IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 2 Ser. III (Mar - Apr 2020), PP 58-66
www.iosrjournals.org

Technical and Financial Implications in Providing Combined Footings for Closely Spaced Columns

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Abstract:
In reinforced concrete construction, foundation is the part of a structure that is usually placed below the surface of the ground to transmit the load to the underlying soil and rock. Spread footing supporting more than one column or walls is termed as combined footing. Combined footings are provided in two different situations: (a) if a column is very near or adjacent to the property line, single-column footings cannot be provided without projecting beyond that line; (b) if more than one columns or walls very close to each other, individual footings overlaps each other. In an individual footing, reinforcements for flexural moments are provided at the bottom. In contrast to individual footings, reinforcements in combined footing are generally seen on both faces: top and bottom due to flexural moment. It is generally believed that combined footings are more expensive than the individual footings for a particular load. Apart from technical implications, financial involvement in providing a combined footing may not always be larger than two individual footings.Some factshave been found from the detail parametric study on this topic. In this research, parametric study is conducted to get introduced with the method of evaluating stresses under shallow footings, to estimate the cost of construction of individual and combined footings under closely spaced columns, to conduct or parametric study for making comparative economical involvement in closely spaced individual footings and some combined footings, to evaluate the overstressing under closely spaced individual footings.Analytically using the MicrosoftExcel 2016 program, about 252 nos. individual footings and 252 nos. combined footings are analyzed and designed respectively. After doing all these study, we can say that vertical depth stress is rapidly decreased at a distance of significant depth. When L/a (where L is the column to column spacingand a is the distance between column center to outer face of the footing) ratio is small, the individual footing shows lower cost as compared to combined footing. Over stressing of soil between two closely spaced individual column footing may lead to failure of footing.

***Key Words**: Combined Footing;Individual Column Footing; Overstress; Microsoft Excel 2016.*

Date of Submission: 21-03-2020 Date of Acceptance: 07-04-2020

I. Introduction

1.1 GENERAL

Stresses, beneath the foundation, are induced in a soil mass due to weight of overlying soil and due to the applied loads[1,3,5,6]. The stresses due to self-weight of soils are generally large in comparison to those stresses induced due to imposed loads. If adequate strength of soil is found immediately below the structure or satisfactorily soil directly underlies the structure, it becomes necessary to spread the load by footings or other means; such substructures are known as spread foundations. Spread footing may be of different types[3,6]. For instance, individual footing, combined footing, raft or mat. An individual footing supports a column individually, while a combined footing supports two or three columns. If a shallow footing supports majority of the columns or all the columns, then the foundation is known as raft or mat.Spread footing supporting more than one columns or walls is termed as combined footing. These types of combined footings may be necessary when the soil is poor; even the footing of one column overlaps the adjacent footing. The shape of the combined footing may be rectangular or trapezoidal. In most cases, a rectangular combined footing is preferred[1,7]. The B.N.B.C. (2006), Section 3.8, and the ACI Code (2005), Section 15.10, do not provide a detailed approach for the design of combined footings[2,4]. The design, in general, is based on the structural analysis.Detail analysis approach is obtained from text books[7,8,9].A footing may fail in different modes: overstressing the soil beneath the footing, punching of the columns and excessive compressibility of soil for settlement, flexural moment and shear of the footing body[8].Equations have been developed to compute stresses at any point under the footing in a soil mass on the basis of the theory of elasticity. When a load is applied to the soil surface, it increases the vertical stresses within the soil mass. The increased stressesact directly under the loaded area, but extend indefinitely in all directions. Many formulas based on the theory of elasticity have been used to compute stresses in soils[5]. They are all similar but differ only in the assumptions made to represent the elastic conditions of the soil mass. The formulas that are most widely used is the Boussinesq's formula[3]. This formula was first developed for point loads acting at the surface. The extent of the elastic layer below the surface loadings may be any one of the following:

1) Infinite in the vertical and horizontal directions.
2) Limited thickness in the vertical direction underlain with a rough rigid base such as a rocky bed.

The loads at the surface may act on flexible or rigid footings. The stress conditions in the elastic layer vary according to the rigidity of the footings and the thickness of the elastic layer. All the external loads considered in this research are vertical loads only as the vertical loads are of practical importance for analyzing and designing of combined footings.

II. Background of the Study

According to the earlier discussion combined footings are provided in two different situations. The present study deals with the situation for closely spaced columns. In a situation of closely spaced columns, engineers have two options: (a) Individual footing of large Length/Breath; (b) Combined footings[1,9]. In an individual footing, reinforcements for flexural moments are provided at the bottom. In contrast to individual footings, reinforcements in combined footing are generally seen at both faces: top and bottom due to flexural moment. It is generally believed that combined footings are more expensive than the individual footings for a particular load(s). Hence, individual footings are observed maintaining a small distance in between. For such a case, technical complexities may arise during and after construction. Casting of footing may become difficult in the case of two footings separated by small gap. In addition, overstressing under the overlapped zone of influence may cause serious consequence during the service life of structures. Apart from technical implications, financial involvement in providing a combined footing may not always be larger than two individual footing.

III. Objectives

The main objective of the study are as follows-

1. To get introduced with the method of evaluating stresses under shallow footings.
2. To estimate the cost of construction of individual and combined footings under closely spaced columns.
3. To conduct or parametric study for making comparative economical involvement in closely spaced individual footings and some combined footings.
4. To evaluate the overstressing under closely spaced individual footings.

IV. Methodology

1. Parameter selection such as columns load (P), column to column spacing (L) and net allowable soil bearing capacity (q_{all}(net)).
2. Selection the method of stress distribution equation.
3. Stress calculation under foundation.
4. Sketch the pressure bulb diagram.
5. Design individual and combined footings.
6. Estimate cost effectiveness for both types of footings.
7. Verify technical aspects and soundness.

4.1 PARAMETRIC STUDY

1. Dead Loads (D.L.) - The self-weight of the building and superimposed load which are not capable to change with respect to time. Example: (150, 140, 115, 85) Kips for column no-01 and (140, 130, 104, 78) Kips for column no-02.
   Live Loads (L.L.) - Any load from occupancy which are capable to change with respect to time (furniture, people, etc.). Minimum live loads are dictated by Building Codes. Residential = 40 psf, commercial office = 50 psf, Library stack room = 125 psf. Example: (120, 110, 90, 70) Kips for column no-01 and (110, 100, 80, 60) Kips for column no-02.
2. Columns size:
   12´´ X 12´´; 12´´ X 15´´; 12´´ X 18´´; 12´´ X 20´´; 15´´ X 15´´; 15´´ X 18´´ and 15´´ X 20´´
3. Net allowable bearing capacity of soil = (2.5, 3.0, 3.5) Ksf
4. Center to center distance between column, L = 6´, 8´, 10´, 12´
5. Materials property: fc´= 3500 psi and fy = 60000 psi

4.2 SELECTION THE METHOD OF STRESS DISTRIBUTION EQUATION

In thisstudy, we considered only Boussinesq's formula to evaluate stresses in soil mass under the foundation because this formula is most widely used in foundation design.

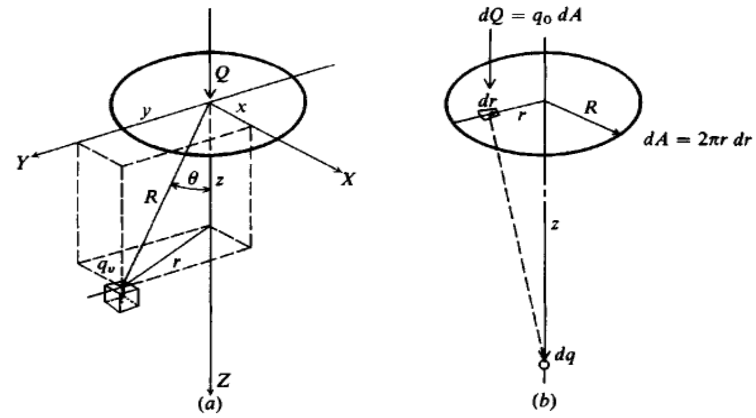

Figure 4.1 (a) Intensity of pressure q based on Boussinesq's approach;
(b) Pressure at point of depth z below the center of the circular area acted by the intensity of pressure q_o.

Figure shows a horizontal surface of an elastic continuum subject to a point load Q at a point O. Using logarithmic stress function for solution of elasticity problem, From Figure4.1,

$R^2 = r^2 + z^2$
$\tan\theta = (^r/_Z)$
$\cos 5\theta = (^Z/_R)^5$

$$q_v = (^Q/_Z)^2 * A_b$$

Where, A_b term is a function of the (r/z) ratio.

(r/z)	0.000	0.100	0.200	0.300	0.400	0.500	0.750	1.000	1.500	2.000
A_b	0.477	0.466	0.433	0.385	0.329	0.273	0.156	0.084	0.025	0.008

4.3 SKETCH THE PRESSURE BULB DIAGRAM

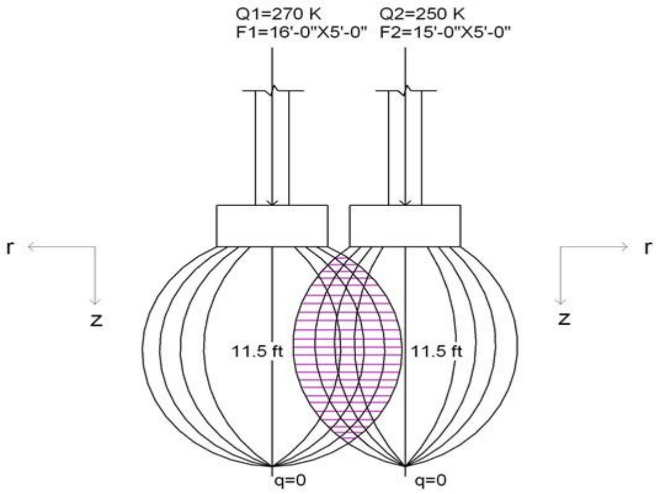

Figure 4.2 Pressure isobars based on the Boussinesq's equation for individual footings

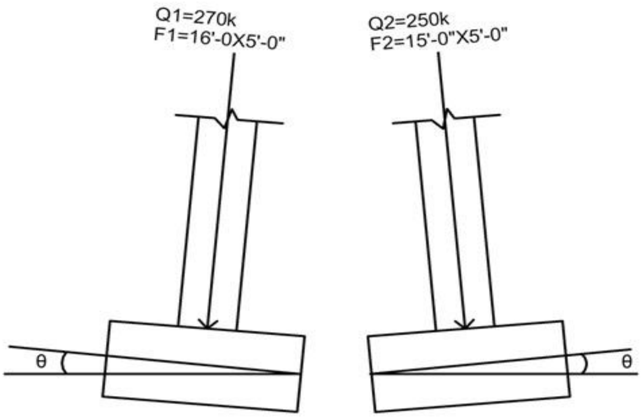

Figure 4.3 Effect of closely spaced Individual footings (tilting due to over stressing)

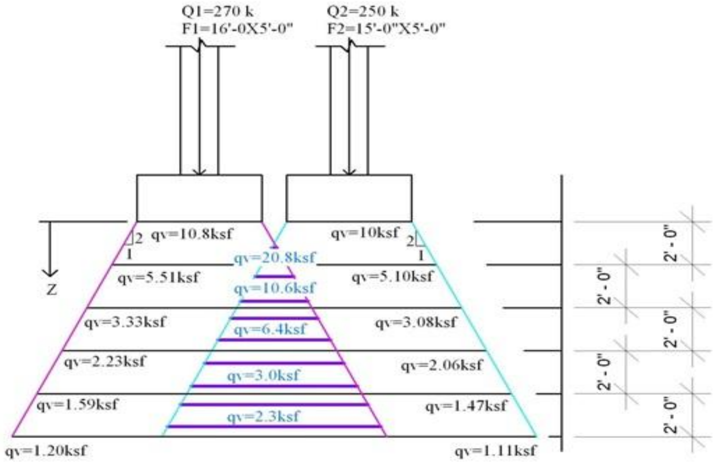

Figure 4.4 Approximate methods of obtaining the stress increase q_v in the soil at a depth z beneath the footing

4.4 DESIGN, SKETCH AND ESTIMATE

One typical design, sketch and estimate for individual and combined footing are shown in this paper. Others were conducted by following the typical one.

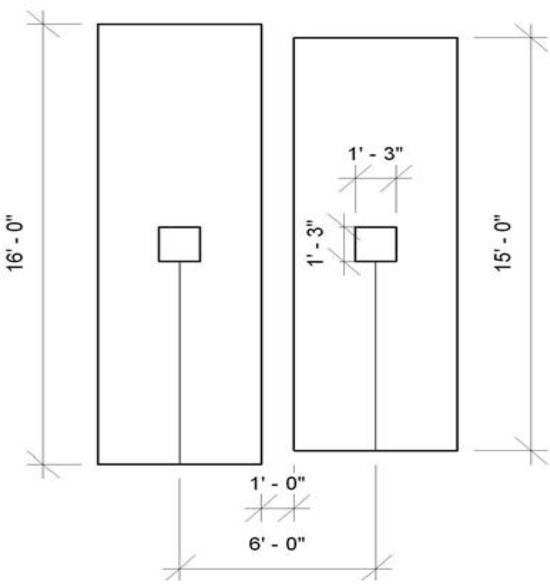

Figure 4.5 Dimension of Individual footing

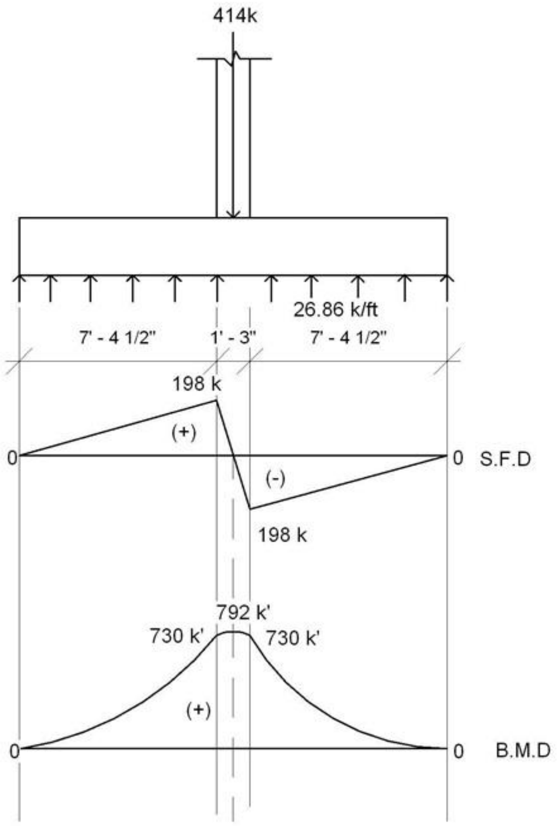

Figure 4.6 Moment and Shear diagrams of Individual footing-01

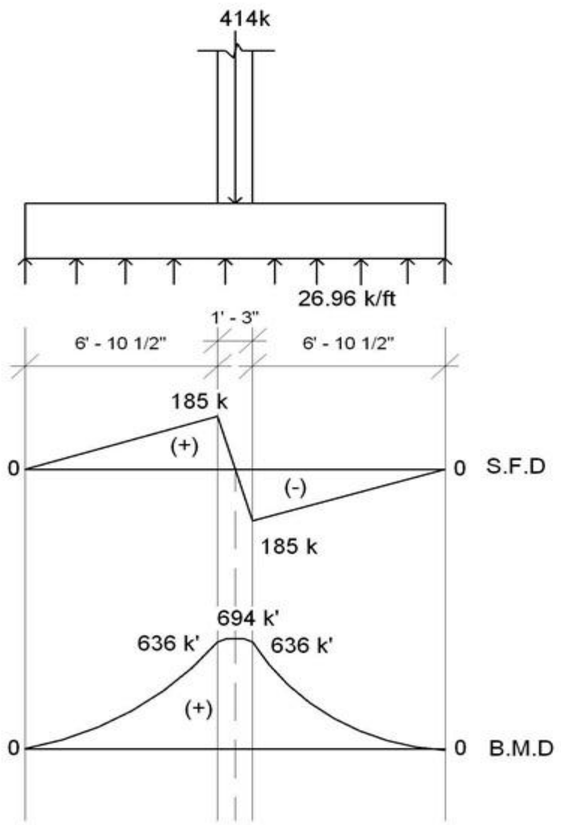

Figure 4.8 Moment and Shear diagrams of Individual footing-02

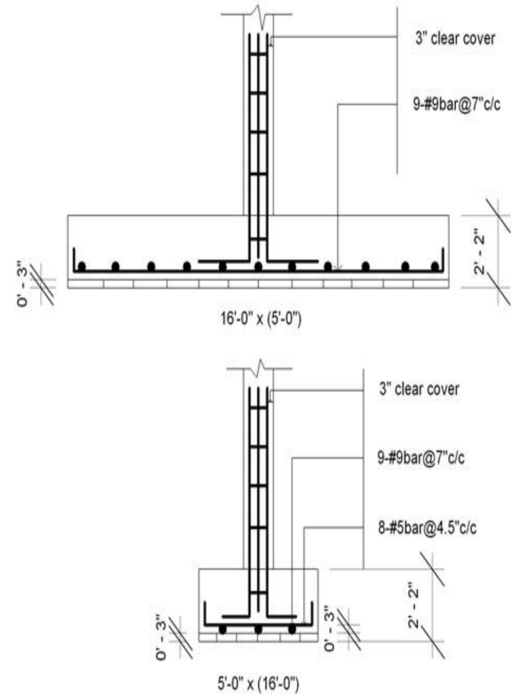

Figure 4.7 Reinforcement details for Individual footing-01

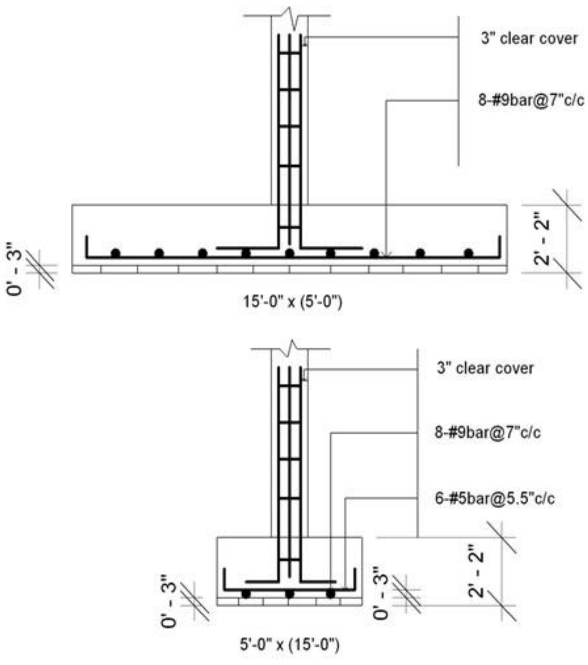

Figure 4.9 Reinforcement details for Individual footing-02

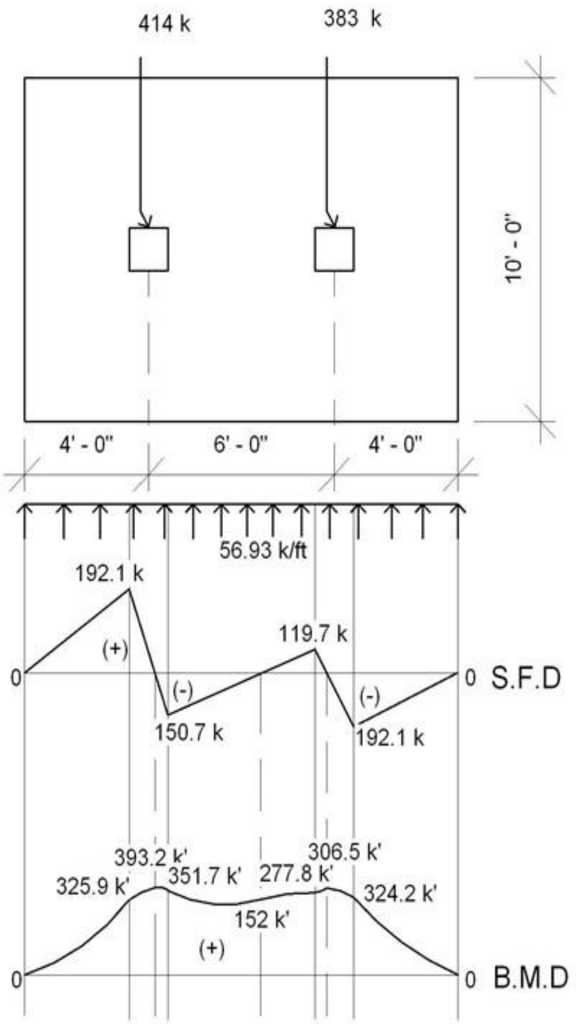

Figure 4.10 Moment and Shear diagrams of Combined footing

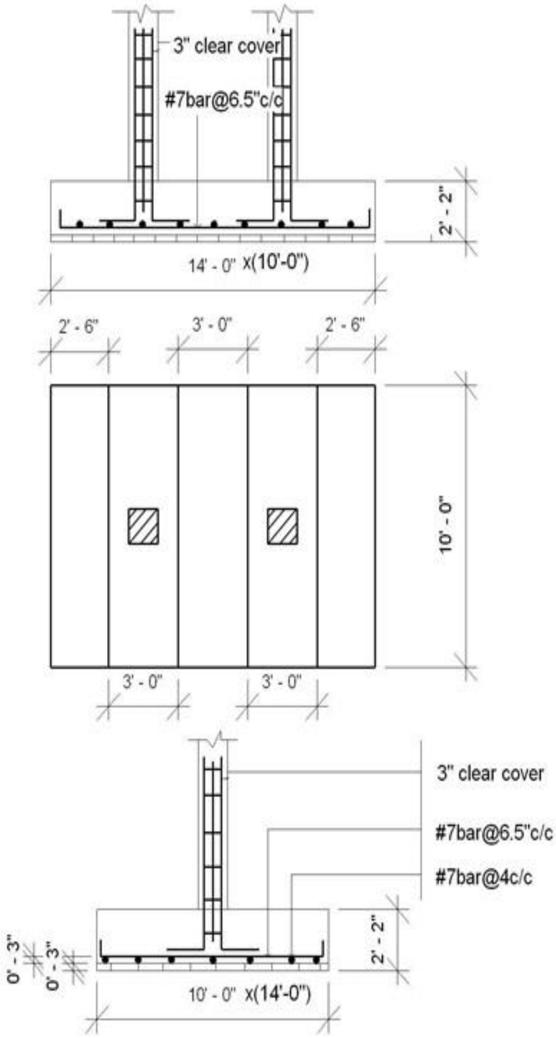

Figure 4.11 Reinforcement details for Combined footing

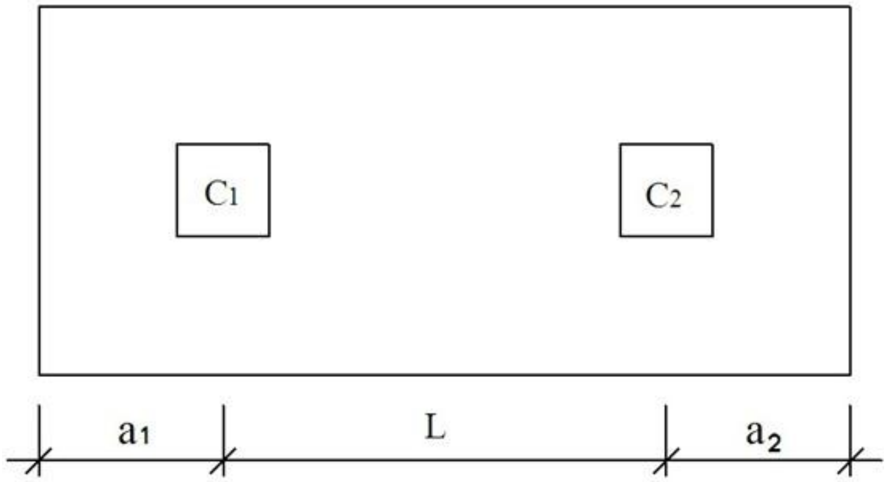

Figure 4.12 Dimension of Combined Footing for plotting graph (where a-maximum of a_1 or a_2)

V. Result

The results obtained from the different types of footings are discussed in the following sections.

Table 5.1 Cost of different types of individual and combined footing:

S.L. NO	D.L. (Kips) Column-01	L.L. (Kips) Column-01	D.L. (Kips) Column-02	L.L. (Kips) Column-02	COLUMN SIZE (inch)	BEARING CAPACITY (ksf)	SPACING BETWEEN COLUMNS (ft)	TOTAL COST (Taka) Individual Footing	TOTAL COST (Taka) Combined Footing	L/a
1	150	120	140	110	12´´ X 12´´	2.5	4	208328	176541	0.44
2	150	120	140	110	12´´ X 12´´	2.5	6	196869	152588	0.75
3	150	120	140	110	12´´ X 12´´	2.5	8	132706	135515	1.14
4	150	120	140	110	12´´ X 12´´	2.5	10	103242	137614	1.67
5	150	120	140	110	12´´ X 12´´	2.5	12	86337	142734	2.40

Table 5.2 Cost of different types of individual and combined footing:

S.L. NO	D.L. (Kips) Column-01	L.L. (Kips) Column-01	D.L. (Kips) Column-02	L.L. (Kips) Column-02	COLUMN SIZE (inch)	BEARING CAPACITY (ksf)	SPACING BETWEEN COLUMNS (ft)	TOTAL COST (Taka) Individual Footing	TOTAL COST (Taka) Combined Footing	L/a
1	150	120	140	110	12´´ X 12´´	3	4	168356	127550	0.55
2	150	120	140	110	12´´ X 12´´	3	6	149265	112322	0.96
3	150	120	140	110	12´´ X 12´´	3	8	103378	112730	1.52
4	150	120	140	110	12´´ X 12´´	3	10	81660	117125	2.35
5	150	120	140	110	12´´ X 12´´	3	12	68916	122245	3.69

Table 5.3 Cost of different types of individual and combined footing:

S.L. NO	D.L. (Kips) Column-01	L.L. (Kips) Column-01	D.L. (Kips) Column-02	L.L. (Kips) Column-02	COLUMN SIZE (inch)	BEARING CAPACITY (ksf)	SPACING BETWEEN COLUMNS (ft)	TOTAL COST (Taka) Individual Footing	TOTAL COST (Taka) Combined Footing	L/a
1	150	120	140	110	12´´ X 12´´	3.5	4	145249	99012	0.70
2	150	120	140	110	12´´ X 12´´	3.5	6	119382	96038	1.26
3	150	120	140	110	12´´ X 12´´	3.5	8	84288	98137	2.13
4	150	120	140	110	12´´ X 12´´	3.5	10	67387	102533	3.64
5	150	120	140	110	12´´ X 12´´	3.5	12	57225	107653	7.86

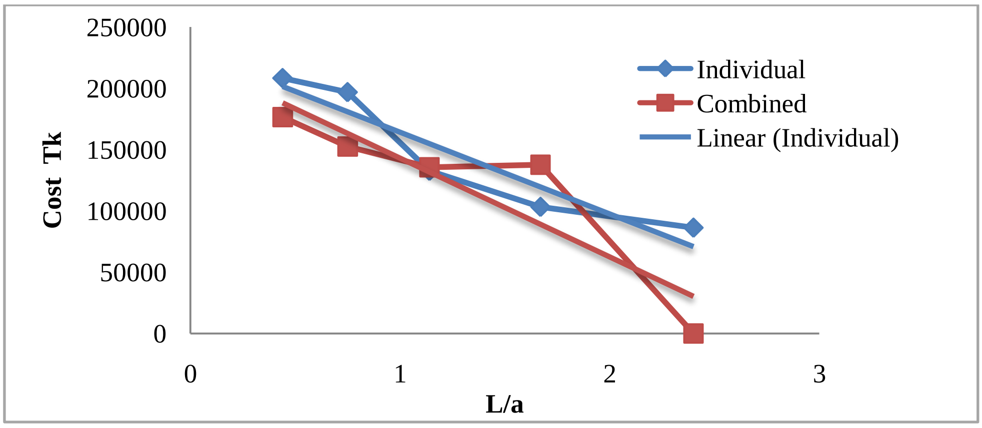

Figure 5.1 Cost Analysis of Individual and Combined Footing (Table 5.1)

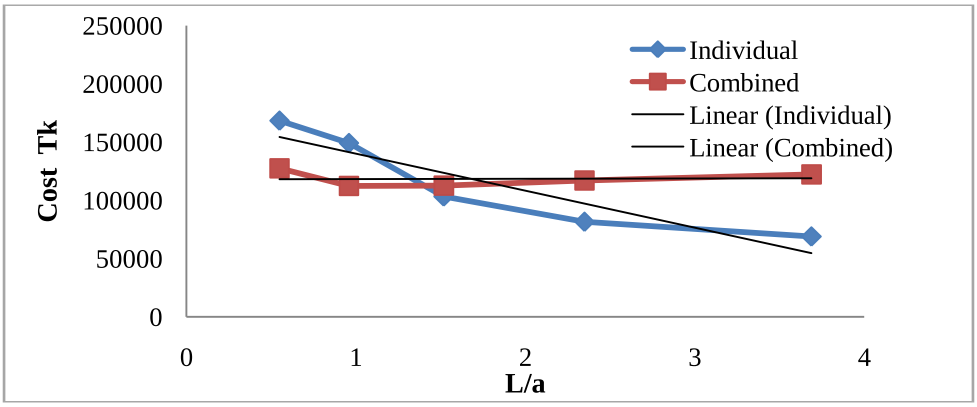

Figure 5.2 Cost Analysis of Individualand Combined Footing (Table 5.2)

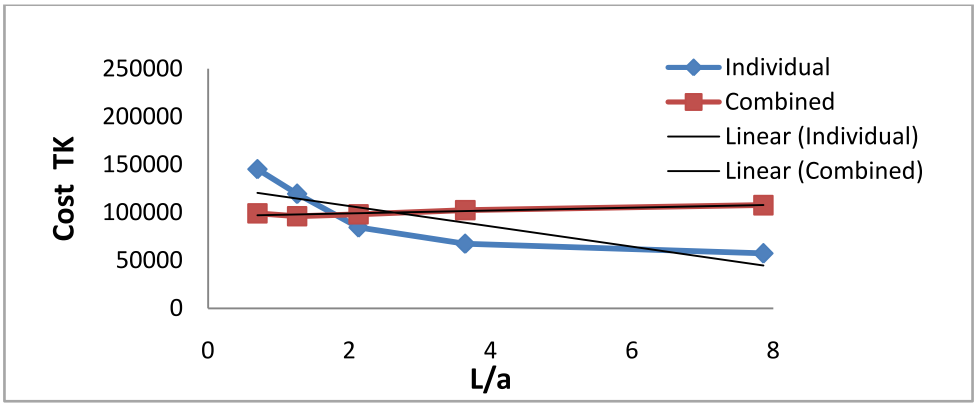

Figure 5.3 Cost Analysis of Individual and Combined Footing(Table 5.3)

5.1 VERTICAL STRESS BENEATH A POINT LOAD

Vertical stress beneath a point load for the Figure 4.2 was calculated as follows:

Table 5.4 Vertical Stress Beneath a Point Load

Type of Column	r (ft)	Z (ft)	r/z	$A_b = \frac{(^3/_{2\pi})}{(1+(r/z)\text{^}2)^{(^5/_2)}}$	$q_v = \frac{Q}{Z^2} * A_b$
Column-01 Q= 270 Kip Footing= 16'-0" X 5'-0"	0	0.1	0	0.477464829	12891.55039
	0	11.5	0	0.477464829	0.974786419
	1.0	0.1	10	4.65734E-06	0.125748182
	1.0	11.5	0.09	0.468557122	0.956600552
	1.5	0.1	15	6.21828E-07	0.016789357
	1.5	11.5	0.13	0.457746337	0.934529383
	2.0	0.1	20	1.48279E-07	0.004003540
	2.0	11.5	0.17	0.443189345	0.904810005
	2.5	0.1	25	4.86974E-08	0.001314829
	2.5	11.5	0.22	0.425408492	0.868508830
	3.0	0.1	30	1.95943E-08	0.000529046
	3.0	11.5	0.26	0.405004125	0.826854522
Column-02 Q= 250 Kip Footing= 15'-0" X 5'-0"	0	0.1	0	0.477464829	11936.62073
	0	11.5	0	0.477464829	0.902580018
	1.0	0.1	10	4.65734E-06	0.116433502
	1.0	11.5	0.09	0.468557122	0.885741252
	1.5	0.1	15	6.21828E-07	0.015545701
	1.5	11.5	0.13	0.457746337	0.865304984
	2.0	0.1	20	1.48279E-07	0.003706982
	2.0	11.5	0.17	0.443189345	0.837787042
	2.5	0.1	25	4.86974E-08	0.001217434
	2.5	11.5	0.22	0.425408492	0.804174842
	3.0	0.1	30	1.95943E-08	0.000489857
	3.0	11.5	0.26	0.405004125	0.765603261

VI. Conclusion

A brief conclusion regarding the study is presented in this section. About 252 nos. individual footings and 252 nos. combined footings were analyzed and designed respectively.The following conclusions were found from this study:

1. It is seen from the Table 5.4, along the vertical depth stress is rapidly decreased at a distance of significant depth.
2. According to the Boussinesq's theory, it is found from the Figure 4.2-4.4that the pressure bulb beneath the footings overlaps with each other due to closely spaced columns, as a result over stressing occurred within overlapped portion of soil when the columns are in close proximity.
3. From Figure 5.1-5.3, when the L/a ratio is small then the individual footing shows higher cost as compared to combined footing.
4. Over stressing of soil between two closely spaced individual column footing may lead to failure of footing which is shown in Figure 4.3.

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Md. Mahfujur Rahman,etal. "Technical and Financial Implications in Providing Combined Footings for Closely Spaced Columns." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 17(2), 2020, pp. 58-66.