STUDY ON THE BEARING CAPACITY OF PILE FOUNDATION IN KHULNA SOIL

MD. ARMAN HOSSAIN

Department of Civil Engineering
Khulna University of Engineering & Technology (KUET)
Khulna, Bangladesh

6 July 2014

STUDY ON THE BEARING CAPACITY OF PILE FOUNDATION IN KHULNA SOIL.

A dissertation submitted to the Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), and Khulna in partial fulfillment of the requirements for the Degree of

M.Sc. Engineering

By

Md. Arman Hossain

Department of Civil Engineering
Khulna University of Engineering & Technology (KUET)
Khulna, Bangladesh

Approval

This is to certify that the thesis work submitted by Md. Arman Hossain entitled **"Study on The Bearing Capacity of Pile Foundation in Khulna Soil"** has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering from the department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in July 2014.

BOARD OF EXAMINERS

Dr. Md. Abul Bashar Professor Department of Civil Engineering Khulna University of Engineering & Technology	**Chairman** (Supervisor)
Dr. Md. Saiful Islam Professor & Head Department of Civil Engineering Khulna University of Engineering & Technology	Member
Dr. Md. Keramat Ali Molla Professor Department of Civil Engineering Khulna University of Engineering & Technology	Member
Dr. Md. Rokonuzzaman Associate Professor Department of Civil Engineering Khulna University of Engineering & Technology	Member
Md. Nuruzzaman Professor Department of Civil Engineering Dhaka University of Engineering & Technology	Member (External)

ABSTRACT

Khulna is situated at the southwest region of Bangladesh. Due to the variation of soil profile in different areas, the city area is divided into two zones. Zone-I is situated at the west side of Khulna city which includes the area of Daulatpur, Natun Rastar Mor, Bastuhara, west part of Rayer Mahal, Chak Mathurabad, Khulna University area. While Zone-II is situated at the east side of Khulna city which includes the area of Khalishpur, east part of Rayer Mahal, Khulna Medical College area, Sonadanga, New Market, Dakbangla, Borobazar, KCC office area, Baniakhamar, Gollamari, Tutpara, Labanchura.

In zone-I the sub-soil consists of predominantly silt which is at greater depth than 125 ft. In most areas of this zone the sub-soil is of very soft to soft consistency ranging N-value from about 1 to 5 up to about 50 to 70 ft depth. From sub-soil investigation it was not possible to find out the depth of sandy layer because boring was not performed up to this depth. There exists an organic layer which is mainly at depth 15ft to 25 ft in most of the areas. In some places this organic layer exists from top of the existing ground level. Most probably this area was filled up with dumping garbage and organic sold wastes. In zone-II the sub-soil consists of predominantly silt up to about 50 ft depth in most areas. The soil is of very soft to soft consistency ranging N-value from 1 to 5. Below silt deposit, the soil contains mainly sandy soil. In this zone there exists an organic layer from 10 ft to 20 ft depth in most of the areas of this zone.

To find out the suitability of any existing equation with the pile capacity from static load test, ten pile load tests were performed in two zones of the city in which seven load test in zone-I and three in zone-II. From load tests 9 piles did not show failure point and their maximum settlements were about 16.87 mm. In this case allowable pile capacities were determined from permissible settlement. Among all the equations, only Mayerhof's equation gave the pile capacity at maximum places which is near the value of load test. Other equations gave much higher values than load test values. So no suitable common equation was selected to compare with the pile capacity in both the zones. However, in the south end of zone-I Meyerhof's equation gave close value to pile load test for the four sites in Khulna University area and Mayur Bridge.

ACKNOWLEDGEMENT

The author expresses his heartiest appreciation to his thesis supervisor Prof. Dr. Md. Abul Bashar, Professor of Civil Engineering Department, KUET, Khulna for his continuous encouragement and guidance in the thesis work. His keen interest in this topic and valuable suggestion and advice at every stage made this thesis work possible.

The Author is also grateful to Prof. Dr. Keramat Ali Molla Department of Civil Engineering, KUET, Khulna and Prof. Dr. Quazi Sazzad Hossain, Department of Civil Engineering, KUET, Khulna for their help and encouragement.

Profound appreciation is expressed to Consultancy Research and Testing Services (CRTS) of KUET, Khulna Development Authority (KDA), Public Works Department (PWD), Local government Engineering Department (LGED) etc. for their help, co-operation and supply of useful data and material for the preparation of this thesis report.

The Author would like to extend his thanks to all teachers of Civil Engineering Department of Khulna University of Engineering & Technology (KUET), Khulna for their kind help and sincere co-operation throughout the course of his study at this University.

Profound gratitude is also express to Brig. Gen. Mohammad Samsul Alam Khan afwc. Psc. PEng, Chairman, KDA; Engr. ATM Wahid Azhar, Chief Engineer, KDA & Engr. Kazi Md. Sabirul Alam, Superintending Engineer, KDA, Khulna at several times they helped to perform the study peacefully.

The Author would like to express his thank to all the laboratory technician of Civil Engineering Department for their cordial help in the field and laboratory tests during the thesis works.

Finally, recognition due to author's father late Althaf Hossain, mother Mrs. Mazeda Khatun, brother Md. Imran Hossain, sister Mrs. Rubaiya Gul Shahanara and uncle Dr. Md. Jamal Uddin Mondol for their constant inspiration and encouragement to complete this course.

DECLARATION

This is to certify that the thesis work entitled "Study on the Bearing Capacity of Pile Foundation in Khulna Soil" has been carried out by Md. Arman Hossain in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

Signature of the Supervisor

Signature of the Student

NOTATIONS

A_s = surface area of pile
A_p = area of pile tip
B = dia of pile
B_p= width of pile point
C_u = undrained shear strength
c = cohesion of the clay in the zone surrounding the pile tip
$\overline{c}$= average cohesion along the shaft length
D_c = critical depth
E_s = stress-strain modulus (or modulus of elasticity)
F_w = weighting factor
f_s = skin resistance
f_{su} = ultimate skin friction
SF = safety factor
G′=shear modulus
I_r= rigidity index
I_{rr} =reduced rigidity index
k_a = coefficient of lateral earth pressure
k = co-efficient of lateral earth pressure for bored pile
L= length of pile
N = SPT value
N_c, N_q, N_γ = bearing capacity
N′q = bearing capacity factor
N_q'= Janbu's bearing capacity factor
Q_p = point (or base or tip) resistance of pile
Q_s = shaft resistance developed by friction (or adhesion) between the soil and the pile shaft.
q_u = unconfined compressive strength
q_{pu} = ultimate end bearing of pile
q′= effective vertical (or over burden) pressure at pile point.
S = shear strength
α = cohesion reduction factor
$\propto$ = adhesion factor
β = skin resistance factor
γ = unit weight of soil
γ' = effective unit weight computed
δ = effective friction angle between soil & pile material
ΔL= increment of embedment length
ϵ_v = volumetric strain
μ = poisson's ratio
$\overline{\sigma}_v$ = effective vertical pressure
σ_1= vertical pressure or Stress
ϕ= angle of internal friction of sand

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER

1

INTRODUCTION

1.1 General Remarks

Khulna is situated in the south-western part of Bangladesh near the world largest mangrove forest Sundarban. The sub-soil of this region consists of fine grained soils with a considerable part of decomposed and semi-decomposed organic matter (Rafizul et al. 2006). In Khulna region, the soft soil deposit extends up to a considerable depth, as a result of recent alluvial deposits with organic composition which creates problem to Geotechnical Engineers in designing economic foundation of any infrastructure (Alamgir et al. 2001).

As soft soil stratum is of very large depth the shallow foundation is not possible for tall or high rise building. In this case we are bound to consider deep foundation, mainly pile foundation. The carrying capacity of pile may be determined by pile load test, but it is very tough to determine the exact capacity as the soil in this zone is highly erratic and this non-homogeneity defers zone to zone in the Khulna City area.

At the same it is possible to determine the carrying capacity of any pile from Bearing capacity equations by knowing the soil properties, especially shear strength parameters of the undisturbed sample collected from different depths of soil. But many researchers have been established different equations for the same soil and the value is not same for all formulae. In this study it is under consideration that which formula gives almost same or adjacent result to the capacity of pile load test at the same location.

At present there are many more existing equations available for identification the carrying capacity of pile foundation. Carrying capacity of pile depends on the properties of soil, angle of internal friction, cohesion or cohesion lees and SPT value of soil and shape size & length of pile. A series of study have been done to compare with the soft soil is of large depth the tall building is not possible at shallow depth. Load carrying capacity of pile obtained from different existing equations & pile load test

1.2 Background of the study

There are many more existing equations are available to identify the carrying capacity of pile. The existing equations like Meyerhof Equation for clay & sand (end bearing + skin friction), Dr. K. R. Arora Equation (end bearing + skin friction), Hansen equation for end bearing (clay& sand); Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand, Vasic's equation for end bearing (clay& sand); Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand, Janbu's equation for end bearing(clay& sand); Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand, Terzaghi equation for end bearing(clay& sand); Tomlinson equation (α

method) for skin friction for clay & Burland equation (β method) for skin friction for sand have been used for identification of pile carrying capacity.

A soil profile has been drawn in Khulna city area from sub-soil investigations in field & laboratory test. According to the soil parameter, the Khulna city area is divided in two zones. One zone contain fully predominantly silt & another zone contain predominantly silt & fully sand.

In respect of soil parameter many more equations are available to find out the bearing capacity of soil. For selection of a suitable equation for Khulna soil from many more equations of pile design, sub-soil parameter, zoning profile of sub-soil in city area & the pile caring capacity from load test need to be investigated.

1.3 Objective

Sub soil condition of Khulna & its surrounding is not good. From sub-soil investigations, there was looked little bearing capacity up to the remarkable depth. An organic layer is present all over the city area. For low bearing capacity of soil, sometimes shallow foundation is not economic in Khulna region.

The principal objectives of this research are to find out the most suitable equation for pile capacity of Khulna soil.

i. To establish the proper soil profile in Khulna city corporation area.
ii. To find out the carrying capacity of pile foundation by pile load test at some selected locations in Khulna city area.
iii. To determine the carrying capacity of pile foundation from different existing equations using the value of geotechnical parameters from soil profile.
iv. To select the best suitable equation for Khulna soil from comparative study between load test data and carrying capacity from equations.

1.4 Statement of the Experimental Study

Soil test reports have been collected from CRTS, KUET, KDA & Khulna University & prepared a general soil profile for different zone in Khulna city area. As per soil condition & SPT value, as per zoning profile soil samples have been collected & performed direct Shear test, unconfined compression test for determination of Shear parameters which will be applied to know the bearing capacity of soil at different depths. Most of these tests have been performed in Geotechnical Engineering laboratory of KUET and some tests have been performed by private company through KDA, Khulna. To determine pile capacity of Khulna soil, 10 (ten) pile load tests have been performed. During soil boring SPT-values have been observed at different depths.

The piles are designed by various equations accordinn to Meyerhof, Dr. K. R. Arora, Hansen, Vasic's , Janbu's, Terzaghi, Tomlinson & Burland equation for identifying the bearing capacity of situ pile. Ten nos of pile load test test to be carried out. The test has been standardized as ASTM D 1143.

CHAPTER 2

LITERATURE REVIEW

2.1 General

No research work has been done till date for investigation the best suitable equation among the various existing equations, which is more accurate for pile design on Khulna soil. For construction of structures on poor ground in Khulna city area, in this research was tried to develop an equation among the different equations of pile design. Considering the inherent limitations on shallow foundation systems, deep foundation especially pile foundation has been practiced from long time ago. In comparison to shallow foundations pile reduces the settlement effectively, the differential settlement and the bending moment proportionally (Metsihafe Mekbib, 1999). Many types of foundation have been practiced under structure for Khulna sub-soil.

Khulna is one of the fast growing cities in Bangladesh. It has a lot of business friendly environment. The Mongla sea port, Benapole land port, Bhomra land port & Jessore air port is also near from this city. Day by day population is increased in this city and simultaneously industries & infrastructure is also increased. Big infrastructure in this city such as bridge, embankment, industrial building, high rise building & power plant etc are rapidly growing. Before design & construction of heavy structure sub-soil investigation for foundation design is needed. The Sub-soil investigation companies are too limited here; most of the sub-soil investigations have been done by CRTS, KUET. Khulna city & its surrounding an organic layer is present in between natural ground level to 25 ft depth.

2.2 Sub- soil Condition in Khulna city area

Khulna is the fast growing city in the Bangladesh. A lot of heavy structure are constructing in this city. Pile foundation is used for the heavy structure in this city area. To know the sub-soil condition in Khulna city, total 129 numbers of sub-soil investigations were done in field and laboratory, all over the city area. From sub-soil investigation in field & laboratory, a soil characteristics profile has been made. It was seen from soil profile that Khulna is divided in two zones. Zone-I contains fully predominantly silt from natural ground level to 125 ft depth. There is an organic layer and its thickness 5ft to 15 ft and the organic layer is exists in between natural ground level to 25 ft depth. There is also present predominantly sand layer below the 125 ft depth from ground level.

Zone-II contains predominantly silt layer, fully sand and an organic layer. Predominantly sand layer exists from natural ground level to 50 ft depth. Below 50 ft depth, sand layer is started up to the 150 ft depth. An organic layer is available all over the area. Its thickness 5 ft to 15 ft and it is exists in between ground level and 25 ft depth.

- (i) Predominantly silt layer.
- (ii) Organic layer.
- (iii) Sand layer.

(i) **Predominantly Silt Layer:** The soil contains clayey silt or sandy silt but the quantity of clay & sand is too little in that case may call predominantly silt. The N-value of this layer may varies between 5 to 8, unit weight is 7.1 kN/m^3 to 7.2 kN/m^3, specific gravity is 2.66 to 2.67 and cohesion generally varies between 15.83 kN/m^2 to 21.11 kN/m^2. Somewhere of this layer may content sand pocket. The top layer of Khulna soil contain predominantly silt. 10 % to 15 % Clay & sand are exists in little quantity in silt in Khulna soil.

(ii) **Black Organic Layer:** It is very highly compressible layer. Generally this layer is present all over the Khulna city. The N-value of this layer may vary between 2 to 3, the moisture content of this layer is varied between 80 to 300% and specific gravity is 2.00 to 2.52.

(iii) **Sand Layer:** The N-value of sand layer may vary 10 to 70. And the moisture content of this layer is varied between 10 to 15% and specific gravity is 2.66 to 2.68.

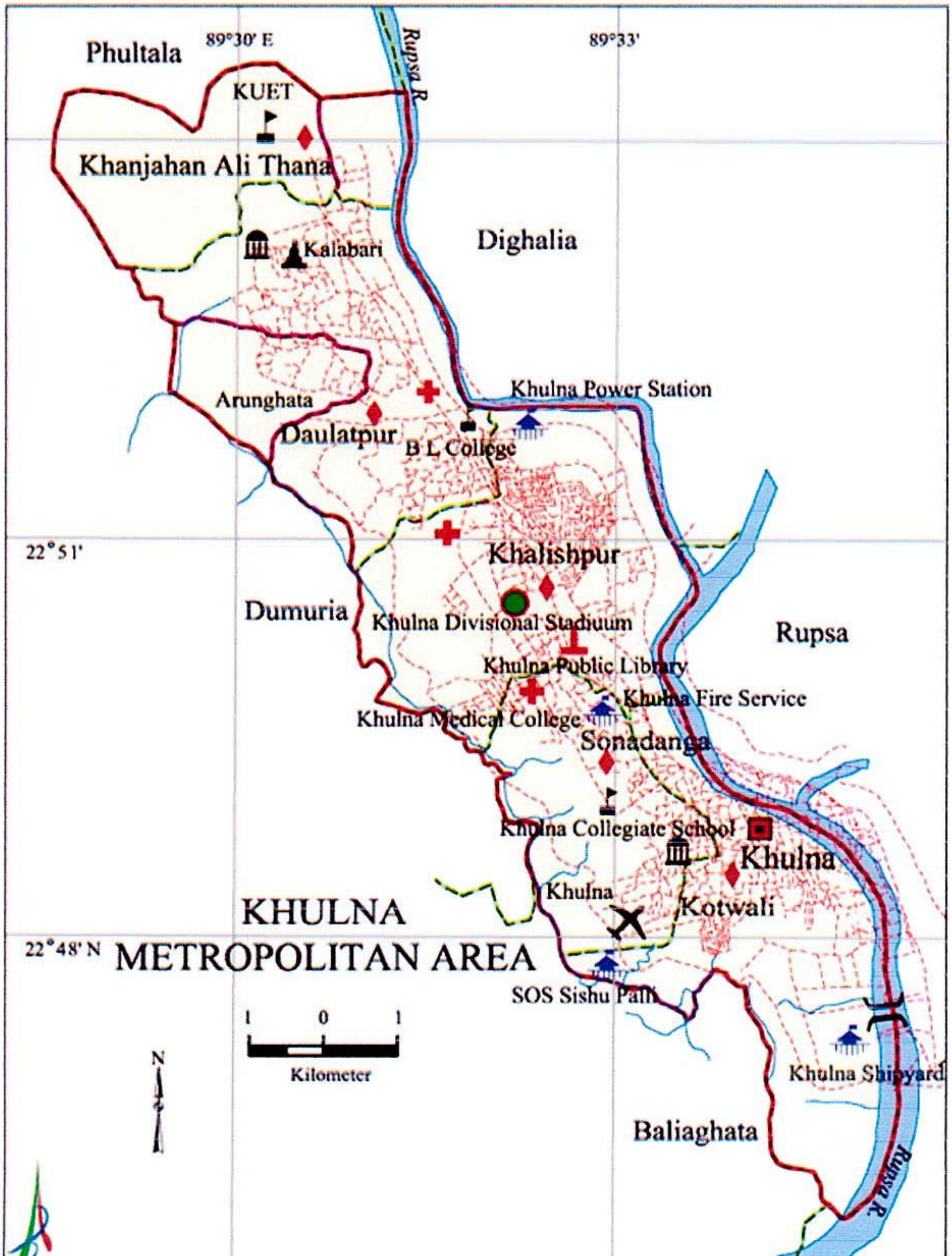


Fig-2.1 Khulna City Area Map

2.3 Cast-in-situ Piles

A cast-in-situ pile is formed by drilling a hole in the ground and filling it with concrete. The hole may be drilled or formed by driving shell or casing into the ground. The casing may be driven using a mandrel, after which withdrawal of the mandrel empties the casing. The casing may also be driven with a driving tip on the point, providing a shell that is ready for filling with concrete immediately, or the casing may be driven upon-end, the soil entrapped in the casing being jetted out after the driving is completed. The commonly available patented cast-in-situ piles are shell (cased) shell less (uncased) & pedestal type.

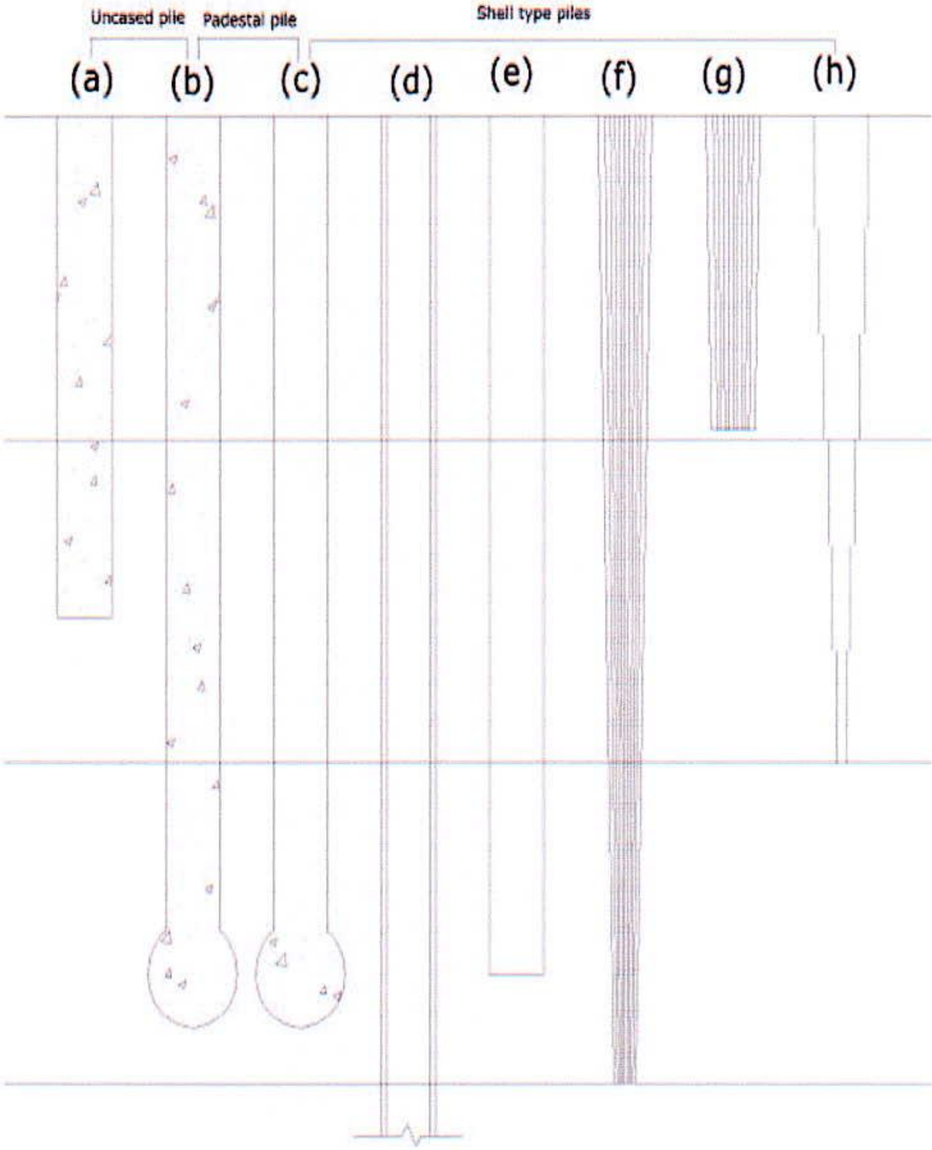


Fig-2.2. Some common types of cast-in-situ piles

2.4 The Behavior of a Pile Under Load

When a pile is subjected to a progressively increasing compressive load at a rapid or moderately rapid rate of application, the resulting load-settlement curve is as shown in fig-2.7. Initially the pile-soil system behaves elastically. There is a straight-line relationship up to some point A on the curve and if the load is released at any stage up to this point the pile head will rebound to its original level. When the load is increased beyond point A there is yielding at, or close to, the pile-soil interface and slippage occurs until point B is reached, when the maximum shaft friction on the pile shaft will have been mobilized. If the load is released at this stage the pile head will rebound to point C, the amount of 'permanent set' being the distance OC. The movement required to mobilize the maximum shaft friction is quite small and is only of the order of 3% to 1% of the pile diameter. The base resistance of the pile requires a greater downward movement for its full mobilization, and the amount of movement depends on the diameter of pile. It may be in the range of 10% to 20% of the base diameter. When the stage of full mobilization of the base resistance is reached (point D in fig2.2) the pile plunger downward without any further increase of load or small increase in load produce increasingly large settlements.

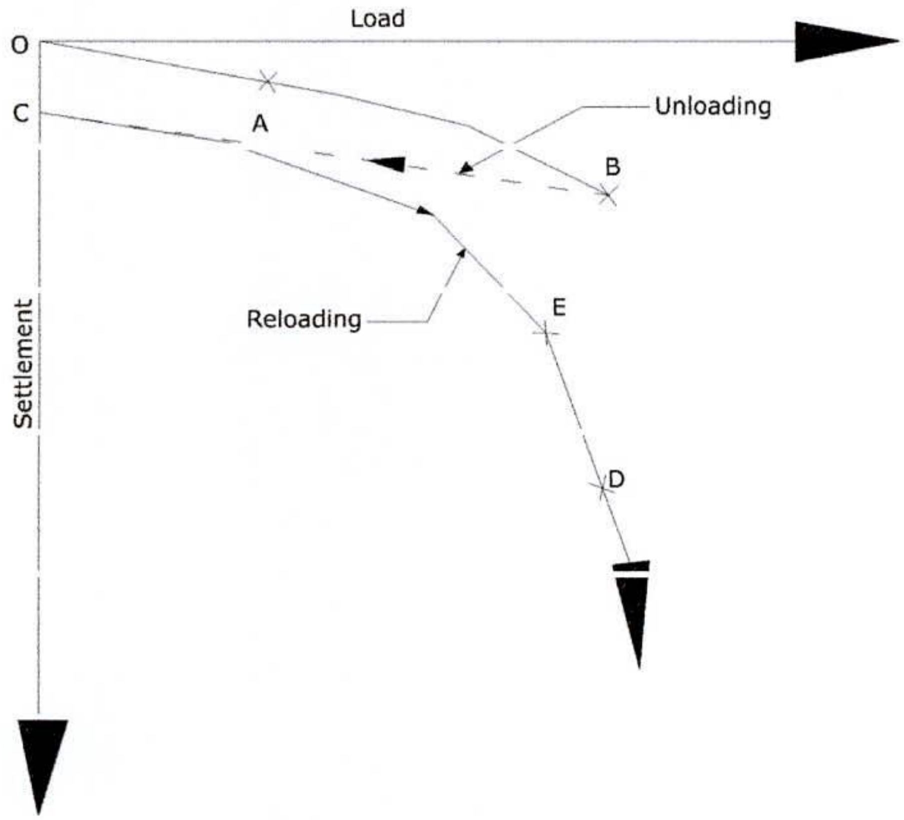


Fig-2.3 Load settlement curve

2.5 Ultimate Load Capacity from Initial Load Test

The following criteria have been recommended to determine the allowable pile capacity by Narayan V Nayak (1979, 1996):

i) The working load shall be considered minimum two-thirds of the load causing total settlement of 3 percent of pile diameter.

ii) The working load shall be considered minimum two-thirds of the load causing a net settlement of 1.5 percent of pile diameter.

iii) The working load shall be considered minimum two-fifth of the final load, in case of piles subjected to static loadings and one-third of the final load.

The allowable pile capacity should be considered minimum value among the loads obtained from the above three criteria.

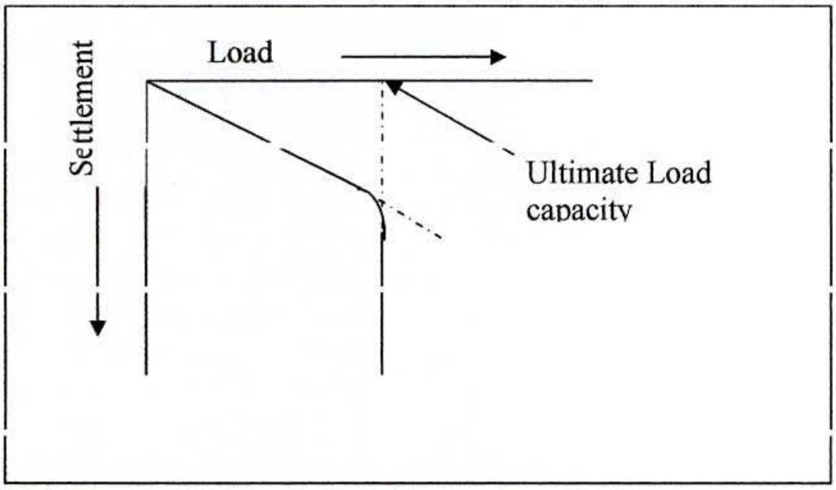


Fig-2.4 Load - Settlement Curve from Pile load Test

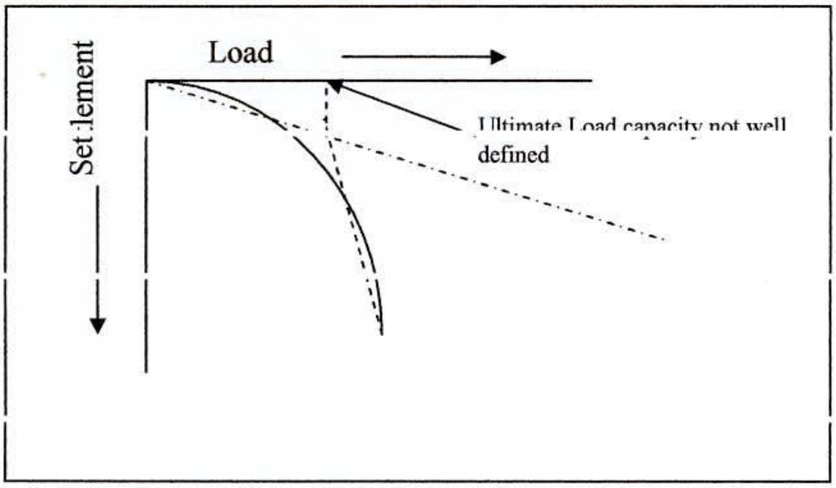


Fig- 2.5 Load - Settlement Curve from Pile Load Test

2.6 Different Existing Equation for Determination of Bearing Capacity of Pile Which is Used for Determination of Bearing Capacity of Pile for Khulna soil

For soil under cohesive group i.e., for clay & plastic silt, the skin friction & the end bearing capacities of square or circular pile may be evaluated by the following ***general formulae.***

$f_{su} = \alpha C_u$

$q_{pu} = N_c C_u$

Where. f_{su}= Ultimate skin friction

α= Adhesion factor (table given below)

C_u=q_u Undrained Shear Strength

q_{pu}= Ultimate end bearing of pile

N_c= Bearing capacity factor for deep foundation=9

α = Adhesion factor for cohesive soil (Table 2.1)

The adhesion factor is determined from the corresponding unconfined compressive strength based on the ***Peck, Hanson & Thornburn*** (1973) and are given below

Table 2.1 Adhesion factor α for cohesive soil

q_u (tsf)	α	q_u (tsf)	α	q_u (tsf)	α	q_u (tsf)	α
0.1	0.99	0.6	0.943	1.1	0.80	1.6	0.657
0.2	0.986	0.7	0.92	1.2	0.78	1.7	0.62
0.3	0.98	0.8	0.89	1.3	0.75	1.8	0.565
0.4	0.97	0.9	0.87	1.4	0.72	1.9	0.535
0.5	0.957	1.0	0.836	1.5	0.674	2.0	0.550

2.6.1 Meyerhof Suggested the Formulae for End bearing & Skin friction of Bored Pile in Non-Cohesive Soil:

For non-cohesive soil of silt, fine to medium sand the skin friction and the end bearing capacities of pile may be evaluated by the following formulae, suggested by ***Meyerhof (1956, 1976)***

f_{su}= 4N/200 tsf

q_{pu}= 4N tsf

Where, f_{su}= Skin friction

q_{pu}= End bearing of pile

N = SPT value

2.6.2 Dr. K.R. Arora Suggested the Formulae for End bearing & Skin friction of Bored Piles in Non-cohesive soil:

The load capacity of bored piles can be determined by the following formulae, suggested by ***Dr. K.R. Arora***

$Q_u = Q_p + Q_s$

$Q_p = (\bar{q} N_q) A_p$

$Qs = \sum_{i=1}^{n} (k\ \bar{\sigma}_v \tan\delta)\ A_s$

$Q_u = (\bar{q}\ N_q) A_p + \sum_{i=1}^{n} (k\ \bar{\sigma}_v \tan\delta)\ A_s$

$Q_a = Q_u / F.S$

$\bar{\sigma}_v = D_c\, \gamma\ kN/m^2$

D_c= B *(value obtained from φ vs D_c/B from Fig: 5.13)

Where, $\bar{\sigma}_v$= effective vertical pressure $\leq \bar{\gamma}\, D_c$ (from soil test report)

k= lateral earth pressure co-efficient for bored pile

An approximate value of k can be obtained from $k = 1 - \sin\emptyset$

The value of k generally varies between 0.3 to 0.75. An average value of 0.5 is usually adopted.

$\tan\delta$ = Co-efficient of friction between sand & concrete

The value of $\tan\delta$ can be taken equal to $\tan\emptyset$ (from soil test report)

A_s= Surface area of pile.

A_p= Area of pile tip.

Q_p= Point (or base or tip) resistance of pile

Qs= Shaft resistance developed by friction (or adhesion) between the soil and the pile shaft.

$\bar{q}$= effective vertical pressure at the pile toe

N_q= Bearing capacity factor for deep foundations. (Fig: 2.7)

FS=2.5

γ=unit weight of soil in the zone of the pile tip. kN/m^2 (Table- 2.2)

φ= angle of internal friction of sand (from below mentioned N- φ table)

D_c= Critical depth (Fig: 2.6)

Table 2.2 Correlation among N-value, D_r, ϕ and γ (Bowles 1997)

N value	Compactness	Relative Density, D_r %	ϕ (degree)	γ Unit weight (pcf)	γ Unit weight (kN/m^3)
1-2	Very Loose	0-15	26-28	70-100	11-16
3-6	Loose	15-35	28-30	90-115	14-18
7-15	Medium	35-65	30-34	110-130	17-20
16-30	Dense	65-85	33-38	110-140	17-22
>30	Very Dense	>85	>50	130-150	20-23

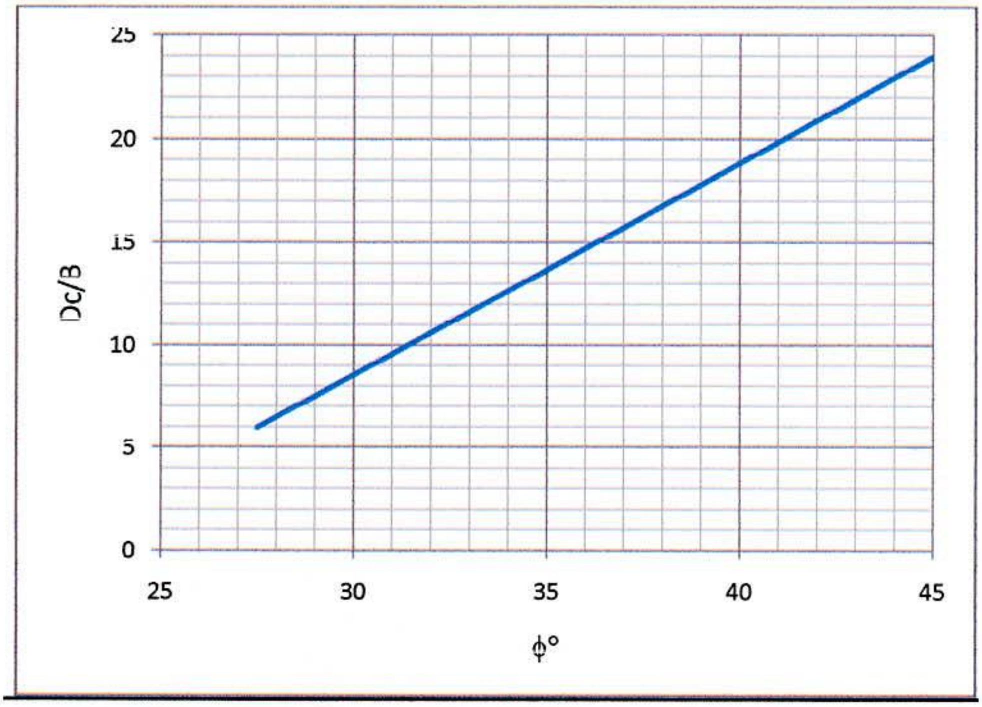


Fig. 2.6 Relation between Critical Depth & Angle of Internal Friction

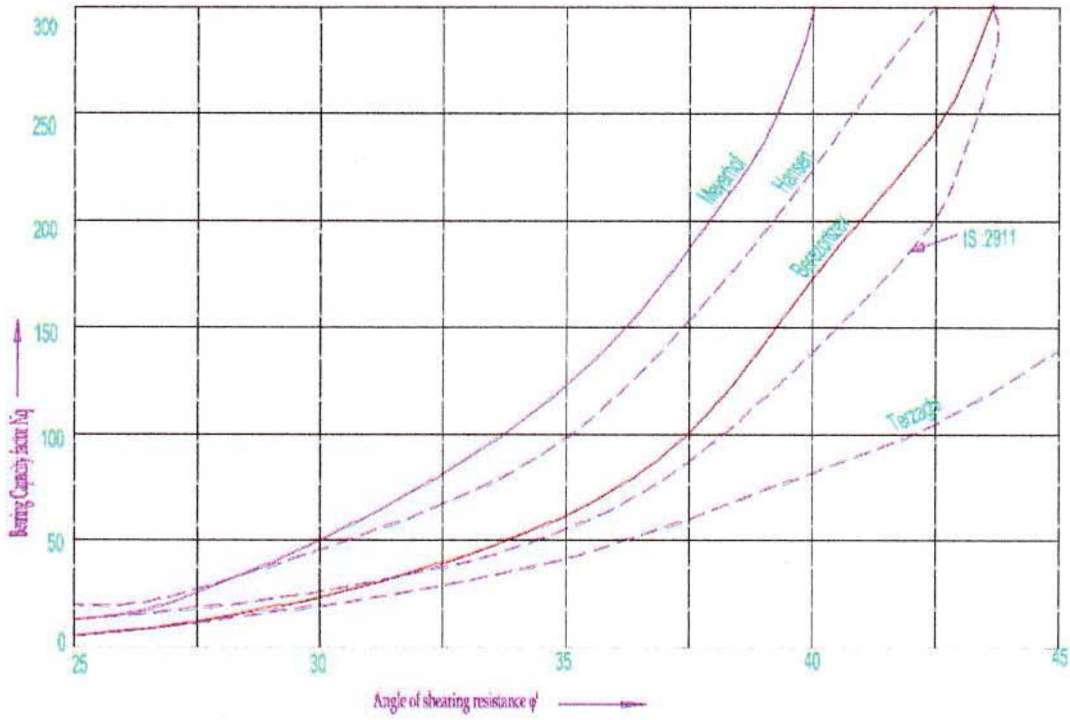


Fig. 2.7 Relation between Bearing Capacity and Angle of Internal Friction

2.6.3 Dr. K.R. Arora Suggested the Formulae for End bearing & Skin friction of Bored Piles in Cohesive soil:

The load capacity of bored piles can be determined by the following formulae, suggested by ***Dr. K.R. Arora***

$Q_u = (c\ N_c\ A_p + \propto \bar{c}\ A_s)$ kN

$Q_a = Q_u/F.S$

Where, $\propto$ = Adhesion factor

$\propto = 0.3$ for wash boring

The value of cohesion (c) should be 75% of the value obtained from the triaxial test.

N_c= Bearing capacity factor for deep foundations.

The value of the N_c depends upon the D/B ratio and it varies from 6 to 9. A value of $N_c = 9$ is generally used for the piles.

c= cohesion of the clay in the zone surrounding the pile tip. kN/m^2

$c = q_u/2$

q_u= Unconfined compressive strength (Table 2.3)

$\bar{c}$= Average cohesion along the shaft length kN/m^2

A_s= Surface area of pile.

A_p= Area of pile tip.

FS=2.5

Table 2.3 Value of Unconfined compressive strength based on N value for cohesive soils

N-value	Condition	Unconfined compressive strength q_u (tsf)
Below 2	Very soft	Below 0.25
2-4	Soft	0.25-0.50
4-8	Medium stiff	0.50-1.00
8-15	Stiff	1.00-2.00
15-30	Very stiff	2.00-4.00
Over 30	Hard	Over 4.00

2.6.4 Hansen's suggested the Formulae for End bearing of Bored Piles in Cohesive or Cohesion less Soil:

$P_{pu} = A_p (cN_c d_c + \eta \bar{q} N_q d_q + \frac{1}{2}\gamma' B_p N_\gamma)$

$A_p cN_c d_c$ = for Cohesive soil (clay)

$A_p (\eta \bar{q} N_q d_q + \frac{1}{2}\gamma' B_p N_\gamma)$ = for Cohesio less soil (sand)

c= cohesion of the clay beneath pile point. kN/m^2

$c = q_u/2$

$c = s_u$

N_c= bearing capacity factor for cohesion. A value of $N_c = 9$ is generally used for the piles.

$d_c = 1 + 0.4 \tan^{-1} L/B$ and when $\phi = 0$; $c = s_u$; $N_c' = 9$

$\eta = 1.0$

$\bar{q} = \gamma L$ = effective vertical (or over burden) pressure at pile point.

N_q= bearing capacity factor (Table: 2.4)

$d_q = 1 + 2 \tan \phi (1 - \sin\phi)^2 \tan^{-1} L/B$

γ'=unit weight of soil kN/m^3

B_p= width of pile point

N_γ= bearing capacity factor (Table: 2.4)

L= length of pile

B= dia of pile

Table 2.4 Bearing capacity factors for the Meyerhof, Hansen, and Vesic bearing capacity equations

ϕ	N_q	N_γ	$2\tan\phi(1-\sin\phi)^2$
26	11.8	7.9	0.308
28	14.7	10.9	0.299
30	18.4	15.1	0.289
32	23.2	20.8	0.276
34	29.4	28.7	0.262
36	37.7	40	0.247
38	48.9	56.1	0.231
40	64.1	79.4	0.214

2.6.5 Tomlinson proposed (1971) α Method for Skin friction of Bored Piles in Cohesive Soil:

Skin resistance= $\sum_{1}^{n} As\ fs$

As = effective pile surface computed as perimeter X embedment increment ΔL

ΔL= increment of embedment length (to allow for soil stratification and variable pile shaft perimeters in the embedment length L)
fs= skin resistance to be computed using the methods α

fs= $\alpha c + \bar{q} K \tan\delta$
Above equation is not much used in this general form but rather simply as
fs= αc or αsu
α= coefficient (Fig.2.8)
c= average cohesion for the soil stratum of interest
$\bar{q}$= effective average vertical stress
k= coefficient of lateral earth pressure ranging from k_o to about 1.75
K= $(Ka+FwK_o+Kp)/(2+Fw)$
δ=effective friction angle between soil & pile material

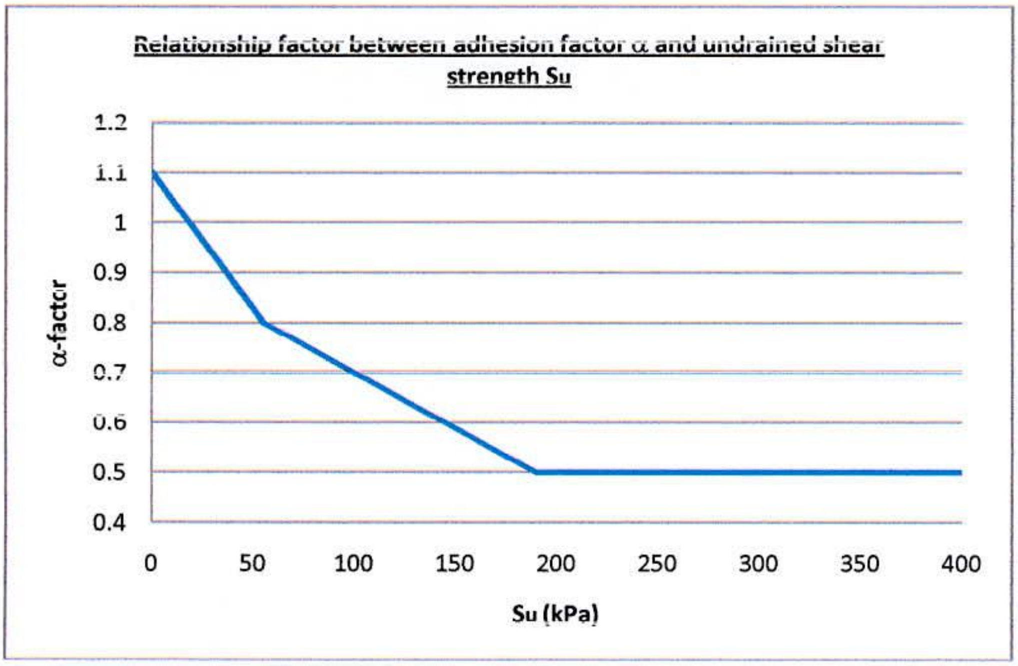


Fig-2.8 Relationship factor between adhesion factor **α** and undrained shear strength S_u

2.6.6 Burland proposed β Method for Skin friction of Bored Piles in Cohesion less Soil:

$fs = K\bar{q}\tan\delta$

Taking $\beta = k\tan\delta$ we can rewrite the equation for skin resistance as

$fs = \beta\bar{q}$

Since $\bar{q}$ = effective overburden pressure than

$fs = \beta(\bar{q} + qs)$

$K = \frac{Ka + Fw\,Ko + Kp}{2 + Fw}$ (from Table 2.5& 2.6)

$\bar{q} = \gamma h/2 = q/2 = c$

$P_{su} = p1L\bar{q}K\tan\delta$

K= coefficient of lateral earth pressure

F_w= weighting factor

q = effective overburden pressure

c= average cohesion

Table 2.5 Ranking active earth pressure coefficient K_a

β	∅=26	28	30	32	34	36	38	40	42
0	0.3905	0.3610	0.3333	0.3073	0.2827	0.2596	0.2379	0.2174	0.1982

Table 2.6 Ranking passive earth pressure coefficient Kp

β	∅=26	28	30	32	34	36	38	40	42
0	2.5611	2.7698	3.000	3.2546	3.5371	3.8518	4.2037	4.5989	5.0447

2.6.7 Vesic's Method for End bearing of Bored Piles in Cohesive or Cohesion less Soil:

$P_{pu} = A_p(cN_c d_c + \eta\,\bar{q}\,Nq'dq + \frac{1}{2}\gamma' B_p N_\gamma)$

$N'q = \frac{3}{3-\sin\emptyset}\{\exp[(\frac{\pi}{2}-\emptyset)\tan\emptyset]\tan^2(45° + \frac{\emptyset}{2})Irr^{\frac{1.33\sin\emptyset}{1+\sin\emptyset}}\}$

$Irr = \frac{Ir}{1+\epsilon v Ir}$

$I_r = \frac{G'}{c+q'\tan\emptyset} = \frac{G'}{S}$

$G' = \frac{Es}{2(1+\mu)}$

$\epsilon_v = \frac{1-2\mu}{2(1-\mu)} \frac{\sigma 1}{G}$

I_{rr}=Reduced rigidity index

I_r= Rigidity index (Table: 2.7)

ϵ_v= Volumetric strain, when undrained soil conditions exist or the soil is in a dense state. ϵ_v=0.0

$N'q$ = Bearing capacity factor

G'=Shear modulus

Es= Stress-strain modulus (or modulus of elasticity)

μ= Poisson's ratio

S= Shear strength

σ_1=Vertical pressure or Stress

Table 2.7 Ir value for different type of soil

Soil	Ir
Sand(D=0.5-0.8)	75-150
Silt	50-75
Clay	150-250

2.6.8 Janbu's Method for End bearing of Bored Piles in Cohesive or Cohesion less Soil :

$P_{pu} = A_p(cN_c d_c + \eta \bar{q} N_q' d_q + \frac{1}{2}\gamma' B_p N_\gamma)$

$A_p cN_c d_c$= for Cohesive soil (clay)

$A_p(\eta \bar{q} N_q d_q + \frac{1}{2}\gamma' B_p N_\gamma)$= for Cohesio less soil (sand)

$N_q' = (\tan\phi + \sqrt{1+\tan^2\phi})^2 \exp(2\psi \tan\phi)$

c= cohesion of the clay beneath pile point. kN/m^2

$c = q_u/2$

$c = s_u$

N_c= bearing capacity factor for cohesion. A value of N_c=9 is generally used for the piles.

$d_c = 1 + 0.4 \tan^{-1} L/B$ and when $\phi=0$; $c = s_u$; $N_c'=9$

η= 1.0

$\bar{q} = \gamma L$ = effective vertical (or over burden) pressure at pile point.

N_q'= Janbu's bearing capacity factor

$d_q = 1+2\tan\phi(1-\sin\phi)^2 \tan^{-1} L/B$

γ'=unit weight of soil kN/m^3

B_p= width of pile point

N_γ= bearing capacity factor

L= length of pile

B= dia of pile

$\Psi=60°$

2.6.9 Terzaghi's Method for End bearing of Bored Piles in Cohesive or Cohesion less Soil

$P_{pu} = A_p(cN_c s_c + \bar{q} Nq + \frac{1}{2}\gamma B N_\gamma s_\gamma)$

$N_q = \frac{a^2}{a \cos^2(45+\frac{\emptyset}{2})}$

$a = e^{(0.75\pi - \emptyset/2)\tan\emptyset}$

$N_c = (N_q - 1)\cot\emptyset$

$N_\gamma = (\frac{\tan\emptyset}{2} \frac{Kp\gamma}{\cos^2\emptyset} - 1)$

s_c, s_γ, from Table 2.8
Ka= from Table 2.9
Kp= from Table 2.10

Table 2.8 S_c, S_γ, factor

	Strip	Round	Square
s_c	1.0	1.3	1.3
s_γ	1.0	0.6	0.8

Table 2.9 Ranking active earth pressure coefficient Ka

β	ϕ=26	28	30	32	34	36	38	40	42
0	0.309	0.3610	0.3333	0.3073	0.2827	0.2596	0.2379	0.2174	0.1982
5	0.3959	0.3656	0.3372	0.3105	0.2855	0.2620	0.2399	0.2192	0.1997
10	0.4134	0.3802	0.3495	0.3210	0.2944	0.2696	0.2464	0.2247	0.2044
15	0.4480	0.4086	0.3729	0.3405	0.3108	0.2834	0.2581	0.2346	0.2129
20	0.5152	0.4605	0.4142	0.3739	0.3381	0.3060	0.2769	0.2504	0.2262
25	0.6999	0.5727	0.4936	0.4336	0.3847	0.3431	0.3070	0.2750	0.2465
30			0.8660	0.5741	0.4776	0.4105	0.3582	0.3151	0.2784
35						0.5971	0.4677	0.3906	0.3340
40								0.7660	0.4668

Table 2.10 Ranking active earth pressure coefficient Kp

β	ϕ=26	28	30	32	34	36	38	40	42
0	2.5611	2.7698	3.00	3.2546	3.5371	3.8518	4.2037	4.5989	5.0447
5	2.5070	2.7145	2.9431	3.1957	3.4757	3.7875	4.1360	4.5272	4.9684
10	2.3463	2.5507	2.7748	3.0216	3.2946	3.5980	3.9365	4.3161	4.7437
15	2.0826	2.2836	2.5017	2.7401	3.0024	3.2926	3.6154	3.9766	4.3827
20	1.7141	1.9176	2.1318	2.3618	2.6116	2.8857	3.1888	3.5262	3.9044
25	1.1736	1.4343	1.6641	1.8942	2.1352	2.3938	2.6758	2.9867	3.3328
30			0.8660	1.3064	1.5705	1.8269	2.0937	2.3802	2.6940
35						1.1239	1.4347	1.7177	2.0088
40								0.7660	1.2570

CHAPTER 3

ZONING OF KCC AREA

3.1 General

The jurisdiction area of KCC is 40.79 sqkm and the ward number is 33. KCC is bounded by Digholia Upazila and Khanjahan ali thana on the North, Batiaghata upazila on the South, Rupsha and Digholia upazila on the East and Dumuria upazila on the West as shown in Figure 3.1.

From sub-soil investigation profile, it has been found that Khulna city area is divided in two zones Zone-I & Zone-II as shown in Figure 3. Near about 129 numbers of sub-soil investigations were performed in Khulna city area. According to soil types, a common soil profile of Khulna city area was drawn as shown in Figure 3.3.

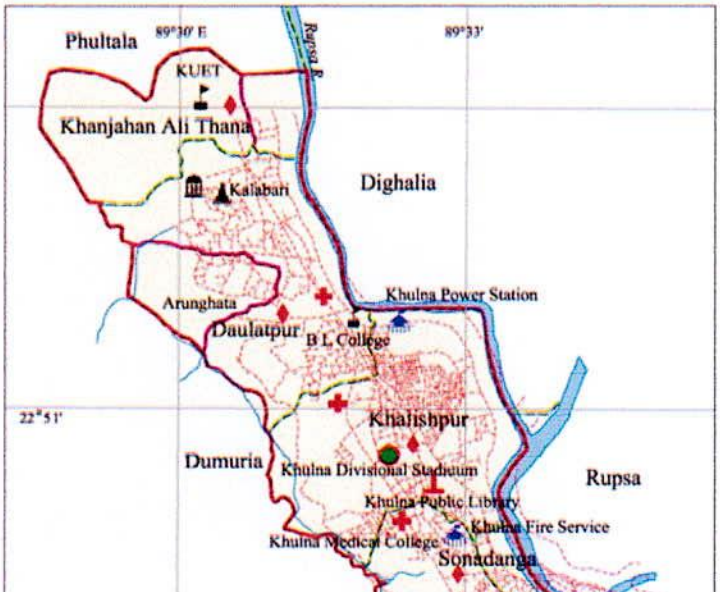


Fig-3.1 Khulna City Area Map

Fig-3.2 Location of Zone-I & Zone-II

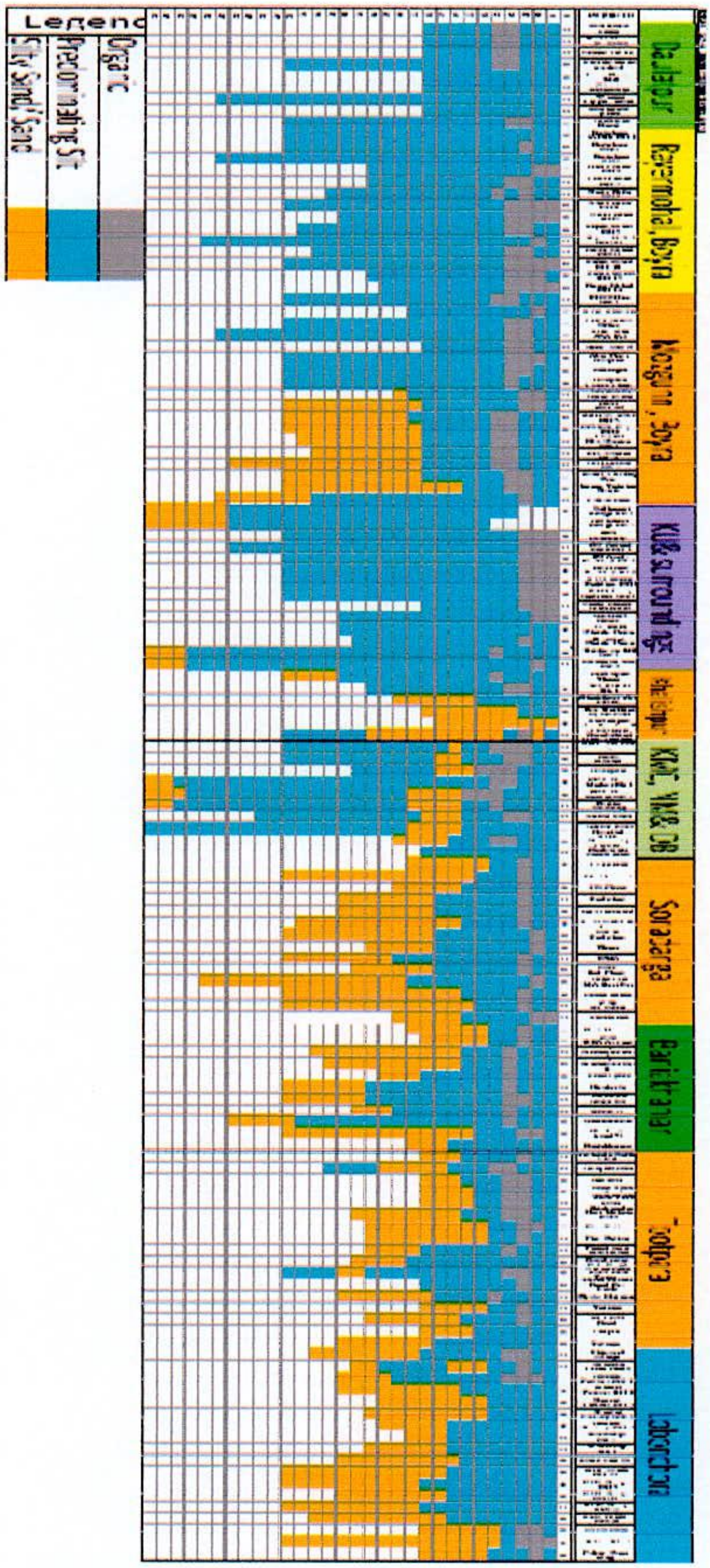


Fig-3.3 Sub-soil Profile in KCC Area

3.2 Sub-soil Condition in Zone-I

From sub-soil investigation Zone-I includes the places Daulatpur, Natun Rasta, Bastuhara, Rayer Mohal, Chalk Mathurabad & Khulna University area (see figure 3.3). The soil profile is made for Zone –I from west part of Khulna city to East part of Khulna city i.e Daulatpur to Baniakhamar.

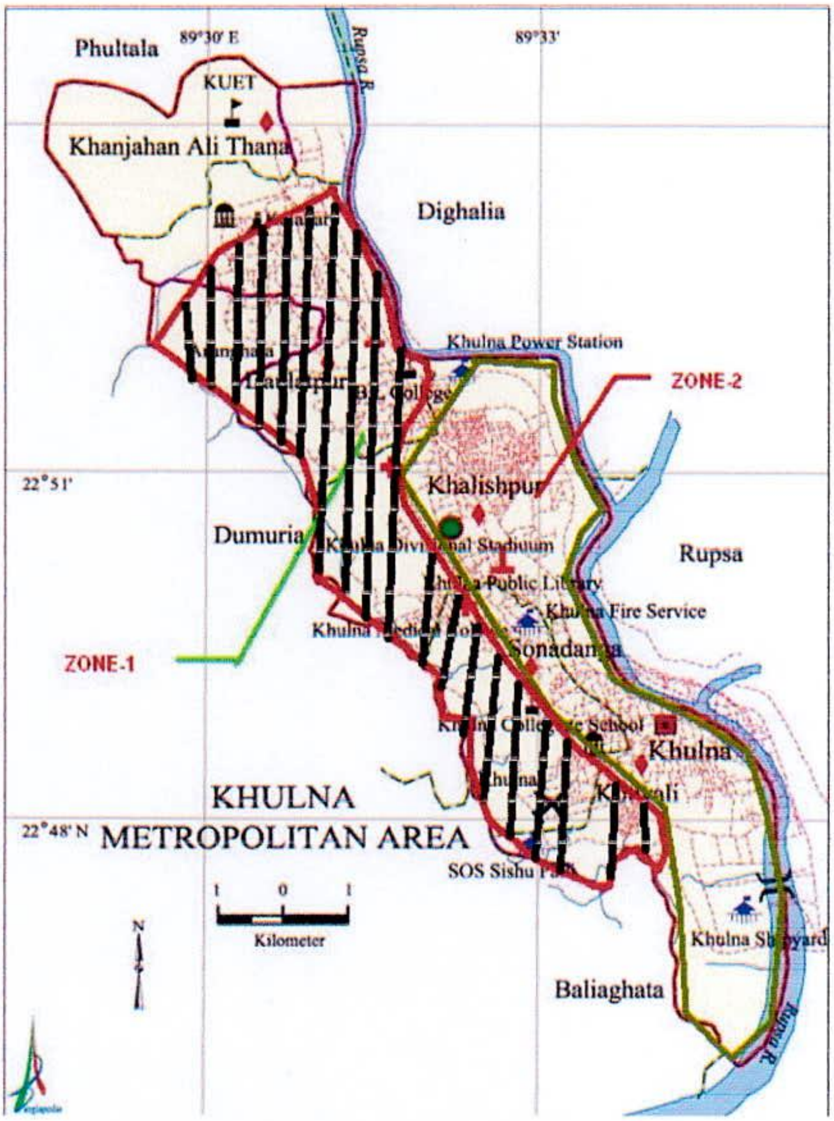


Fig-3.4 Location Map of Zone-I

A profile of soil characteristic is drawn towards Rayermahal from Daulatpur (see figure 3.5). The soil characteristics in Daulatpur were shown that there is no any sand layer up to the 125 ft depth from natural ground level. The soil contains clayey silt & some portion sandy silt. Percentage of sand & clay is near about 10% to 15%. So the sub-soil in Daulatpur may be classified as predominantly silt layer (see figure 3.5). There exists an organic layer but it is not available on the whole area of Daulatpur. The layer thickness is 10 ft and it is situated in between 15 ft to 25 ft depth. Some portions of this area contain a 10 ft to 15 ft thick fully sand layer.

In Rayermohal the sub-soil contains predominantly silt up to the depth of 130 ft from natural ground layer (see figure 3.5). There is exists a thick sand layer in between 40 ft depth to 100ft dept but it is not available in whole area of Rayermohal. From Bastuhara to Gazir bhita a thick sand layer depth 20 ft to 30 ft is exists in between 45 ft to 70 ft depth. Some area on Rayermahal contains a thick layer of sand in sub-soil, depth 25 ft to 35 ft and it is exists in between 55 ft to 100 ft depth. There is present some clay & sand in silt but the percentage of clay & sand too little i.e not more than 20%. So it may called predominantly silt. Organic layer is also present all over the whole area and the layer thickness is 5 ft to 25 ft. The organic layer is present from in between natural ground level to 25 ft depth.

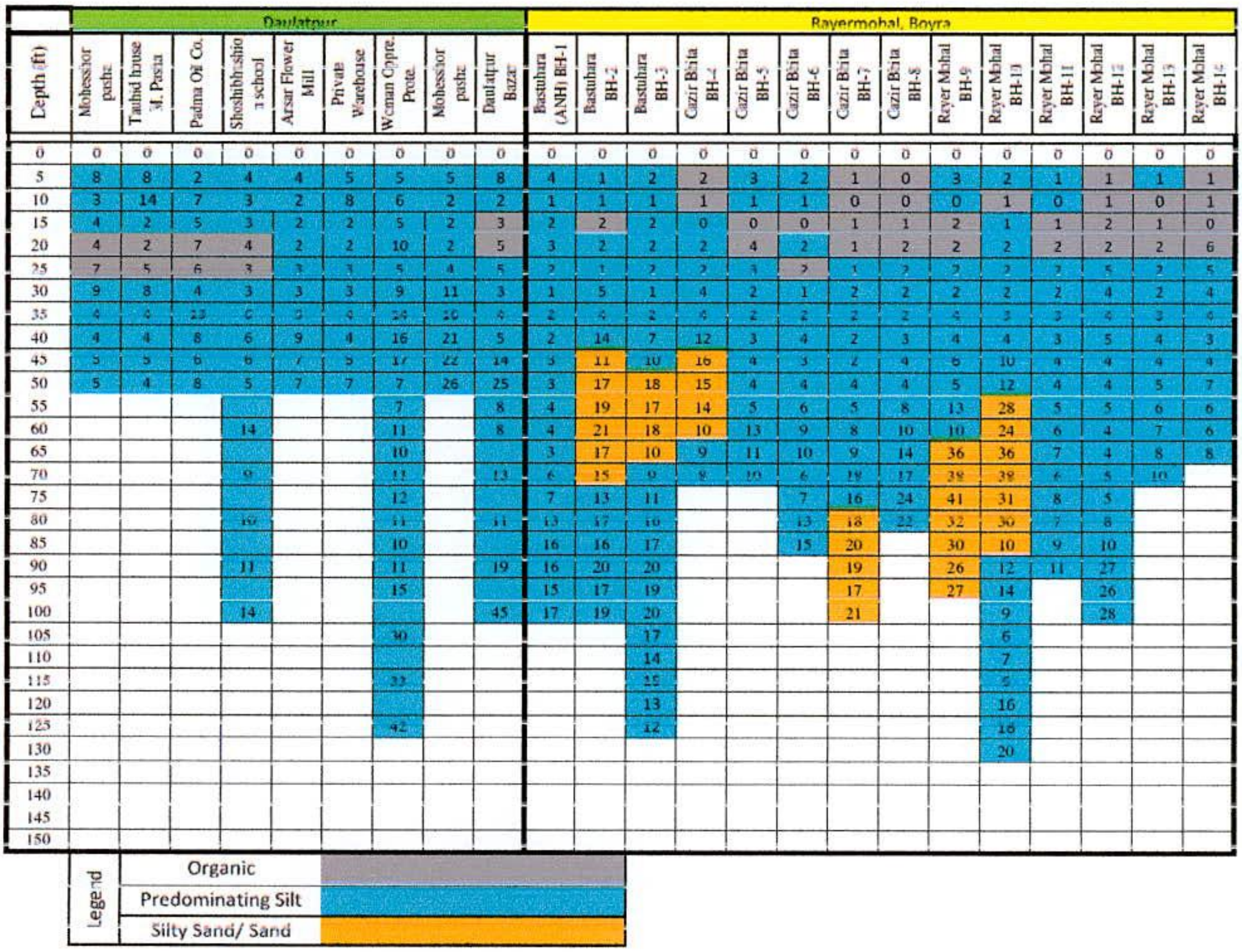


Fig-3.5 Sub-soil Profile towards Rayer Mohal from Daulatpur

Mozguni, Boyra is divided in two zones. Zone-I contains fully predominantly silt from existing ground level to 125 ft depth (see figure 3.6) and Zone-II contain up to the depth 50 ft from natural ground level is predominantly silt than started sand layer. There is exists all over the whole area a thick organic layer, thickness 5 ft to 10 ft. And the organic layer started from 5 ft depth of natural ground layer.

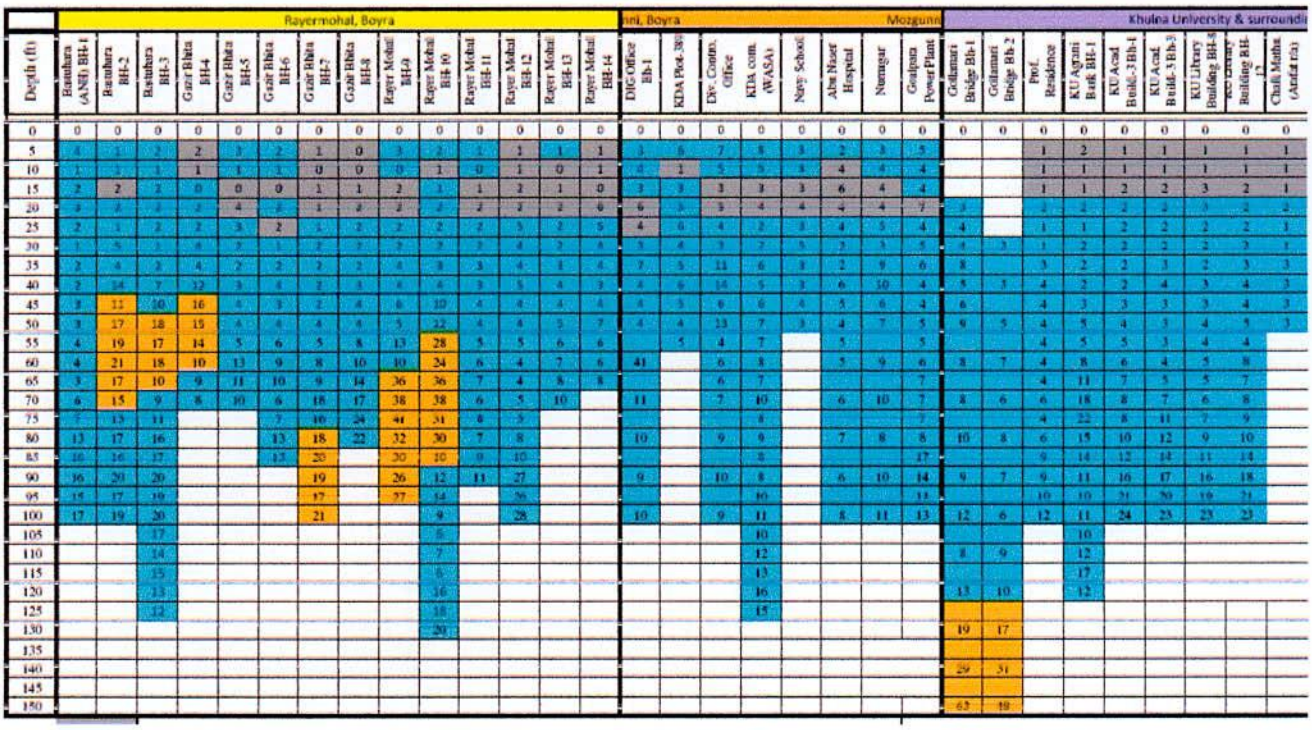


Fig-3.6 Sub-soil Profile of Mozgunni, Boyra

Khulna University & its surrounding are situated in Chalk Mathurabad Mouza. The soil layer of this area contains fully predominating silt up to the depth of 120 ft from natural ground level (see figure 3.7). There is exists a fully sand layer below the depth 120 ft from ground level. Also a thick organic layer is available in between natural ground level to 25 ft depth. All over the area the thickness of organic layer is not same.

	Mozgunni, Boyra								Khulna University & surroundings													
Depth (ft)	DIG Office Bh-1	KDA Plot-389	Div. Contro. Office	KDA con. (WASA)	Navy School	Abu Naser Hospital	Nurnagar	Goalpara Power Plant	Gellamari Bridge Bh-1	Gellamari Bridge Bh-2	Prof. Residence	KU Agrani Bank BH-1	KU Acad. Build.-3 Bh-1	KU Acad. Build.-3 Bh-3	KU Library Building BH-8	KU Library Building BH-12	Chalk Mathu. (Arafat r/a)	Endadul House	Z point Chrish. Nagar	Z point Chrish. Nagar	Bridge on MR Bh-1	Bridge on MR Bh-4
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3	6	7	8	3	2	3	5			1	2	1	1	1	1	1	2	3	6	2	2
10	4	1	5	5	3	4	4	4			1	1	1	1	1	1	1	3	2	2	2	2
15	3	3	3	3	3	6	4	4			1	1	2	2	3	2	1	5	2	2	2	2
20	6	5	5	4	4	4	4	7	3		2	2	2	2	3	2	2	4	3	3	2	2
25	4	6	4	2	3	4	5	4	4		1	1	2	2	2	2	1	4	3	2	2	2
30	3	4	3	2	5	3	3	5	4	3	1	2	2	2	2	3	1	4	2	2	2	2
35	7	5	11	6	3	2	9	6	8		3	2	2	3	2	3	3	2	2	1	3	2
40	4	6	14	5	3	6	10	4	5	3	4	2	2	4	3	4	3	3	3	3	3	3
45	4	5	6	6	4	5	6	4	6		4	3	3	3	3	4	3	4	4	4	5	4
50	4	4	13	7	3	4	7	5	9	5	4	5	4	3	4	5	3	4	4	3	8	3
55		5	4	7		5		5			4	5	5	3	4	4		4	6	3	4	4
60	41		6	8		5	9	6	8	7	4	8	6	4	5	8		4	8	5	5	4
65			6	7				7			4	11	7	5	5	7			12	4	6	5
70	11		7	10		6	10	7	8	6	6	18	8	7	6	8		3	16	3	7	5
75				8				7			4	22	8	11	7	9		5	15	4	14	6
80	10		9	9		7	8	8	10	8	6	15	10	12	9	10			15		8	7
85				8				17			9	14	12	14	11	14					12	8
90	9		10	8		6	10	14	9	7	9	11	16	17	16	18					13	8
95				10				11			10	10	21	20	19	21					14	10
100	10		9	11		8	11	13	12	6	12	11	24	23	23	23					7	10
105				10								10									7	10
110				12					8	9		12									8	10
115				13								17									8	10
120				16					13	10		12									8	11
125				15																	9	10
130									19	17											9	10
135																					11	10
140									29	31												28
145																						
150									63	48												

Legend	
Organic	
Predominating Silt	
Silty Sand/ Sand	

Fig-3.7 Sub-soil Profile of Khulna University & Surrounding

3.3 Sub-soil Condition in Zone-II

According to sub-soil investigation report the Zone-II is touched the places, Khalishpur, Rayer Mahal, Khulna medical college, Sonadanga, Baniakhamar, Tootpara & Lobon chora area (see figure 3.8). The soil profile is made for Zone –II from North-West part of Khulna city to South part of Khulna city i.e Khalishpur to Lobonchora. In this zone sub-soil layer contain predominantly silt from natural ground level 50 ft depth. Below the 50 ft depth from natural ground level the soil consists of mainly sand. All over this region a layer of organic clay exists in between natural ground to 25 ft depth (see figure 3.9).

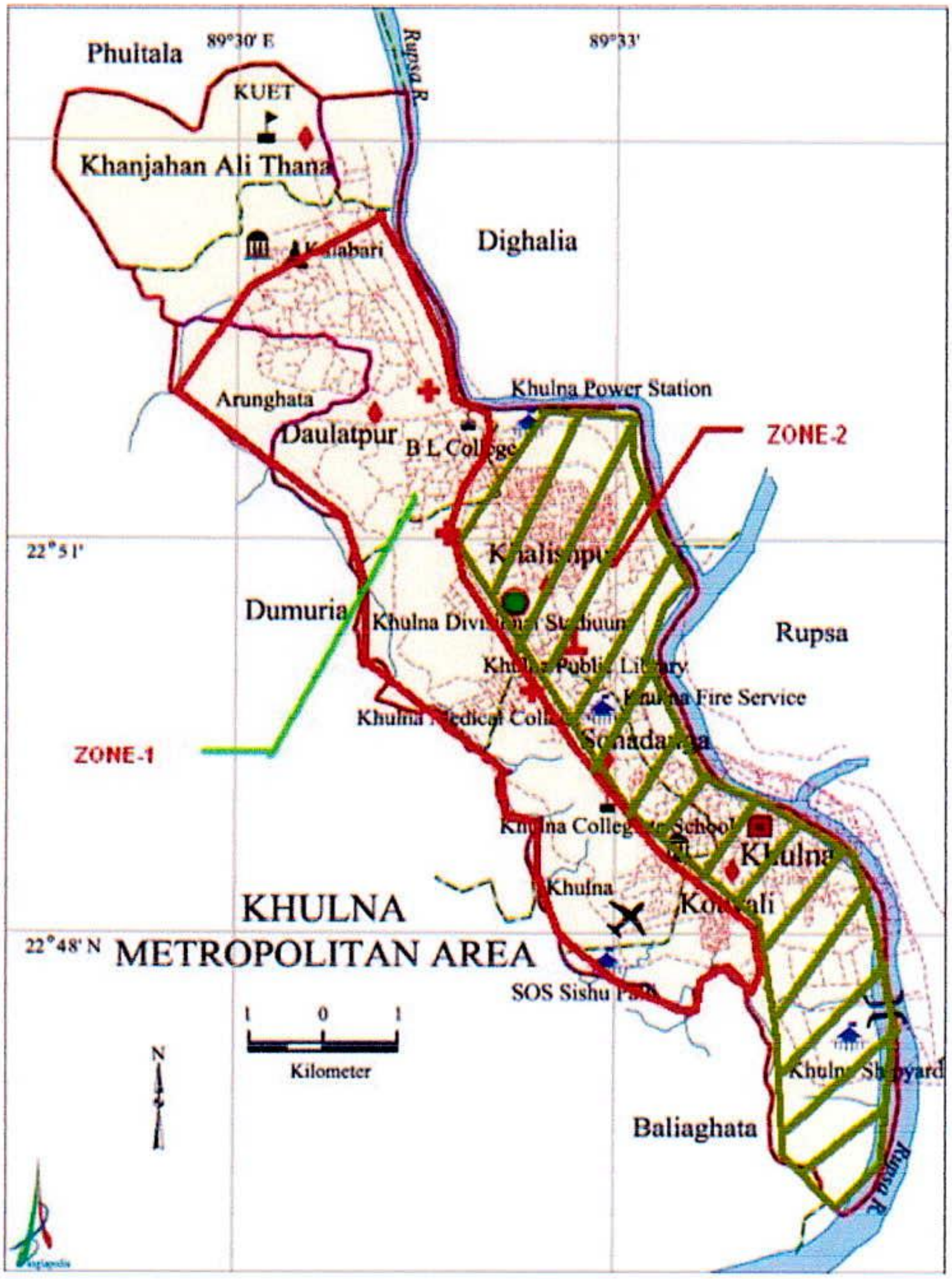


Fig-3.8 Location Map of Zone-II

A profile of soil characteristic is drawn towards Khulna Medical College from Khalishpur (see figure 3.8). The soil characteristics in Khalishpur were seen that there is exists predominantly silt & fully sand layer. Predominantly silt is exists in various layer. In some places predominantly silt started from natural ground level & some places sand layer started from natural ground level. The silt layer started from gound level to 80 ft depth. In some portions the sand layer started from ground level to 70 ft depth. There were seen in sub-soil stratification a thick organic layer is present. Organic layer is not present all over the area. At those places where this layer is present, it exists in between 10 ft to 25 ft and the thickness 5 ft to 10 ft.

In Khulna Medical college area the predominantly silt is started from natural ground level to the 150 ft depth (see figure 3.9). There exists a thick layer of fully sand. The thickness of sand layer is variable. It is started from 5 ft to 20 ft thick. This layer is exists in between 35 ft to 60 ft depth from existing ground level. Also an organic layer is present all over this area. The thickness of organic layer is variable. Thickness started from 5 ft up to 15 ft. And the organic layer is exists in between 15 ft to 35 ft depth.

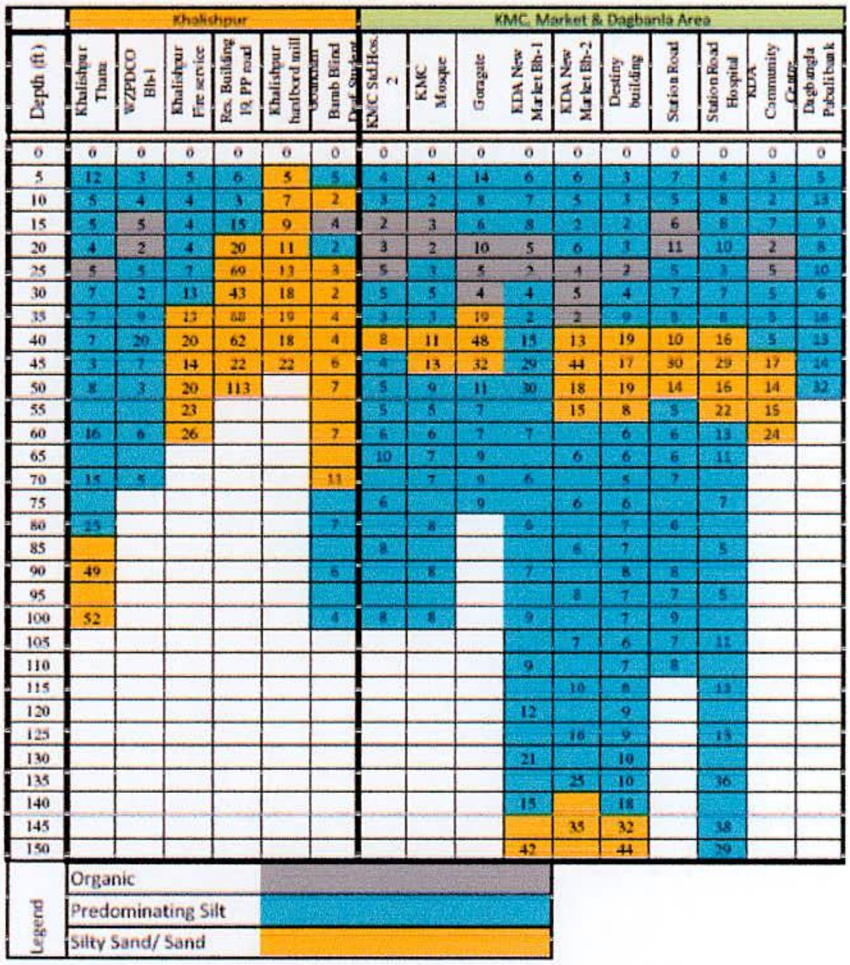


Fig-3.9 Sub-soil Profile of Khalishpur & Khulna Medical College

In sonadanga and Baniakhamar area the sub-soil stratification was done. A soil charecterisics profile made (see in figure 3.10) . The sub-soil contain in this area Predominantly silt layer, Sand layer and an Organic layer. Predominantly sand layer was found from natural ground level to 60 ft depth. Sand started from the 30 ft depth to 130 ft. And the sand layer thickness is about 100 ft. The organic layer thickness all over the sonadanga & Baniakhamar area is 5 ft. And the layer is exists in between natural ground level to 15 ft depth.

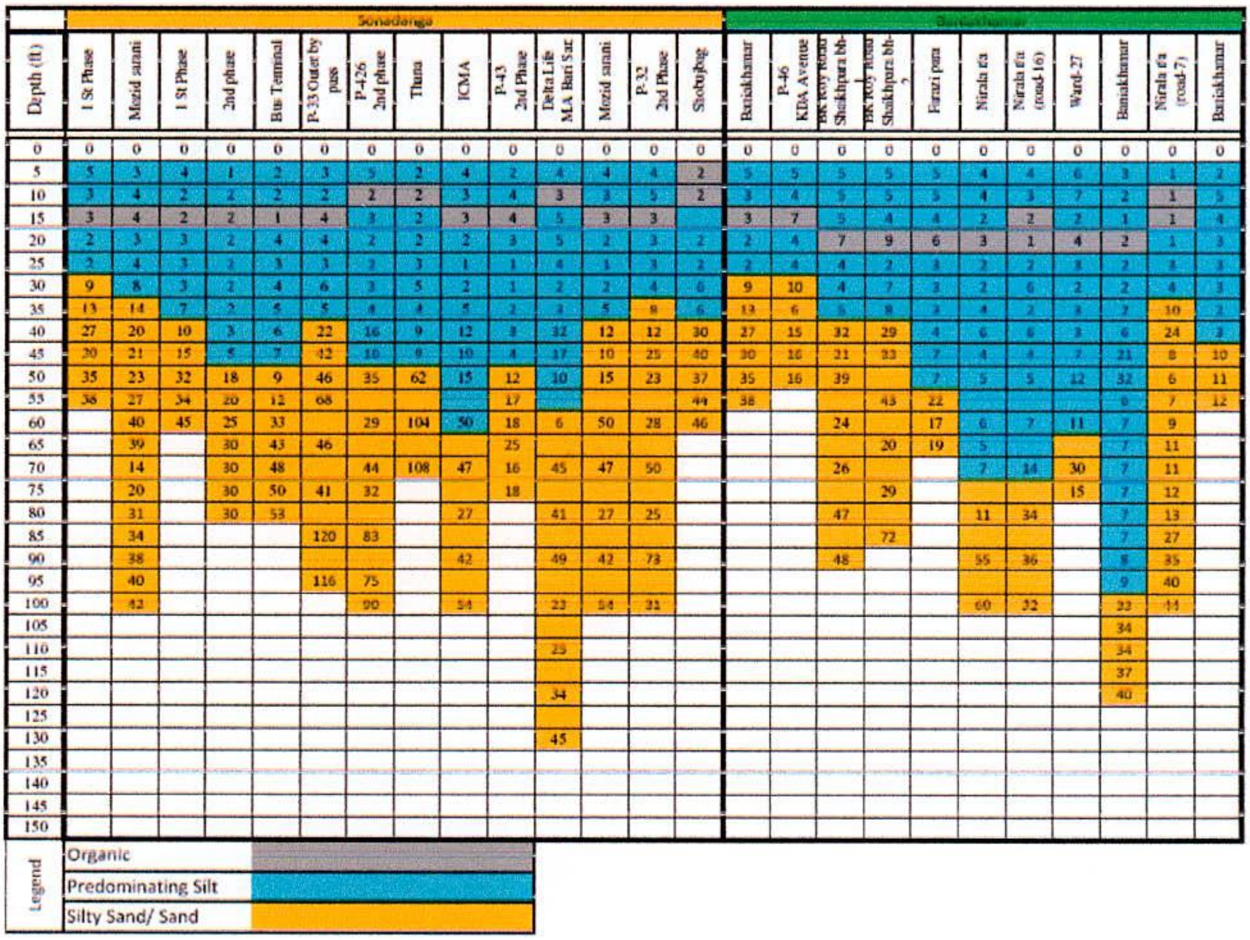


Fig-3.10 Sub-soil Profile of Sonadanga & Baniakhamar

In Tootpara area the soil contain An Organic layer, predominantly silt & Sand layer (see in figure 3.11). Predominantly sand layer started from existing ground level to 70 ft. A sand layer is exists from 30 ft depth to 80 ft depth. Thickness of predominantly silt layer is average 40 and the thickness of sand layer is about 50 ft. An organic layer which thickness 5 ft to 10 ft. It is exists in between 5 ft to 25 ft depth.

	Tootpara																
Depth (ft)	Helatola Goffar Store	Sir Iqbal road	Helatola	Babu Khan Road Shishusadan	Babu Khan Road Shishusadan	Hazi Mohsin Road	Fire Station	Fire Station	Farazi para Moylapota	Royal more Kakalibagh	Gagan Babu Road Hadi Tower	Ahsan Ahmed Road Dr. Lucky	Choto Mirjapur	Tutpara	TB Cross Road	Tutpara	Tutpara
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6	5	6	7	8	6	7	7	4	5	3	6	5	3	1	1	5
10	3	7	3	7	7	5	2	3	4	5	3	5	4	1	2	5	5
15	5	4	5	4	5	4	2	4	5	2	1	5	4	1	2	2	1
20	4	5	3	5	6	4	3	4	3	5	4	2	3	2	1	3	2
25	4	5	6	5	5	2	3	4	4	4	2	4	2	2	2	1	3
30	3	4	3	6	6	2	3	2	3	4	1	4	4	15	3	6	4
35	4	5	3	9	6	5	3	6	3	4	3	4	5	20	5	8	5
40	7	7	9	19	20	15	18	10	4	6	6	5	5	17	18	12	7
45	9	11	19	21	20	12	16	13	5	7	5	7	6	19	22	18	9
50	10	17	8	15	17	9	15	17	6		10	4	8	20	13	26	15
55		33				31			11	5			9		15		14
60						18	30	29	16	15	18		10		15		16
65		12				32			17				13		23		20
70						14	11	35	28	28	14		18		26		26
75		19				25				22			30				30
80											38		36				35
85		17															
90											10						
95																	
100											13						
105																	
110																	
115																	
120																	
125																	
130																	
135																	
140																	
145																	
150																	

Legend	
Legend	
Predominating Silt	
Silty Sand/ Sand	

Fig-3.11 Sub-soil Profile of Tootpara

Lobonchora is the south part of KCC area and moreover it is situated on the bank of Rupsha River. Sub-soil investigation was done in this area and made the sub-soil profile (see figure 3.12). In this region the soil condition is good. Predominantly silt layer started from natural ground level and its depth average is 50 ft depth. Sand layer started from 30 ft to 90 ft. There is no Organic layer except some places.

	Lobonchora																	
Depth (ft)	Shipyard college	Shipyard Crane sheed	Cement Factory BH-1	Cement Factory BH-2	Cement Factory BH-3	Cement Factory BH-5	Cement Factory BH-4	Workshop Bh-7	Workshop Bh-1	Achia Fish co.	RAB Comp. BH-01	RAB Comp. BH-5	RAB Comp. BH-15	RAB Comp. BH-23	RAB Comp. BH-36	Police Phari	Police Phari	Police Cons. bldg.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	2	1	4	4	5	3	3	2	5	2	2	3	1	1	2	2	2	2
10	2	5	2	2	2	3	2	3	2	2	2	3	1	1	2	2	2	2
15	2	2	3	2	2	3	2	1	2	2	2	3	1	1	1	2	3	4
20	2	5	2	8	2	3	3	4	4	2	2	3	2	1	1	3	2	
25	5	2	2	3	3	2	3	1	2	4	3	2	1	2	2	2	4	3
30	7	10	2	3	6	11	6	3	11	8	3	6	5	5	2	11	4	3
35	12	24	3	4	11	8	6	14	10	11	9	7	3	3	2	7	10	4
40	9	7	2	6	11	7	5	11	9	16	12	5	5	8	2	8	5	4
45	3	5	4	8	11	10	13	17	13	19	16	8	9	3	12	15	26	7
50	7	7	4	15	11	14	21	6	14	19	15	9	11	9	15	17	14	7
55		8	8	8	22	20	18	15		23							17	
60	15	7	4	4	28	14	17		22	25	28	19	39	42	37		22	
65		10	12	8	20	14	13			26								
70	22	21	15	21		21			36	29	39	60	46	25	43		10	
75		31	32	18						30								
80	51		23	29						31	112	73	49	16	35		44	
85																		
90	43										28	104		18	36		42	
95																		
100											31	85		21			40	
105																		
110																		
115																		
120																		
125																		
130																		
135																		
140																		
145																		
150																		

Legend	Legend	
	Predominating Silt	
	Silty Sand/ Sand	

Fig-3.12 Sub-soil Profile of Lobonchora

CHAPTER 4

FIELD TEST FOR PILE CAPACITY

4.1 General

In Khulna city area from sub-soil investigations, according to soil characteristics the area is divided in two zones. The zones are Zone-I & Zone-II. 7(seven) numbers of situ pile are casted in Zone-I and 3 (three) numbers of situ piles area casted in Zone-II. Total 10 (ten) numbers of pile load test were performed in Khulna city. 7 (seven) numbers of load test were done in Zone-I and 3 (three) numbers load test were done in Zone-II.

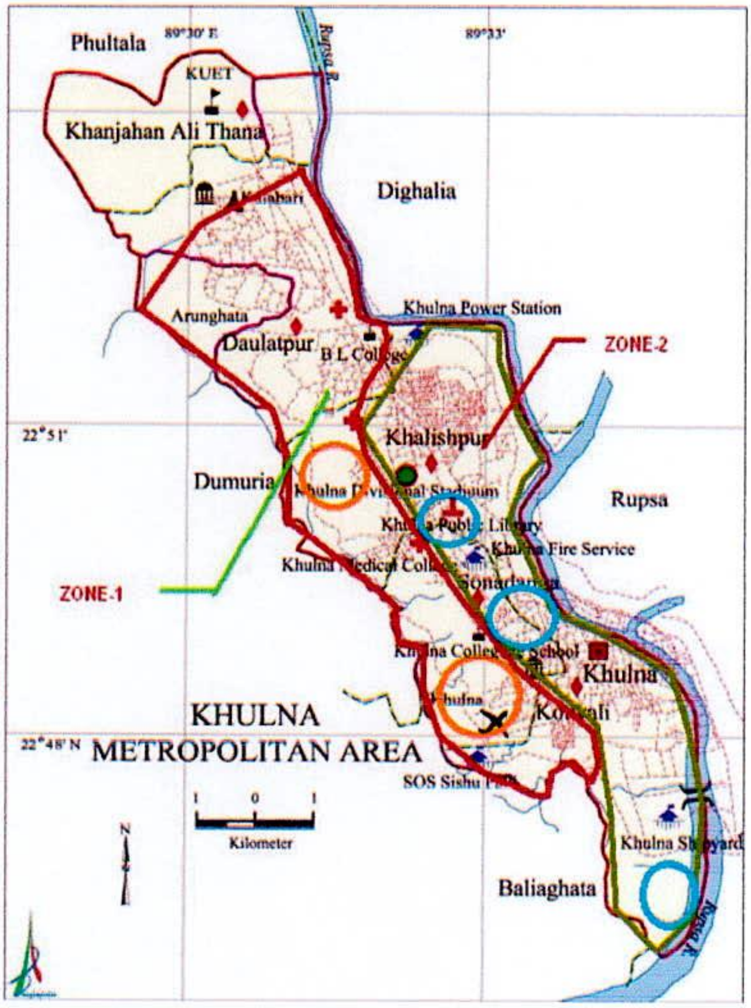


Fig-4.1 Pile Load test points In Zone-I & Zone-II

4.2 Static Pile Load Test

Static Pile Load Test is one of the most common methods to determine the actual in-situ capacity of a pile.

The test program involves the direct measurement of pile head displacement in response to a physically applied load. The test pile was loaded using a calibrated hydraulic jack that applies the test load to the pile by pushing against a beam placed directly over the test pile. The test beam was restrained by an anchorage system consisting of reaction piles installed in the adjacent ground to provide tension resistance (see diagram). From load test frame the hydraulic jack applied the test load in a series of increments according to the testing requirements. Each load was holed for a predetermined amount of time until either twice the design load or pile failure is reached, whichever comes first. Pile movement is recorded with each incremental load and the results are typically presented in a graphical format.

Piles have been tested for compression. By providing actual capacity and deflection values, the test results has been used to confirm that the pile design load can be adequately supported. Depending on the test pile's performance, the results may also allow for project cost savings by permitting an increase in the pile design load, a reduction in the overall pile length, and a quantification of capacity in difficult or unknown soil conditions.

4.2.1 Brief of Static Pile Load Test

Procedures for conducting axial compressive load tests on piles are presented in **ASTM D 1143** — Standard Test Method for Piles under Axial Compressive Load.

The pile load test can take a considerable amount of time and effort to properly set-up.

The location of the pile load tests should be at the most critical area of the site, such as where the bearing stratum is deepest or weakest. The first step involves driving or installing the pile to the desired depth. The next step is to install the anchor piles, which are used to hold the reaction frame in place and provide resistance to the load applied to the test piles.

The most common type of pile load test to determine its vertical load capacity is the simple compression load test. A schematic set-up for this test is shown in Fig. 4.2 to 4.4 and includes the test pile, test beam, hydraulic jack, load cell, and dial gauges. Figure 4.3 to 4.4 shows an actual load test where the reaction frame has been installed on top of the anchor piles and the hydraulic loading jack is in place. A load cell is used to measure the force applied to the top of the pile. Dial gauges, such as shown in Fig.3.8 & 3.9, are used to record the vertical displacement of the piles during testing. As the load is applied to the pile, the deformation behavior of the pile is measured. The pile is often subjected to a vertical load that is at least two times the design value.

In most cases, the objective is not to break the pile or load the pile until a bearing capacity failure occurs, but rather to confirm that the design end-bearing parameters used for the design of the piles are adequate. The advantage of this type of approach is that the piles that are load-tested can be left in-place and used as part of the foundation. Figure 3.10 presents the actual load test data for the pile load test shown.

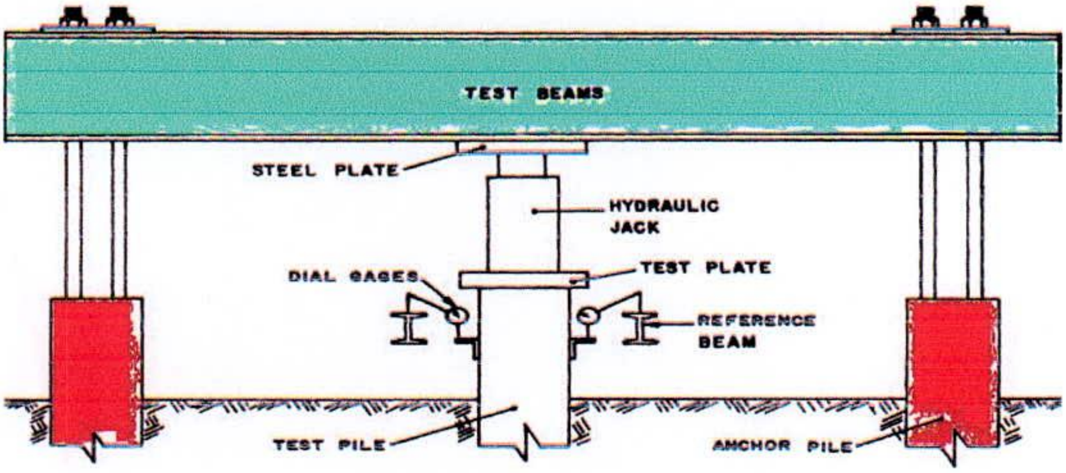


Fig-4.2 Schematic set-up for Pile Load Test

Fig-4.3 Static Pile Load Test

Fig-4.4 Static Pile Load Test

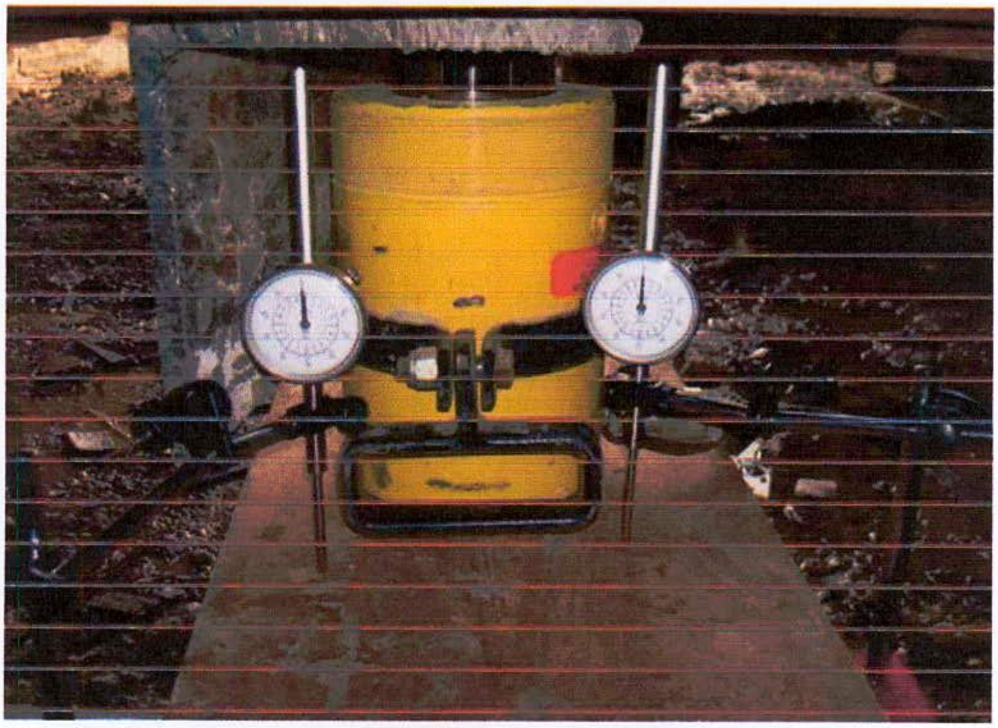


Fig-4.5 Hydraulic jack & dial gauge

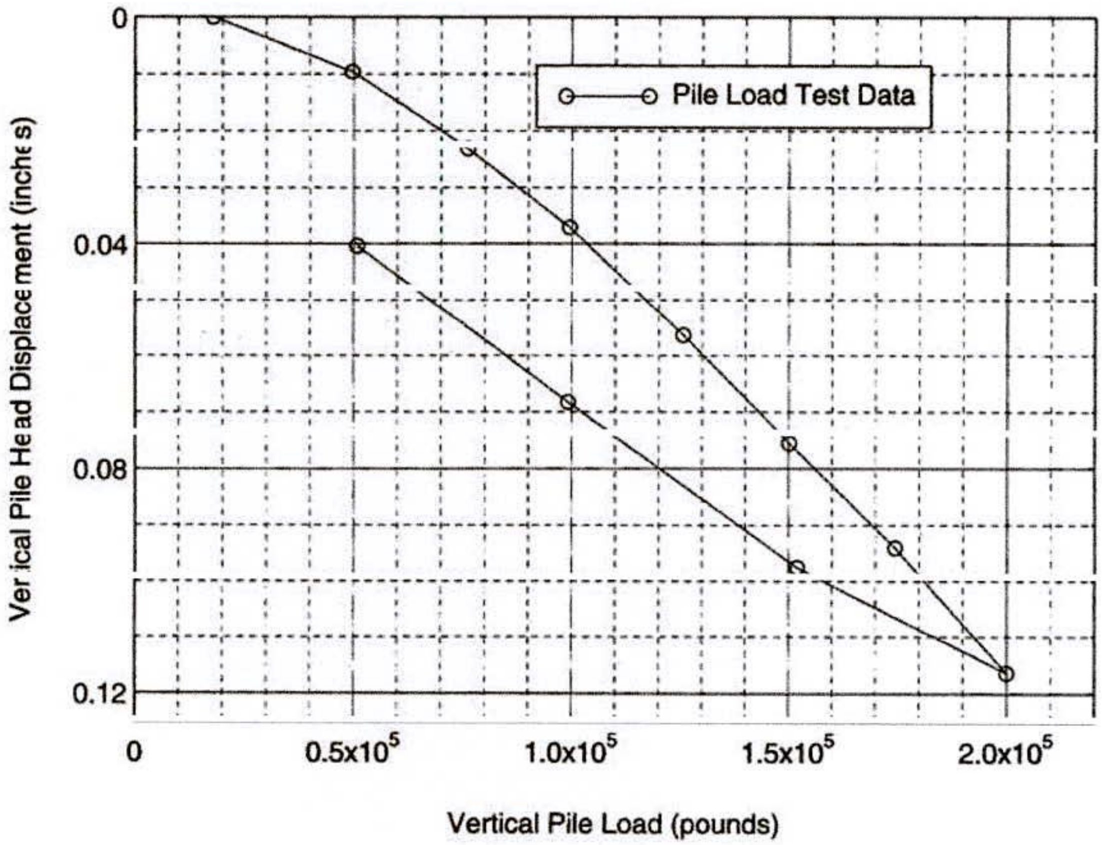


Fig-4.6 Load Settlement curve

4.2.2 Caring Capacity of Cast-in-situ Pile from Static Pile load Test

To find out the carrying capacity of Cas-in-sity pile, 10 (ten) numbers of static pile load test were done at various place in Khulna city. The places are Bastuhara, in between Basuhara & Rayer mohal, Rayer Mohal, Chak mathurabad, Khulna Medical college, Sonadanga R/A, Khulna Medical college campass and at Lobonchora. From load-settlement curve the ultimate capacity of pile cannot be obtained because most of the piles practically were not been failed in static load test. The applied load was 200% of design load.

4.3 Pile Load Test on a Pile at Bastuhara Bridge

A pile load test was done on a pile at Bastuhara Bridge. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.6 and the Load versus net settlement curve is shown in Fig. 4.8. The situ pile diameter was 750 mm & length was 30.60 m. The Test load was 982.42 kN. After completion the load test the max settlement was found 8.704 mm and the net settlement was 7.01mm. The pile was not failed for applied 982.42 kN load. From Load versus Net settlement Curve, in respect of 6 mm net settlement. we found the ultimate load is 980 kN

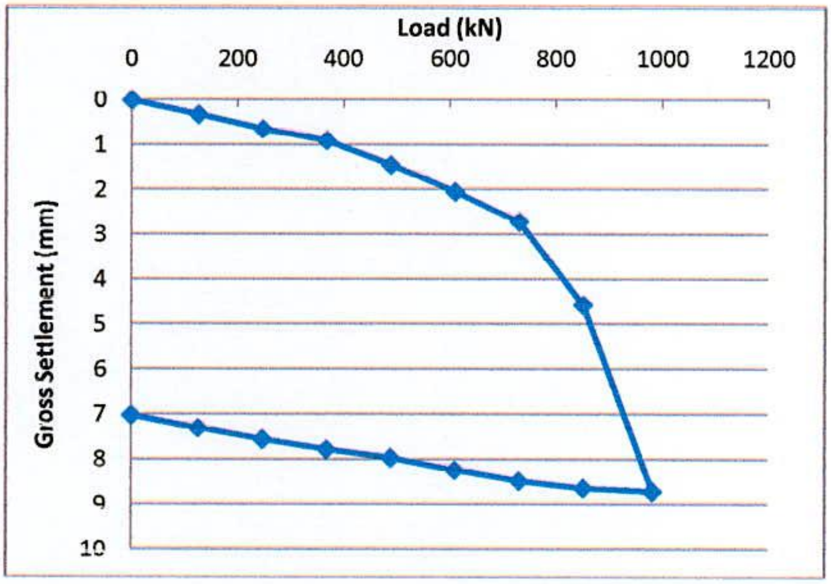


Fig-4.7 Load versus Gross Settlement Curve of a Pile at Bastuhara Bridge

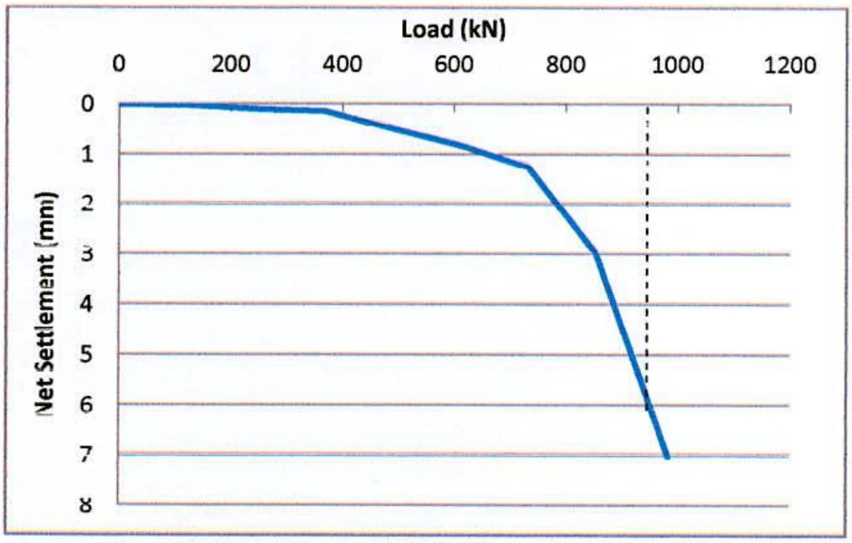


Fig-4.8 Load versus Net Settlement Curve of a Pile at Bastuhara Bridge

4.4 Pile Load Test on a Pile at a Location in Between Bastuhara and Rayer Mahol Area

A pile load test was done on a pile at a location in between Bastuhara and Rayer Mahol area. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.9 and the Load versus net settlement curve is shown in Fig. 4.10. The situ pile diameter was 750 mm & length was 30.10 m. The Test load was 982.442 kN. After completion the load test the max settlement was found 8.99 mm and the net settlement was 7.401mm. The pile was not failed for applied 982.42 kN load. From Load versus Net settlement Curve, in respect of 6 mm net settlement, the result is obtained 950 kN Ultimate load and 633.33 kN.

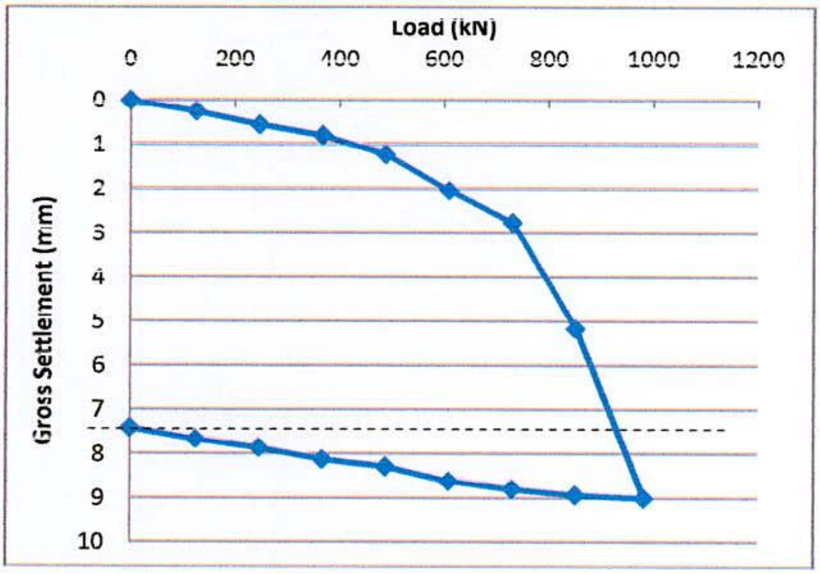


Fig-4.9 Load - Settlement Curve of a Pile at a location in between Bastuhara and Rayer Mahol area

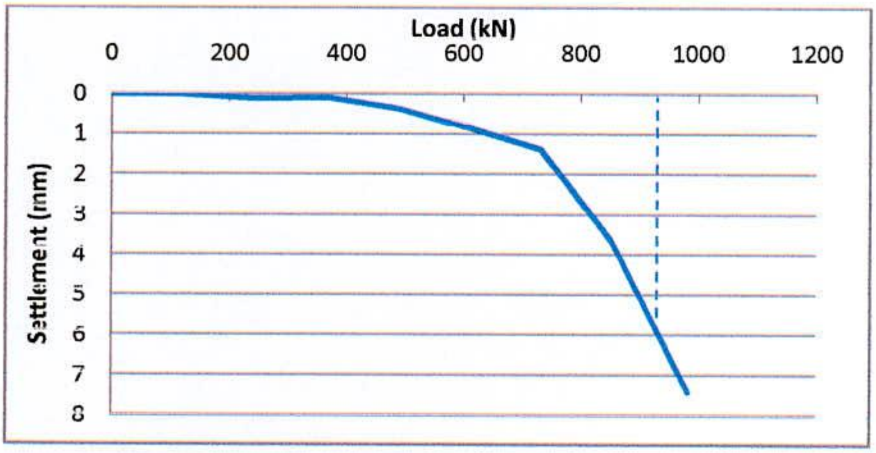


Fig-4.10 Load versus Net Settlement Curve of a pile at a location in between Bastuhara and Rayer Mahol area

4.5 Pile Load Test on a Pile at Rayer Mahol Bridge

A pile load test was done on a pile at at Rayer Mahol Bridge. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.11 and the Load versus net settlement curve is shown in Fig. 4.12. The situ pile diameter was 750 mm & length was 30.60 m. The Test load was 982.442 kN. After completion the load test the max settlement was found 16.87 mm and the net settlement was 10.575 mm. The pile was not failed for applied 982.442 kN load. From Load versus Net settlement Curve, in respect of 6 mm net settlement. the ultimate load is obtained as 830 kN.

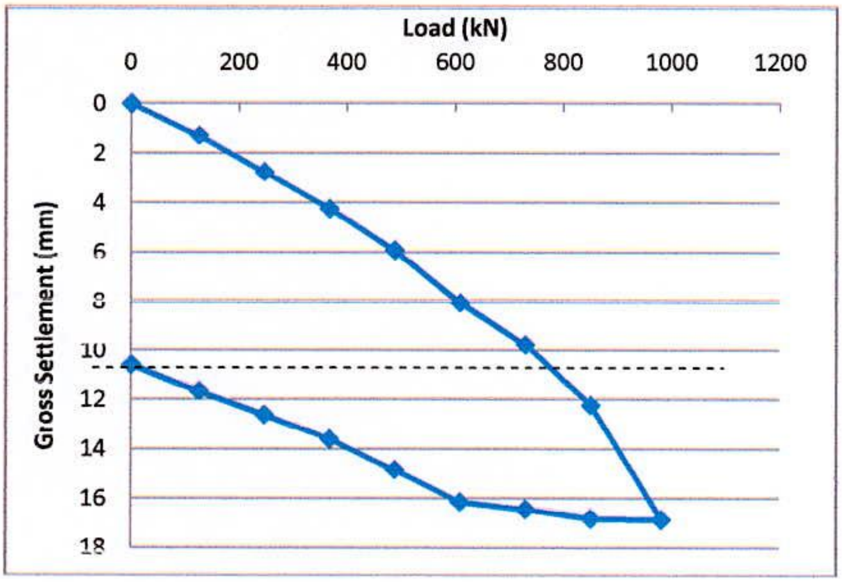


Fig-4.11 Load versus Gross Settlement Curve of a Pile at Rayermahol Bridge

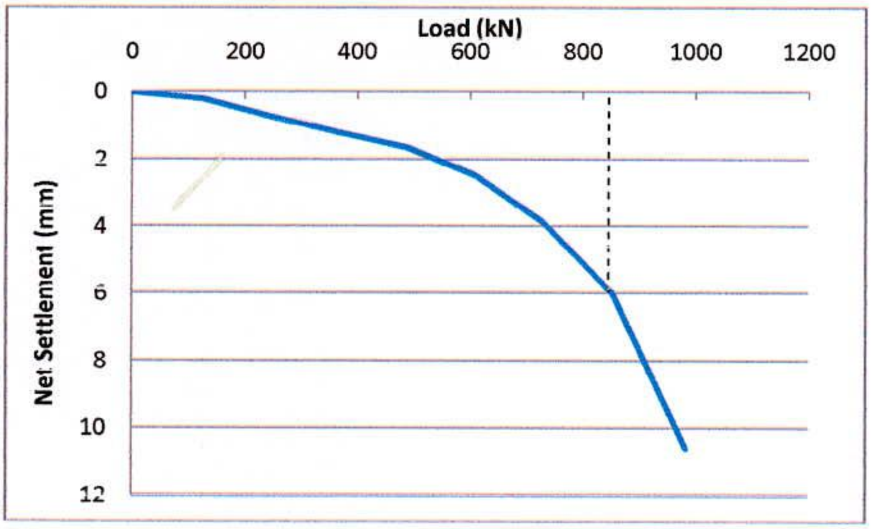


Fig-4.12 Load versus Net Settlement Curve of a Pile at Rayermahol Bridge

4.6 Pile Load Test on a Pile at Mayur River Bridge

A pile load test was done on a pile at Mayer River Bridge. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.10. The situ pile diameter was 1000 mm & length was 48 m. The Test load was 1962 kN. After completion the load test the max settlement was found 5.76 mm and the net settlement was 3.13 mm. The pile was not failed under the applied load 1962 kN. The maximum settlement was too little and it was below the 6mm. From the figure 4.10 it can be concluded that the ultimate load is 1962 kN against the 5.76 mm settlement.

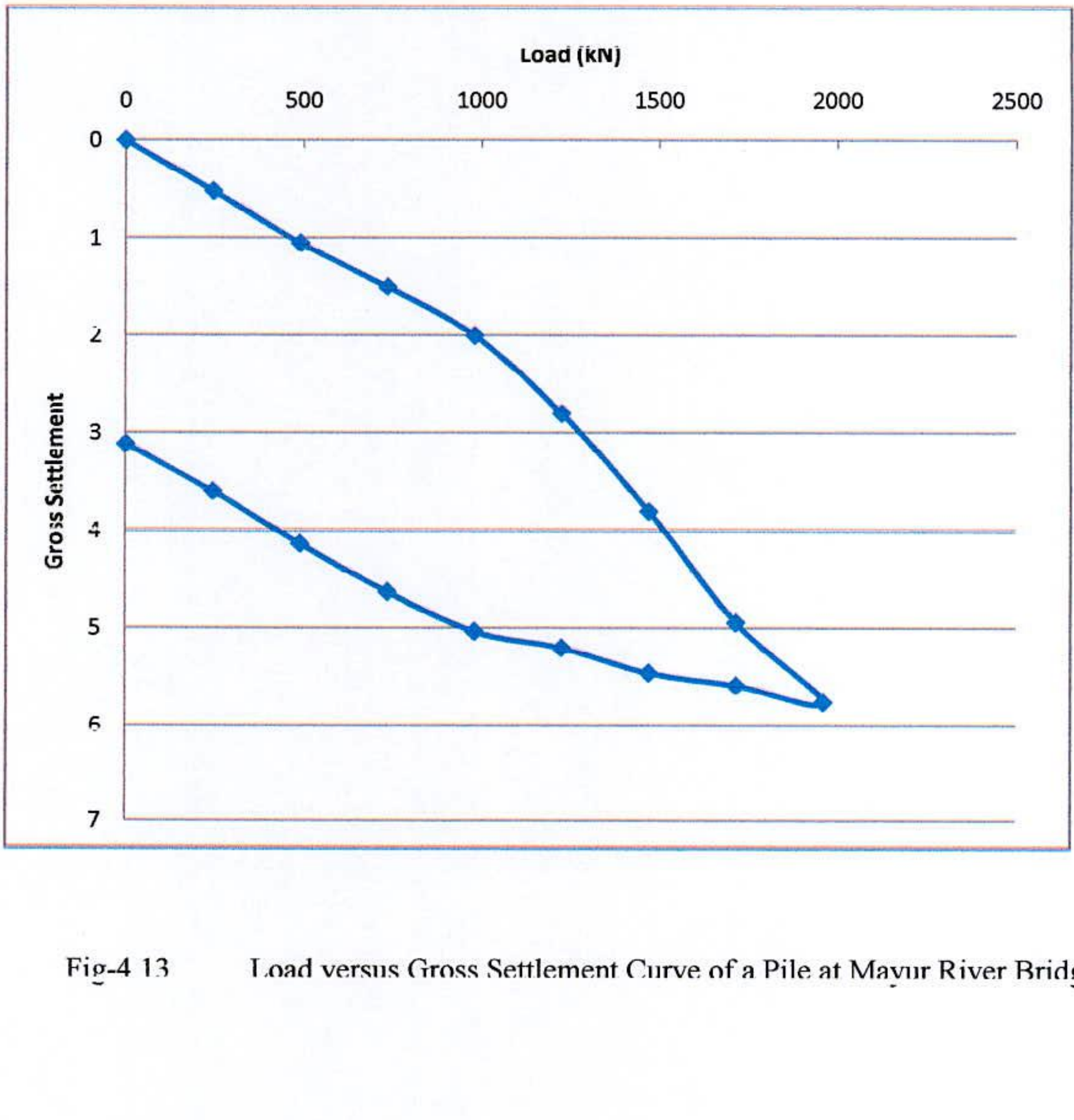


Fig-4.13 Load versus Gross Settlement Curve of a Pile at Mayur River Bridge

4.7 Pile Load Test on a Pile at KU Library Building

A pile load test was done on a pile at at KU Library Building. After completion of static pile load test the load versus gross settlement curve is shown in Fig. 4.14 and the Load versus net settlement curve is shown in Fig. 4.15. The situ pile diameter was 500 mm & length was 27.44 m. The Test load was 882.90 kN. After completion the load test the max settlement was found 13.23 mm and the net settlement was 8.35 mm. The pile was not failed under the applied load 882.90 kN. From Load versus Net settlement Curve, in respect of 6 mm net settlement. the ultimate load is 825 kN.

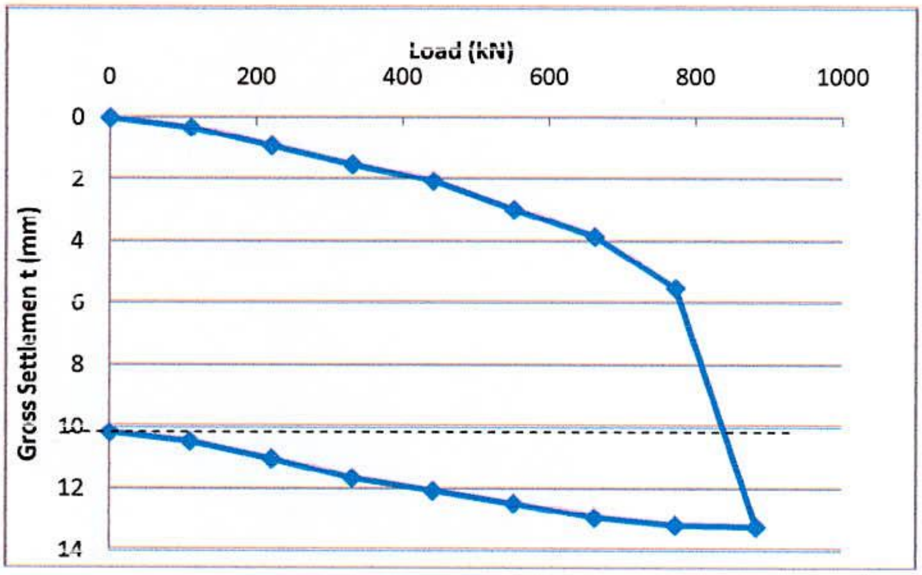


Fig-4.14 Load versus Gross Settlement Curve of a Pile at KU Library Building

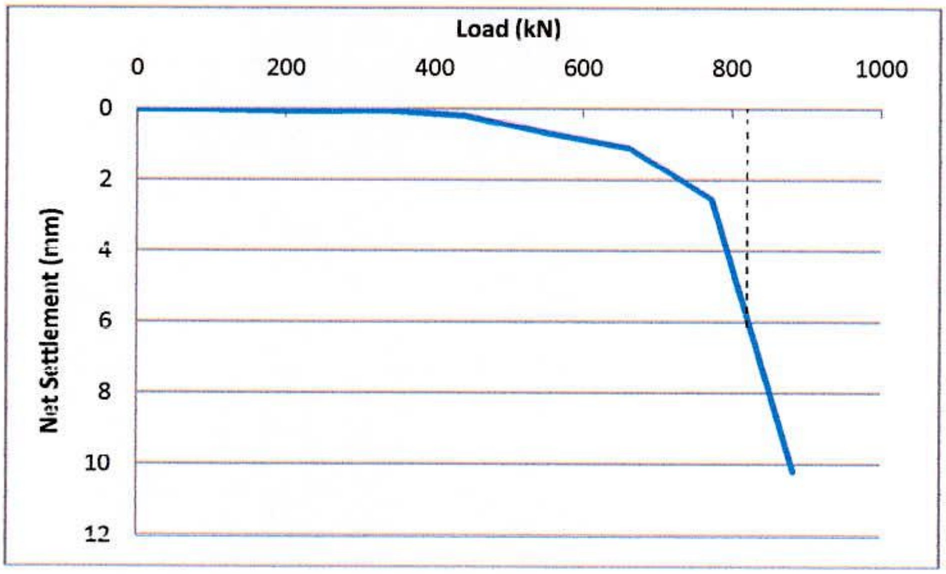


Fig-4.15 Load versus Net Settlement Curve of a Pile at KU Library Building

4.8 Pile Load Test on a Pile at KU Male Student Hall

A pile load test was done on a pile at KU Male Student hall. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.16. The situ pile diameter was 500 mm & length was 30.50 m. The Test load was 1079 kN. After completion the load test the max settlement was found 0.81 mm and the net settlement was 0.56 mm. The pile was not failed under the applied load 1079 kN. The maximum settlement was too little and it was below the 6mm. So the pile capacity is much higher than the curve shown as 1079 kN.

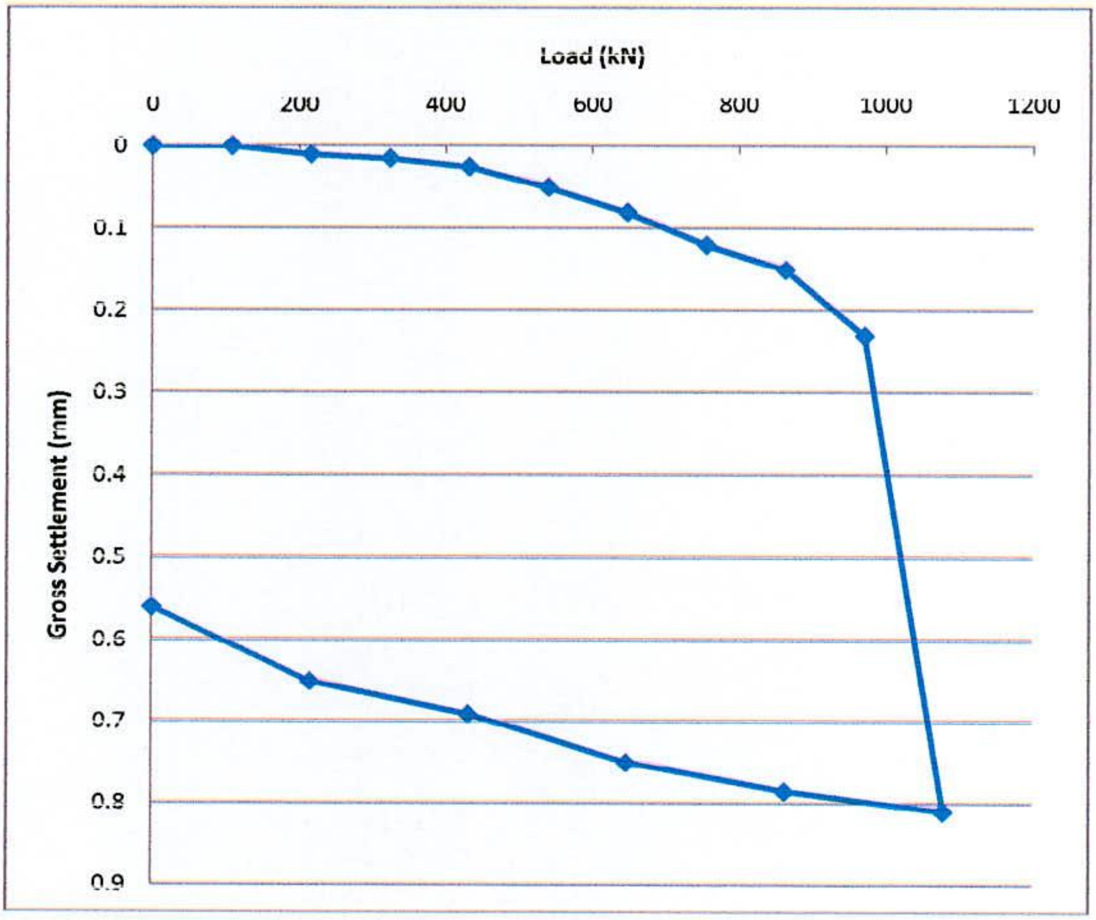


Fig-4.16 Load versus Gross Settlement of a Pile at KU Male Student hall

4.9 Pile Load Test on a Pile at KU Agrani Bank Bhaban

A pile load test was done on a pile at at KU Library Building. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.17 and the Load versus net settlement curve is shown in Fig. 4.18. The situ pile diameter was 450 mm & length was 26 m. The Test load was 882.90 kN. After completion the load test the max settlement was found 13.81 mm and the net settlement was 11.567 mm. The pile was not failed under the applied load 882.90 kN. From load versus net settlement curve, in respect of 6 mm net settlement. the ultimate load is obtained as 725 kN.

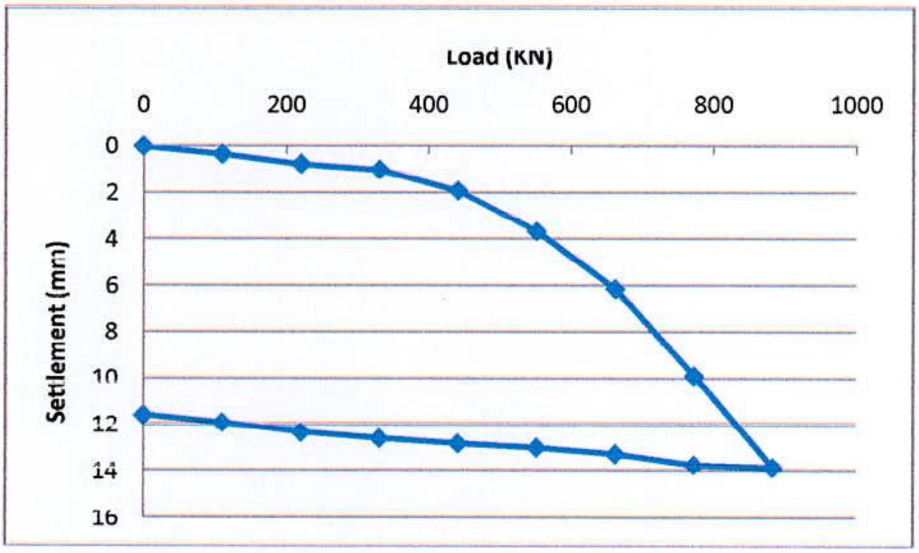


Fig-4.17 Load versus Gross Settlement Curve of a Pile at KU Agrani Bank

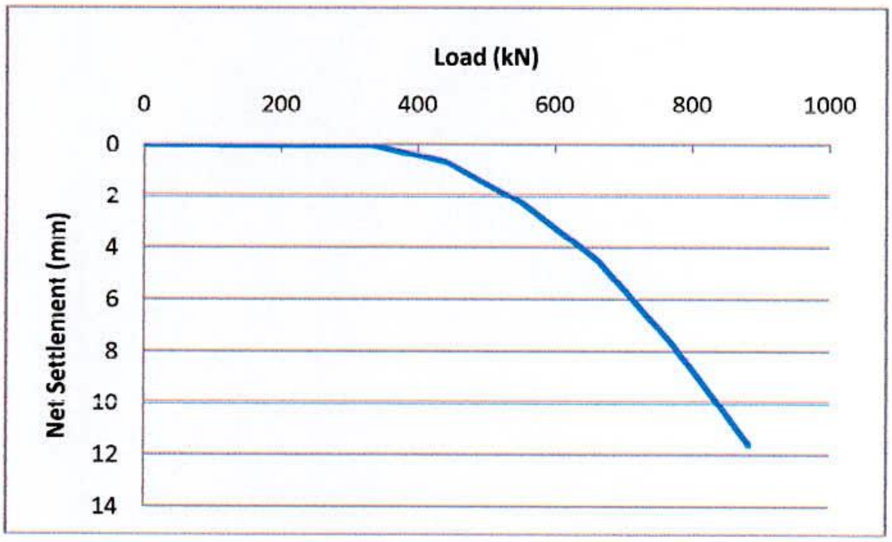


Fig-4.18 Load versus Net Settlement Curve of a Pile at KU Agrani Bank

4.10 Pile Load Test on a Pile at Khulna Medical College ICU

A pile load test was done on a pile at Khulna Medical College ICU. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.19 and the Load versus net settlement curve is shown in Fig. 4.20. The situ pile diameter was 500 mm & length was 24.39 m. The Test load was 981 kN. After completion the load test the max settlement was found 11.5 mm and the net settlement was 9.8 mm. The pile was not failed under the applied load 981 kN. From Load versus Net settlement Curve, in respect of 6 mm net settlement. the ultimate load is obtained as 925 kN.

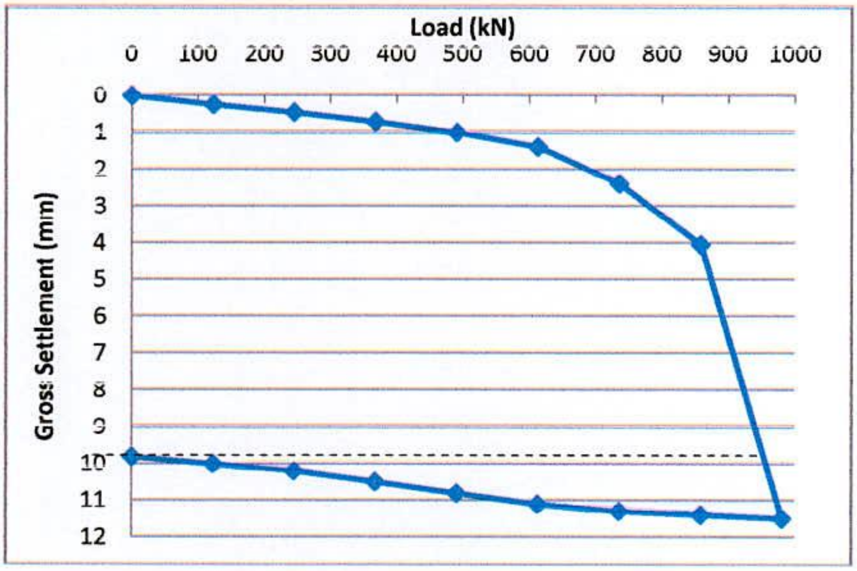


Fig-4.19 Load versus Gross Settlement Curve of a Pile at KMC ICU

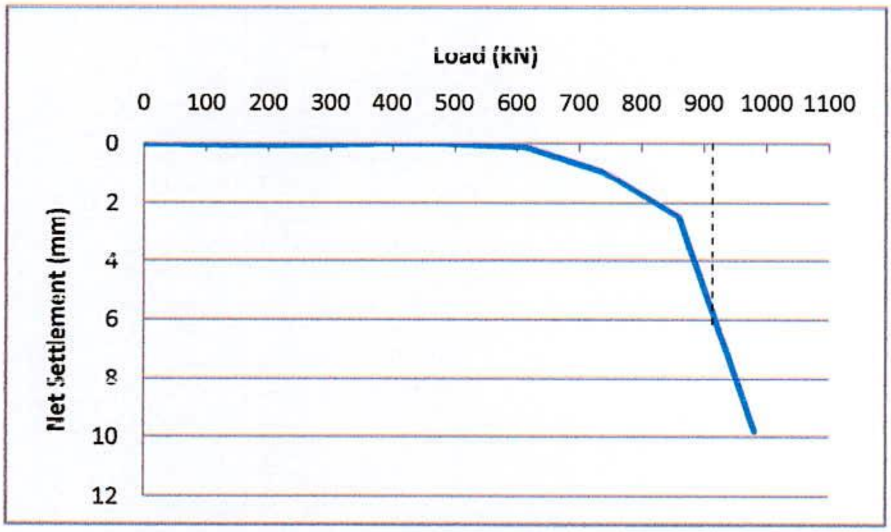


Fig-4.20 Load versus Net Settlement Curve of a Pile at KMC ICU

4.11 Pile Load Test on a Pile at Shun shin Cement Factory, Lobonchora

A pile load test was done on a pile at Shun Shin Cement Factory, Lobonchora. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.21. The situ pile diameter was 600 mm & length was 24 m. The Test load was 2207 kN. After completion the load test the max settlement was found above 25 mm. The pile was failed under the applied load. A tangent is drawn on the load versus gross settlement curve to find out the ultimate carrying capacity of pile. From load settlement curve the ultimate load is 1360 kN.

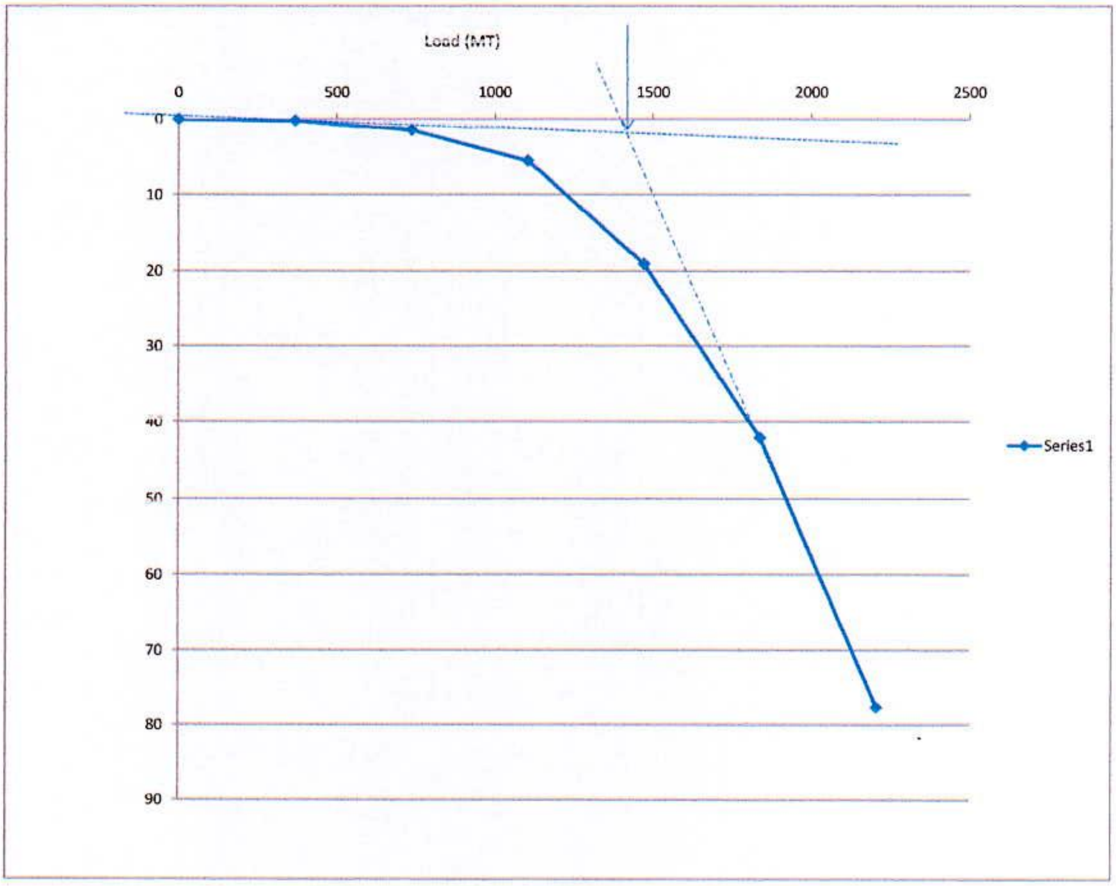


Fig-4.21 Load versus Gross settlement Curve of a Pile at Shun Shin Cement Factory, Lobonchora

4.12 Pile Load Test on a Pile for a Building at Sonadanga

A pile load test was done on a pile at a building Sonadanga. After completion of static pile load test the following load versus gross settlement curve is shown in Fig. 4.22 and the Load versus net settlement curve is shown in Fig. 4.23. The situ pile diameter was 450 mm & length was 24.39 m. The Test load was 662.175 kN. After completion the load test the max settlement was found 14.105 mm and the net settlement was 10.65 mm. The pile was not failed under the applied load 662.175 kN. From Load versus Net settlement Curve, in respect of 6 mm net settlement. the ultimate load is obtained as 510 kN.

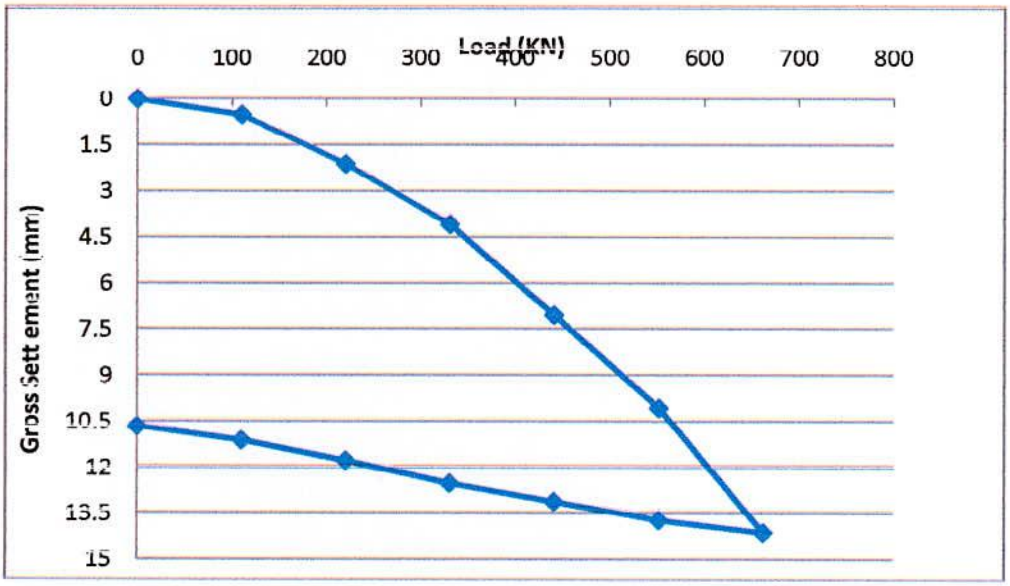


Fig-4.22 Load versus Gross Settlement Curve of a Pile at Sonadanga

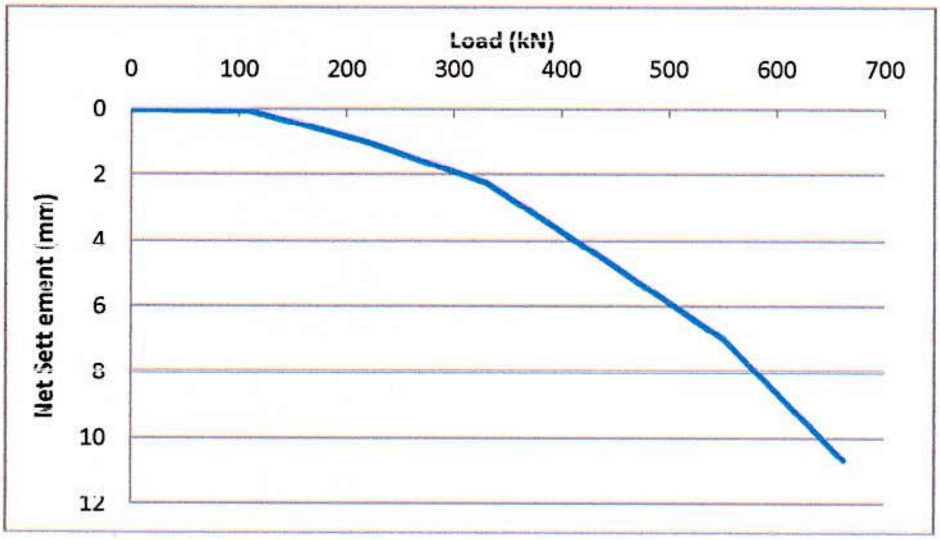


Fig-4.23 Load versus Net Settlement Curve of a Pile at Sonadanga

CHAPTER 5

PILE CAPACITY FROM EQUATIONS

5.1 General

Many researchers have been established different equations to determine the allowable bearing capacity of pile. Eight equations were selected for the determination of allowable bearing capacity of pile which is discussed in this chapter for the pile capacity installed at ten locations.

5.2 Allowable Pile Capacity from Different Existing Equations

Meyerhof Equation has been used to identify the end bearing and skin friction for the pile. This equation is suitable for cohesive and cohesionless soil.

Hansen equation has been used for identification of end bearing of cast in situ pile and it is suitable for cohesive and cohesionless soil.

Tomlinson equation (α method) has been used for identification of skin friction of cast in situ pile installed in cohesive soil.

Burland equation (β method) has been used to identify the skin friction of pile and it is suitable for cohesionless soil.

Vasic's equation has been used to identify the end bearing capacity of pile and it is suitable for cohesive soil and cohesionless soil.

Janbu's equation has been used to identify the end bearing capacity of pile and it is suitable for cohesive soil and cohesionless soil.

Terzaghi equation has been used to identify the end bearing capacity of pile and it is suitable for cohesive soil and cohesionless soil.

5.3 Allowable Pile Capacity of a Pile in Bastuhara from different Equations

The equations as mentioned in article 5.2 were used to find out the pile capacity of a pile at Bastuhara Bridge. For each equation, pile capacity against depths is shown in Fig. 5.1 and also in Table 5.1. The sub soil investigation depth was 31.50 m. The pile length was 30.50 m and diameter was 750 mm. The soil parameters from sub soil investigation are used in above equations to find out the bearing capacity of pile. Most of the cases the bearing capacities are not same in same depth of pile. For cohesive soil the result is same for Hansen and Vasic's equation. From table, in the depth of 30 m, the minimum calculated load is obtained 1659.16 kN by using the Janbu's equation for end bearing for cohesive and cohesion less soil, Tomlinson equation (α method) for skin friction for cohesive soil & Burland equation (β method) for skin friction for cohesionless soil. The equations might be suitable for the Bastuhara area. The bore log of the site is shown in appendix A1.

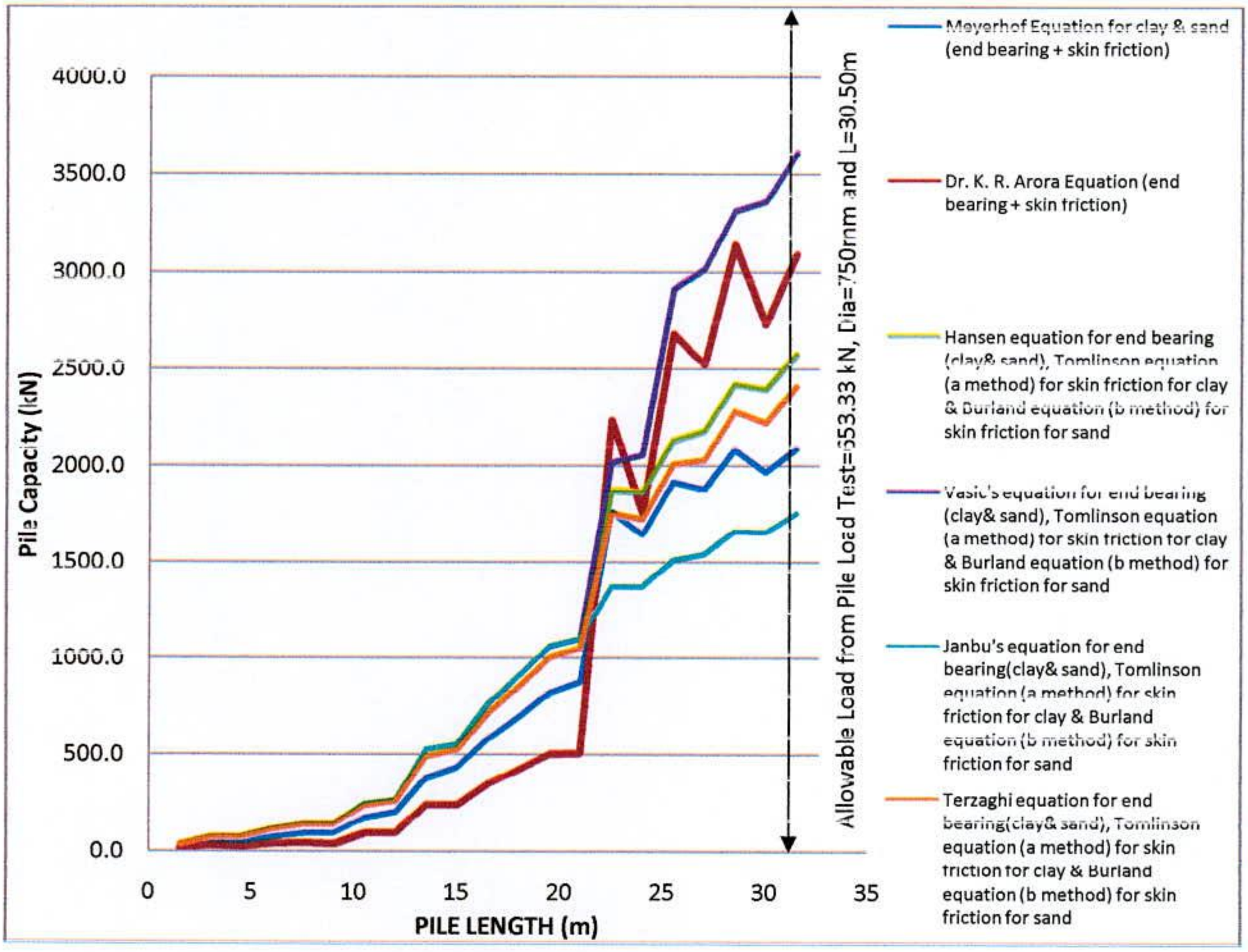


Fig. 5.1 Pile Capacity versus Depth from Various Equations at Bastuhara Bridge

TABLE 5.1 Allowable Pile Capacity of of a Pile at Bastuhara Bridge

Project	Depth	Summary of allowable bearing capacity of pile: Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (α method) for skin friction for clay & Burland equation (β method) for skin friction for sand		Test Load
		Load(KN)	Load(KN)	Load(KN)	Load(KN)	Load(KN)	Load(KN)	(KN)	(KN)
		Dia=750mm, L=30.50m, FS=2.5							
		1	2	3	4	5	6	7	8
Bastuhara Bridge	1.5	18.6	13.28	30.97	30.97	30.97	29.48		
	3	46.6	29.36	72.17	72.17	72.17	67.34		
	4.5	47.1	21.67	72.30	72.30	72.30	69.55		
	6	75.1	37.75	113.26	113.26	113.26	107.42		
	7.5	94.1	43.34	137.70	137.70	137.70	131.65		
	9	94.6	35.65	136.96	136.96	136.96	133.87		
	10.5	176.0	91.57	246.98	246.98	246.98	231.26		
	12	203.9	92.27	266.15	266.15	266.15	253.42		
	13.5	382.7	236.27	528.62	528.62	528.62	483.69		
	15	435.0	235.58	556.28	556.28	556.28	520.71		
	16.5	581.6	346.02	763.95	763.95	763.95	708.66		
	18	697.5	420.12	911.35	911.35	911.35	849.26		
	19.5	823.7	499.81	1064.83	1064.83	1064.83	995.92		
	21	880.1	505.40	1103.53	1103.53	1103.53	1047.55		
	22.5	1767.8	2234.72	1870.30	2020.03	1370.81	1731.34		
	24	1647.7	1756.87	1863.13	2056.33	1373.56	1721.72		
	25.5	1921.8	2679.42	2131.40	2910.96	1513.58	2005.34		
	27	1884.9	2520.23	2179.98	3018.87	1541.02	2027.71		
	28.5	2085.1	3139.49	2421.32	3311.41	1665.10	2278.17		
	30	1971.1	2727.85	2394.72	3360.45	1659.16	2219.20		982.42
	31.5	2091.2	3088.71	2575.46	3607.71	1757.37	2408.06		

5.4 Allowable Pile Capacity of a Pile in between Bastuhara and Rayer Mahal from Different Equations

Different existing equations are used to find out the allowable bearing capacity of a pile in between Bastuhara and Rayer Mahal. For each equation, pile capacity against depths is shown in Fig. 5.2 and also in Table 5.2. In this point the sub soil pile investigation depth was 39m. The pile length was 30.10 m and diameter was 750 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.2 it was found that the predicted loads from equations at 30 m depth is about two times higher than pile capacities from pile tests. End bearing and skin friction were predicted from Meyerhof equation for both cohesive and cohesionless soils.

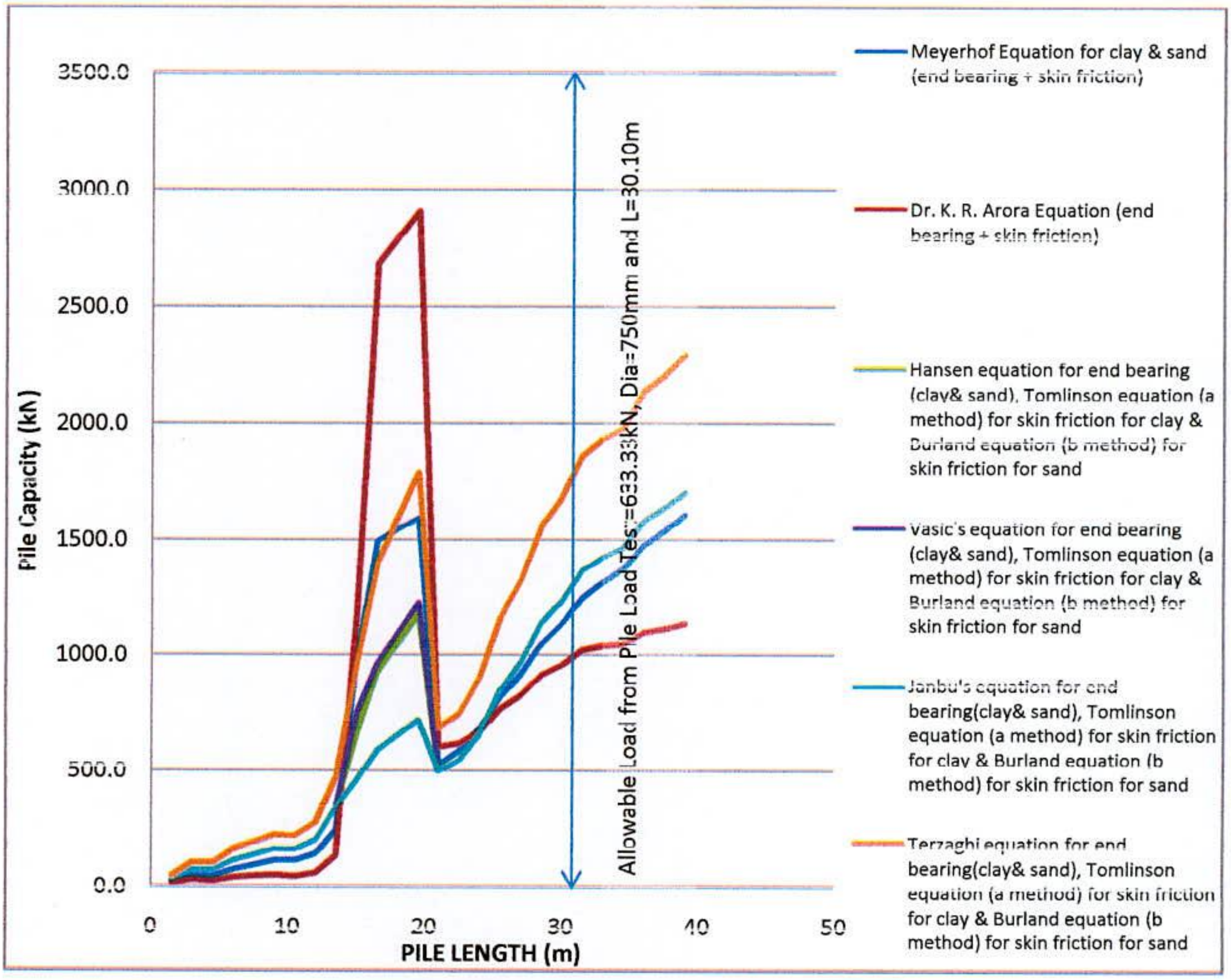


Fig-5.2 Pile Capacity versus Depth from Various Equations a place in between Bastuhara and Rayer Mahol

TABLE 5.2 Allowable Bearing Capacity Table of a Place in between Bastuhara and Rayer Mahal

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=750mm, L=30.10m, FS=2.5							
		1	2	3	4	5	6	7	8
Bridge in between Bastuhara and Rayer Mahal	1.5	18.6	13.28	30.97	30.97	30.97	45.36		
	3	46.6	29.36	72.17	72.17	72.17	101.90		
	4.5	47.1	21.67	72.30	72.30	72.30	98.80		
	6	75.1	37.75	113.26	113.26	113.26	155.34		
	7.5	94.1	43.34	137.70	137.70	137.70	187.65		
	9	113.0	48.93	162.07	162.07	162.07	219.96		
	10.5	113.5	41.24	161.24	161.24	161.24	216.86		
	12	141.6	57.32	202.32	202.32	202.32	273.40		
	13.5	246.6	129.32	342.05	342.05	342.05	468.51		
	15	984.4	1190.42	660.61	748.54	461.43	961.99		
	16.5	1495.7	2682.03	924.02	961.39	588.28	1397.63		
	18	1545.0	2793.52	1048.64	1092.54	654.25	1591.53		
	19.5	1594.3	2905.02	1173.32	1223.76	720.25	1785.43		
	21	527.5	600.57	497.87	497.87	497.87	680.50		
	22.5	587.7	615.25	547.30	547.30	547.30	744.62		
	24	685.2	666.97	659.18	659.18	659.18	896.98		
	25.5	817.3	764.14	846.92	846.92	846.92	1155.35		
	27	918.8	822.16	970.15	970.15	970.15	1321.13		
	28.5	1048.9	909.54	1138.58	1138.58	1138.58	1550.41		
	30	1137.7	952.18	1235.06	1235.06	1235.06	1677.30	490.50	982.42
	31.5	1249.8	1018.59	1369.57	1369.57	1369.57	1858.11		
	33	1315.1	1034.67	1424.88	1424.88	1424.88	1926.96		
	34.5	1376.6	1042.36	1467.95	1467.95	1467.95	1979.53		
	36	1475.2	1094.79	1582.86	1582.86	1582.86	2134.25		
	37.5	1539.3	1110.16	1637.38	1637.38	1637.38	2203.72		
	39	1608.1	1133.23	1703.20	1703.20	1703.20	2289.84		
	40.5								
	42								
	43.5								
	45								
	46.5								
	48								

5.5 Allowable Pile Capacity of a Pile at Rayer Mahal from different Equations

Different existing equations are used to find out the allowable bearing capacity of a pile at Rayer Mahal. For each equation, pile capacity against depths is shown in Fig. 5.3 and also in Table 5.3. In this point the sub soil pile investigation depth was 36 m. The pile length was 30.50 m and diameter was 750 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.3 it was found that the predicted loads from equations at 31.5 m depth are about two times higher than pile capacities from pile tests. End bearing and skin friction were predicted from Meyerhof equation for both cohesive and cohesionless soils.

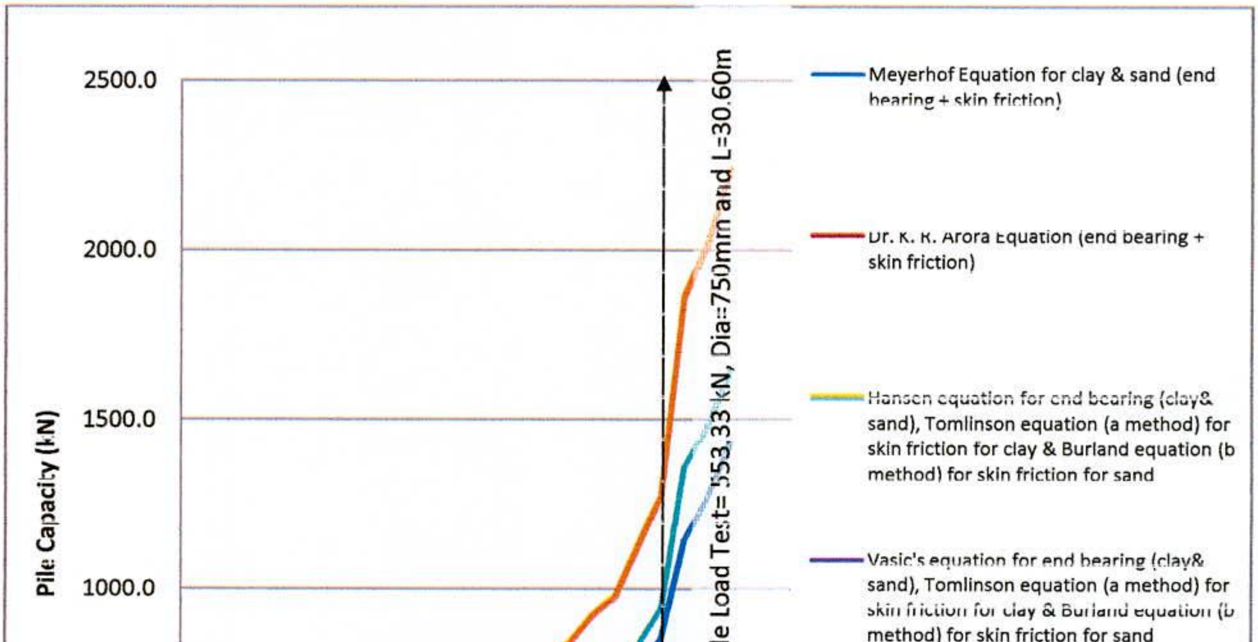


Fig. 5.3 Pile Capacity versus Depth curve from Various Equations at Rayer Mahal Bridge

TABLE: 5.3 Allowable Bearing Capacity Table of at Rayer Mahal Bridge

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vesic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=750mm, L=30.60m, FS=2.5							
		1	2	3	4	5	6	7	8
Bridge at Rayer Mahal	1.5	18.6	13.28	30.97	30.97	30.97	45.36		
	3	9.5	16.08	47.74	47.74	47.74	66.49		
	4.5	28.1	18.87	63.92	63.92	63.92	87.61		
	6	56.1	34.95	104.87	104.87	104.87	144.16		
	7.5	75.1	40.54	129.31	129.31	129.31	176.47		
	9	147.5	85.98	222.50	222.50	222.50	306.33		
	10.5	175.4	86.68	241.77	241.77	241.77	329.82		
	12	212.2	97.87	277.70	277.70	277.70	377.54		
	13.5	266.6	122.33	337.54	337.54	337.54	458.94		
	15	294.4	123.03	356.58	356.58	356.58	482.43		
	16.5	331.3	134.22	392.45	392.45	392.45	530.15		
	18	385.7	158.68	452.28	452.28	452.28	611.55		
	19.5	413.5	159.38	471.23	471.23	471.23	635.04		
	21	450.4	170.57	507.06	507.06	507.06	682.76		
	22.5	504.8	195.03	566.91	566.91	566.91	764.16		
	24	532.6	195.73	585.80	585.80	585.80	787.64		
	25.5	569.5	206.91	621.63	621.63	621.63	835.36		
	27	623.9	231.38	681.48	681.48	681.48	916.76		
	28.5	669.3	245.36	724.39	724.39	724.39	973.93		
	30	760.7	299.19	835.72	835.72	835.72	1127.16		
	31.5	853.8	348.12	942.41	942.41	942.41	1272.56	490.50	982.442
	33	1146.3	601.87	1364.47	1364.47	1364.47	1862.36		
	34.5	1271.2	664.09	1478.45	1478.45	1478.45	2012.61		
	36	1433.4	763.35	1645.62	1645.62	1645.62	2238.53		

5.6 Allowable Pile Capacity of a Pile at Mayur river from different Equations

Different existing equations are used to find out the allowable bearing capacity of a pile at Mayur River Bridge. For each equation, pile capacity against depths is shown in Fig. 5.4 and also in Table 5.4. In this point the sub soil pile investigation depth was 48 m. The pile length was 48 m and diameter was 1000 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. From Table 5.4 it was found that the predicted loads from equations at 48 m depth are 1.2 times higher than pile capacities from pile tests. End bearing was predicted from Vesic equation for both cohesive and cohesionless soils, while for skin friction of cohesive and cohesion less soils, Tomlinson equation (α method) and Burland equation (β method) respectively were considered.

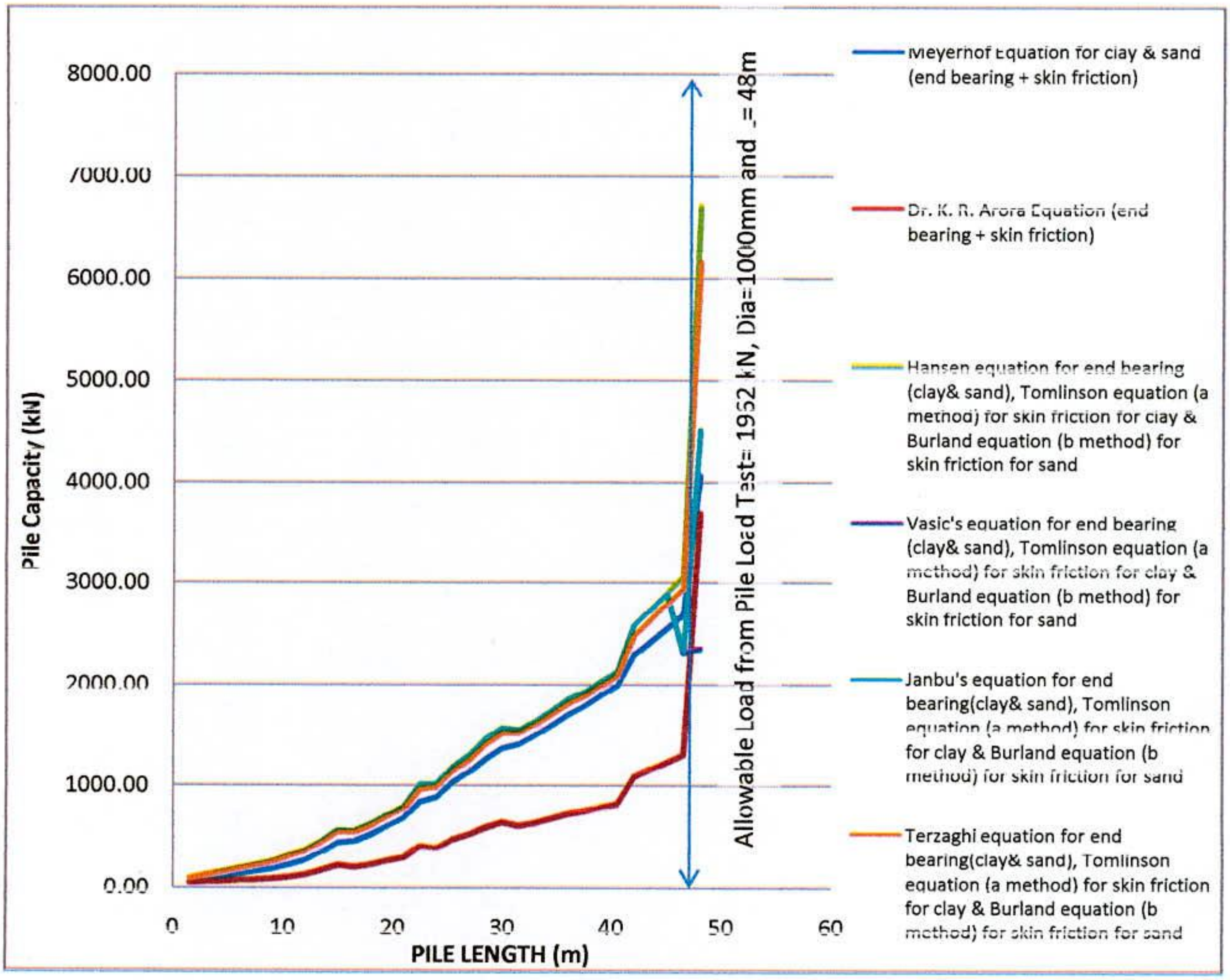


Fig-5.4 Load versus Depth curve from Various Equations at Mayur River Bridge

TABLE: 5.4 Allowable Bearing Capacity Table of a pile at Mayur River Bridge

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=1000mm, L=48.00m, FS=2.5							
		1	2	3	4	5	6	7	8
Bridge on Mayur River	1.5	57.40	44.74	84.25	84.25	84.25	80.78		
	3	82.71	52.19	120.53	120.53	120.53	113.09		
	4.5	108.02	59.65	154.38	154.38	154.38	145.40		
	6	133.33	67.11	187.49	187.49	187.49	177.71		
	7.5	158.64	74.56	220.29	220.29	220.29	210.02		
	9	183.95	82.02	252.92	252.92	252.92	242.33		
	10.5	223.41	100.66	308.37	308.37	308.37	294.84		
	12	269.17	121.17	360.36	360.36	360.36	343.86		
	13.5	348.51	165.90	458.96	458.96	458.96	433.90		
	15	443.42	216.24	569.61	569.61	569.61	555.87		
	16.5	460.47	193.87	557.80	557.80	557.80	535.12		
	18	523.76	219.96	626.60	626.60	626.60	600.92		
	19.5	606.37	259.11	719.60	719.60	719.60	688.04		
	21	685.24	290.80	800.36	800.36	800.36	765.77		
	22.5	849.55	402.65	1017.55	1017.55	1017.55	959.64		
	24	893.16	384.00	1021.85	1021.85	1021.85	978.28		
	25.5	1033.38	467.89	1194.07	1194.07	1194.07	1135.80		
	27	1142.48	516.36	1311.06	1311.06	1311.06	1249.69		
	28.5	1270.35	589.06	1466.70	1466.70	1466.70	1396.40		
	30	1374.16	655.79	1577.21	1577.21	1577.21	1506.75		
	31.5	1409.21	600.24	1557.51	1557.51	1557.51	1507.50		
	33	1500.41	631.93	1643.16	1643.16	1643.16	1593.06		
	34.5	1600.85	674.80	1746.67	1746.67	1746.67	1693.53		
	36	1706.41	719.54	1855.09	1855.09	1855.09	1798.92		
	37.5	1790.80	743.78	1928.45	1928.45	1928.45	1875.16		
	39	1896.37	788.51	2036.87	2036.87	2036.87	1980.54		
	40.5	1993.91	823.93	2130.20	2130.20	2130.20	2073.81		
	42	2288.24	1083.04	2587.12	2587.12	2587.12	2471.24		
	43.5	2422.14	1155.74	2742.33	2742.33	2742.33	2626.33		
	45	2556.04	1228.44	2897.53	2897.53	2897.53	2781.42		
	46.5	2689.94	1301.14	3052.73	2308.87	2308.87	2936.51		
	48	4069.23	3685.22	6696.87	2352.41	4518.79	6149.36	981.00	1962.00

5.7 Allowable Pile Capacity of a Pile at KU Library Building

Different existing equations are used to find out the allowable bearing capacity of a pile at KU Library Building. For each equation, pile capacity against depths is shown in Fig. 5.5 and also in Table 5.5. In this point the sub soil pile investigation depth was 30m. The pile length was 28.5 m and diameter was 500 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.5 it was found that the predicted loads from equations at 28.5 m depth are 1.12 times higher than pile capacities from pile tests. End bearing and skin friction were predicted from Meyerhof equation for both cohesive and cohesionless soils.

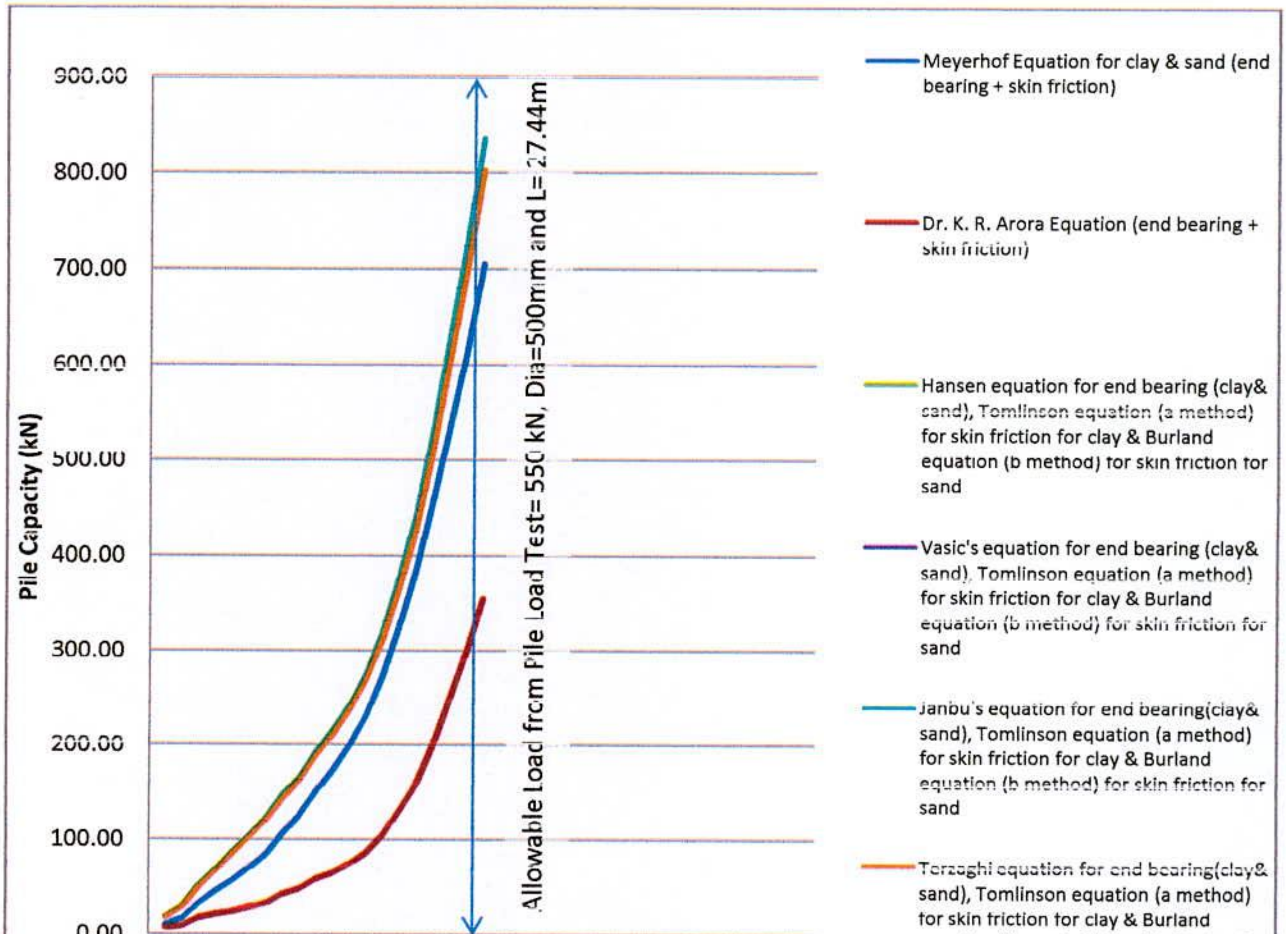


Fig-5.5 Pile Capacity versus Depth curve from Various Equations at KU Library Building

TABLE: 5.5 Allowable Bearing Capacity Table of at KU Library Building

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(KN)	Load(KN)	Load(KN)	Load(KN)	Load(KN)	Load(KN)	(KN)	(KN)
		Dia=500mm, L=27.44m, FS=2.5							
		1	2	3	4	5	6	7	8
KU Library Building	1.5	10.36	6.52	17.55	17.55	17.55	16.62		
	3	16.72	8.39	28.41	28.41	28.41	27.18		
	4.5	33.38	16.78	52.05	52.05	52.05	49.40		
	6	46.04	20.51	68.30	68.30	68.30	65.55		
	7.5	56.97	23.15	86.49	86.49	86.49	83.91		
	9	70.29	27.65	103.93	103.93	103.93	101.08		
	10.5	84.67	32.47	122.71	122.71	122.71	119.59		
	12	106.88	41.94	147.45	147.45	147.45	143.09		
	13.5	125.75	47.53	165.93	165.93	165.93	161.54		
	15	151.25	57.48	193.52	193.52	193.52	188.14		
	16.5	174.07	64.31	216.10	216.10	216.10	210.69		
	18	199.97	73.32	242.49	242.49	242.49	236.57		
	19.5	231.31	85.13	275.37	275.37	275.37	268.45		
	21	273.73	103.61	320.42	320.42	320.42	311.26		
	22.5	328.69	130.33	380.83	380.83	380.83	368.17		
	24	387.77	158.14	444.77	444.77	444.77	429.36		
	25.5	458.76	199.15	531.96	531.96	531.96	511.55		
	27	535.04	247.46	629.89	629.89	629.89	604.22		
	28.5	615.07	297.95	729.63	729.63	729.63	699.68	441.45	882.9
	30	706.07	354.80	836.65	836.65	836.65	802.17		

5.8 Allowable Pile Capacity of a Pile at KU Male Student Hall

Different existing equations are used to find out the allowable bearing capacity of a pile at KU Male student hall. For each equation, pile capacity against depths is shown in Fig. 5.6 and also in Table 5.6. In this point the sub soil pile investigation depth was 30 m. The pile length was 30.5 m and diameter was 500 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.6 it was found that the predicted loads from equations at 30 m depth are 1.25 times less for the equation of Terzaghi for end bearing for both cohesive and cohesion less soils, while for skin friction of cohesive and cohesionless soils, Tomlinson equation (α method) and Burland equation (β method) were considered respectively. In case of Meyerhof equation the predicted load is 1.45 times less for the end bearing and skin friction of cohesive and cohesionless soil.

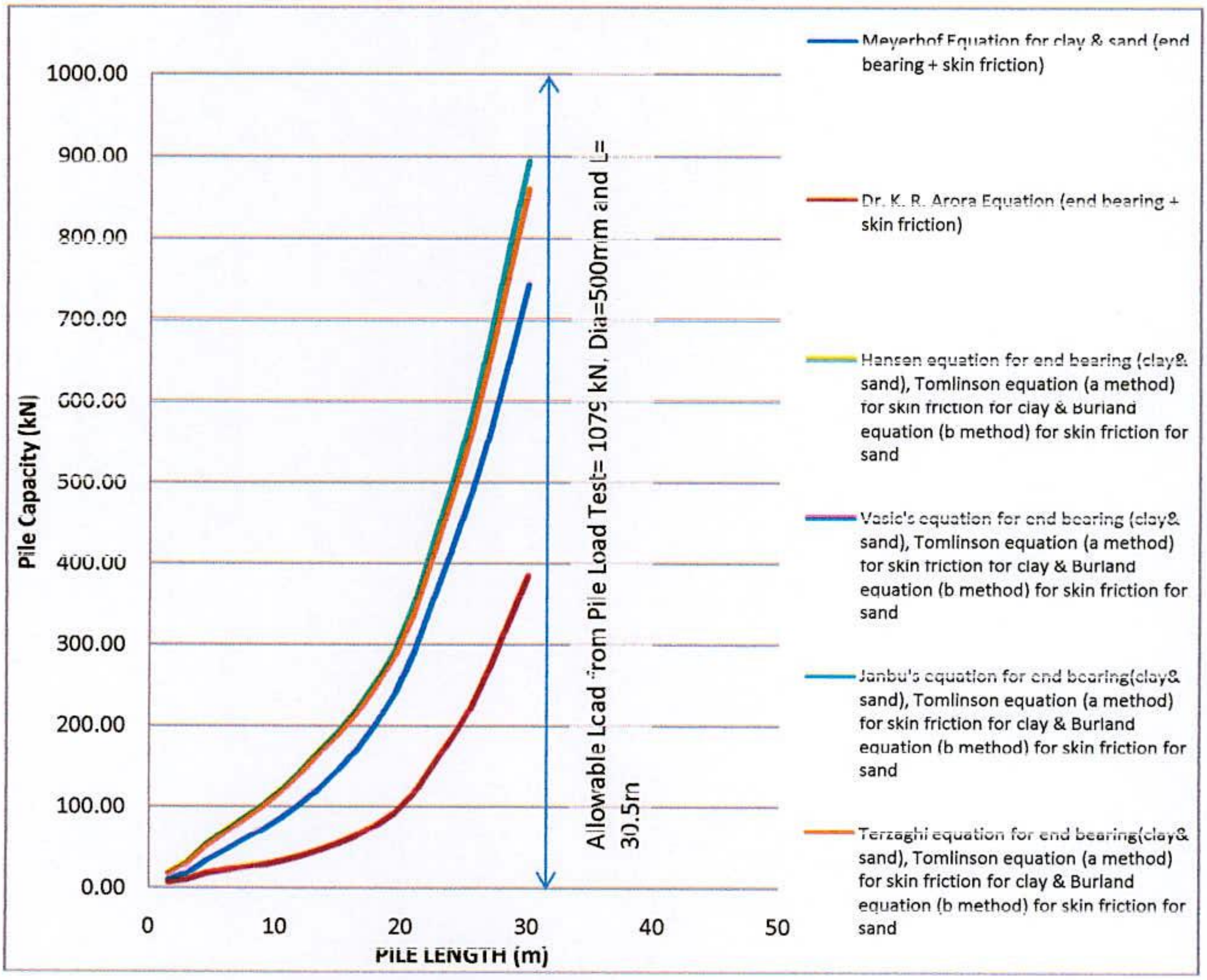


Fig-5.6 Pile Capacity versus Depth curve from Various Equations at KU Male Student Hall

TABLE: 5.6 Allowable Bearing Capacity Table of at KU Male Student Hall

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=500mm, L=30.5m, FS=2.5							
		1	2	3	4	5	6	7	8
KU Male Student hall	1.5	10.36	6.52	17.55	17.55	17.55	16.62		
	3	18.44	9.48	31.38	31.38	31.38	29.96		
	4.5	34.44	17.09	53.81	53.81	53.81	51.16		
	6	47.10	20.82	70.06	70.06	70.06	67.31		
	7.5	59.75	24.54	86.28	86.28	86.28	83.47		
	9	72.41	28.27	102.48	102.48	102.48	99.63		
	10.5	86.79	33.09	121.26	121.26	121.26	118.14		
	12	103.84	39.30	143.98	143.98	143.98	140.35		
	13.5	123.00	46.14	169.40	169.40	169.40	165.26		
	15	145.76	54.68	193.68	193.68	193.68	188.79		
	16.5	171.62	64.16	221.05	221.05	221.05	215.40		
	18	203.63	76.74	255.19	255.19	255.19	248.29		
	19.5	241.09	91.96	295.14	295.14	295.14	286.74		
	21	291.92	115.57	350.74	350.74	350.74	339.35		
	22.5	356.76	150.53	427.17	427.17	427.17	411.04		
	24	418.89	183.77	501.50	501.50	501.50	482.16		
	25.5	487.26	221.83	582.94	582.94	582.94	560.53		
	27	562.33	270.45	681.39	681.39	681.39	654.22		
	28.5	652.00	328.24	791.88	791.88	791.88	759.19		
	30	744.33	384.16	895.15	895.15	895.15	858.92	539.55	1079.00

5.9 Allowable Pile Capacity of a Pile at KU Agrani Bank

Different existing equations are used to find out the allowable bearing capacity of a pile at KU Agrani Bank. For each equation, pile capacity against depths is shown in Fig. 5.7 and also in Table 5.7. In this point the sub soil pile investigation depth was 36 m. The pile length was 27 m and diameter was 450 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.7 it was found that the predicted loads from equations at 27 m depth are 1.17 times higher than pile capacities from pile tests. End bearing and skin friction were predicted from Meyerhof equation for both cohesive and cohesion less soils.

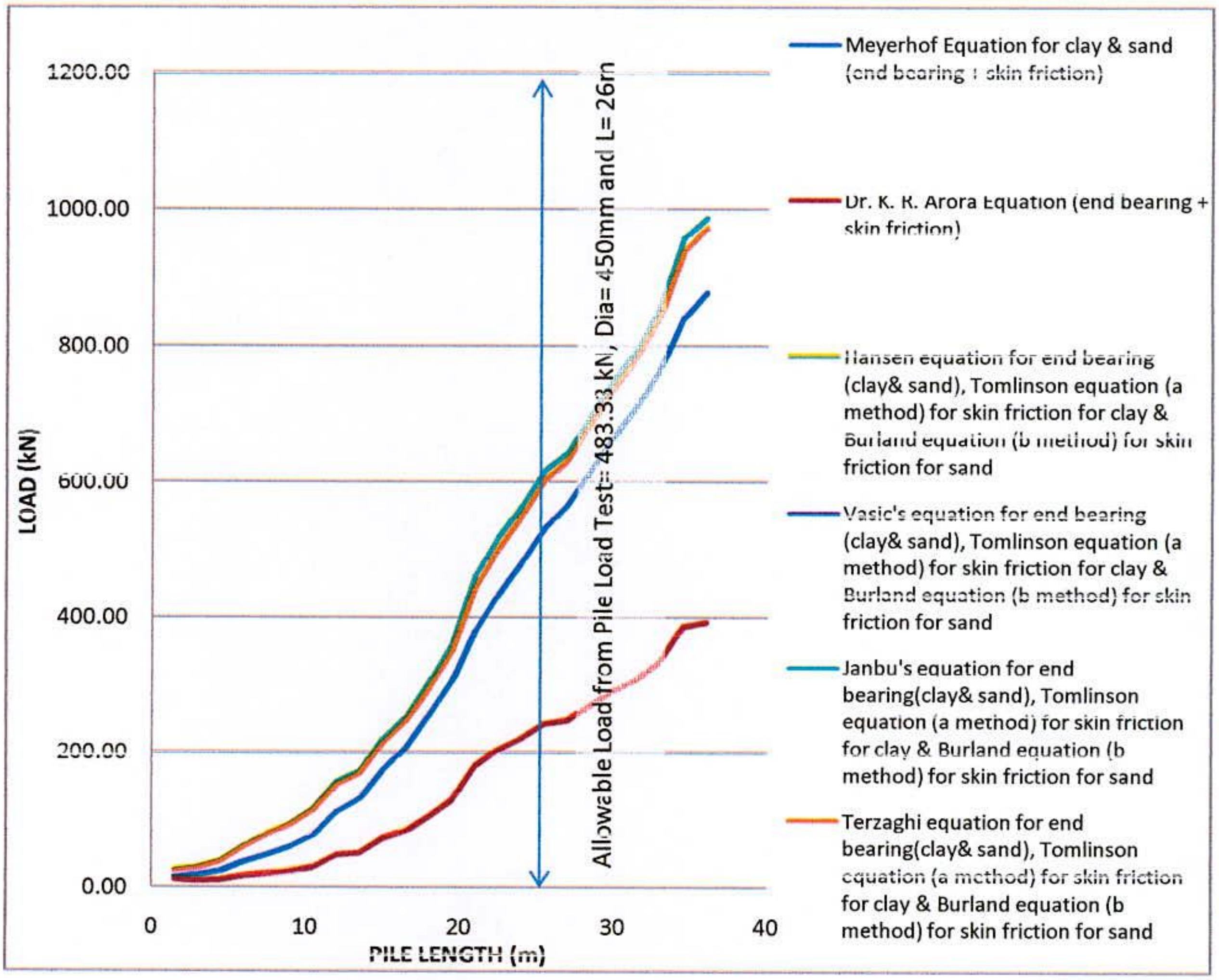


Fig-5.7 Load versus Depth curve from Various Equations at KU Agrani Bank

TABLE: 5.7 Allowable Bearing Capacity Table of at KU Agrani Bank

Project	Depth	Summary of allowable bearing capacity of situ pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=450mm, L=26m, FS=2.5							
		1	2	3	4	5	6	7	8
KU AGRANI BANK	1.5	17.89	10.90	25.95	25.95	25.95	24.35		
	3	20.36	8.81	29.97	29.97	29.97	28.95		
	4.5	26.07	10.49	39.55	39.55	39.55	38.46		
	6	38.92	16.53	61.53	61.53	61.53	59.50		
	7.5	49.17	19.55	78.68	78.68	78.68	76.61		
	9	61.21	23.66	94.46	94.46	94.46	92.13		
	10.5	77.88	30.28	117.03	117.03	117.03	113.98		
	12	112.91	47.73	157.40	157.40	157.40	151.48		
	13.5	131.77	50.67	172.80	172.80	172.80	168.05		
	15	174.14	71.55	221.17	221.17	221.17	213.29		
	16.5	208.07	82.63	253.68	253.68	253.68	245.77		
	18	256.09	104.60	304.87	304.87	304.87	294.54		
	19.5	306.99	128.85	361.26	361.26	361.26	348.74		
	21	381.30	180.10	463.25	463.25	463.25	443.21		
	22.5	435.28	203.59	520.24	520.24	520.24	501.14		
	24	482.56	220.28	565.63	565.63	565.63	548.68		
	25.5	532.86	241.59	618.73	618.73	618.73	602.23		
	27	567.52	246.96	644.52	644.52	644.52	631.90	441.45	882.9
	28.5	618.17	269.86	699.11	699.11	699.11	685.25		
	30	668.54	291.16	751.73	751.73	751.73	737.37		
	31.5	713.17	307.69	795.67	795.67	795.67	782.03		
	33	766.94	335.20	858.45	858.45	858.45	842.85		
	34.5	840.72	386.12	958.72	958.72	958.72	936.52		
	36	878.79	392.66	988.11	988.11	988.11	971.27		

5.10 Allowable Pile Capacity of a Pile in Khulna Medical College ICU

Different existing equations are used to find out the allowable bearing capacity of a pile at Khulna Medical college. For each equation, pile capacity against depths is shown in Fig. 5.8 and also in Table 5.8. In this point the sub soil pile investigation depth was 30m. The pile length was 24 m and diameter was 500 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. For cohesive soil the result is same for Hansen and Vesic's equations. From Table 5.8 it was found that the predicted loads from equations at 24 m depth are 1.02 times lesser than pile capacities from pile tests. End bearing was predicted from Hansen equation for both cohesive and cohesionless soils, while for skin friction of cohesive and cohesionless soils, Tomlinson equation (α method) and Burland equation (β method) respectively were considered.

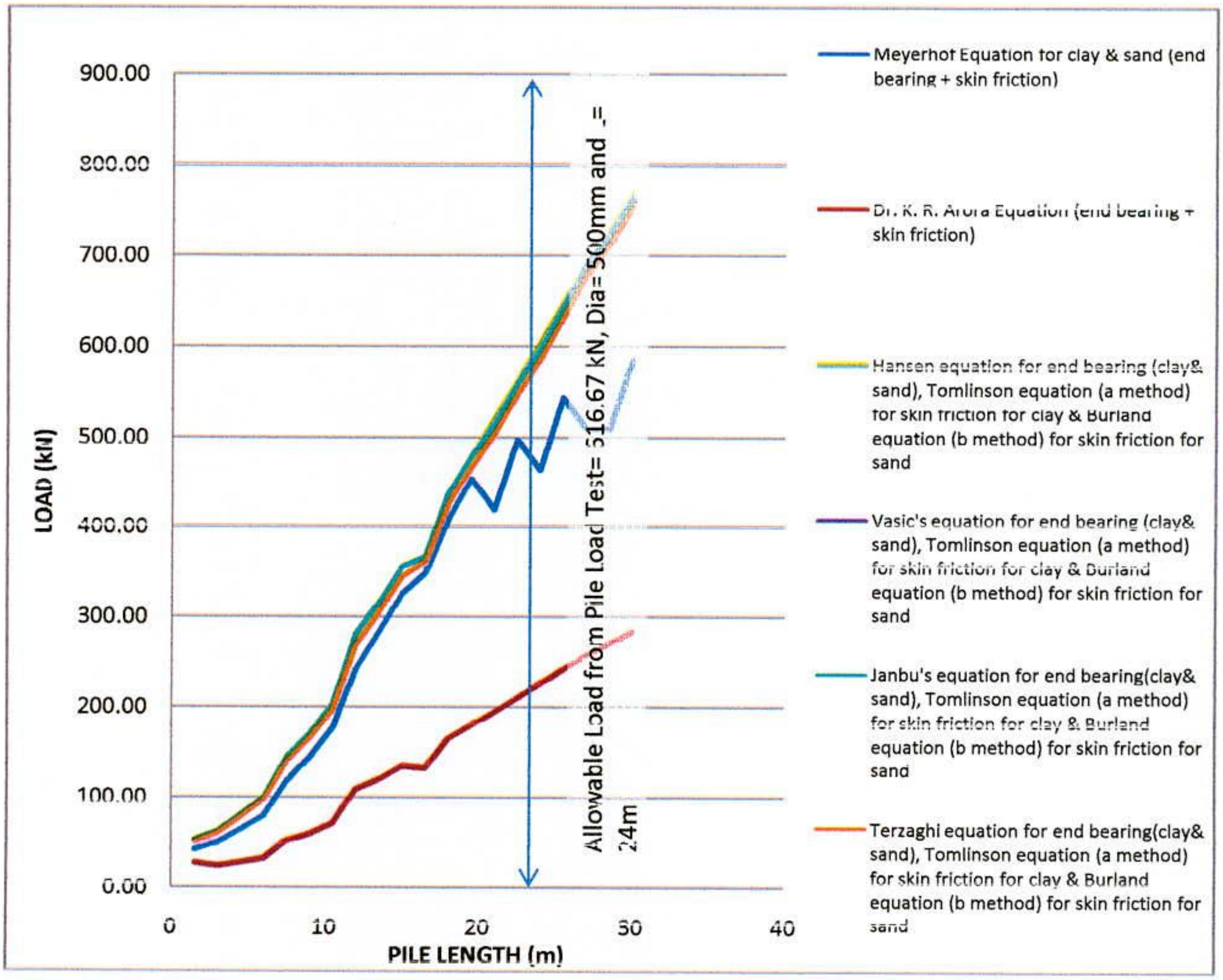


Fig-5.8. Load versus Depth curve from Various Equations at KMC ICU

TABLE: 5.8 Allowable Bearing Capacity Table of at Khulna Medical College ICU

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=500mm, L=24m, FS=2.5							
		1	2	3	4	5	6	7	8
KHULNA MEDICAL COLLEGE ICU	1.5	42.30	27.18	53.97	53.97	53.97	50.10		
	3	51.34	24.08	63.25	63.25	63.25	60.19		
	4.5	65.43	27.65	81.12	81.12	81.12	78.03		
	6	80.20	32.00	100.09	100.09	100.09	96.88		
	7.5	118.22	51.57	145.42	145.42	145.42	138.85		
	9	145.19	59.19	171.11	171.11	171.11	164.69		
	10.5	177.45	70.84	203.51	203.51	203.51	196.30		
	12	242.75	108.43	281.92	281.92	281.92	268.37		
	13.5	283.44	119.30	316.43	316.43	316.43	304.25		
	15	326.59	133.75	356.33	356.33	356.33	344.35		
	16.5	349.18	131.57	367.74	367.74	367.74	359.63		
	18	409.42	164.66	438.32	438.32	438.32	425.01		
	19.5	454.58	179.26	479.46	479.46	479.46	466.61		
	21	419.82	193.68	519.76	514.73	514.73	502.84		
	22.5	497.95	208.90	561.22	559.21	559.21	546.80		
	24	464.52	224.87	604.02	596.98	596.98	585.05	490.50	981
	25.5	544.22	241.18	647.58	643.55	643.55	630.86		
	27	510.13	256.38	689.12	680.06	691.53	678.07		
	28.5	510.13	269.42	726.38	720.34	724.25	712.27		
	30	585.28	283.25	766.50	760.46	764.38	752.63		

5.11 Allowable Pile Capacity of a Pile at Shun Shin Cement Factory, Lobonchora

Different existing equations are used to find out the allowable bearing capacity of a pile at Shun shin cement factory, Lobonchora. For each equation, pile capacity against depths is shown in Fig. 5.9 and also in Table 5.9. In this point the sub soil pile investigation depth was 24 m. The pile length was 24 m and diameter was 600 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. From Table 5.9 it was found that the predicted loads from equations at 24 m depth are 1.3 times higher than pile capacities from pile tests. End bearing was predicted from Janbu's equation for both cohesive and cohesionless soils, while for skin friction of cohesive and cohesionless soils, Tomlinson equation (α method) and Burland equation (β method) respectively were considered.

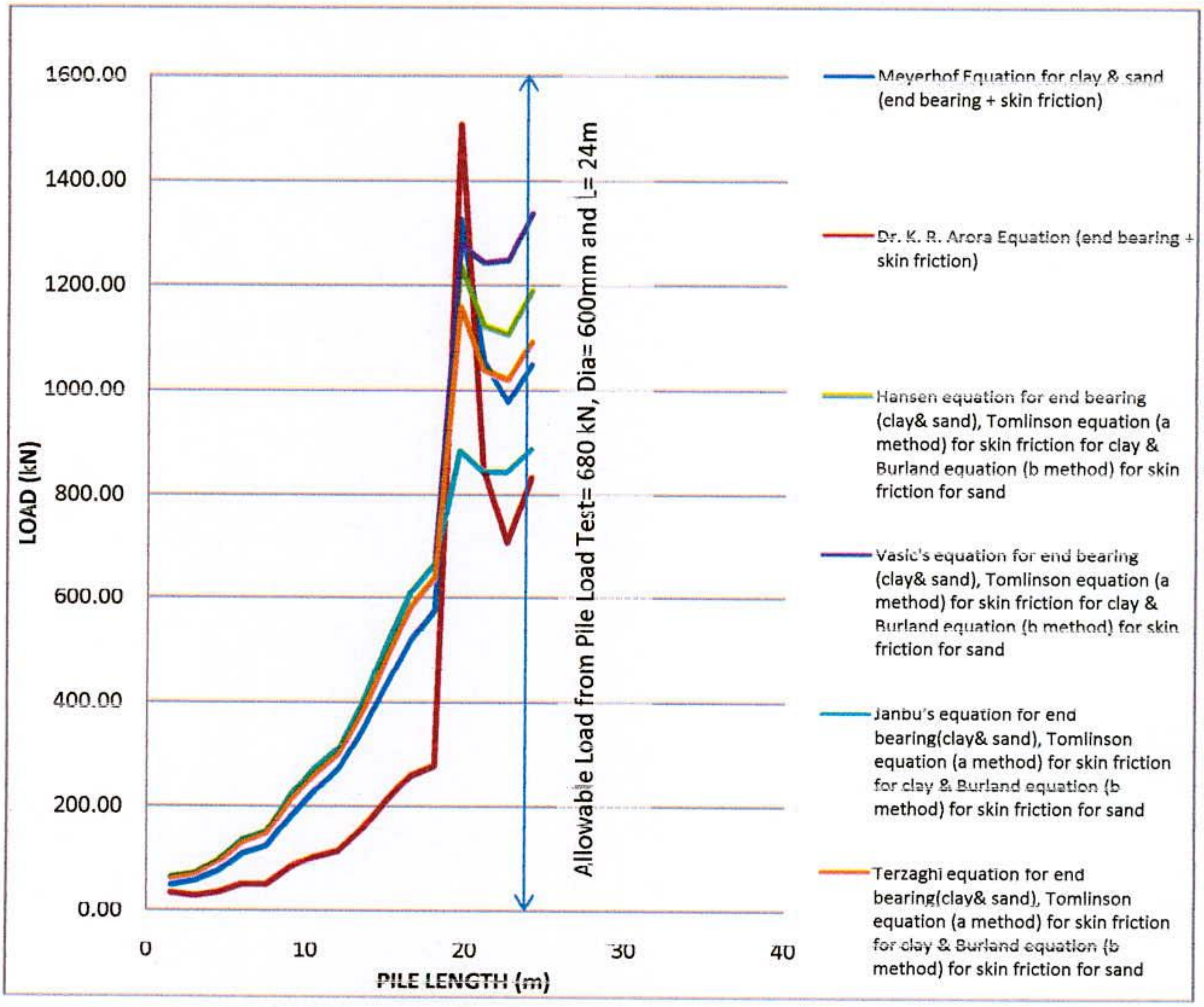


Fig-5.9 Load versus Depth curve from Various Equations at Shun Shin Cement Factory, Lobonchora

TABLE: 5.9 Allowable Bearing Capacity Table of at Shun Shin Cement Factory at Lobonchora

Project	Depth	Summary of allowable bearing capacity of pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=600mm, L=24m, FS=2.5							
		1	2	3	4	5	6	7	8
SHUN SHING CEMENT FACTORY, LOBONCHORA	1.5	50.33	34.00	65.69	65.69	65.69	61.20		
	3	57.80	28.19	72.25	72.25	72.25	68.57		
	4.5	77.06	34.90	98.01	98.01	98.01	93.58		
	6	110.89	51.00	137.59	137.59	137.59	130.62		
	7.5	124.73	50.11	152.27	152.27	152.27	147.10		
	9	181.73	82.77	223.02	223.02	223.02	211.69		
	10.5	230.22	102.45	273.78	273.78	273.78	260.66		
	12	272.99	114.98	312.43	312.43	312.43	299.60		
	13.5	346.99	155.69	399.14	399.14	399.14	379.96		
	15	434.71	210.27	511.12	511.12	511.12	483.88		
	16.5	519.99	259.04	614.41	614.41	614.41	582.40		
	18	577.39	276.93	667.96	667.96	667.96	639.64		
	19.5	1328.00	1506.24	1237.92	1277.17	885.42	1158.45		
	21	1056.93	849.12	1121.82	1243.97	845.12	1037.05		
	22.5	978.07	707.24	1106.43	1248.90	846.07	1018.95		
	24	1049.53	831.58	1189.13	1337.22	888.09	1091.40	1716.75	3433.5

5.12 Allowable Pile Capacity of a Pile at Sonadanga

Different existing equations are used to find out the allowable bearing capacity of a pile at Sonadanga. For each equation, pile capacity against depths is shown in Fig. 5.10 and also in Table 5.10. In this point the sub soil pile investigation depth was 22.5 m. The pile length was 16.5 m and diameter was 450 mm. The bearing capacity was determined at every 1.5 m depth of pile from various existing equation using soil parameters at that point. It was found that in most of the cases the bearing capacity is not same at same depth for different equations. From Table 5.10 it was found that the predicted loads from equations at 16.5 m depth are 1.08 times lesser than pile capacities from pile tests. End bearing was predicted from Janbu's equation for both cohesive and cohesionless soils, while for skin friction of cohesive and cohesionless soils, Tomlinson equation (α method) and Burland equation (β method) respectively were considered.

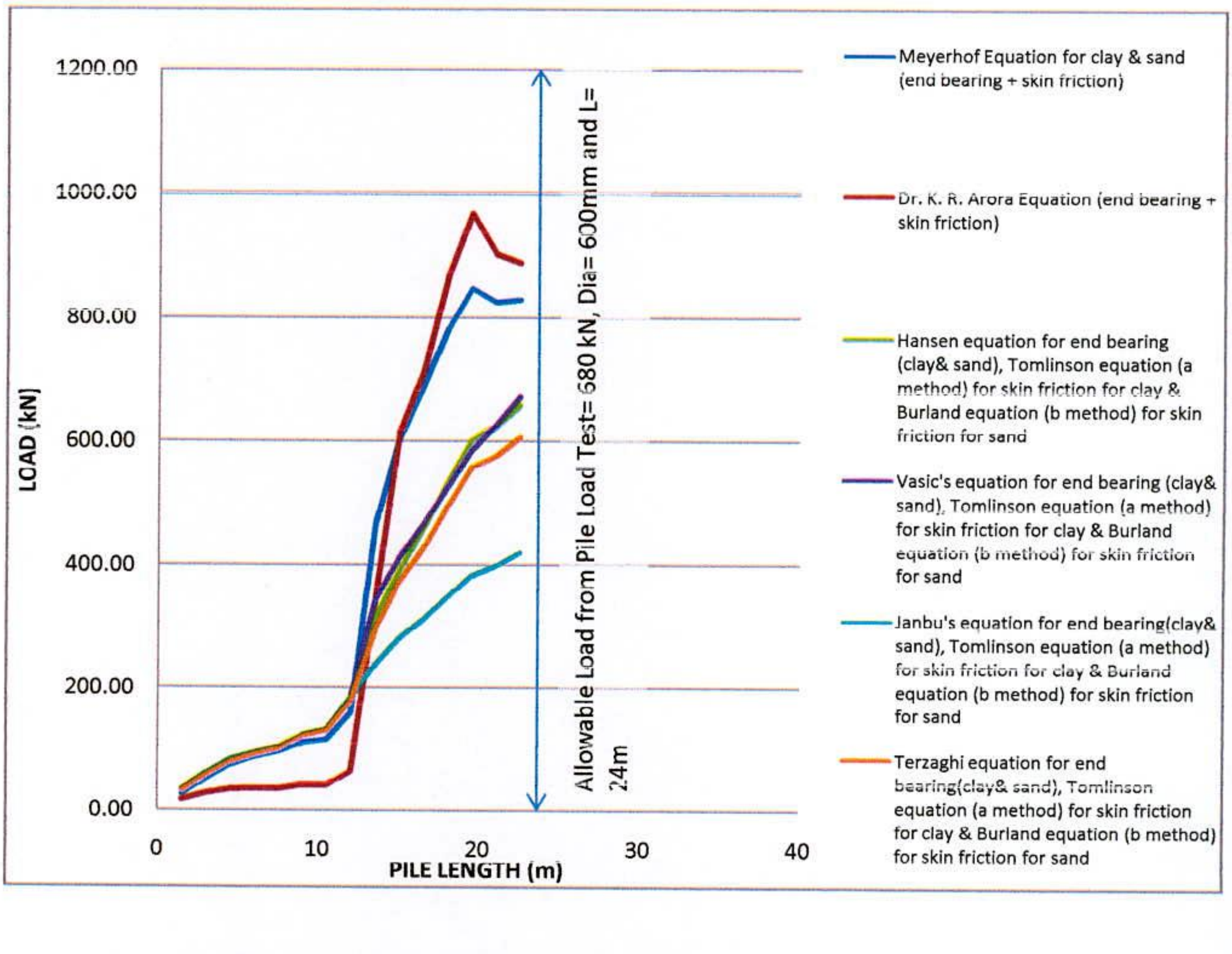


Fig-5.10 Load versus Depth curve from Various Equations at a Building in Sonadanga

TABLE: 5.10 Allowable Bearing Capacity Table of at a Building in Sonadanga

Project	Depth	Summary of allowable bearing capacity of situ pile							
		Meyerhof Equation for clay & sand (end bearing + skin friction)	Dr. K. R. Arora Equation (end bearing + skin friction)	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	Design Load	Test Load
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load(kN)	(kN)	(kN)
		Dia=450mm, L=16.77m, FS=2.5							
		1	2	3	4	5	6	7	8
`PLOT#43, ROAD#5, SONADANGA R/A	1.5	26.73	16.36	33.73	33.73	33.73	31.33		
	3	52.08	26.84	61.77	61.77	61.77	57.71		
	4.5	74.19	33.55	83.54	83.54	83.54	79.19		
	6	87.93	34.81	94.27	94.27	94.27	90.89		
	7.5	96.07	34.39	102.82	102.82	102.82	100.52		
	9	111.84	40.47	124.06	124.06	124.06	121.15		
	10.5	117.17	39.22	132.27	132.27	132.27	130.50		
	12	160.12	63.54	184.93	184.93	184.93	178.43		
	13.5	467.53	342.65	313.45	342.84	238.99	293.33		
	15	606.15	613.61	390.58	412.56	281.54	371.75		
	16.5	693.02	713.76	458.40	466.99	312.43	426.64	529.7	662.18
	18	783.58	866.84	533.32	526.46	348.73	494.54		
	19.5	848.26	967.69	601.20	585.76	382.80	556.77		
	21	826.09	902.63	624.62	626.53	399.85	575.51		
	22.5	829.78	888.26	658.19	672.09	420.96	605.23		

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 General

The observation of this thesis work has analyzed & discussed here. The discussion has been made in two stages one on pile capacity from suitable eight equations and another on pile capacity from ten pile load tests. Finally it was under consideration to select a suitable equation which is more appropriate to determine the pile capacity.

6.2 Soil Profile of the KCC Area

The whole area was divided into two zones. The Zone-I includes west side of the city as shown in Fig. 3.2. In this zone the sub-soil consists of predominantly silt below 125 ft. In this zone up to about 50 to 70 ft depth the soil is of very soft to soft consistency and N-value ranges from about 1 to 5 in most areas. In sub-soil investigation it was not possible to find out the depth of sandy layer because boring was not performed below this depth. There exists an organic layer which is mainly at depth 15ft to 25 ft in most of the areas. In some places this organic layer exists from top of the existing ground level. Most probably this area was filled up with dumping garbage and organic sold wastes.

The zone-II includes the east side of the city area as shown in Fig. 3.2. In this zone the sub-soil consists of predominantly silt up to about 50 ft depth in most areas. The soil is of very soft to soft consistency ranging N-value from 1 to 5. Below this silt deposit the soil contains mainly sandy soil. In this zone there exists an organic layer from 10 ft to 20 ft in most of the areas of this zone.

6.3 Allowable Pile Capacities from Load Tests and Equations

To find out the allowable pile capacity, the minimum value among three criteria is selected. These criteria for safe or allowable load are (i) one-half of the load at which the total settlement is equal to 10 percent of the pile diameter, (ii) two-thirds of the final load at which the total settlement is 12 mm and (iii) two-thirds of the final load at which the net settlement is 6 mm. But in these pile tests only one criterion as (iii) was satisfied for very less settlement due to load test that observed in field. So this load was the recommended safe load in this investigation. The allowable capacities from ten pile load tests are shown in Table 6.1. The corresponding capacities for each pile from selected equations are also shown in Table 6.2. From comparative study among the pile capacity from load tests and equations, pile capacity from equations are 2.58, 1.8, 1.44, 1.2, 1.01, 1.13 and 1.3 times increased than that from pile load tests, while in two areas pile capacity from equations are decreased by 1.02, 1.17 and .065 times than load test values. But these increased or decreased are not for all equations or any single equation. So no suitable common equation was selected to compare with the pile capacity in both the zones. However, in the south end of zone-I Meyerhof's equation gave close value to pile load test for the four sites in Khulna University area and Mayur bridge and the variation of load is from 1% to 28%.

TABLE 6.1 Allowable Load From Pile Load Tests

Zone	Location of Pile Load Test	Final Load at 6 mm net settlement (kN)	Allowable Pile Capaity (kN)
II	Bastuhara Bridge	980	653.33
II	Bridge in Between Bastuhara and Rayer Mahal	950	633.33
II	Rayer Mahal Bridge	830	553.33
II	Bridge on Mayur River	-	1962
II	KU Library Building	825	550
II	KU Male Student Hall	-	1079
II	KU Agrani Bank Building	725	483.33
I	Khulna Medical College ICU Building	925	616.67
I	Shun Shing Cement Factory in Lobonchora	-	680
I	A Building at Sonadanga	510	340

TABLE 6.2 Comparative Study of Pile Capacities from Pile Load Tests and Equations

Sl no	Name of Equation	Summary of allowable bearing capacity of pile									
		Bastuhara Bridge	Bridge in between Bastu. & Ray. mahol	Bridge in Rayer Mahol	Bridge on Mayur River	KU Library Building	KU Male Student Hall	Agrani Bank Building in KU	Khulna Medical College ICU unit	Shun Shing Cement Factory, Lobonchora	Plot # 43, Road # 5, Sonadanga
		Load(kN)	Load(kN)	Load(kN)	Load(kN)	Load (kN)	Load (kN)	Load (kN)	Load (kN)	Load(kN)	Load(kN)
		F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5	F.S=2.5
		Dia=750mm L=30.50m	Dia=750mm L=30.10m	Dia=750mm L=30.60m	Dia=1000mm L=48.00 m	Dia=500mm L=27.44 m	Dia=500mm L=30.5 m	Dia=450mm L=26.00 m	Dia=500mm L=24.00 m	Dia=600mm L=24.00 m	Dia=450mm L=16.77 m
		1	2	3	4	5	6	7	8	9	10
1	Meyerhof Equation for clay & sand (end bearing + skin friction)	2011.14	1145.20	797.96	4069.23	558.52	775.11	544.41	464.52	1049.5	709.32
2	Dr. K. R. Arora Equation (end bearing + skin friction)	2848.14	956.61	343.23	3685.22	262.27	402.80	243.38	224.87	831.6	741.31

3	Hansen equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	2454.97	1244.03	878.40	6696.87	659.15	929.57	627.33	604.02	1189.1	471.89
4	Vasic's equation for end bearing (clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	3442.87	1244.03	878.40	2352.41	659.15	929.57	627.33	596.98	1337.2	477.69
5	Janbu's equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	1691.90	1244.03	878.40	4518.79	659.15	929.57	627.33	596.98	888.1	318.96
6	Terzaghi equation for end bearing(clay& sand), Tomlinson equation (a method) for skin friction for clay & Burland equation (b method) for skin friction for sand	2282.15	1689.35	1185.32	6149.36	632.22	892.16	612.12	585.05	1091.4	438.86
7	Pile Test load	982.44	982.44	982.44	1962.00	882.90	1079.00	882.90	981.00	1575.00	662.18
8	Allowable Load From Load Test	653.33	633.33	553.33	1962.00	550.00	1079.00	483.33	616.67	680.00	340.00
9	Max Settlement (mm)	8.70	8.99	16.87	5.76	13.23	0.81	13.81	11.500	25.00	14.105
10	Net settlement (mm)	7.01	7.40	10.575	3.11	8.35	0.56	11.57	9.800	25.0	10.650

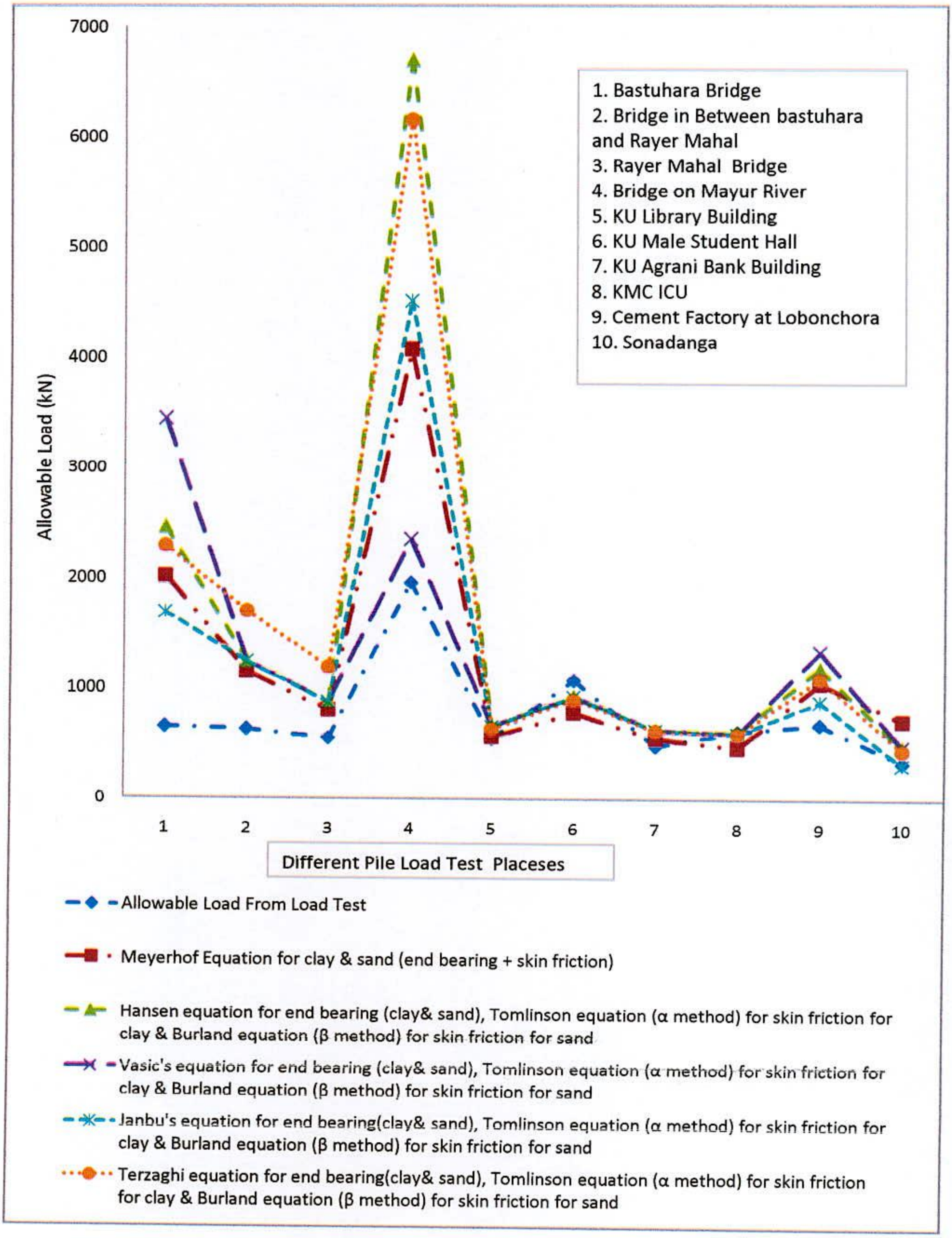


Fig-6.1 Estimated Pile Capacity versus Actual Pile Capacity curve from Various Equations at Different Placeses in Khulna City Area.

CHAPTER7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

From the present study the following conclusions can be drawn:

(i) On the basis of soil profile the whole area was divided into two zones. The Zone-I includes west side of the city. In this zone the sub-soil consists of predominantly silt which is more below than 125 ft depth from G.L. In this zone up to about 50 to 70 ft depth the soil is of very soft to soft consistency and N-value ranges from about 1 to 5 in most areas. In sub-soil investigation it was not possible to find out the depth of sandy layer because boring was not performed below this depth. There exists an organic layer which is mainly at depth 15ft to 25 ft in most of the areas. In some places this organic layer exists from top of the existing ground level. Most probably this area was filled up with dumping garbage and organic sold wastes.

(ii) The zone-II includes the east side of the city area. In this zone the sub-soil consists of predominantly silt up to about 50 ft depth in most areas. The soil is of very soft to soft consistency ranging N-value from 1 to 5. Below silt deposit, the soil contains mainly sandy soil. In this zone there exists an organic layer from 10 ft to 20 ft depth in most of the areas of this zone.

(iii) From static pile load test, among 10 load tests, 9 load tests at nine locations did not fail for 200% load of design load and their maximum settlements were about 16.87 mm. So allowable pile capacities were determined from permissible settlement.

(iv) Among all the equations, only Mayerhof's equation gave the pile capacity at maximum places which is near the value of load test. Other equations gave much higher values than load test values. So no suitable common equation was selected to compare with the pile capacity in both the zones. However, in the south end of zone-I Meyerhof's equation gave close value to pile load test for the four sites in Khulna University area and Mayur bridge

7.2 Recommendations

The following recommendations are suggested for future study:

(i) There might be a scope for future study for ultimate pile capacity from load settlement curve obtained from static pile load test & theoretical bearing capacity calculation for more load tests.

(ii) A future study can be initiated to determine the ultimate bearing capacity of pile by dynamic pile load test.

(iii) Pile load tests might be performed up to failure to compare the results with the pile capacity from different equations.

APPENDIX

LIST OF FIGURES

Project: Connecting Road from Bastuhara main Road to City By-pass Road

1/2

Client: Khulna Development Authority (KDA)

Location: Bastuhara (Bridge-1)

Bore Hole Number : 01 | **G.W.T. 3' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (3, 6, 9, 12, 15, 18, 21, 24)	Sample US	Sample DS	Remark
0 5	Gray very soft clayey silt		1			DS	
10			2			DS	
15	Black soft decomposed wood		1			DS	
20	Gray very soft clayey silt		2		US	DS	
25			2			DS	
30			1			DS	
35	Gray very loose fine sandy silt		5			DS	
40			4			DS	
45	Gray medium dense silty fine sand with trace mica		14			DS	
50			11			DS	
55			17			DS	
60			19				
65			21				
70	Gray medium dense fine sandy silt		17			DS	
75			15			DS	
80	Gray medium dense silt with trace clay & trace fine sand		13			DS	
85			17				

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A1 SUB-SOIL INVESTIGATION BORE

Project: Connecting Road from Bastuhara main Road to City By-pass Road

Client: Khulna Development Authority (KDA)

Location: Bastuhara (Bridge-1)

Bore Hole Number : 01 | **G.W.T. 3' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (3, 6, 9, 12, 15, 18, 21, 24)	Sample US	Sample DS	Remark
90	Gray medium dense silt with trace clay & trace fine sand		16				
95			20				
100			17				
105			19				

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A2 SUB-SOIL INVESTIGATION BORE

Project: Sub-soil Investigation Bore Log in between Bastuhara and Rayer mahal Area

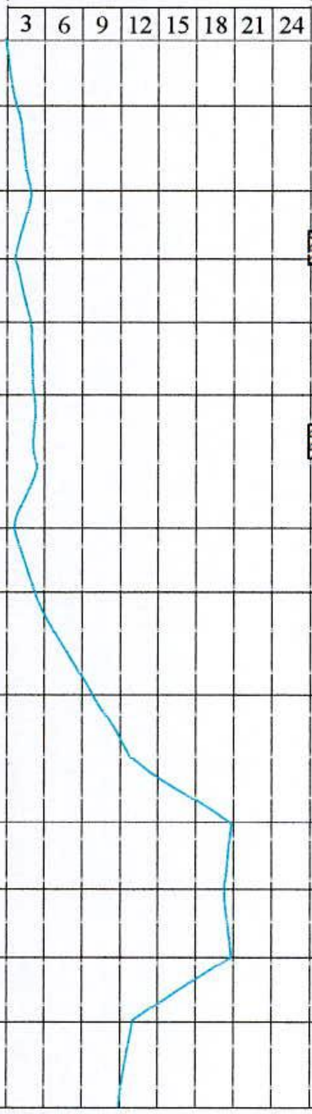
1/2

Location: In between Bastuhara and Rayer Mahal

Bore Hole Number : 01 | **G.W.T. 2' - 6"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value
0–5	Gray very soft clayey silt		1
10			2
15			1
20			2
25			2
30			2
35			1
40			2
45	Gray medium stiff Silt with trace clay & trace fine sand		7
50	Gray medium dense silt fine sand with trace mica		10
55			18
60			17
65			18
70	Gray loose to medium dense silt with trace clay & trace fine sand		10
75			9

Blow number



Sample: US | DS | Remark

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

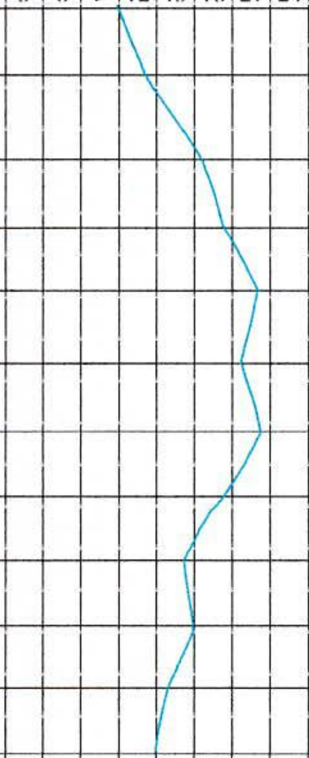
FIG. A3 SUB-SOIL INVESTIGATION

Project: Sub-soil Investigation Bore Log in between Bastuhara and Rayer mahal Area

Location: In between Bastuhara and Rayer Mahal

Bore Hole Number : 01 | **G.W.T. 2' - 6"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (3, 6, 9, 12, 15, 18, 21, 24)	Sample US	Sample DS	Remark
80	Gray loose to medium dense silt with trace clay & trace fine sand		11				
85			16				
90			17				
95			20				
100			19				
105	Gray stiff to stiff clayey silt		20				
110			17				
115			14				
120			15				
125			13				
130			12				

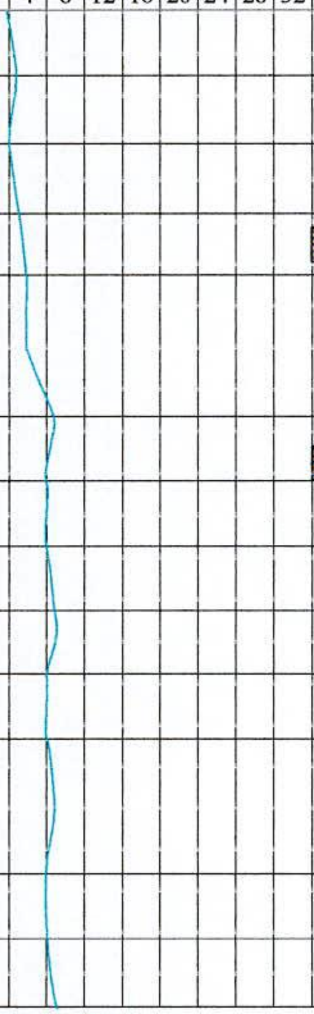


UNDISTURBED: | SAND: | CLAYEY:
DISTURBED: | SILT. | LITTLE SAND:

FIG. A4 SUB-SOIL INVESTIGATION

Project: Sub-soil Investigation Bore Log at Rayer Mahal Bridge	1/1
Location: Rayer Mahal Bridge	
Bore Hole Number : 01	**G.W.T. 0' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	Sample US	Sample DS	Remark
0	Black very soft decomposed						
5			1				
10			0				
15			1				
20			2				
25	Gray soft to medium stiff & stiff clayey silt		2				
30			5				
35			4				
40			4				
45			5				
50			4				
55			4				
60			5				
65			4				
70			4				
75			5				



UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A5 SUB-SOIL INVESTIGATION BORE LOG

Project: Sub-soil Investigation Bore Log at Rayer Mahal Bridge				1/1			
Location: Rayer Mahal Bridge							
Bore Hole Number : 01		**G.W.T. 0' - 0"**			Sample		Remark
Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4 8 12 16 20 24 28 32)	US	DS	
80	Gray soft to medium stiff & stiff clayey silt		5				
85			8				
90			10				
95	Gray medium dense Silt with trace clay & trace fine sand		27				
100			26				
105			28				

UNDISTURBED: | SAND: | CLAYEY:

DISTURBED: | SILT: | LITTLE SAND:

FIG. A6 SUB-SOIL INVESTIGATION

Project: Sub-soil Investigation at Mayur River Bridge

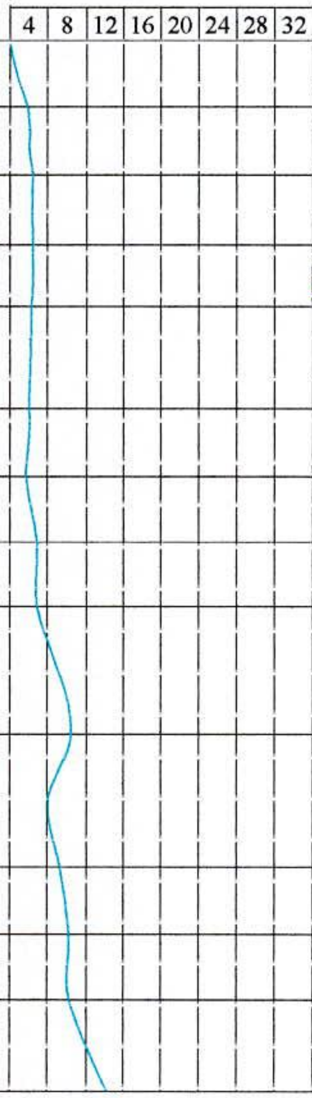
1/2

Location: Mayur River bank (Bridge on Mayur river)

Bore Hole Number : 01 | **G.W.T. 0' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value
0 5	Gray soft clayey silt		2
10			2
15			2
20			2
25	Black soft clayey silt with trace organic		2
30	Gray soft to medium stiff clayey silt		2
35			3
40			3
45			5
50			6
55			4
60			5
65			6
70			6
75	Gray medium dense silt with trace clay & trace fine sand		10

Blow number



Sample: US | DS — Remark

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A7 SUB-SOIL INVESTIGATION BORE

Project: Sub-soil Investigation at Mayur River Bridge

Location: Mayur River bank (Bridge on Mayur river)

Bore Hole Number : 01		**G.W.T. 0' - 0"**			Sample		Remark
Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	US	DS	
80	Gray stiff to medium stiff clayey silt		8				
85			10				
90			11				
95			12				
100			12				
105			9				
110			9				
115			9				
120			10				
125			9				
130			10				
135	Brown stiff silty clay		10				
140	Brown very dense silty fine SAND		20				
145			20				
150			20				
155			20				
160			20				

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A8 SUB-SOIL INVESTIGATION BORE

Project: Sub soil Investigation report for Library Building of Khulna University

1/1

Location: Khulna University Campus

Bore Hole Number : 01 | **G.W.T. 5' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	Sample US	Sample DS	Remark
0	Black very soft organic silty clay, trace fine sand						
5			1				
10			1				
15			2				
20	Grey very soft to soft silty clay trace fine sand		2				
25			2				
30			2				
35			2				
40			3				
45			3				
50			4				
55			4				
60			4				
65			5				
70	Light grey medium stiff to stiff clayey silt with fine sand		6				
75			9				

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG: A9 SUB-SOIL INVESTIGATION

Project: Sub soil Investigation report for Library Building of Khulna University

1/1

Location: Khulna University Campus

Bore Hole Number : 01 | **G.W.T. 5' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4 8 12 16 20 24 28 32)	Sample US	Sample DS	Remark
80	Light grey medium stiff to stiff clayey silt with fine sand		10				
85			14				
90			17				
95			20				
100			23				

UNDISTURBED: | SAND: | CLAYEY:

DISTURBED: | SILT: | LITTLE SAND:

FIG: A10 SUB-SOIL INVESTIGATION

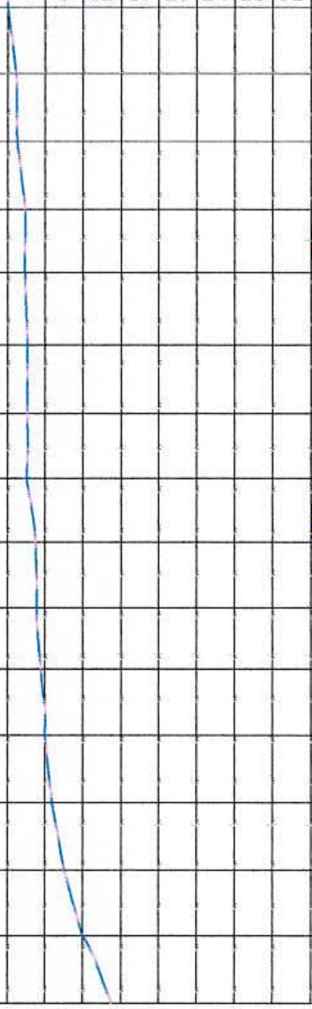
Project: Sub soil Investigation report for Male Student hall of Khulna University

1/2

Location: Khulna University Campus

Bore Hole Number : 01 | **G.W.T. 5' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4 8 12 16 20 24 28 32)	Sample US	Sample DS	Remark
0	Black very soft organic silty clay, trace fine sand						
5			1				
10			1				
15			2				
20	Gray to light gray stiff clayey silt trace fine sand		2				
25			2				
30			2				
35			2				
40			3				
45			3				
50			3				
55			4				
60			5				
65			6				
70			8				
75			11				



UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A11 SUB-SOIL INVESTIGATION BORE

Project: Sub soil Investigation report for Male Student hall of Khulna University

2/2

Location: Khulna University Campus

Bore Hole Number : 01 | **G.W.T. 5' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	Sample US	Sample DS	Remark
80	Ligth grey medium dense sandy silt, trace clay		13				
85			15				
90			18				
95			22				
100			24				

UNDISTURBED: | SAND: | CLAYEY:

DISTURBED: | SILT: | LITTLE SAND:

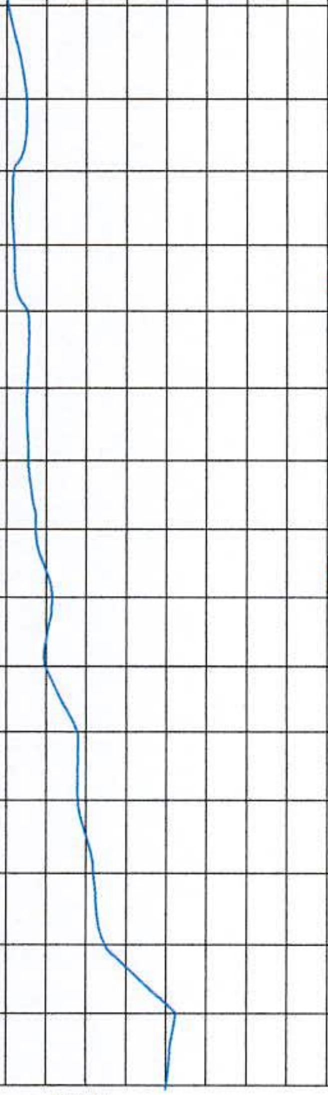
FIG. A12 SUB-SOIL INVESTIGATION

Project: Sub soil Investigation report for Agrani Bank Bhaban at Khulna University Campus

Location: Khulna University Campus

Bore Hole Number : 01 **G.W.T. 5' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	Sample US	Sample DS	Remark
0 5	Grey very soft silt, trace clay		2				
10	Blackish very soft organic silt		1				
15			1				
20	Gray very soft to very stiff clayey silt, trace fine sand		2				
25			2				
30			2				
35			3				
40			5				
45			4				
50			7				
55			7				
60			9				
65			10				
70	Gray very soft to very stiff clayey silt, trace fine sand		17				
75			16				



UNDISTURBED: SAND: CLAYEY:

DISTURBED: SILT: LITTLE SAND:

FIG. A13 SUB-SOIL INVESTIGATION BORE LOG

Project: Sub soil Investigation report for Agrani Bank Bhaban at Khulna University Campus				2/2			
Location: Khulna University Campus							
Bore Hole Number : 01		**G.W.T. 5' - 0"**			Sample		Remark
Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4, 8, 12, 16, 20, 24, 28, 32)	US	DS	
80	Gray very stiff clayey silt, trace fine sand		14				
85			14				
90			10				
95			11				
100			12				
105			11				
110			13				
115	Blackish gray very stiff organic silt		18				
120	Gray stiff clayey silt, trace fine sand		14				

UNDISTURBED: SAND: CLAYEY:
DISTURBED: SILT: LITTLE SAND:

FIG. A14 SUB-SOIL INVESTIGATION BORE LOG

Project: Sub soil Investigation report of Khulna Medical College

1/1

Location: Khulna Medical College Campus

Bore Hole Number : 01 | **G.W.T. 3' - 0"**

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4 8 12 16 20 24 28 32)	Sample US	Sample DS	Remark
0	Clay Light Brown						
5	Clay Light Brown		4				
10	Clay Light Brown		3				
15	Organic Clay black		2				
20	Organic Clay black		2				
25	Organic Clay black		5				
30	Silty Clay Light Gray		5				
35	Silty Clay Light Gray		5				
40	Fine Sand Gray		9				
45	Clay Light Gray		8				
50	Silty Clay Gray		8				
55	Silty Clay Gray		6				
60	Silty Clay Gray		9				
65	Silty Clay Gray		9				
75	Silty Clay Gray		8				
85	Clay Gray		9				
100	Clay Gray		8				

UNDISTURBED: SAND: CLAYEY:

DISTURBED: SILT: LITTLE SAND:

FIG. A15 SUB-SOIL INVESTIGATION BORE LOG

Project: Sub soil Investigation report of Shun Shing Cement Factory				1/1		
Location: Lobonchora						
Bore Hole Number : 01		**G.W.T. 1' - 11"**			Sample	Remark
Depth (ft)	Strata Encountered	Bore Log	SPT Value	Blow number (4 8 12 16 20 24 28 32)	US / DS	
0 5	Dark Gray Silty Clay		4			
10	Very dark grayish brown organic clay		2			
15	Dark gray clay, organic traces		2			
20	Very dark grayish brown organic clay		4			
25	Dark gray clay, organic traces		3			
30	Dark Gray Silty Clay		6			
35	Gray silty clay		6			
40	Gray clayey silt, sand traces		6			
45	Gray silty clay		9			
50			13			
55	Dark Gray Silty Clay		15			
60	Dark gray clayey silt		13			
65	Gray fine sand, mica traces		19			
70	Gray very fine sand, mica traces		11			
75	Gray very fine sand		10			
80	Gray very sand, mica traces		10			

UNDISTURBED: SAND: CLAYEY:

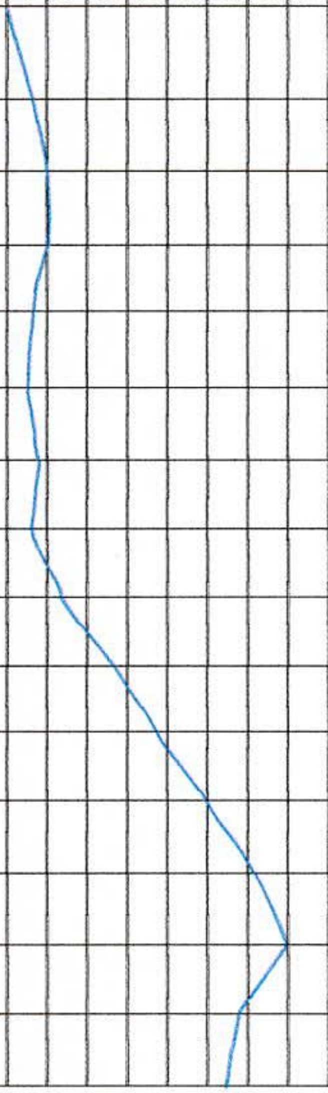
DISTURBED: SILT: LITTLE SAND:

FIG. A16 SUB-SOIL INVESTIGATION BORE LOG

Project: Sub soil Investigation report for Polt# 43, Road # 5, KDA Sonadanga R/A			1/1
Location: Sonadanga, khulna			
Bore Hole Number : 01		**G.W.T. 0' - 0"**	

Depth (ft)	Strata Encountered	Bore Log	SPT Value	Sample US	Sample DS	Remark
0 5	Soft Clay		3			
10			4			
15	Soft Organic Clay		4			
20	Soft Clay		3			
25			2			
30			3			
35			2			
40	Medium stiff Silty Clay with trace Sand		6			
45			11			
50			15			
55			20			
60	Dense Silty Sand with trace Clay		25			
65	Medium dense silty sand with trace Clay		28			
70			23			
75			22			

Blow number: 4 8 12 16 20 24 28 32



UNDISTURBED: SAND: CLAYEY:

DISTURBED: SILT: LITTLE SAND:

FIG. A 17 SUB-SOIL INVESTIGATION BORE LOG

REFERENCES

ACI Committee 318. 2005. Building Code Requirement for Structural Concrete (ACI 318-05), American Concrete Institute, Detroit.

Bowles, J.E. (1996), Foundation Analysis and Design, 5th ed., McGraw-Hill, Inc., New York.

Bhushan, K. (1982), "Discussion: New Design Correlations for Piles in Sands," Journal of Geotechnical Engineering Division, ASCE, GT 11, Nov., pp. 1508-1510.

Bogard, J.D. and Matlock, H. (1990), "In-Situ Pile Segment Model Experiments at Harvey, Louisiana," Paper presented at the 22nd Annual Offshore Technology Conference, Houston, Texas, May 7-10.

Bond A.J., Jardine, R.J. and Dalton, J.C.P. (1991), "Design and Performance of the Imperial College Instrumented Pile, " Geotechnical Testing Journal, Vol. 14, No. 4, pp. 413-424.

Bangladesh National Building Code, (1993), Housing and Building Research Institute, Bangladesh.

K. R. Arora (1997), "Soil Mechanics and Foundation Engineering", 4th ed., N.C. Jain, Delhi, India.

Amit Prasant, "Discussion: Pile Foundations," Journal of Foundation Analysis and Design, CE-632.

Fintel, Mark (1986), "Hand book of Concrete Engineering", Van Nostrand Reinhold Company, 2nd edition, U.S.A.

Goble, G., Likins, G. and Rausche, F. (1970), "Dynamic Studies on the Bearing Capacity of Piles", Phase III, Report No. 48, Division of Solid Mechanics, Structures and Mechanical Design, Case Western Reserve University.

G.M.M Rahman (2001), *"Study on Pile Capacity in Khulna Sub Soil."* M. Engg. Thesis, Department of CE, KUET.

Karlsrud, K., and Haugen, T. (1981), "Cyclic Loading of Piles and Pile Anchors, Field Model Tests at Haga," Contract Research Report, Norwegian Geotechnical Institute (NGI), Feb 5.

Lehane, B.M., and Jardine, R.J. (1994), "Displacement-Pile Behavior in a Soft Marine Clay, " Canadian Geotechnical Journal, Vol. 31, pp. 181-191.

Tomlinson Michael, and Woodward John (2008), "Pile Design and Construction practice", 5th ed., Taylor & Francis, London and New York.

Metsihafe Mekbib (1999), "*Performance of Piled Raft Foundations for Addis Ababa Soil,*" M. Sc. Engg. Thesis, Department of CE, Addis Ababa University. Satyendra Mittal (1988), Pile Foundation Design and Construction, 1st ed., CBS Publishers, New Delhi, India.

Nilson, Arthur. H. (2006), "Design of Concrete Structure", Mc. Graw-Hill International, 13th edition, New York.

Narayan V Nayak (1979, 1996), "Foundation Design Manual", 4th ed., N.C. Jain, Bombay, India.

Tomlinson, M.J. (1980), "Foundation design and Construction", Pitman Press, 4th edition, Great Britain.