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Interference Effects of Adjacent Footings on Settlement Estimates

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Introduction

In most instances settlement criteria governs the analysis and design of foundations. In the case of coarse grained soils as sands, engineers commonly use settlement estimate procedures based on plate load tests, pressuremeter tests and field penetrometer tests. Schmertmann (1970) presented a simple approach to evaluate the settlement of footings founded on cohesionless soils based on static cone penetrometer tests which has a sound theoretical and practical basis. In southern peninsular India Schmertmann's (1970) method is being very frequently used in most instances because of its simplicity and reliability. Through an ingenuous correlation of static cone point resistance q_c with the modulus of deformation E_z and adapting Ahlvin and Ulerys (1962) elastic solution, Schmertmann formulated an expression for total settlement at the centre of a footing of width 2B founded on sand deposits as :

$$S_c = C_1 C_2 q_0 \sum_{0}^{2B} \frac{\Delta z}{E_z} I_z \qquad (1)$$

where, S_c = total settlement at the centre of a footing of width/diameter 2B.

E_z = modulus of deformation of the foundation soil, correlated to the static cone point resistance q_c by an equation to $E_z = 2\, q_c$

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C_1, C_2 = correlation factors to take into account the foundation embedment and creep effects.

q_0 = the net foundation pressure increase at the base of the foundation.

I_z = $(1-\mu)\left[(1-2\mu)A + B_1\right]$ is called as strain influence factor.

μ = Poisson's ratio

A, B_1 = dimensionless factors which depends on geotechnical location of the point under consideration and can be obtained from tables compiles by Ahlvin and Ulrey (1962).

Schmertmann has further attempted to simplify the procedure for computation of settlement using Eqn. 1 by approximating the strain influence factor distribution diagram by (2 B − 0.6 I_z) distribution or by slightly modifies form depending on the geometrical shape of the footing. During the past two decades this simplified method of formulation has gained much popularity and confidence in practicing engineers. While theoretically Eqn. 1 predicts the settlement at the centre of a flexible footing subjected to uniformly distributed loading and founded on homogenous isotropic semi-infinite soil., Schmertmann has validated the adaptability of this equation for non-homogenous sandy soils with varying modulus of deformation along with depth by correlating the observed settlement of large number of footings founded on sandy soils with conjunction with Eqn. 1. In formulating his method Schmertmann has taken cognizance of the effects of depth of embedment, creep shape and the influence of adjacent loads on the predicted settlement. However, while he has more or less quantified the effects of first three factors, due to the complicated non-linear, stress dependent, stress strain behaviour of sandy soils, and the dependency of strain and settlement not only on the position and magnitude of adjacent loads but also on their sequence of applications, he felt more research is needed to regulate design rules to solve a problem involving the influence of interference effects of adjacent loads on settlement estimates. In such circumstances he recognised the need for atleast a conservative treatment. In the southern part of peninsular India, in many instances, due to the necessity for going in for economical designs and due to the presence of weak loose sands, the designers are adopting simultaneous construction of individual footings at close spacing where certain amount of interference effects on the predicted settlement estimates of a single footing based on Schmertmann's recommendation could not be ruled out (Fig. 1). Very recently, the construction of a tall temple tower 66 m high at Srirangam (South India) has

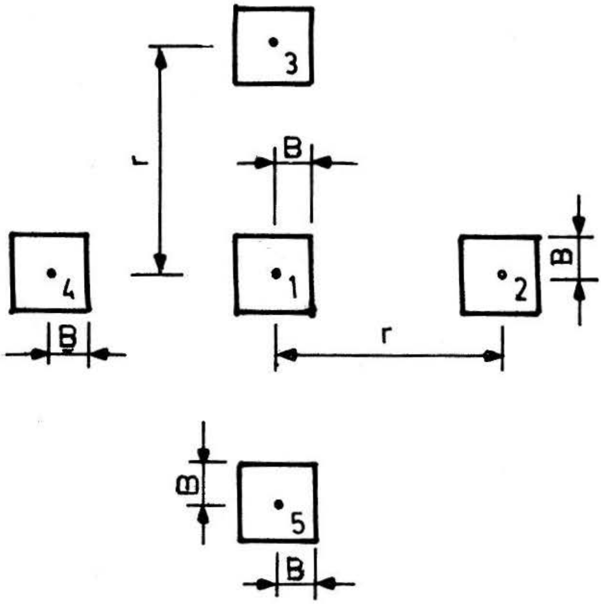

FIGURE 1 : Simultaneous Construction of Group of Footings

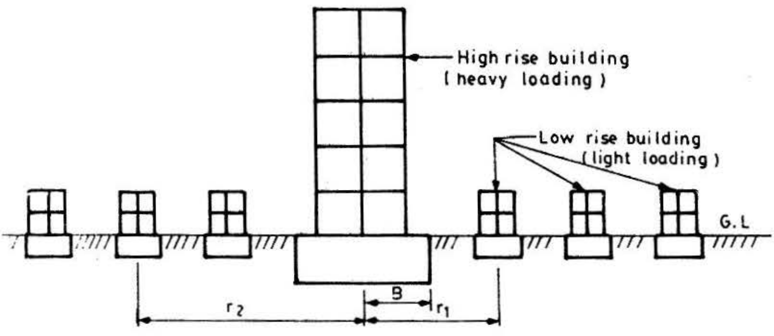

FIGURE 2 : Construction of High Rise Building Adjoining to Existing Light Structures

resulted considerable damage to the existing low rise buildings adjacent to the temple tower. In the city of Madras, many high rise buildings are now being built on mat foundations in close proximity of existing low rise buildings (Fig. 2) founded on continuous footings. In such circumstances, some guidelines based on either approximate theoretical reasoning or practical experience are likely to be of some value to the designers. Keeping this in view, the usefulness of elasticity solutions presented by Ahlvin and Ulrey (1962) for axisymmetry problems and Gray (1936) for Plane strain problems were examined in the following few paragraphs to study the interference effects of adjacent footings on Schmertmann's settlement estimate. In making such attempt, the confining effect of adjacent footing on the deformation behaviour of underlying sand soil and the effect of redistribution of contact pressure due to relative rigidity of superstructure and substructure are neglected and accordingly the elasticity solutions so attempted are likely to be conservative and may serve at best as a rough estimate.

Interference Effects on Settlement Estimate

Using the design charts and formulae developed by Ahlvin and Ulrey and Gray for axisymmetry (circular) and plan strain (strip) problems respectively, the pattern of distribution of strain influence factors, I_z were obtained at the centre of the footing and at different distances from the centre for various r/B values ranging from 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 and for various values of Poisson's ratios of 0.3, 0.4 and 0.5. Typical distribution pattern so obtained are shown in Figs. 3 to 6 for r/B ratios of 0 and 1. Using Schmertmann's recommendation the anticipated settlement of the soil at various radial distances (Fig. 7) from the centre of the footing can then be obtained for both circular shaped and strip foundations from the following equations :

Settlement at the centre of the footing r/B = 0

$$S_c = C_1 C_2 q_0 \sum_{0}^{2B} \frac{\Delta z}{E_z} I_{zc} \tag{2}$$

and settlement at a point = X (r/B = Y)

$$S_c = C_1 C_2 q_0 \sum_{0}^{2B} \frac{\Delta z}{E_z} I_{zx} \tag{3}$$

where, I_{zc} and I_{zx} are strain influence factors which can be obtained from approximate formulations as illustrated in Figs. 3 to 6. Defining settlement ratio as S_x/S_c and from Eqns. 2 and 3,

$$\frac{S_x}{S_c} = \frac{\sum \Delta z I_{zx}}{\sum E_z I_{zc}} = \frac{A_x}{A_c} \tag{4}$$

where, A_x and A_c are the corresponding areas of settlement influence factors distribution diagrams pertaining to point C and X (Fig. 7). Hence the anticipated settlement of the natural ground at any distance from the centre

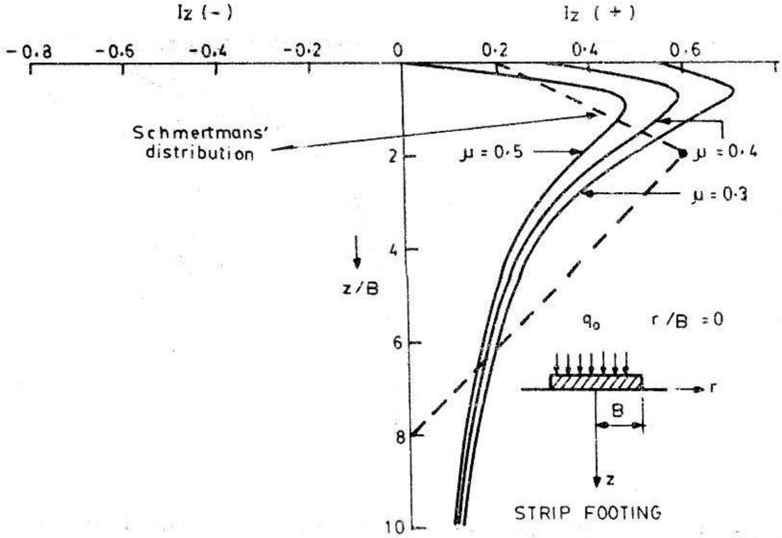

FIGURE 3 : Settlement Influence Diagram for Strip Foundation (r/B = 0)

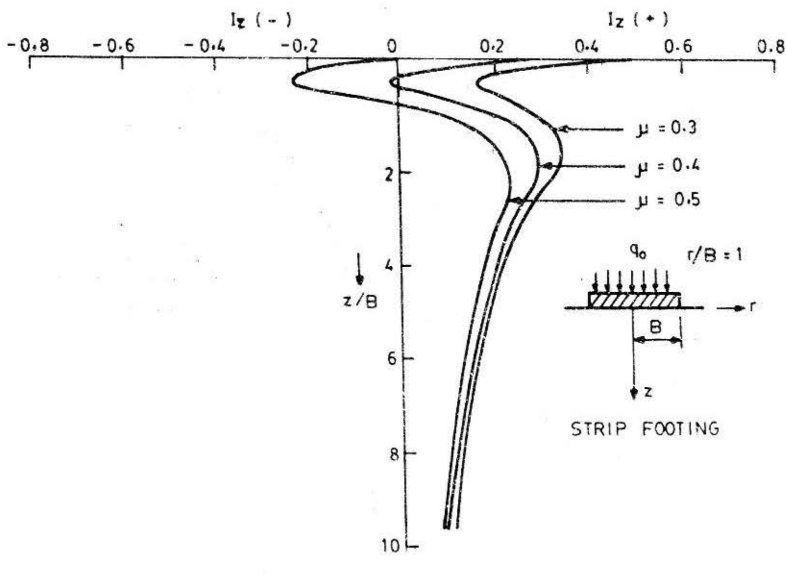

FIGURE 4 : Settlement Influence Diagram for Strip Foundation (r/B = 1)

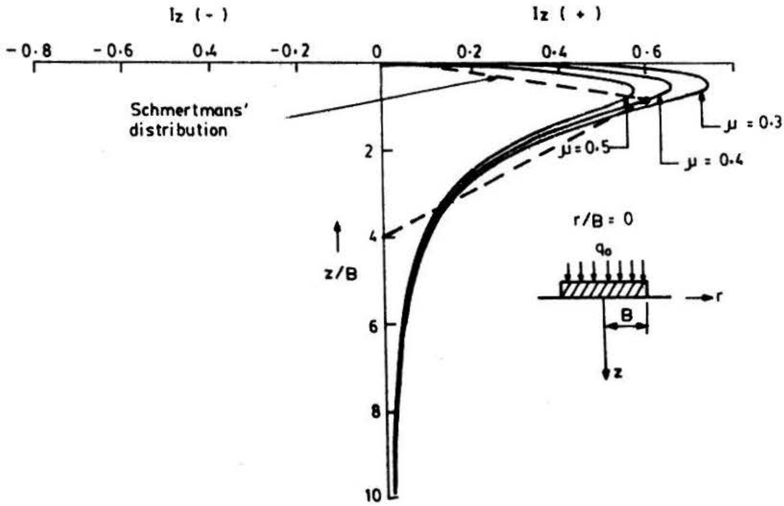

FIGURE 5 : Settlement Influence Diagram for Circular Foundation (r/B = 0)

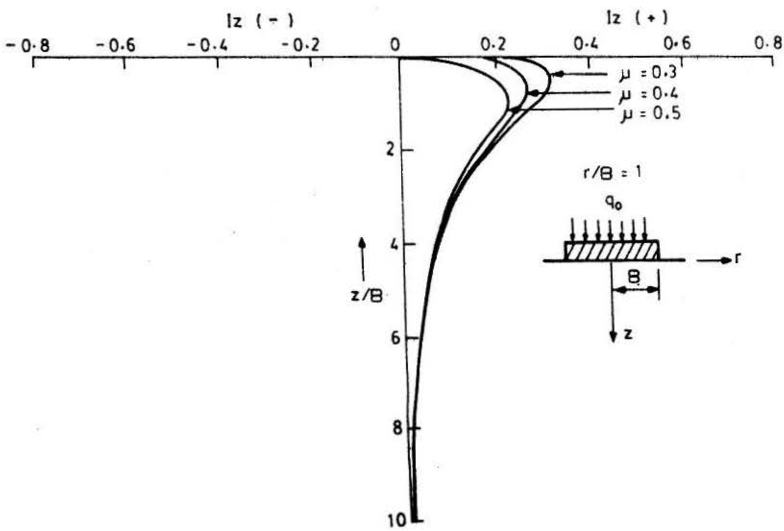

FIGURE 6 : Settlement Influence Diagram for Circular Foundation (r/B = 1)

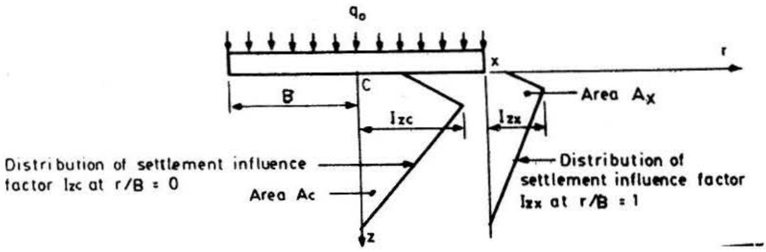

FIGURE 7 : Assumed Pattern of Disturbance of Strain Influence Factor (I_z)

of the footing due to uniformly distributed net intensity of loading q_0 can be calculated from the equation :

$$S_x = S_c \frac{(A_x)}{A_c} \tag{5}$$

where, S_c is Schmertmann's settlement at the centre of the footing. From the elasticity solutions of Ahlvin and Ulrey (1962) and Gray (1936), after obtaining the distribution pattern of strain influence factors as indicated in Figs. 3 to 6 and using a numerical integration procedure adapting Simpsons rule the settlement ratio for various r/B ratios and Poisson's ratios of 0.3, 0.4 and 0.5 are obtained and presented in Tables 1 and 2. Depending on the geometry of the footing and using approximate Poisson ratio if a settlement estimate for the centre of the footing can be made using Schmertmann's formulation, the entire region of settlement trough caused by the contemplated loading can be traced from Eqn. 5 using the Tables 1 and 2 indicated in Fig. 8. The tabulated values of settlement ratios in Tables 1 and 2 can be used to arrive at a fairly reasonable estimate of the probable magnitude of elastic settlements which the adjacent structures are likely to undergo due to the construction of high rise building in their close

Table 1 : Settlement Ratio Coefficients S_x/S_c for Circular Footing (Axisymmetry Loading)

(r/B) / μ	0	1.0	1.5	2.0	3.0	4.0
0.5	1	0.5970	0.3001	0.2061	0.1795	0.1695
0.4	1	0.5973	0.3021	0.2117	0.1854	0.1702
0.3	1	0.6195	0.3038	0.2243	0.2014	0.1842

Table 2 : Settlement Ratio Coefficients S_x/S_c for Circular Footing (Plane Strain Loading)

$(r/B)/\mu$	0	1.0	1.5	2.0	2.5	3.0	3.5	4.0
0.5	1	0.5989	0.4016	0.2771	0.1887	0.1287	0.0651	0.0577
0.4	1	0.6828	0.4603	0.3497	0.2591	0.2039	0.1415	0.1251
0.3	1	0.7370	0.5100	0.4073	0.3012	0.2526	0.2034	0.1978

proximity. In the case of simultaneous construction of adjacent footings, the interference effects of adjacent footings on the settlement of each one of the footings can also be estimated adapting the above procedure, but however these estimates are likely to be approximate and conservative since the proposed formulation do not take into account the influence of relative rigidity of super structures and substructures on the redistribution of contact stress below each one of the footing under consideration. Computation of additional settlement of a rigid circular foundation founded on an isotropic elastic half space due to multiple distributed external loads has already been attempted by Selvadurai (1982). His solutions are applicable for rigid foundations and may require extensive computations which may not be very attractive to practicing consultants, who have become accustomed to the use of simple Schmertmann's technique which achieved a judicious integration of more rigorous elastic half space solution with in-situ static cone penetrometer test results through an ingenuous semi-graphical procedure.

Figure 8 indicates that the interference effects of adjacent footings on the settlement estimate of individual footings are almost negligible with r/B ratio exceeding 4. In the case of construction of a tall tower of 66 m height in Southern peninsular India (Srirangam) (Fig. 9), due to poor

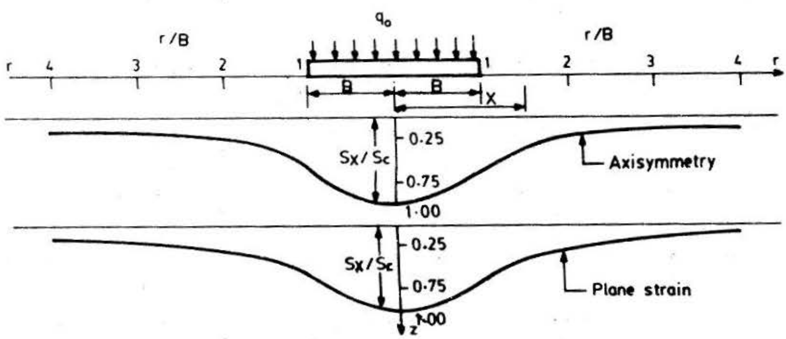

FIGURE 8 : Pattern of Settlement Trough

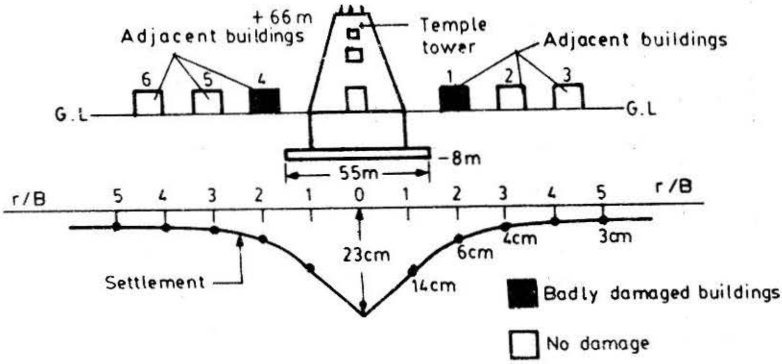

FIGURE 9 : Computed Theoratical Deflection Profile in the Foundation Soil

geotechnical planning and because of interference effects discussed earlier, two lightly loaded structures (numbered 1 and 4) in close proximity of the tower, suffered severe damages. Even though settlement records were not maintained, still ample evidence was obtained regarding the formation of settlement trough as shown in Fig. 9, which has resulted in serious damages not only to the adjoining lightly loaded structures but to the main tower also.

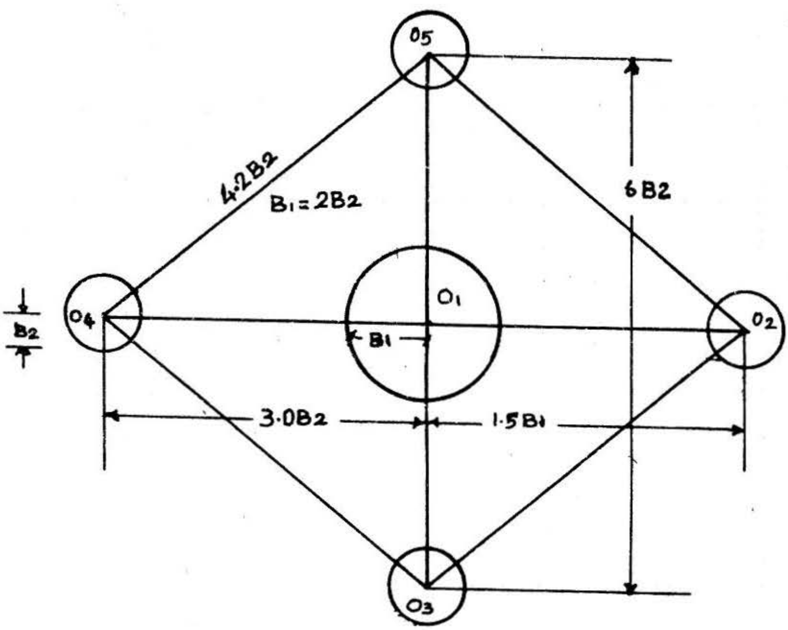

FIGURE 10 : Group of Circular Footings

Table 3 : Illustrative Settlement Estimate Incorporating Interference Effects of Adjacent Footings

S.No.	Description	μ	r/B	Settlement of the Centre of Footing				
				O_1	O_2	O_3	O_4	O_5
1.	Due to Loading on Respective Independent Footings	0.3	0	S_1*	S_2*	S_2	S_2	S_2
2.	Die to Interference Effects from Footings :							
	O_1	0.3	1.5	—	$0.3038S_1$	$0.3038S_1$	$0.3038S_1$	$0.3038S_1$
	O_2	0.3	3, 4.20 and 6	$0.2014S_2$	—	$0.1842S_2$	— **	$0.18424S_2$
	O_3	0.3	3, 4.20 and 6	$0.2014S_2$	$0.1842S_2$	—	$0.1842S_2$	— **
	O_4	0.3	3, 4.20 and 6	$0.2014S_2$	— **	$0.1842S_2$	—	$0.18424S_2$
	O_5	0.3	3, 4.20 and 6	$0.2014S_2$	$0.1842S_2$	— **	$0.1842S_2$	—

* Settlement Estimates S_1 and S_2 made through Schmertmanns Technique using Static Cone Penetrometer Readings. Settlement of Footings O_2 to O_5 are assumed as equal to S_2 for illustrations.

** Interference Effect from Footings with Spacing 6B is neglected

Total Settlement of Footing O_1 = $S_1 + 0.8056\ S_2$

Total Settlement of Footings O_2, O_3, O_4 and O_5 = $1.3685\ S_2 + 0.3038\ S_1$

The usefulness of the solutions presented for evaluating the interference effects of adjacent footings is explained in Table 3 for the field situation shown in Fig. 10. In evaluating the interference effects, as a first step the settlement estimates S_1 and S_2 of the respective footings are evaluated using Schmertmann's semi-graphical procedure and in-situ static cone penetrometer test results. After neglecting the superstructure and substructure rigidity the interference effects are then evaluated as illustrated in Table 3. Superstructure and substructure rigidity normally tends to even out the settlement distributions which may result in redistribution of axial column loads originally evaluated to act on each one of the footings. Such a realistic evaluation of interference effects may need a further in-depth analysis which will form a basis for future refinement of the concepts illustrated above.

Conclusions

Using approximate elasticity solutions and based on certain simplifying assumptions, tables of influence coefficients were complied and presented to make a conservative estimate of interference effects of adjacent footings on Schmertmann's settlement estimates. The theoretical solutions indicate that the interference effects of adjacent footings become negligible as the radial distance of adjacent footings exceed 2 times the width of the footing under loading. The need for taking cognisance of the superstructure substructure rigidity in the evaluation of interference effects for a more realistic appraisal of settlement estimates involving a group of interconnected footings is also brought out.

Acknowledgement

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