Analysis of Economic and Pragmatic Viability of Shallow Foundations on Reclaimed Lands of Urban Areas in Bangladesh

Mohammad Ali*, Mahfuza Khanum, Sadman A. Sakib

Abstract—The population of Bangladesh is rapidly augmenting due to multitude of reasons. One of the upshots of increasing population is expansion of constructions on polder lands, specially near the urban areas. Though on such areas classical pile foundation is the most conventional and illustrious method, yet it is uneconomical and quality control is also difficult. Hence, Mirpur Defense Officers' Housing Scheme (Mirpur DOHS) which has weak soil of soft to medium consistency was selected as a potential study area for bearing capacity analysis of shallow foundations. The majority of the sites are built by filling the marshy lowlands using dredge filling materials from engulfing areas. The maximum SPT-N value of the filling materials is limited within 13. Grain size analysis of the distributed and undistributed samples below the foundation depth was done and the value of Cu and Cc were 1.75 and 0.89. The obtained angle of internal friction (φ) was almost near 30° and the SPT-N value of the grey sandy soil was approximately 8. A shallow foundation of 5*5 ft^2 was adopted on reinforced based soil for the full scale load test. After the experimental field load test the upshots depicted the value of ultimate bearing capacity (Qu) to be 400 kPa. The theoretical bearing capacities was determined using Tarzaghi, Modified Tarzaghi, Meyerhof, Hansen, EC-7 bearing equations and the depicted upshots were 257, 204, 298, 350 and 214. Thus, the full scale load test illustrated minimum and maximum improvement of 50kPa and 196kPa. To encapsulate, this study sheerly depicts the pragmatic and economic viability of shallow foundations on polder lands of urban areas in Bangladesh.

Keywords—*Polder Lands, Bearing Capacity, Shallow Foundation, Full Scale Load Test, Urban Areas, Mirpur DOHS*

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1 Introduction

THE denizens in Bangladesh are escalating so the infrastructural developments at different parts of the country are also expanding rapidly. Due to such rapid urbanization polder lands are being reclaimed and used for development purpose at massive rate. In such cases filling of low lands with depth in-between 1.5m to 13.5m are done by using engulfing filling materials [7] The most generic type of foundation used in the polder lands is pile or deep foundation. Unfortunately, pile foundations are highly exposed to threats like negative skin friction and soil liquefication. However, the traditional analysis and calculations also discourages shallow foundations on polder lands (reclaimed lands). If the existing ground is liquefiable then the deformation mechanism of the shallow foundation become quite complex. It is anticipated to undergo multitude of factors like: conditions of ground, shear-induced deformation, development of excess pore pressure, configuration of foundation, induced cyclic stress, inertial and kinematic interaction within the soil-foundation structure system, localized drainage and post liquefication reconsolidation [5]. It is hence important to improve the bearing capacity of shallow foundations. Bearing capacity is the potentiality of a ground to confront the loads which are caused by the foundation, which is actually the maximum amount of stress that can be endured by the soil before shear failure [10]. In Dhaka, the capital city of Bangladesh, it has been observed by field load test verification that bearing capacity of shallow foundations on the polder lands can be ameliorated by providing ground reinforcement. Appropriate estimation of the ultimate bearing capacity of the shallow foundations plays a crucial role in foundation design of various structures. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement. The onset of failure is associated with the full mobilization of shear strength along a prescribed failure surface and excessive displacement as the soil target stiffness approaches zero. A schematic diagram of the stress-displacement-capacity relationship of an axially-loaded footing is shown:

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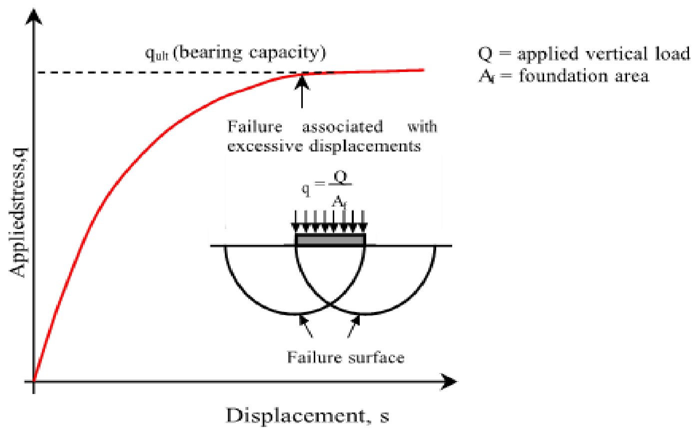


Fig.1 Idealized axial load-displacement-capacity response of shallow foundations

In practical engineering the estimation of ultimate bearing capacity of shallow footings is normally done by various methodologies like: limit equilibrium: Terzaghi [9]; limit plasticity: Meyerhof [5]; cavity expansion: Vesić [1] are more versatile, thus making them more widely used in combination with a number of laboratory and in-situ tests. The bearing capacity of a shallow, vertically loaded, strip footing resting on a homogeneous medium is classically determined using the Terzaghi (1943) superposition method:

$$q_{ult} = cNc + 0.5B\gamma\, N\gamma + q\, Nq \qquad (1)$$

where, q_{ult} = ultimate stress underneath the footing, c = effective cohesion intercept for drained behavior (c′) or the undrained shear strength (cu = su) for undrained loading, B = foundation width, γ= effective or total unit weight depending on the ground water level, q= effective overburden stress at the foundation level, and Nc, Nγ, Nq are dimensionless bearing capacity factors. A proper assessment of the bearing factors Nc, Nq, and Nγ is essential for the correct evaluation of bearing capacity. Hence, available bearing capacity factors Nc, Nq, and Nγ determined using analytical, numerical, and statistical methods were reviewed from published sources. But the conventional theories are subjected to plethora of limitations and also simplification of assumptions. As a result of these issue the results are not always accurate as per the experimental data.

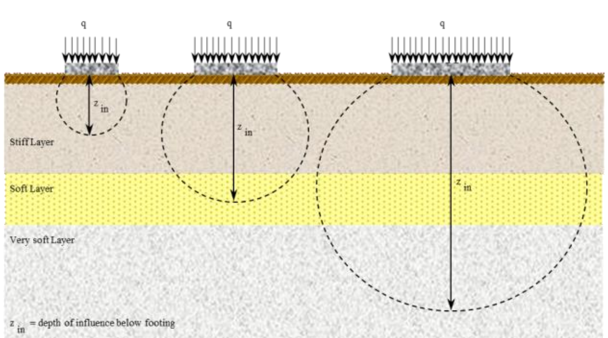


Fig.2 Effect of footing size on the zone of influence beneath shallow footings in layered soil profiles

The most definitive means for determining the bearing capacity is to conduct full-scale load tests [4].

In delicate soils, the hegemonizing criteria is settlement rather than the bearing capacity. As a result, it is sheerly necessary to consider the improvement of bearing capacity at a particular settlement level. The recourse of using and adopting reinforced shallow foundation has not been taken into consideration until very recently. For the polder lands of urban areas in Bangladesh there is still shortage of appropriate bearing capacity analysis. In the past some studies were conducted by Banik,S. on bearing capacity of shallow footing for soil in Dhaka, the capital of Bangladesh by using classical methods and finite element methods [3].

Because load tests are very expensive and time consuming, they are essentially restricted to research programs or large special projects involving very poor ground conditions and/or critical structures. Conducting plate load tests [2] which are smaller scaled-down versions at full-scale tests, are easier and more economical. Nevertheless, plate load test data need to be manipulated to account for the difference in size between the prototype and plate. This could especially be problematic in layered soil profiles or ground conditions with varying stiffness with depth because of the variation in soil properties with depth, as shown in Figure 2-2, and small plate load tests would not scale up conservatively. Employment of a field compressonmeter (screw plate) could be used at different depths [11] to alleviate this concern.

Also, study conducted by Jadid, M.N illustrated that using vibrio replacement method augments soil bearing capacity (isolated and raft) foundation for any conventional building under small or moderate state conditions [8].

In this study, a shallow foundation was integrated with reinforced aggregate and geotextile in order to undergo full scale load test and the obtained results were satisfactory enough since the bearing capacity improved and the results from conventional equations were less compared to the yielded.

2 Study Area

2.1 Review and Analysis Stage

The study area that was selected for the field test experiment was Mirpur DOHS, which is an ideal and potential illustration of polder land. It is one of the most significant reclaimed areas of northern Dhaka city, the capital of Bangladesh. At this place plethora of robust construction and infrastructural development is happening. The selected study area is bounded by few more reclaimed areas such as Shagufta Housing at north and Eastern Housing at west having good construction development potentials. The Geographic coordinates of the selected research study area site is 23°83′74″N latitude and 90°36′40″E Longitude as shown in the Figure 3.

Fig.3 Location of the study area and experiment site

Soil profiles of Mirpur DOHS are comparatively poor and requires 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.

3 Methodology

After the site was selected for the study field and laboratory tests were conducted for comprehensive soil characterization. Standard ASTM D1586 test method was used to perform field investigation in the form of SPT and the wash boring technique was adopted for this SPT. Both disturbed and undisturbed soil samples were collected from borehole and SPT N-values were recorded at a depth of every 1.5m interval. All the tests of the collected soil samples were conducted in the laboratory of Military Institute of Science and Technology (MIST) at Mirpur Cantonment.
Grain size distribution, Atterberg limit tests, Direct shear tests, 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 was reinforced by a layer of aggregate with geotextile underneath. As a result, the upshots of all the test were positive as per the anticipations.

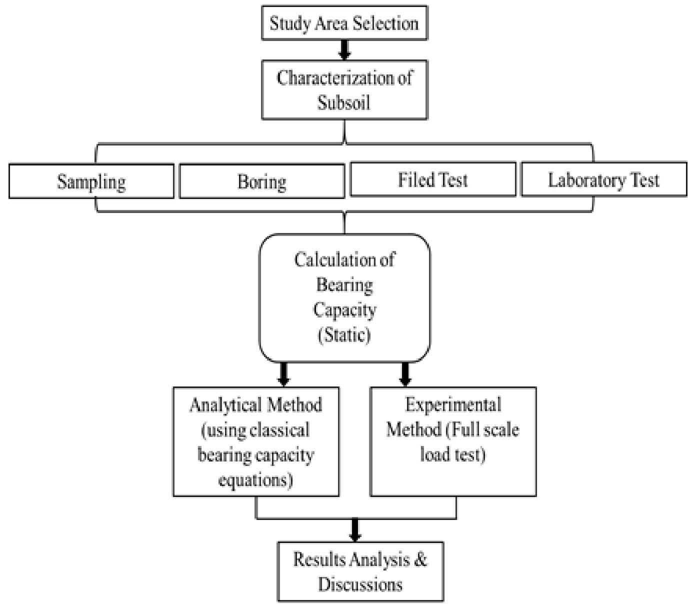
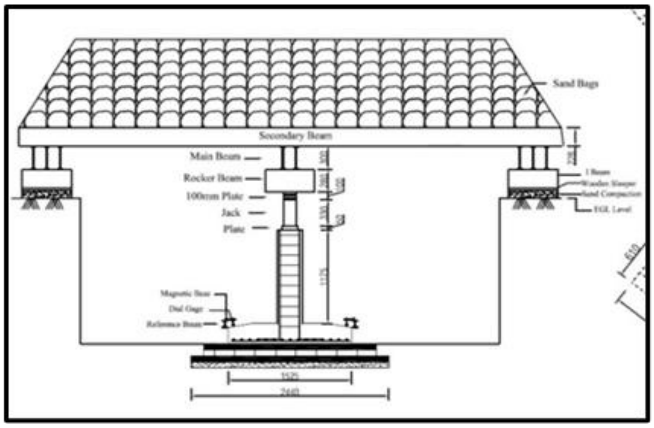


Fig 4. Methodological Flow Diagram

3.1 Experimental Setup at Site

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 has been illustrated in the following figures:

(a)



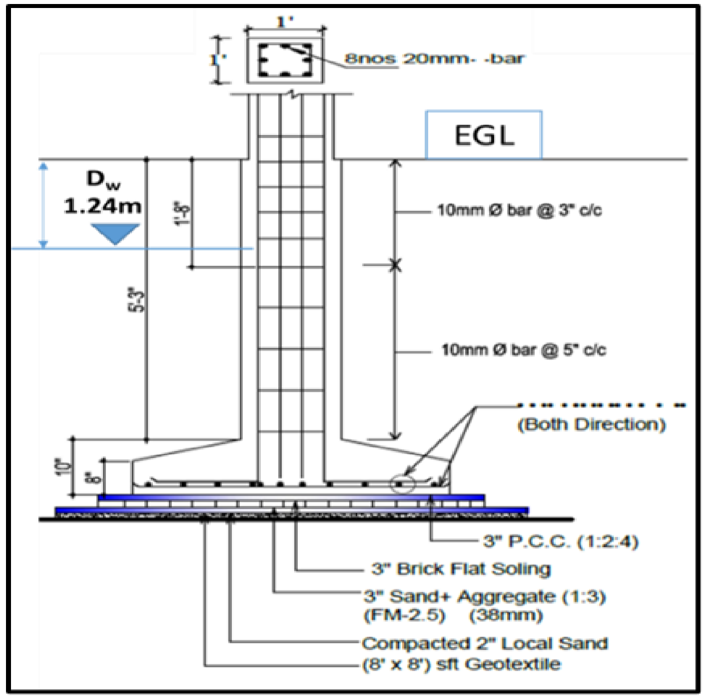
(b)

Fig.5 (a, b) Full Scale Field Load Test

It was seen that the foundation size confirms to average adopted found size of a normal five to seven story 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.

By Using these properties 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.

(a)



(b)

Fig.6 (a, b) Foundation Cross section with ground photgraph

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TABLE 1
PROPERTIES OF SHALLOW FOUNDATION AND SOIL

Geometry of the shallow foundation	Property of Soil
Foundation Depth = 1.98 m (excluding reinforcement)	Angle of friction $\phi_u = 28^0$
Fc' =3000psi	Undrain cohesion ,C_u=0 kpa
Fy= 60000psi	Specific gravity, G_s= 2.68
Area = (1.524 x 1.524)sqm	Fines%= 35
Depth of water table,Df= 1.219m (from EGL)	Moisture content W%=27.3
Where, Geotextile =2.5mm Sand=75mm Aggregate=75mm	Unit weight, Υ_{bulk} =17.75 kN/m^3

TABLE 2
FORMULAS FOR ANALYTICAL CALCULATION OF BEARING CAPACITY OF SHALLOW FOUNDATION

Methods	Equation
Terzaghi	$q_u = S_c.C.N_c + S_q.q.N_q + S_\gamma B_\gamma N_\gamma$ $N_q = \frac{a^2}{2\cos^2(45+\frac{\varphi}{2})}$, $a = e^{(0.75\pi - \varphi/2)\tan\varphi}$, $N_c = (N_q - 1)\cot\varphi$, $N_\gamma = \frac{\tan\varphi}{2}\left(\frac{k_{p\gamma}}{\cos^2\varphi} - 1\right)$ Assumptions: 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	$q_u = CN_cS_cd_ci_c + qN_qS_qd_qi_q + 0.5S_\gamma d_\gamma BN_\gamma i_\gamma$ $N_q = e^{\pi\tan\varphi}\tan^2(45+\varphi/2)$, $N_c = (N_q - 1)\cot\varphi$, $N_\gamma = (N_q - 1)\tan(1.4\varphi)$ Assumptions: 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	$q_u = -C\cot\varphi + (q' + C\cot\varphi)N_qs_qd_qi_q + 0.5\gamma_eBN_\gamma s_\gamma d_\gamma i_\gamma$ $N_q = e^{\pi\tan\varphi}\tan^2(45+\varphi/2)$, $N_c = (N_q - 1)\cot\varphi$, $N_\gamma = 1.5(N_q - 1)\tan\varphi$ Assumptions: 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.

3.2 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-2.

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-3 provides results of bearing capacity used by different methods as presented in the Table-2.

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 3
BEARING CAPACITY CALCULATION RESULT BY DIFFERENT METHODS

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

3.3 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:

$$S_{e\ (flexible)} = q(\alpha B')\frac{1-\nu}{E}\ I_s\ I_f \quad (2)$$

TABLE 4
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
ν = 0.3		m' =(L/B) =1	I_f= 0.64
E=4192.5 kN/mm^2		A_2=0.007	

Referring to the Figure-5 parameters of equation (2) may be summarized as in Table-4. 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-4 calculated settlement versus pressure represents a linear graph as shown in the Figure-6. 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.

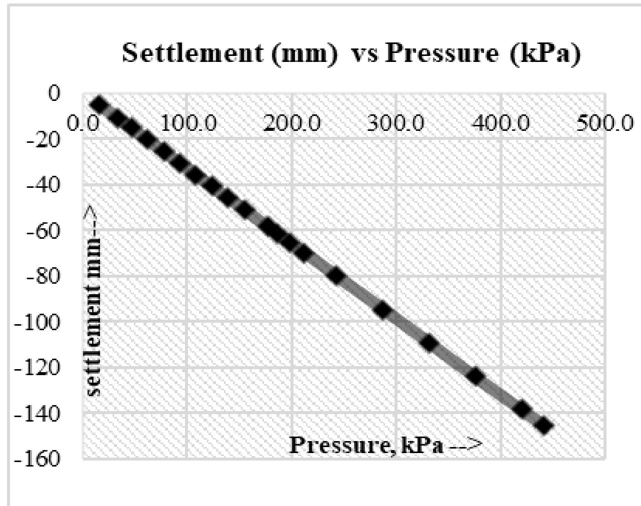


Fig.7 Elastic Settlement Curve

3.4 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-7 shows a nonlinear shape close to the parabolic form whereas empirical method shows a linier shape as presented in the Figure-6.

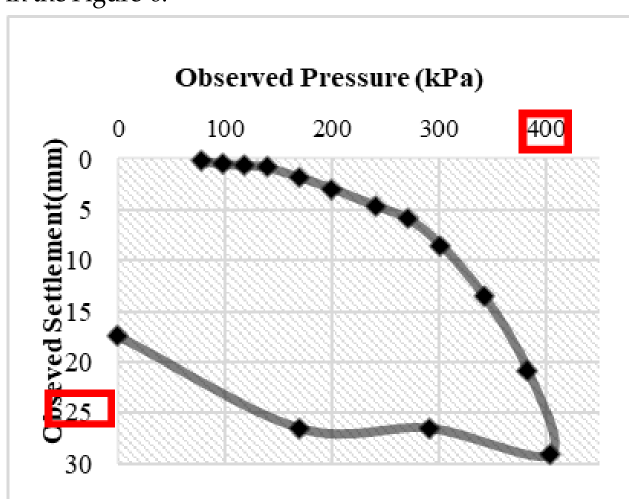
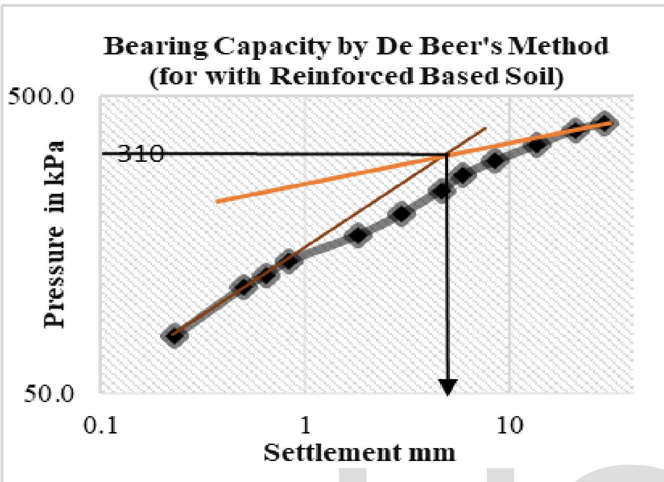


Fig.8 Field Load Settlement Curve

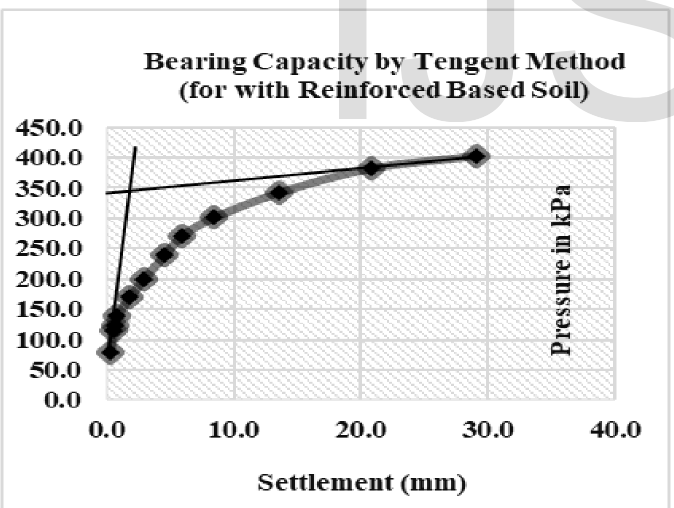
The parabolic shape indicates local share failure. Considering maximum 25mm settlement the ultimate bearing capacity from

Figure-7 is determined as 400kPa with corresponding applied load of around 90 tons. 25mm settlement shows a critical state for foundation. A little amount of load increases can be caused drastic change in settlement. For this type situation the safe design bearing capacity can determine by De Beer method or tangent method.

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 310 kPa and from Tengent Method 350 kPa



9(a)



9(b)

Fig.9 Design bearing capacity by DeBeer Method and Tengent Method

4 Results & Discussions

4.1 Comparsion

Bearing capacity from settlement only consider the elastic behavior and bearing capacity with various equations calculation for both analytical and field load test summary is shown in table 5. where field load test with ground improvement provides 400kPa for 25mm settlement.

TABLE 4
PARAMETERS FOR ELASTIC SETTLEMENT

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 Layer Reinforcement

From table 3 and figure-9 for 5'*5' shallow foundation with and without base shear reinforcement bearing capacity can compare as Figure -10. This figure clearly shows the improvement of bearing capacity for ground reinforcement.

Method Bearing Capacit kPa (Q_{ult}) Variation of Q_{ult} from Field load test (%) Discussion

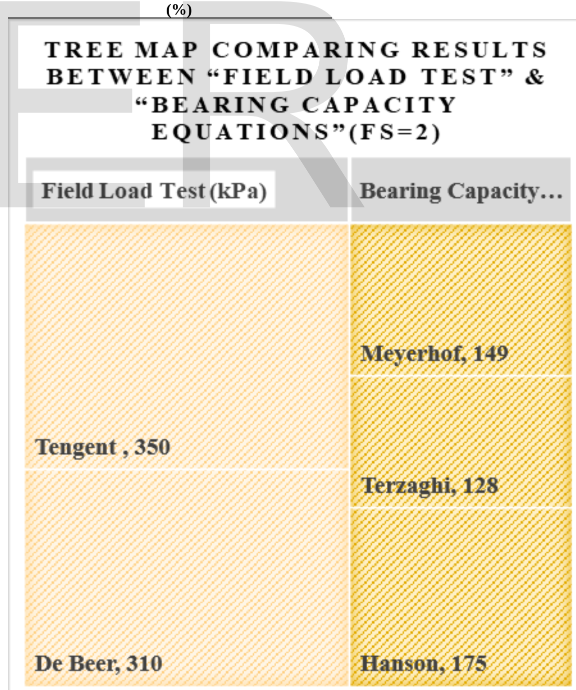


Fig.10 Comparison Between design bearing capacity (Q_U) using Field Load Test (kPa) and Bearing Capacity Equations (kPa)

5 Conclusions

In polder lands, pile foundation is one of the most conventional and illustrious choice for construction engineers. It can be concluded from this study that shallow foundation along with reinforced ground improvement using geotextile might help in apt construction in similar types of soil. However, if the water table is lowered or reduced then the upshots of shallow foundation will be ameliorated. The lower is the ground water table the lower will be the chances of liquefication. Lastly, to encapsulate, shallow foundations can also be integrated with deep foundation, more particularly for circumferential footings that experience analogously low reaction at the base.

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