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PILED FOOTING IS AN EFFICIENT FOUNDATION SYSTEM IN CLAY: A CASE STUDY

Er. Ritesh Agarwal

Senior Lecturer, Civil Engineering Department Government Polytechnic College Nowgong MP

ABSTRACT

To an engineer the term soil may be defined as the un-aggregated or un-cemented deposits of mineral or organic particles or fragments covering large portion of earth's crust. This wide terminology includes different materials like boulders, sand, gravels clays and silts.

Soil Mechanics or Geo Technique being one of the youngest disciplines of Civil Engineering involving the study of soil, its behavior and application as an engineering material. The loads of the structures, buildings, bridge etc. are transmitted to under lying soil at base of the foundations. The soil being a compressible material gets compressed due to the stresses transmitted to them. This recalls an engineering terminology called the **Bearing Capacity**.

The naturally occurring soil is the mixture of particles of different sizes and exhibits definite characteristics. A **foundation** is that part of structures, which is the interfacing element between the super structure and under lying soil, and thus is in direct contactand transmits the load to the soil.

Footings are enlarged base of columns or walls to evenly distribute the load on to the soil so as not to exceed the bearing capacity. Heavily loaded and closely spaced columns often tend to have their footings touching or overlapping each other. Insuch cases large slab with or without beams is provided to support the column load. These are called as **'Rafts' or 'Mats'**. Providing rafts, substantially reduces total differential settlement, but are not **economical/feasible solutions**, and are **time consuming** too.

This approach is diverted towards "Piled footing" to over come the above mention limitations.

INTRODUCTION

Pile foundations come under the category of deep foundation which is commonly design by adopting the high factor of safety. Piles are columnar elements in the foundation, which transfer the super-structural load onto stiffer or more compact and less compressible soils via week compressible strata or water.

In cases like portal frames, retaining walls, load acting on the foundation may be eccentric; there can be chances of high eccentricity of column load, thus the pressure on soil increases and settlement too, thereby vastly increasing the tilt. As a result, larger footings make the design uneconomical and sometimes unfeasible also. The piled footing may form good alternative for this type of foundation.

Major concern of the foundation engineers is focused on problematic situations associated with foundation system such as space restriction, unavoidable eccentric loading on foundation and week soils. Therefore the constructional field demands a modified structural system capable of transmitting loads by effective stress distribution.

This paper is an attempt to give a detailed overview about the settlement behavior of piled-footing, and its feasibility against conventional footing. This approach is driven by FORTRAN programming, comparing the cases on the basis of loads and soil properties, considered for Girls hostel extension at Shri G. S. Institute of Technology & Science, Indore.

Piled-footing is a semi deep foundation, rather an improved shallow footing. This consists of a conventional footing pad supported on friction piles extending below it in clay. The load on the column is shared between the pile and base of footing, and thus proving to be a feasible approach to improve serviceability of foundation performance by reducing settlements appreciably.

Approach during this dissertation was to design, analyze and conduct a comparative study on Piled Footing. On the basis of analytical calculations and past references, it can be concluded that a conventional footing may provide adequate bearing area but will give excessive values of settlement, due to this excessive settlement many forces are generated and cracks will developed.

Piled footing provides an economical option for circumstances where, performance of conventional footings does not satisfy design requirements. Under these situations the addition of a limited number of piles may improve the settlement and differential settlement performance as well as maintain economy.

In this paper a hybrid approach is used treating footing pad as a system of inter connected beam supported on springs and friction pile as a stiff spring. Soil behavior has been defined using '**Winkler model'**.
In this paper a hybrid approach is used treating footing pad as a system of inter connected beam supported on springs and friction pile as a stiff spring. Soil behavior has been defined using 'Winkler model'.
In conventional design all the loads are assumed to be transmitted to the under laying ground directly by the foundation element,
i.e. footing, this approach deals with another alternative design which introduces the concept of piled footing.
Piled footing, raft is idealized as a plate because its thickness relatively small when compare with the other dimensions. 'Winkler model' concept is being opted for the analysis of soil and piles supporting the footing. 'Winkler model' is used to get the 'spring constant' for modeling the soil and pile in piled-footing. Few assumptions made in Winkler model:

- Soil is Isotropic, Homogeneous and elastic in nature.
- Shear resistance in the soil is neglected.
- Soil outside the loaded area doesn't undergo any deformation.

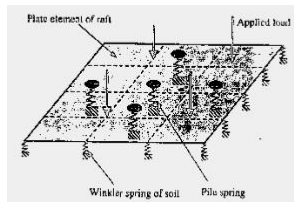

Fig.1: Finite element model of pile of raft footing

Fig 1 shows a detailed schematic diagram of finite element model representing soil and pile as springs. In piled-footing the term'**Modulus of Subgrade--Reaction'** characterizes the soil stiffness which to the soil to the consequent deflection.

The spring constants are defined using 'Elastic Method' proposed by Poulos. This approach is based on 'Finite Element Analysis (FEA)' of this system. In this paper considered two cases one of isolated footing and second one of combined footing for comparison from the mention site. A conclusion drawn from above study gives a clear indication about feasibility of piled footingin clay, when compared to conventional footings.

FORMULATION OF PROBLEM

The theme of paper was funneled down from the practical issues foreseen from the constructional field. It talks about the settlement behaviour of conventional foundations in low bearing capacity soils.
The approach for formulation of the problem was picked up from above observations. On the basis of thorough study the work moved forward with a new approach that is the study & analysis of piled footing concept.
A system was developed which comprises of uniform thickness pad and number of pile(s), which could support and sustain total load of column. This particular system was studied and analyze in detail with various combinations like single pile, two piles and four piles cases, for various diameters and various checks for Shear force and Bending moment were implemented.

Apart from this, study also dealt with conversion of a conventional combined footing to two piled footings. FORTRAN programming using Finite Element Method supported the overall formulation.

To analyze and conclude the above mention intent the inputs were drawn from Shri GSITS Girl's hostel extension project. The loads and soil properties were taken from the actual site data and kept same for all the cases irrespective of the various options used during formulation and analysis of the problem

Table 1 (a):Isolated Footing Table 1(b): Combined footing

Soil Properties

Based on the data obtained through a Plate Load Test conducted at site, following properties are worked out: -Bearing capacity of soil (SBC) = $10t/m^2 = 100\ KN/m^2$
C_p (cohesion) = $1\ Kg/cm^2 = 100\ KN/m^2$ $_{(adopted)}$ #
#Range ($0.25-5.0\ kg/cm^2$) depends on depth of soil layer
$\phi u = 0$ (For clayey soil)

Young's Modulus 'Es' = $10856\ KN/m^2$Poisson's ratio 'γ' = 0.40

Depth of ground water table = 10m.
Applied axial load = 596kN ~ 600kN (for one particular group)

Cases for Study

In this work a system of pile supported footing in order to reduce settlement of column footing and to reduce differential settlement in structure. For this comparison, following cases have been considered for the analysis.
Modulus of elasticity of footing Material = $2.23x10^7\ KN/m^2$
Size of footing pad 2.0x2.0 m instead of 2.6x2.6 m and depth=200mmVaried parameters are

- Ratio of pile - $\frac{L}{D}$ varied between 10-20
- No. of pile - single pile, two piles and four piles
- Dia. of piles - 250mm, 300mm and 400mm

TABLE 2 Cases taken for analysis

Cases were dealt separately so as to get a massive and versatile data clearly explaining the settlement behavior of the footing with various combinations like single central pile, two piles, four piles variable L/D ratio, diameter, stiffness etc.

METHODOLOGY

In this analysis a hybrid approach is used treating footing pad as a system of inter connected beams supported on springsand friction pile as a stiff spring. Soil behaviour has been defined using 'Winkler model'

In Winkler model soil mass is replaced by a bed of infinitesimally close independent springs.

The basic approaches to generalized finite element method are

- Grid analysis (or line element)
- Finite element (two dimensional elements like rectangular, triangular etc.)

In the finite element analysis, element continuity is maintained through the use of displacement function. The displacement function is of the form.

$U = a_1 + a_2x + a_3y + a_4x^2 + a_5xy + a_6y^2 + a_7x^3 + a_8x^2y + a_9xy^2 + a_{10}y^3 + a_{11}x^4 + a_{12}x^3y + a_{13}x^2y^2 + a_{14}xy^3 + a_{15}y^4$

Modulus of Subgrade Reaction (Ks)

Subgrade Reaction is simply pressure required to produce unit settlement

The modulus of **Subgrade Reaction** is defined as "The ratio between pressure against the footing or mat or raft and the settlement at a given point", and mathematically explained by given equation In other words "the coefficient of subgrade reaction is unit pressure required to produce a unit settlement". In clay soil, settlement under the load takes place over a long period of time and the coefficient is calculated on the basis of final settlement.

The soil stiffness is characterized by the modulus of Subgrade reaction "Ks" defined by equation: $Ks = P/\Delta$

P = Intensity of load transmitted to the soil

Δ = Consequent deflection

This may be defined as the ratio between the pressure against the footing and the settlement at a given point.

Assumptions

- 'Ks' is independent of magnitude of soil pressure.
  - 'Ks' has the same value at the every point of the surfaceVesic (1961) proposed a formula to calculate Ks

$Ks = Es / B (1-\gamma_s^2)$

Where, Es = modulus of elasticity of soilB = width of footing

γ_s = Poisson's ratio of soil

DEFORMATION MODULUS (SECANT MODULUS)

Deformation modulus refers to the relation between stress and strain. For linearly elastic material the 'deformation modulus' is known as the Young's Modulus or Elastic modulus 'E'. The stress – strain behaviour of soil is very complex.

The slope of a straight line drawn as tangent at a particular point on a stress – strain curve is termed the tangent modulus, which will vary with the point selected. Its value at initial point of the curve is the "Initial tangent modulus".

The slope of straight line joining any two separate points on the curve is 'Secant Modulus'. As two points comes close together the secant modulus tends to become equal to the tangent modulus. The secant modulus may also be called simply "Deformation Modulus".

Deformation modulus = $\dfrac{\Delta\sigma}{\Delta \in}$

SPRING CONSTANT OF PILE

In this analysis pile below the footing is assumed as to act as a spring having spring constant according to compressibility. This spring constant is equal to the 'Stiffness of pile' that may be defined as the axial force required, producing a unit displacement at the pile head.

METHODS TO PREDICT SETTLEMENT AND LOAD DISTRIBUTION IN SINGLE PILE

- Load transfer method
- Method based on theory of elasticity*
- Numerical method (FEM)

*In present analysis for calculating the stiffness of the pile the '**method based on elastic theory**' is used

SETTLEMENT OF FLOATING PILES

As with the tip load of a pile, the settlement of the top of the pile may be expressed to sufficient accuracy, in terms of an incompressible pile in half space, with correction factors for the effect of pile compressibility and so on.

For a homogeneous soil mass having constant Young's Modulus E_s and Poisson's ratio I_s the settlement of a single floating pilecan be given as

Where,
ρ= PI/E_sD
$I = I_oR_kR_hR_v$

ρ= Settlement of the pile head. P = applied axial load.
I_o = Settlement-influence factor for incompressible pile in semi-infinite mass, for Poisson's ratio = 0.4R_k = Correction factor for pile compressibility
R_v = Correction for soil Poisson's ratio.
R_h = Correction factor for finite depth of layer on a rigid base.h = Total depth of soil layer.

Curves for finding I_o, R_k, R_h, and R_v are shown in Fig. 4.4
Now having this equation, the stiffness of pile can be easily calculated as

$S_p = P/\rho$

$$S_p = \frac{EsD}{I}$$

And the stiffness calculated from the above formula can be used as the spring constant of pile with sufficient accuracy.

For the values of I_O R_K R_h R_V refer GRAPHS

ULTMATE LOAD CARRYING CAPACITY OF PILES

load carrying capacity of an under reamed pile may be worked out from the following expression: -Qu = Ap Nc Cp + Aa Nc C'a + C'a A's + αCa As

Where,

Qu (kN) = Ultimate bearing capacity of pile
Ap (m^2) = Cross-sectional area of pile stem at toe levelNc = Bearing capacity factor, usually taken as '1' Cp (kN/m^2) = Cohesion of the soil around toe.
Aa (m^2) = (D^2u - D^2), where Du (m) and D (m) are the bulb and stem diameter respectively;C'a (kN/m^2) = average cohesion of soil around the underred bulbs.
α = Reduction factor (usually taken 0.5 for clay) Ca (kN/m^2) = Average cohesion of soil along the pile stem.As (m^2) = surface area of the stem.
A's (m^2) = surface area of the cylinder circumscribing the under reamed bulbs.

In this analysis (case) Friction piles are considered, and the equation for under reamed pile reduces to,

Qu = Ap Nc Cp + α Ca As Ultimate bearing capacity of pile is calculated using this equation

CHECKS

The analysis part of the paper was developed and supported by a FORTRAN program customized so as to convert the design inputs into permissible output. The customized programming considers the following checks so as to achieve a value, which is very well within the permissible limits.

- Maximum settlement < 75mm
- Difference in settlement < 1/20 x raft thickness *
- Maximum settlement x Ks < SBC of soil

Where,
SBC = Safe bearing capacity of soilKs = Modulus of Subgrade reaction

** This check is useful for combined footing*

Let's understand why the above mention checks were only considered for the analysis?
To be very simple, the whole approach was concentrated only on the settlement behaviour of the piled footing. The results of analysis i.e. settlements behaviour, expected to be in safer and permissible zone with respect to the bearing capacity of soil.

RESULTS AND DISCUSSION –

The gist of this work is analytically resolved and documented in graphical and tabular format explaining clearly the study carried on settlement and thus enumerating the contribution of pile(s) in improving load carrying capacity and reduction in settlement behaviour. The respective justification under following heads-

- Study of Load Shared by Pile(s).
- Study of Settlements.

- Study of Load Shared by Pile(s)
Load shared of pile(s) for different diameters, L/D ratio of pile and no. of pile(s) below one column are presented in table. With increase in diameter and L/D ratio of pile the load shared by pile(s), obviously increases because of increase in contact surface area between concrete and soil. In the range of this study this variation is ranging between 20%-66%.
In the entire cases load shared by single pile placed below the column is larger than the load shared by a pile in two or four piles evenly distributed below the column. In single pile case 48% - 66% sharing is observed where is the same lies from 31% - 39% for two piles cases and 19% - 21.60% for four piles cases, for each pile.
Together all the piles in a group share 48%- 89% of column load of all the cases studied in table 3.

TABLE 3 Study of Load Shared by Piles

Study of Settlements-

Settlements are of greater concern for a designer then the costs. Conventional isolated footings, on low bearing capacity soils are prone to larger individual settlements, due to large size footings and also greater differential settlements due to variation in pressure intensities below footing.

Results presented in table 6.2 clearly indicate usefulness of this hybrid system of foundation in controlling absolute and differential settlements. In this case study expected settlements of isolated footings (conventional) lie between 23mm – 34mm where as for combined footing they would be 42mm – 62mm. By providing pile(s) below footing these settlements would be around 5.5mm – 8.0mm.which are considerably lower then conventional footings.

Converting a combined footing into two-isolated footing resting on pile(s) is very much effective in controlling the absolute and differential settlement. Settlements of piled footings are observed to be reducing from 12.96mm – 5.40mm where L/D ratio varies 10 – 15.

For a given pile length (3.0m) and diameter varies 250mm, 300mm and 400mm then settlements are, single pile case 12.96mm – 12.43mm, for two piles 10.44mm – 10.01mm, and four piles 7.68mm – 7.36mm.

Effect of footing pad thickness on settlements: - When there is an in increase the footing pad thickness, then the absolute and differential settlements gradually reduce. For example in a Four Piles Case, having 300mm diameter and length 3.0 mtr for various thickness like 20, 25, 30, 35 and 40mm, the value of absolute settlement are 7.36, 6.19, 5.67,
5.40 and 5.24 respectively.

TABLE 4 study of settlement

TABLE 5 Comparison of settlements

CONCLUSION

Following the analysis of results, following broad conclusions may be summarized:-

1. With increase in thickness of footing pad 200mm (with pile cases) and 350mm (without pile case) uniform settlement pattern and thus pressure distribution below footing can be achieved.
2. Application of piled- footing results in reduction of area of footing in low bearing capacity soils, also overlapping of footing can be avoided. In turn one combined footing may be replaced by two Isolated footings; economically.
3. By increasing L/D ratio of pile, the settlement reduces and the percentage load taken by piles increases.

Load shared by friction pile vary as under, for L/D ratio from 10-18.

	One pile	**Two piles**	**Four piles**
(I) 250ϕ pile case	48.28%-58.35%	31.28%-35.42%	18.98%-20.40%
(II) 300ϕ pile case	50.40%-66.18%	32.19%-38.27%	19.30%-21.30%

4. When no. of piles below a column increase, then load shared by individual pile decrease. Load carried by one pile in case of one, two and four

pile(s) cases goes on reducing with increasing no. of piles:

One pile		Two piles	Four piles
For 250ϕ pile case (%)	58.35	35.41	20.39
For 300ϕ pile case (%)	66.18	38.27	21.30

5.

- Settlements of piled footing are much less when compare to conventional footing. In this case study maximum settlement of piled footing is 7.68mm in comparison of 23.40mm settlement conventional footing.
- Maximum settlement of combined footing (conventional) is 49.11mm which is much higher value compares to pile footing settlement which is 5.49mm.
- Differential settlements are greatly reduced.

Conventional footings require much more concrete. Piled footing reduces 25% cost compare to conventional footing. As a case study cost of two isolated piled footings comes out to be less than one combined conventional footing and a conventional trapezoidal footing can be 'effectively' and 'economically' replaced by a cuboidal footing supported on friction piles.

Limitation

(1) The analysis results presented here are subject to accuracy in evaluating values of
(a) Modulus of Sub grade reaction of soil.
(b) Cohesive force between pile & soil.
(c) Variation in soil strata below footing.
(2) Modeling of footing pad is done on 'GRID' analogy, the refinement will occur through modeling as plate.
(3) Stiffness of column has not been account for.
(4) Winkler model incorporates independent soil springs and cohesion between soil particles is neglected.

Table 1(a) Isolated Footings

Column group	Load(kN)	Size (m^2)	Depth(mm)
G_1 G_2 G_3 G_4 G_5 G_6 G_7	**596** 900 632 797 830 694 885	**2.6 x 2.6** 3.1 x 3.1 2.75 x 2.75 2.2 x 3.5 2.6 x 3.3 2.6 x 2.8 2.6 x 3.8	**650** 750 700 800 750 650 900

Table 1(b) Combined Footings

$G_{11}G_{13}G_{14}$	**1086+970=2056** 1086+970=2056 1045+1223=2268	**6.8 x 2.6** 3.0 x 6.80 2.0 x 6.80	**1000** 900 1000

Table 2(a)

WITHOUT PILE CASES					
SNO.	Es (kN/m²)	Ksx10³ (kN/m³)	Sp (kN/m)	SIZE (m²)	THIKNESS (mm)
1	10856	6.46	–	2.72x2.72	350
2	10856	6.46	–	2.72x2.72	400

Table 2 (b)

WITH PILE CASES								
S.NO.	O.OF PILE (S)	LEN-GTHOF PILE (m)	L/D	Es (kN/m²)	Ksx10³ (kN/m³)	Sp (kN/m)	SIZE (m²)	THIKNESS (mm)
For 250mmΦ Single pile cases								
1	1	3000	12	10856	6.46	22358	2.0x2.0	200
2	1	3300	13.2	10856	6.46	24619	2.0x2.0	200
3	1	3600	14.4	10856	6.46	26881	2.0x2.0	200
4	1	3900	15.6	10856	6.46	29412	2.0x2.0	200
5	1	4200	16.8	10856	6.46	31404	2.0x2.0	200
6	1	4500	18	10856	6.46	33665	2.0x2.0	200
Two piles cases								
7	2	3000	12	10856	6.46	22358	2.0x2.0	200
8	2	3300	13.2	10856	6.46	24619	2.0x2.0	200
9	2	3600	14.4	10856	6.46	26881	2.0x2.0	200
10	2	3900	15.6	10856	6.46	29412	2.0x2.0	200
11	2	4200	16.8	10856	6.46	31404	2.0x2.0	200
12	2	4500	18	10856	6.46	33665	2.0x2.0	200
Four piles cases								
13	4	3000	12	10856	6.46	22358	2.0x2.0	200
14	4	3300	13.2	10856	6.46	24619	2.0x2.0	200
15	4	3600	14.4	10856	6.46	26881	2.0x2.0	200
16	4	3900	15.6	10856	6.46	29412	2.0x2.0	200
17	4	4200	16.8	10856	6.46	31404	2.0x2.0	200
18	4	4500	18	10856	6.46	33665	2.0x2.0	200

CONT…

WITH PILE CASES								
S.NO.	O.OF PILE (S)	LEN-GTHOF PILE (m)	L/D	Es (kN/m²)	Ksx10³ (kN/m³)	Sp (kN/m)	SIZE (m²)	THIKNESS (mm)
For 300mmΦ Single pile case								
19	1	3000	10	10856	6.46	24330	2.0x2.0	200
20	1	3300	11	10856	6.46	28901	2.0x2.0	200
21	1	3600	12	10856	6.46	33472	2.0x2.0	200
22	1	3900	13	10856	6.46	38042	2.0x2.0	200
23	1	4200	14	10856	6.46	42613	2.0x2.0	200
24	1	4500	15	10856	6.46	47184	2.0x2.0	200
Two piles cases								
25	2	3000	10	10856	6.46	24330	2.0x2.0	200
26	2	3300	11	10856	6.46	28901	2.0x2.0	200
27	2	3600	12	10856	6.46	33472	2.0x2.0	200
28	2	3900	13	10856	6.46	38042	2.0x2.0	200
29	2	4200	14	10856	6.46	42613	2.0x2.0	200
30	2	4500	15	10856	6.46	47184	2.0x2.0	200
Four piles cases								
31	4	3000	10	10856	6.46	24330	2.0x2.0	200
32	4	3300	11	10856	6.46	28901	2.0x2.0	200
33	4	3600	12	10856	6.46	33472	2.0x2.0	200
34	4	3900	13	10856	6.46	38042	2.0x2.0	200
35	4	4200	14	10856	6.46	42613	2.0x2.0	200
36	4	4500	15	10856	6.46	47184	2.0x2.0	200
For 400mmΦ (single pile, two piles and four piles cases)								
37	1	4500	11.25	10856	6.46	44002	2.0x2.0	200
38	1	5000	12.5	10856	6.46	52700	2.0x2.0	200
39	2	4500	11.25	10856	6.46	44002	2.0x2.0	200
40	2	5000	12.5	10856	6.46	52700	2.0x2.0	200
41	4	4500	11.25	10856	6.46	44002	2.0x2.0	200
42	4	5000	12.5	10856	6.46	52700	2.0x2.0	200

Table 3 Study of Load Shared by Piles

STUDY OF LOAD SHARED BY PILE (S)						
L/D RATIO	LOAD SHARED BY SINGLE PILE (kN)			TAGE OF LOAD CARRIEDBY ONE PILE (%)		
	NE PILE CASE	/O PILESCASE	FOUR PILES CASE	ONE PILE CASE	TWO PILES CASE	FOUR PILES CASE
FOR 250mm Φ						
12.00	289.70	187.67	113.87	48.20	31.27	18.97
13.20	304.06	193.83	116.08	50.67	32.30	19.35
14.40	317.06	199.35	117.95	52.84	33.22	19.65
15.60	329.01	204.17	119.65	54.83	34.02	19.94
16.80	339.98	208.56	121.12	56.67	34.76	20.19
18.00	350.12	212.50	122.37	58.35	35.41	20.39
FOR 300mm Φ						
10.00	302.37	193.11	115.81	50.39	32. 18	19.30
11.00	327.82	203.63	119.76	54.64	33.94	19.96
12.00	349.35	212.15	122.27	58.23	35.36	20.38
13.00	367.60	221.12	124.51	61.27	36.85	20.75
14.00	383.35	224.83	126.35	63.89	37.47	21.05
15.00	397.05	229.64	127.82	66.18	38.27	21.30
FOR 400mm Φ						
11.25	387.75	226.35	126.81	64.62	37.72	21.13
12.50	411.48	243.57	129.32	68.58	39.09	21.60

Table 4 Study of Settlement

S No	NO. OF PILE (S)	ENGTH OF PILE (mm)	L/D	MAXIMUM SETTLEMENT (mm)
1	1	3000	12	12.96
2	1	3300	13.2	12.35
3	1	3600	14.4	11.8
4	1	3900	15.6	11.29
5	1	4200	16.8	10.83
6	1	4500	18	10.4
7	2	3000	12	10.44
8	2	3300	13.2	9.94
9	2	3600	14.4	9.5
10	2	3900	15.6	9.11
11	2	4200	16.8	8.76
12	2	4500	18	8.45
13	4	3000	12	7.68
14	4	3300	13.2	7.32
15	4	3600	14.4	7.01
16	4	3900	15.6	6.74
17	4	4200	16.8	6.5
18	4	4500	18	6.29
19	1	3000	10	12.43
20	1	3300	11	11.34
21	1	3600	12	10.44
22	1	3900	13	9.66
23	1	4200	14	8.99
24	1	4500	15	8.42
25	2	3000	10	10.01
26	2	3300	11	9.15
27	2	3600	12	8.47

28	2	3900	13	7.92
29	2	4200	14	7.46
30	2	4500	15	7.06
31	4	3000	10	7.36
32	4	3300	11	6.77
34	4	3600	12	6.3
35	4	3900	13	5.94
36	4	4200	14	5.65
37	4	4500	15	5.4
38	1	4500	11.25	8.81
39	1	5000	12.5	7.81
40	2	4500	11.25	7.33
41	2	5000	12.5	6.67
42	4	4500	11.25	5.57
43	4	5000	12.5	5.16
44	4	4500	11.25	5.49
45	4	3900	13.00	5.45

Table 5 Comparisonof Settlement

Footing on Winkler Model		**Conventional Footing**	
Size (m^2)	**Maximum Settlement (mm)**	**Size (m^2)**	**Maximum Settlement (mm)**
2.0X2.0	7.68	2.6X2.6 **Iso.**	23.4
2.6X2.6 (1086)*	5.49	6.8X2.6 **Com.**	49.11
2.6X2.6 (970)*	5.45		
Remark*: Combined footing is converted into two equal Isolated Piled Footings.			

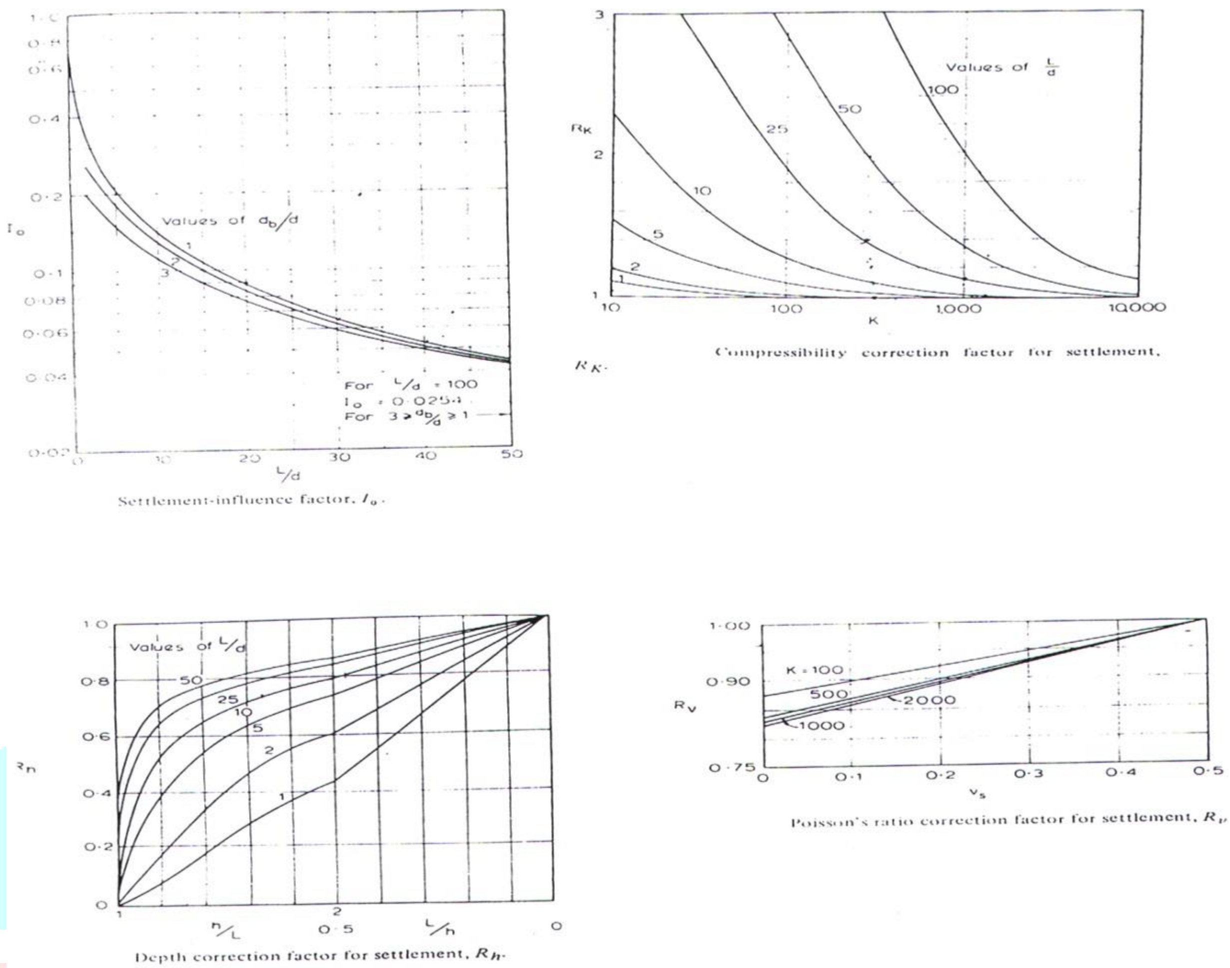

Fig. 3.3: curves for determination of correction factors

(Reproduced From Poulos And Davis, 1986)[11]

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