640	4276	4703	5515	6138
	1.5	**surface**	539	915	1267	1617	1729
		0.2H	1068	1414	1958	2428	2848
		0.4H	1770	2265	2799	3066	3560
		0.6H	2426	3270	3600	4456	4968
		0.8H	3885	4446	5091	6070	6410
(D) Strip Footing without Skirt	**0**	**surface**	205	460	675	794	811
		0.2H	588	928	1245	1666	2015
		0.4H	1125	1600	2012	2444	2938
		0.6H	1866	2306	2842	3392	3968
		0.8H	2730	3361	3985	4525	5070

Table (5) Efficiency Factor(**ζ**).

Skirt Type	**(ds/B)**	**(b/B)** **(De)**	**0**	**1**	**2**	**3**	**4**
(A) One Side Vertical Skirt	**0.5**	**surface**	1.13	1.06	1.06	1.03	1.06
		0.2H	1.08	1.02	1.07	1.02	1.01
		0.4H	1.05	1.03	1.0	1.01	1.03
		0.6H	1.02	1.04	1.0	1.02	1.01
		0.8H	1.04	1.03	1.00	1.03	1.01
	1	**surface**	2.20	1.11	1.12	1.14	1.17
		0.2H	1.26	1.17	1.14	1.02	1.08
		0.4H	1.15	1.11	1.09	1.09	1.09
		0.6H	1.09	1.10	1.06	1.07	1.07
		0.8H	116	1.10	1.03	1.12	1.13
	1.5	**surface**	1.57	1.18	1.17	1.32	1.26
		0.2H	1.33	1.26	1.26	1.16	1.17
		0.4H	1.21	1.14	1.15	1.16	1.16
		0.6H	1.19	1.18	1.14	1.14	1.15
		0.8H	1.3	1.18	1.14	1.14	1.13

(B) Two Sides Vertical Equal Skirt	**0.5**	**surface**	1.94	1.52	1.53	1.61	1.03
		0.2H	1.49	1.35	1.33	1.231	1.26
		0.4H	1.36	21.2	1.2	1.19	1.23
		0.6H	1.3	1.26	1.20	1.22	1.17
		0.8H	1.30	1.22	1.17	1.19	1.14
	1	**surface**	2.81	2.08	2.00	2.23	2.43
		0.2H	1.98	1.76	1.69	1.60	1.85
		0.4H	1.72	1.50	1.51	1.48	1.40
		0.6H	1.60	1.52	1.501	1.47	1.41
		0.8H	2.63	1.47	1.41	1.38	1.37
	1.5	**surface**	4.31	2.79	2.54	2.83	3.27
		0.2H	2.46	2.24	2.047	1.70	1.85
		0.4H	1.94	1.80	1.78	1.71	1.58
		0.6H	1.98	1.522	671.	1.47	1.52
		0.8H	1.93	1.86	1.66	1.59	1.54
(C) Two Sides Vertical Unequal Skirts	**0.5**	**surface**	1.62	1.37	1.37	1.46	1.63
		0.2H	1.29	1.22	1.27	1.13	1.15
		0.4H	1.19	1.13	1.09	1.17	1.15
		0.6H	1.10	1.15	61.1	1.20	1.10
		0.8H	1.16	1.62	1.13	1.10	1.08
	1	**surface**	2.08	1.63	1.52	1.77	2.08
		0.2H	1.60	1.37	1.40	1.28	1.27
		0.4H	1.38	1.26	1.31	1.23	1.20
		0.6H	1.32	1.27	71.2	1.21	1.17
		0.8H	1.33	1.27	1.18	1.21	1.21
	1.5	**surface**	1.17	1.35	1.60	2.03	2.13
		0.2H	1.81	1.52	1.57	1.45	1.41
		0.4H	1.57	1.41	1.39	1.25	1.21
		0.6H	1.30	1.41	61.2	1.31	1.25
		0.8H	1.42	1.32	1.27	1.43	1.64

The deep analysis of the results has been carried out to observe the difference between various parameters which are studied in this research as following:

4.1. The Effect of Embedment Depth

The variations of P_{ult} that obtained from numerical analysis against (De/B) ratio for different skirts types shown in Figure (5). The figure clearly shows that, the footing response much improved as the ratio (D_e/B) increases. Furthermore, in all skirts configurations, it can be state that the growth percentage in ultimate load bearing capacity at embedment depths (De) of 0.6H reaches 60.19%

comparing with 53.8% at 0.8H when symmetrical skirt is laying beneath the footing, whereas, the rate of improvement in the ultimate load is nearly 31% at 0.6H comparing with 26.4% at 0.8H with the two sides unequal skirts, also, this behavior is similar in one side vertical skirt. From the figure (6) it is clearly to notice that the P_{ult} began to increase with increase of De up to 0.6H then the curve starts to steady. Therefore, the ultimate load bearing capacity observed to be increased up to embedment depth (De= 0.6H) which represented the optimum depth of embedment.

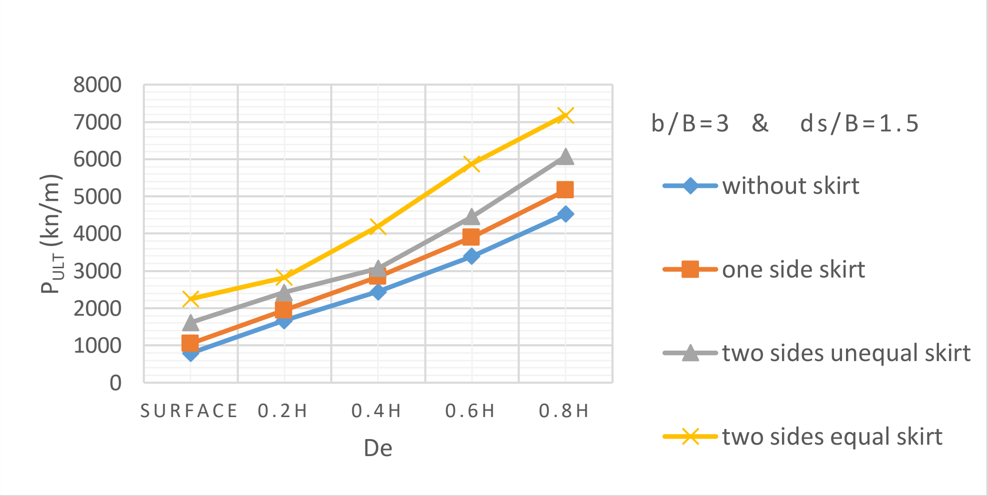


Figure (5): Variation of P_{ult} with embedment depth De at b/B=3

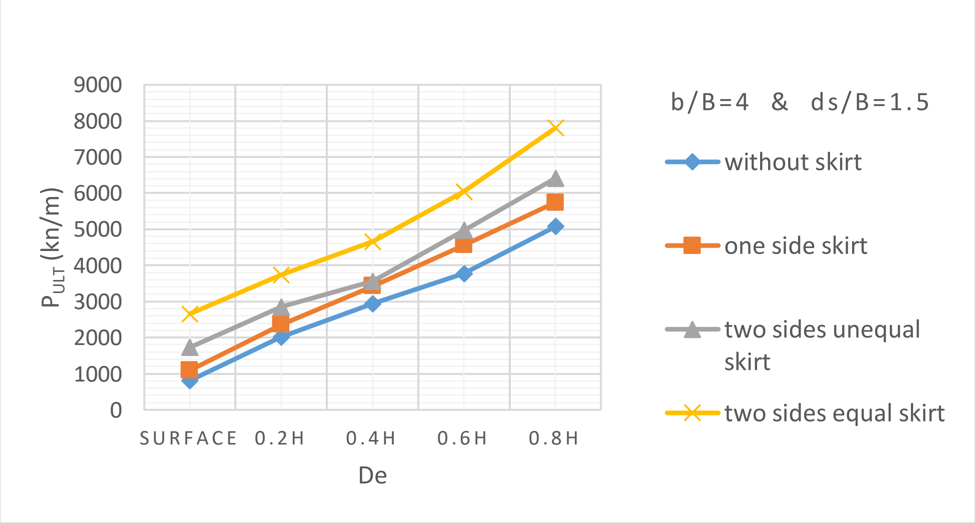


Figure (6): Variation of P_{ult} with embedment depth De at b/B=4

4.2. The Effect of Crest Distance

the tests results shows that the effect of crest distance on the ultimate load bearing capacity of skirted strip footing are greater at greater value of the ratio of (B/b) with different skirts types. From figure(7) it obviously interpret that the ultimate load carrying capacity value observed significant gain at crest distance b/B=0, 1, & 2, whereas, the improvement in ultimate carrying load percentage is higher at crest distance of b/B=3 than &b/B= 4, with percentage of increasement for two sides equal vertical skirts is 73.1% at b=3 comparing with 60.19% at b=4, while, for two sides unequal vertical skirts the improvement percentages 31.37% at b=3 compare to 31.85% at b=4. Therefore, the rate of the increase in the ultimate load bearing capacity of footing is observed to be significant up to the ratio of b/B= 3 after which the effect becomes much lower. Figure (8) shows the effect of crest distance on the ultimate load bearing capacity with various skirts types.

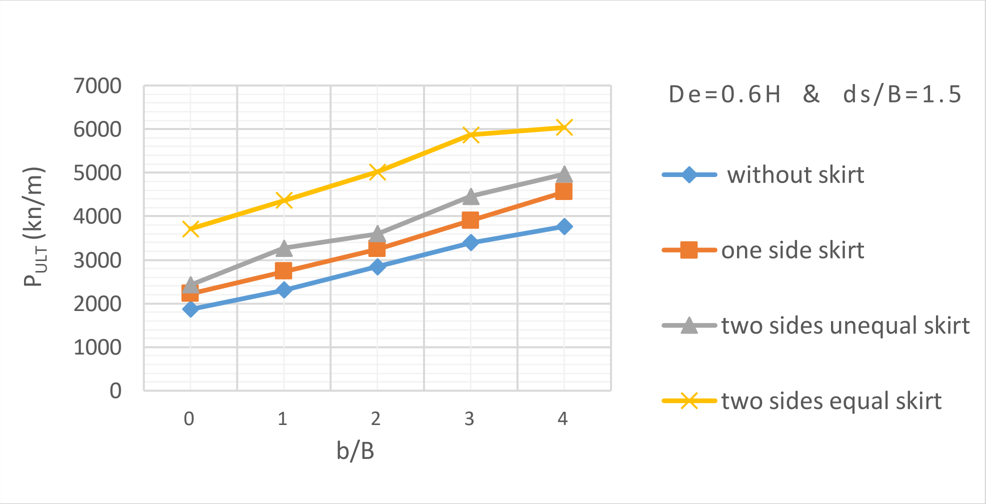


Figure (7): Variation of P_{ult} with crest distance b/B at De= 0.6H.

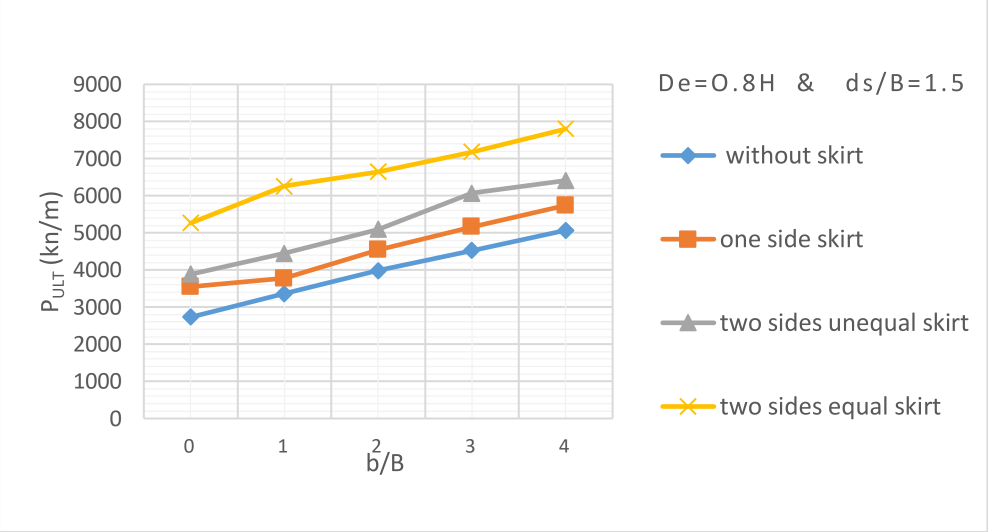


Figure (8): Variation of P_{ult} with crest distance b/B at De= 0.8H .

4.3. The Effect of Skirt Depth

Results of prototype strip footing are plotted in figures (9&10). It is clear that the ultimate load bearing capacity (P_{ult}) increases with increasing skirt depth. Skirt of two vertical sides equal which is placed in confinement with strip footing had a greater effect on the ultimate load than when it has two vertical sides unequal or one vertical side with all skirt's depth (do/B). However, this improvement in the ultimate load bearing capacity with increasing skirt depth is significant until a value of (do/B=1.5) beyond this which further increase in depth of skirt does not show significant contribution in improving the ultimate load of the footing. Figures (9&10) shows the relationship between the ultimate load carrying capacity and (ds/B) for different skirts types at B/b=3 and De/B=0.6H, The value of P_{ult} increases as the (ds/B*)* ratio increases and significant increase in P_{ult} has been observed up to (ds/B *=1.5)*, after that there is slight increase in q_{ult}. Based on this improvement in the bearing capacity, ds = 1.5B may be taken as effective depth of the skirt. The maximum improvement in the ultimate load bearing capacity with the optimum depth of skirt of tested skirted strip footing is up to 60 % with two vertical sides equal skirt and 32% with two vertical sides unequal skirt.

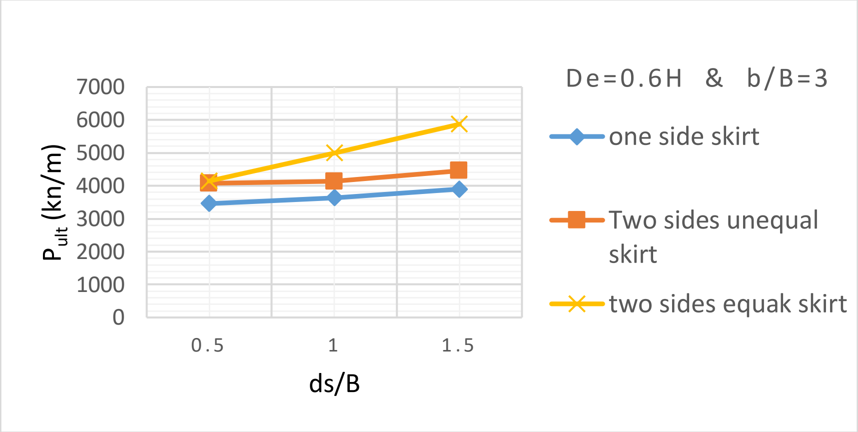


Figure (9): Variation in P_{ult} with skirts types at De= 0.6H & b/B= 3

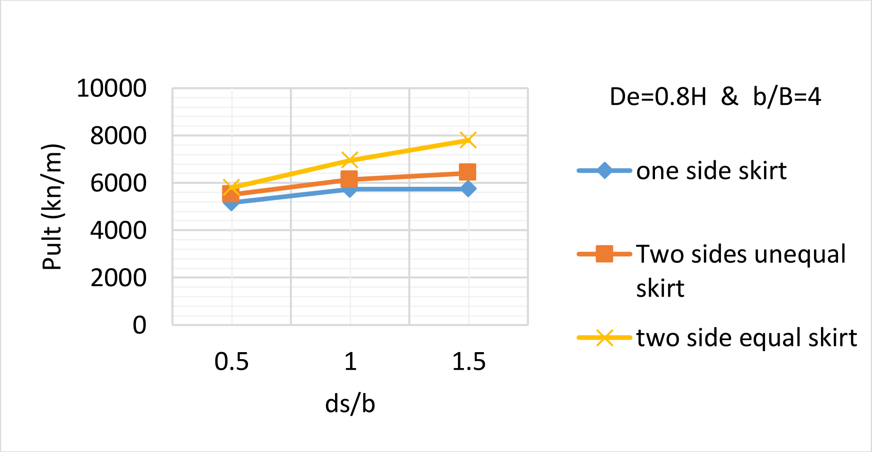


Figure (10): Variation in P_{ult} with skirts types at De= 0.8H & b/B= 4

5. Conclusions

A series of numerical analysis tests has been carried out to evaluate the strength and settlement characteristics of skirted strip footing resting on unsupported slope sand. Based on this study, the following summaries are made:

1- The provision of skirt in the strip footing at appropriate location in the body of unsupported slope sand has significant effect in increase the ultimate load carrying capacity of skirted footing.

2- The optimum embedment depth of the skirted strip footing is at De= 0.6H which improved the ultimate load carrying capacity of skirted strip footing by 53.83% for two sides vertical equal skirts, and by 26.85% for two sides vertical unequal skirts.

3- The edge distance ratio of b/B =0 up to 3 observe significant increase in the ultimate load carrying capacity of skirted strip footing with all kind of skirts configurations such as 73.10%for the two sides vertical equal skirts. However, at crest distance greater than 4B,the ultimate load does not seem to be affected.

4- The effectiveness of skirts in improving the ultimate load carrying capacity of the footing on unreinforced slope is attributed to its depth (ds) and configuration of skirts. The gain in the ultimate load percentage at (ds= 1.5B, b= 3B and De= 0.6H) is 14.97% for one side skirt, 31.37% for unequal sides vertical skirts, and 73.05% for two sides vertical equal skirts.

6. Future works

Based on the results of this research, some recommendations for future studies may be given as:

1- Using this reinforcement system with other footing types.

2- Use PLAXIS 3D instead of PLAXIS 2D to show the three dimensions of the deformation shape.

3- Repeat the research by experimental study and comparing the results.

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