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Numerical Analysis of Single Pile in Soft Clay

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Abstract:- **This paper aims at analyzing the load deformation characteristics of a single pile of varying length(5,10,15m) and varying diameter (0.4,0.5,0.6,0.8,1m) in cohesive soil with varying cohesive values (10,20,30,40 kN/m²) using PLAXIS 3D software. The results of the analysis has been compared based on the safe bearing capacity of the pile under different conditions. A 3D numerical model was developed to simulate the single pile in clay soil. Variation in safe bearing capacity of pile with cohesion for piles of different diameter and different length were studied. The extensive parametric study concluded that there is a linear variation between SBC and diameter of pile, SBC and cohesion of clay soil and SBC and length of pile**

Keywords—Single pile, safe bearing capacity , cohesion, PLAXIS 3D

I. INTRODUCTION

Piles are deep foundation used when shallow foundations do not satisfy the settlement and bearing capacity criteria. Piles are classifies based on the material of the pile, the displacement properties and the nature of load support. The pile load displacement characteristics of single pile are affected by pile properties, soil properties, installation methods and loading conditions. Pile foundations transfer the superstructure loads to deeper part of the soil strata .Based on the nature of load support (end bearing and friction pile), the piles transfer loads either to an end bearing stratum or via the skin friction developed along the shaft of the pile. In soft soil the pile makes use of the strength of the soil by skin resistance along the shaft of the pile. Here the load transfer of piles is the sum of the toe resistance and skin resistance in soft soils [1]. Methods adopted to find the bearing capacity of piles are static formula, dynamic formula and field load tests. The static formula method relates soil shear strength to the skin friction along the pile shaft and to end-bearing below the pile point. Both the skin friction and the end bearing resistance are used to calculate the bearing capacity of piles of any dimension in cohesive and cohesion less soils [2].

Many studies have been performed to determine the behavior of axially loaded pile in cohesive soils. In this study a comparison of the Safe bearing capacity of single pile of different length and diameter are tested in cohesion soil of different cohesion values.

II. MODEL VALIDATION

A. *Validation of soil model*

The Alzey Bridge pile load test is an axially loaded validation case, which is widely used by researchers for validating new soil models. The Alzey Bridge pile load test was carried out near Frankfurt. During the test, load cells were installed at the foot of the pile to measure the loads that are carried directly by the pile base. The test results and other parameters are presented by Engin et al.[13]. The Alzey Bridge pile load test considers an axially loaded pile with a diameter of 1.3 m and a lengthof 9.5 m. The ground water table is approximately 3.5 m below the ground surface. The pile was modeled in the Mohr -Coulomb soil model using PLAXIS 3D software. Embedded pile was used to model the pile. Point load was assigned to the pile top and the soil was meshed. Medium mesh was use for meshing. Figures 1 and 2shows the modeling of soil and pile using PLAXIS 3D.

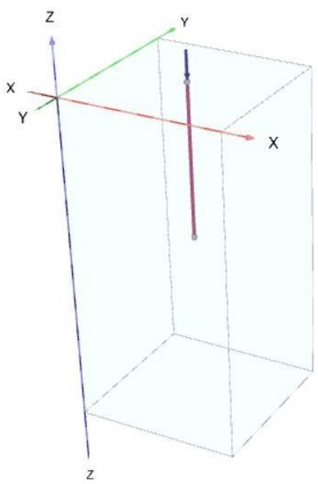

Fig. 1

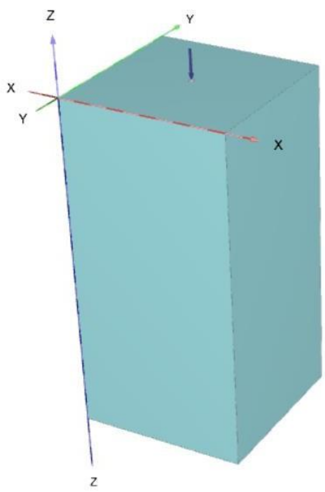

Fig. 2

Fig.1and 2: Model of Embedded Pile and Point Load in soil in PLAXIS 3D

Table 1 and 2 presents the data available for modeling the pile and soil mass, taken from Engin et al.[3].

Table 1 – Soil Properties for Validation [3]

Property	Value	Unit
Saturated unit weight	20	kN/m^3
Dry unit weight	20	kN/m^3
Poissons ratio	0.2	
Cohesion	20	kN/m^2
Internal friction angle	20	degree
Dialatancy angle	0	degree
Interface ratio	1	

Table 2 – Pile Properties for Validation [3]

Property	Value	Unit
Pile diameter	1.3	m
Pile length	9.5	m
Modulus of elasticity	1×10^7	kN/m^2
Poissons ratio	0.20	
Base resistance	1320	kN
Skin friction	201.37	kN/m

The pile was modeled in the Mohr -Coulomb soil model using PLAXIS 3D software. Embedded pile was used to model the pile. Point load was assigned to the pile top and the soil was meshed. Medium mesh was use for meshing. Figure 3 compares the experimental load displacement behavior of piles with that obtained using PLAXIS 3D software.

From Fig. 3, it may be noted that, except at the initial linear elastic stage, the experimental and theoretical load displacement behavior of pile are comparable. Hence, the modeling of soil and pile using PLAXIS 3D has been validated and the same approach can be followed for further study.

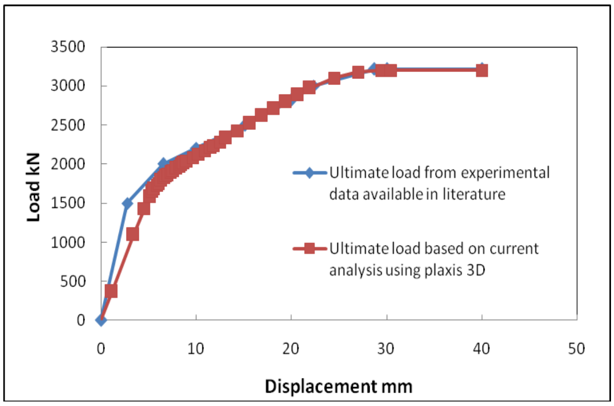

Fig.3 Comparison of Validation of the Soil Mode

III. PARAMETRIC STUDY SAFE BEARING CAPACITY OF PILE

The load deformation analysis on a single pile of varying length(5,10,15m) and varying diameter (0.4,0.5,0.6,0.8,1m) in cohesive soil with varying cohesive values (10,20,30,40 kN/m²) using PLAXIS 3D software was studied. The results of the analysis has been compared based on the safe bearing capacity of the pile under different conditions. A 3D numerical model was developed to simulate the single pile in clay soil.

As the first step of the modeling process, the geometry of the single pile and the soil block were defined. The soil volume was modeled as a 10-noded tetrahedral element and has a depth twice the length of the pile in Mohr- Colomb soil model. The soft clay was modeled in the undrained condition.

The piles are modeled as embedded beam element with special interface element. The pile-soil interaction for an embedded pile involves a skin resistance and a tip resistance.

The input parameters that are required for modeling the soil are modulus of elasticity, poisons ratio, angle of friction, dialatancy angle and unit weight of soil[4]. The modulus of elasticity of cohesive soil has been determined as per the following relation [5]

Modulus of elasticity =500C ……………………….. (1)

Where, C is the cohesion of the soil.

With respect to the pile, the parameters like Modulus of elasticity, poissons' ratio, skin friction per unit length and end resistance are required for the analysis. The skin friction per unit length and end resistance of pile were determined as per the guidelines specified in BIS for the calculation of pile capacity in cohesive soils[6] and accordingly, following equations were used.

Skin friction per unit length of pile =As×α×C …………. (2)

End resistance of pile = Ap×Nc×Cp …………..(3)

Where,

Ap- cross-sectional area of pile tip, in m²

Nc- bearing capacity factor (taken as 9)

Cp- average cohesion at pile tip, in kN/m²

As- surface area of pile shaft, in m²

α - adhesion factor of soil, depending on the consistency of soil (taken as 1 up to C = 40kN/m²)

C- average cohesion of soil, in kN/m²

Table 3 gives the input parameters for pile in soft clay soil.

Table 3 – Input Data for the Analysis of Piles in Clayey Soil

Sl. No	Pile Diameter (m)	Cohesion (kN/m²)	Modulus of elasticity of soil[15] (kN/m²)	End resistance of pile (kN)	Skin friction in pile (kN/m)
	d	C	500×C	Ap×Nc×C	As×α×C
1	0.4	10	5000	11.3	12.56
		20	10000	22.61	25.12
		30	15000	33.91	37.68
		40	20000	45.22	50.24
2	0.5	10	5000	17.66	15.7
		20	10000	35.33	31.4
		30	15000	52.99	47.1
		40	20000	70.65	62.8
3	0.6	10	5000	25.43	18.84
		20	10000	50.87	37.68
		30	15000	76.3	56.52
		40	20000	101.74	75.36

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4	0.8	10	5000	45.22	25.12
		20	10000	90.43	50.24
		30	15000	135.65	75.36
		40	20000	180.86	100.48
5	1	10	5000	70.65	31.4
		20	10000	141.3	62.8
		30	15000	211.95	94.2
		40	20000	282.6	125.6

Figure 4 is an example of load displacement graph for pile of length 10m and diameter 0.8m

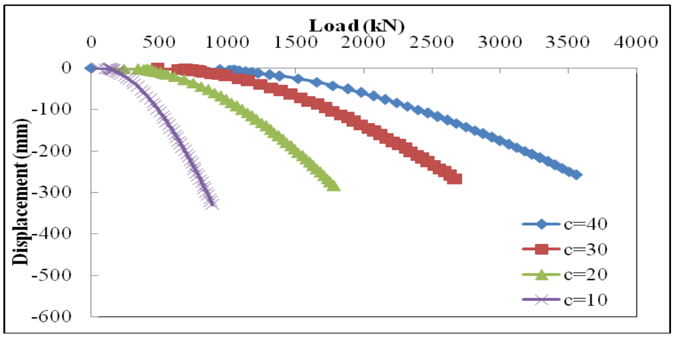

Fig.4 Load vs. Displacement Graph for Pile of Length 10m and Diameter 0.8m

The load capacity of pile for a specified displacement is higher for soil with higher value of cohesion. Similarly, as the diameter of pile is more, the load capacity of pile for a specified displacement is higher. These behaviors are expected, as the end bearing capacity as well as frictional resistance of pile shaft are proportional to the diameter of pile and the cohesion. Similar behavior has been observed for piles of different length.

IV. SAFE BEARING CAPACITY OF PILE

The Safe Bearing Capacity (SBC) of piles could be determined from the load- displacement graphs of piles and as per the guidelines specified in BIS [7]. According to this code of practice, the safe vertical load on single pile for initial test shall be least of the following :

a) For piles up to and including 600 mm diameter

i) Two –thirds of final load at which the total displacement attains a value of 12mm
ii) Fifty percent of the final load at which the total displacement equal to 10 percent of the pile diameter in case of uniform diameter piles
b) For piles of diameter more than 600 mm
i) Two –thirds of final load at which the total displacement attains a value of 18mm
ii) Fifty percent of the final load at which the total displacement equal to 10 percent of the pile diameter in case of uniform diameter piles

Figure 5 explains the method of determining the safe bearing capacity of 10 m long, 0.50 m diameter pile in soil having different cohesion from the load-displacement curve, as a typical example, and is self explanatory. Out of the two values, the least one is taken as the SBC.

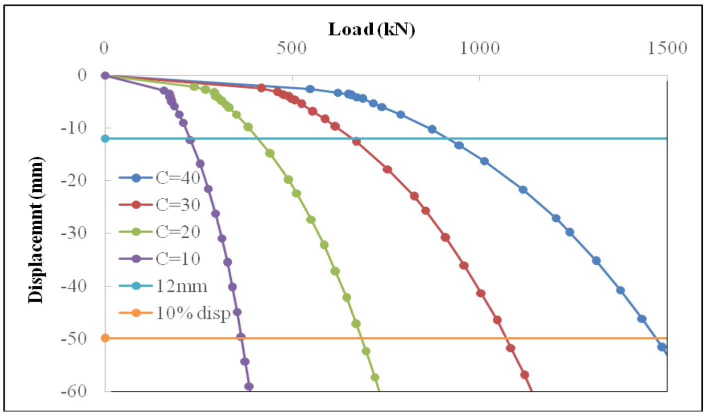

Fig. 5 Typical example showing the method of determination of safe bearing capacity of pile from load-displacement curve.

In a similar way, the SBC of all other piles were determined, and the details are presented in tables 4,5 and 6 for piles of length 5m, 10m and 15m respectively. It may be observed from tables 4. 2 to 4.4 that, in all the cases considered, the criteria of "(2/3)× load corresponding to 12mm" is critical when compared with the criteria of "50% of load corresponding to deformation equivalent to 10% of pile diameter".

V. RESULTS AND DISCUSSION

Table 4 Safe Bearing Capacity (SBC) of 5m Long Pile having Different Diameter in Soil with Different Cohesion

Diameter(m)	Cohesion (kN/m²)	(2/3)× load corresponding to 12mm (kN)	50% of load corresponding to deformation equivalent to 10%of pile diamter (kN)	Safe Bearing Capacity (kN)
0.4	10	62.74	78.10	62.74
	20	146.02	170.16	146.02
	30	225.25	261.34	225.25
	40	249.09	289.25	249.09
0.5	10	65.79	91.60	65.79
	20	159.23	201.46	159.23
	30	249.42	311.63	249.42
	40	337.52	418.85	337.52
0.6	10	68.96	103.34	68.96
	20	171.64	230.01	171.64
	30	323.62	393.12	323.62
	40	370.05	482.07	370.05
0.8	10	89.87	146.50	89.87
	20	229.84	329.75	229.84
	30	368.22	515.93	368.22
	40	503.28	699.80	503.28
1	10	102.21	215.67	102.21
	20	378.02	877.75	328.54
	30	447.83	537.71	447.83
	40	583.00	1015.85	583.00

Table 5 Safe Bearing Capacity (SBC) of 10m Long Pile having Different Diameter in Soil with Different Cohesion

Diameter (m)	Cohesion (kN/m²)	(2/3)× load corresponding to 12mm (kN)	50% of load corresponding to deformation equivalent to 10%of pile diamter (kN)	Safe Bearing Capacity (kN)
0.4	10	112.38	139.60	112.38
	20	244.01	294.55	244.01
	30	426.72	445.79	426.72
	40	537.41	627.67	537.41
0.5	10	150.48	182.53	150.48
	20	271.50	342.37	271.50
	30	438.12	535.39	438.12
	40	608.57	735.29	608.57
0.6	10	127.28	185.21	127.28
	20	297.14	405.41	297.14
	30	486.35	636.02	486.35
	40	674.46	873.66	674.46
0.8	10	154.34	219.50	154.34
	20	386.08	503.44	386.08
	30	639.08	796.44	639.08
	40	896.18	1096.19	896.18
1	10	152.67	262.41	152.67
	20	525.41	620.95	712.65
	30	847.55	989.22	847.55
	40	1015.32	1365.94	1015.32

Table 6 Safe Bearing Capacity (SBC) of 15m Long Pile having Different Diameter in Soil with Different Cohesion

Diameter (m)	Cohesion (kN/m²)	(2/3)× load corresponding to 12mm (kN)	50% of load corresponding to deformation equivalent to 10%of pile diamter (kN)	Safe Bearing Capacity (kN)
0.4	10	159.39	193.71	159.39
	20	336.73	403.28	336.73
	30	592.96	649.55	592.96
	40	439.72	626.74	439.72
0.5	10	173.57	221.77	173.57
	20	380.47	474.98	380.47
	30	585.32	727.00	585.32
	40	804.23	988.04	804.23
0.6	10	181.91	245.37	181.91
	20	424.16	538.00	424.16
	30	664.04	832.13	664.04
	40	915.98	1135.52	915.98
0.8	10	217.78	297.26	217.78
	20	545.01	683.86	545.01
	30	875.76	1073.92	875.76
	40	1224.49	1476.31	1224.49
1	10	212.68	351.59	212.68
	20	603.42	842.18	603.42
	30	987.31	1335.39	987.31
	40	1407.75	1846.06	1407.75

A. Variation of SBC with cohesion for different diameter of piles

Figures 5,6 and 7 show the variation of SBC for different diameter of piles of length 5m, 10m and 15m.

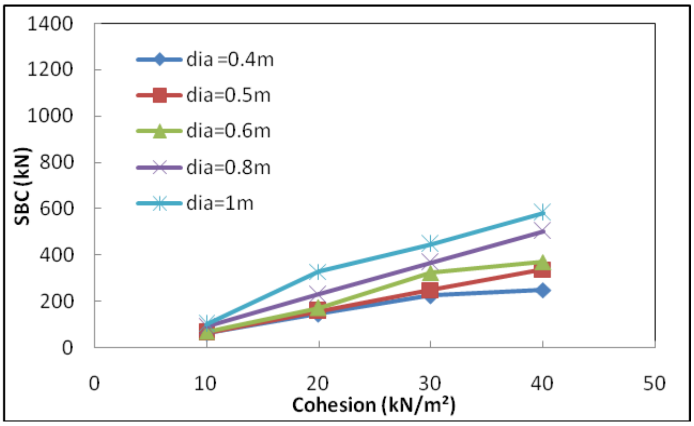

Fig.5 Variation SBC with Cohesion for different diameter of piles of Length 5m

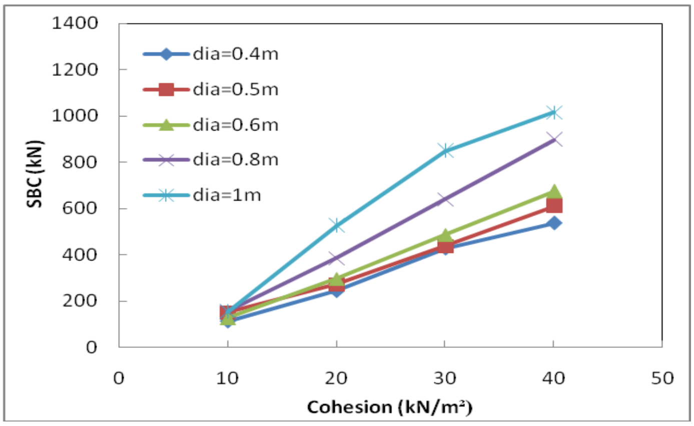

Fig.6 Variation SBC with Cohesion for Different Diameter of Pile of Length 10m

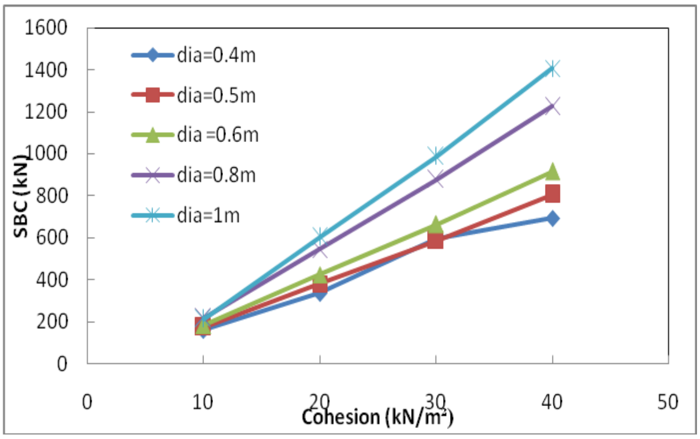

Fig.7 Variation SBC with Cohesion for Different Diameter of Pile of Length 15m

B. The variation of SBC with cohesion for different length of piles

Figures 8,9,10,11 and 12 variation of SBC with cohesion for different length of piles having diameter of 0.40m, 0.50m, 0.60m, 0.80m and 1.0m respectively

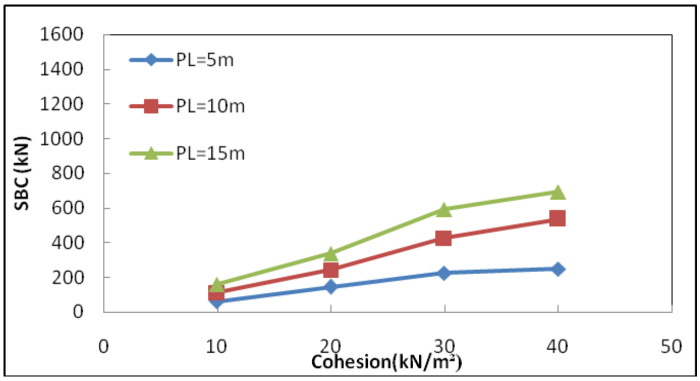

Fig.8 Variation of SBC with Cohesion for different length of piles having the diameter of 0.4m

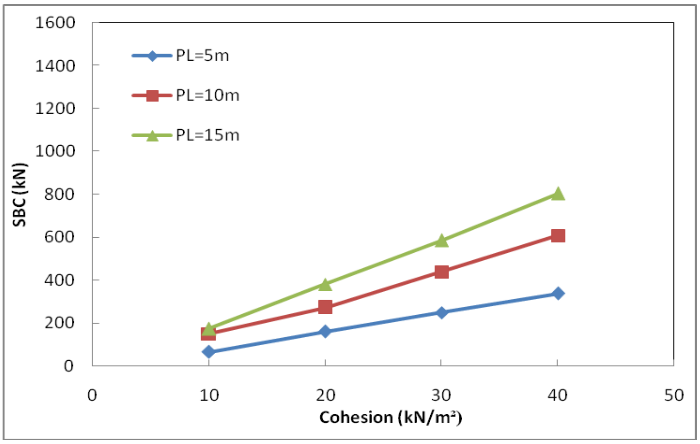

Fig.9 Variation of SBC with Cohesion for different length of piles having the diameter of 0.5m

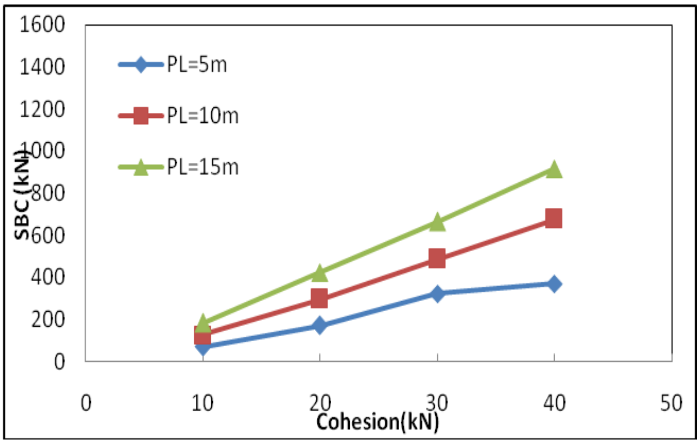

Fig.10 Variation of SBC with Cohesion for different length of piles having the diameter of 0.6m

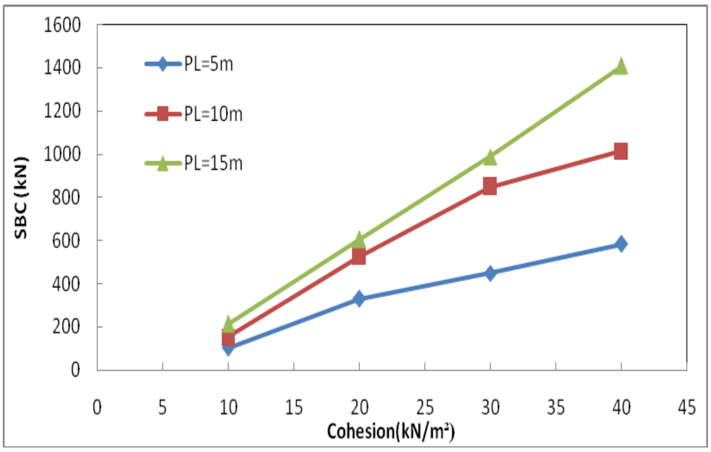

Fig.11 Variation of SBC with Cohesion for different length of piles having the diameter of 0.8m

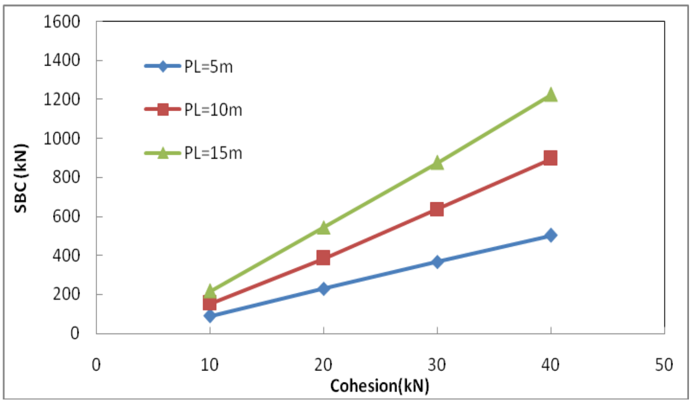

Fig.12 Variation of SBC with Cohesion for different length of piles having the diameter of 1.0m

VI. CONCLUSIONS

Based on present study the following conclusions could be made:

1) There is a linear variation between SBC and diameter of pile, SBC and cohesion of clay soil and SBC and length of pile.

2) For low value of cohesion (10 kN/m$^{2)}$, difference in the SBC of pile with different length and diameter is not significant. However, as the value of cohesion increases (up to 40 kN/m^2), the difference in the SBC of pile with different length and diameter becomes significant.

VII. ACKNOWLEDGEMENT

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