A Major Project Report On

"Cyclic Pile Load Test on Model Piles in Sand"

Submitted by

Md Khalid Iqubal

Roll No. 18831

Under the guidance of

Prof. A. Trivedi

In Partial Fulfillment of

MASTER OF ENGINEERING

IN

CIVIL ENGINEERING

(With specialization in Structure)

For the Award of Degree by University of Delhi

DEPARTMENT OF CIVIL ENGINEERING
DELHI COLLEGE OF ENGINEERING
DELHI – 110042

2011

Acknowledgement

I am extremely grateful and thankful to my supervisors Prof. A. Trivedi & Mr. Naresh Kumar, Department of Civil Engineering, Delhi College of Engineering, Delhi for his invaluable guidance and encouragement through the course of this work.

I would also like to thank Prof. Dr. A.K Gupta, Head, Civil Engineering Department and other faculty members of the Civil Engineering Department for their cooperation.

Md Khalid Iqubal

Master of Engineering
(Structural Engineering)
College Roll No: 21/STR/07
University Roll No: 18831
Department of Civil Engineering
Delhi College of Engineering, Delhi

Certificate

This is to certify that major project report entitled "**Cyclic Pile Load Test on Model Piles in Sand"** is an authentic record of my own work carried out in fulfillment of the requirements for the award of Master of Engineering (Structural Engineering), department of Civil Engineering, Delhi College of Engineering, Delhi under the guidance of Prof. A. Trivedi & Mr. Naresh Kumar.

Dated:

Name Md Khalid Iqubal
Roll No. 18831

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Prof. A. Trivedi
Civil Engineering Department,
Delhi College of Engineering,
Delhi.

Abstract

Piles are vertical or slightly slanting structural foundation members, having relatively small cross-sectional dimensions With respect to their length. They are introduced into the soil and transmit the loads and forces acting on the superstructure to the subsoil. The length, method of installation, and way of acting of piles can vary greatly, and thus they are easily adaptable to various conditions and requirements.

Conducting a load test on a pile to determine its ultimate or safe load carrying capacity is indeed a costly and time-consuming enterprise. However, as stated earlier, it is the most reliable means of determining the load carrying Capacity of a pile, since, as a deep foundation; a pile passes through a number of different layers of soil with varying sometimes uncertain properties. Hence, in spite of the cost, time and effort, one may have to resort to a load test in many instances where one may be doubtful whether calculation by static or dynamic formulae would be sufficiently reliable. In fact, in most piling jobs, it is usual to stipulate that load test should be conducted on one pile, if not more. The load test on pile involves measuring deflection against loads applied in stages till the soil fails under the load. The data is plotted as a cyclic load settlement curve from which the ultimate load carrying capacity is interpreted.

When a pile is loaded by an axial load at ground level, initially the applied load is distributed as friction load within a certain length of the pile measured from its top. When the pile is loaded first the load is taken by surface of pile in entire length. This is due to friction of surface this is called skin friction. After that the load of superstructure is taken by the base of pile in case of cohesionless soil. This resistance of pile is known as tip resistance. It is only after the full length of the pile develops frictional resistance at a certain stage of loading, that a part of the load is transferred to the soil at the base as point load. With the increase in load at the top after this stage, both the frictional as well as point loads increase. The frictional load attains a maximum value at a certain load level and will not further increase upon increase in axial load. But the point load still keeps on increasing till the soil at the base fails in local shear. The total settlement S of a pile obtained from a pile load test comprises of two components, namely, elastic settlement, *Se* and plastic settlement *Sp*.

The elastic settlement, *Se* is due to the elastic recovery of the pile material and the elastic recovery of soil at the base of the pile. In the cyclic loading procedure of the pile load test, it is easy to obtain the elastic settlement and the plastic settlement at every stage of loading. This report presents the results of cyclic pile load test carried out on four steel piles with same length but varying cross-sectional area. The piles were of following x-sectional:

a) Circular Pile having length 100 cm with outer diameters 27 cm of x-section.
b) Circular Pile having length 100 cm with outer diameters 10 cm of x-section.
c) Circular Pile having length 100 cm with outer diameters 7.5 cm of x-section.
d) Circular Pile having length 100 cm with outer diameters 4.0 cm of x-section.

The test is conducted in the field lab having sand with Average moisture content 9.86%.The compressive load on the pile is coming from reaction of steel beam arrangement system by using hydraulic jack. Piles were driven into the soil with same length inserted into the soil by hammer driving and these are compressed by compressive load through hydraulic jack arrangement. The test is conducted with dense and loose sand condition. Dense sand is condition of sand in natural condition as fully compacted. Loose sand is the sand with partial compaction which occurs when sand is poured from a height of 50cm.

The ultimate capacity of pile in loose sand reaches to dense with increasing diameter. For higher diameter pile the skin friction in loose sand increases more than lower diameter pile. The load carried by pile load test is maximum as compared to other static formulae. For cyclic pile load test for same settlement load requires much as compared to direct pile load test. The skin friction obtained from pile load test is higher as calculated from static load formulae.

Contents

Acknowledgement.. (i)

Certificate.. (ii)

Abstract.. (iii)

Table of contents .... (v)

List of figures .... (vii)

List of tables.. (viii)

CHAPTER 1

INTRODUCTION

1.1 Introduction.. 1
1.2 General.. 1
1.3 Type of load test.. 2
1.4 Static pile load formulae... 2
1.5 Pile load test.. 3
1.6 Cyclic load test... 5
1.7 Dynamic pile load formulae 6
1.8 Objective of study 6
1.9 Organisation of thesis 7

CHAPTER 2

LITERATURE REVIEW

2.1 General.. 8
2.2 Behaviour of single piles 9
2.3 Classification of pile... 11
  2.3.1 Types of piles based on construction materials.............................. 11
  2.3.2 Types of piles based on construction methods............................... 12
  2.3.3 Classification of piles based on functional behaviour 13
  2.3.4 Preference of steel piles over other types of piles 14
2.4 Mechanics of load transfer through piles 15
2.5 Skin friction 16
2.6 Negative skin friction 16
2.7 Piles in sand 17
  2.7.1 Point-bearing piles in sand... 17
  2.7.2 Friction piles in sand.. 17
  2.7.3 Compaction piles 18
2.8 Pile load capacity in compression... 18

2.8.1 Static pile load formulae 19
2.8.2 Dynamic pile formulae 21
2.8.3 Pile load test 24
2.9 Cyclic pile load test 28
2.10 Studies 31
2.11 Codal Provisions 32

CHAPTER 3

EXPREMENTAL PROGRAMME

3.1 Tests conducted before performing pile load test 34
3.2 Specific gravity of sand 35
3.3 Fabrication of apparatus 36
3.3.1 Construction of pit 36
3.3.2 Sand filling in the pit 37
3.3.3 Fabrication of steel piles 38
3.3.4 Loading arrangement for the test 40
3.3.5 Arrangement of dial gauge 40
3.4 Experimental procedure 43
3.5 Observation for cyclic load test 45
3.6 Dynamic pile test observation 53
3.7 Precaution 54

CHAPTER 4

DISCUSSION ON RESULTS

4.1 General 55
4.2 Relation with pile load test and static formulae 56
4.3 Calculation of pile capacity by static formulae 63
4.4 Calculation of pile capacity by dynamic formulae 69

CHAPTER 5

CONCLUSIONS
5.1 General 78
5.2 Future scope of work 79

References

List of figures

Figure no.	Description	Page no.
Figure 2.1	Zone of deformation around pile driven in sand	10
Figure 2.2	Increase of the internal friction in sand due to pile driving	11
Figure 2.3	Piles subjected to compressive loads	15
Figure 2.4	Negative skin friction	17
Figure 2.5	Friction pile in sand: maximum resistance	19
Figure 2.6	Pile load test in compression using anchor piles	26
Figure 2.7	Typical load settlement curve for pile load test	29
Figure 2.7a	Axial load P = B + F	30
Figure 2.7b	P vs $S_{e,}$ $(S_e - \Delta)$	30
Figure 2.8	Displacement of piles and compaction area for each pile	32
Figure 3.1	Particle size distribution curve	35
Figure 3.2	Specific gravity determination by pycnometer	36
Figure 3.3	Pit at initial stage	37
Figure 3.4	Formation of cone in lathe	39
Figure 3.5	Formation of pile cap	39
Figure 3.6	100mm ,75mm&40mm complete pile ready to use	40
Figure 3.7	Dial gauge arrangement on site	41
Figure 3.8	Complete arrangement	41
Figure 3.9	Concept drawingof loading arrangement	42
Figure 3.10	Enlarge view of concept drawing	42
Figure 3.11	Loading from hydraulic jack during testing	43
Figure 4.1	270 mm dia pile (dense & loose sand)	57
Figure 4.2	270 mm dia pile (dense & loose sand)cumulative	57
Figure 4.3	100 mm dia pile (dense sand)	58
Figure 4.4	100 mm dia pile (dense &loose sand)cumulative	58
Figure 4.5	75 mm dia pile (dense & loose sand)	59
Figure 4.6	75 mm dia pile (dense & loose sand) cumulative	59
Figure 4.7	40 mm dia pile (dense & loose sand)	60
Figure 4.8	40 mm dia pile (dense & loose sand) cumulative	60
Figure 4.9	270, 100, 75, mm dia pile (dense sand)	61
Figure 4.10	270, 100, 75, mm dia pile (dense sand) cumulative	61
Figure 4.11	270, 100, 75, mm dia pile (loose sand)	62
Figure 4.12	270, 100, 75, mm dia pile (loose sand) cumulative	62
Figure 4.13	Pile load test vs static formulae (dense sand)	68
Figure 4.14	Pile load test vs static formulae (loose sand)	68
Figure 4.15	Dynamic load test vs static formulae (dense sand)	76
Figure 4.16	Dynamic load test vs static formulae (loose sand)	76
Figure 4.17	Comparison of all three method(dense)	77
Figure 4.18	Comparison of all three method(loose)	77

List of tables

Table no.	Description	Page no.
Table 3.1	Steel pile specifications	38
Table 3.2	Static pile no.1: (dia= 270mm,dense sand)	45
Table 3.3	Static pile no.1: (dia= 270mm, loose sand)	46
Table 3.4	Static pile no.2: (dia= 100mm, dense sand)	47
Table 3.5	Static pile no.2: (dia= 100mm,loose sand)	48
Table 3.6	Static pile no.3: (dia= 75mm,dense sand)	49
Table 3.7	Static pile no.3: (dia= 75mm,loose sand)	50
Table 3.8	Static pile no.4: (dia= 40mm,dense sand)	51
Table 3.9	Static pile no.4: (dia= 40mm,loose sand)	52
Table 3.10	Dynamic pile load test observation(dense sand)	53
Table 3.11	Dynamic pile load test observation(loose sand)	54
Table 4.1	Load carrying capacity according to pile load test	55
Table 4.2	Load carrying capacity according to static formulae	67
Table 4.3	Comparison of pile load test and static load formulae results	67
Table 4.4	Comparison of plate load, dynamic and static load formulae	75

CHAPTER 1
INTRODUCTION

1.1 Introduction

For the superstructure to its transfer loads and moments to the underlying soil or rock it need some support, here comes the role of foundation, also designated as substructure as they are placed below the ground level. Thus, the foundation structure effectively supports the superstructure. The need for deep foundations arises when the soil at shallow depths from the ground level are not competent enough to support shallow foundations such as footings or rafts.

1.2 General

Piles are vertical or slightly slanting structural foundation members, having relatively small cross-sectional dimensions With respect to their length. They are introduced into the soil and transmit the loads and forces acting on the superstructure to the subsoil. The length, method of installation, and way of acting of piles can vary greatly, and thus they are easily adaptable to various conditions and requirements.

Piling has come a very long way, not only through the thousands of years of human history, but also in the technological age itself, and even since the establishment of soil mechanics. The piles of the past were 10 to 20 m long and about 0.2 to 0.5 m diameter, but today we have giant piles with a length of 50 to 100 m and a diameter of 3 to 5 m. The use of piles has become more varied and complex than ever before (Fang, 1975).

Steel has been used to an increasing extent for piling due to its ease of fabrication and handling and its ability to withstand hard driving. Problems of corrosion in marine structures have been overcome by the introduction of durable coatings and cathodic protection.

Piles may be used for the following purposes:

1. To transfer loads through water or soft soil to a suitable bearing stratum by means of end bearing of the piles (end-bearing or point-bearing piles).

2. To transfer loads to a depth of a relatively weak soil by means of "skin friction" along the length of the piles (friction piles).
3. To compact granular soils, thus increasing their bearing capacity (compaction piles).
4. To carry the foundation through the depth of scour to provide safety in the event the soil is eroded away.
5. To anchor down the structures subjected to uplift due to hydrostatic pressure or overturning moment (tension piles or uplift piles).
6. To provide anchorage against horizontal pull from sheet piling walls or other pulling forces (anchor piles).
7. To protect water front structures against impact from ships or other floating objects (fender piles and dolphins).
8. To resist large horizontal or inclined forces (batter piles).

1.3 Type of Load Test

Pile load capacity in compression can be found out using:

1. Static pile load formulae
2. Pile load test
3. Pile driving formulae
4. Correlations with penetration test data

Load Capacity is usually found out using the static load formulae or pile load test but pile load test is generally preferred for finding out the load capacity of the piles as it is the most reliable method for finding the load carrying capacity of the piles. Pile load test is generally carried out in field but here to carry it out on the model piles we have tried to develop our own apparatus for the pile load test a schematic diagram for which is given below.

1.4 Static Pile Load Formulae

The maximum load which a pile can support through the combined resistance of skin friction and point bearing is known as ultimate load capacity, Q_u of the pile is;

$$Q_u = Q_{pu} + Q_f$$

If $Q_{pu} >> Q_f$, the pile is called a point bearing pile else if $Q_{pu} << Q_f$ it is called a friction pile. The relative proportion of loads carried by point load and skin friction depends on the shear strength and elasticity of the soil. The vertical movement of the pile required to mobilize full skin friction resistance is much smaller than that required to mobilize full point bearing resistance.

1.5 Pile Load Test

Pile load test is the only direct method for determining the allowable load on piles. It is considered to be the most reliable of all the approaches, primarily due to the fact that it is an in situ test. Pile load tests are very useful for cohesion less soils. Three types of tests, namely, vertical load test (compression), lateral load test and pull out test (tension) can be carried out. Generally, vertical load test is carried out to establish load-settlement relationship under compression and determine the allowable load on pile.

Two categories of tests on piles, namely, initial test and routine test are usually carried out. Initial test should be carried out on test piles to estimate the allowable load or to predict the settlement at a working load. Routine test is carried out as a check on working piles and to assess the displacement corresponding to the working load.

Here, we have used model/Test piles for pile load test. Test pile is a pile which is used only in a load test and does not carry the load of the superstructure, the minimum test load for the test piles should be twice the safe load or the load at which the total settlement attains a value of 10 percent of the pile diameter in case of a single pile and 40 mm in case of a pile group.

A working pile is a pile which is driven or cast in situ along with other piles to carry load from the superstructure. The test load on such piles should be up to one and a half times the safe load or up to the load at which total settlement attains a value of 12mm for a single pile and 40mm for a group of piles, whichever is earlier.

For the non-availability of reliable procedures for assessing the load transfer mechanisms between piles and surrounding soil, or for determining the ultimate capacity of piles, full-scale load tests are conducted. It is a standard practice to conduct load tests in large projects in the design phase or during construction.

The significance of a properly conducted load test is that it furnishes the actual soil resistance at the site upon which design can be based reliably. In practice, load tests are more commonly conducted to determine that the foundation is capable of sustaining working loads with sufficient factor of safety. In other instances, load transfer characteristics are required to identify the mechanism by which load is transferred to the soil.

Load tests depend upon their procedure, equipment, instrumentation, and load application method. There are two types of tests conducted for axial types of loading, which are compression tests and pullout tests. For compression tests, the load can be applied either by adding dead weight or by hydraulic jacking. Direct application of dead weight can be done with concrete or steel blocks, sand bags or any other type of weights. However, the use of this method has decreased considerably, and it became more common to use hydraulic jacks to vary the load on the test pile, especially for high loading conditions.

The arrangement for an axial compression test is generally done using either a dead load platform, or a hydraulic jack with reaction (or anchor) piles. The hydraulic jack with reaction piles arrangement is used routinely in load testing. In order to minimize the effect of stresses transferred from the reaction piles to the soil near the test shaft, a minimum distance is required between the reaction piles and the test pile. It is generally accepted to allow for a minimum spacing of 3 reaction pile diameters between each reaction pile and the test pile, provided that this distance is greater than 1.5m (Hirany and Kulhawy, 1988).

A reaction beam is installed on top of the reaction piles. The test pile is loaded by utilizing a hydraulic jack that is placed on the center of the test pile. The applied load is measured with a load cell placed between the hydraulic jack and the pile or by a pressure gauge installed between the pump and the jack.

Instruments are primarily employed to record two types of movement in load tests. First is the pile head movement and second are the incremental strain measurements along the pile length. Measurements of the pile head movement is essential in all load tests and is done by the use of dial gauges. The incremental strain measurements along the pile length are taken only if load transfer distribution needs to be determined. Instruments that can be installed for such measurements are the telltales (strain rods) and electric strain gauges.

Several arrangements are possible for conducting pullout tests (Hirany and Kulhawy, 1988). However, two arrangements are more common than others. In the first setup as a hydraulic jack is located between a beam and a reaction frame that is hydraulic jacks acting on top of the reaction supports. In this setup, the load on the test pile is taken as twice the jacking load. The instruments and measurements for the pullout tests are similar to those for compression load tests.

1.6 Cyclic Load Test

In case of an end bearing and friction pile, it may be necessary for us to know what portion of working load is shared by skin friction and tip resistance. This is not possible from a normal pile load test which is 'monotonic'. Such information will be useful to us in arriving at the distribution of axial compression in the pile section, for a more realistic structural design of the pile, besides its settlement analyses. One method of determining the end resistance and skin friction, but at twice the cost, is to conduct the pile load test in pair, subjecting one pile to compression and the other to tension.

The former giving the total capacity and the latter, the capacity in skin friction alone. Determination of the corresponding break-up at the working load from the above ultimate load is still a matter of conjecture. One method which can yield the above information directly is to conduct a 'cyclic load test' on the pile. In the test the load is applied in stages of about 20% of the estimated working load, and at each stage, after noting the total settlement the load is released in full and the residual settlement is measured. The pile is now loaded to the second stage and then unloaded in full measuring residual settlement as above.

The scope of the pile load tests included a static vertical, cyclic vertical and cyclic lateral loading, with a sustained constant vertical load. Cyclic loads were applied through a hydraulic system interfaced with an automated electronic-electromechanical closed loop servo system to achieve controlled load intensity to the pile in a specific shape at specific frequency. The load-deflection, load transfer, and configuration of the pile during pile driving and after each load increment was measured through an instrumentation system that consisted of load cells, deflectometers, strain gages, accelerometers, and inclinometers (Arora, 1997).

Data obtained in this investigation indicated that:

1. Axial deformation of the pile remained essentially constant prior to and after cyclic axial load application. The behaviour of the pile was essentially elastic during cyclic load application.

2. Within the scope of testing performed, cyclic vertical load increments do not effect the load carrying capacity or load transfer characteristics of the pile.

3. Load transfer characteristics varied with the magnitude of applied axial load. The ratio of point bearing resistance to the applied load increased with the applied load. However, the rate of increase generally decreases with increasing applied load.

During this test, loading stages are performed as in the maintained load test.

After each loading, the pile is again unloaded to previous stage and deformation is measured. Then, load is again increase up to the next loading step. The process continues until failure load.

The recovered settlement is treated as elastic component and permanent deformation as plastic

1.7 Dynamic Pile Load Formulae.

Dynamic pile formulae are used in estimating pile capacity. These are based on the laws governing the impact of elastic bodies. The input energy of the hammer blow is equated to the work done in overcoming the resistance of the ground to the penetration of the pile.

1.8 Objective of Study

The basic objectives of the present study are as below:

1. To determine the ultimate failure load for a single pile.

2. To perform the cyclic pile load test for different diameter, and determine the ultimate load.
3. Drawing load settlement curves for different loads.
4. Compare the effect of change in cross section by keeping the same length on the ultimate failure load/bearing capacity of the pile.

1.9 Organisation of Thesis

1. Present thesis consists of five chapters in all. The first chapter as its name Introduction suggests, the need/objective of the study pile and pile foundation, it also includes different types of pile load tests dynamic formulae and static formulae. The tests conducted to calculate the pile load capacity and finally outline is given.
2. In the second chapter, named Literature Review, in which a brief but critical review of work of some important investigators is presented. A brief introduction to pile foundation system and IS 2911(Part IV) and ASTM codal provisions has also discussed.
3. Third chapter, named Experimental Programme, includes the laboratory tests which are conducted before the pile load test. It also includes the experimental setup for conducting the pile load test and observations made after performing pile load test.
4. In the fourth chapter titled Discussion on Results, which consists of experimental results of the pile load test conducted on single pile.
5. Fifth chapter consists of Conclusion of this thesis work.

CHAPTER 2
LITERATURE REVIEW

2.1 General

The need for deep foundations arises when the soil at shallow depths from the ground level are not competent enough to support shallow foundations such as footings or rafts. The three basic forms in which deep foundations appear are, the 'pile', 'pier' and the 'caisson'. Among them, while the cross section of a precast concrete pile may be square, octagonal or circular, that of cast-in-situ piles and piers is always circular. Since a caisson is virtually precast, its cross section can be of various shapes. The basic distinction between the three types of deep foundations is essentially a matter of the cross sectional dimensions in relation to depth. Thus while the cross sectional width of a pile can be typically about 300 mm that of a pier is about a metre and that of a caisson, several metres. As a result of this difference, while a pile bends under a horizontal load, caissons and piers of large diameters essentially undergo rotation as rigid bodies under a horizontal load (Bowles, 1970).

The increasing importance of pile foundations is clearly represented by the great number of contributions to international conferences and other publications dealing with the different aspects of pile foundations; in most recent year’s monographs and state-of-the-art reports give relevant information.

This modern and rapidly developing foundation method is, at the same time, one of the oldest. In river valleys, and flood areas with unreliable soil conditions this method has been used since prehistoric times; pile-dwellings can be found at the beginning of many cultures. For this purpose well-grown pine trees act as excellent material. From these beginnings today's variety was developed, with a pile system for almost every foundation system.

Piling has come a very long way, not only through the thousands of years of human history, but also in the technological age itself, and even since the establishment of soil mechanics. The piles of the past were 10 to 15 m long and about 0.3 m in diameter, but today we have giant piles with a length of 50 to 100 m and a diameter of 3 to 5 m.

The use of piles has become more varied and complex than ever before. Methods of construction underwent rapid changes and evolution; the timber piles and the hand-powered rammers of the past have given place to very complicated machines and highly specialized methods (Fang, 1975).To solve foundation problems, use of piles generally comes up in the following cases:

1. A soil layer having a reliable bearing capacity can be found at a greater depth only.
2. The layers immediately beneath the structure can be washed out, scours may occur.
3. For structures transmitting unusually high and/or horizontal loads
4. For structures which are very sensitive to settlements.
5. For offshore constructions.

In some cases piles serve only to improve the bearing capacity of the surrounding soil without direct participation in carrying the load of the structure.

2.2 Behaviour of Single Piles

In order to be able to design a safe and economical pile foundation, we have to analyse the interactions between pile and soil, establish the modes of failure, and estimate the settlement resulting from soil deformation under dead load, service load, etc (Fang, 1975).

Design should comply with the following requirements:

(a) it should ensure adequate safety against failure; the factor of safety depending on the importance of the structure and financial losses in case of failure, on the reliability of the information about soil and water conditions, structural behaviour and loading systems;

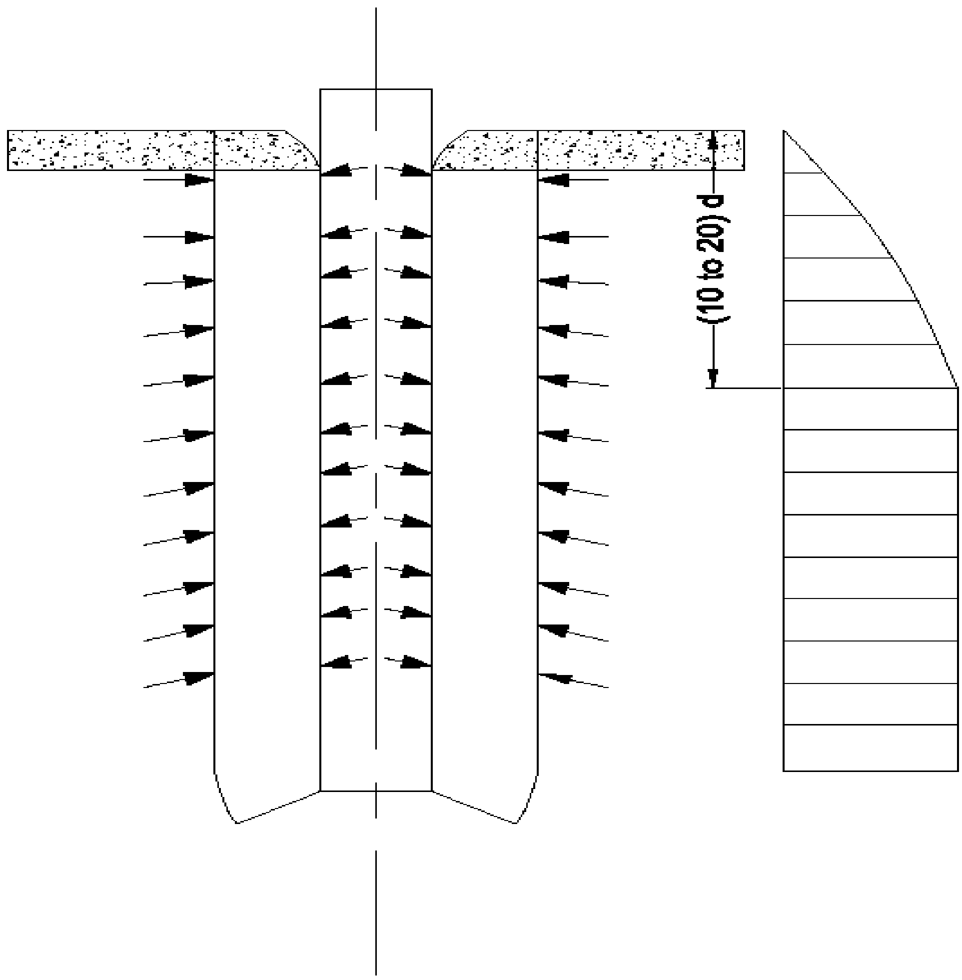


Fig 2.1:- Zone of deformation around pile driven in sand (after Kurian, 2006)

(b) The settlements should be compatible with an adequate behaviour of the superstructure to avoid impairing its efficiency.

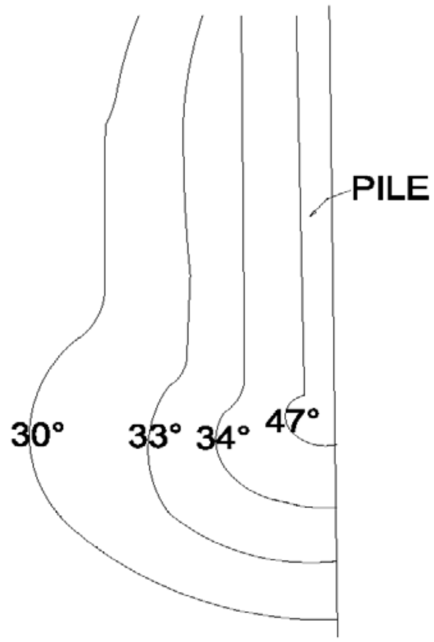


Fig 2.2:- Increase of the internal friction in sand due to pile driving (after Kurian, 2006)

2.3 Classification of Pile

2.3.1 Types of Piles Based on Construction Materials.

1. Concrete Piles
2. Steel Piles
3. Timber Piles
4. Composite Piles

Concrete piles

Concrete is adaptable for a wide range of pile types. It can be used in precast form in driven piles, or as insertion units in bore piles. Dense well-compacted good-quality concrete can withstand fairly hard driving and it is resistant to attack by aggressive substances in the soil, or in seawater or ground water. However, concrete is precast piles is liable to damage (possibly unseen) in hard driving conditions. Weak, honeycombed concrete in cast-in-situ piles is liable to disintegration when aggressive substances are precast in soils or in ground water.

Steel piles

More expensive then timber or concrete but this disadvantage may be outweighed by the ease of handling of steel piles, by their ability to withstand hard driving, by their resilience and strength in bending, and their capability to carry heavy loads. Steel piles can be driven in very long lengths and cause little ground displacement. They are liable to corrosion above the soil line and in disturbed ground, and they require cathodic protection of a long life is desired in marine structures. Long steel piles of slender section may suffer damage by buckling if they deviate from their true alignment during driving.

Timber piles

Untreated timber piles may be used for temporary construction, revetments, fenders and similar work; and in permanent construction where the cutoff elevation of the pile is below the permanent ground water table and where the piles are not exposed to marine borers. They are also sometimes used for trestle construction, although treated piles are preferred. Timber piles are difficult to extend, hard to anchor into the footing to resist uplift, and subject to damage if not driven carefully. Timber piles also have a maximum allowable bearing capacity of 45 Tons, whereas most structure piles are designed for at least 70 Tons.

Composite piles

Materials may be used in combination in piles and the most common example is the use of steel and concrete. This may be by using driven steel casings of various types filled with a structural core of concrete, or a steel pile protected externally by concrete casing; the latter is normally only possible for exposed lengths of piles such as would be encountered in a jetty structure. There are, however, forms of steel pile, which have grout pipes throughout their length, which are used for forming a protective outer casing after driving.

2.3.2 Types of Piles Based on Construction Methods.

- Displacement piles.
- Non-displacement piles.

Displacement piles

If a pile is forced into the ground, the soil is displaced downwards and sideways, but material is not actually removed. Piles inserted in this way are called displacement piles.

Non-displacement piles

Sometimes a shaft (or hole) is excavated and the soil is replaced with concrete to form a pile. This type of pile is called a replacement pile, or a non-displacement pile.

2.3.3 Classification of Piles Based on Functional Behaviour

- End bearing piles (point bearing piles)
- Friction piles
- Combination of friction and end bearing piles

End bearing piles

These piles transfer their load on to a firm stratum located at a considerable depth below the base of the structure and they derive most of their carrying capacity from the penetration resistance of the soil at the toe of the pile (see figure 1.1). The pile behaves as an ordinary column and should be designed as such. Even in weak soil a pile will not fail by buckling and this effect need only be considered if part of the pile is unsupported, i.e. if it is in either air or water. Load is transmitted to the soil through friction or cohesion. But sometimes, the soil surrounding the pile may adhere to the surface of the pile and causes "Negative Skin Friction" on the pile. This, sometimes have considerable effect on the capacity of the pile. Negative skin friction is caused by the drainage of the ground water and consolidation of the soil. The founding depth of the pile is influenced by the results of the site investigate on and soil test.

Friction and cohesion piles

Carrying capacity is derived mainly from the adhesion or friction of the soil in contact with the shaft of the pile.

Cohesion piles

These piles transmit most of their load to the soil through skin friction. This process of driving such piles close to each other in groups greatly reduces the porosity and compressibility of the soil within and around the groups. Therefore piles of this category are sometimes called compaction piles.

During the process of driving the pile into the ground, the soil becomes moulded and, as a result loses some of its strength. Therefore the pile is not able to transfer the exact amount of load which it is intended to immediately after it has been driven. Usually, the soil regains some of its strength three to five months after it has been driven.

Friction piles

These piles also transfer their load to the ground through skin friction. The process of driving such piles does not compact the soil appreciably. These types of pile foundations are commonly known as floating pile foundations.

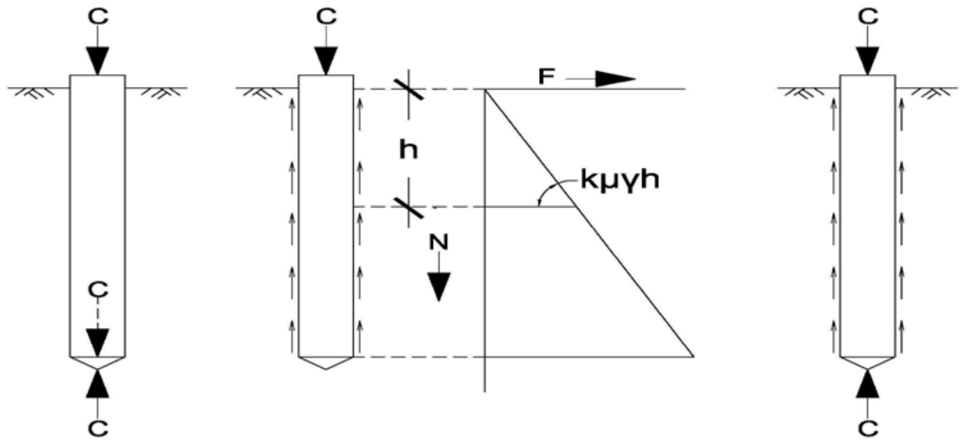
2.3.4 Preference of steel piles over other types of piles

a. The maximum length of Steel pile is practically unlimited. Whereas timber piles can be maximum up to 35 m, Cast-in-place concrete piles (shells driven without mandrel) can be 10- 25 m and Cast-in-place concrete piles (shells withdrawn) can be up to 36m.
b. The Optimum length of Steel pile is 12 to 50 m. Where as timber piles can be maximum up to 35 m, Cast-in-place concrete piles (shells driven without mandrel) can be 9- 25 m and Cast-in-place concrete piles (shells withdrawn) can be up to 8-12 m.
c. Hence the maximum load Carrying capacity (Maximum allowable stress, Cross Section) of steel pile is also much higher than the other types of piles.
d. Steel Pile additionally has the following advantages over the other piles (Teng, 1969).

- Easy to splice
- High capacity
- Small displacement
- Able to penetrate through light obstructions.

2.4 Mechanics of Load Transfer Through Piles

Piles are basically classified as 'end-bearing' piles and 'friction' piles. This is the classification which is most relevant to the subject of geotechnical design of piles. If the soil near the surface is too weak to support the applied load, it is sought to transfer this load to a firm stratum available at a reasonable depth below by a point-bearing pile which transmits the load to the firm soil at the point of support. If the soil condition is such that soils which can offer some amount of shearing resistance at the interface with the pile is available to sufficient depth, Piles are used to transfer the applied load to the surrounding soil by skin resistance mobilised over the entire surface area. If the soil is cohesionless, the shearing resistance will be in the form of skin friction. The unit value of skin friction at depth h in the case of such a soil = $K.\gamma.h.\mu$. Where K is the coefficient of earth pressure appropriate to the situation, and μ the coefficient of friction. $\mu = \tan \delta$, where δ is called the angle of 'wall' friction.



End Bearing Pile | Friction Pile | End bearing Cum Friction Pile

Fig 2.3:- Piles subjected to compressive loads

In the case of cohesive soil, we have an interface shear parameter corresponding to each of shear strength parameters c and φ of the soil.

The shear strength of a c- φ soil is given (by Coulomb) as $s = c + \sigma \tan \varphi$ where, σ is the normal pressure. In this, c and φ are the shear strength parameters within the soil which are invoked between two parts of the same soil, or in other words, between soil and soil. The corresponding properties which are invoked between soil and a foreign body referred to as 'wall', which in this case is the pile, are a and δ, so that the skin resistance mobilised at the interface between the soil and the pile can be stated as s' = a+ σ tan δ.

In a c-soil, adhesion 'a' develops on the pile surface; even though it may need some time to develop in full. Thus the skin resistance in the case of the φ, c- φ and c-soils is due to friction, adhesion and friction, and adhesion, respectively. As a general term, piles of this type are called 'friction piles: even though, strictly speaking it is a misnomer in respect of c-φ and particularly c-soils (Kurian, 2006).

2.5 Skin Friction

In case of a pier where the applied load is fully resisted by the skin friction, the unit value of ultimate skin friction may be taken as βc, where β is a 'reduction coefficient' whose value lies around 0.45, and c, the un drained shear strength, which is taken as half the unconfined compressive strength. The unit value of ultimate skin friction so obtained is not normally allowed to exceed 100 kN/m^2. For computing the load carrying capacity of the pier, the ultimate value of skin friction obtained above must be divided by a suitable safety.

2.6 Negative Skin Friction

The fill shown in above the original soil in which the pile group is established will settle with time under its own weight. This will exert a drag on the pile on account of the friction existing at the interface between the pile and the soil. Since this down-drag adds to the load on the pile, instead of resisting it, it is called 'negative skin friction'. Being an extra load, it must be duly taken into account in design (Fellenius, 1998).

Piles installed in freshly placed fills of soft compressible deposits are subjected to downward drag, a consequence of the consolidation of the strata after piles are installed. This downward drag on the pile surface, when the soil moves down relative to the pile, adds to the structural loads and is called negative skin friction. This is in contrast to the usual shaft friction which is mobilised when the pile moves down relative the soil. Thus negative skin friction has an effect of reducing the allowable load on pile. Negative skin friction may also develop if the fill material is a loose sand deposit.

It can also occur due to lowering of the ground water table which increases the effective stress, thus causing consolidation of the soil with the resultant down drag on piles (Poulos, 1998).

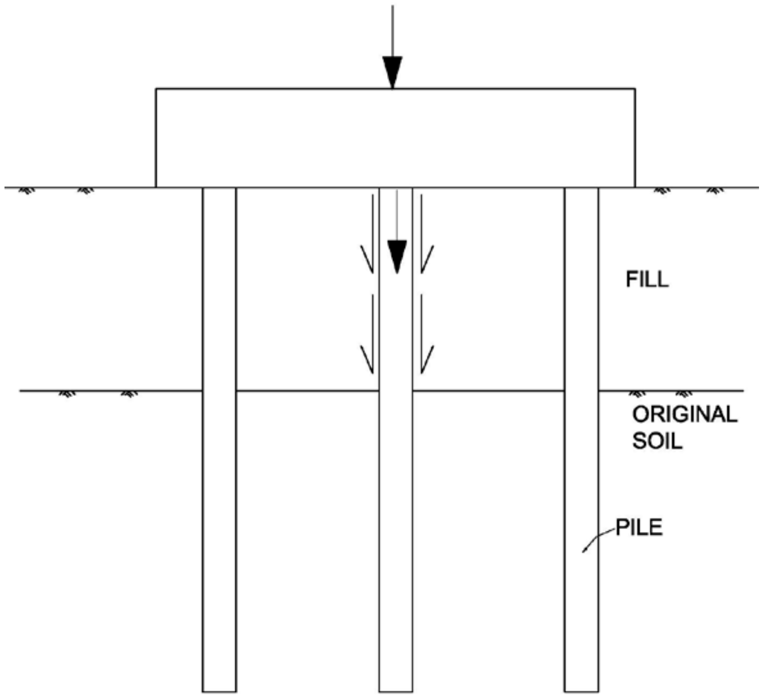


Fig.2.4:- Negative skin friction

2.7 Piles in Sand

2.7.1 Point-bearing piles in sand

In sand point-bearing piles are used to transfer the loads to a layer of dense sand underlying weak deposits. Such piles must be driven to depths necessary for adequate bearing depending upon the relative density of the sand. Load tests are the best means of predicting the load carrying capacity of such piles. Determining the load bearing capacity by analysis based on wave equation is equally reliable in the case of these piles.

2.7.2 Friction piles in sand

The maximum frictional resistance available to resist the load on pile in sand can be taken as $(\pi/2)*d*K\gamma L^2 \tan\delta$, where K is the coefficient of earth pressure.

The uncertainty associated with expression is confined to the value of K, which depends upon the relative density of the sand surrounding the pile. The value of K varies from 1 for loose sand to above 3 for dense sand. The angle of wall friction δ should chosen depending upon the material of the pile and by such consideration as whether the driving of the pile has been assisted by jetting.

2.7.3 Compaction Piles

Driving piles into a bed of loose sand is an effective means of compacting the latter. These piles should therefore be looked upon as constituting a 'soil improvement technique' rather than as structural element supporting load.

Compaction is the result of the displacement of the soil from the space occupied by the pile. In the case of loose sand this results in reduction of the void ratio of the soil surrounding the pile. Since the compaction decreases with the distance from the Pile, the closer the spacing the more is the compaction. This is in addition to the compaction produced by the vibrations associated with pile driving. (Kurian, 2006)

2.8 Pile Load Capacity in Compression

General requirements for satisfactory behavior of pile foundations are the same as for other foundations, namely, adequate safety against shear failure and excessive settlement. The load capacity of the pile can be estimated by several methods as following:

(a) Static pile load formulae

(b) Pile load test

(c) Pile driving formulae

(d) Correlations with penetration test data

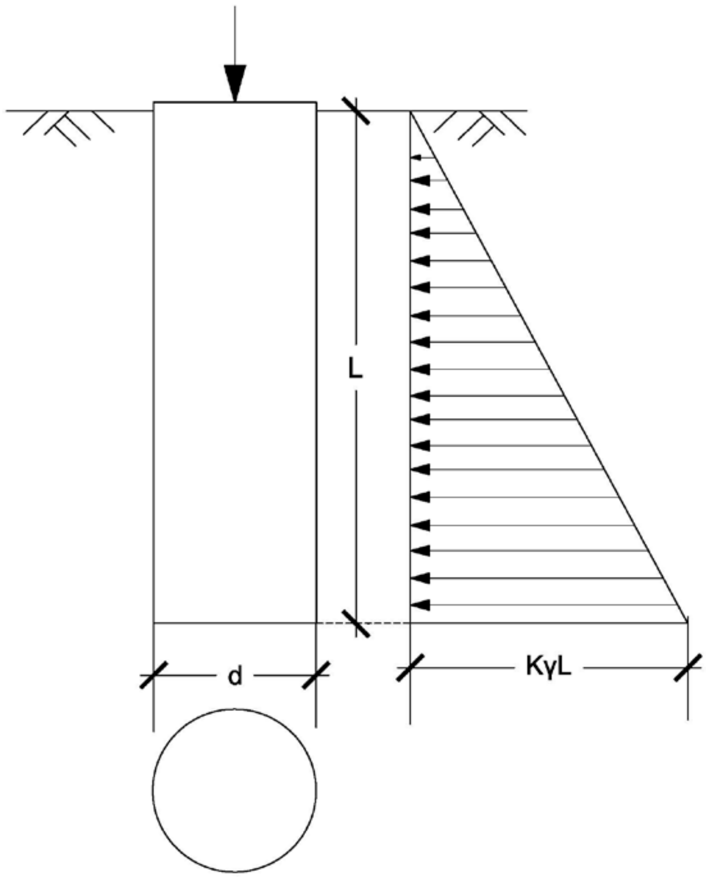


Fig 2.5: -Friction pile in sand: maximum resistance

2.8.1 Static Pile Load Formulae

When a compressive load Q is applied at the top of a pile, the pile will tend to move vertically relative to the surrounding soil. This will cause shear stresses to develop between the soil and the surface of the shaft. As a result, the applied is distributed as friction load along certain length of the pile measured from the top. As the load at the top is increased, friction load distribution will extend more and more towards the tip of pile, till at certain load level, the entire length of pile is involved in generating the frictional resistance. This is the ultimate frictional resistance of the pile, Qf. It is only when the load at top of pile exceed that the load in excess or Qf begins to be transferred to the soil at the base of pile. This load known as point load goes on increasing till the soil at the base of the pile fails by punching shear failure. The load in bearing at this stage is the ultimate point load, Qpu.

The maximum load which the pile can through the combined resistance of skin friction and point bearing is known as ultimate bearing capacity, Q_u of the pile.

$$Q_u = Q_{pu} + Q_f$$

If $Q_{pu} >> Q_f$ the pile is called as point bearing pile. If $Q_f >> Q_{pu}$, it is called a friction pile.

The relative proportion of loads carried by point load and skin friction depends on shear strength and elasticity of soil.The vertical movement of pile required to mobilize full skin friction resistance is much smaller than that require to mobilize full point bearing resistance. It has been observed that when the ultimate skin friction resistance is mobilised, only a fraction of the ultimate point load is mobilised and when the ultimate point load is mobilised, the skin friction resistance has decreased to a lower value than its peak.

The general equation for unit point bearing resistance written in the form

$$q_{pu} = cN_c + P_D\, N_q + 0.5\, \gamma\, DN\, \gamma$$

D = width or diameter of the pile
P_D = effective overburden pressure
Nc , *Nq* and *Ny* = bearing capacity factors
c = unit cohesion
L = Length of embedment of the pile
γ = unit weight of soil

$$Q_{ult} = A_p\,(\,0.5\, D\gamma\;\; N_\gamma + P_D\, N_q\,) \;+ \Sigma\, K\, P_{Di}\, \tan\delta\, A_s$$

For pile in granular soil , the design is based on an effective stress analysis. In clays it is common to use a total stress analysis in which the load capacity is related to undrained shear strength cu. However some investigators believe that even pile in clay should be designed using effective stress approach. For one thing, in pile s in over consolidated clays, the drained load capacity may be more critical than the undrained load capacity. Even otherwise, the excess pore water pressure due to pile loading develops in a limited area around the pile and can dissipate rapidly through fissures in the soil or even through the concrete pile itself.

2.8.2 Dynamic Pile Formulae

Dynamic pile formulae are used in estimating pile capacity. These are based on the laws governing the impact of elastic bodies. The input energy of the hammer blow is equated to the work done in overcoming the resistance of the ground to the penetration of the pile. Allowance is made for the losses of energy due to elastic contractions of the pile, pile cap and subsoil and also the losses due to the inertia of the pile (Ranjan, 2000).

Some of these formulae are discussed in the following below.

A. Engineering News Formula

The Engineering News Formula, proposed by A.M. Wellington, (1888) is the simplest and the most popular of the dynamic pile formulas.

The dynamic resistance of soil, Q_u is assumed to be ultimate pile load capacity.

Equating the input energy and work done.

$Q_u S' = W H$,

from which the allowable pile load, Q" is expressed as

$$Q_a = \frac{WH}{F(S+C)}$$

where W = weight of the hammer falling through a height H

S =real set per blow

C = empirical factor allowing reduction in the theoretical set due to loss.

F = factor of safety.

The theoretical set S' =S=C. where H, S and C are same unit.

For Drop Hammer, $Q_a = \frac{WH}{6(S+C)}$

For Drop Hammer, $Q_a = \frac{WH}{6(S+0.25)}$

Where,

Q_a and W are expressed in kg and H fall of hammer in cm.

S is the final set cm/blow.

The allowable pile load is also expressed in another form:

$$Q_a = \frac{166.64E}{S+2.54}$$

Where

Q_a = allowable pile load in kilo Newtons (kN)
E = energy per blow in kilo joules (kJ)
S= average penetration in mm per below for the final 150 mm of driving.

B. Modified Hiley Formula

Modified Hiley formula, (1930) is considered to be superior to the Engineering News formula, as it takes into account various energy losses during driving in a more realistic manner.

Equating the available energy with useful work done and losses,

$$R = \frac{Wh\eta}{S+C/2}$$

$$= \frac{Wh\eta}{S+\frac{1}{2}(C1+C2+C3)}$$

Where

R= ultimate driving resistance in tones.

W= Weight of hammer in tones.

h= effective fall of hammer.

η =efficiency of blow.

S = the final set or penetration per blow in cm.

C = total elastic compression=C1+ C2 + C3

C1 = temporary elastic compression of dolly and packing.

C2 = temporary elastic compression of pile.

C3 = temporary elastic compression of soil.

The values of C1, C2 and C3 are obtained by using the equations below:

Where

C1 = 1.771R/A, where the driving is without dolly or helmet and cushion about 2.5 cm thick

C2 = 0.657RL/*A*

C3 = 3.55R/*A*

L = length of pile in meters and
A= area of the pile in cm2

When $W > Pe$ and pile is driven into penetrable ground,

$$\eta = \frac{W+Pe^2}{W+P}$$

When $W < Pe$ and pile is driven into penetrable ground,

$$\eta = \frac{W+Pe^2}{W+P} - \left(\frac{W-Pe}{W+P}\right)^2$$

where, P= weight of pile, anvil, helmet and follower (if any) in tonnes
e = coefficient of restitution of the materials under impact.

The values recommended by IS: 2911 (Part I-1979 are tabulated below:

(a) For steel ram of double acting hammer striking on steel anvil and driving reinforced concrete, e = 0.5

(b) For cast-iron ram of single acting or drop hammer striking on head of reinforced concrete, e = 0

(c) For single-acting or drop hammer striking a well-conditioned driving cap and helmet with hard wood dolly while driving reinforced concrete piles or directly on head of timber pile, $e=0.25$.

(d) For a deteriorated condition of the head of pile or of dolly, e = 0.

C. Danish Formula

Danish formula is used for calculating capacity of pile in our test.

According to Danish formula (Danish, 1970)

$$Q_u = \frac{\eta_h WH}{(S + \frac{S_0}{2})}$$

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0= elastic compression of pile,

D=length of pile,

A= cross-sectional area,

E=modulus of elasticity of pile material.

2.8.3 Pile Load Test

A wide range of field and laboratory experiments has been performed by researchers. These experimental methods have been concerned with the load-deformation behaviour of soil-pile systems both singly and in groups, at small to large strains, loaded statically, cyclically, dynamically, or seismically, by exciting the pile head or the soil mass, and covering a variety of pile types and soil conditions. In-situ tests have the advantage of providing “correct” soil and pile stress conditions, whereas laboratory tests offer the flexibility and economy of making parametric studies in a controlled environment.

Experimental research published in the literature; the purpose of such a review is to understand the adequacy of previous work and the dimensions of further research needs. Attention is particularly focused on experimental work applicable to cyclic pile load test. A pile load test is the only direct method for determining the allowable load on piles. It is considered to be the most reliable of all the approaches, primarily due to the fact that it is an insitu test.

Pile load test are very useful for cohesionless soils. However, in case cohesive soils the data from pile load test should be used with caution on account of disturbance due to pile driving, development of pore pressure and the inadequate time allowed for consolidation settlement. Three type of test namely vertical load test, lateral load test, pull out test can be carried out. Generally vertical load test is carried out to establish load settlement curve under compression and determine the allowable load of pile. The other type of test may be carried out only when piles are required to resist large lateral loads or uplift loads.

Two categories of test on piles, namely initial test and routine test are usually carried out. Initial test should be carried out on test piles to estimate the allowable load, or to predict the settlement on working load. Routine test are carried out as a check on working piles and to assess the displacement corresponding to the working load.A test pile is a pile which is used only in a load test and does not carry the load of the superstructure. The minimum test load on such piles should be twice the safe load (safe load calculated for this purpose using static formula) or the load at which the total settlement attains a value of 10 per cent of pile diameter in case of a single pile and 40 mm in case of a pile group.

A working pile is a pile which is driven or cast in *situ* along with other piles to carry load from the superstructure. The test load on such piles should be upto one and a half times the safe load or upto the load at which total settlement attains a value of 12 mm for a single pile and 40 mm for a group of piles, whichever is earlier.

Conducting a load test on a pile to determine its ultimate or safe load carrying capacity is indeed a costly and time-consuming enterprise. However, as stated earlier, it is the most reliable means of determining the load capacity of a pile, since, as a deep foundation , a pile passes through a number of different layers of soil with varying sometimes uncertain properties. Hence, in spite of the cost, time and effort, one may have to resort to a load test in many instances where one may be doubtful whether calculation by static or dynamic formulae would be sufficiently reliable. In fact, in most piling jobs, it is usual to stipulate that load test should be conducted on one pile, if not more. As in the-case of the plate bearing test,

The load test on pile involves measuring deflection against loads applied in stages till the soil fails under the load. The data is plotted as a load-settlement diagram from which the ultimate load carrying capacity is interpreted (Kurian, 2006).

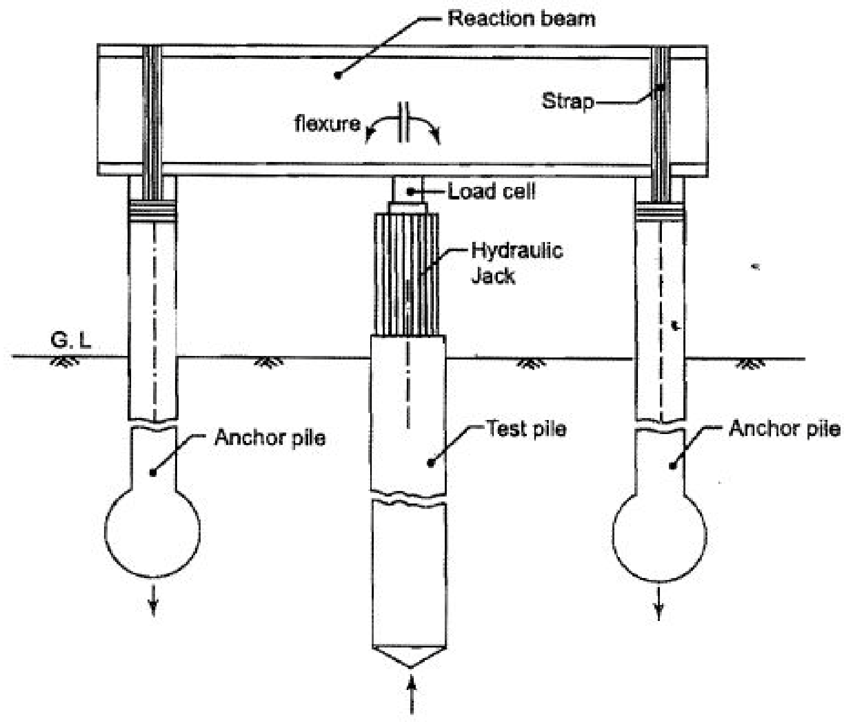


Fig 2.6:- Pile load test in compression using anchor piles(after (Kurian, 2006).)

IS: 2911 Part IV (1985) details the procedure for carrying out the load tests and assessing the allowable load. According to the code, the test shall be carried out by applying a series of vertical downward loads on a pile. The load shall preferably be applied by means of a remote controlled hydraulic jack taking reaction against a loaded platform.

An alternative method is using anchor piles. In this method of loading, be described as which may be described as 'structural', the jack reacts against a stout horizontal beam above, which is fixed across two anchor piles established on either side of the test pile.

Thus when the jack is worked, the beam is subjected to bending (hogging); the anchor piles, to tension and the test pile, to compression. The theoretical limit of the load that can be applied to the test pile by this method is the sum of the anchoring capacity of the anchor piles. Hence it should be ensured in the test pile by this method in the sum of anchoring capacity of the anchor piles has a comfortable margin over load the failure on the test pile.

Further, the anchor piles should be spaced sufficiently away so that there is .no interface between the zones of influence of the anchor and test piles. Note that the wider the spacing anchor piles, the heavier the bending moment on the beam, and the heavier its section, under the same load, due to increased span.

In many instances the ultimate load is reckoned against a specific empirical value for the settlement of the pile at the tip. Since the settlements are measured in the test at the top of the pile, the measured settlement includes the tip settlement and the elastic compression of the pile. In the case of a point bearing pile since the section of the pile is subjected to a uniform axial compression, equal to the applied load, over the full depth, the elastic compression at any load $P = (PL/AE)$, where L is the length, A, the sectional area and E, the Young's modulus of the pile material.

Determination of elastic compression in this manner assumes that the pile response continues to be elastic- linearly elastic -even when the soil below fails (This is analogous to assumption of a perfectly rigid test plate in the plate bearing test. In the above it is seen that, while specified tip settlement is a constant, elastic settlement is a function -linear function of the unknown load Pu which we want to determine. In other words, our effort is to locate the point on the load-settlement diagram corresponding to a specific value of tip settlement, if the latter serves as criterion for determining the ultimate load (Kurian, 2006).

The test load shall be applied in increments of about 20 per cent of the assumed safe load. Each stage of loading shall be maintained till the rate of movement of pile top is not more than 0.1 mm per hours whichever is later. The loading shall be continued upto twice the safe load or the load at which the total settlement of the pile cap equals the appropriate value as indicated in the criteria stated below:

The allowable load on a single pile shall be the lesser of the following:

(a) Two-thirds the final load at which the total settlement attains a value of 12 mm, unless it is specified that a total settlement different from 12 mm is permissible in a given case on the basis of the nature and type of structure. In the latter case, the allowable load shall correspond to the actual permissible total settlement.

(b) Fifty per cent of the final load at which the total settlement equals 10 per cent of the pile diameter in case of uniform diameter piles and 7.5 per cent of bulb diameter in case of underreamed piles.

The allowable load on a group of piles shall be the lesser of the following:

(a) Final load at which the total settlement attains a value of 25 mm, unless a total settlement different from 25 mm is specified in a given case on the basis of the nature and type of structure.

(b) two thirds the final load at which the total settlement attains a value of 40mm.

The procedure for the routine test should be the same as for an initial test with maximum loading and settlement requirements.

2.9 Cyclic Pile Load Test

In the case of an end bearing-cum-friction pile, it may be necessary for us to know what portion of the working load is shared by skin friction and tip resistance. This is not possible from a normal pile load test which is 'monotonic'. Such information will be useful to us in arriving at the distribution of axial compression in the pile section, for a more realistic structural design of the pile, besides its settlement analyses. One method of determining the end resistance and skin friction, but at twice the cost, is to conduct the pile load test in pair, subjecting one pile to compression and the other to tension, the former giving the total capacity and the latter, the capacity in skin friction alone. Determination of the corresponding break-up at the working load from the above ultimate load is still a matter of conjecture. One method which can yield the above information directly is to conduct a 'cyclic load test' on the pile. In this test the load is applied in stages of about 20% of the estimated working load, and at each stage, after noting the total settlement the load is released in full and the residual settlement is measured. The pile is now loaded to the second stage and then unloaded in full measuring residual settlement as above. The test is continued through each of the loading stages in cycles of loading and unloading till the working load is reached. The data consisting of the total and residual settlements measured at each stage is now processed as explained below, to obtain the result.

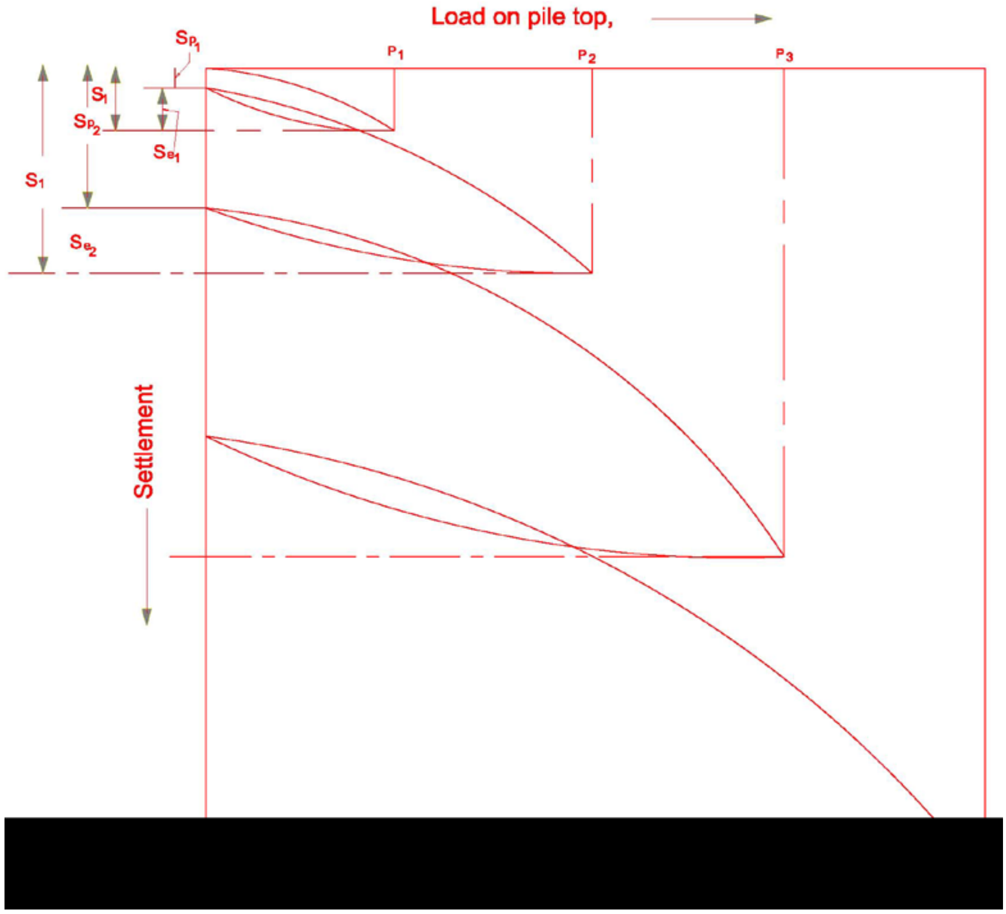
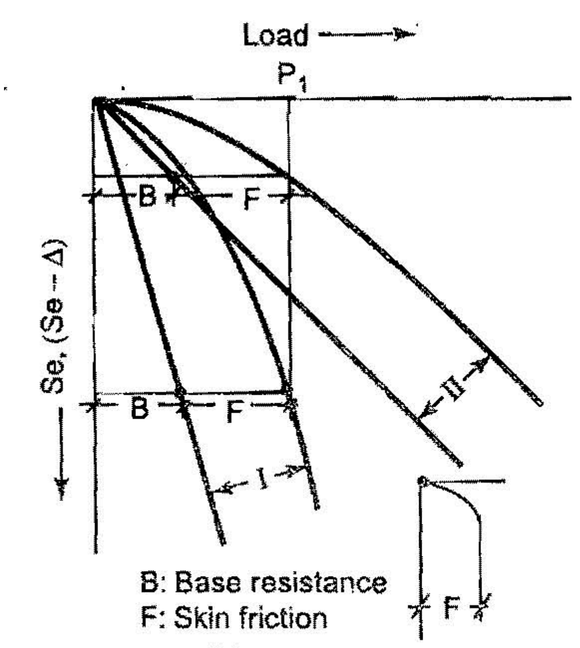


Fig2.7:-Typical load settlement curve for pile load test

As shown in given figure corresponding to load stage 1 “P_1” we have measured S_1 and S_{p1} (plastic), the difference giving the elastic rebound, S_{e1}, which is the same as the recovered part of the settlement. A plot is now made between P and S_e as shown in Fig. 2.7b. This curve I is seen to be initially curved but becoming substantially straight thereafter. A line is now drawn through the origin parallel to the straight portion. If a vertical is now dropped from any load stage to this curve followed by a horizontal from the point of intersection, we get the break-up of the load between point bearing and skin friction as shown. The logic of this division is that the load transfer at the tip has a greater chance of linearity with elastic deformation, when compared to skin friction which takes a curved path initially until it straightens up.



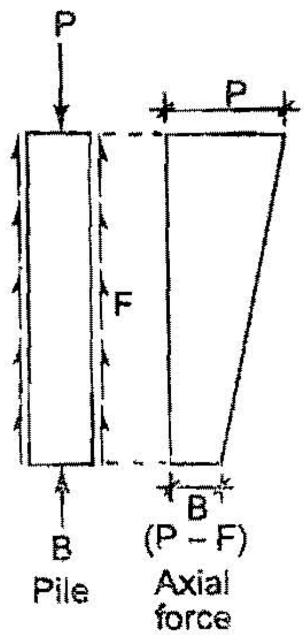


Fig2.7a:-Axial load P = B + F

(Kurian,2006)

Fig2.7b:-P vs S_{e}, ($S_e - \Delta$)

(Kurian,2006)

Even though S_e is the elastic component of the deformation, since it is measured at the top, it is actually sum of the elastic compression of the sub grade soil and the elastic compression of the body of the pile. Our effort therefore shall be to re plot the load against the elastic compression of the subgrade alone which is equal to (S_e - Δ), where Δ is the elastic compression of the pile. In order to determine the elastic compression of the pile at each load stage we make use of the frictional resistance, *F*, obtained at each load stage. Refer Fig. 2.7b,

The average load on the pile section $= \dfrac{P+(P-F)}{2}$

$= (P-F/2)$

Then, Elastic compression $\Delta = \dfrac{(P-F/2)L}{AE}$

Where L is the length of pile

A is cross sectional area of pile and

E is modulus of elasticity of pile material

The value of Δ obtained from above equation, P is plotted against (S_e - Δ). The curve obtained is Curve II. A parallel is drawn through the origin and new values of F are obtained as earlier corresponding to each stage of loading. Obtaining base resistance in this manner is more realistic because of the elimination of Δ from total elastic deformation S_e. New values of Δ are now obtained using the new values of F obtained from Curve II and the work is repeated to obtain Curve III and its parallel. The work is continued until the difference between the results obtained from successive steps become sufficiently small. It is possible to terminate the work normally with curve III. It may be noted in respect of the test that at the end of last cycle, the load may be continued directly without cycles, till failure (Arora, 1975).

2.10 Studies

As per Analysis of the Effect of Pile Skin Resistance Verses Pile Diameter by Marandi, Kerman, and Karimzadeh (Poulos & Davis, 1980).

We have the following conclusions

I. The average ultimate loads at failure for grouted piles with diameters of 35, 50 and 60 mm were 12% greater than pipe piles.

II. The pile skin resistance for grouted piles was approximately 42% greater than for the pipe piles (using Hansen theory) while, when using Meyerhof theory there was a twofold increase for consecutive diameters. Overall, the pile skin roughness was found to be an effective factor on pile bearing capacity.

III. The load transfer response was more plastic with increasing pile diameter in the siliceous desert sand. Larger diameter grouted piles may show a lower peak shear stress than the smaller diameter and pipe piles.

IV. The skin friction of the pile is not linearly proportional to the pile diameter for siliceous desert sand.

V. The design of the grouted pile installation system achieved good results in final uniformity of the tested pile improving the shape and positioning of the paddle blades behind the pile head showed that it is possible to conduct experimental research in near field conditions.

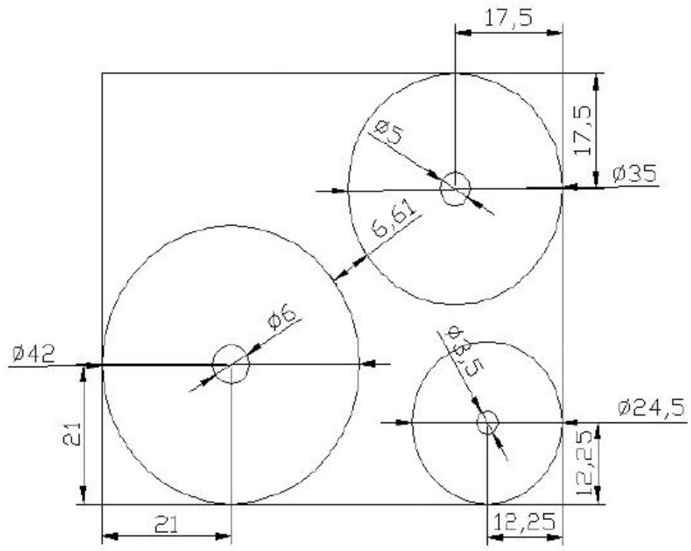


Fig 2.8:- Displacement of piles and compaction area for each pile (cm)

2.11 Codal Provisions

There are two types of tests for each type of loading (that is, vertical, lateral and pullout), namely, initial and routine test as per *IS: 2911 (Part 4)-1985*.

Initial test: This test is required for one or more of the following purposes. This is done in case of important and/or major projects and number of tests may be one or more depending upon the number of piles required.

Routine test:

This test is required for one or more of the following purposes. The number of tests may generally be one-half percent of the total number of piles required. The number of the test may be increased up to 2 percent in a particular case depending upon nature, type of structure and strata condition:

a) One of the criteria to determine the safe load of the pile;
b) Checking safe load and extent of safety for the specific functional requirement of the pile at working load; and
c) Detection of any unusual performance contrary to the findings of the initial test, if carried out.

Application of Load: The vertical load test should be carried out by applying a series of vertical downward incremental load each increment being of about 20 percent of safe load on the pile. For testing of raker piles it is essential that loading is along the axis.

The safe load on single pile for the initial test should be least of the following:

I. Two-thirds of the final load at which the total displacement attains a value of 12 mm unless otherwise required in a given case on the basis of nature and type of structure in which case, the safe load should be corresponding to the stated total displacement permissible.

II. 50 percent of the final load at which the total displacement equal 10 percent of the pile diameter in case of uniform diameter piles and 7.5 percent of bulb diameter in case of under-reamed piles (IS-2911 part4 1985)

As per D 1143/D 1143M – 07(ASTM Standard) the failure load *n*—for the purpose of terminating an axial compressive load test, the test load at which rapid continuing, progressive movement occurs, or at which the total axial movement exceeds 15 % of the pile diameter or width, or as specified by the engineer.

CHAPTER 3
EXPREMENTAL PROGRAMME

3.1 Tests Conducted Before Performing Pile Load Test

There are some properties of soil that we must know before performing pile load test. Following are the properties which have been observed before performing the test.

Medium of sand: Loose and Dense
Density y loose: 16.7 kN/m3
Density y loose: 15.6 kN/m3
Diameter Variation: 270mm, 100mm,75mm, 40mm
Water content: 9.8%
Specific gravity: 2.5
Observation: Pile load test, Static formula, Dynamic formula
Angle of internal friction: 33(loose), 37(dense)

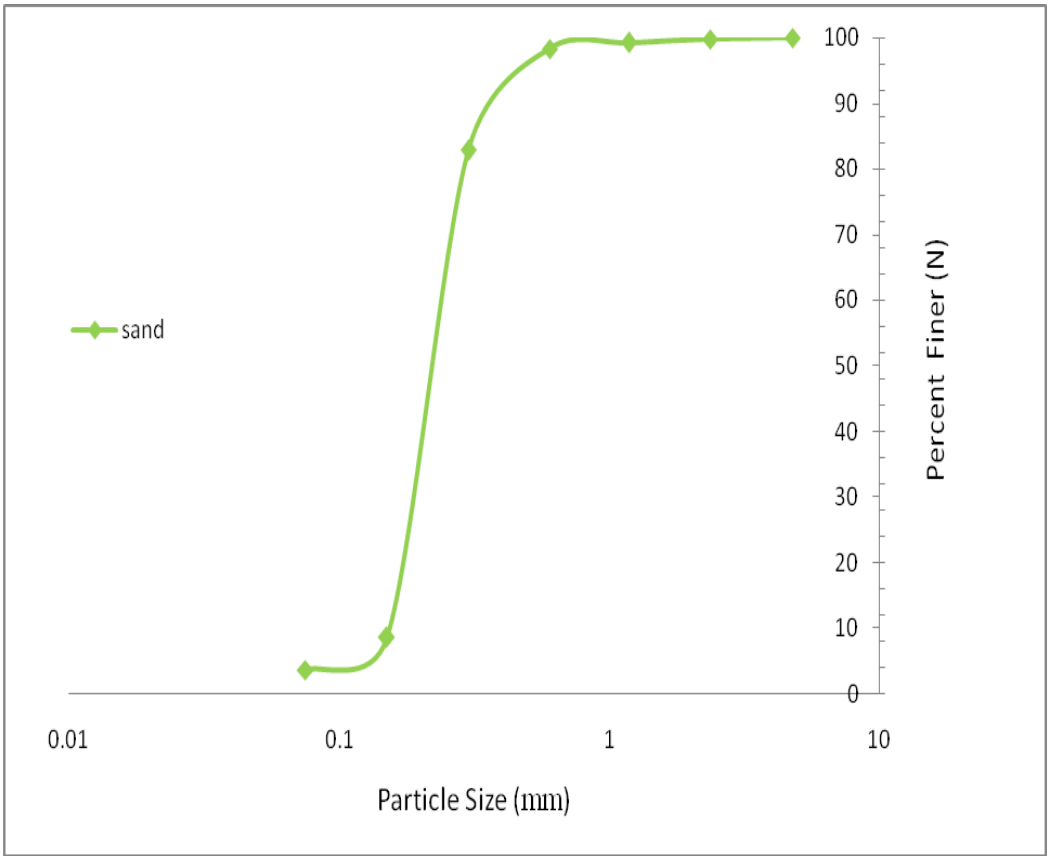


Fig 3.1:- Particle size distribution curve

3.2 Specific gravity of sand (G)

Specific gravity (G) is the ratio of the weight in air of a given volume of soil solids at a stated temperature to the weight in air of an equal volume of distilled water at that temperature. Specific gravity of sand is determined by Pycnometer.

Figure 3.2:-Specific Gravity Determination By Pycnometer

3.3 Fabrication of Apparatus

The experimental setup for carrying the Pile load test is consisting of following stages

3.3.1 Construction of Pit

The first step was the construction of pit where the experiments were to be conducted, for this we thought of various options, like using an open container, cylindrical tanks etc but none of them could replicate the field conditions to the maximum. So we decided to construct our own pit using bricks and cement mortar. The dimensions of the pit were kept 3.0m*3.65m*2.2m, the size was chosen so that the field conditions can be replicated while conducting the test of model piles.

Fig 3.3:-Pit at Initial Stage

3.3.2 Sand filling in the pit

The second step was the filling of material i.e sand inside the testing pit. For this we contact with building material dealer. The total quantity of sand and gravel filled in chamber of the pit is about 25m^3.

3.3.3 Fabrication of steel Piles

Since the basic purpose of the research is to study the load settlement behaviour of model piles in Sand, the most important point was the fabrication of the model piles. For this purpose, we purchased hollow cylindrical mild steel pipes of nearly same roughness for circular section, as roughness is an important factor while studying the behaviour of pile foundations. The specifications of the various sections used are as follows:

Table: 3.1 Steel Pile Specifications

Material	Shape	Diameter(mm)	Length(mm)
Mild steel	Circular	270	1000
Mild steel	Circular	100	1000
Mild steel	Circular	75	1000
Mild steel	Circular	40	1000

The next step was the fabrication of the conical tips at the end of the Cylindrical piles, we got them fabricated at a lathe workshop, the material used for this purpose is M.S. (mild steel), and the angle of the conical end is 60degress. We made total four sections.

Fig 3.4:-Formation of cone in lathe

Fig 3.5:-Formation of pile cap

Fig 3.6:-100mm ,75mm & 40mm complete pile ready to use

3.3.4 Loading Arrangement for the test

This was by far the most complicated thing to do in the whole research, the loading arrangement had to be such that it provided concentric loading to the model piles, could withstand the large loads it had to transfer and get easily fixed with the model piles. For this we go for hydraulic jack loading, the arrangement for hydraulic jack loading is shown below:

3.3.5 Arrangement of Dial Gauge

The last step in the experimental setup was the fixing of dial gauge, for this we use supporting arrangement of two dial gauge with the help of steel frame as shown if photograph. A steel rod of fixing arrangement with the frame is used to maintain the required position of dial gauge.

Fig 3.7:-Dial gauge arrangement on site

Figure 3.8:-Complete arrangement

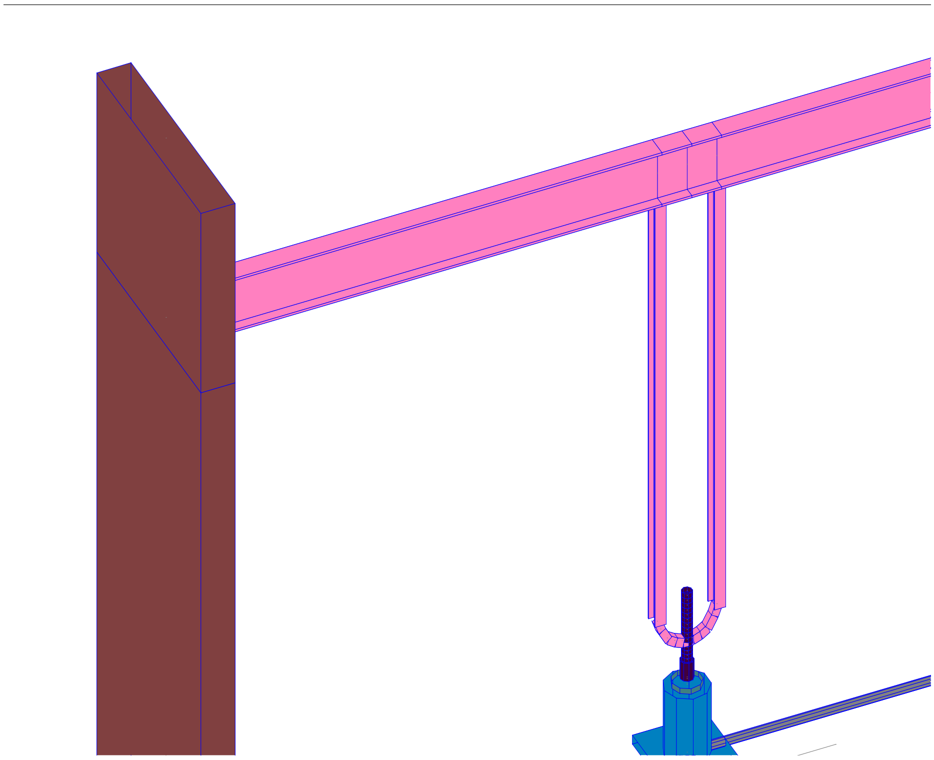


Fig 3.9:-Concept Drawingof Loading Arrangement

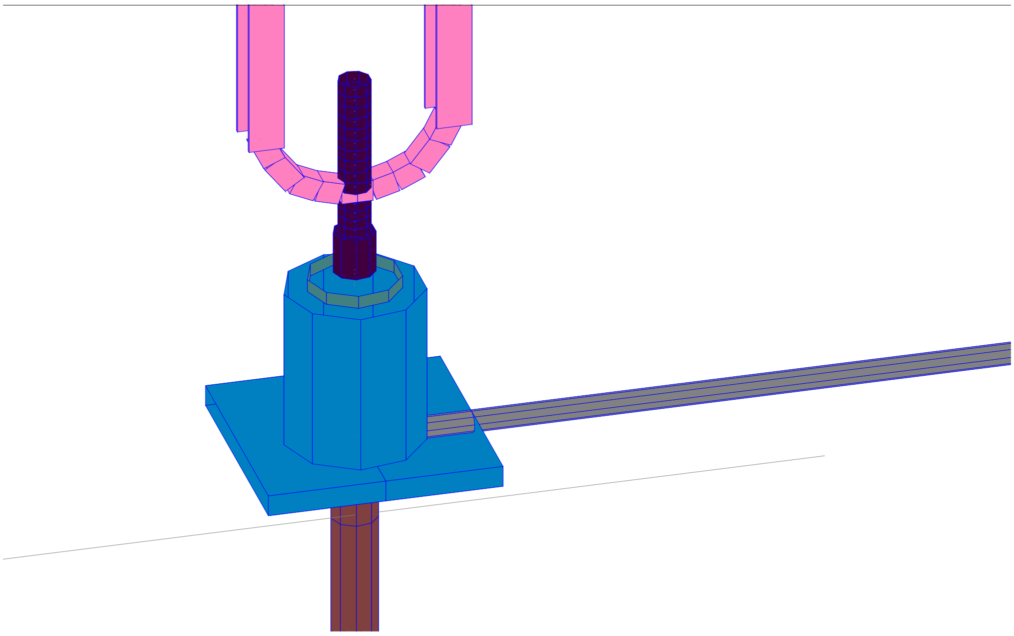


Fig 3.10:-Enlarge view of concept drawing

Fig 3.11:-Loading from hydraulic jack during testing

3.4 Experimental procedure

A following procedure was adopted for the experimental programme.

1. Dry the sand in open for about 2-3 days before use.

2. Pour the sand in the testing pit from a constant height for each level. In this case we have poured the sand in the pit from a constant height of 1.60m. This is done so that the sand in the pit has uniform density.

3. Drive the model pile with loading arrangement in the sand using a standard hammer up to the desired depth.

4. Fix a dial gauge of sensitivity 0.01mm adequately for calculating the settlement in the model pile.

5. Note the initial reading on the dial gauge.

6. Apply the loading on the pile using the hydraulic jack.

7. Maintain each stage of loading till the rate of movement of the pile top is not more than 0.01mm per minute.

8. Note the reading when the rate of movement of the pile is not more than 0.01mm per minute. This is the final reading of the dial gauge.

9. The difference of the initial dial gauge reading and final dial gauge reading gives the settlement for the particular loading.

10. Release hydraulic jack pressure so that load on pile becomes zero and pile is not loaded.

11. When pile is unloaded note down the reading on dial gauge which gives the displacement in upward direction.

12. Apply the next loading on the pile, in the same manner note the settlement for this loading and also measure the negative displacement after releasing the load in each step.

13. Find the cumulative settlement after each loading till the cumulative settlement value exceeds 10 percent of the pile diameter or 12mm.

14. The load at which the settlement exceeds 10 percent of the pile diameter is the ultimate load capacity of the model pile.

15. Plot the load settlement curves for the different piles.

16. Compare the results of ultimate load capacity of the piles of different cross-sectional area.

17. Compare the results of Pile load test and static load formulae. Also compare the results of Dynamic formulae and static formulae.

3.5 Obseravation for cyclic load test

PILE NO.1:

Length = 1000mm

Dia = 270mm

Dense sand

Table -3.2 Static Pile No.1: (dia= 270mm,dense sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	17.5	17.5	9.0	9.0	+10.0	10.0
2	0.0	0.0	9.0	0.5	-0.5	9.5
3	18.75	36.25	6.0	6.0	+10.0	19.5
4	0.0	0.0	6.0	6.5	-0.5	19.0
5	20.0	56.25	4.0	4.0	+10.0	29.0
6	0.0	0.0	4.0	4.5	-0.5	28.5
7	20.0	76.25	4.0	4.0	+10.0	38.5
8	0.0	0.0	4.0	4.7	-0.7	37.8

PILE NO.1:

Length = 1000mm

Dia = 270mm

Loose Sand

Table -3.3 Static Pile No.1: (Dia= 270mm, loose sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	15.0	15.0	4.0	4.0	+10.0	10.0
2	0	0	4.0	4.5	-0.5	9.5
3	16.25	31.25	5.0	5.0	+10.0	19.5
4	0	0	5.0	5.5	-0.5	19.0
5	16.25	47.5	4.0	4.0	+10.0	29.0
6	0	0	4.0	4.5	-0.5	28.5
7	16.25	63.75	6.0	6.0	+10.0	38.5
8	0	0	6.0	6.5	-0.5	38.0

PILE NO.2:

Length = 1000mm

Dia = 100mm

Dense sand

Table -3.4 Static Pile No.2: (dia= 100mm, dense sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	5.0	5.0	8.0	0.0	8.0	8.0
2	0.0	0.0	0.0	3.0	-3.0	5.0
3	7.5	12.5	2.5	5.0	7.5	12.5
4	0.0	0.0	5.0	7.0	-2.0	10.5
5	6.25	18.75	6.0	0.0	6.0	16.5
6	0.0	0.0	0.0	2.5	-2.5	14.0
7	5.625	24.375	1.0	5.0	6.0	20.0
8	0.0	0.0	5.0	9.0	-3.0	17.0

PILE NO.2:

Length = 1000mm

Dia = 100mm

Loose Sand

Table -3.5 Static Pile No.2: (dia= 100mm,loose sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	4	4	5	7	8	8
2	0	0	7	5	-2	6
3	6.25	10.25	5.5	7.0	7.5	13.5
4	0	0	7	8	-1	12.5
5	5	15.25	3.5	7.5	6	18.5
6	0	0	7.5	7.5	0	18.5
7	5	20.25	1.5	5.5	6	24.5
8	0	0	5.5	6.5	-1	23.5

PILE NO.3:

Length = 1000mm

Dia = 75mm

Dense Sand

Table -3.6 Static Pile No.3: (dia= 75mm,dense sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	4.375	4.375	6	8	8	8
2	0	0.0	8	8.5	-0.5	7.5
3	5.0	9.375	9	1.5	7.5	15.0
4	0.0	0.0	1.5	1.25	-0.25	14.75
5	5.0	14.375	5	9.0	6.0	20.75
6	0.0	0.0	9	8.0	-1	19.75
7	4.375	18.75	6	0.0	6.0	25.75
8	0.0	0.0	0	0.25	-0.25	25.50

PILE NO.3:

Length = 1000mm

Dia = 75mm

Loose Sand

Table -3.7 Static Pile No.3: (dia= 75mm,loose sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	3.75	3.75	1	3	8	8
2	0	0	3	3.7	-0.7	7.3
3	3.125	6.875	3	5.5	7.5	14.8
4	0	0	5.5	5	-0.5	14.3
5	3.125	10.0	4	8	6	20.3
6	0	0	8	8	0	20.3
7	3.75	13.75	9	3	6	26.3
8	0	0	3	3.25	0.25	26.05

PILE NO.4:

Length = 1000mm

Dia = 40mm

Dense Sand

Table -3.8 Static Pile No.4: (dia= 40mm,dense sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	1.875	1.875	0	2	8	8
2	0	0	2	2	0	8
3	2.5	4.375	2	4	8	16
4	0	0	4	4.5	-0.5	15.5
5	1.875	6.25	2	4	8	23.5
6	0	0	4	4.5	-0.5	23.0
7	1.875	8.125	5	7	8	31
8	0	0	7	7.5	-0.5	30.5

PILE NO.4:

Length = 1000mm

Dia = 40mm

Loose Sand

Table -3.9 Static Pile No.4: (dia= 40mm,loose sand)

S.no	Incremental Load (kN)	Cumulative Load(kN)	Initial Reading on Dial Gauge(A)	Final Reading on Dial Gauge(B)	Settlement (A-B) (mm)	Cumulative Settlement ∑(A-B) (mm)
1	1.0	1.0	2.0	4.0	8.0	8.0
2	0.0	0.0	4.0	4.0	0.0	8.0
3	0.75	1.75	6.0	8.0	8.0	16.0
4	0.0	0.0	8.0	8.0	0.0	16.0
5	0.75	2.5	8.0	0.0	8.0	24.0
6	0.0	0.0	0.0	0.0	0.0	24.0
7	0.75	3.25	0.0	2.0	8.0	32.0
8	0.0	0.0	0.0	0.0	0.0	32.0

3.6 Dynamic Pile Test Observation

Wt of hammer(W) 0.1175 kN

Ht of Hammer(H) 50.00 cm

Length of Pile (D) 100.00 cm

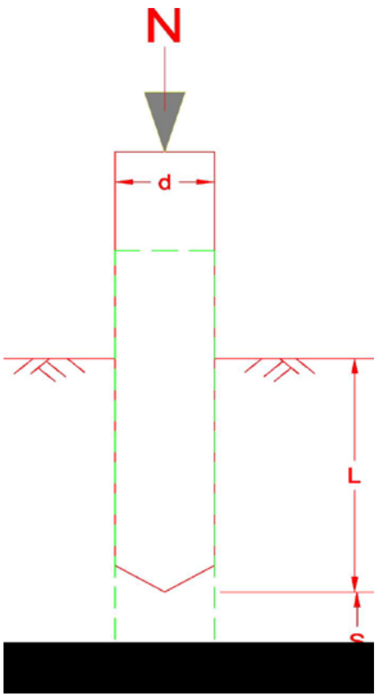


Table 3.10:Dynamic pile load test observation(dense sand)

Dia(mm)	Depth of obs.(L)	No. of Blows(N)	Cumulative settlement(mm)
100	400	5	30
100	430	5	60
100	460	5	90
100	490	24	240
75	400	5	50
75	450	5	100
75	500	5	150
75	550	15	300
40	400	5	200
40	600	5	390
40	790	4	540

Table 3.11:Dynamic pile load test observation(loose sand)

Dia(mm)	Depth of obs.(L)	No. of blows(N)	Cumulative settlement(mm)
100	400	5	40
100	440	5	80
100	480	5	120
100	520	18	270
75	400	5	67.5
75	467.5	5	132.5
75	532.5	5	197.5
75	597.5	12	347.5
40	400	1	75
40	475	1	150
40	550	2	300

3.7 Precautions

- Sand used for the experiment should be dried in sun such that it becomes perfectly dried.
- Before pouring sand in to the pit the sand should be filtered for the removal of the leaves, paper, dried plants etc.
- Sand when poured in the testing pit should be dropped from a specified height as discussed earlier so as to have a homogeneous soil of the desired density.
- The positioning of the pile should be done properly so that no moment act while applying the loads
- The dial gauge should be properly fixed so that no errors occur while taking reading through it.
- Special precaution must be taken that no vibration is taking place near the loading system and soil filled as the liquefaction of soil gives wrong results.
- While applying loads with hydraulic jack no leakage of oil should take place.
- The load should be applied without any eccenticity because it will lead to wrong results.

CHAPTER 4
DISCUSSION ON RESULTS

4.1 General

The results of the pile load test conducted on model Steel piles are shown as below:

Table 4.1: Load carrying capacity according to pile load test.

Size(mm)/Medium	x-sectional shape	Length(mm)	Load Capacity(kN)
270dia. Dense	Circular	1000	56.25
270dia. Loose	Circular	1000	47.50
100dia. Dense	Circular	1000	12.50
100dia. Loose	Circular	1000	10.25
75dia. Dense	Circular	1000	9.375
75dia. Loose	Circular	1000	6.875
40dia. Dense	Circular	1000	4.375
40dia. Loose	Circular	1000	1.75

Above Results Shows that:

- For different cross-section area and same length, the load carried by circular section are as follow:

  During performing Cyclic load test we observe that when releasing the load on pile the negative deflection on dial gauge reading occur. The negative settlement is more in case of higher diameter of pile.

  - For 100 mm dia pile in dense sand ultimate capacity is 1.2 times than in loose sand.
  - For 75 mm dia pile in dense sand ultimate capacity is 1.36 times than in loose sand.

- For 40 mm dia pile in dense sand ultimate capacity is 2.5 times than in loose sand.

4.2 Relation With Pile Load Test and Static Formulae.

Like a shallow foundation a pile foundation should be safe against shear failure and also the settlement shall be within the permissible limits. The methods for estimating load carrying capacity of pile foundation by static methods are as follows.

The static method gives the ultimate capacity of an individual pile, depending upon characteristics of soil.

$$Qult = Qp+Qs$$

The ultimate capacity "Qult" are sum of skin resistance and point resistance.

$$Q_{ult} = Ap\ (\ 0.5\ D\ \gamma\ \ N_{\gamma} + P_D\ N_q\ )\ \ + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$$

Where, Ap = Sectional Area of the pile at the base.

P_D = Over Burden Pressure

Nq $N\gamma$ = Bearing Capacity Factor as per IS 2911 Part 1.

Here, γ = 16.7 kN/m3, Nq = 70 for φ = 37°. (for dense)

γ = 15.6 kN/m3, Nq = 50 for φ = 33°.(for loose)

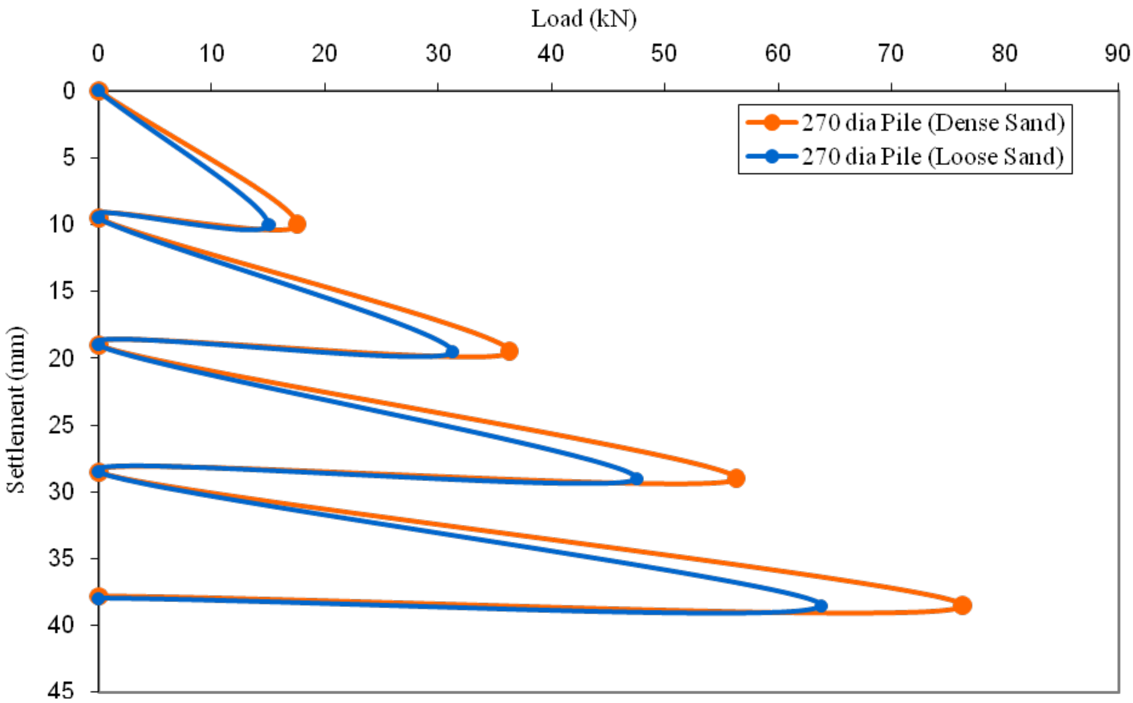


Fig 4.1 :- 270 mm dia pile (dense & loose sand)

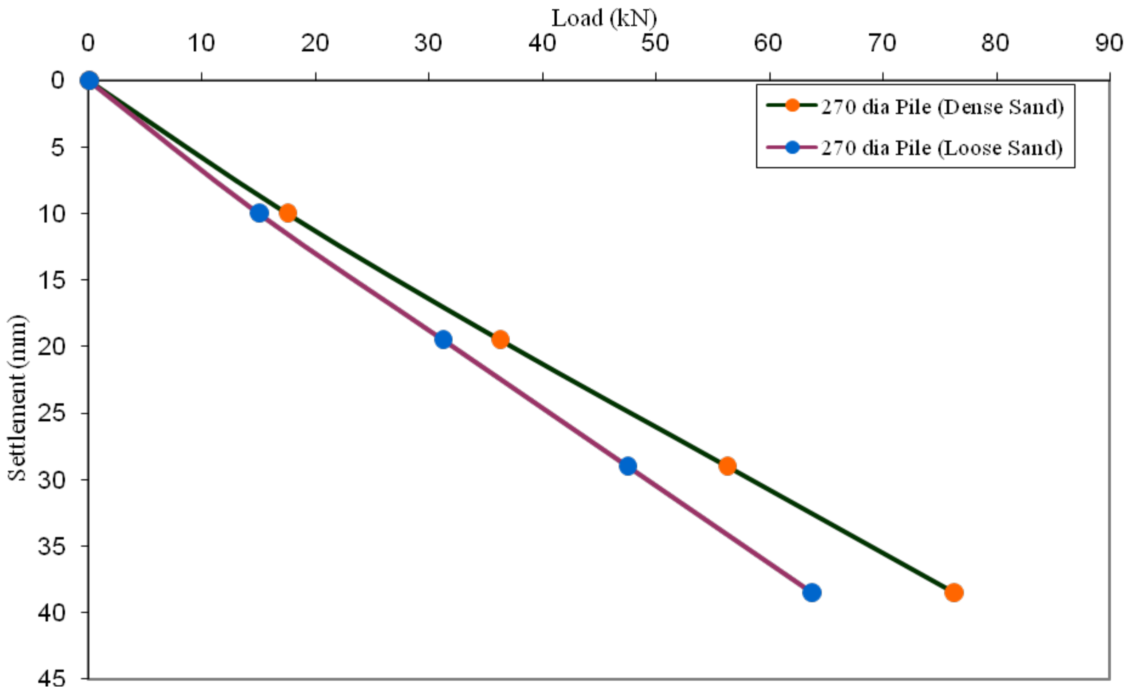


Fig 4.2 :- 270 mm dia pile (dense & loose sand)cumulative

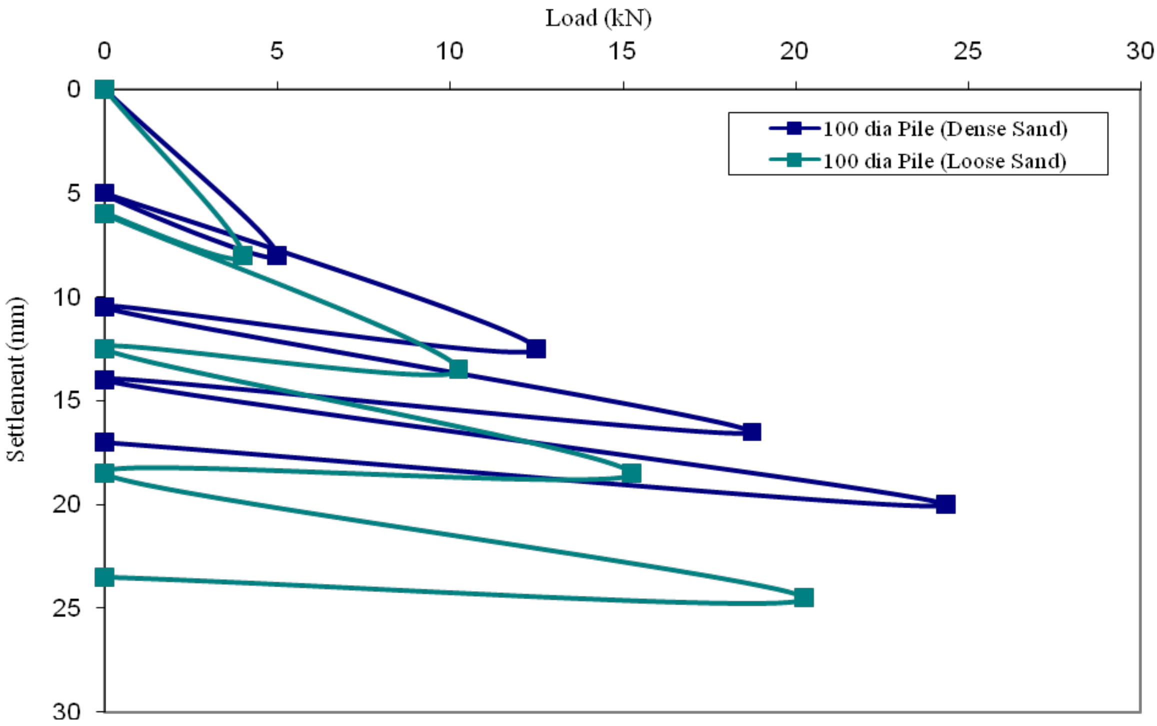


Fig 4.3:- 100 mm dia pile (dense sand)

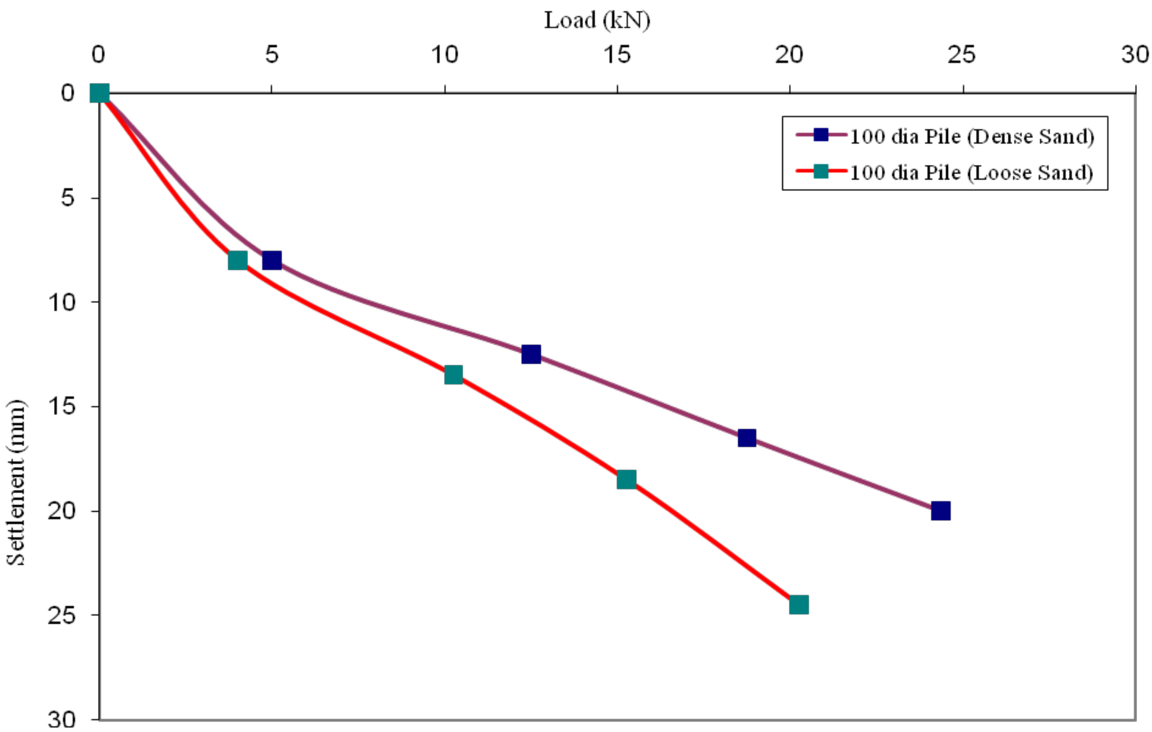


Fig 4.4:- 100 mm dia pile (dense & loose sand)cumulative

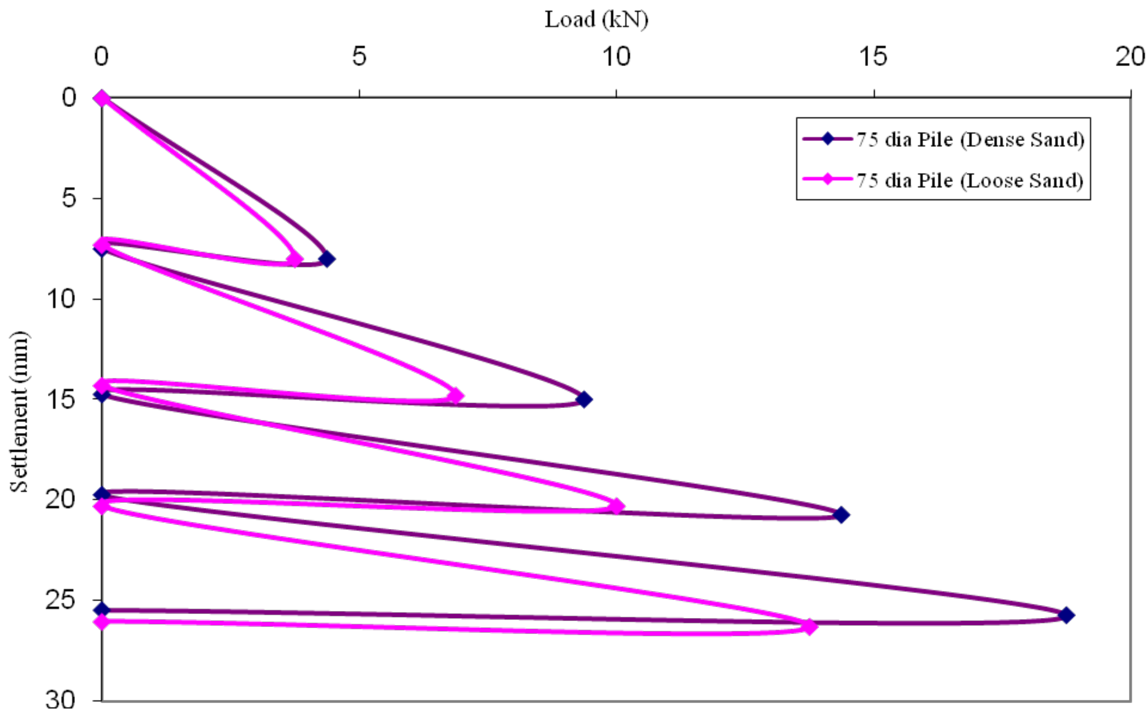


Fig 4.5:- 75 mm dia pile (dense & loose sand)

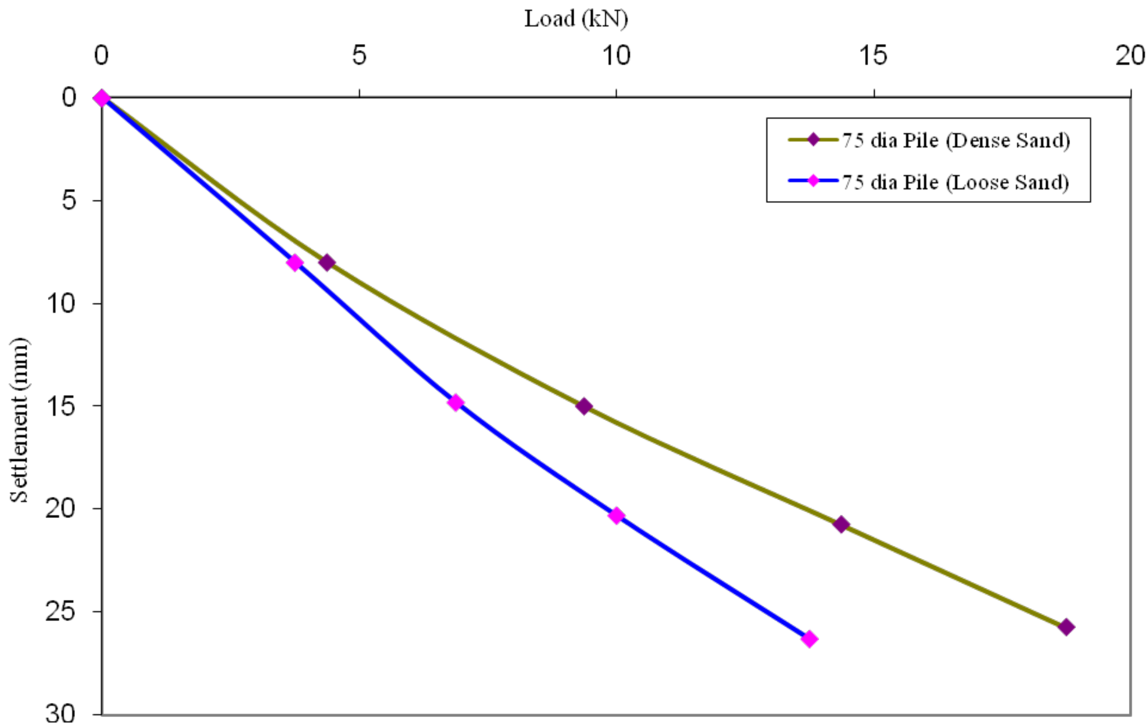


Fig 4.6:-75 mm dia pile (dense & loose sand) cumulative

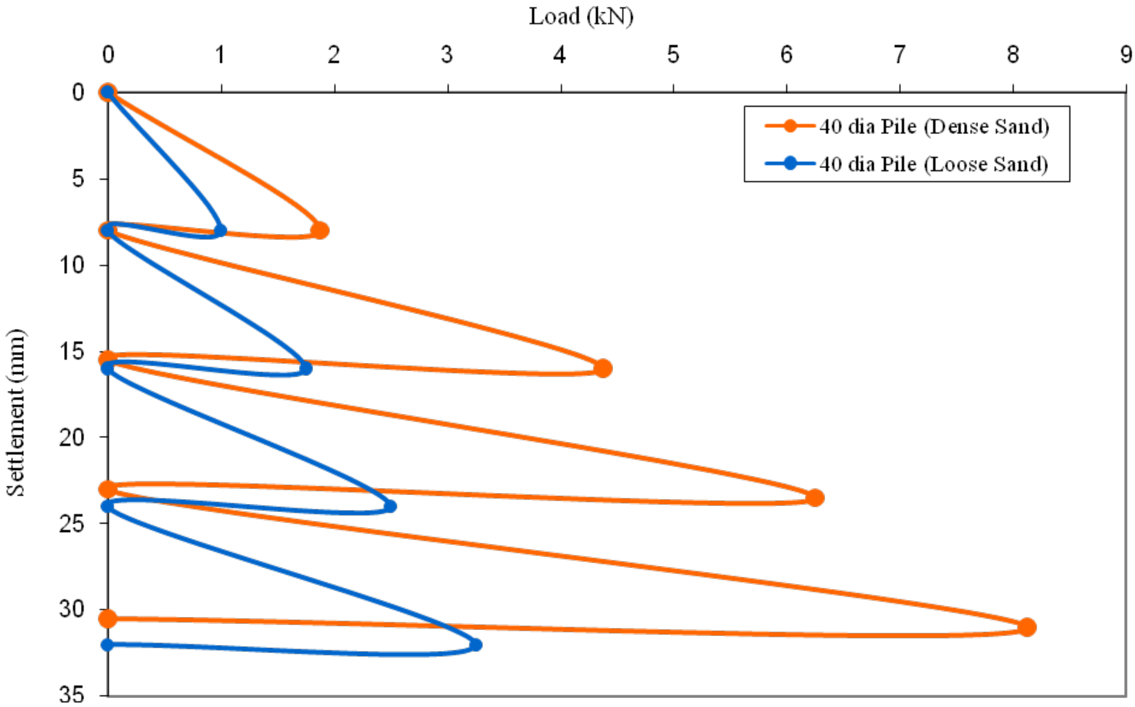


Fig 4.7:- 40 mm dia pile (dense & loose sand)

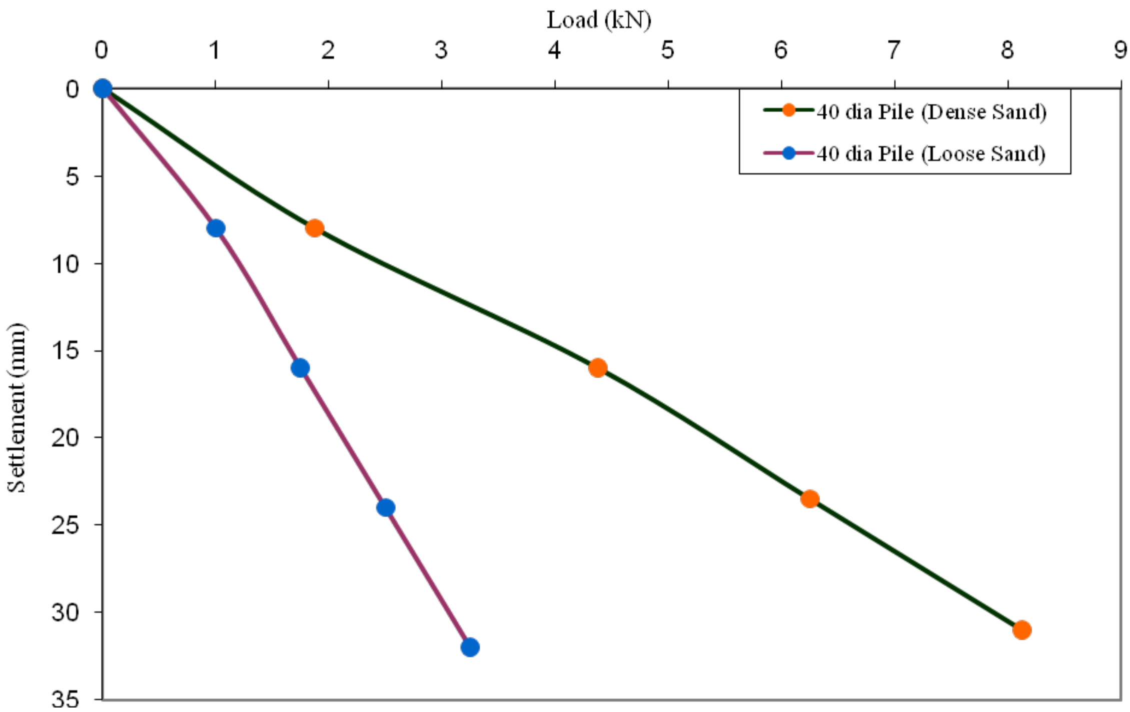


Fig 4.8:- 40 mm dia pile (dense & loose sand) cumulative

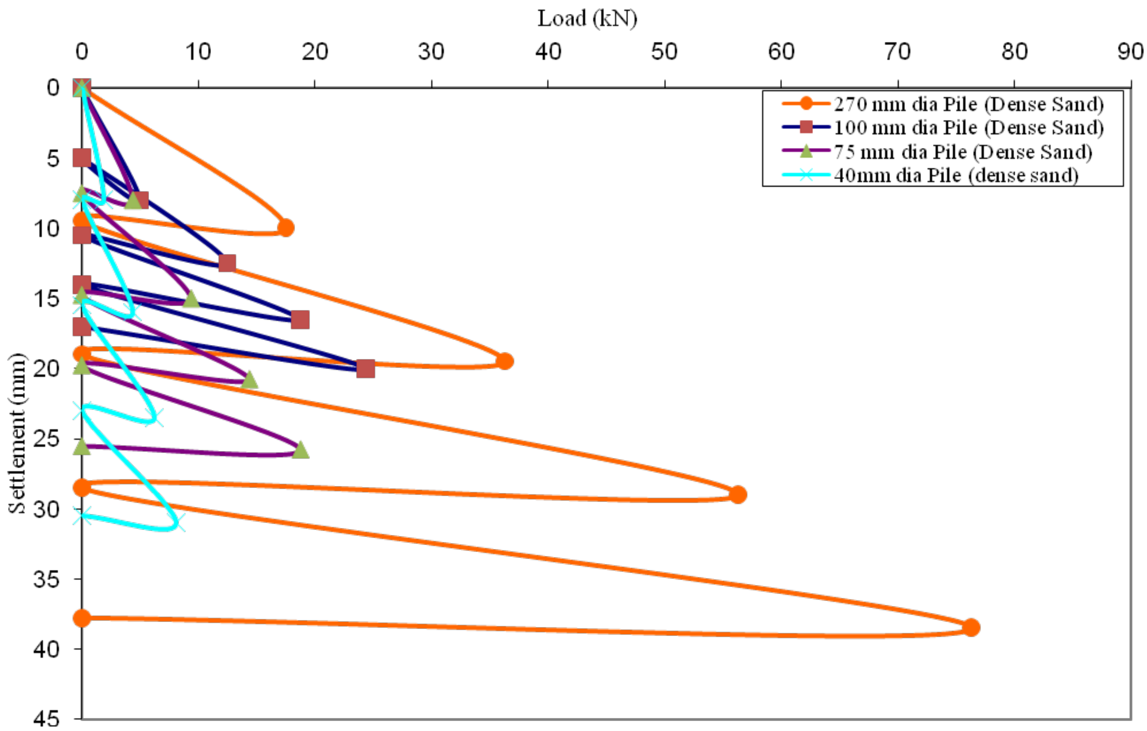


Fig 4.9:- 270, 100, 75, mm dia pile (dense sand)

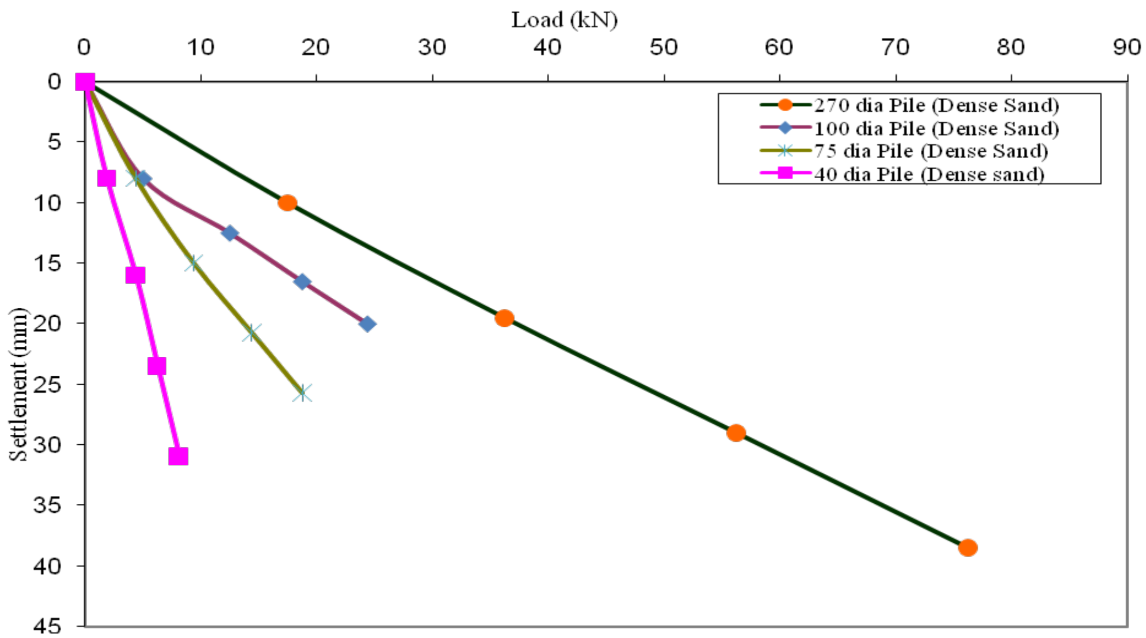


Fig 4.10:- 270, 100, 75, mm dia pile (dense sand) cumulative

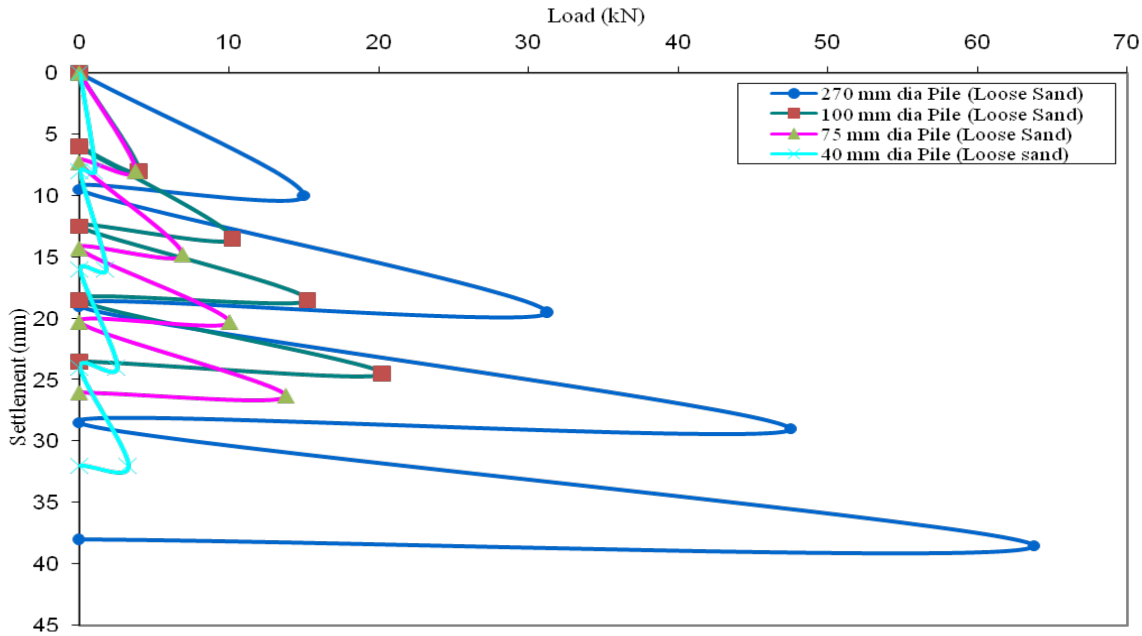


Fig 4.11:- 270, 100, 75, mm dia pile (loose sand)

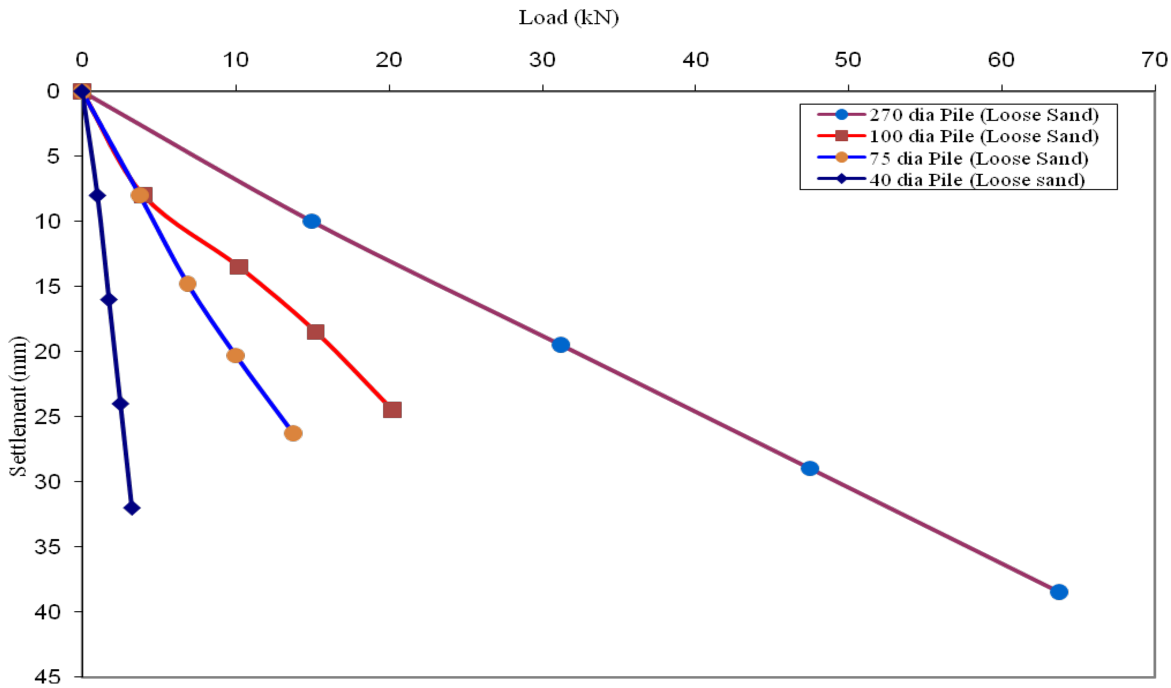


Fig 4.12:- 270, 100, 75, mm dia pile (loose sand) cumulative

4.3 Calculation of Pile Capacity by Static Formulae

Load carrying capacity of piles has been calculated using Indian Recommendations for different diameter and different length of piles. Pile capacity calculation is presented below.

A.1 PILE CAPACITY FOR PILE (DIA = 270MM AND LENGTH = 1M)Dense Sand

$Q_{ult} = Ap\ (0.5\ D\ \gamma\ N_{\gamma} + P_D\ N_q) + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.27	m	γ =	16.70	kN/m3
cross sectional area of pile Ap =	0.057	m2	Φ =	37	DEG
length of pile =	1.0	m			
			N_q =	70	
overburden at pile toe P_D =	16.7	kN/m2	K =	1	

Q_{ult}	**=**	**72.27**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	28.9	kN

A.2 PILE CAPACITY FOR PILE (DIA = 270MM AND LENGTH = 1M)Loose sand

$Q_{ult} = Ap\ (0.5\ D\ \gamma\ N_{\gamma} + P_D\ N_q) + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.27	m	γ =	15.50	kN/m3
cross sectional area of pile Ap =	0.057	m2	Φ =	33	DEG
length of pile =	1.0	m			
			N_q =	50	
overburden at pile toe P_D =	15.5	kN/m2	K =	0.5	

Q_{ult}	**=**	**46.51**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	18.6	kN

A.3 PILE CAPACITY FOR PILE (DIA = 100MM AND LENGTH = 1M)Dense Sand

$Q_{ult} = Ap\ (\ 0.5\ D\ \gamma\ \ N_{\gamma} + P_D\ N_q\ )\ \ + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.1	m	γ =	16.70	kN/m3
cross sectional area of pile Ap =	0.008	m2	Φ =	37	DEG
length of pile =	1.0	m			
			N_q =	70	
overburden at pile toe P_D =	16.7	kN/m2	K =	1	

Q_{ult}	**=**	**11.16**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	4.5	kN

A.4 PILE CAPACITY FOR PILE (DIA = 100MM AND LENGTH = 1M)Loose sand

$Q_{ult} = Ap\ (\ 0.5\ D\ \gamma\ \ N_{\gamma} + P_D\ N_q\ )\ \ + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.1	m	γ =	15.50	kN/m3
cross sectional area of pile Ap =	0.008	m2	Φ =	33	DEG
length of pile =	1.0	m			
			N_q =	50	
overburden at pile toe P_D =	15.5	kN/m2	K =	0.5	

Q_{ult}	**=**	**6.88**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	2.8	kN

A.5 PILE CAPACITY FOR PILE (DIA = 75MM AND LENGTH = 1M)Dense sand

$Q_{ult} = Ap\ (\ 0.5\ D\ \gamma\ \ N_{\gamma} + P_D\ N_q\ )\ \ + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.075	m	γ =	16.70	kN/m3
cross sectional area of pile Ap =	0.004	m2	Φ =	37	DEG
length of pile =	1.0	m			
			N_q =	70	
overburden at pile toe P_D =	16.7	kN/m2	K =	1	

Q_{ult}	**=**	**6.65**	**kN**
factor of safety	=	2.50	
safe load carrying capacity of pile	=	2.66	kN

A.6 PILE CAPACITY FOR PILE (DIA = 75MM AND LENGTH = 1M)Loose sand

$Q_{ult} = Ap\ (\ 0.5\ D\ \gamma\ \ N_{\gamma} + P_D\ N_q\ )\ \ + \Sigma\ K\ P_{Di}\ \tan\delta\ A_s$

dia of pile D =	0.075	m	γ =	15.50	kN/m3
cross sectional area of pile Ap =	0.004	m2	Φ =	33	DEG
length of pile =	1.0	m			
			N_q =	50	
overburden at pile toe P_D =	15.5	kN/m2	K =	0.5	

Q_{ult}	**=**	**4.0**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	1.6	kN

A.7 PILE CAPACITY FOR PILE (DIA = 40MM AND LENGTH = 1M)Dense sand

$Q_{ult} = Ap\,(0.5\,D\,\gamma\,N_\gamma + P_D\,N_q) + \Sigma\,K\,P_{Di}\tan\delta\,A_s$

dia of pile D =	0.040	m	γ =	16.70	kN/m3
cross sectional area of pile Ap =	0.001	m2	Φ =	37	DEG
length of pile =	1.0	m			
			N_q =	70	
overburden at pile toe P_D =	16.7	kN/m2	K =	1	

Q_{ult}	**=**	**2.26**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	0.9	kN

A.8 PILE CAPACITY FOR PILE (DIA = 40MM AND LENGTH = 1M)Loose sand

$Q_{ult} = Ap\,(0.5\,D\,\gamma\,N_\gamma + P_D\,N_q) + \Sigma\,K\,P_{Di}\tan\delta\,A_s$

dia of pile D =	0.040	m	γ =	15.50	t/m3
cross sectional area of pile Ap =	0.001	m2	Φ =	33	DEG
length of pile =	1.0	m			
			N_q =	50	
overburden at pile toe P_D =	15.5	kN/m2	K =	0.5	

Q_{ult}	**=**	**1.29**	**kN**
factor of safety	=	2.5	
safe load carrying capacity of pile	=	0.5	kN

Table 4.2: Load carrying capacity according to static formulae.

Dia(mm)	Medium	Length(mm)	Capacity(kN)
270	Dense	1000	72.27
100	Dense	1000	11.61
75	Dense	1000	6.65
40	Dense	1000	2.26
270	Loose	1000	46.51
100	Loose	1000	6.88
75	Loose	1000	4.0
40	Loose	1000	1.29

Table 4.3: Comparison of pile load test and static load formulae results.

Dia(mm)	Medium	Pile load test(kN)	Static formula(kN)
270	Dense	56.25	72.27
100	Dense	12.5	11.61
75	Dense	9.375	6.65
40	Dense	4.375	2.26
270	Loose	47.50	46.51
100	Loose	10.25	6.88
75	Loose	6.875	4.0
40	Loose	1.75	1.29

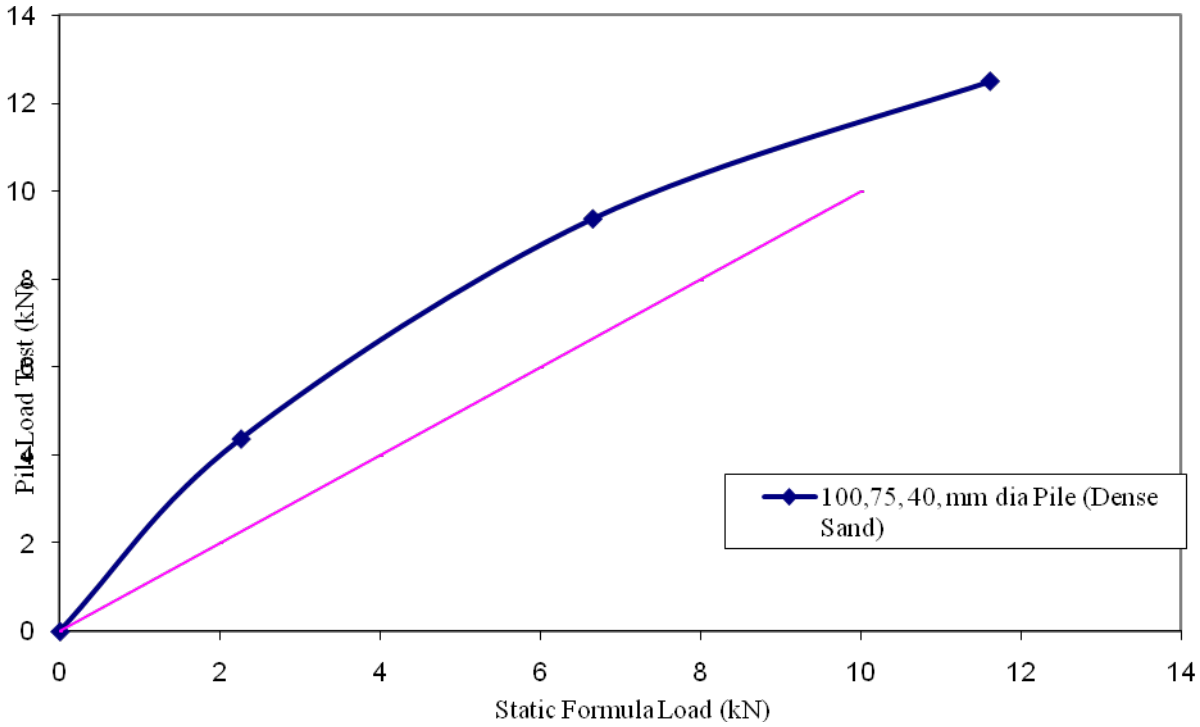


Fig4.13:-Pile load test Vs static formulae (dense sand)

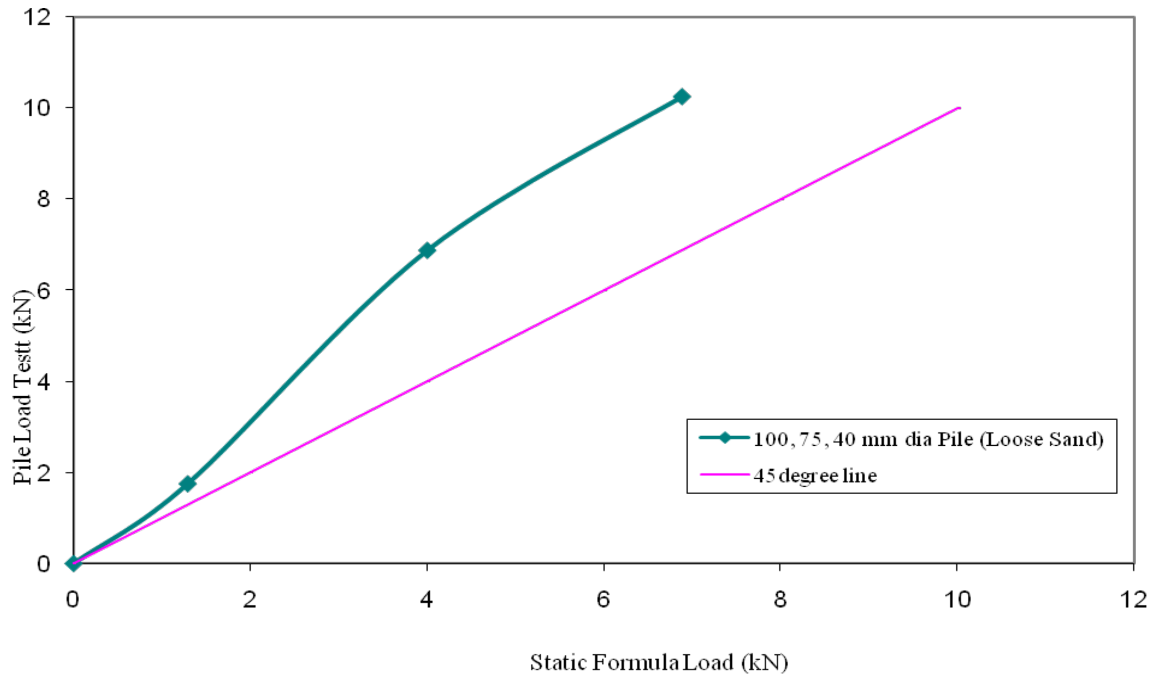


Fig4.14:- Pile load test Vs static formulae (loose sand)

4.4 Calculation of Pile Capacity by Dynamic Formulae

Pile Capacity By Dynamic Formulae			
Pile Diameter 100mm (Dense Sand)			
S(settlement per blows)	0.625	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	10	cm	
Xsection Area(A)	78.5	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h W H}{\left(S + \frac{S_0}{2}\right)}$$

Where

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0274**	**cm**
Q_u =	**9.20**	**kN**

Pile Diameter 100mm (Loose Sand)			
S(settlement per blows)	0.83	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	10	cm	
Xsection Area(A)	78.5	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h W H}{(S + \frac{S_0}{2})}$$

Where

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0274**	**cm**	
Q_u =	**6.96**	**kN**	

Pile Diameter 75mm (Dense Sand)			
S(settlement per blows)	1	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	7.5	cm	
Xsection Area(A)	44.156	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h WH}{(S + \frac{S_0}{2})}$$

Where

$$S_0 = \left(\frac{2\eta_h(WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0365**	**cm**
Q_u =	**5.77**	**kN**

Pile Diameter 75mm (Loose Sand)			
S(settlement per blows)	1.25	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	7.5	cm	
Xsection Area(A)	44.156	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h W H}{\left(S + \frac{S_0}{2}\right)}$$

Where

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0365**	**cm**
Q_u =	**4.63**	**kN**

Pile Diameter 40mm (Dense Sand)			
S(settlement per blows)	3.75	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	4	cm	
Xsection Area(A)	12.56	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h W H}{(S + \frac{S_0}{2})}$$

Where

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0684**	**cm**
Q_u =	**1.55**	**kN**

Pile Diameter 40mm (Loose Sand)			
S(settlement per blows)	7.5	cm	From table
Efficiency of Hammer(η_h)	1		
Wt of hammer(W)	0.1175	kN	
Ht of Hammer(H)	50	cm	
Length of Pile (D)	100	cm	
Diameter of Hammer	4	cm	
Xsection Area(A)	12.56	cm2	
E For Steel pile	20000	kN/cm2	

$$Q_u = \frac{\eta_h W H}{\left(S + \frac{S_0}{2}\right)}$$

Where

$$S_0 = \left(\frac{2\eta_h (WHD)}{AE}\right)^{1/2}$$

S_0 =	**0.0684**	**cm**
Q_u =	**0.78**	**kN**

The pile load test static formulae &Dynamic formula results are compared as Shown below.

Table 4.4:Comparison of plate load test, dynamic formulae and Static load formulae.

Dia(mm)	Medium	Pile load test(kN)	Static formula(kN)	Dynamic formula(kN)
270	Dense	56.25	72.27	_
100	Dense	12.5	11.61	9.2
75	Dense	9.375	6.65	5.77
40	Dense	4.375	2.26	1.55
270	Loose	47.50	46.51	_
100	Loose	10.25	6.88	6.96
75	Loose	6.875	4.0	4.63
40	Loose	1.75	1.29	0.78

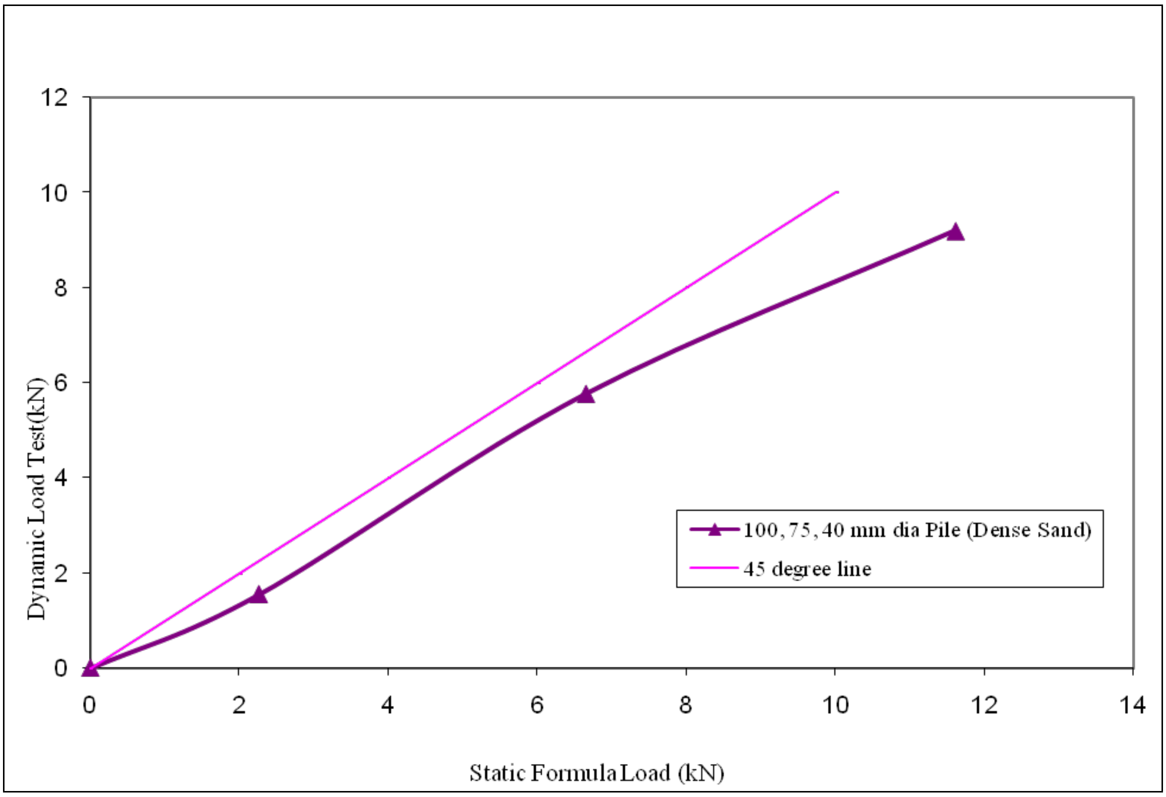


Fig4.15:-Dynamic load test Vs Static formulae (dense sand)

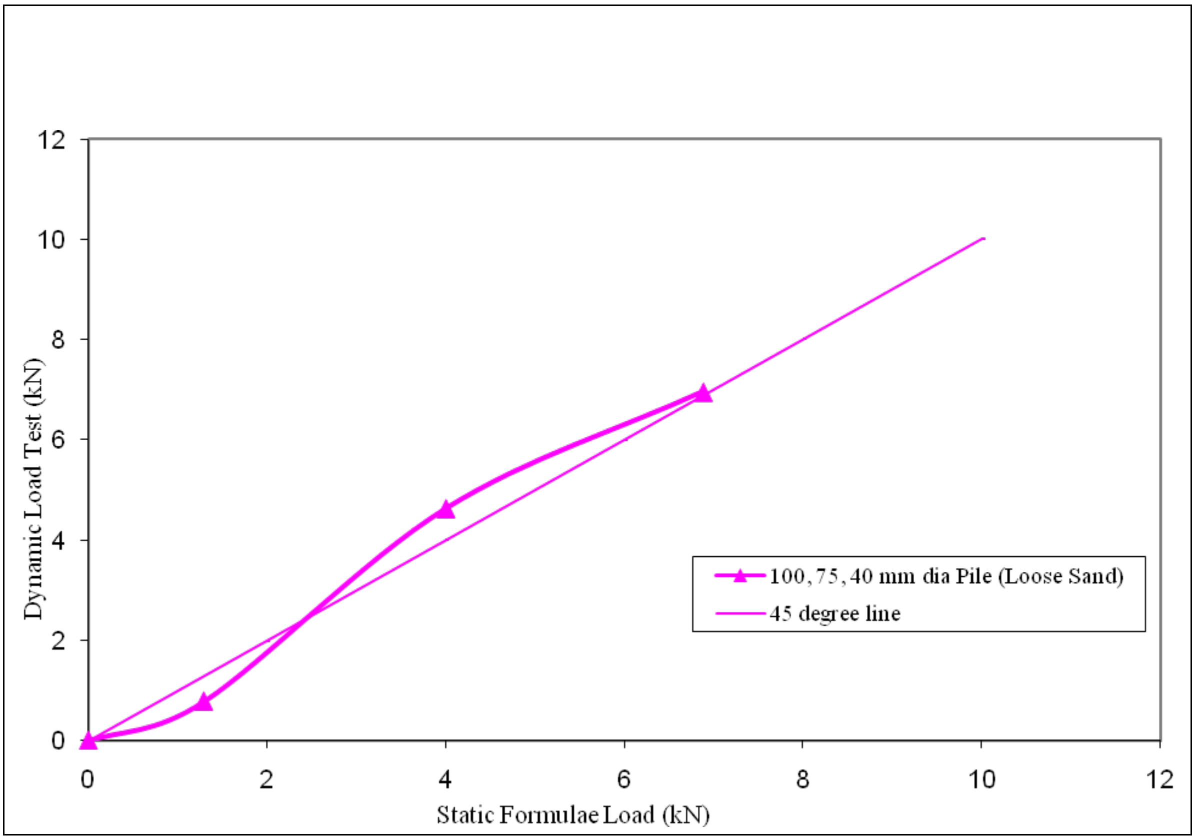


Fig4.16:-Dynamic load test Vs Static formulae (loose sand)

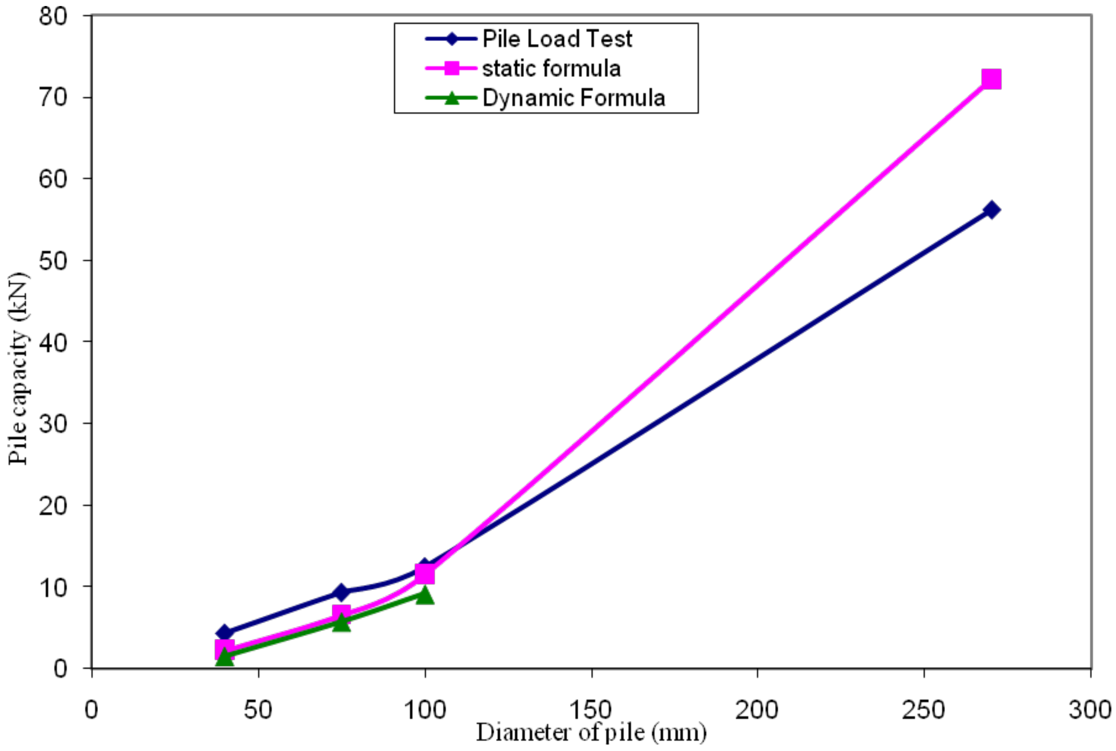


Fig 4.17:-comparision of all three method(dense)

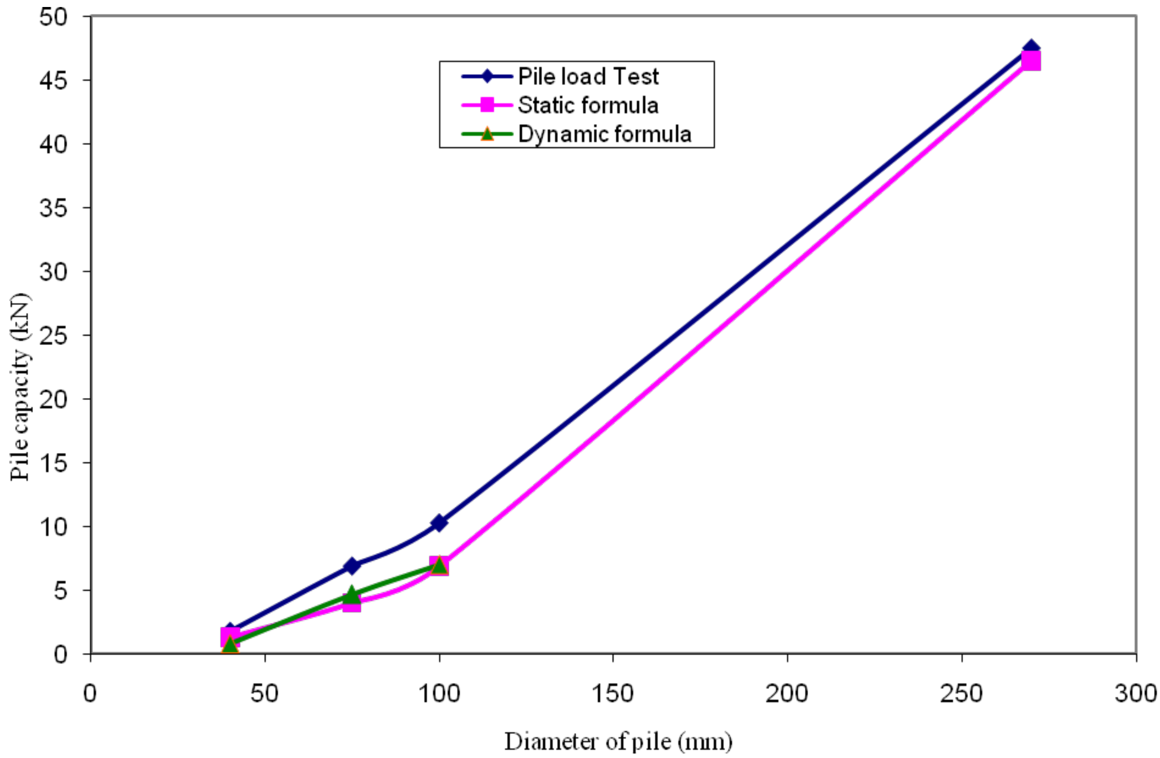


Fig4.18-:comparision of all three method(loose)

CHAPTER 5
CONCLUSIONS

5.1 General

A pile load test is conducted on model steel piles in sandy soil having same length but varying cross-sectional area. In this experimental work a testing pit is prepared in which the sand is filled to reach the field conditions and hydraulic jack arrangement is made for applying compressive loading on the piles. The results obtained from cyclic pile load test are also compared with static load formulae. The following conclusions are drawn:

- The value obtained by pile load test is higher as compared to static and dynamic formulae.
- For cyclic pile load test for same settlement load requires more as compared to direct pile load test.
- For 100 mm dia pile in dense sand ultimate capacity is 1.2 times than in loose sand.
- For 100 dia pile in dense sand pile load test results gives 8% more than static formula.
- For 75 dia pile in dense sand pile load test results gives 40% more than static formula.
- For 40 dia pile in dense sand pile load test results gives 93% more than static formula.
- For 100 dia pile in dense sand static formula results gives 26% more than dynamic formula.

- For 75 dia pile in dense sand static formula results gives 15% more than dynamic formula.
- For 40 dia pile in dense sand static formula results gives 45% more than dynamic formula.
- For 270 dia pile static formula results in dense sand gives 18% more than loose sand.
- For 100 dia pile static formula results in dense sand gives 22% more than loose sand.
- For 75 dia pile static formula results in dense sand gives 36% more than loose sand.

- For 40 dia pile static formula results in dense sand gives 150% more than loose sand.
- Frictional stress decreases with increase in diameter(for 270 dia. $93kN/m^3$, 100 dia. $252kN/m^3$, 75 dia. $335kN/m^3$, 40 dia. $628kN/m^3$).

5.2 Future scope of work

a) The test can be performed on different types of other soils other than sand i.e gravels, silty soil etc

b) Test can be performed with different material of pile.

c) Test can be performed for piles having different surface coating bitumen, anticorrosive paint etc.

d) Tests can be performed for piles having different surface characteristics like of indentation, smooth and rough etc.

e) Effect of vibrations can be studied so as to know the behaviour of piles under the wind load/earthquake conditions.

f) The shape of tip of the pile can be changed to get varied results.

References

1. IS-2911 (Part-4), 1985, **“**Code of Practice for Design and Construction of Pile Foundations, Part 4 Test on Piles*”*. Reaffirmed 2006, Edition 2.1.
2. American Society for Testing and Materials (2007), **“**Standard Test Methods for Deep Foundations Under Static Axial Compressive Load”, D-1143/D 1143M, Annual Book of ASTM Standards.
3. C. Teng Wayne (1969), **“**Foundation Design**”**, 5th edition, Prentice Hall of India Pvt. Ltd.
4. Joseph E.Bowles (1970), “Foundation Analysis and Design”, 5th edition, The Mcgraw-Hill companies, New York.
5. Nainan P. Kurian(2006), “Design of Foundation System (Principle and Practice)”, Third edition, Narosa Publishing House Pvt.Ltd.
6. H Y fang(1975), “The Foundation Engineering Handbook”, Van Nostrand Reinhold Company.
7. Meyerhof, G.G. (1976), Bearing Capacity and Settlement of Pile Foundations, Journal of Geotechnical Engineering, ASCE, 102(3), pp. 197-228.
8. Gopal Ranjan (2000), “Basic and Applied Soil mechanics”, 2nd edition, New Age International publishers.
9. Fellenius, B.H., (1998). Recent Advances in the Design of Piles for Axial Loads, Drag Loads, Down Drag, and Settlement. By American Society of Civil Engineers.
10. Poulos, H.G. and E.H. Davis, (1980). Pile Foundation Analysis and Design.John Wiley and Sons.
11. Hansen, J.B., (1970). A Revised and Extended Formula for Bearing Capacity. Danish Geotechnical Institute, Copenhagen.
12. Poulos, H.G. and K.F. Chan, (1986). Laboratory Study of Pile Skin Friction in Calcareous Sand. Proc. GeoTech. Eng.
13. Poulos, H.G., (1989). Cyclic Axial Loading Analysis of Piles in Sand. J. Geotech. Eng. ASCE,115 (6): 836-851.