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Performance of Vertical Skirted Strip Footing On Slope Using PLAXIS 2D

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Abstract: *The soil around foundation plays a very critical role during its performance. The skirted foundation is one in which vertical or inclined wall surrounds one or more sides of the soil mass beneath the footing. The skirts form an enclosure in which soil is confined and works as a unit with the overlain foundation to transfer superstructure load to soil essentially at the level of skirt tip resulting increase in the bearing capacity and reduction in the settlement of the structure. The present work focused on the analysis of skirted strip footing on slopes using a finite element software PLAXIS 2D. The various parameters considered for present study were vertical load, depth of embedment of footing in terms of height of slope (H), the ratio of distance of footing from crest to the width of footing (b/B), the ratio of depth of skirt to width of footing (d_s/B). The skirt was provided on one side, both side equal vertical skirts and unequal vertical skirt. The result indicates that skirted strip foundation had a significant effect in improving the bearing capacity with different configurations of skirt. The improvement found to be increases with increase in skirt depth. The skirted strip footing at crest shows significant improvement in bearing capacity. The depth of embedment of footing does not show any improvement in bearing capacity.*
Keyword: *Strip Footing, Skirt, PLAXIS 2D, Bearing Capacity*

I. Introduction

The skirted foundations had been extensively used for offshore structures like wind turbine due to easy installation compared to deep foundation. The shallow skirted foundations had been use in structures for oil, gas industry. The skirt foundation serves variety of functions such as control of 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. The vertical and horizontal load capacity on footing is improved by confinement and resistance to sliding. Therefore, it may become an alternative approach for improving the bearing capacity of footing adjacent to slope. To know the performance of skirted footing on slopes, a numerical study had been carried considering different parameters such as depth of embedment of footing, distance of footing from crest, skirt depth and compared with the performance of strip footing on slope without skirt.

The angle shaped square footing under eccentric loading using ANSYS was studied with parameters such as depth of footing projection, eccentricity to width ratio [1]. It was concluded that for given e_x/B, the tilt can be reduced to zero by providing a vertical footing projection of required depth at edge near the load. The settlement analysis of shallow circular footings with and without structural skirts resting on sand shows that the use of structural skirts reduces the settlement of footings and modifies the load–displacement behavior [2].

The performance of skirted strip footing subjected to eccentric inclined load studied by laboratory work and numerical analysis using PLAXIS [3]. 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 angle shaped rectangular footing with variable angle of footing projection under eccentric vertical load had shows that in the angle shaped rectangular footing, at any angle of footing projection with vertical, the projection along the longer side of the footing becomes more effective as compared with footing projection along the shorter side [4]. The horizontal displacements in the footing due to vertical eccentric loading had been found to be almost zero.

The analysis of bearing capacity of footing on soft clay with sand pile with/without skirts shows that the improvement of load bearing capacity was remarkable; using both partially replaced sand pile with and without confinement by skirts [5]. 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 [6]. The skirts had been found to be helpful in reducing tilt due to eccentric loading.

The results of experimental and numerical analysis skirted square footing on sand revealed that skirted foundations exhibit bearing capacity and settlement values that are close, but not equal, to those of pier foundations of the same width and depth [7]. The enhancement in bearing capacity of shallow foundation increases with increasing skirt depth and decreasing relative density of sand.

The analysis of raft foundation with vertical skirt using PLAXIS 2D shows that the increase in skirt depth increases bearing capacity and decreases settlement [8]. Two sided vertical skirt raft foundation shows decrease in settlement with increase in skirt depth. One sided vertical skirt raft foundation shows increase in settlement. The horizontal load carrying capacity of circular skirted footings embedded in sand shows that there was a substantial increase in horizontal load carrying capacity with increase of skirt depth and relative density of sand [9]. 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 [10].

The literature shows that confinement of soil below footing, provision of skirt for strip footing, improves the bearing capacity and reduces the settlement of foundation under concentric as well as eccentric loading. In order to give an optimum solution for footing on slope with the use of skirt, the study of skirted strip foundation on slope with different parametrical aspect were considered in the present study. The performance of skirted strip footing with and without skirt on slope was studied using PLAXIS 2D, a FEM based geotechnical software.

II. Numerical Modeling

The geometry of the finite element soil model in PLAXIS 2D was adopted as 10B X 20B with the width of strip footing B=2m. The analysis was calculated for the configuration of one side vertical skirt, both side equal vertical skirt, both side unequal vertical skirt (long side = 2 x short side) as shown in Fig.1. The model used for analysis is as shown in Fig.2. The details of the parameter studied are shown in Table 1.

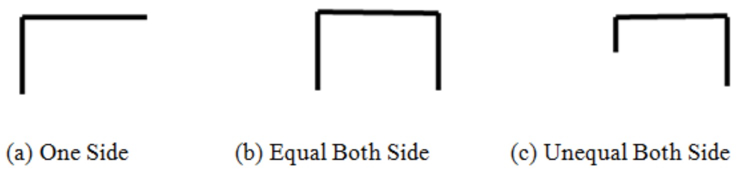


Figure 1: Configuration of Skirted Footing

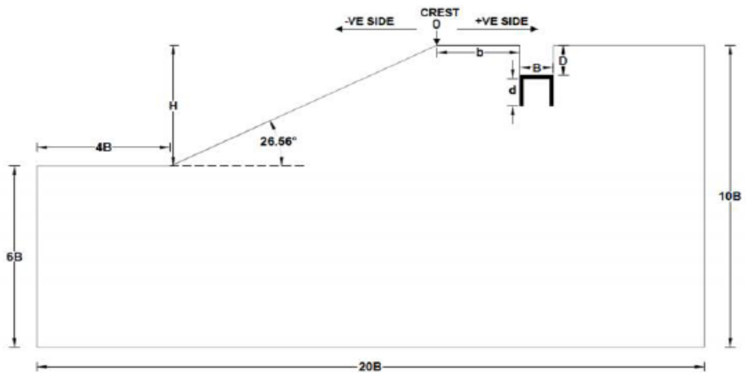


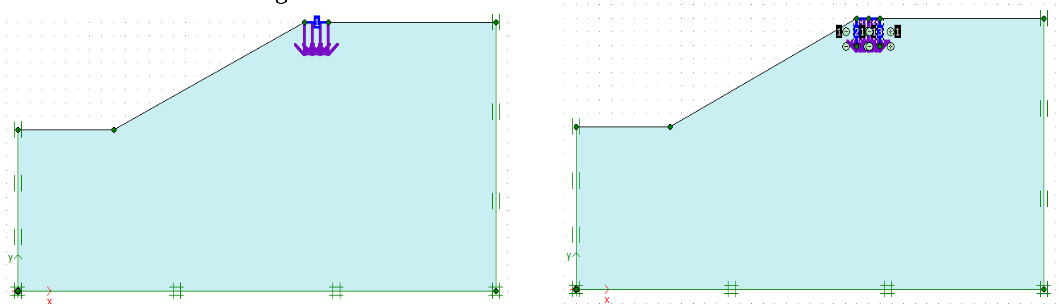
Figure 2: Footing Adjacent to Slope

Table 1: Details of Parametric Study

Sr. No	Parameters	Details of parameters
1	Slope angle (β)	26.56°
2	Type of footing	Strip footing
3	Type of load	Vertical
4	Depth of embedment of footing	0.2H to 0.6H
5	The ratio of distance of footing from crest to the width of footing (b/B)	-2.0* to 3.0
6	The ratio of depth of skirt to width of footing (d_s/B)	1.0 to 3.0
7	One side vertical skirt Both side equal vertical skirt Unequal both vertical skirt	

*(-) sign indicate the footing was placed on left side of slope assuming crest as origin

The geometry model of strip foundation on slope without skirt and with skirt for a typical case modeled in PLAXIS 2D is as shown in Fig.3.



(a) Without skirt (b) With skirt

Figure 3: Geometry model of strip foundation without and with skirt

III. Soil And Plate Properties

While analyzing slope in plaxis 2D, the material properties of soil and footing were required. The soil was considered for slope as sand while strip footing of concrete was considered for analysis. The properties of soil used in the analysis are as follows in Table 3 and while for strip footing are given in Table 2.

Table 2: Material Properties for Strip Footing

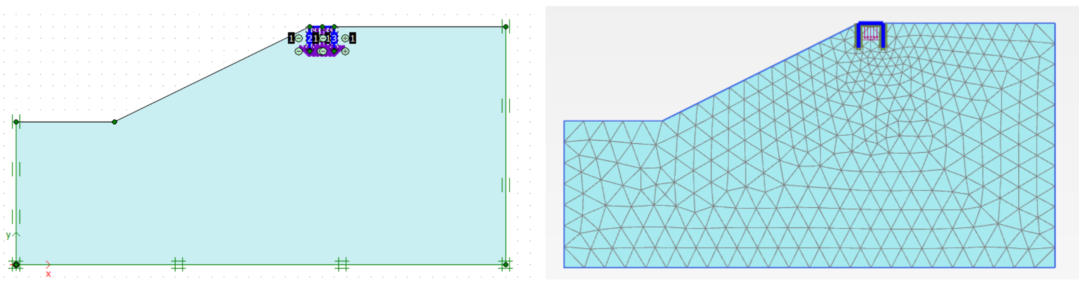
Sr. No.	Parameter	Value
1	Type of material	Elasto-plastic
2	Normal stiffness, EA (kN/m)	8944000
3	Flexural rigidity, EI ($kN/m^2/m$)	119253.33
4	Poisson's ratio	0.15

Table 3: Material Properties of Soil

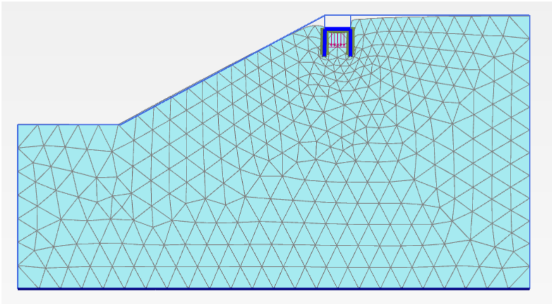
Sr. No.	Parameter	Value
1	Type of material	Sand
2	Material Model	Mohr - Coulomb
3	Young's modulus of sand (kN/m^2)	50000
4	Cohesion (kN/m^2)	1
5	Poisson's ratio	0.30
6	Friction angle(Φ)	36°
7	Angle of dilatancy	5°
8	Interface reduction factor R_{inter}	0.67
9	Dry density(kN/m^3)	18

IV. Results And Discussion

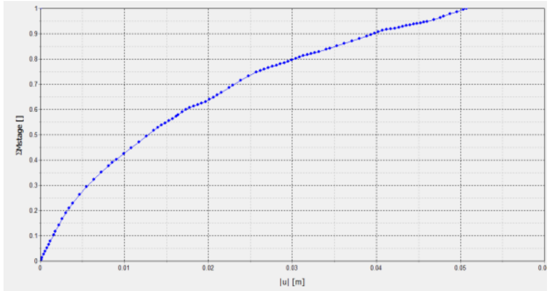
The analysis was carried out using PLAXIS 2D for strip footing without skirt and with skirt placed on slope of 26.56^0. The footing was placed at different location from crest and embedment depth. Fig.4 illustrates the analysis of two sided vertical skirt in PLAXIS 2D. The slope was modeled with skirt footing in PLAXIS 2D (a) and then mesh is generated during the analysis (b). Fig. 4 (c) shows the footing at failure during the analysis. The ultimate load carrying capacity of skirted footing was obtained from load settlement curve plotted as shown in Fig. 4(d). Similar, analysis was carried out during entire study.



(a): Geometry Model in PLAXIS (b): Generated Mesh



(c): Deformed Mesh

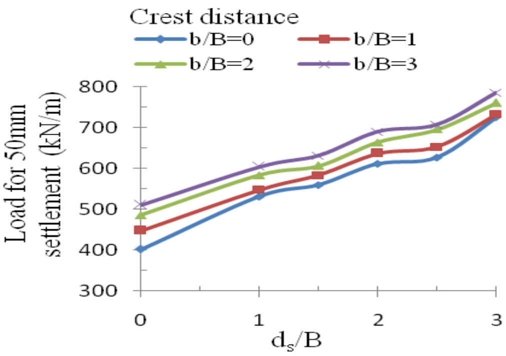


(d): Load-displacement Curve

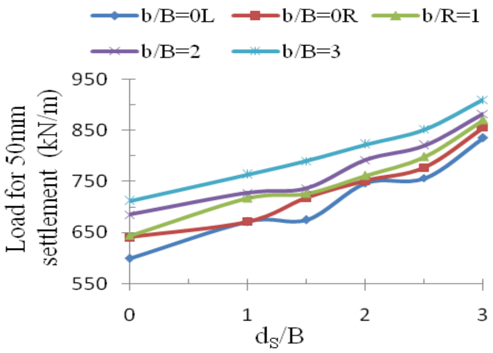
Figure 4: Results in PLAXIS 2D for Strip Foundation for Two Sided Vertical Skirt

The maximum permissible settlement for the strip footing was considered as 50mm. The allowable load for the footing was considered as load which causes a settlement of 50mm. The analysis was carried in similar way for different skirt configuration, skirt depth, footing location and embedment depth. The allowable load obtained in all analysis was used for discussion and finding efficiency factor. The efficiency factor (ξ) is defined as ratio of allowable load for skirted footing to allowable load for footing without skirt at that embedment depth and location of footing from crest.

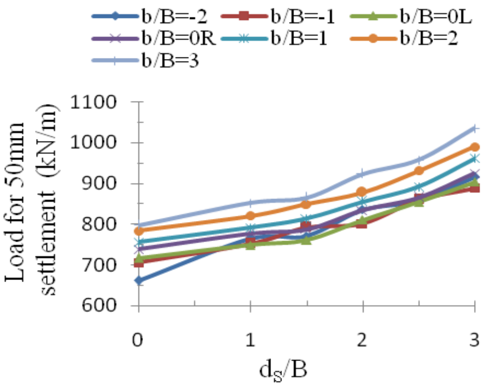
Fig. 5 shows the allowable load on strip footing with one side skirt of different depth and different footing location for crest. It can be seen that the bearing capacity increases with the depth of skirt and the depth of embedment of footing. It was also observed that the bearing capacity of strip footing placed on slope side is less than when it is placed on embankment side of slope. As the distance of footing from crest increases towards embankment, the bearing capacity observed to be increases.



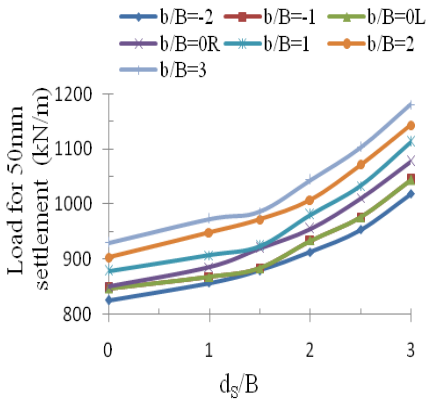
A) Surface footing



(B) 0.2H depth of embedment



(C) 0.4H depth of embedment



(D) 0.6H depth of embedment

Figure 5: Effect of Depth of Skirt from Crest for One Side Vertical Skirt

Fig.6 and Fig.7 shows the variation of allowable load on strip footing with two side skirt having equal and unequal length respectively. It was observed that the bearing capacity increases as the footing was placed away from crest of slope within embankment. If the footing was placed at crest the bearing capacity was more than when it was placed on slope. For the footing kept at any position, the bearing capacity of footing increases with depth of embedment of footing and increase of skirt depth.

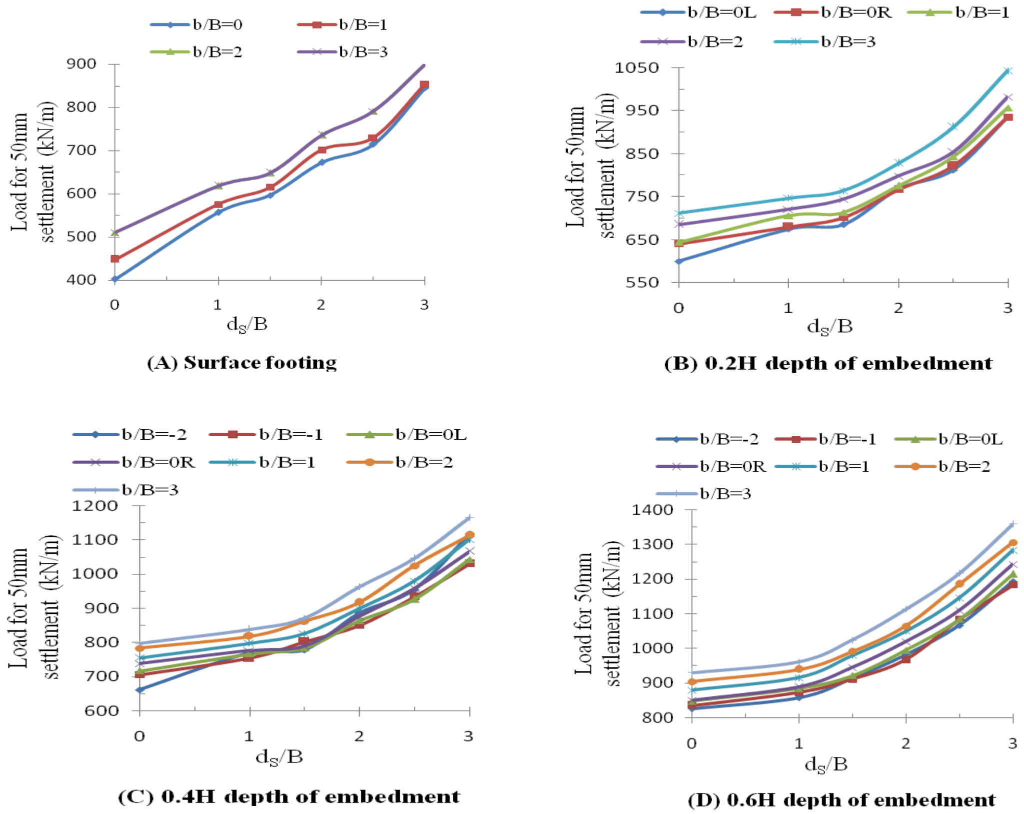


Figure 6: Effect of Depth of Skirt from Crest for Two Sided Equal Vertical Skirt

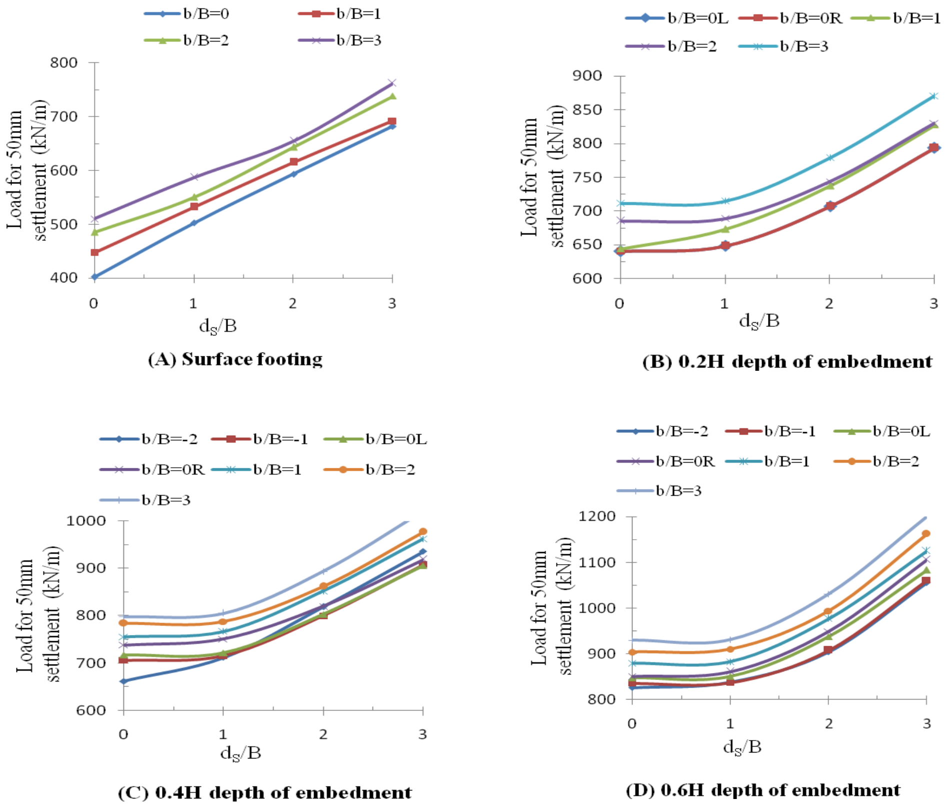


Figure 7: Effect of Depth of Skirt from Crest for Two Sided Unequal Vertical Skirt

To compare the effect of skirt on the bearing capacity for any location and depth, the bearing capacity of plane footing was calculated for that location and depth. Then, the efficiency factor (ξ) was calculated for all conditions. The efficiency factor of various configurations of footing for different skirt depth and depth of embedment of footing from crest distances is given in Table 4.

The efficiency factor shows that the skirted footing on slope shows improvement in bearing capacity of footing for all locations. It shows the effect of skirt considering various parameters at different footing locations. It may be due to confinement of soil beneath the footing. It can be seen that the efficiency factor was maximum when the footing was placed on the surface. As the embedment of the footing is increases the improvement in the efficiency factor over simple footing is marginal.

V. Conclusions

A series of various numerical model were analyzed using PLAXIS 2D to evaluate the bearing capacity of a strip footing with and without structural skirts resting on sand slopes. The skirt plays important role to distribute the shear stresses to increase bearing capacity. The study investigated the effect of skirts depth, depth of embedment of footing and footing location on the bearing capacity for strip footing on slope. From the study it was conclude that:

1. Skirted strip footing adjacent to slope crest shows a significant improvement in the bearing capacity of footing.
2. The bearing capacity of a strip footing with skirt was found to be maximum when footing was placed both at positive or negative side of crest.
3. The bearing capacity of footing increase as footing moves away from crest towards embankment.
4. The depth of embedment of footing improves the bearing capacity.
5. The skirt strip footing on surface shows maximum efficiency factor i.e. improvement over simple footing.
6. The embedded skirt strip footing shows marginal improvement over simple footing in terms of efficiency factor.

Table 4: Efficiency Chart

Details	**(d/B)**	**De**	**Crest Distance (b/B)**						
			-2	**-1**	**0**	**0**	**1**	**2**	**3**
(A) ONE SIDED VERTICAL SKIRT	1	Surface	-	-	-	1.32	1.22	1.2	1.18
		0.2H	-	-	1.11	1.04	1.11	1.06	1.07
		0.4H	1.04	1.06	1.15	1.05	1.04	1.04	1.06
		0.6H	1.02	1.03	1.03	1.04	1.03	1.04	1.04
	1.5	Surface	-	-	-	1.39	1.3	1.24	1.23
		0.2H	-	-	1.12	1.12	1.12	1.07	1.11
		0.4H	1.06	1.12	1.16	1.06	1.07	1.08	1.08
		0.6H	1.04	1.05	1.06	1.08	1.05	1.07	1.06
	2	Surface	-	-	-	1.52	1.42	1.36	1.35
		0.2H	-	-	1.24	1.17	1.18	1.15	1.15
		0.4H	1.13	1.13	1.26	1.12	1.13	1.12	1.15
		0.6H	1.1	1.09	1.1	1.12	1.11	1.11	1.12
	2.5	Surface	-	-	-	1.56	1.45	1.43	1.38
		0.2H	-	-	1.26	1.21	1.23	1.19	1.19
		0.4H	1.19	1.21	1.29	1.17	1.18	1.18	1.2
		0.6H	1.15	1.15	1.15	1.18	1.17	1.18	1.18
	3	Surface	-	-	-	1.8	1.63	1.56	1.54
		0.2H	-	-	1.39	1.33	1.35	1.28	1.27
		0.4H	1.26	1.25	1.38	1.25	1.27	1.26	1.29
		0.6H	1.23	1.22	1.23	1.26	1.26	1.26	1.27
(B) TWO SIDED VERTICAL EQUAL SKIRT	1	Surface	-	-	-	1.38	1.28	1.23	1.2
		0.2H	-	-	1.12	1.06	1.09	1.05	1.04
		0.4H	1.06	1.06	1.16	1.05	1.05	1.02	1.05
		0.6H	1.04	1.04	1.03	1.04	1.04	1.03	1.03
	1.5	Surface	-	-	-	1.48	1.37	1.3	1.27
		0.2H	-	-	1.14	1.09	1.1	1.08	1.07
		0.4H	1.09	1.13	1.17	1.07	1.09	1.08	1.09
		0.6H	1.08	1.08	1.1	1.11	1.11	1.09	1.1
	2	Surface	-	-	-	1.67	1.56	1.47	1.44
		0.2H	-	-	1.28	1.19	1.2	1.16	1.16
		0.4H	1.2	1.2	1.33	1.18	1.19	1.15	1.2
		0.6H	1.17	1.15	1.18	1.19	1.19	1.17	1.19
	2.5	Surface	-	-	-	1.77	1.63	1.58	1.55
		0.2H	-	-	1.35	1.28	1.3	1.24	1.28
		0.4H	1.29	1.32	1.44	1.29	1.29	1.28	1.31
		0.6H	1.27	1.29	1.29	1.3	1.3	1.31	1.3

	3	Surface	-	-	-	2.1	1.9	1.81	1.76
		0.2H	-	-	1.56	1.45	1.48	1.43	1.46
		0.4H	1.45	1.45	1.68	1.44	1.45	1.39	1.46
		0.6H	1.43	1.41	1.44	1.46	1.45	1.44	1.46
(C) TWO SIDED UNEQUAL VERTICAL SKIRT	1	Surface	-	-	-	1.25	1.18	1.13	1.15
		0.2H	-	-	1.04	1.01	1.04	1	1
		0.4H	1.07	1.01	1	1.01	1.01	1	1
		0.6H	1.01	1	1	1.01	1	1	1
	2	Surface	-	-	-	1.47	1.37	1.32	1.28
		0.2H	-	-	1.17	1.1	1.14	1.08	1.09
		0.4H	1.23	1.13	1.11	1.11	1.12	1.1	1.12
		0.6H	1.09	1.08	1.1	1.11	1.11	1.09	1.1
	3	Surface	-	-	-	1.69	1.54	1.52	1.49
		0.2H	-	-	1.31	1.23	1.28	1.21	1.22
		0.4H	1.41	1.28	1.26	1.24	1.27	1.24	1.28
		0.6H	1.27	1.27	1.27	1.3	1.27	1.28	1.29

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