Performance of skirted footings in sand

La performance de la fondation contournée dans le sable

Nainan P. Kurian – *Department of Civil Engineering, Indian Institute of Technology, Madras, India*
N.C. Nimala Devi – *Department of Civil Engineering, N.S.S. Engineering College, Kerala, India*

ABSTRACT: This paper discusses the rigorous analysis of the footing-skirt-soil system, by the finite element method, with the aim of examining the influence of key skirt and soil parameters on the behaviour of the system, as needed by designers. Since between 'bearing capacity' and 'settlement', the latter governs the design of footings in sand in the majority of cases, the emphasis in the present studies has been the aspect of settlement. The theoretical investigations have been supplemented by model tests which confirm the trends predicted by the analysis. The conclusions drawn from the studies should serve as useful guidelines for the more efficient design of skirted footings in sand.

RESUME: Puisque l' information disponible sur le sujet dans la documentation est peu concluant, nous avons commence' la recherche actuelle en analysant rigoureusement le système " fondation - contournee - terre " par la methode " finite element en visant 'a examiner l' influence des contournées dominantes et le paramètre de la terre, le fonctionnement des systèmes exigé par les dessinateurs. Piusque entre " bearing capacity" et, "settlement " c'est le dernier equi détermine le projet des fondations dans le sable, dans le plupart des cas, nous mettons l' accent sur l' aspect de " settlement " dans notre recherche actuelle. L' investigation théorique est completée par des tests modèles qui confirment les tendances prevues par des analyses. Les conclusions des études serviront comme des lignes directrices très utiles pour des projets beaucoup plus efficaces des fondations contournees dans le sable.

1 INTRODUCTION

'Soil improvement' or 'Ground improvement' methods are techniques by which soils which are otherwise unsuitable in their natural state are improved by geotechnical methods to make them suitable for serving as foundations for the proposed structures, with the increasing tempo of construction activity the world over, sites which have been deemed unsuitable are increasingly being put to use for the construction of new and challenging structures, this reveals the scope and potential of ground improvement as a geotechnical engineering tool [Kurian 1992].

Abandoning the site in search of better locations, or reduction of design loads, like for example by reducing the number of floors, are redundant in the context of present technological growth, since the new techniques are either available or constantly emerging in such a manner as to make the soil behave according to the project requirements rather than having to change the project to subserve the soil limitations. Today's ground improvement techniques are indeed surficiently well developed to transform a weak soil into a competent stratum possessing strength and compressibility to the desired degrees.

2 SKIRTING OF FOUNDATIONS

There are several ground improvement methods employing the principle of 'inclusions' of which the most prominent example is 'reinforced earth'. 'Skirting' is another technique that falls in this category. In this method a rigid R.C.wall called "skirt" is constructed around a footing in order to confine this soil below the footing. The provision of such a skirt is found to increase the bearing capacity and reduce settlement significantly. The latter is the result of the restraint to lateral deformation of the soil created by the presence of the skirt. Large scale field tests have confirmed the above findings [Bhandari and Rao 1980] in place of R.C.walls, brick panels, contiguous or intermittent piles, etc., have also been used for skirting. Among the uses of these techniques, in addition to footings, can be cited structures such as storage tanks, grainsilos, industrial chimneys, etc.

3 SCOPE OF INVESTIGATIONS

The present study is confined to the skirting of isolated footings in sand. Between the geotechnical parameters of bearing capacity and settlement that enter the design of any foundation, what invariably governs the design of footings in sand is settlement, contrary to popular belief [Kurian 1992]. Therefore, the focus of study in the present case is the aspect of settlement. Since the information available on the influence of key design parameters such as the size of the skirt, its location, etc., are incomplete as found in literature, a detailed analytical study has been undertaken in the first instance, involving the numerical analysis of the system by the finite element method. Since experimental verification and validation was envisaged for some select cases covered by the analysis by laboratory model testing, the model test system was used for the above numerical analysis. Even though rigorous, since the analysis was linear and elastic, and not using interface elements, the role of analytical study had to be limited to indicating comparative trends in behaviour. Even though the analysis was elastic, in the test that were conducted on the model footing under different conditions of skirting the loading was continued upto failure, which therefore yielded information on bearing capacity in addition to settlement.

4 ANALYTICAL STUDIES BY FINITE ELEMENT METHOD

Since rigorous closed-form solutions of the skirted footing problem are bound to be complex, a linear elastic numerical analysis of the problem has been attempted by the finite element technique, using the SAPIV package program. Since the results of such a linear analysis without considering interface elements between the footing, skirt and the soil, cannot be compared with the actual behaviour of the soil which is essentialy non-linear as would be obtained in a test, the main purpose of this analysis has been to obtain comparative results between footings skirted under a variety of conditions and their plain (unskirted) counterparts. It essentially took the form of a parametric study, the aim of which was to observe the trend of results under the variation of the parameter being considered and expresses the same quantitatively as percentage reduction in settlement against the value of the parameter. Fig.1 illustrates the parameters chosen for the analysis. The system is discretised for the finite element analysis using the eight-noded brick elements for the soil and the footing, and plate elements for the skirt. Because of the symmetry of the system both in terms of geometry and loading, the analysis was confined to one quarter of the system.

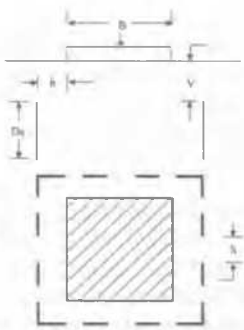

Fig.1: Skirted Footing : Parameters for Analysis

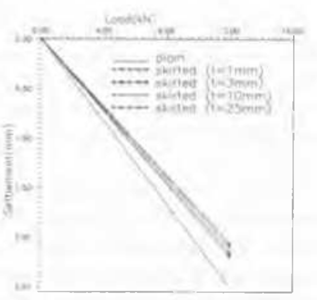

Fig.2: Load - Settlement Diagrams Parameter-Thickness of the Skirt

Table 1. Variation of Parameters used in the analysis

Sl.No.	t (mm)	h (mm)	D (mm)	v (mm)	s (mm)	E (N/mm²)	No.of analyses
1 unskirted	0	0	0	0	0	0	1
2	1,3,10,25	25	100	0	0	2.0×10^5	4
3	3	5,50, 100, 200	100	0	0	2.0×10^5	4
4	3	25	150,175 200,300	0	0	2.0×10^5	4
5	3	25	100	25,50 75, 100	0	2.0×10^5	4
6	3	25	100	0	50, 100	2.0×10^5	2
7	3	25	100	0	0	1.5×10^4	1
Typical	3	25	100	0	0	2.0×10^5	0
E_s =15 N/mm², μ = 0.3						Total	= 20

Table 1 read with Fig.1, presents the cases analysed under the different parameters. By way of example, the load settlement diagrams pertaining to the parameter *t* are plotted in Fig.2, bounded by two extreme cases, viz., without skirt and with a perfectly rigid skirt. Since the results are linear the percentage reduction in settlement from the unskirted to skirted cases under each case are the same at any value of load. Fig.3 plots the percentage reduction in settlement vs. thickness of the skirt member. Table 2, gives percentage reduction in settlement obtained under all the cases analysed. Since the reductions have been achieved at the expense of the steel used in the skirt, the material input of steel in each case is also entered in this table. The cost-benefit considerations, which apply to all ground improvement methods in general, would acquire

Table 2. Summary of analysis and experimental results

Analysis No.	Parameters of skirted footing (all values in mm)	Volume of steel (mm³ x 10^{-4})	% Reduction in settlement	Test: Bearing capacity (kN)	Test: BCR (skirted/ Plain)
1.	Plain, unskirted	0	0	8.3	1
2	t = 1(h=25, D=100, v=0, s=0)	10	12.5		
3	t = 3(h=25, D=100, v=0, s=0)	30	14	33.7	4.1
4	t = 10(h=25, D=100, v=0, s=0)	100	16	44.2	5.3
5	t = 25(h=25, D=100, v=0, s=0)	250	17.5	67.5	8.1
6	h = 5(t=3, D=100, v=0, s=0)	25.2	20		
7	h = 50(t=3, D=100, v=0, s=0)	90	11		
8	h = 100(t=3, D=100, v=0, s=0)	480	8	9.9	1.2
9	h = 200(t=3, D=100, v=0, s=0)	780	1.6		
10	D=150(t=3, h=25, v=0, s=0)	45	18		
11	D=175(t=3, h=25, v=0, s=0)	52.2	19.5		
12	D=200(t=3, h=25, v=0, s=0)	60	22	75.1	9.1
13	D=300(t=3, h=25, v=0, s=0)	90	30		
14	v=25, (t=3, h=25, D=100, s=0)	30	16		
15	v=50, (t=3, h=25, D=100, s=0)	30	18	50	6.0
16	v=75, (t=3, h=25, D=100, s=0)	30	13		
17	v=100, (t=3, h=25, D=100, s=0)	30	12.5		
18	s=50, (t=3, h=25, D=100, v=0)	18	11.5	9.9	1.2
19	s=100, (t=3, h=25, D=100, v=0)	12	10		
20	E_r = 1.5×10^4 N/mm² (t=3, h=25, v=0, D=100)		12		

a positive picture in this case only when the saving realised in the design of the footing more than offsets the extra expenditure on account of the skirt. Fig.4 shows the important result that steel and wood perform almost equally well as material for the skirt. For a typical case (*t*=3mm, *h*=25mm, *D*=100mm and *v*=0) the contours of vertical stresses in the soil on the central vertical plane are plotted in Fig.5, juxtaposed with the plain case. It is seen that the stress contours of the skirted case get pushed upwards in the top region on account of the confinement effect produced by the skirt.

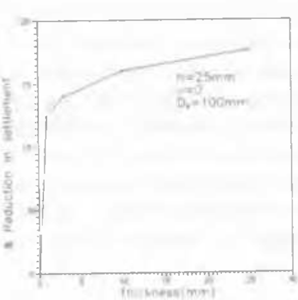

Fig.3: Reduction in Settlement vs. Thickness of Skirt

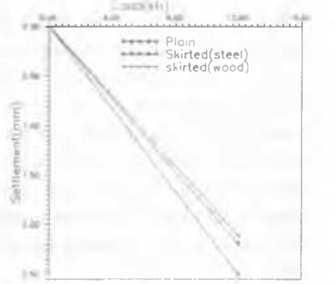

Fig.4: Load - Settlement Diagrams Parameter-Young's Modulus of the Skin

5 EXPERIMENTAL INVESTIGATION

As stated earlier, it was sought to verify the trends observed from the analysis by direct experimentation using a model footing in mild steel of size 200x200x25mm, loaded on a bed of medium sand in a tank of dimensions 1000x1000x550mm. The material used for the skirt was also mild steel. The incremental loadings on the footing were continued until the soil failed in bearing. Load-settlement diagrams have been plotted in all cases, Fig.6 showing

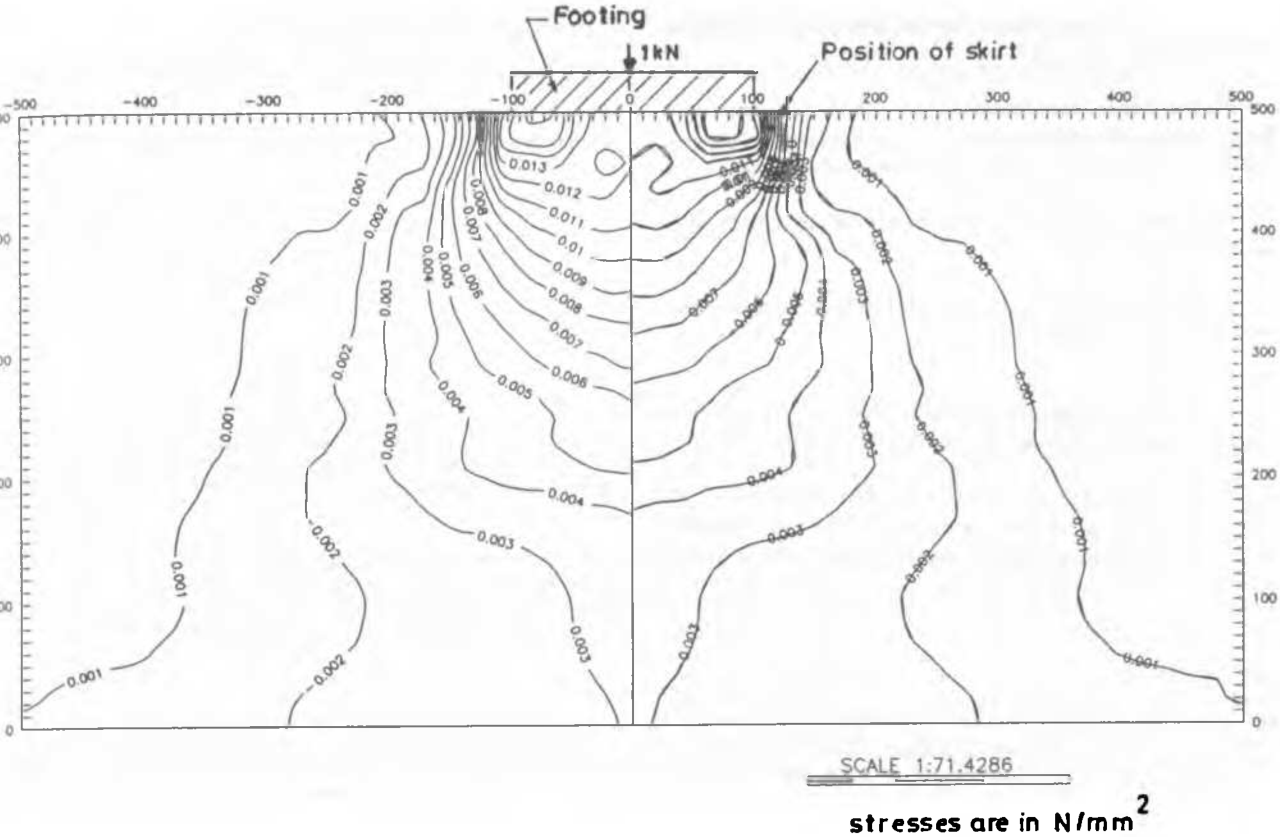

Fig.5: Vertical Stress Contours of Plain and Skirted Footings.

the same for different values of t. Table 2 gives the bearing capacity in respect of the tested cases and the bearing capacity ratio between the skirted and plain cases. The hyperbolic idealisation of the load-settlement data [Kurian et al.1995] leads to a linear variation of the sub-grade modulus k with applied pressure. Fig.7 shows the results in respect of the plain and the typical skirted case, which testifies to the substantial increase in k resulting from skirting, considering it as an equivalent plain case. (The relationships beyond half the ultimate values of pressure are shown dotted in the figure, since k as an elastic parameter is not meaningful in the inelastic region.)

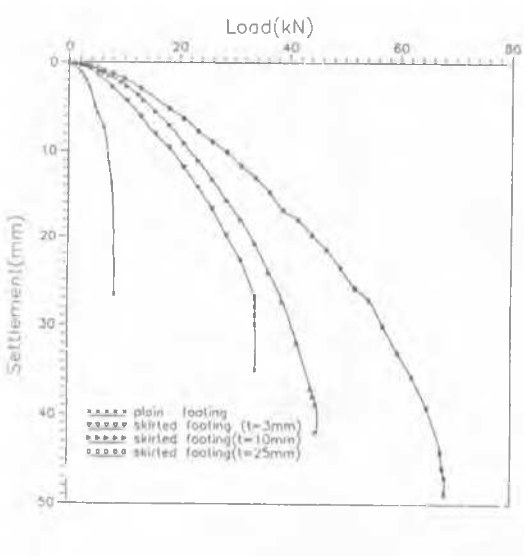

Fig.6: Load-Settlement Diagrams vs. Thickness of Skirt-Experimental Results

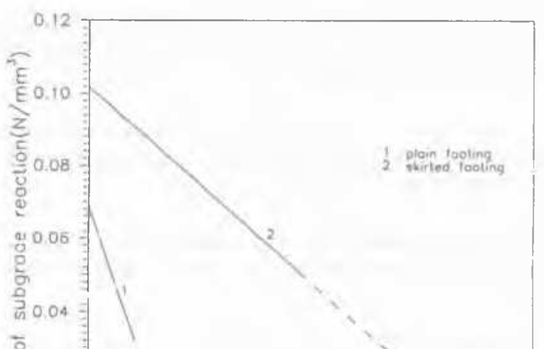

Fig.7: Subgrade Modulus vs. Stress for Plain and Skirted Footings

6 CONCLUSIONS

The following are the relevant conclusions obtained from the above investigation, with regard to the performance of skirted footings in sand.

1. Introduction of a skirt in the soil around the footing leads to a substantial gain in bearing capacity and reduction in settlement. Since bearing capacity is seen to be more favourably influenced than settlement, the latter will continue to govern the design in the case of skirted footings also in sand.

2. As regards the thickness of the skirt, the benefit of skirting is realised substantially even at lower thicknesses.

3. With regard to the relative size between the footing and the skirt, the most advantageous case is the one representing the least practical gap between the edge of the footing and the skirt.

4. The depth of skirting may be varied from B/2 to B, where B is the width of the footing.

5. Placing the skirt at a depth equal to B/4 from the base of the footing appears to be advantageous.

6. Non-continuous skirts are inferior and their performance suffer with increasing gap between the individual members.

7. The benefit of skirt is found to be rather insensitive to the material used for the skirting. This has a bearing on cost, since inferior material can be put to use for skirting to substantial advantages.

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