Cost Effective Foundation System for Medium Rise Residential on Typical Soft Kolkata Soil

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Abstract. In present scenario due to rapid growth in population, it is not possible to construct each and every residential building on hard soil. Some time it is necessary to construct building on soft soil. One of the examples is Newtown, Rajarhat, Kolkata. Rajarhat is a developing area in Kolkata where most of the residential buildings are medium rise i.e. four or five storied. In that area, soil consists of very soft clay having very low value of SPT value (2 to 5) up to a depth of 12m or below, followed by hard strata. In most of the cases shallow foundation cannot give feasible solution and structural designers prefer pile foundation before adopting other alternatives techniques to improve the soil. Pile foundations are not very cost effective. Cost of the foundation constitutes a significant part of the total cost of the structure. Hence reduction in cost of the foundation leads to reduction in total cost of the structure. In this study an effort has been made to recommend feasible cost effective foundation system by using ground improvement technique (by using stone column) vis-vis pile foundation. A typical medium rise building (G+4) has been chosen on a typical soft soil profile, typical to Rajarhat area. A comparative study has been made to suggest cost effective foundation system for medium rise residential building in that area.

Keywords: Ground improvement; Stone column; Pile foundation

1 Introduction

1.1 Problem Statement

A multi storied building (G+4) is taken in to consideration for this project work. Soil test of the proposed site is carried out by a reputed organization and it is adopted for analysis. A typical soil profile, floor plan and grid plan are shown in Figure 1, Figure 2 and Figure 3 respectively.

The soil profile consists of four layers including reclaimed top fill of mainly soft silty clay with grass roots as STRATUM I. STRATUM II consists of very soft silty clay with varying percentage of decomposed wood. In STRATUM III, very stiff bluish grey/brown silty clay/clayey silt with traces of kankar and micaceous fine sand are present. Dense brown silty fine sand with traces of mica and clay as binder are present in STRATUM IV.

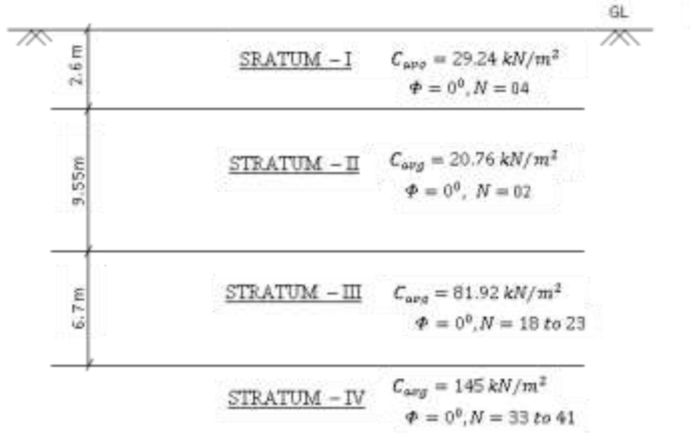

Fig. 1. Typical Soil Profile

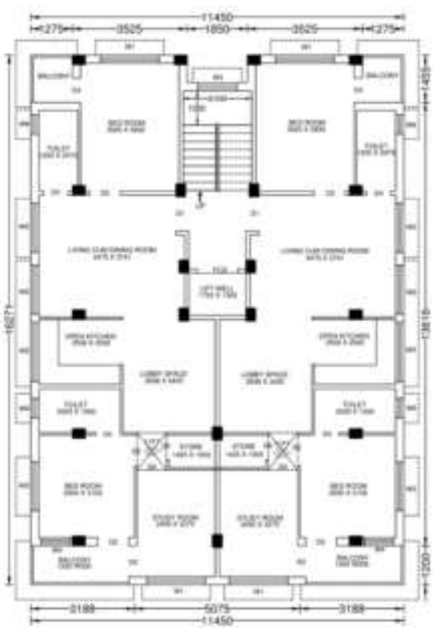

Fig. 2. Typical Floor Plan of the Building

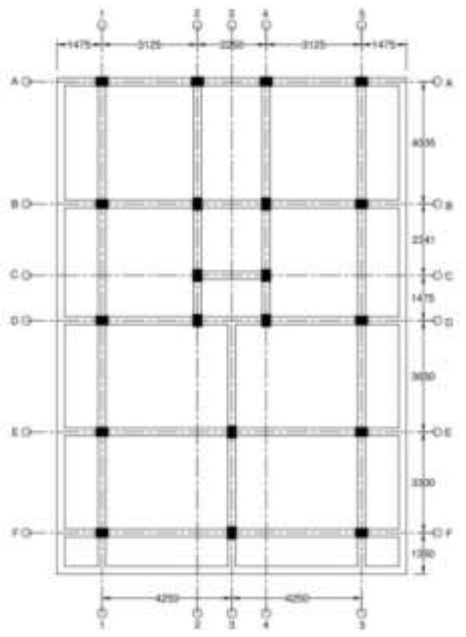

Fig. 3. Grid Plan of the Building

1.2 Objective of the Work

Objective of the present study is to optimize i.e. minimize the cost of foundation system of a medium rise building (G+4) on a typical soft soil profile in Kolkata. After getting cost of construction of different foundation system a comparative study has been made to choose best foundation for this particular building.

For solving the problem, building is modeled and analyzed by STAAD Pro for different combinations of loads. Then computer program is developed in Microsoft excel solver for designing different types of foundation system.

2 Methodology

Design of structural system should be done in a systematic manner and for a particular structural system there are more than one solution which satisfies both safety and serviceability requirement. For designing a foundation system some design parameters such as bearing capacity and settlement of the foundation are calculated according to IS 6403 [5] and IS 8009 (Part 1 & Part 2) [6,7] respectively.

2.1 Ground Improvement Technique

Load carrying capacity of individual stone column as well as bearing capacity of improved ground is calculated according to IS 15284 [8].

2.2 Load Carrying Capacity of Pile and Pile Group

Load Carrying Capacity of Pile and pile group in cohesive soil and granular soil is calculated in accordance with IS 2911 (Part 1) [4]

2.3 Structural Design of the Foundations

The structural design of the foundation systems were carried out as per the recommendations of IS 456 -2000 [1].

2.4 Cost Analysis of Footing

Cost of the footing depends on the quantity of different item of work and the cost incurred per unit for these each item of work. Total cost of the footing is calculated by summing up the total cost incurred by concrete, steel and formwork. The construction cost of footing can be estimated as –

$$C_{Footing} = Q_c R_c + Q_{st} R_{st} + Q_f R_f$$

where

Q_c = Quantity of concrete $= B \times L \times D$

Q_{st} = Quantity of steel $= A_{st} \times L \times \gamma$

Q_f = Quantity of formwork $= 2(B + L)D$

R_c = Unit price of concrete

R_{st} = Unit price of steel

R_f = Unit price of formwork

The main objective of optimization is to select design variables in such a way so that the cost of the foundation will minimum. At the same time the design variable should satisfy all the requirements and provisions specified in Indian standard.

3 Result and Discussions

The building model is done in STAAD Pro as shown in figure below then it is analyze to obtain the forces for which foundation is to be designed. For this analysis following assumption are done –

i. Column Section = 300mm × 400mm
ii. Beam Section = 250mm × 400mm
iii. Dead Load = As per IS 875 (Part I): 1987
iv. Imposed Load = As per IS 875 (Part II): 1987
v. Wind Load = As per IS 875 (Part III): 2015
vi. Earth Quake Load = As per IS 1893: 2016

3.1 STAAD Pro Analysis Result

After analyse in STAAD Pro, maximum loads in columns are shorted out from different combination of load and tabulated in Table 1.

Table 1. Column Load

Column Marked	F_x	F_y	F_z	M_x	M_y	M_z	Remarks
A1& A5	45.4	1136.5	32.1	40.3	0.9	47.2	
A2& A4	55.9	939.6	27.6	35.6	0.7	53.7	
B1& B5	33.5	1421.6	36.8	42.5	0.7	42.9	
B2& B4	50.4	904.4	38.4	41.0	0.6	51.8	
C2 &C4	30.6	753.6	50.0	46.4	0.8	45.3	Max M_x
D1& D5	36.4	1284.9	41.2	44.5	1.1	49.5	
D2& D4	55.3	822.9	32.3	38.1	1.2	59.6	Max M_y
E1& E5	45.0	1234.4	48.1	47.9	1.0	61.4	Max F_z
E3	51.3	965.3	41.3	43.8	0.9	65.6	
F1 & F5	40.6	1499.5	21.6	35.7	1.1	67.5	Max F_y
F3	60.7	1259.0	17.6	32.9	0.9	77.3	Max F_x & M_z

3.2 Calculation of Allowable Bearing Capacity of Existing Soil.

Net safe bearing capacity with factor of safety 2.5 for different type and size of foundation is calculated and vertical load carrying capacity of different type of foundation based on net allowable bearing capacity is plotted in Fig. 4.

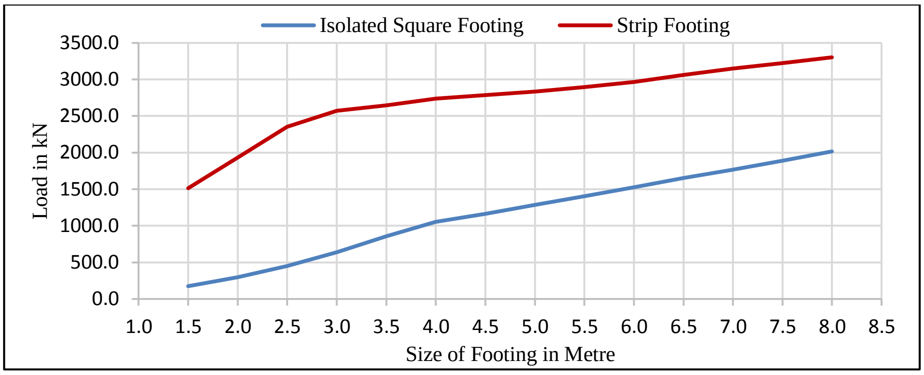

Fig. 4. Foundation Size Vs Vertical Load Carrying Capacity Plot

In practical situation it is not possible to design each and every foundation for individual load. Hence all the column loads are divided into five groups according to the vertical load only and foundations are design accordingly to support the group load. From the above chart dimension of the foundations are easily calculated and shown below –

Table 2. Foundation Group with Design Load and Foundation Size

Group No	Foundation Marked	Column No	Vertical Load (*kN*)	Foundation Size (m x m)
G1	F1	B1, B5, F1 & F5	1500	6m × 6m
G2	F2	D1, D5, E1, E5 & F3	1300	5m × 5m
G3	F3	A1 & A5	1150	4.5m × 4.5m
G4	F4	A2, A4, B2, B4, D2. D4 & E3	1000	4m × 4m
G5	F5	C2 & C4	800	3.5m × 3.5m

3.3 Selection of Type of Foundation Based on Existing Condition

Bearing capacity of the soil on which these foundations are to be rest, is very less. Therefore area required for the foundation to transfer the load safely is more and it is seen from the foundation layout as shown in Figure 5, that isolated footing is not possible for this type of soil because they overlap with each other. Again it is found that shallow foundation is not possible for this typical soil. Hence deep foundation such as pile may be adopted. But before going into the pile foundation, ground improvement technique may be adopted.

In this present study, it is seen that ***isolated footing is not possible as it overlap to each other*** as shown in Figure 5. It is also seen that no shallow foundation is suitable for this particular type of soil without applying ground improvement technics.

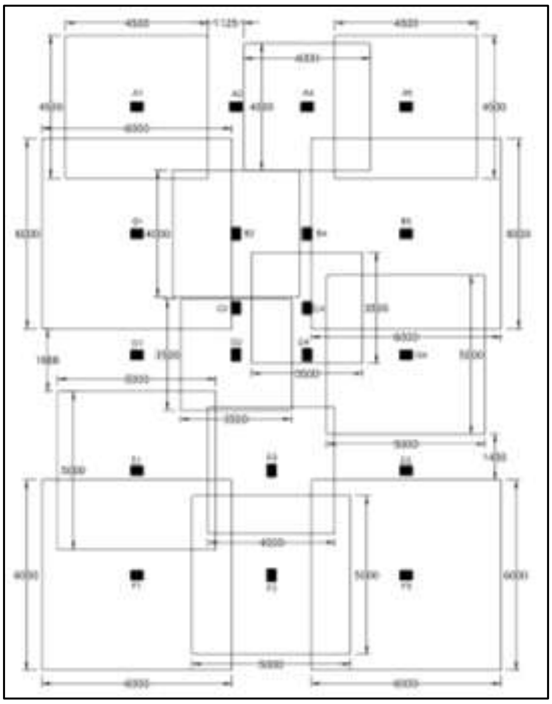

Fig. 5. Probable Foundation Layout of Isolated Footing

3.4 Bearing Capacity After Ground Improvement by Stone Column

In soft soil, bearing capacity may be improved either by preloading with vertical drains or stone column. In this case stone column method is considered. According to IS 15284 (Part 1) [8] capacity of a stone column is calculated with the following parameter as shown in Table 3.

Table 3. Stone Column Parameter

Sl. No	Description	Value
1.	Diameter of stone column	D
2.	Spacing of stone column	2D, 2.25D, 2.5D, 2.75D, 3D
3.	Angle of internal friction of column material	40^o
4.	Avg. co-efficient of lateral earth pressure for clay	0.6
5.	Avg. value of cohesion.	24.06 kN/m^2
6.	Stone column pattern	Square

Load carrying capacity of a stone column, mainly depend on its diameter for a particular soil. A load carrying capacity of a stone column Vs diameter of the stone column with different spacing is plotted in Figure 7.

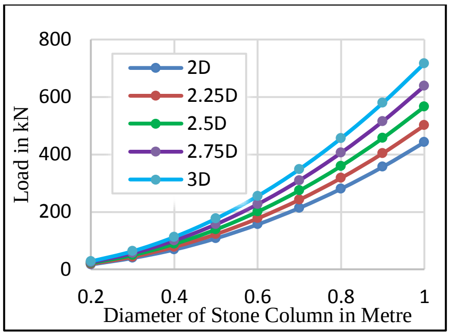

Fig. 6. Diameter of Stone Column Vs Load Carrying Capacity Plot

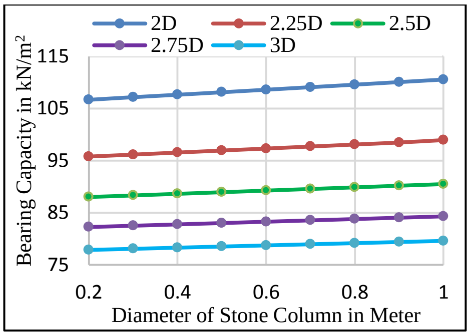

Fig. 7. Diameter of Stone Column Vs Bearing Capacity Plot

From the Figure 7, assume diameter of the stone column 0.5 m with a spacing of 2D i.e. 1 m centre to centre for this building. Stone columns are used in square pattern. One unit cell of stone column carries a load of 108 kN.

Bearing capacity of treated soil may be calculated by dividing the load carrying capacity of unit stone column by its tributary area and is found as 108 kN/m^2. In case of ground improvement by stone column in a particular soil, bearing capacity mainly depends on the spacing between the stone columns as shown in Figure 7.

3.5 Load Carrying Capacity of Pile and Pile Group

Capacity of Single Pile. Capacity of a single pile of different length in typical given soil is calculated as per IS 2911 [4] and shown in Figure 8.

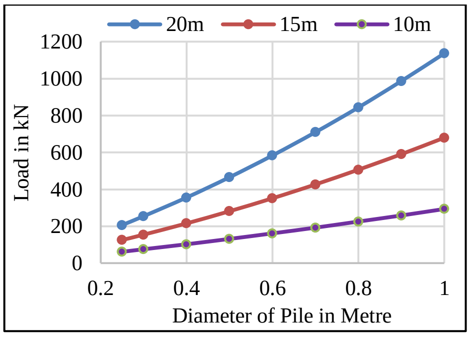

Fig. 8. Diameter of Pile Vs Load Carrying Capacity of Single Pile Plot

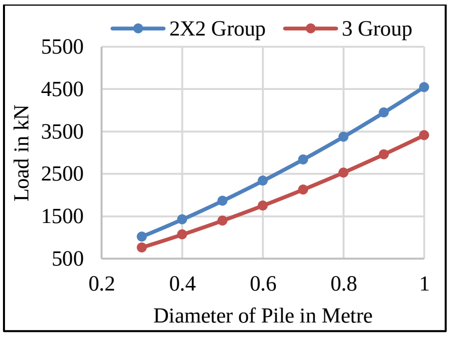

Fig. 9. Diameter of Pile Vs Capacity of Pile Group Plot

Adopt pile of length 20m for this building and diameter of the pile is selected from the Figure 8 according to the required load carrying capacity of the pile. Use pile diameter of 0.45 m and load carrying capacity of single pile is 466 kN including its self-weight.

Capacity of Group Pile. Capacity of pile group is estimated assuming 20m length of pile. Pile group capacity for different diameter of pile is shown in Figure 9 with a spacing of 2D i.e. 900 mm C/C. It is seen that group capacity of pile for this particular soil is always greater than the sum of the capacity of individual pile in a group.

3.6 Design of Foundation System (Isolated Footing) on Stone Column

After improving the soil parameter by stone column it is possible to provide isolated footing as one solution for this typical soil profile. Now optimum dimension of isolated foundation is found out to transfer the column load safely. Size of the footing on stone column for different column load is tabulated in Table 4.

Table 4. Size of the Isolated Footing on Stone Column

Group No	Foundation Marked	Column No	Design Load (*kN*)	Foundation Size (m x m)
G1	F1	B1, B5, F1 & F5	1500	3.0m × 3.0m
G2	F2	D1, D5, E1, E5 & F3	1300	2.8m × 2.8m
G3	F3	A1 & A5	1150	2.6m × 2.6m
G4	F4	A2, A4, B2, B4, D2. D4 & E3	1000	2.4m × 2.4m
G5	F5	C2 & C4	800	2.2m × 2.2m

Pre-assign Parameter for Design of Shallow Foundation. Isolated footing is designed, taking the following input parameters are constant –

i. Grade of concrete and steel = M25 and Fe 500
ii. Clear cover = 50mm
iii. Diameter of reinforcing bar = 16 mm
iv. Pedestal size = 450 mm X 450 mm
v. Safe bearing capacity = 110 kN/m^2
vi. Weight of the footing and backfill – 10 % of the axial load.

Design Constrains. For designing isolated footing fixed constrains are size of the footing i.e. length and breadth and variable constrains are depth of footing and percentage of reinforcement.

Rate of Different Item of Work Related to Shallow Foundation. Cost of different item of work is calculated as per West Bengal PWD, Schedule of Rates 2017 [9] for Kolkata. To get the current rate of different item of work a multiplying factor i.e. Cross Index is applied with this rate as per WBPWD norms. Standard rate of the stone column is not specified in the WBPWD schedule, so site specific analysis of rate is carried out and calculated rate of the stone column of 450mm diameter for per meter length is Rs. 995.90.

Different Design Options for Shallow Foundation. Design is carried out for different thickness and percentage of steel to obtain optimum solution –

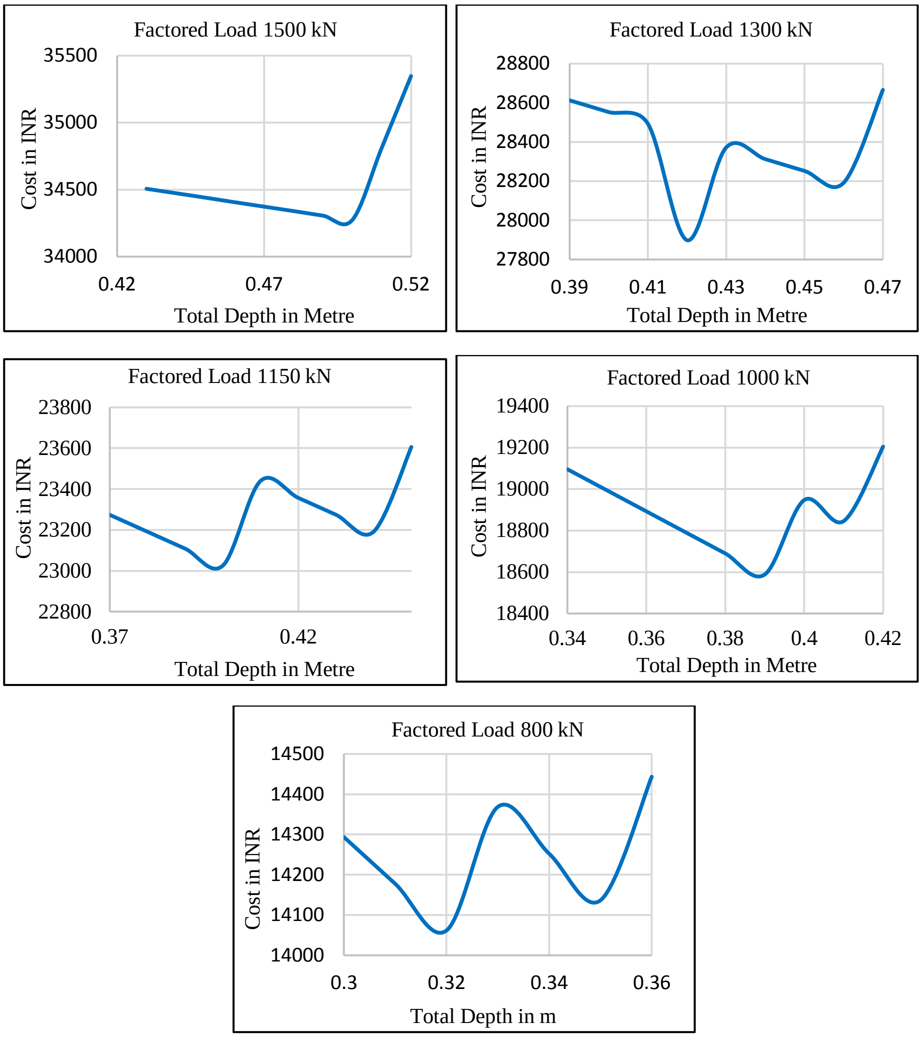

Fig. 10. Cost Vs Total Depth of Isolated Footing Plot for Different Factored Load

From Figure 10, it is seen that the optimum cost is Rs 34273, Rs 27899, Rs 23026, Rs 18589 & Rs 14137 for a footing depth of 500 mm, 420mm, 400mm, 390mm & 350mm respectively.

3.7 Design of Foundation System (Pile) in Untreated Soil

Pile foundation gives a general solution for all type of foundation problem. For this building optimum cost of the pile foundation is calculated. Different design options for pile cap is determined with the help of Microsoft excel spread sheet and presented below.

Design Constrains. For designing pile length and diameter of the pile are fixed constrains. In case of designing of pile cap fixed constrains are size of the pile cap and variable constrains are depth of the pile cap and percentage of reinforcement.

Design and Cost of Pile. Pile is designed as slender column with the following input parameters –

i. Axial load on pile = 466 kN
ii. Length and diameter of pile = 20 m and 450 mm
iii. Depth of fixity = 7.44m (Calculated as per IS 2911[4])
iv. Clear cover to the reinforcement = 50 mm
v. Diameter of longitudinal bar and lateral tie = 20 mm and 8 mm
vi. Grade of concrete and steel = M25 and Fe 500

Pile has been designed with the above mention input parameters. The design output parameters along with the total cost of the pile are tabulated in Table 5. Actual Cost of the pile per 'm' length is obtained by adding cost of concrete for 1m length of pile.

Table 5. Design Details of a Single Pile

Sl. No.	Description	Unit	Rate	Quantity	Cost
1	Pile of 450 mm diameter and 20 m length.	m	1536.00	20	30720
2	Steel reinforcement of grade Fe500				
	a) 12 nos. longitudinal bar (16 Φ)	kg	58.30	378.80	22084
	b) 8Φ lateral tie @ 150 mm c/c			54.50	3177
	c) 16Φ spacer bar @ 1.5 m c/c			22.88	1334
Total					57315

Pre-assign Parameter for Design of Pile Cap. Pile cap is designed to transfer the load from the column to the pile. It should be rigid. For designing of pile cap following pre assign parameters are given below.

i. Spacing between piles = 900 mm
ii. Minimum depth of pile cap = 300 mm
iii. Overhang of the pile cap from pile = 150 mm
iv. Cover to the reinforcement = 75 mm
v. Grade of concrete and steel = M25 and Fe 500

Different Design Options for Pile Cap. Design is carried out for different thickness and percentage of steel to obtain optimum solution –

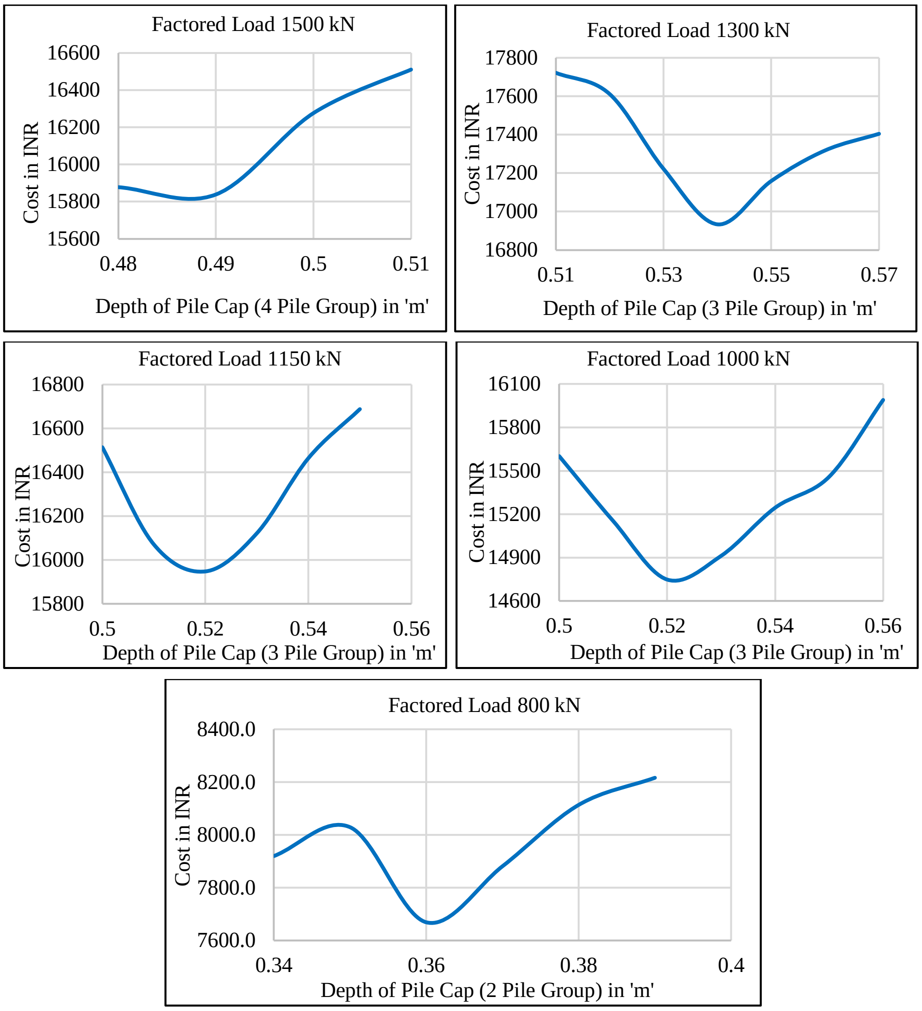

Fig. 11. Cost Vs Total Depth of Pile Cap Plot for Different Factored Load

From Figure 11, it is seen that the optimum cost is Rs 15839, Rs 16934, Rs 15948, Rs 14749 & Rs 7669 for pile cap of depth of 490 mm, 540mm, 520mm, 520mm & 360mm respectively.

3.8 Comparison between Two Types of Foundation System.

Table 6. Total Cost of Foundation System (Isolated Footing) on Stone Column

Sl. No.	Description	Rate	Quantity	Cost
1.	500mm diameter stone column	9959	205	2001759
2.	Isolated footing of			
	Size for column in Group 1	34273	4	137092
	Size for column in Group 2	27899	5	139495
	Size for column in Group 3	23026	2	46052
	Size for column in Group 4	18589	7	130123
	Size for column in Group 5	14137	2	28274
Total Cost				2482795

Table 7. Total Cost of Foundation System (Pile Foundation)

Sl. No.	Description	Unit	Rate	Quantity	Cost
1.	450mm diameter pile	per Pile	57315	71	4069365
2.	Pile cap of				
	4 pile group for Group 1	per Cap	15837	4	63348
	3 pile group for Group 2	per Cap	16934	5	84670
	3 pile group for Group 3	per Cap	15948	2	31896
	3 pile group for Group 4	per Cap	14749	7	103243
	2 pile group for Group 5	per Cap	7669	2	15338
Total Cost					4367860

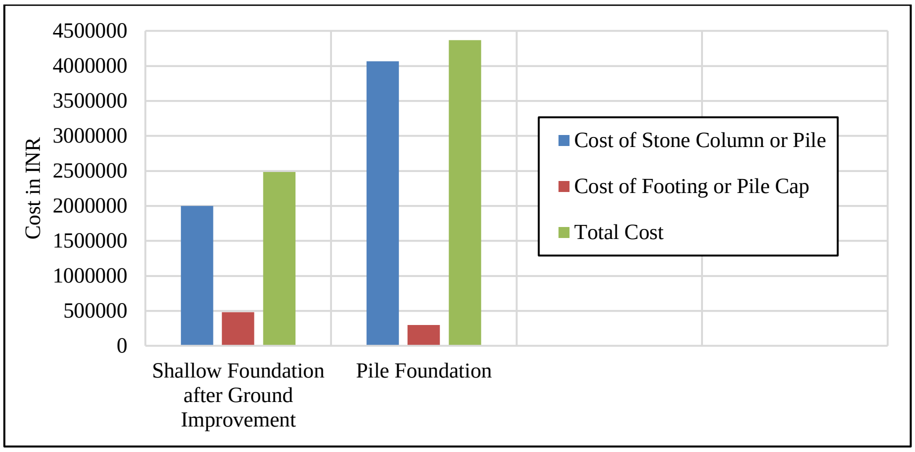

Fig. 12. Comparison between Cost of Shallow Foundation over Stone Column and Pile Foundation

From the Figure 12, it is seen that cost of the shallow foundation over stone column is 43.16% less than the cost of the pile foundation.

4 Conclusions and Future Scope

In this study concluding remarks are also drawn based on the application of methodology and developed computer program for cost minimization of foundation system. Main objective of this study is to minimize the cost of different type of foundation system for a typical medium rise residential building (G+4) on typical soil profile. Cost of the footing is primarily depending on the area of footing and area of reinforcement. The following conclusions and future scope of this study are discussed below.

In this study ground improvement method considered is installation of stone columns. Similar study can be carried by other type of ground improvement techniques. The present study is carried out in vertical axial load on footing. The study can be carried out for different loading such as lateral load, moment etc. Flat type isolated square footing have been considered in this study. Similarly it can be carried out other type and shape of footing.

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