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VIABILITY OF CONSTRUCTING SHALLOW FOUNDATIONS IN RECLAIMED LANDS- BY COMPARING FIELD EXPERIMENT & THEORETICAL RESULTS

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Shallow Foundation, Bearing Capacity, Reclaimed Land, Mirpur DOHS, Full Scale Load Test, Soil and Settlement

ABSTRACT
The primary purpose of this study is to analyze the bearing capacity of shallow foundations in a reclaimed land of Dhaka city known as Mirpur Defense Officers' Housing Scheme (DOHS) having weak soil of soft to medium consistency. In this study, analytical method of bearing capacity determination has been verified through practical field experiment by full scale load test. The results depict that improved bearing capacity by ground reinforcement may present a better choice of adopting shallow foundation in reclaimed land considering the axial load case. At the base of the shallow foundation depth (6' from existing ground level) filling grey sandy soil has a good angle of internal friction of 28^o having approximate SPT N Value of 8. A shallow foundation (5'x5') with a layer of reinforced aggregate base coupled with geotextile was placed for full scale load test. Ultimate bearing capacity was found approximately 400 kPa from field load test (experimental method). On the other hand, theoretical bearing capacity calculation by various renowned methods returns conservative values. The case worsens further if elastic settlement is taken into consideration. The conventional methods of bearing calculation proposed by Terzaghi, Meyerhof and Hansen's exhibited 56%, 35% and 14% less capacity respectively compared to the yielded field load test result. The study thus illustrates viability of shallow foundation design in reclaimed land of Dhaka city identical to the selected site for low rise or low occupancy structures. This study is based on static load case for simplicity though regular foundation design warrants dynamic analysis too.

1. INTRODUCTION

Land is rudimentary to any kind of infrastructural construction, and therefore, expansion of urbanization. Dhaka city is gradually expanding towards north in reclaimed lands due to rapid urbanization. The most ommonly adopted foundation system of the reclaimed area is deep foundation. In reclaimed land deep foundation is exposed to the threats of negative skin friction and soil liquefaction. For low rise or low standard occupancy structures shallow foundation may sometime replace costly deep foundation system. Traditional analysis and calculation techniques often discourages shallow foundation in reclaimed lands. It has been noticed that improved bearing capacity by ground reinforcement may present a better choice of adopting shallow foundation in many places of reclaimed land of Dhaka city with field load test verification. The use of geo-synthetic materials as reinforcement to improve the bearing capacity and settlement performance of shallow foundation has gained much attention in the field of geotechnical engineering. But in Bangladesh this is not widely practiced. This study shows that the bearing capacity and the settlement characteristics of shallow foundation in reclaimed land can be improved by the inclusion of reinforcements in the ground. For the design of shallow foundations in weak soils, settlement becomes the controlling criteria rather than the bearing capacity. Hence, it is important to evaluate the improvement in the bearing capacity of foundations at particular settlement level. From the finding of numerous researchers, it can be summarized that the bearing capacity of soil varies with various factors, like type of reinforcing materials, number of reinforcement layers, and ratio of different parameters of reinforcing materials and foundations geometry and base soil properties etc.

For reclaimed land of Dhaka city such as Mirpur DOHS no significant bearing capacity analysis study is reported in the recent past. Banik, S. studied the bearing capacity of shallow footing for Dhaka soil using both classical methods and finite element method (Sub-loading t_{ij} model) [1]. Jadid, M. N presented a general innovative procedure for designing, erecting, and testing stone columns using the vibro-replacement method to improve soil bearing capacity under shallow foundations (isolated and raft foundations) for any typical building under small or medium loading conditions [2].

2. EXPERIMENTAL METHODS

2.1 Site Selection

Mirpur DOHS is one of the most significant reclaimed areas of northern Dhaka city where plethora of construction works is undergoing at present. This area is bounded by few more reclaimed areas such as Shagufta Housing at north and Eastern Housing at west having good construction development potentials. Soil profiles of Mirpur DOHS are comparatively poor and demands special attention for designing economic foundation. It has been observed that all the reclaimed areas in and around the Dhaka city are now facing an increasing demand of housing developments. As such this study has carefully selected a prominent reclaimed site like Mirpur DOHS that may through some light in development potential of shallow foundation in weak reclaimed land with its future applicability prospective. Geographic coordinate of selected research site is 23°83’74” N latitude and 90°36’40” E Longitude as shown in the Figure-1.

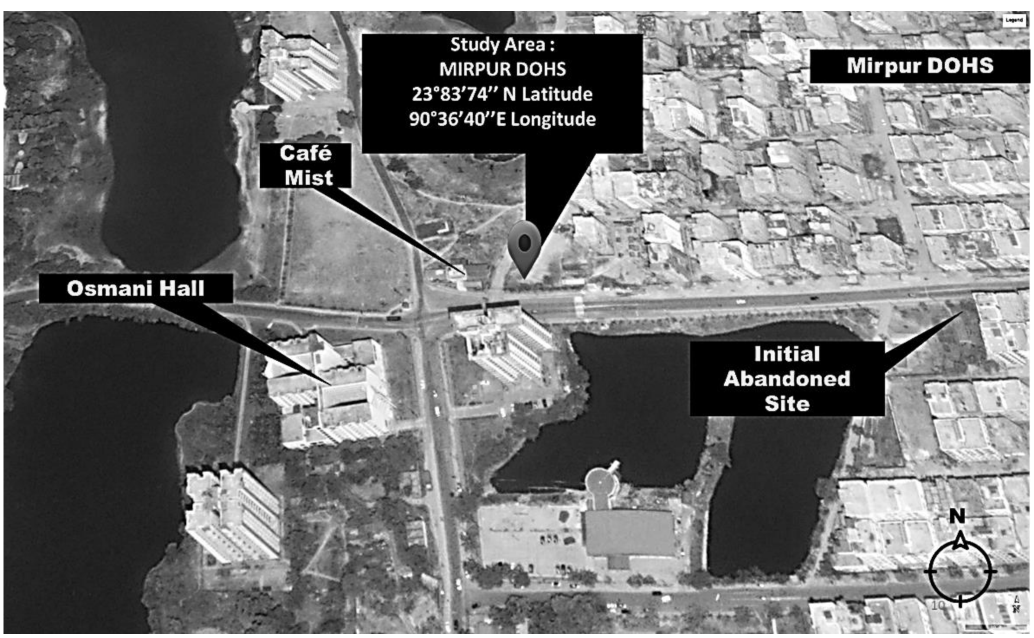

Fig.1 Study Area Site at Mirpur DOHS, Dhaka, Bangladesh

2.2 Methodology

The whole testing and experimental procedure of the research work has been illustrated by the Figure-2. After the site was selected, comprehensive soil characterization was done through field and laboratory tests. Field investigations were performed in the form of SPT following standard test method as per ASTM D1586. Disturbed and undisturbed samples were collected from borehole and SPT N-values were recorded at a depth of every 1.5m interval. Collected soil samples were tested in the MIST laboratory. Grain size distribution, Atterberg limit tests, Direct shear stests, Triaxial tests and consolidation tests were conducted for proper sub soil characterization. From the sub soil property following few analytical methods foundations bearing capacities were calculated followed by verification of test result by a full scale load test. To achieve a better performance the foundation base soil soil was reinforced by a layer of aggrigate with getextile underneath.

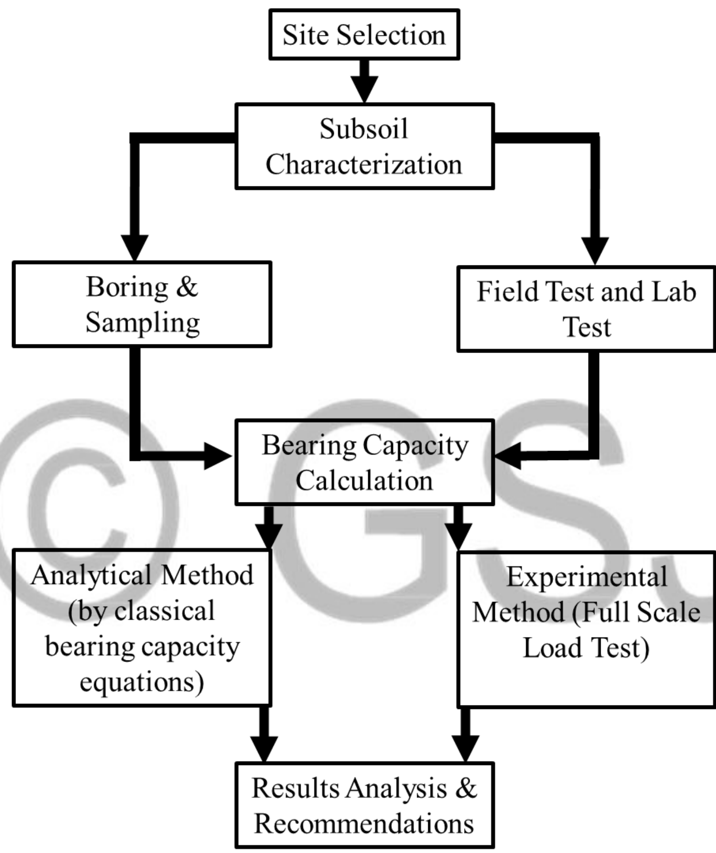

Fig.2 Flow chart showing the sequence of work

2.3 Sub Soil Profile

The bore log and subsoil profile including field SPT N values are presented in Figure-3. Nearly up to 5m depth the soil is a filled deposit dominated by silty sand. After this black organic clay layer with rubbish exists up to 7.5m depth. A soft high plastic clay and a black organic clay layer continues beneath the organic clay layer having poor SPT N value of 2 to 4. After this a grey silty layer extends up to 17m. Beyond this depth SPT gradually increases where dense silty sand with little gravel is found. Laboratory tests of collected sample from each layer have been conducted with adequate care. Basic laboratory tests include grain size analysis, Atterberg limit, specific gravity, direct shear, triaxial and consolidation test etc. Test results are used to calculate the bearing capacity of shallow foundation.

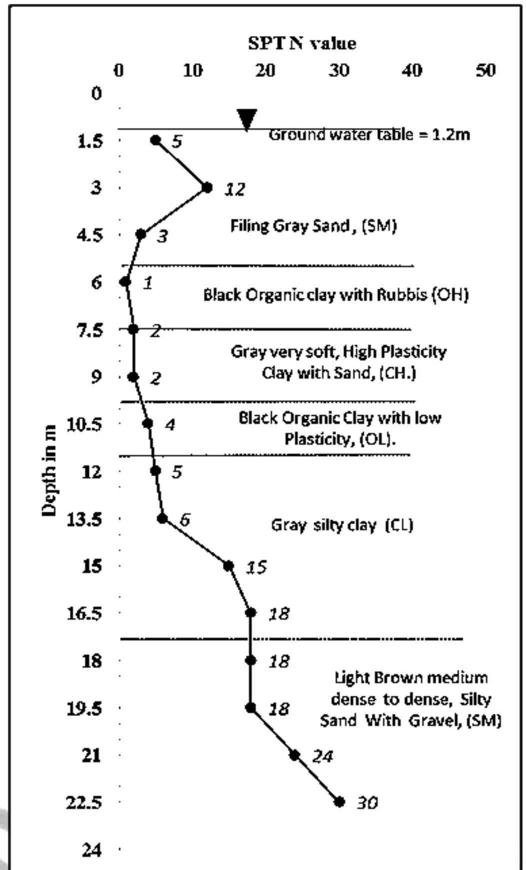

Fig.3 Sub Soil Profile Based on SPT N Value

2.4 Filed Test Setup

With the help of field and lab test data theoretical bearing capacity of a widely adopted 5t x 5ft isolated column footing was calculated. To verify the calculated bearing capacity a full scale load test was conducted following ASTM D-1194. Total loading process is done under 12 steps and unloading steps occurred in 3 steps. The load was applied with the help of a hydraulic jack of about one-tenth of the ultimate bearing capacity. The field experimental setup is presented by Figure-4 and Figure-5.

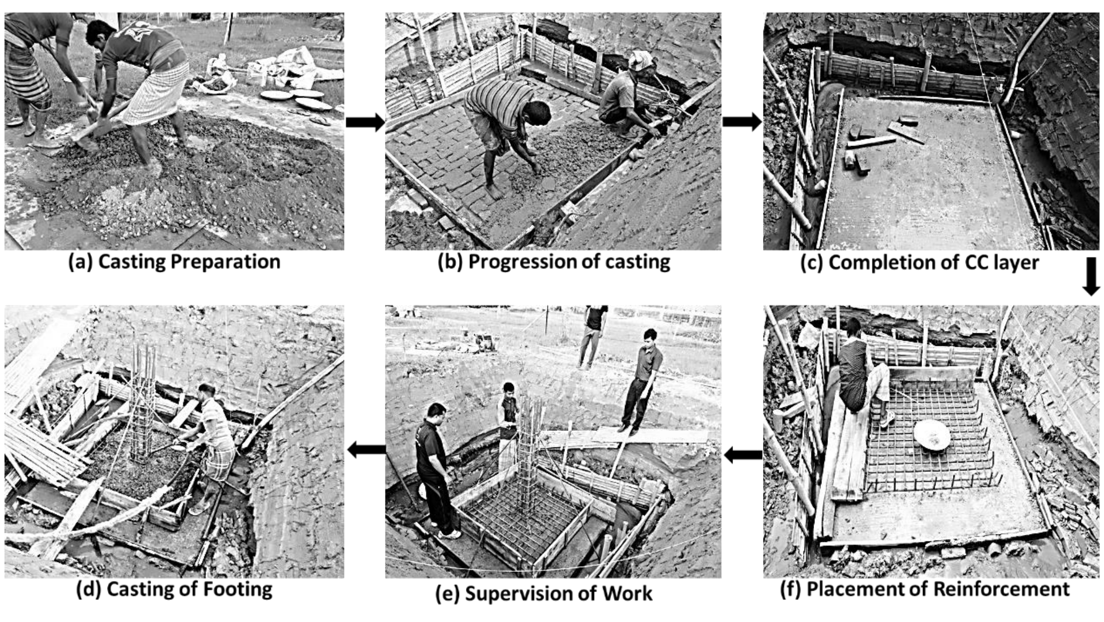

Fig.4 Progression and Supervision of Field Work

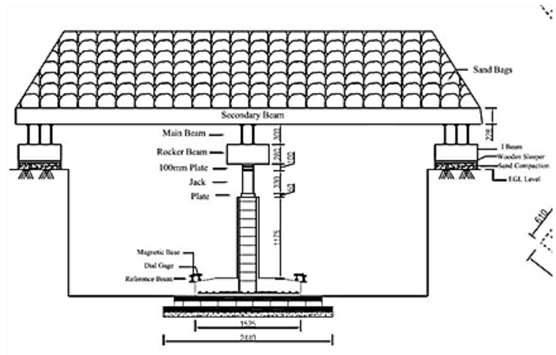

Fig.5 Schematic Diagram of Full Scale Field load Test Setup

2.5 Layout of Foundation

The bearing capacity of shallow foundation has been calculated by different conventional methods. Settlement calculation is also done for the selected geometric configuration of the foundation. The foundation size confirms to average adopted foundation size of a normal five to seven storied residential building of the selected study area. In order to provide better stability base soil layer has been reinforced by a layer of sand and aggregate mix followed by another compacted sand layer underneath with 2.5mm thick geotextile at bottom.

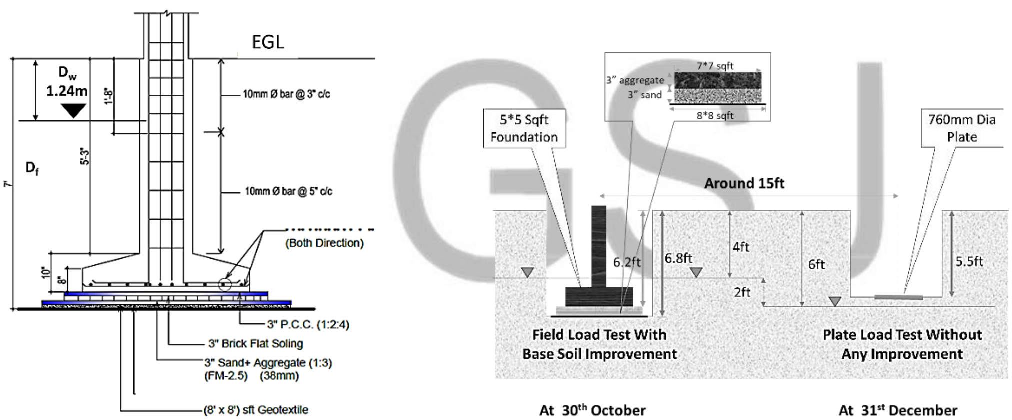

Fig.6 Cross Section of the foundation, experimental setup with and without improvement

3. BEARING CAPACITY CALCULATION BY ANALYTICAL METHODS AND FIELD EXPERIMENT

3.1 Bearing Capacity Under Axial Load

Theoretical bearing capacity of selected foundation under axial load has been calculated by the methods and associated formulas shown in the Table-1. Different methods of bearing capacity equations have different assumptions. As such this study highlights bearing capacity determination by using all the widely used methods that are closely related to the selected ground conditions. As field verification test of theoretical calculation has been done through full scale load test, so it provides a good overview and reliability of each theoretically calculated bearing capacity. Table-2 provides results of bearing capacity used by different methods as presented in the Table-1. It is to be noted that effect of reinforced base layer has not been considered in the conventional bearing capacity calculation formulas used in different methods. However, this effect was best judged by the field load test which is most reliable and authenticated since no scale down approach was followed.

Table 1: Fomulas for Analytical Calculation of Bearing Capacity of Shallow Foundation

Methods	Equation	Factors	Assumptions
Terzaghi	$q_u=S_c.C.N_c+S_q.q.N_q+S_\gamma B_\gamma N_\gamma$	$N_q=\frac{a^2}{a\cos^2(45+\frac{\varphi}{2})}$ $a=e^{(0.75\pi-\phi/2)\tan\phi}$ $N_c=(N_q-1)\cot\phi$ $N_\gamma=\frac{\tan\varphi}{2}(\frac{k_{p\gamma}}{\cos^2\varphi}-1)$	• Base of the footing is rough. • Soil above bottom of foundation has no shear strength; it is only a surcharge load against the overturning load. • Surcharge up to the base of footing is considered. • Load applied is vertical and non-eccentric. • The soil is homogenous and isotropic. • Elastic zone has straight boundaries inclined at an angle equal to Φ to the horizontal.
Meyerhof	$q_u=CN_cS_cd_ci_c+qN_qS_qd_qi_q+0.5S_\gamma d_\gamma BN_\gamma i_\gamma$	$N_q=e^{\pi\tan\phi}\tan^2(45+\phi/2)$ $N_c=(N_q-1)\cot\phi$ $N_\gamma=(N_q-1)\tan(1.4\phi)$	• Logarithmic failure surface ends at the ground surface. • The resistance offered by the soil and surface of the footing above the base level of the foundation is considered. • The effects of shearing resistance within the soil above foundation level are considered. • Correction factors for eccentric and load inclination is considered.
Hansen	$q_u=-C\cot\phi+(q'+C\cot\phi)N_qs_qd_qi_q+0.5\gamma_eBN_\gamma s_\gamma d_\gamma i_\gamma$	$N_q=e^{\pi\tan\phi}\tan^2(45+\phi/2)$ $N_c=(N_q-1)\cot\phi$ $N_\gamma=1.5(N_q-1)\tan\phi$	• Hansen's equation takes into consideration of base tilting and footings on slopes. • Hansen proposed a more generalized equation with shape(s) and depth(d) of foundation and the inclination factors for load (i), footing base and ground over which footing is resting.

Table 2: Bearing Capacity Calculation Result by Different Methods

Bearing Capacity Factors		Terzaghi	Meryerhof	Hansen
N_c		17.24	14.45	14.45
N_q		7.14	6.15	6.15
N_γ		5.07	2.68	2.75
S_c		1.3	1.46	1.39
S_q		1	1.23	1.39
S_γ		0.4	1.23	0.6
d_c		1	1.39	20.96
d_q		1	1.2	1.41
d_γ		1	1	1
Ultimate bearing capacity, Q_u	**kPa**	**256**	**297**	**350**
	tsf	**2.43**	**2.82**	**3.32**

3.2 Bearing Capacity from Settlement

Bearing capacity in the field often limited by tolerable foundation settlement. In absence of field load-settlement curve theoretical settlement calculation based on elastic behaviors of soil provides rough idea of foundation bearing capacity based on settlement limit set by the code of practice. As soil is not a perfectly elastic material so settlement calculation based on conventional theories may not present a dependable result. However, still it can be used for primary prediction of foundation bearing capacity.

Consider a foundation measuring L×B (L= length; B= width) located at a depth D_f below the ground surface. A rigid layer is located at a depth H below the bottom of the foundation. Theoretically, if the foundation is perfectly flexible according to Bowles (1987), the settlement may be expressed as:

$$S_{e\ (flexible)} = q(\alpha B')\frac{1-v^2}{E} I_s I_f \qquad \text{(I)}$$

Referring to the Figure-5 parameters of equation (I) may be summarized as in Table-3. Details of equation may be found in any standard text books of geotechnical engineering, such as equations 8.14 to 8.21 of [5]. Using Table-3 calculated settlement versus pressure represents a linear graph as shown in the Figure-7. Considering maximum 25mm settlement expected pressure (theoretical bearing capacity) is 77kPa. So, according to the elastic consideration of soil maximum 18.34-ton load can be applied to the selected foundation. Interestingly this 18.34ton load is far below the actual capacity as can be seen subsequently in the field load test result.

Table 3: Parameters for Elastic Settlement

B=1.5m	D_f =1.9m	n' =(H/B) =11.96	F_1=0.356
B'= 0.752m	L= 1.5	A_0=0.798	F_2=0.757
α =4	H=9m	A_1=0.321	I_s=0.789
v = 0.3		m' =(L/B) =1	I_f= 0.64
E=4192.5 kN/mm^2		A_2=0.007	

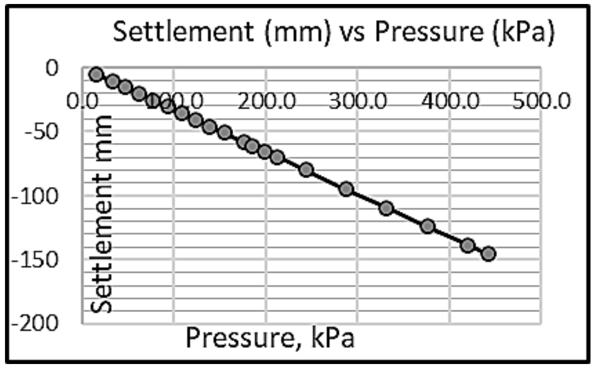

Fig.7 Elastic Settlement Curve

3.3 Bearing Capacity from Field Load Test

In order to validate the theoretical results obtained from classical methods a full-scale load test on the selected foundation was conducted. From field load test obtained settlement curve presented in the Figure-8 shows a nonlinear shape close to the parabolic form whereas empirical method shows a linear shape as presented in the Figure-7. The parabolic shape indicates local shear failure. Considering maximum 25 mm settlement the ultimate bearing capacity from Figure-9 is determined as 400 kPa with corresponding applied load of around 90 tons. 25 mm settlement shows a critical state for foundation. A little amount of load increase can cause drastic change in settlement. For this type of situation, the safe design bearing capacity can be determined by De Beer method or tangent method.

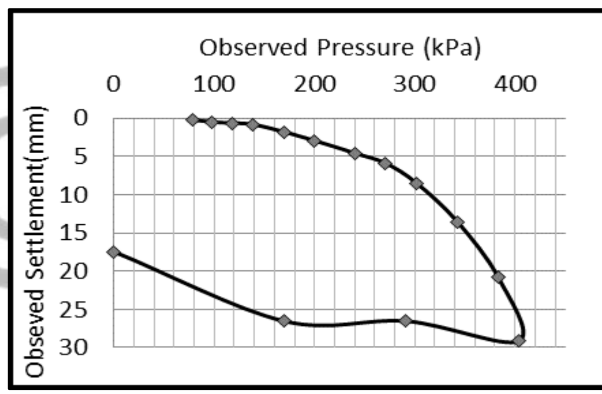

Fig.8 Field Load Settlement Curve

From De Beer and tangent method, the design bearing capacity found for field load test with Ground improvement. From Figure-9 the design bearing capacity is 310kPa and from Tengent Method 350kPa

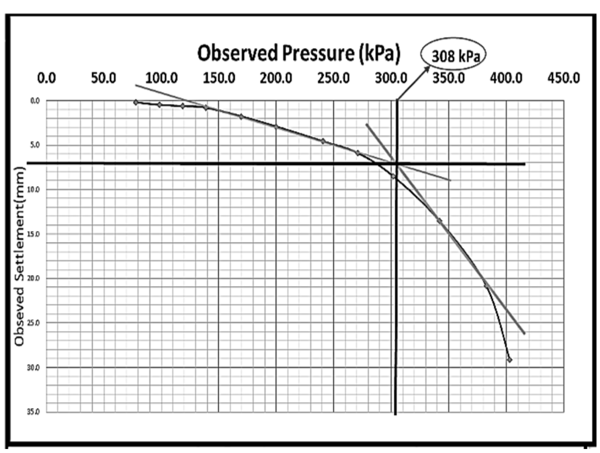

Fig.9 Design bearing capacity by DeBeer Method

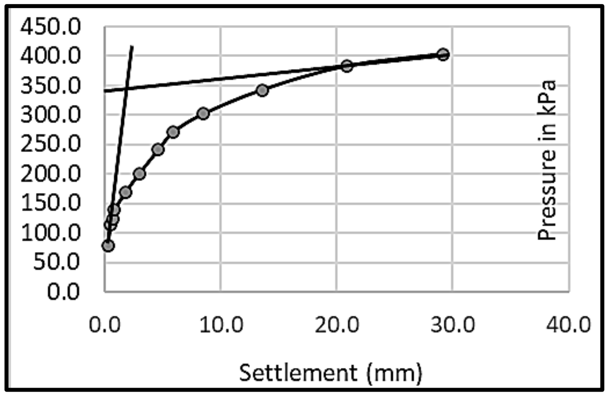

Fig.10 Design Bearing Capacity by Tengent Method

4. RESULTS

4.1 Comparsion between theoretical and field test results

Bearing capacity from settlement only consider the elastic behaviour and bearing capacity with various equations calculation for both analytical and field load test summary is shown in table 4. where field load test with ground improvement provied 400kPa for 25 mm settlement.

Table 4 Summary of Results

Method	Bearing Capacity, kPa (Q_{ult})	Variation of Q_{ult} from Field load test (%)	Discussion
Terzaghi	256	56%	Limitation of each Equation. Also for Ground reinforcement
Meyerhof	297	35%	
Hansen	350	14%	

4.2 Effect of encorporating layer reinforcement

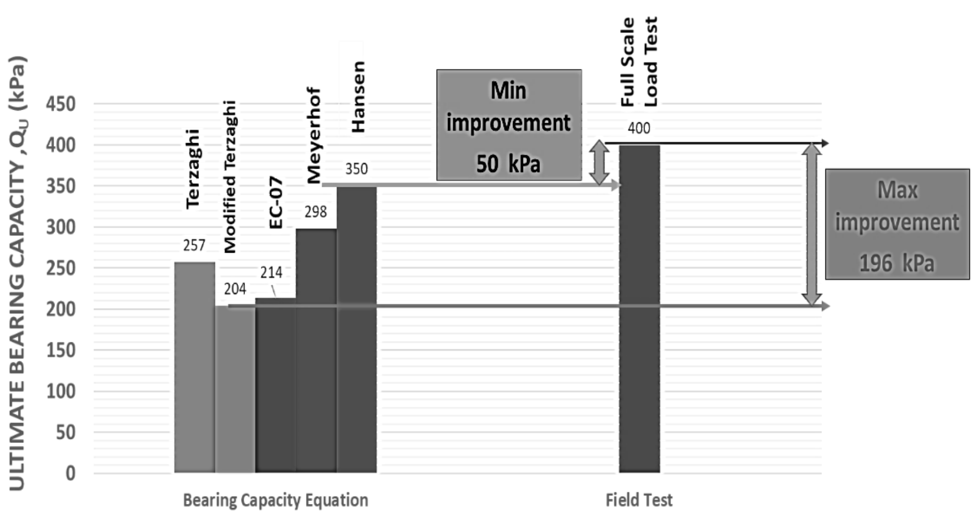

Fig.11 Predicted effect of base shear on bearing capacity

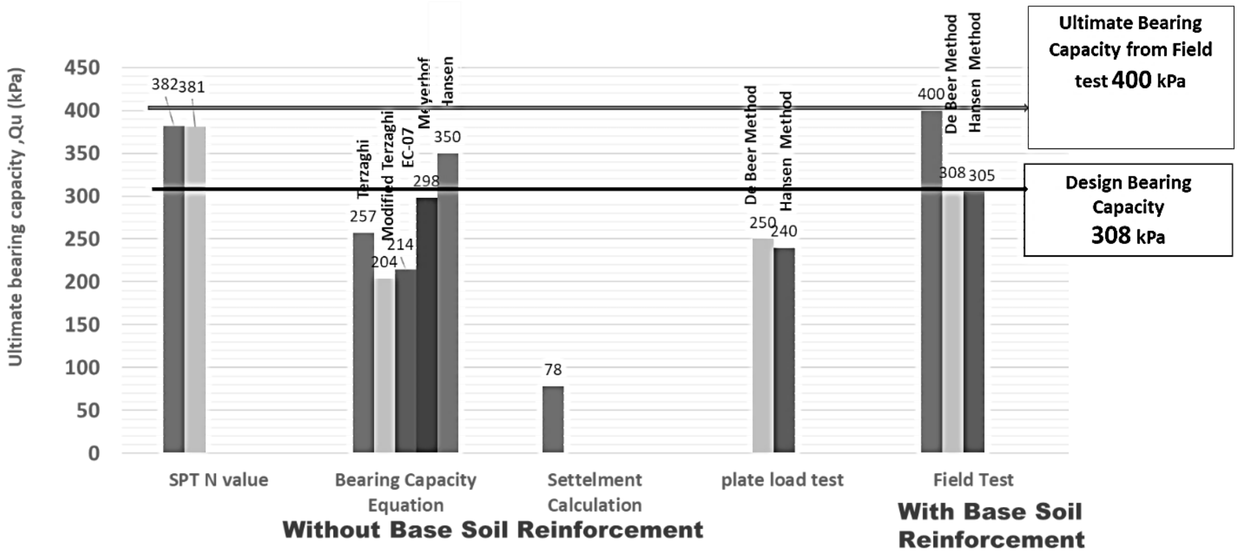

Fig.12 Comparison of Bearing Capacity

From Table 2 and Figure-9 for 5'*5' shallow foundation with and without base shear reinforcement bearing capacity can be compared as in Figure -10. This figure clearly shows the improvement of bearing capacity for ground reinforcement. From Figure -10 the Bearing Capacity increment for ground improvement is 161 kPa

Conclusion

Though pile foundation is the most conventional technique that is basically used in the reclaimed lands but for some specific cases shallow foundations can also be a good and economic choice for construction works. The upshots form the study shows that in some specific cases where similar soil profile like this study site is available, shallow foundation with ground improvement and with geotextile may be adopted. In addition, if the ground water is lowered then performance of this shallow foundation will be comparatively better. Lower ground water table reduces the chance of liquefaction effect. Alternately this type of shallow foundation may be used in conjunction with deep foundation specially for peripheral footing that experiences comparatively low base reaction.

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