FRICTIONAL RESISTANCE OF POLYMER FLUID AS A BOREHOLE STABILIZER

A Dissertation submitted in partial fulfillment of the requirement for the
Award of degree of

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

BY

DEEPANSHU JAIN
(ROLL NO. 2K13/GTE/05)

Under the Guidance of

Dr. AMIT KUMAR SHRIVASTAVA

Assistant Professor
Department of Civil Engineering
Delhi Technological University, New Delhi

DELHI TECHNOLOGICAL UNIVERSITY
(FORMERLY DELHI COLLEGE OF ENGINEERING)
NEW DELHI - 110042
June-2015

CANDIDATE'S DECLARATION

I do hereby certify that the work presented is the report entitled "**Frictional resistance of polymer fluid as a borehole stabilizer**", in the partial fulfillment of the requirements for the award of the degree of "Master of Engineering" in geotechnical engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of our own work carried out from December 2014 to June 2015 under the supervision of Dr. Amit Kumar Shrivastava (Assistant Professor), Department of Civil Engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: 19 June 2015

Deepanshu Jain
(2K13/GTE/05)

CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge.

Dr. Amit Kumar Shrivastava
(Assistant Professor)
Department of Civil Engineering
Delhi Technological University

ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to Dr. Amit Kumar Shrivastava (Assistant Professor, Civil Engineering Department, DTU) for his exemplary guidance, monitoring and constant encouragement throughout the course of this project work. The blessing, help and guidance given by him from time to time shall carry me a long way in life on which I am going to embark.

I would also like to thank Dr. Nirendra Dev (Head of Department, Civil Engineering Department, DTU) for extending his support and guidance.

Professors and faculties of the Department of Civil Engineering, DTU, have always extended their full co-operation and help. They have been kind enough to give their opinions on the project matter; I am deeply obliged to them. They have been a source of encouragement and have continuously been supporting me with their knowledge base, during the study. Several of well-wishers extended their help to me directly or indirectly and we are grateful to all of them without whom it would have been impossible for me to carry on my work.

ABSTRACT

Since last 60 years, for the construction of bored cast-in-situ piles, bentonite has been used as a borehole stabilizer, which forms a filter cake of low permeability around soil particles, helping in its stabilization. But the filter cake, required to be formed for borehole stabilization, in return reduces the shaft resistance of the pile, as it forms a soft interface layer between concrete and soil. To overcome the problems associated with bentonite as a stabilizer, in the present work polymers as a substitute has been analyzed. To achieve the objectives the effect of polymer fluid on the frictional resistance of pile has been studied. Laboratory tests were conducted to determine the effect of various parameters such as polymer concentration, silt content, bleaching powder etc. on the rheological properties of the drilling fluid. The results shows that a small amount of polymer can increase the marsh funnel viscosity of water as compared to bentonite. The effect of pH and time on the viscosity of polymer fluid helped to optimize the drilling fluid which was used to perform the direct shear test, with a layer of different concentration of polymer fluid along the predefined failure plane, to check its effect on internal angle of friction and cohesion of soil. A real life problem of pile is physically modeled and pull out test has been performed on a fabricated laboratory setup. The results of the pull out test marked decrease in the shaft resistance of pile with the increase in polymer concentration. The theoretical relations, given by various researchers, and the experimental results were then compared to give a modification factor ‘F’, depending on the internal angle of friction of soil.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 GENERAL

From last 6 decades, mineral slurries have been commonly used, for the stabilization of the borehole in various constructions such as pile foundation, diaphragm wall panels etc. Bentonite being economical and easily available material has been the most commonly used mineral slurry. Bentonite shows a thixotropic behavior with time, as it regains its strength due to remolding, when allowed to hydrate in water. The particles of bentonite form an impermeable layer of filter cake around the exposed soil layer, which thus helps in borehole stabilization.

For pile foundation, the ultimate bearing capacity is the sum of end bearing resistance as well as frictional resistance around the shaft, but various researchers have shown that with the use of bentonite as a borehole stabilizer, the frictional resistance offered by the pile is found to be reduced due to the formation of a soft layer. The soft layer formation is necessary to keep the soil intact in the borehole, thus indulges in compromising with the reduction in the overall ultimate load carrying capacity of the pile. This had led to the development of material, such as polymer fluids which helps in stabilizing the borehole without significantly affecting the frictional resistance of the pile.

Polymer can be natural (xanthum) as well as synthetic. Polymers though have the same function as mineral slurries (of borehole stabilization), but have different composition. They possess high molecular weight and when added in water, their ionic molecules interact with each other, to form long chain hydrocarbons, which further interacts with the soil particles on the vertical walls of the excavated borehole and keeps it intact maintaining its stability. The slippery texture of fluid would appear to lubricate the interface between concrete and soil but at the time of concreting, due to presence of lime, the pH rises at the contact interface of concrete-polymer-soil and it is thought to breakdown the polymer and thus eliminating such concerns.

The quantity of polymer required to form same amount of suspension as compared to bentonite have been much lesser, reducing the overall cost of the project in terms of storage unit, transportation charges etc. Through literature it has been found that one of the major disadvantages of using bentonite is its disposal. When bentonite, with additives used during slurry formation, is disposed in landfills and lakes, it contaminates the surrounding environment such as aquatic life whereas since last decade non-hazardous polymers have been developed which possess no harm to environment. Apart from these benefits polymers have found to increase the frictional resistance of pile foundations when compared to their counter-part, bentonite slurry which makes it essential to switch our concern from bentonite to polymer study.

In the present study, the project was taken to understand and analyze the effect of polymer fluid on frictional resistance of pile along with some other secondary objectives. The report presents all the test results and the conclusion drawn from the experimental program performed in the laboratories of Delhi Technological University, Delhi.

1.2 OBJECTIVES OF THE PROJECT

The main objective of the project entitled, "Frictional Resistance of Polymer Fluid as a Borehole Stabilizer", was to provide an understanding of the effect of polymer fluid on the frictional resistance of pile developed at the soil-concrete interface of bored cast insitu concrete piles. The project had various secondary objectives. They were to:

a) Determine the effect of concentration of polymer crystals on the viscosity, pH and density of water.
b) Determine the effect of increase in pH on the viscosity, density and pH of polymer fluid.
c) Show the effect of time on viscosity, pH and density of polymer fluid.
d) Show the effect of bleaching powder i.e. hypochlorite (degrading agent) on viscosity and pH of polymer fluid.
e) Understand the effect of a layer of polymer fluid (placed along failure plane) on the internal angle of friction (ϕ) of soil.

1.3 SCOPE OF THE PROJECT

The project topic is: "Frictional Resistance of Polymer Fluid as a Borehole Stabilizer". In recent advances polymer fluid have been used as a borehole stabilizer, replacing its counterpart, the mineral slurries which were used as conventional borehole stabilizers. The present work intends to understand the positive aspects of polymer fluid, such as its small concentration enhancing the viscosity of water and formation of colloidal particles on reaction with hypochlorite (bleach) which settles down making its final disposal ecofriendly and its impact on the frictional resistance of the pile. High rise buildings are the demand of today's urban infrastructure and a high pressure on the soil has made the use of pile group as a safe option for load bearing and as settlement reducer for which foundation system need to be strong. The results and discussion hence can be used as a reference for future work concerning the improvement in the overall load carrying capacity of the foundation system. The topic is taken up with a view to study the effect of polymer fluid on the frictional resistance of bored cast in-situ concrete pile where drilling fluid plays a vital role of a stabilizer of soil in the borehole, and as quoted by various researchers that it can provide many advantages in terms of:

a) Construction time
b) Construction cost
c) Ease of construction with less man-power.
d) Increase in strength of the foundation system
e) Environment friendly
f) Storage and transportation ease
g) With proper construction technique, can be used for clays, silts and sands.

1.4 ORGANIZATION OF DISSERTATION

CHAPTER 1: INTRODUCTION

This chapter gives a general view about the recent development of polymer fluid and its relevance when compared to its counterpart bentonite slurry. It signifies the importance and states the objectives of the project work. Further, it emphasizes on the scope of the project and mechanism of polymer action keeping in view the modern constructional aspects.

CHAPTER 2: LITERATURE REVIEW

This chapter enlightens various research works that has been carried out. For fulfilling the objectives of the project, a thorough study of the literature was done, as it is the first step of every planning to have better understanding about the topic.

CHAPTER 3: METHODOLOGY AND DRILLING FLUID CHARACTERSTICS

In this chapter, a schematic diagram of the working procedure of the project work undertaken has been shown. The chapter embarks the procedure along with the reason for various laboratories testing performed to determine the effect of polymer concentration, time, silt content and bleach (hypochlorite) on the rheological properties of the drilling fluid.

CHAPTER 4: LABORATORY EXPERIMENTS & THEORETICAL ANALYSIS

The chapter presents the basic properties of soil such as its gradation, specific gravity, maximum dry density and optimum moisture content along with the direct shear test conducted to account the impact of different concentrations of polymer fluid on the frictional resistance of soil.

CHAPTER 5: PHYSICAL MODELLING AND FIELD TESTING

This chapter deals with the details of the field work carried out in a steel tank in D.T.U. premises. It includes the selection criteria of steel tank and concrete mix along with the designing of pulley system for performing pull out test. It explains the testing program to find out the uplift capacity of bored cast in-situ concrete piles casted with and without using the drilling fluid.

CHAPTER 6: RESULTS AND DISCUSSION

This chapter plots the results obtained from the laboratory as well as the field testing and try to enlighten the causes behind the results. It includes the advantages and disadvantages that can be drawn from the results.

CHAPTER 7: CONCLUSIONS

The conclusions of the project report have been presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 FOUNDATION PERFORMANCE

Stability of the structure depends on the stability of its foundation. If the foundation is weak than no matter what have been the other benefits of the material it will be never be of any use. Foundation systems, such as pile foundation, attains its strength from the end bearing action as well as from the frictional resistance of the shaft making it more important to understand the role of polymer fluid as a borehole stabilizer.

Majano et al. (1994) inferred higher angle of wall friction for polymers as compared to mineral slurry of bentonite as they were believed to be either scoured by the rising mortar or reacted with alumina silicates in the cement to yield sound interfaces.

Ata and O’Neill (2000) studied the physiochemical interaction between polymer slurry and cement mortar, and explained the process of coiling of polymer strands, as release of divalent calcium ions breakdowns the polymer which causes strands to coil. Their microscopic examination also showed the squeezing of polymer into the narrow pores of different soil and attains different diameters and shape assisting in the production of drag force.

A higher end bearing resistance was observed in pile with bentonite slurry as compared to piles with polymer fluids, when 3 piles were tested in Miami, Florida by Frizzi et al. (2004) resulting in bentonite stabilized shaft exhibiting a higher ultimate equivalent top load than the polymer stabilized shafts. In contrast, Brown (2002) quoted that polymer slurry material appeared to promote an excellent bond between the concrete and soil as in there experiment in fine grained silty-sand, shafts installed using bentonite slurry had a reduced capacity compared to shafts with polymer slurry.

Through their research work, Ilampruthi and Kumar (2011), have shown asymptotic response of the load-displacement curve when they performed a pull out test on a fabricated model pile. They also concluded 17.5% reduction in frictional factor “Ktanδ” for bentonite slurry interface as compared to interface without slurry.

Lam et al. (2010) from full-scale field test in East London analyzed the functioning of three instrumented piles constructed under polymer fluid and bentonite fluid and concluded that the pile with polymer fluid had outperformed the pile with bentonite in terms of strength. Lam et al. (2014) in an ICE proceeding shown the risk of soft toes i.e. when coarser soil particles of silt and sand settles down, effecting the strength of the foundation however they also suggested some common construction practices that may can help to avoid the situation.

2.2 VISCOSITY OF THE DRILLING FLUID

The viscosity of the drilling fluid can be an important parameter in deciding the active concentration of polymer. The functional groups present in the polymer cross links to form long chains of hydrocarbons and thus increasing the viscosity of water. Ilampruthi and Kumar (2011) through their experimental study on the effect of filter cake on interfacial friction concluded an exponential increment in the Marsh funnel viscosity of both bentonite as well as polyacrylamide solution but increment being more significant in the later. Lam and Jefferis (2013) stated that polymers are used one-fifth to one-twentieth of the bentonite concentrations to produce same viscosity of the drilling fluid and thus their small dosage helps in their final disposal.

Brown (2012) has quoted several advantages of polymer, used as a drilling fluid, one of them being its efficiency in increasing the viscosity of the fluid. He also stated that in order to avoid the formation of excessive filter cake there is need to restrict the upper limits of viscosity for bentonite fluid but for polymers can utilize significantly higher viscosity in order to provide effective stabilization.

2.3 ENVIRONMENTAL CONCERN

In recent time, environment protection has evolved to be one of the major concerns for the world. Thus several restrictions have been imposed on the final disposal of liquid waste. Sil et al. (2012) studied the effects of complex mixtures such as drilling fluid on the aquatic life. They conducted a laboratory study to determine the lethal concentration of drilling fluid for three different fish species. As per Indian guidelines, MoEF, the LC_{50} 96h should be greater than 30000 mg/L for drilling fluid to be non-toxic.

Lam and Jeffris (2013) have mentioned that since polymer is used in very small concentration as compared to bentonite, can be broken down easily with oxidizing agents such as hypochlorite (bleach) so that after the colloidal particles settles the supernatant liquid be disposed to sewer.

2.4 OPERATIONAL CONCERN

Industry always needs materials which require less input and at the same time producing better output. One of the traditional reasons behind switching from bentonite to polymer is its operational benefit. There are certain sites where it becomes difficult to construct a separate bentonite plant due to space restrictions thereby leading to the use of polymer as drilling fluid. Lam and Jefferis (2013) has mentioned such a site in Glasgow as polymer fluids neither require multiple holding tanks for slurry hydration nor separations to recover the used fluid.

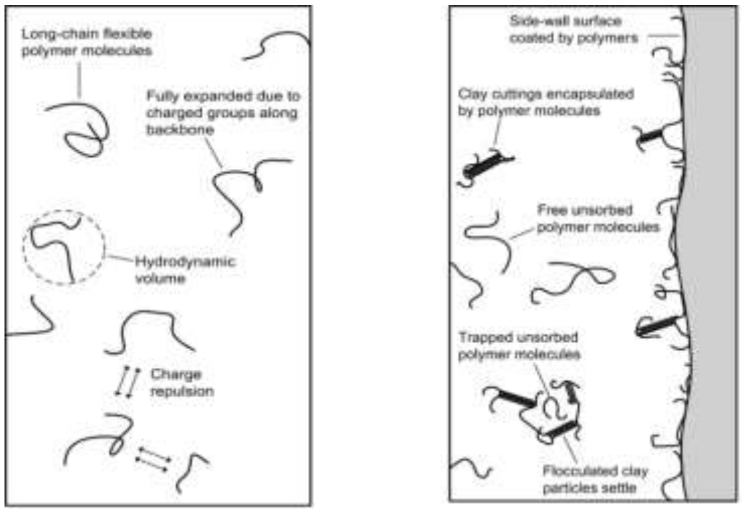
2.5 UPLIFT CAPACITY

The uplift capacity of the pile foundation depicts the frictional resistance offered by the soil particles around the pile shaft. In order to determine the effect of drilling fluid on the frictional resistance of pile, pull out test thus becomes the best possible solution. Various researchers, over the years have performed tests to determine the uplift capacity of the foundation systems.

Khaled E. Gaaver (2013) and also quoted that as per Poulos and Davis, the uplift capacity of piles should be taken as two-third of the downward shaft resistance and also reported that as per O'Neill and Reese, the shaft resistance in tension could be 12–25% smaller than shaft resistance obtained from compression test due to Poisson's ratio effect Many theories have been developed to find the net uplift capacity of a bored pile (D. R. Levacher et. al. 1985;Chattopadhyay and Pise 1986) and validated through experimental measurements.

2.6 POLYMER AND ITS MECHANISM

The polymer used in the research work was partially hydrolyzed polyacrylamide (PHPAs), as hydrolyzing prevents the dispersion of shale's. They were available in dry state in the form of white crystals, which were then required to be mixed with water to form the polymer fluid (drilling fluid). Lam et al. (2015) has stated that the polymer fluids act by exerting the hydrostatic pressure on the side walls of the excavation to maintain its stability. Fig 2.1 shows the mechanism behind the molecular interactions in a polymer fluid and its working condition.



(a) **(b)**

Fig 2.1: Schematic diagram showing various conditions of polymer supported fluids; (a) Clean (b) Working Condition [9]

As polymer available in the crystalline form is added in water, the cross linking functional groups carrying ionic charges forms long chains with each other through hydrodynamic and electrostatic forces increasing the viscosity of the solution. The polymer fluid is used as a drilling fluid; the polymer molecules bind to the soil particles and form a thin membrane which stabilizes the excavation. Polymer molecules encapsulate the soil particles and inhibit the breakup of lumps of cut soil and the dispersion of fine soil into the fluid. Due to low dosage of polymers, the density of polymer fluids is almost equal to that of water, allowing the soil particles to settle down and can be removed before concreting.

For pile foundations when bentonite slurry is used as a drilling fluid it forms a soft layer referred to as “filter-cake” between the soil and concrete interface and reduces the frictional resistance of the pile affecting the overall load carrying capacity of the pile foundation, but for polymer fluids, during concreting, it is said that as lime, present in the concrete, comes in contact with polymer-soil interface, the pH rises, due to which polymer layer breaks down leaving the concrete-soil interface and thus it doesn’t affect the frictional resistance of pile significantly.

CHAPTER -3

METHODOLOGY AND DRILLING FLUID CHARACTERIZATION

3.1 METHODOLOGY

Every project work requires a proper planning in terms of series of data collection and a methodology which is then executed to achieve the objectives of the research. A detailed study, in the form of literature review, was carried followed by a series of laboratory experiments which forms the backbone of the field work. The excavated soil from Noida region, required to be used as foundation soil, was then tested in the laboratory and the properties were then utilized in the theoretical analysis of the frictional resistance of pile foundation. The series of data collection and the methodology followed is as given in the flow chart:

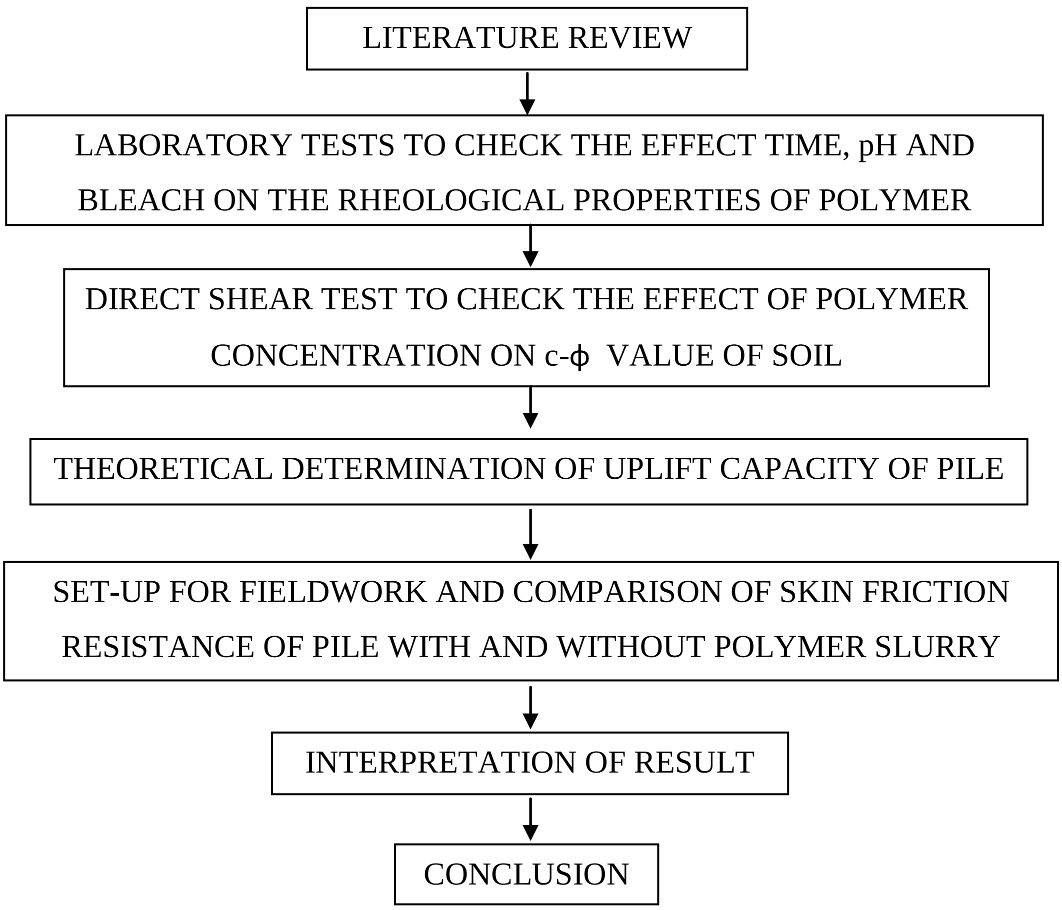


Fig 3.1 Flow chart for the methodology

3.2 MORPHOLOGY OF POLYMER

Polymer was available in dry state, as off-white crystals. In an attempt to study the morphology of the polymer, scanning electron microscope (S.E.M.) and energy-dispersive X-ray spectroscopy (E.D.X.) tests were performed in the Nano-Technology laboratory of Delhi Technological University.

A scanning electron microscope produces images of a sample by scanning it with a focused beam of electron. It includes signals obtained from secondary electrons and back-scattered electrons i.e. when electron beam strikes with atoms at or near surface of sample, they interact and produce signals revealing details even less than 1nm. Sample is placed on specimen stub and generally coated with ultrathin coating of electrically conducting material which includes gold or platinum. The coating provides a conductive medium as non conductive samples may get charge when scanned by electron beams causing scanning faults and other image artifacts. The samples are then placed in the testing machine where electron beam is thermionically emitted and results in the form of images are obtained.

Energy-dispersive X-ray spectroscopy (EDX) test helps in the chemical characterization of the sample. In this test high energy beam of electrons or beams of X-rays are focused into the sample. The incident beam may excite the electron in an inner shell, due to which it ejects out leaving an electron hole. This hole is then filled by the electron from higher energy outer shell and thus the difference in energy is released in the form of characteristic X-ray depending on the atomic structure of the sample. EDX thus measures the elemental composition of the specimen as the energies of the X-rays are characteristics of the difference in energy between two shells and depends on the atomic structure of the emitting electron.

3.3 RHEOLOGICAL PROPERTIES OF POLYMER FLUID

The polymer, available in the crystalline form, when mixed with water form long chains which increases the viscosity of water. From the literature review, it’s inferred that there is no upper limit to the viscosity of polymer fluid to be used as the drilling fluid and the density of the fluid should be kept low so that at the time of concreting, the fluid must rise without penetrating the concrete. Thus the rheological properties such as pH, density and viscosity of the fluid were measured to meet the secondary objectives of the project work to see the effect of polymer concentration, added silt, hypochlorite (bleach) etc.

The viscosity of the solutions has been measured as marsh-funnel viscosity of the samples i.e. the time taken, in seconds, by one liter solution up to a marked level to pass through the marsh-funnel, as shown in Fig.3.2 (a). The pH value of the solutions were noted using the electronic pH meter device, after neutralizing it in a buffer solution of pH value 7 and the density of the fluid solutions were measured using a calibrated hydrometer as shown in Fig.3.2 (b) and Fig.3.2 (c) respectively. The experimental work helped to find an optimum dosage of reactants for the polymer fluid, to be used as drilling fluid for the field work.

3.3.1 Effect of Polymer Concentration

As polymer was available in dry state, an optimum dosage was required to be known in order to form the drilling fluid. Polymer was added in different concentrations to check its effect on the viscosity, density and pH of the water. Marsh viscosity of the fluid should be enough to stabilize the soil without affecting the frictional resistance of the foundation.

In order to investigate the effect of polymer concentration, different concentrations of polymer ranging from 0.002% to 0.5 percent were added in a liter of water. To obtain lump free solution as well as for proper mixing a mechanical device called jar apparatus, as shown in Fig.3.2 (d), was used in which solutions were mixed for 30 min. at 250 rpm. The properties of the solution were determined after 2 hrs of the sample preparation.

Studying from the literature review, since there is no upper limit to the viscosity of polymer fluid, two suitable concentrations were selected i.e. a low concentration value (0.006%) and a high concentration (0.1%) value of the polymer to check the effect of other factors.

3.3.2 Effect of Increase in pH

These tests were performed to check the influence of change in pH of drilling fluid on its properties, so that fluid with desirable properties can be selected for the field experiment. Some of the journals have explained the phenomenon of breakdown and coiling of polymer i.e. when the pH value of the polymer fluid rises beyond a limit the long chain polymers may breakdown or may coil together, effecting the rheological properties of the fluid. During casting of pile foundation, drilling fluid comes in contact with different materials such as concrete, soil particles and various electrolytes present in water which may affect the pH of the system, thus making it more essential to find its effect.

(a) **(b)**

(c) **(d)**

Fig 3.2 Instruments used for experiments; (a) Marsh funnel apparatus (b) pH meter (c) Hydrometer (d) Jar apparatus for mixing

The polymer fluids of low and high concentrations were formed after mixing them for 30 min. at 250 rpm in jar apparatus and the rheological properties mentioned above were determined just after mixing these solutions. Solution of sodium hydroxide (NaOH) with normality of 6N (available in laboratory) was added in different concentrations (0.01%, 0.05%, 0.1%, and 0.5%), for increasing the pH of the drilling fluid, and the solutions were mixed again using the jar apparatus, for 30 min. at 250 rpm. To compare the changes in the Marsh viscosity, pH and density of the solutions, the values of these properties were again measured, instantly after the mixing of samples.

3.3.3 Effect of Passage of Time

Mineral slurries are thixotropic in nature and usually gains their strength with the passage of time, thus required to be stored before brought to use, but the effect of passage of time was still unknown for the polymer fluids. From the process of excavation till the time of concreting, polymer fluid must retain its properties for its efficient working as a borehole stabilizer, making essential to study this effect.

In this investigation low and high concentration polymers were added separately in 1.5 lt. of water and the solution were mixed for 30 min. at 250 rpm in the jar apparatus. The Marsh viscosity, pH and density of the prepared solutions were then measured after different time intervals from the time of mixing.

3.3.4 Effect of Addition of Silt Content

When excavation proceeds, there is a possibility that loose soil particles of soil may fall in the drilling fluid. The presence of silt or sand may affect the density of the fluid affecting the working condition. When concrete is poured using tremie, it is required to have low density drilling fluid, which should rise due to its light weight. Moreover silt if present in the suspension, may collect on the reinforcement; this may hinder the proper bonding between concrete and reinforcement.

It depend on the properties of the drilling fluid whether the soil particles will remain in suspension or will get settle down. In this investigation, polymer fluids with 0.006% and 0.1% concentration of polymers were formed, in two separate jars each, after mixing the solutions using jar apparatus. The initial properties of the fluid were determined. Thereafter, 5% silt content was added in each one of the jars of 0.006% and 0.1% concentration of the polymer solutions and the solution were mixed again at the rate of 250 rpm for 30 min. The properties, Marsh viscosity, density and pH of the suspensions, instantly after mixing, were determined. The solutions were then kept stable for 2 h and the properties of top fluid were determined again.

3.3.5 Effect of Bleaching Powder (Hypochlorite)

One of the major concerns for the world is environment protection. Many countries have posed regulations on the disposal of wastes in landfills as well as in running waters. Thus the drilling fluid must be selected such that it should possess no harm to the environment.

Fig. 3.3: Effect of bleaching powder (hypochlorite)

Very low concentrations of polymer forms highly viscous solutions and can be reused several times. Researchers have shown that when hypochlorite (bleach) is added in the fluid, it reacts with the long chain polymers to form colloidal particles which thereafter settle down because of low density of the fluid. Before final disposal, these settled solids can be removed, and thus waste can be disposed of easily.

Polymer fluid with low concentration of polymer were formed by mixing them for 30 min. using the jar apparatus and after mixing bleaching powder was added in different concentrations (0.01%, 0.05% and 0.1%) and the solutions were again mixed for 30 min. at 250 rpm. The samples were then placed untouched for 2 hrs as shown in Fig 3.6 and thereafter the Marsh viscosity, pH and density of the top fluid were determined, as the bleach had coagulated the polymers which were settled in the jar.

CHAPTER – 4

LABORATORY EXPERIMENTS AND THEORETICAL ANALYSIS

4.1 SOIL PROPERTIES

The excavated soil from a site in Noida region was used as the foundation soil to perform the field experiments and laboratory experiments. The frictional resistance offered by the foundations depends on the surrounding soil properties such as maximum dry density, optimum moisture content, specific gravity and its gradation. To determine these properties following tests were performed:

4.1.1 Specific Gravity

The specific gravity of the soil solids is defined as the ratio of mass of a given volume of solids to the mass of an equal volume of water as given in Eq. (4.1). The value of specific gravity was determined using a pycnometer [21].

$$G = \frac{(M_2 - M_1)}{((M_2 - M_1) - (M_3 - M_4))} \quad \text{... Eq. 4.1}$$

Where, M_1 = Weight of empty pycnometer bottle

M_2 = Weight of pycnometer + soil sample

M_3 = Weight of pycnometer + soil sample + water

M_4 = Weight of pycnometer + water

Table 4.1: Calculation of specific gravity

	Sample 1	**Sample 2**	**Sample 3**
M_1 (g)	696.50	697.03	697.10
M_2 (g)	896.45	896.90	897.18
M_3 (g)	1690.82	1689.73	1689.88
M_4 (g)	1565.20	1565.00	1565.09
G	2.69	2.659	2.654
G_{avg}	$\frac{2.69 + 2.659 + 2.654}{3} = 2.67$		

The value of the specific gravity of the soil tested is taken as average value of the three samples i.e. **G = 2.67.**

4.1.2 Sieve Analysis

Dry sieve analysis method was used for the gradation of soil sample by sieving the samples. According to Indian standard [22], sieves of size 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.425mm, 0.212mm, 0.15mm, 0.075mm and pan were arranged in decreasing order. Dry soil, weighing 1kg was poured on top sieve and the arrangement was vibrated. The mass of soil retained on each sieve was recorded and were used to calculate the percentage finer. A semi-log graph was then prepared between the percentage finer and the sieve size (on log scale) and the value of coefficient of curvature (C_C) and coefficient of uniformity (C_U) were calculated using the Eq. 4.2 and Eq. 4.3.

$$C_C = \frac{D_{30}^2}{D_{10} \times D_{60}} \quad \text{Eq. 4.2}$$

$$C_U = \frac{D_{60}}{D_{10}} \quad \text{Eq. 4.3}$$

Where, D_{10} = particle size such that 10 % of sample is finer

D_{30} = particle size such that 30 % of sample is finer

D_{60} = particle size such that 60 % of sample is finer

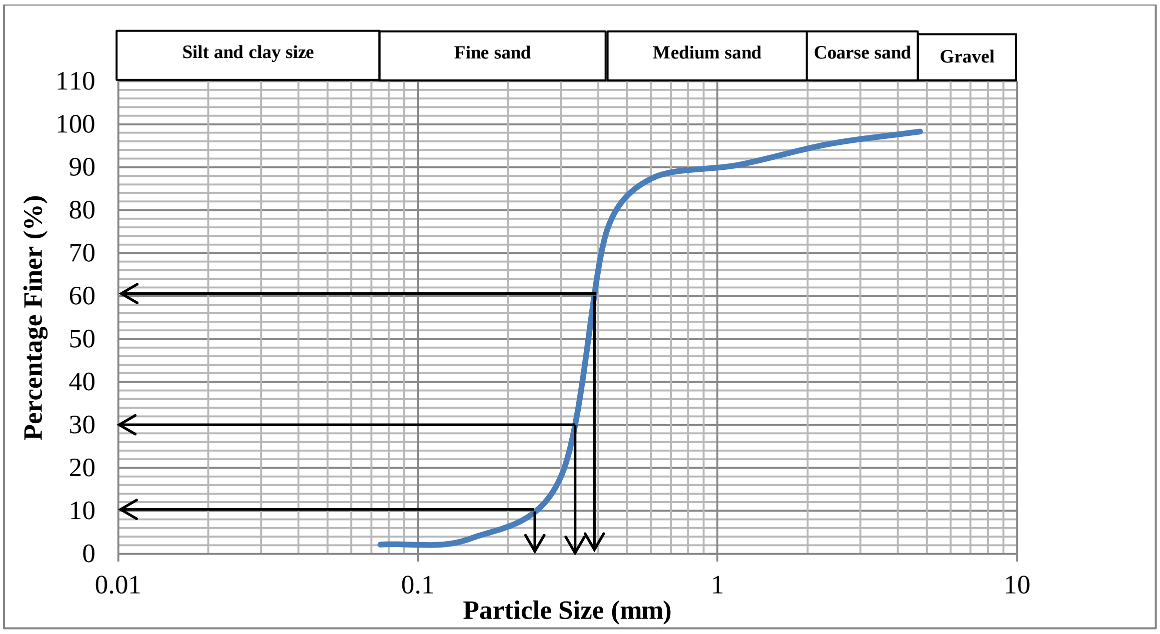


Fig. 4.1 Grain size distribution curve

Table 4.2: Result Data for Sieve Analysis

(1)	(2)	(3)	(4)	(5)
Sieve size (mm)	**Mass retained (g)**	**% Mass retained (3)= ((2)/1000) x100**	**Cumulative % retained**	**% Finer (N) (5) = 100 - (4)**
4.75	17.06	1.706	1.706	98.294
2.36	28.96	2.896	4.602	95.398
1.18	48.44	4.844	9.446	90.554
0.600	32.53	3.253	12.699	87.301
0.425	126.95	12.695	25.394	74.606
0.300	567.33	56.733	82.127	17.873
0.150	143.32	14.332	96.459	3.541
0.075	14.08	1.408	97.867	2.133
Pan	21.34	2.134	100	-

From the semi-log graph plotted between percentage finer and sieve size (on log scale), the value of D_{10}= 0.25 mm, D_{30}= 0.34 mm, D_{60}= 0.39 mm, thus the corresponding value of C_C and C_U are 1.19 and 1.56 respectively. The soil is coarse grained soil as more than 50% particles are retained on 75µ IS sieve and more than 50% particles are passing through 4.75 mm IS sieve, the soil is characterize as sandy soil. As per Indian standard, IS1498:1970, based upon the C_c and C_u value soil is classified as poorly graded sand i.e. SP.

4.1.3 Proctor Compaction Test

Optimum moisture content is the water content at which soil achieves the state of having maximum dry density. The modified Proctor's compaction test was used to determine the maximum dry unit weight of the soil sample corresponding to the optimum moisture content. The dry soil sample was mixed with increasing water content and was compacted each time in a standard mold in five layers, imparting 56 blows with standard hammer. Each time the weight of the mold (with compacted soil) was recorded and the corresponding water content was obtained to plot the compaction curve between dry density and water content. Fig. 4.2 shows the compaction curve of soil to use for experimental purpose giving the maximum dry density and the optimum water content of 18.38 kN/m^3 and 11.8% respectively.

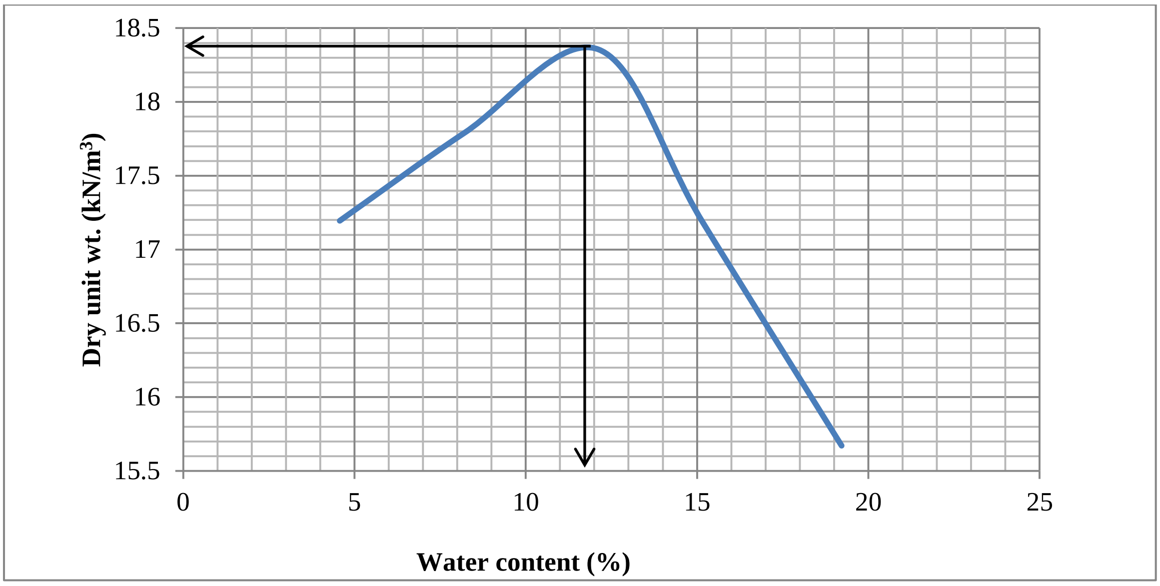


Fig. 4.2 Graph of compaction curve

4.1.4 Direct Shear Test

The shear strength of soil depends on its internal angle of friction (ϕ) and cohesion value (c). Direct shear test[24] was used to find these parameters, in which the maximum horizontal load, that a soil can resist without failure, was found corresponding to the different normal stresses of 50 kN/m^3, 100 kN/m^3 and 150 kN/m^3. The horizontal displacement corresponding to different shear force is noted and curves are plotted for different normal loadings as shown in Fig 4.3. The curve provides the maximum shear force at which the soil sample failed and the corresponding shear stress is calculated.

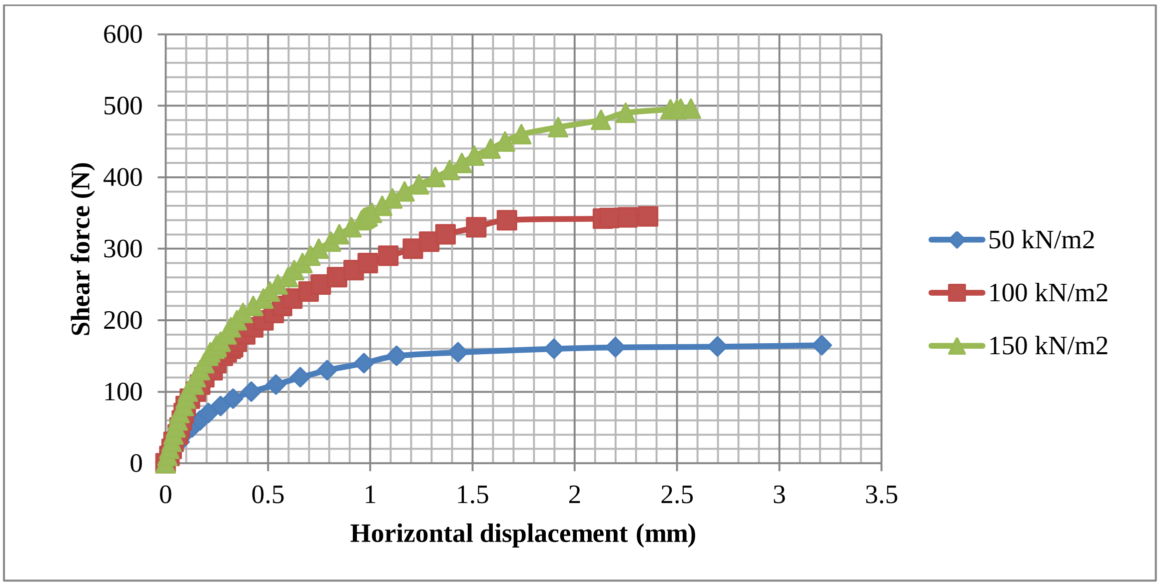


Fig. 4.3 Shear force vs. horizontal displacement curve for different loading conditions

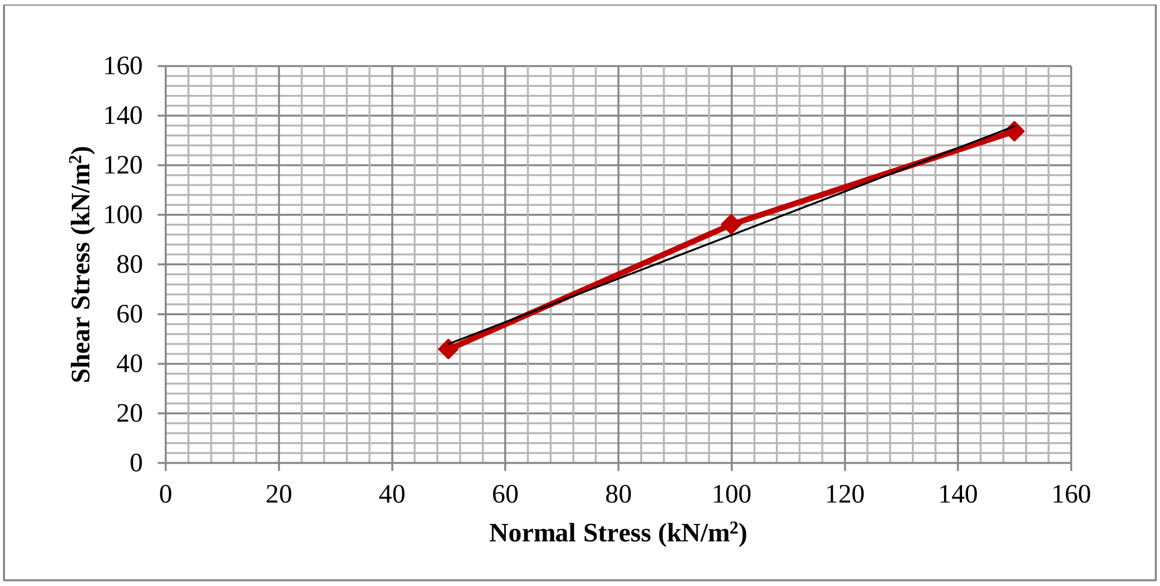


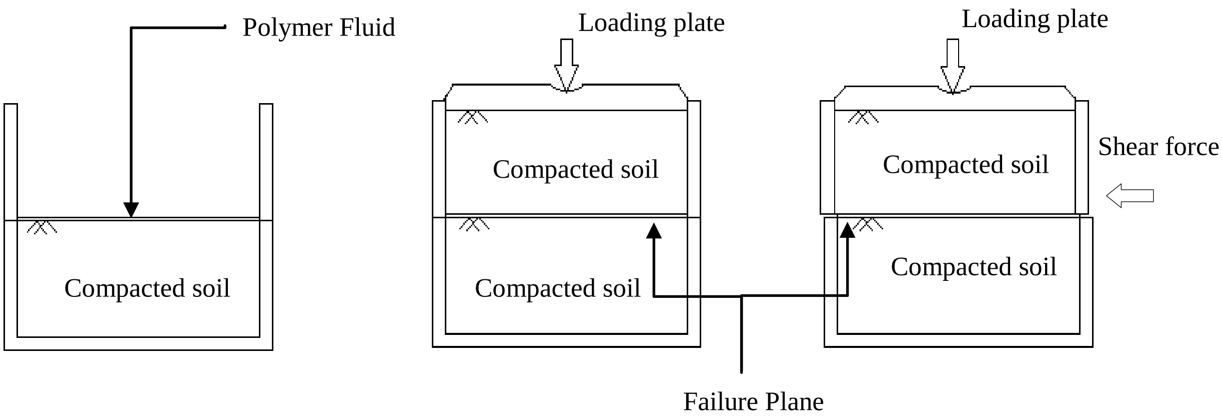
Fig. 4.4 Shear stress versus normal stress curve

These shear stress values corresponding to respective normal stress were plot as shown in Fig. 4.4 and the slope of the curve gave the value of internal angle of friction (ϕ) and its intercept giving the cohesion value (c). The cohesion value 'c' and angle of internal friction 'ϕ' are obtained from the plot of shear stress versus normal stress curve of the given soil are c = 4.07 kN/m^2 and ϕ = 41.28°.

4.2 EFFECT OF POLYMER FLUID ON FRICTIONAL RESISTANCE OF SOIL

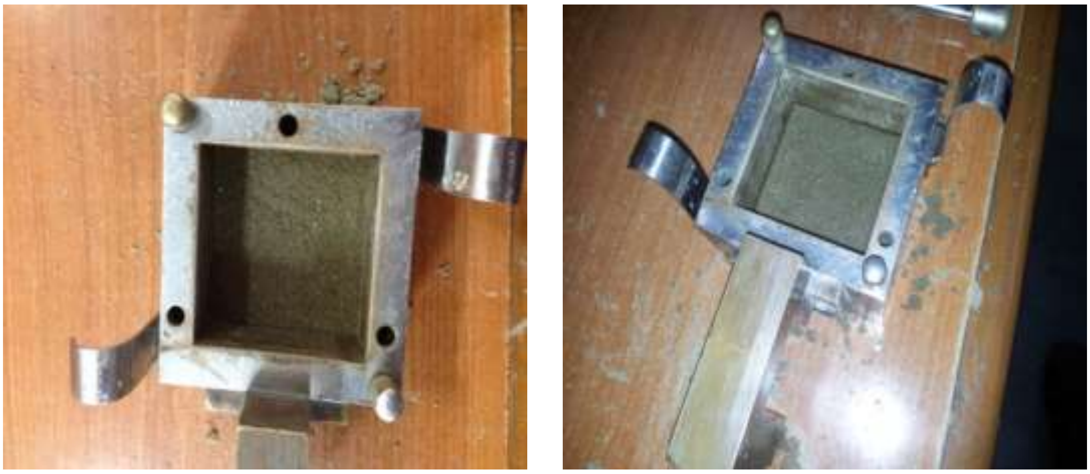
Frictional resistance of soil is the resistance offered by soil-soil particles on application of shear load. Direct shear test, used to determine the internal angle of friction and cohesion value soil, was used to compute the effect of polymer fluid on frictional resistance of soil as it consists of a predefined failure plane.

The direct shear test, mould comprises of two halves, lower and upper half, which on application of horizontal force causes these two halves to move relative to each other. As the soil is sheared along this predefined failure plane, than the horizontal force gives the frictional value between the soil particles around the failure plane. A layer of polymer fluid was placed on this plane and the maximum horizontal load thus corresponds to the friction between soil particles and polymer molecules around that plane. Fig 4.5 shows the schematic diagram of direct shear test performed in the laboratory to determine the effect of polymer fluid on the frictional resistance of soil.



(a) (b) (c)

Fig. 4.5 Sketch diagram showing the arrangement of direct shear mould (a) layer of polymer fluid placed on compacted soil in the lower half of the mould; (b) placement of soil in the upper half of the mould; (c) shear force application.



(a) (b)

Fig. 4.6 Lower part of direct shear mould with layer of polymer fluid (a) just after placement of fluid; (b) sample after 30 min. of placement of polymer fluid.

4.2.1 Sample Preparation

As in the direct shear test, we have a pre-failure plane, the polymer slurries with different polymer concentrations were added and the normal and shear stress values were plotted to obtain the changes in the c-ϕ value of soil. The dry soil was mixed with water at its optimum moisture content (11.8%) and was compacted in the lower part of the direct shear mould. Polymer slurry of 10ml volume was poured evenly and mould was kept for 30 min as shown in Fig 4.6. Thereafter the soil was compacted in the upper half of the direct shear mould and was weighed to obtain the bulk unit weight of the compacted soil. Horizontal load was then applied to obtain maximum shear stress values corresponding to different normal loadings. The same procedure was adopted to see the effect of different polymer concentrations by compacting the soil at same bulk unit weight.

4.2.2 Shear Stress Determination

After the preparation of sample, the mould were placed in direct shear testing machine and normal loads were applied through a static weight hanger and the soil was sheared gradually by applying horizontal force. Each sample was tested for three normal stresses i.e. $50kN/m^2$, $100kN/m^2$ and $150kN/m^2$ and maximum horizontal load were computed. These loads were converted to corresponding shear stresses, to plot a graph shear stress and normal stress.

4.3 THEORETICAL ANALYSIS

The uplift capacity of the pile gives the frictional resistance offered by the pile shaft in order to resist load. Many researchers have given their theories to predict the uplift capacities of pile foundations. Meyerhof et .al. (1986) found the net uplift capacity of the bored piles and based on the assumptions that they have taken with regard to the shape and extent of the failure surface validated through experimental measurements have given a theory. This theory differs from the theory of Chattopadhyay and Pise (1986) as they assumed a curved failure surface within the soil [3]. Indian standard [27], as well as Nabil F. Ismael[16] have given their equations suggesting that the net uplift capacity of the foundation is the sum of skin frictional resistance of pile shaft and the self weight of the pile.

These different theories were therefore used to determine theoretically the uplift capacity of bored cast in-situ concrete pile, to be casted for field experiments (length of the pile and diameter of pile being 0.35m and 0.045m respectively). Since from the results of direct shear test it was computed that polymer layer when comes in contact with soil particles affects their internal angle of friction (effecting the frictional resistance of soil) thus for the theoretical analysis, the internal angle of friction of soil was taken equivalent to angle of friction between soil particles and polymer layer as computed from the direct shear tests. The unit weight of soil was taken equal to 15.85 kN/m^3 i.e. unit of foundation soil (equal to unit weight of soil in direct shear tests).

4.3.1 Meyerhof's Method

Meyerhof suggested an expression for the pull-out resistance of pile (P_u), as given in Eq.4.4, ignoring the self weight of the pile. The uplift coefficient varies from 0.5 to 1 depending upon the various factors such as soil properties, type of pile and method of installation.

$$Q_u = 0.5K_u p\gamma L^2 \tan\delta \qquad \text{Eq. 4.4}$$

Where, p = perimeter of the shaft.

ϒ = unit weight of the soil

L = length of the pile

δ = soil - pile friction angle

K_u = uplift coefficient and can vary with in 0.5 to 1 depending on soil properties, type of pile and method of installation[Lindgren1973].

4.3.2 Nabil F. Ismael's Method

This method is based on an assumption that the lateral earth pressure increases linearly over the length of the pile. The uplift capacity (Q_u) can be obtained using Eq.4.5

$$Q_u = 0.5\,\gamma L^2 \pi\, D\, K_u\, tan\,\phi + W_p \qquad \text{Eq. 4.5}$$

Where, ϒ = unit weight of the soil

L = length of the pile

D = diameter of the pile

W_p = weight of the pile

K_u = coefficient of lateral earth pressure in uplift depends on SPT value [16]

4.3.3 Indian Standard Code Method

According to Indian standard, IS, the net uplift capacity of a pile is given as sum of the frictional resistance offered by pile and the self-weight of the pile. The uplift capacity of pile, given in Eq.4.6, can be obtained from static formula by ignoring end-bearing term and adding weight of the pile as follows,

$$Q_u = \sum K\, P_D \tan\delta\, A_s + W_p \qquad \text{Eq. 4.6}$$

Where, P_D = effective overburden pressure at pile tip

A_s = surface area of the pile shaft

δ = soil - pile friction angle obtained by taking δ equal to ϕ values

K = coefficient of earth pressure, depends on the nature of soil strata, type of pile and method of construction. For driven piles in loose to dense sand with ϕ between 30° and 40°, K values is varying from 1 to 1.5 [27].

4.3.4 Kulhawy et al. Method

The uplift capacity of a pile is given by the following equation with $K_o = \cos^2\phi$ [19]

$$Q_u = 0.5 K_o p \gamma L^2 \tan\delta \qquad \text{Eq. 4.7}$$

These theories were used to calculate the theoretical uplift capacity of model concrete pile and the prototype concrete pile. The maximum theoretical uplift capacity value, among all the different cases calculated from all the mentioned theories, was used the selection of suitable rope and pulley so that they can possess enough breaking strength and bear the load during the pull out test. Moreover, the theoretical results from the theories, were used to find frictional resistance for the prototype pile, which was compared with the calculated frictional resistance, obtained for these pile, from experimental results.

CHAPTER – 5

PHYSICAL MODELING & FIELD EXPERIMENT

5.1 EXPERIMENTAL PROGRAM

Effect of polymer fluid, used as a borehole stabilizer, on the frictional resistance of soil-concrete interface was determined by performing a field test. Three bored cast in-situ concrete piles were casted, one without using drilling fluid and the other two using two different concentrations of polymer fluid, in a steel tank and the 7 days uplift capacity of these piles was computed by performing pull out test. The uplift capacity of the pile casted without using polymer fluid, gives the frictional resistance between soil particles and concrete surface.

When the drilling fluid was added, it formed a layer on the inside wall of excavated soil and as the pile was casted a soil-polymer-concrete interface was obtained. The uplift capacity of these piles thus depicts the friction offered by the polymer layer when placed between soil and concrete layer. In order to fulfill the objectives of the project work, experiments were performed by selecting suitable instruments. The setup and procedure for the experiment work, adopted, is as mentioned below:

5.1.1 Steel Tank

The experiments were performed in a steel tank, located behind the concrete laboratory of Delhi Technological University, which is 1.5 m in length, 0.90 m wide and 0.60m deep. The steel tank was suitable, as for performing the pull out test; a steel girder was already resting above it on the ground surface consisting of two hooks where pulley system was easily clamped. Also the tank size was more than 2.5 times the diameter of pile[23], so that the effect of edges of the tank should not lie in the zone of influence of pile due to loading.

5.1.2 Measuring Device

The displacement of the pile top with respect to loading was recorded using a dial gauge, with 0.01mm accuracy, which was placed at surface of bored cast in situ pile. The dial gauge was fixed with the girder using a magnetic stand. The dead loads of known weight were placed on the loading pan and the corresponding displacement was recorded to plot load versus settlement curve.

5.1.3 Equipments

For a proper setup of experimental program, different equipments were used, to obtain the best results. The following equipments, as listed in Table 5.1, were used to ensure proper compaction of soil, horizontal level of soil, verticality of piles.

Table 5.1: Various equipments used for experiment setup

Equipment	Quantity	Specification
Steel Hammer	2	Weighing 11.5 kg each
Weighing Machine	1	For weighing soil
Cement	1	43 grade OPC
Spirit Level	1	Horizontal as well as vertical
Measuring tape	1	For marking distances
Pulley	2	To carry out pull out test
String	1	To connect pile and loading pan
Loading Pan	1	To apply dead load
Hollow PVC pipe	1	Used as casing

5.1.4 Concrete Mix

The concrete mix, for the casting of pile, was formed as per Indian standard[26], to obtain a compressive strength of 40MPa i.e. M40 grade of concrete. The cubes were tested after 7 and 28 days, and their strength was above 40MPa but the mix was not workable enough to cast pile of 4.5cm diameter as the size of the aggregate were large enough to be placed.

In order to form a concrete mix having good strength as well workable enough to cast the pile, cement and sand (stone dust) ratio of 1:2.5 and water-cement ratio of 0.45 was selected and 5% silica flume was added, as it is used to enhance the strength of the concrete. The average strength of cubes after 7 days and 28 days of casting was found to be 17.1MPa and 28MPa.

5.2 PILE MODELLING

The length and diameter of the pile, 0.35m and 0.045m respectively, for model concrete pile, were selected such that the effect of the edges of the tank should not lie in the zone of influence of pile due to loading.

(a) **(b)**

Fig. 5.1 (a) Concrete cubes casted to compute 7 days and 28 days strength of the concrete mix; (b) unconfined compression test of cube

The corresponding length and diameter of prototype concrete pile, for a scale 1:15, becomes 5.25m and 0.675m respectively.

5.3 DESIGN OF PULLEY

The uplift capacity of the piles was determined by conducting pull-out tests using a pulley system. The size of the string and the pulley were selected such that they should bear enough load. The theoretical analysis of model pile has given a maximum uplift capacity of 0.266 kN. This load was increased by a factor of safety of 3, and the design load was taken as 0.80 kN.

5.3.1 Wire Rope Calculation

The rope must have enough breaking strength so that it should not break in tension during the application of load. The required breaking strength of the rope was calculated as:

Load on rope = 0.80 kN

Factor of safety = Zp*Cdf = 3.5*1.5 = 5.25 (as per IS: 3177/1999, cl: 8.3.2)

Number of falls = 2

Type of bearing = Roller bearing

Efficiency of bearing = 0.98

Hence, load (L) on each fall of wire rope with consideration of pulley efficiencies,

$$L = \frac{0.80}{2} \times \frac{1 - 0.98}{1 - 0.98^2} = 0.20\ kN$$

Where, 0.98 is the pulley efficiency.

The required breaking strength of the rope = 0.20*5.25 kN = 1.05 kN (i.e. 107 kg)

Thus, a wire rope of suitable strength and diameter were selected to perform the pull-out test.

5.3.2 Equilizing Pulley Calculation

As per Indian standard, IS: 3177/1999, cl: 8.5.2 [25], the required root diameter (R_d) of equalizing pulley can be calculated as

Rd = 8* diameter of rope * Cdf

Rd = 8 * 3 * 1.5 mm = 36 mm i.e. 0.036 m

Therefore, two standard pulleys with root diameter of 4cm i.e. 0.04 m were selected for the experimental tests.

5.3 SCHEMATIC DIAGRAM

The sketch diagram of the experimental setup, shown in Fig 5.2 and Fig 5.3 represents a typical plan of the steel tank with concrete pile and the overall setup for the pull out test respectively.

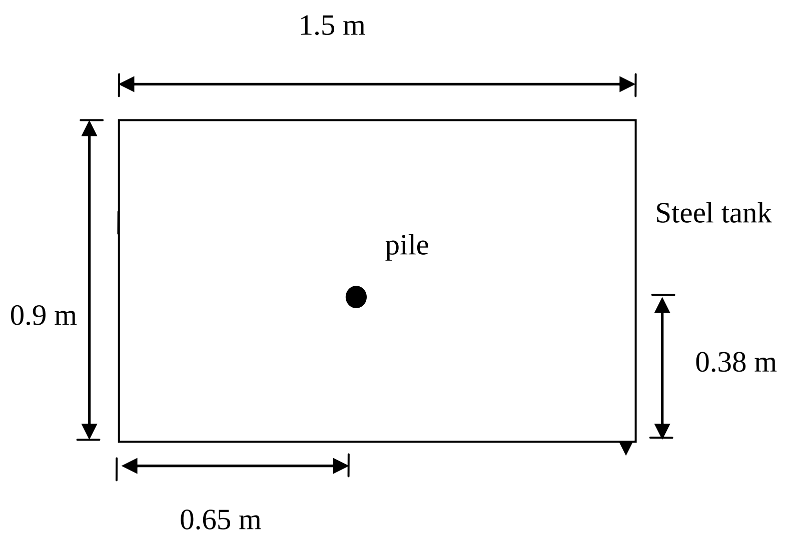
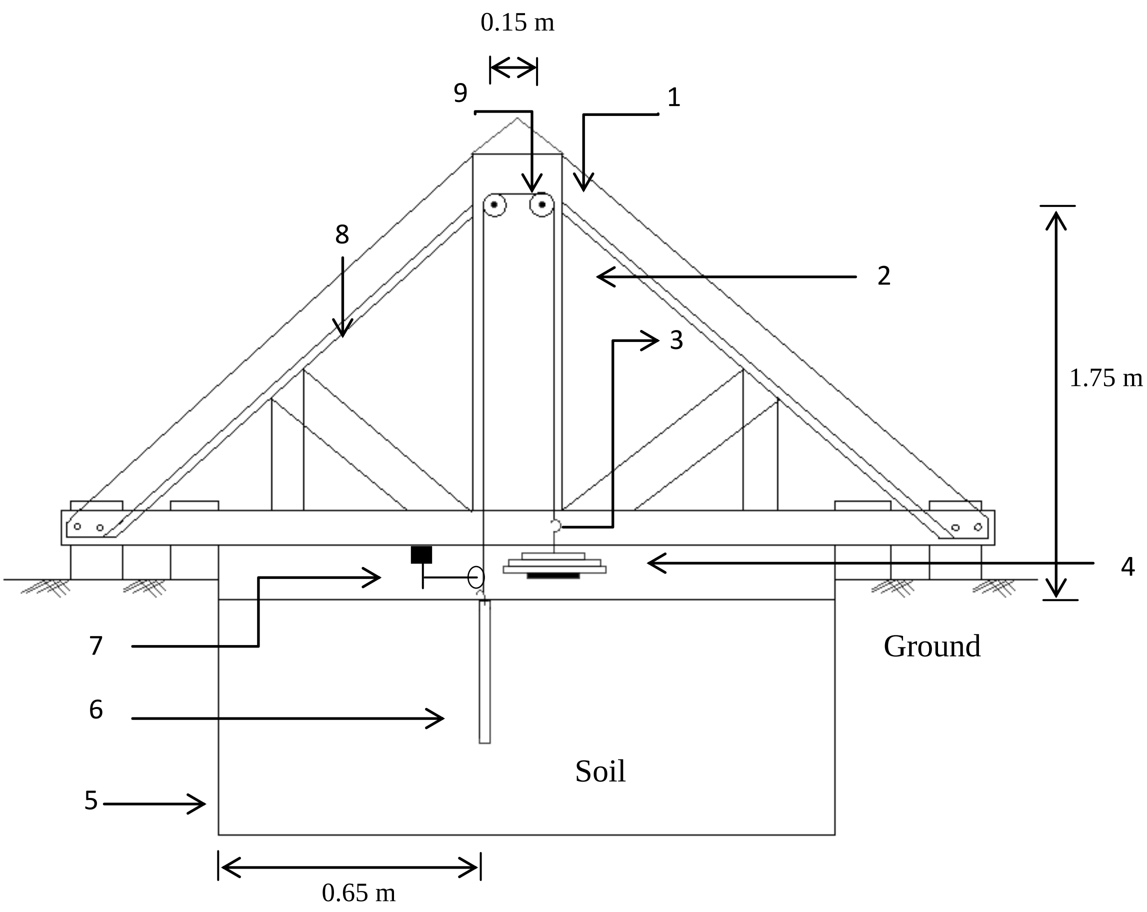


Fig. 5.2 Typical plan view of steel tank with casted concrete pile



Legends

1. Pulley 1
2. String
3. Loading pan
4. Dead weight
5. Steel tank
6. Bored cast in-situ concrete pile
7. Dial Gauge with magnetic stand
8. Girder
9. Pulley 2

Fig.5.3 Experimental setup

5.4 EXPERIMENTAL PROCEDURE

After the selection of steel tank, measuring devices and suitable pulley system the soil, to be used as foundation soil was compacted and the piles were casted following the procedure described below:

a) From the bottom of the steel tank, different levels at a vertical distance of 15cm, 30cm, 45cm and 55cm, were marked inside the tank surface.

b) Soil, was weighed using weighing machine, and was compacted in layers, using heavy steel hammers, up to different marked levels to obtain an overall bulk unit weight of 15.85 kN/m^3 i.e. bulk density of 1.61 g/cc.

c) The horizontal level of the top surface of the foundation soil (55cm) was checked using a spirit level. Once the top surface was leveled, markings were made, using the measuring tape.

d) Pulley system was then clamped using bolts and the string was placed along with the loading pan for centering such that centre of the required casted pile should lie vertically below the string (no eccentricity should be their).

e) For the first case, where pile was casted without any fluid interface, a borehole was excavated by hammering the pvc pipe into the soil, taking care of its verticality and center, using the leveler and the soil collected inside the pipe was taken out and emptied.

f) Concrete mix, with cement and sand (stone dust) ratio of 1:2.5 and water-cement ratio of 0.45 with 5% silica flume, giving a compressive strength of 17.1MPa after 7 days, was used to cast the pile. Concrete was tamped using a steel rod during its placement to avoid the voids. As concreting was done a hook was fixed at the top of the pile, to which the string needs to be attached after 7 days.

g) The load was applied and displacement was recorded after 2-3 min of each loading until there was no change in the observed readings.

h) The displacement readings were noted until; the pile was pulled out i.e. failed.

(a) (b)

(c) (d)

Fig.5.4 Experimental program; (a) compaction of foundation soil (b) concreting of pile without drilling fluid (c) drillling fluid poured to produce a layer of polymer fluid (d) typical pull out test setup.

i) For the other two cases, where drilling fluid was used, the foundation soil was disturbed and compacted again.

j) After the excavation of borehole, the polymer fluid with polymer concentration of 0.006% and 0.1% were poured to fill the top level of the excavated borehole, for their respective cases, and kept undisturbed for 2 hrs.

k) A layer of polymer fluid, stabilizing the soil particles, was formed on the inside wall of the excavation and using above mention procedure concreting was done.

l) The pull out test was performed after 7 days of pile casting to obtain a curve between load and displacement for the uplift capacities of piles.

CHAPTER – 6

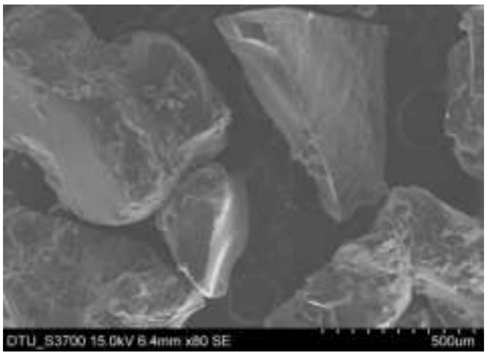
RESULTS & DISCUSSION

6.1 CHARACTERISTICS OF POLYMER CRYSTAL

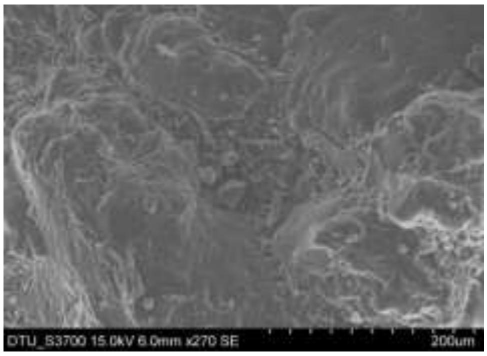
The results obtained from scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), performed to obtain the morphology and chemical characterization of the polymer crystals, were:

6.1.1 Scanning Electron Microscope (SEM)

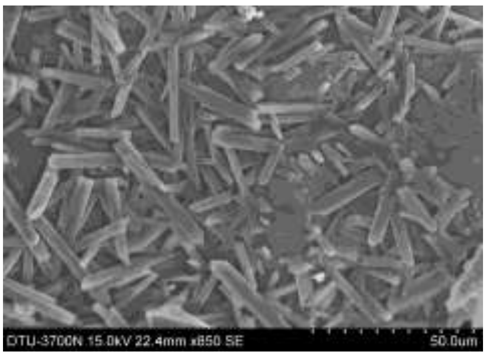
The images obtained from scanning electron microscopy, shown in Fig. 6.1, describes the morphology of the polymer crystals. Fig.6.1(a) was taken at 500μm scale, shows the particles of polymer sample. It shows the crystals of polymer sample separated by voids. The top surface of the polymer crystals, shown in Fig.6.1(b), taken at the scale of 200μm suggests occurrence of reactions due to presence of atmospheric moisture. Fig.6.1(c) shows that the crystals of polymer were composed of this rod like structures.



(a)



(b)



(c)

Fig. 6.1 Morphology of polymer sample with images at (a) 500μm (b) 200μm (c) 50μm

6.1.2 Energy Dispersive X-ray Spectroscopy (EDX)

The chemical characterization of the polymer crystals as shown in Table 6.1, suggests the presence of sodium cation along with oxygen. The spectrum of the polymer crystals obtained from the EDX test, as in Fig. 6.2, shows the peaks of oxygen and sodium elements.

6.2 RHEOLOGICAL PROPERTIES OF POLYMER FLUID

The experimental tests were conducted to determine the rheological properties such as viscosity, pH and density of polymer fluid with different concentrations of polymer and the results obtained from the tests on effect of pH, time, silt content and bleach on the properties of drilling fluid given in this section

Table 6.1: Quantitative results obtained from EDX

Element Line	*Net Counts*	*Int. Cps/nA*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*	*Formula*	*Standard Name*
O K	334	---	65.38	+/- 9.20	73.07	+/-10.28	O	
Na K	185	---	34.62	+/- 5.61	26.93	+/- 4.37	Na	
Total			100.00		100.00			

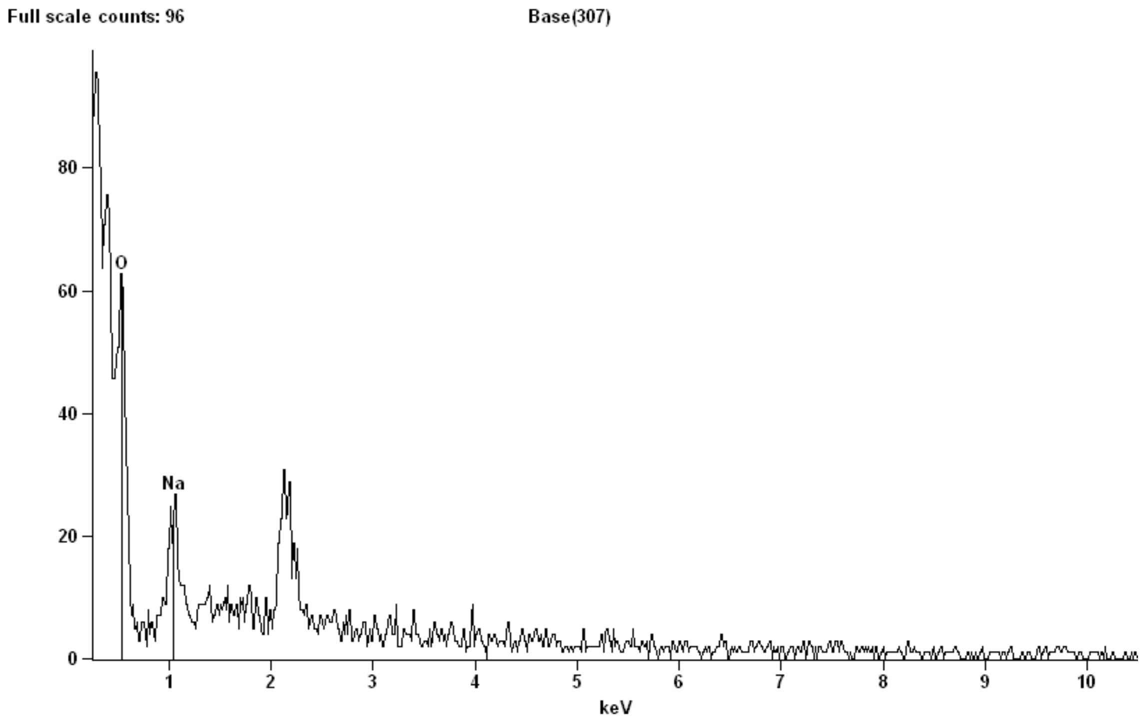


Fig. 6.2 Spectrum of polymer crystal

6.2.1 Effect of Polymer Concentration

The result tabulated in Table 6.2, were obtained from the experimental work to check the effect of increase in polymer concentration in water sample. The density of fluid with increase in the polymer concentration remained constant, i.e. unity, equal to that of water. Fig 6.3 shows the variation of Marsh viscosity of the fluid with the increment in polymer concentration. It can be observed that as polymer concentration increases, the viscosity increases with the change being more effective for higher concentrations. The variation in pH of fluid although increased with addition of polymer, as shown in Fig. 6.4, but has not shown significant effect with increase in polymer concentration. This viscosity of the fluid increases, may be due to presence of functional groups in the polymer which has the ability to form long chains of hydrocarbons.

6.2.2 Effect of Increase in pH

The pH of the fluid was increased by adding different concentrations of sodium hydroxide (NaOH) solution. Table 6.3, shows the result obtained from the test of this effect on low concentration (0.006%) and high concentration (0.1%) of polymer concentrations. The density of the fluid solutions was unaffected due to pH increment i.e. remained equal to unity and thus values have not been inserted.

Table 6.2 Effect of polymer concentration on fluid properties

Polymer(%)	Viscosity (s)	pH	Density (g/cm^3)
0	36.43	7.7	1
0.002	44.29	8.1	1
0.004	50	8.3	1
0.006	60	8.4	1
0.008	67.09	8.4	1
0.01	71	8.4	1
0.02	78.37	8.4	1
0.03	82	8.4	1
0.04	85.89	8.4	1
0.05	100.03	8.4	1
0.1	133	8.4	1
0.5	340.88	8.4	1

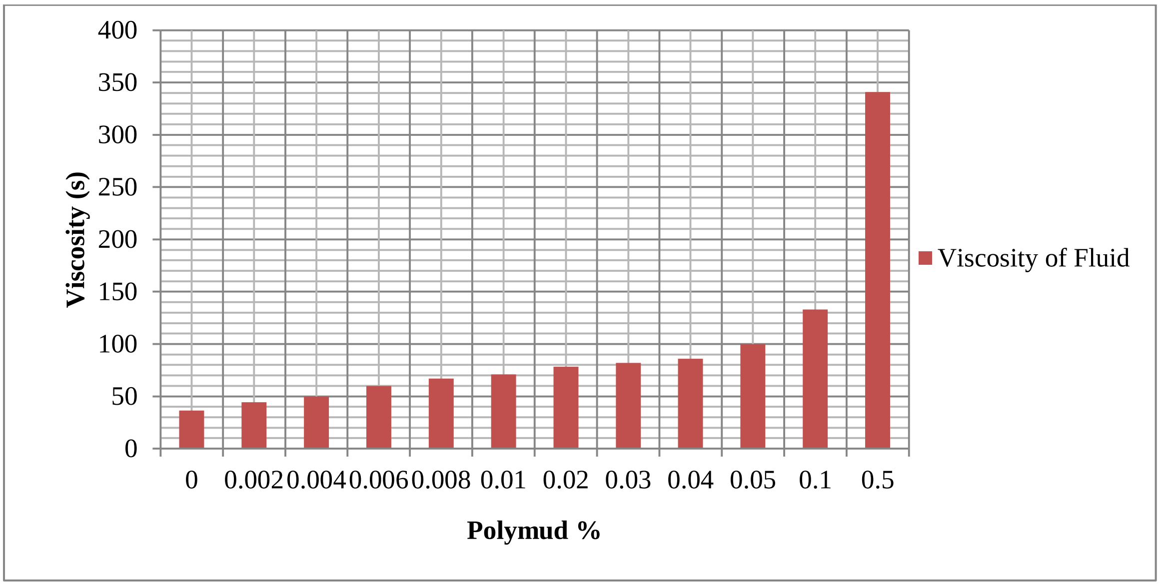


Fig. 6.3 Effect of polymer concentration on Marsh viscosity of fluid

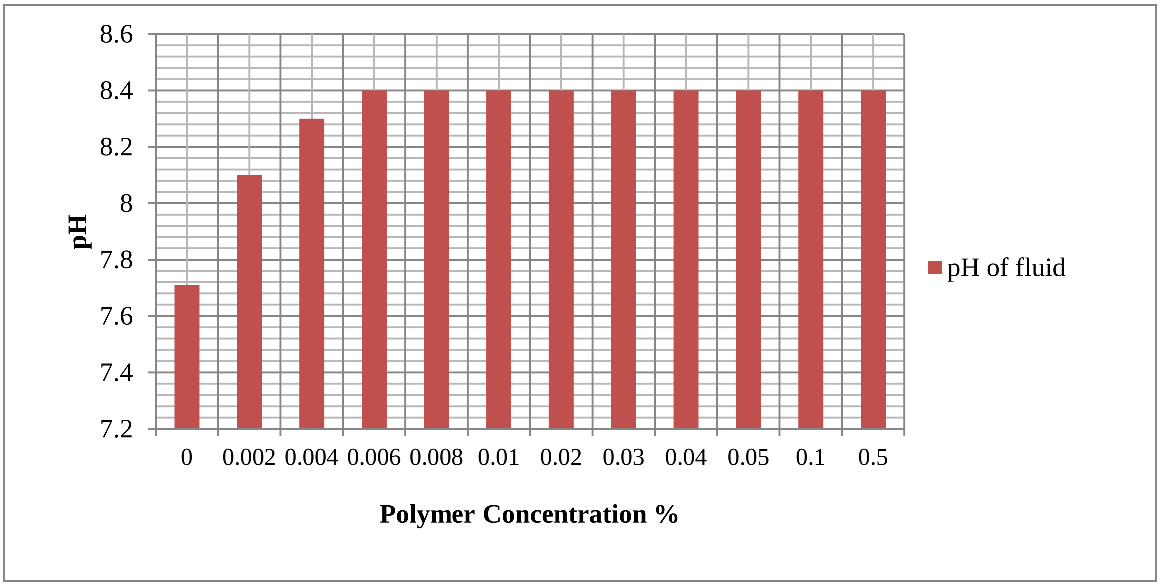


Fig. 6.4 Effect of polymer concentration on pH of fluid

Both, Fig. 6.5 and Fig. 6.6, shows an increment in Marsh viscosity of fluid up to a certain pH value and thereafter it started decreasing, for low concentration as well as high concentration of polymer, respectively. Fig. 6.7, compares the variation in Marsh viscosity of low and high concentration polymer fluids with the increase in sodium hydroxide concentration, added to increase the pH of solutions. It can be inferred from the results and literature, that as pH value of the system increases the long chains of polymer breakdowns thereby decreasing the viscosity of the fluid. Thus during concreting, presence of lime breaks the polymer layer and helps in maintaining the frictional resistance of pile.

Table 6.3 Effect of increase of pH on polymer fluid properties

Sodium Hydroxide NaOH (%)	Polymer Concentration 0.006%		Polymer Concentration 0.1%	
	pH	Viscosity (s)	pH	Viscosity (s)
0	8.3	60.39	8.4	123.46
0.01	8.8	64.24	8.9	157.19
0.05	9.9	69	9.7	160.38
0.1	10.6	68.01	10.2	153.38
0.5	12.1	64.61	11.9	152

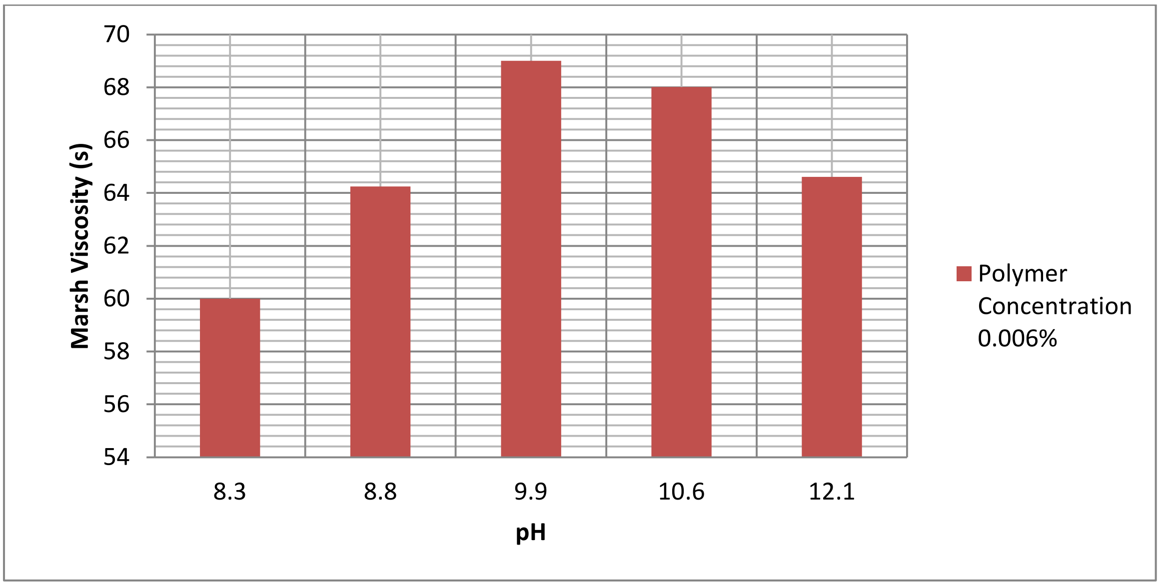


Fig. 6.5 Effect of pH on Marsh viscosity of fluid with low polymer concentration

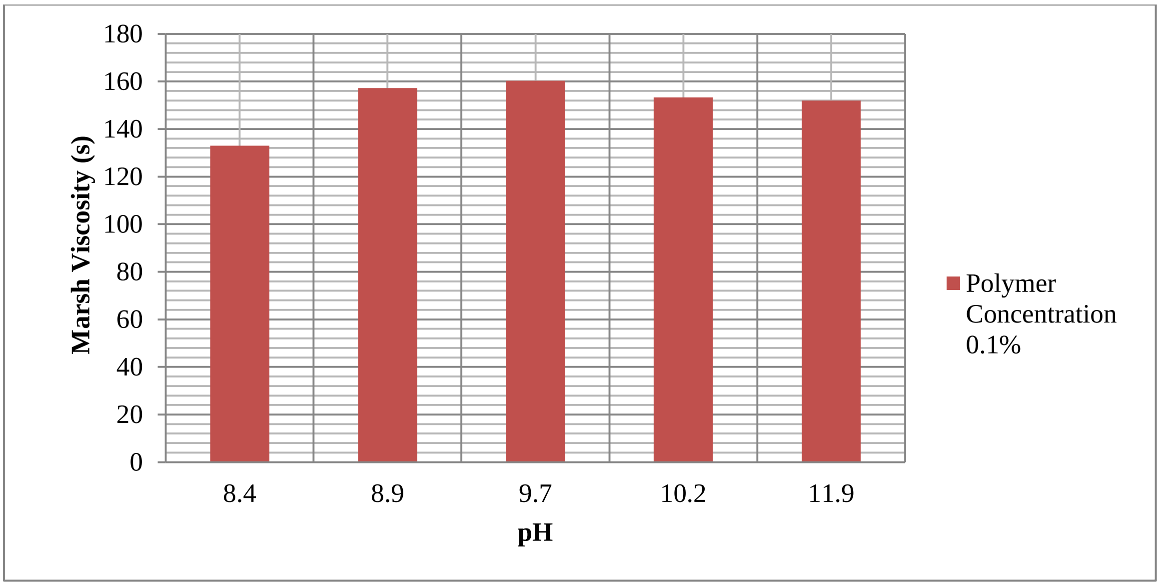


Fig. 6.6 Effect of pH on Marsh viscosity of fluid with high polymer concentration

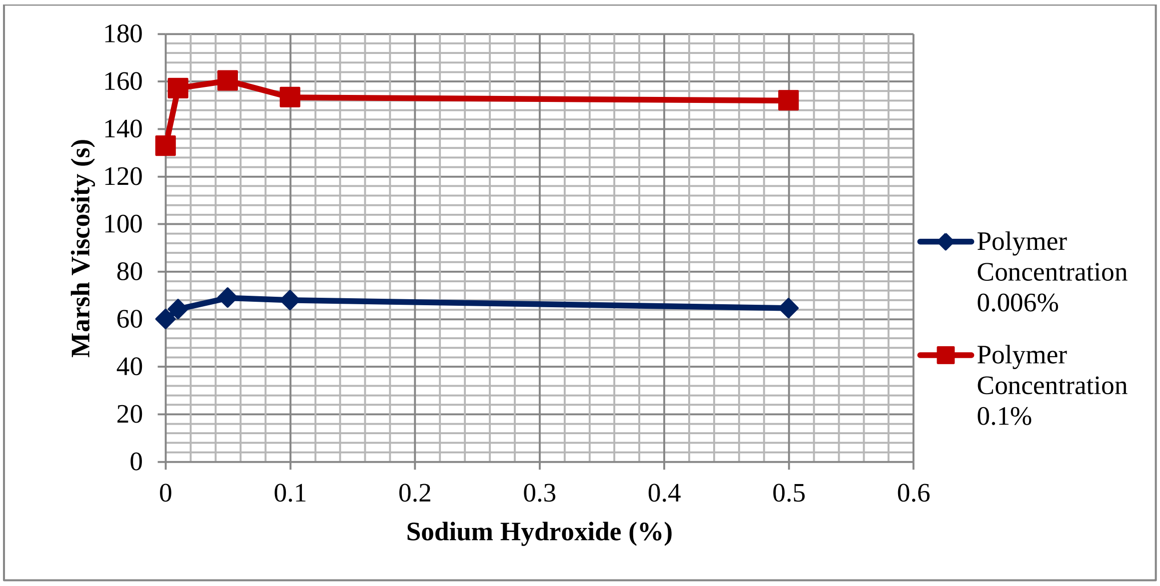


Fig. 6.7 Effect on Marsh viscosity of fluid with low and high concentration polymers with increase in sodium hydroxide (NaOH) concentration

6.2.3 Effect of Passage of Time

Table 6.4, shows the result obtained from this laboratory experiment. The density of the fluid remained constant with time and was equal to unity. Fig. 6.8 shows the effect of time on the Marsh viscosity of low and high concentration polymers. It can be observed that for low concentration fluid, the viscosity increases for the first two hrs after mixing and thereafter it decreases with time whereas for high concentration fluid there was a decreasing trend from the time of mixing. The decrease in active concentration of polymers may be one of the probable reasons for this trend.

Table 6.4 Effect of passage of time on polymer fluid properties

Time (h)	Polymer Concentration 0.006%		Polymer Concentration 0.1%	
	pH	Viscosity (s)	pH	Viscosity (s)
0	8.3	61	8.4	133
0.5	8.3	61	8.4	133
1	8.4	61.1	8.4	130.23
2	8.4	62.23	8.5	128.1
4	8.4	60	8.6	125
24	8.4	56.29	8.6	118.22
48	8.4	52	8.6	114.09

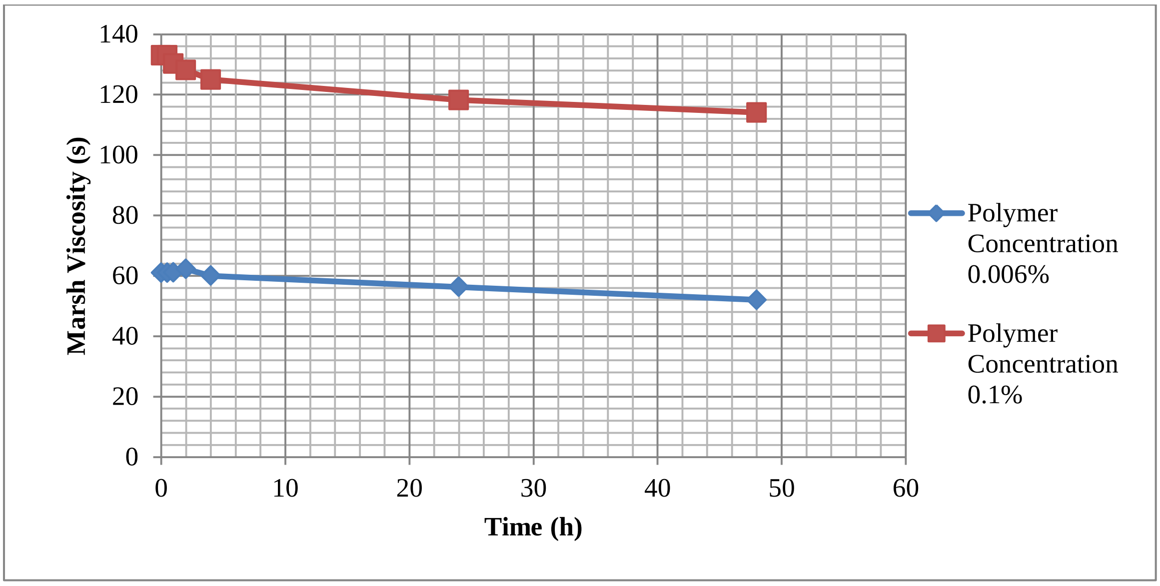


Fig. 6.8 Effect of passage of time on Marsh viscosity of fluid with low and high concentration polymers

6.2.4 Effect of Addition of Silt

When silt content was added in the polymer fluids, it affected their properties as tabulated in Table 6.5 and Table 6.6. The density of the fluid remained unaffected for all the cases.

Table 6.5 Effect of silt content on properties of low concentration polymer fluid

Time after mixing (h)	Silt content added (%)	Polymer Concentration 0.006%			Silt content added (%)	Polymer Concentration 0.006%		
		pH	Viscosity (s)	Density (g/cm^3)		pH	Viscosity (s)	Density (g/cm^3)
0	0	8.3	59.23	1	5	8.1	64.23	1
2	0	8.3	60	1	5	8.1	48.27	1

Table 6.6 Effect of silt content on properties of high concentration polymer fluid

Time after mixing (h)	Silt content added (%)	Polymer Concentration 0.1%			Silt content added (%)	Polymer Concentration 0.1%		
		pH	Viscosity (s)	Density (g/cm^3)		pH	Viscosity (s)	Density (g/cm^3)
0	0	8.4	134.09	1	5	8.1	144	1
2	0	8.5	132.06	1	5	8.1	123.28	1

Fig 6.9 and Fig. 6.10 compares the pH of the low concentration polymer fluid with time, on addition of silt content. It can be observed that the pH of the solutions decreased on addition of silt content in both low as well as high concentrations polymer fluids whereas the effect remain unchanged with time. The marsh viscosity of the fluid, just after mixing, increased due to presence of silt particles (in suspension) but after 2h the viscosity of the top fluid was decreased, Fig. 6.11 and Fig. 6.12, as the silt particles got settled. It suggests that during excavation loose soil particles such as silt and sand may settle down due to low density of the fluid and can be removed with suitable construction technique otherwise will form a soft toe and may lead to reduction in the load carrying capacity of foundation.

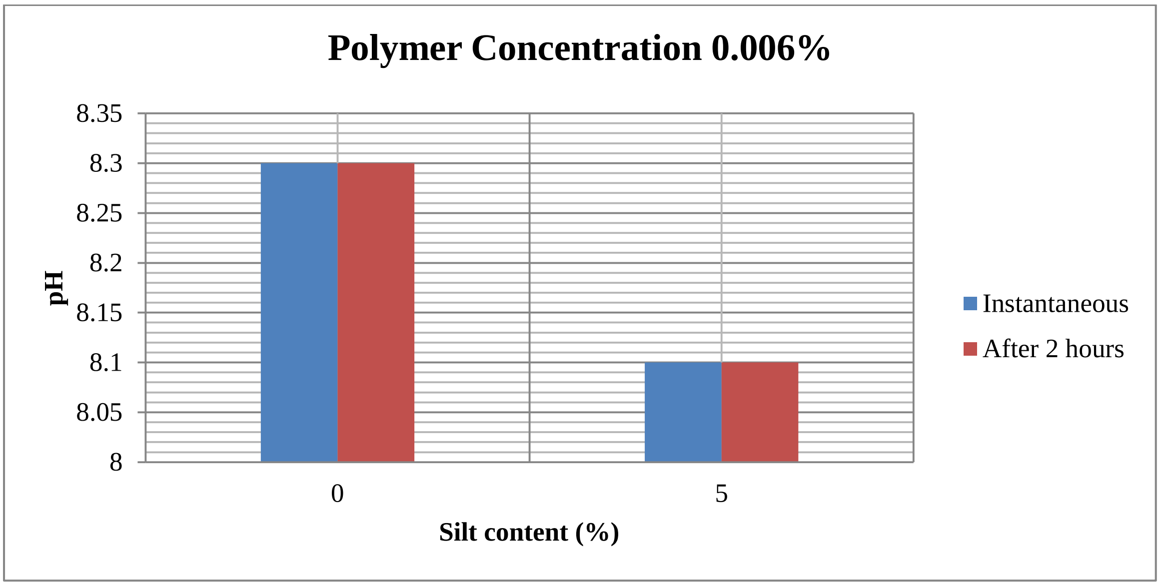


Fig. 6.9 Effect of silt content on the pH of low concentration polymer fluid with time

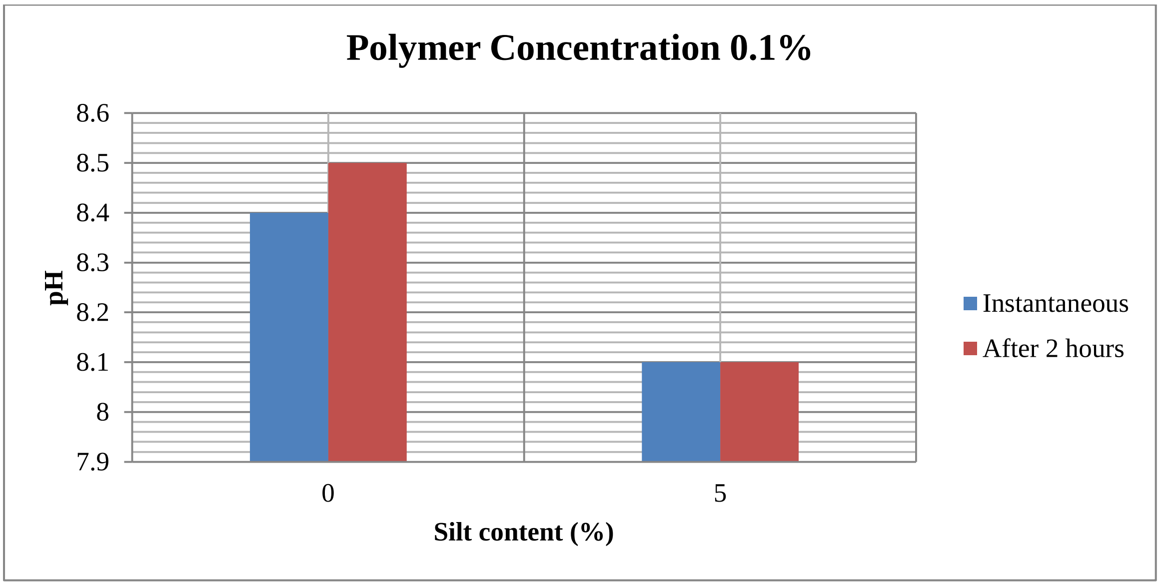


Fig. 6.10 Effect of silt content on pH of high concentration polymer fluid with time

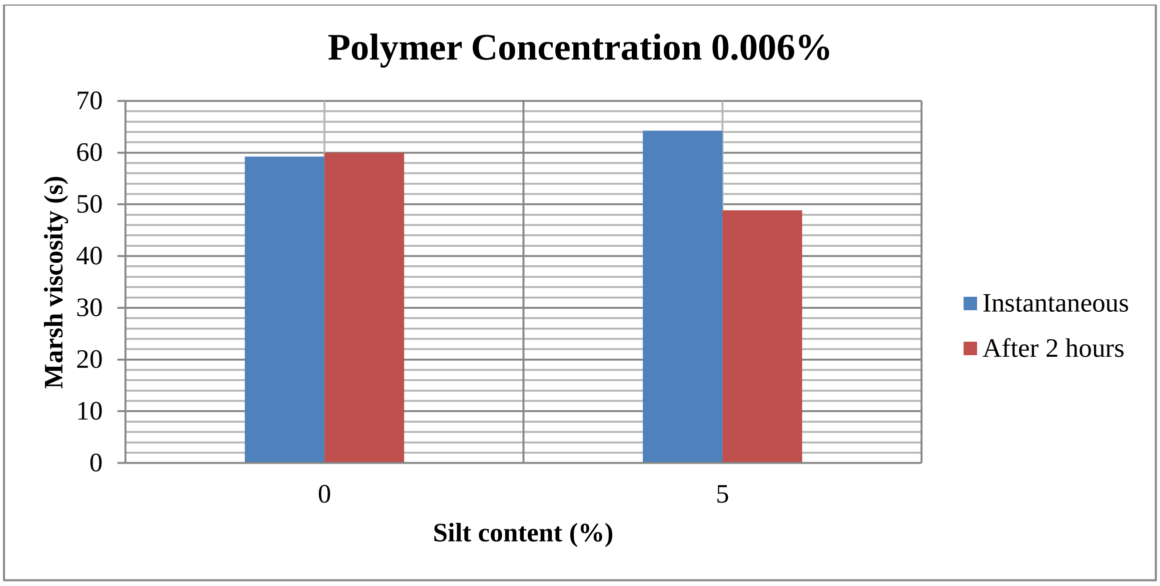


Fig. 6.11 Effect of silt content on the Marsh viscosity of low concentration polymer fluid with time

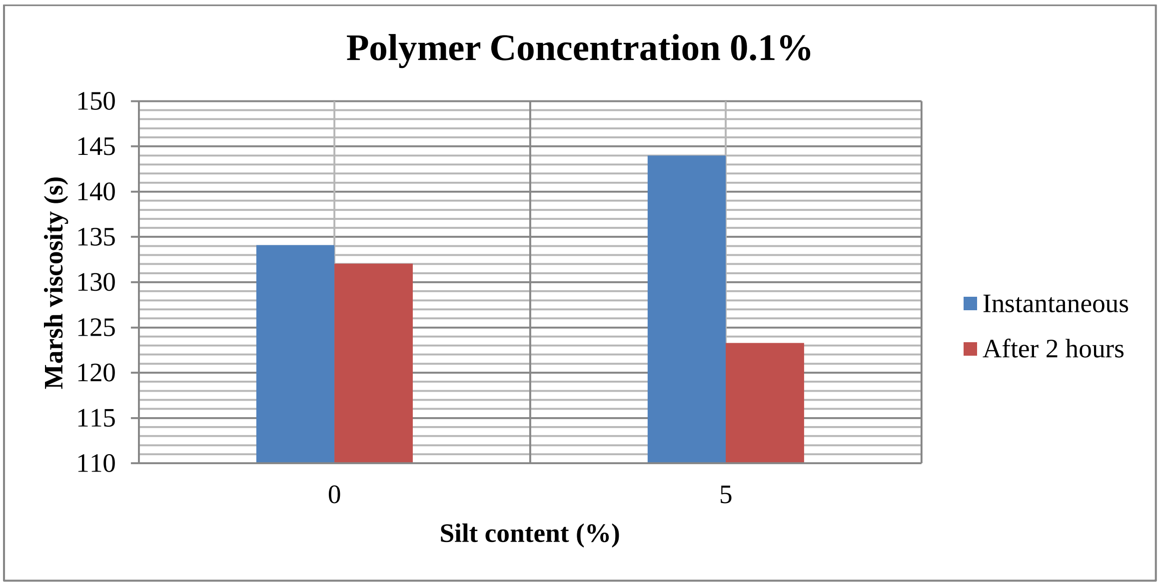


Fig. 6.12 Effect of silt content on the Marsh viscosity of high concentration polymer fluid with time

6.2.5 Effect of Bleaching Powder (Hypochlorite)

After mixing bleaching powder, it was observed that it coagulated with polymer chains and settled in the jar when kept for 2h. Its effects, on the pH and Marsh viscosity of the top fluid have been given in Table 6.7, but the density of the sample was found to be unaffected. From Fig. 6.13, it can be inferred that with increase in bleaching powder concentration, the Marsh viscosity of the fluid reduced significantly as long chains of the

Table 6.7 Effect of bleaching powder on polymer fluid properties

Polymer Concentration (%)	Bleaching Powder (%)	pH	Top Fluid Viscosity (s)
0.006	0	8.3	60.8
0.006	0.01	8.5	51.44
0.006	0.05	8.8	46
0.006	0.1	9.4	42
0.006	0.5	10.1	37.68

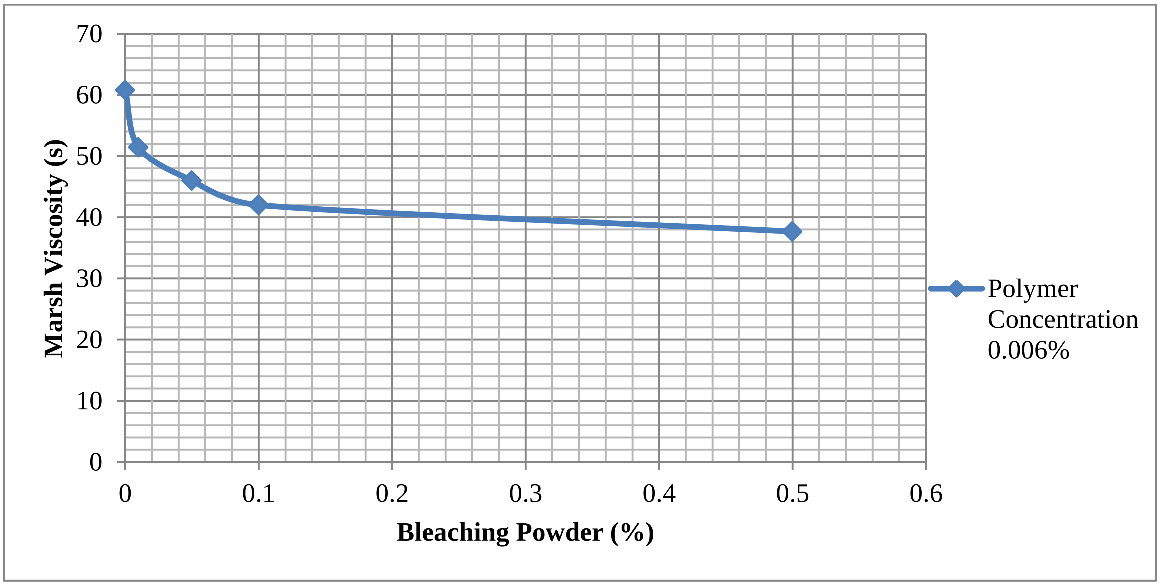


Fig. 6.13 Effect of bleaching powder concentration on the Marsh viscosity of low concentration polymer fluid

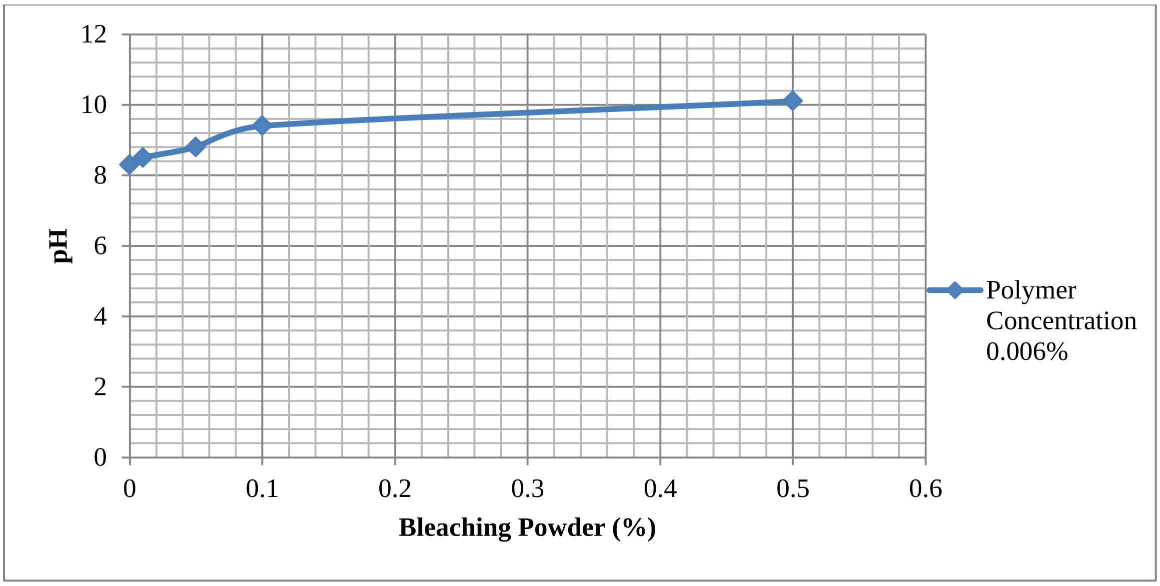


Fig. 6.14 Effect of bleaching powder concentration on the pH of low concentration polymer fluid

polymer must have broken down on reaction with bleaching powder although it increased the pH of the solution as shown in Fig 6.14. This result thus suggests that during final disposal of drilling fluid, addition of bleaching powder will allow polymer molecules to settle down, which thereby can be removed using suitable construction technique, leaving behind polymer free waste fluid.

6.3 EFFECT OF POLYMER FLUID ON FRICTIONAL RESISTANCE OF SOIL

The results obtained from the direct shear tests, as given in Table 6.8, infers that as the concentration of the polymer increases both, internal angle of friction of soil (ϕ) as well as cohesion (c), decreases. Thus it can be stated that as concentration of polymer increased, it might have formed a thin soft layer, coating the soil particles, and thus reduced the shear strength of the soil.

Table 6.8: Result data of direct shear test

Polymer concentration (%)	ϕ^o	c (kN/m^2)
0	41.28	4.07
0.006	40.1	3.32
0.01	39.31	2.87
0.05	38.07	1.84
0.1	37.07	1.01

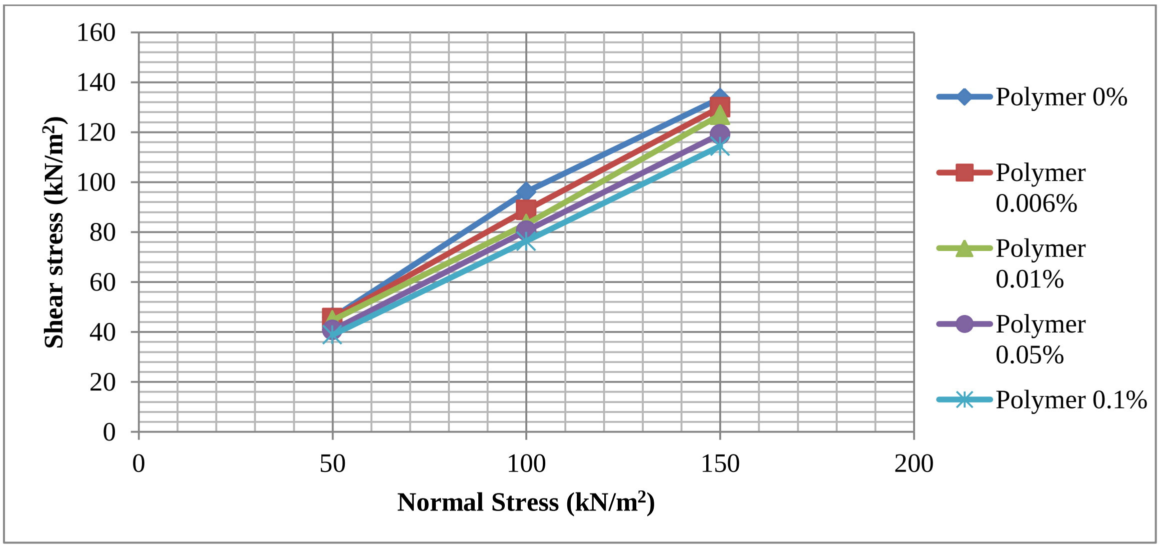


Fig. 6.15 Curve for shear stress versus normal stress response for different concentration of polymer fluid

As the cohesion value of soil is very much less than 1MPa thus it has been neglected and soil can be treated as cohesionless for further experiments. Fig.6.15 shows the curve between shear stress and normal stress of soil with layers of different concentrations of polymer fluid suggesting the decrement in strength with increase in polymer concentration.

6.4 THEORETICAL UPLIFT CAPACITY OF PILE

Based on the results obtained from the direct shear test (to compute the effect of polymer fluid on frictional resistance of soil), different theories, given by various researchers, have been used to compute the uplift capacity of the modeled pile and prototype pile and the results have been tabulated in Table 6.9 and Table 6.10 respectively. It can be observed that method applied using Chattopadhayay et al. predicted the highest theoretical uplift capacity as compared to other theories such as Meyerhof's predicting the lowest of all, for both model as well as prototype.

Table 6.9: Theoretical uplift capacity of model pile

Method applied	Polymer concentration (%)				
	0.0%	0.006%	0.01%	0.05%	0.1%
	Q_{mt} (kN)	Q_{mt} (kN)	Q_{mt} (kN)	Q_{mt} (kN)	Q_{mt} (kN)
Meyerhof	0.121	0.116	0.112	0.107	0.104
N. Ismael	0.194	0.186	0.182	0.175	0.169
Kulhawy et al.	0.266	0.248	0.227	0.197	0.167
IS Code	0.194	0.187	0.182	0.175	0.169

Table 6.10: Theoretical uplift capacity of actual concrete pile (prototype)

Method applied	Polymer concentration (%)				
	0%	0.006%	0.01%	0.05%	0.1%
	Q_{pt} (kN)	Q_{pt} (kN)	Q_{pt} (kN)	Q_{pt} (kN)	Q_{pt} (kN)
Meyerhof	406.49	389.95	379.03	362.71	349.85
N. Ismael	654.96	630.14	613.75	589.27	569.97
Kulhawy et al.	898.35	838.39	765.64	743.56	699.69
IS Code	654.96	630.14	613.75	589.27	569.97

6.5 EXPERIMENTAL RESULTS OF UPLIFT CAPACITY OF MODEL PILE

The experimental results obtained from the pull-out test of model concrete piles have been shown in Fig. 6.16, which shows the load-displacement behavior of the model piles, obtained from the pull-out test for three different cases depending upon the type of drilling fluid. it can be observed that the overall displacement for all piles at the time of failure was between 3-3.25 mm with the pile casted without drilling fluid undergoing the maximum displacement.

The ultimate uplift capacity of the tested piles have been plotted in Fig. 6.17, shows that the use of drilling fluid may have formed a soft layer which caused decrease in the frictional resistance of pile with reduction being more with high concentration polymer fluid (.

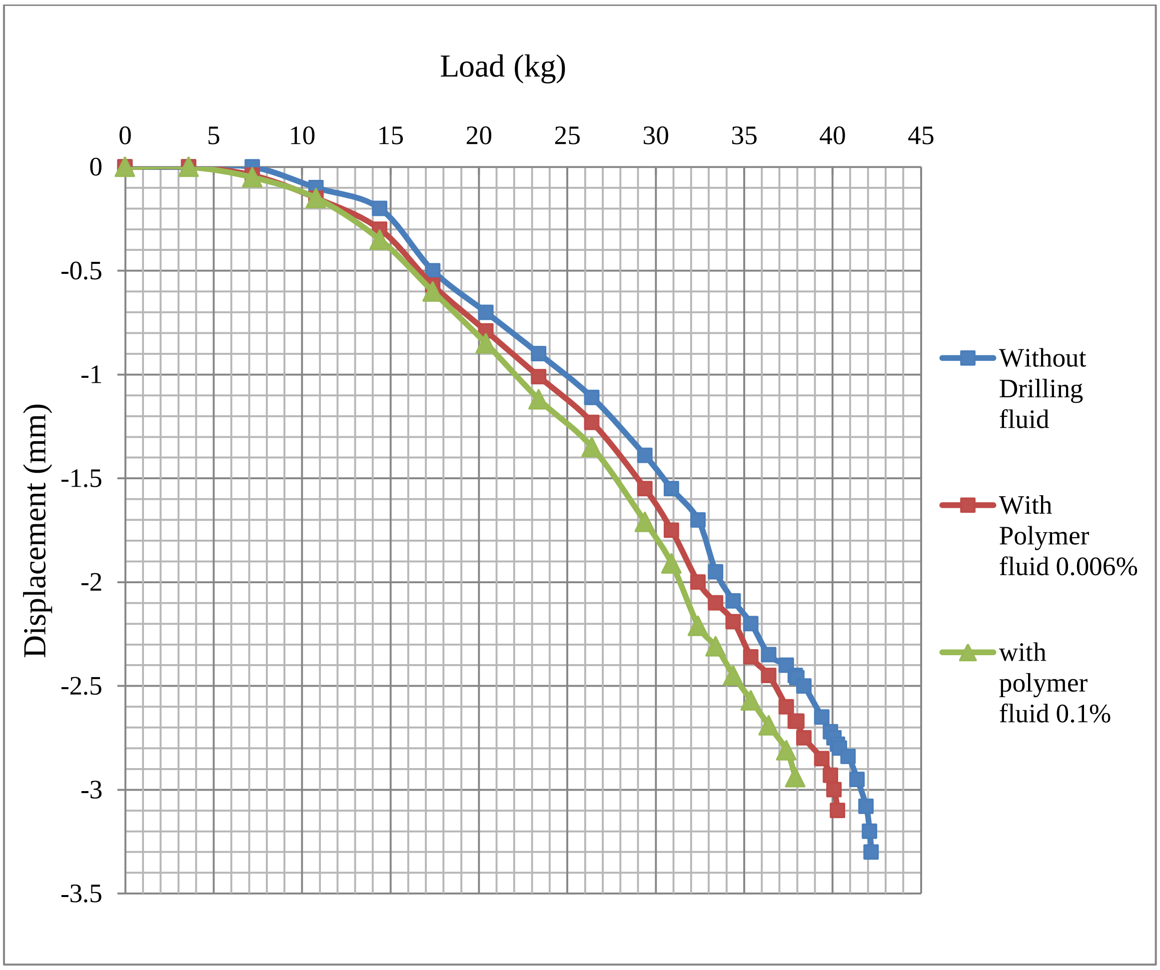


Fig. 6.16 Load-displacement curve for different polymer concentrations as drilling fluid

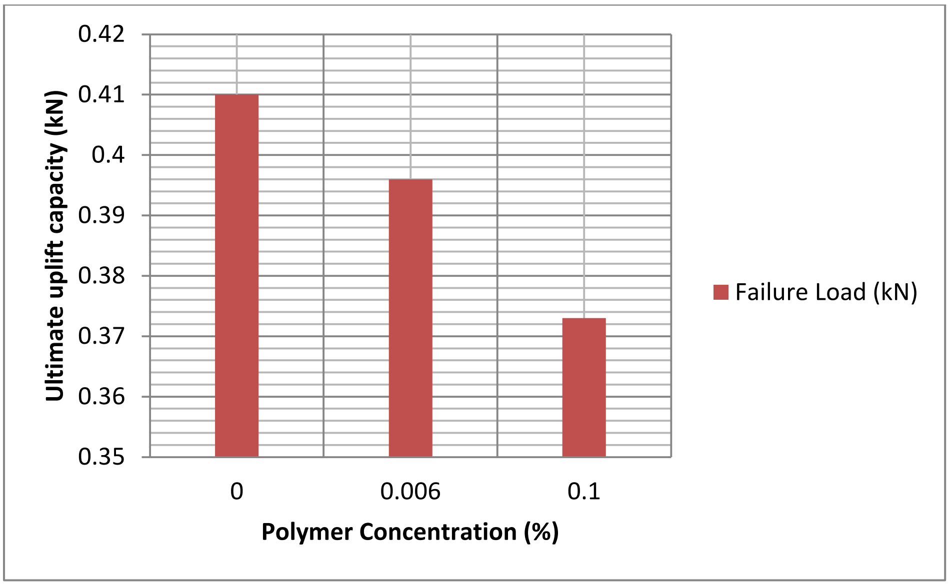


Fig. 6.17 Ultimate uplift capacity of model piles for different polymer concentrations as drilling fluid

The frictional resistance offered by piles in the model experiments as per different methods considering the weight of the casted pile have been calculated in Table 6.11.

Table 6.11: Frictional resistance of experimental model piles for different methods

Case	Uplift Capacity (kN)	Weight of pile (kN)	Frictional Resistance P_{me} (kN)			
			IS Code	Meyerhof	Kulhawy	N. Ismael
No drilling Fluid	0.41	0.0133	0.3967	0.41	0.41	0.3967
Polymer Fluid Concentration 0.006%	0.396	0.0127	0.3833	0.396	0.396	0.3833
Polymer Fluid Concentration 0.1%	0.372	0.0130	0.359	0.372	0.372	0.359

6.6 DETERMINATION OF UPLIFT CAPACITY OF PROTOTYPE PILE

The experimental uplift capacities of the model piles obtained from the pull out test were used to determine the uplift capacities of their corresponding prototypes. The values of constant K called as coefficient of earth pressure, used in the theories, were computed using the experimental uplift resistance of model piles and were back inserted in the equation to calculate the uplift capacities of the prototype pile. The length and diameter for model pile being 0.35m and 0.045m and for prototype was 5.25m and 0.675m for a scale of 1:15.

The value of K-factor increases with the decrease in angle of internal friction. The results obtained using IS code method were similar to results of Nabil F. Ismael's method and the results obtained from Kulhawy's method were same as of Meyerhof's method i.e. factor K_1 came equivalent to factor K_4 and factor K_2 came equivalent to factor K_3.

The frictional resistance of prototype pile decreases with increase in polymer concentration. The reduction was being about 3.37% with low concentration polymer fluid and 9.5% on using higher concentration polymer fluid.

6.6.1 Indian Standard Code Method

Table 6.12: Calculation for K-factor from IS code method using experimental results

Indian Standard Code Method					
Case	**P_{me} (kN)**	**ϕ^o**	**P_D (kN/m^2)**	**C =K_1tanδ**	**K_1**
No drilling Fluid	0.3967	41.28	2.77	2.93	3.29
Polymer Fluid Concentration 0.006%	0.3833	40.1	2.77	2.79	3.32
Polymer Fluid Concentration 0.1%	0.359	37.07	2.77	2.62	3.46

Table 6.13: Ultimate uplift capacity for prototype pile using IS code method

Indian Standard Code Method				
Case	**K_1**	**tanδ=tanϕ**	**P_D (kN/m^2)**	**P_{pe} (kN)**
No drilling Fluid	3.29	0.88	41.61	1338.86
Polymer Fluid Concentration 0.006%	3.32	0.84	41.61	1293.64
Polymer Fluid Concentration 0.1%	3.46	0.76	41.61	1211.62

6.6.2 Meyerhof's Method

Table 6.14: K-factor from Meyerhof's method using experimental results

Meyerhof's Method					
Case	**P_{me} (kN)**	**ϕ^o**	**Perimeter (m)**	**$C = K_2 \tan\delta$**	**K_2**
No drilling Fluid	0.410	41.28	0.1414	3.02	3.40
Polymer Fluid Concentration 0.006%	0.396	40.1	0.1414	2.88	3.43
Polymer Fluid Concentration 0.1%	0.372	37.07	0.1414	2.72	3.59

Table 6.15: Ultimate uplift capacity for prototype pile using Meyerhof's method

Meyerhof's Method				
Case	**K_2**	**$\tan\delta = \tan\phi$**	**Perimeter (m)**	**P_{pe} (kN)**
No drilling Fluid	3.40	0.88	2.1205125	1383.75
Polymer Fluid Concentration 0.006%	3.43	0.84	2.1205125	1336.5
Polymer Fluid Concentration 0.1%	3.59	0.76	2.1205125	1255.5

6.6.3 Kulhawy et al. Method

Table 6.16: K-factor from Kulhawy et al. method using experiment data

Kulhawy et al. Method					
Case	**P_{me} (kN)**	**ϕ^o**	**Perimeter (m)**	**$C = K_2 \tan\delta$**	**K_3**
No drilling Fluid	0.410	41.28	0.1414	3.02	3.40
Polymer Fluid Concentration 0.006%	0.396	40.1	0.1414	2.88	3.43
Polymer Fluid Concentration 0.1%	0.372	37.07	0.1414	2.72	3.59

Table 6.17: Ultimate uplift capacity for prototype pile using Kulhawy et al. method

Kulhawy et al. Method				
Case	**K_3**	**tanδ=tanϕ**	**Perimeter (m)**	**P_{pe} (kN)**
No drilling Fluid	3.40	0.88	2.1205125	1383.75
Polymer Fluid Concentration 0.006%	3.43	0.84	2.1205125	1336.50
Polymer Fluid Concentration 0.1%	3.59	0.76	2.1205125	1255.50

6.6.4 Nabil F. Ismael's Method

Table 6.18: K-factor from N. F. Ismael's method using experimental results

Nabil F. Ismael's Method					
Case	**P_{me} (kN)**	**ϕ^o**	**P_D (kN/m^2)**	**C =K_1tanδ**	**K_4**
No drilling Fluid	0.3967	41.28	2.77	2.93	3.29
Polymer Fluid Concentration 0.006%	0.3833	40.1	2.77	2.79	3.32
Polymer Fluid Concentration 0.1%	0.359	37.07	2.77	2.62	3.46

Table 6.19: Ultimate uplift capacity for prototype pile using N. F. Ismael's method

Nabil F. Ismael's Method				
Case	**K_4**	**tanδ=tanϕ**	**P_D (kN/m^2)**	**P_{pe} (kN)**
No drilling Fluid	3.29	0.88	41.61	1338.86
Polymer Fluid Concentration 0.006%	3.32	0.84	41.61	1293.64
Polymer Fluid Concentration 0.1%	3.46	0.76	41.61	1211.62

6.7 COMPARISON OF FRICTIONAL RESISTANCE BETWEEN THEORETICAL AND EXPERIMENTAL RESULTS

The theoretical frictional resistance of prototype pile were calculated as in Table 6.20, by deducting the theoretical weight of pile from the corresponding uplift capacities for IS code and Nabil F. Ismael's methods whereas for Meyerhof and Kulhawy's methods the frictional resistance is same as the uplift capacities.

The theoretical frictional resistance were compared with the frictional resistance obtained from the experimental results to calculate an increment factor, I_f, as in Table 6.21 and Table 6.22. From the results it can be observed that the frictional resistance from experimental results are about 2.5 times higher from theoretical values from Meyerhof's method while this increment being 1.3 times higher for IS code method and 0.6 times higher from Kulhawy et. al. method.

Table 6.20: Calculation for theoretical frictional resistance of prototype pile

Method applied	Weight of Pile (kN)	Theoretical Frictional Resistance of Prototype Pile (kN)					
		Polymer concentration (%)					
		No Drilling Fluid		0.006%		0.1%	
		Q_{pt}	P_{pt}	Q_{pt}	P_{pt}	Q_{pt}	P_{pt}
Meyerhof	45.088	406.49	406.49	389.95	389.95	349.85	349.85
N. Ismael	45.088	654.96	600.87	630.14	585.05	569.97	524.88
Kulhawy et al.	45.088	898.35	898.35	838.39	838.38	699.69	699.69
IS Code	45.088	654.96	609.87	630.14	585.05	569.97	524.88

Table 6.21: Calculation for Increment factor I_f

Case	IS Code Method			Meyerhof's Method		
	P_{pt} (kN)	P_{pe} (kN)	$I_{f1} = \frac{P_{pe}}{P_{pt}}$	P_{pt} (kN)	P_{pe} (kN)	$I_{f2} = \frac{P_{pe}}{P_{pt}}$
No drilling Fluid	609.87	1338.86	**2.19**	406.49	1383.75	**3.40**
Polymer Fluid Concentration 0.006%	585.05	1293.64	**2.21**	389.95	1336.50	**3.43**
Polymer Fluid Concentration 0.1%	524.88	1211.62	**2.31**	349.85	1255.50	**3.59**

Table 6.22: Calculation for Increment factor I_f

Case	Kulhawy et al. Method			Nabil F. Ismael's Method		
	P_{pt} (kN)	P_{pe} (kN)	$I_{f_3} = \frac{P_{pe}}{P_{pt}}$	P_{pt} (kN)	P_{pe} (kN)	$I_{f_4} = \frac{P_{pe}}{P_{pt}}$
No drilling Fluid	898.35	1383.75	**1.54**	609.87	1338.86	**2.19**
Polymer Fluid Concentration 0.006%	838.89	1336.50	**1.59**	585.05	1293.64	**2.21**
Polymer Fluid Concentration 0.1%	699.69	1255.50	**1.79**	524.88	1211.62	**2.31**

6.8 DETERMINATION OF MODIFICATION FACTOR 'F'

Modification factor is the ratio of constant K-factor obtained from experiment values and the K-factor given by respective method theoretically.

Table 6.23: Calculation for modification factor 'F'

Case	IS Code Method			Meyerhof's Method		
	K_{IS}	K_1	$F_1 = \frac{K_1}{K_{IS}}$	K_M	K_2	$F_2 = \frac{K_2}{K_M}$
No drilling Fluid	1.5	3.29	**2.19**	1	3.40	**3.40**
Polymer Fluid Concentration 0.006%	1.5	3.32	**2.21**	1	3.43	**3.43**
Polymer Fluid Concentration 0.1%	1.5	3.46	**2.31**	1	3.59	**3.59**

Table 6.24: Calculation for modification factor 'F'

Case	Kulhawy's Method			Nabil F. Ismael's Method		
	K_K	K_3	$F_3 = \frac{K_3}{K_K}$	K_N	K_4	$F_4 = \frac{K_4}{K_N}$
No drilling Fluid	2.21	3.40	**1.54**	1.5	3.29	**2.19**
Polymer Fluid Concentration 0.006%	2.15	3.43	**1.59**	1.5	3.32	**2.21**
Polymer Fluid Concentration 0.1%	2	3.59	**1.80**	1.5	3.46	**2.31**

The coefficient of earth pressure obtained experimentally using theoretical methods was compared to their respective actual K values, to obtain a modification factor, F, presented in Table 6.23 and Table 6.24. The calculated experimental frictional resistance of prototype and theoretical frictional resistance of prototype were plotted against the internal angle of friction (ϕ^o) as shown in Fig. 6.18. the modified values of theoretical results were plotted by multiplying them with corresponding modification factor.

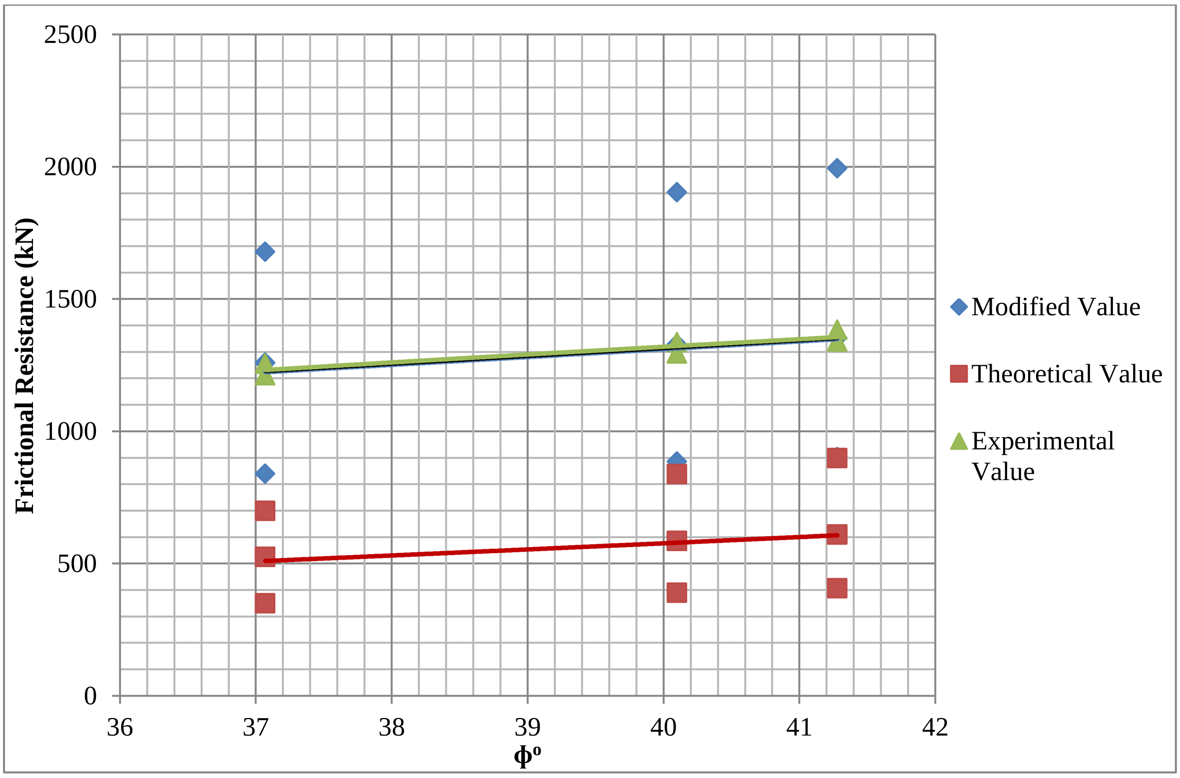


Fig. 6.18 Frictional resistance of prototype pile for different ϕ values

Table 6.25: Calculation for average modification factor 'F'

Case	Method's Applied				$F_{Proposed}$ (From Graph)
	IS Code	Meyerhof	Kulhawy	Nabil. F. Ismael	
	F_1	F_2	F_3	F_4	
No drilling Fluid	2.19	3.40	1.54	2.19	2.22
Polymer Fluid Concentration 0.006%	2.21	3.43	1.59	2.21	2.27
Polymer Fluid Concentration 0.1%	2.31	3.59	1.80	2.31	2.4

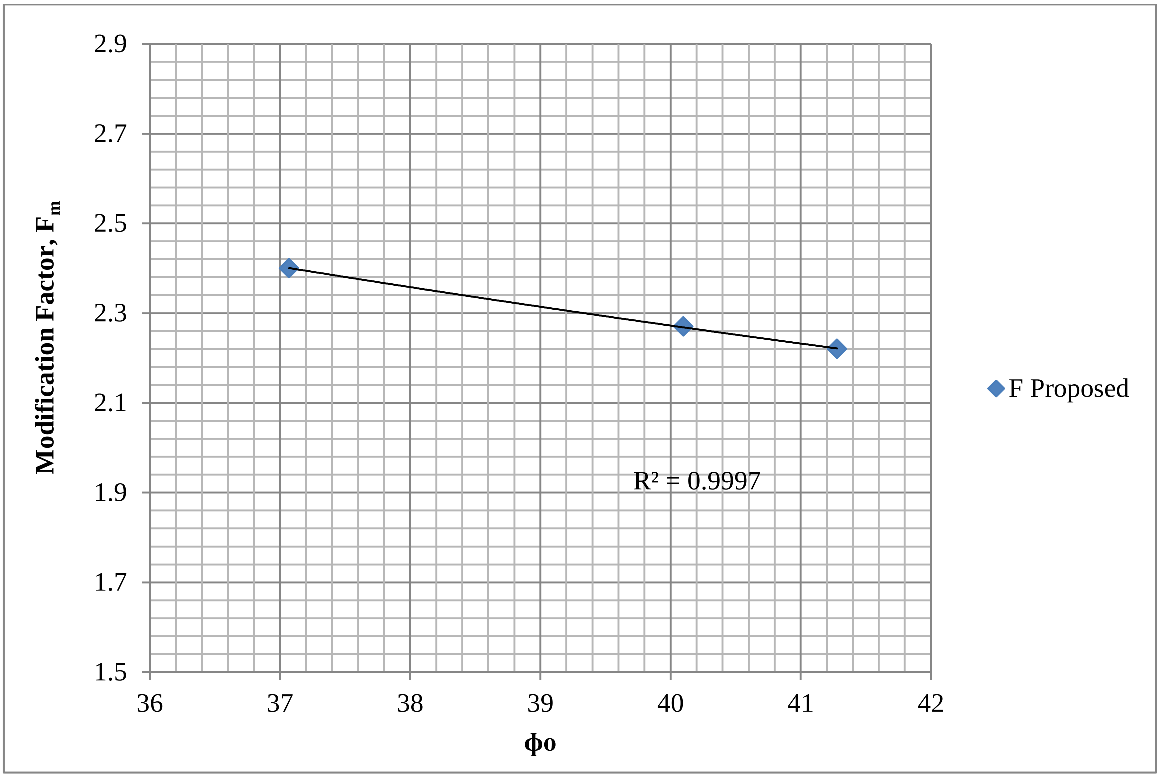


Fig. 6.19 Proposed modification factor for different ϕ values

The average value of modification factor varies from 2.2-2.4 for a range of different angles and can be multiplied with the theoretical results for different values. The modification factor was higher for Meyerhof's method i.e. the frictional resistance for pile is underestimated by this method than the actual value observed in the field.

6.9 PROPOSED K-FACTOR

The theoretical and experimental results varied depending on different theories and for different value of angle of internal friction. The K value can be the active or passive earth pressure coefficient or earth pressure coefficient at rest, used by different theories such as proposed by N.F. Ismael. The experimental results have shown that it is approximately equivalent to the passive earth pressure coefficient but still varying with a constant factor A which has been proposed as:

$$K_i = A_i K_p \qquad \text{Eq. 6.1}$$

Where, K_p = passive earth pressure coefficient, calculated as Eq. 6.2

A_i = constant calculated in Table 6.26 and Table 6.27 and can be obtained from Fig. for different ϕ values.

$$K_p = \frac{1+\sin\phi}{1-sin\phi} \qquad \text{Eq. 6.2}$$

Where, ϕ = angle of internal friction, depends on different cases.

Table 6.26 and Table 6.27, presents the calculations to obtain the factor A_i value for different methods depending on different angle of internal friction.

Table 6.26: Calculation for constant 'A_i' factor

Case	ϕ°	IS Code Method		Meyerhof's Method	
		K_1	A_1	K_2	A_2
No drilling fluid	41.28	3.29	**0.67**	3.4	**0.7**
Polymer Fluid Concentration 0.006%	40.1	3.32	**0.72**	3.43	**0.74**
Polymer Fluid Concentration 0.1%	37.07	3.46	**0.86**	3.59	**0.89**

Table 6.27: Calculation for constant 'A_i' factor

Case	ϕ°	Kulhawy et al. Method		N. Ismael's Method	
		K_3	A_3	K_4	A_4
No drilling fluid	41.28	3.4	**0.7**	3.29	**0.67**
Polymer Fluid Concentration 0.006%	40.1	3.43	**0.74**	3.32	**0.72**
Polymer Fluid Concentration 0.1%	37.07	3.59	**0.89**	3.46	**0.86**

Table 6.28: A_i factors for different ϕ values

Considering Weight of Pile		Without Considering Weight of Pile	
ϕ°	**$A_1 = A_4$**	**ϕ°**	**$A_2 = A_3$**
41.28	0.67	41.28	0.7
40.1	0.72	40.1	0.74
37.07	0.86	37.07	0.89

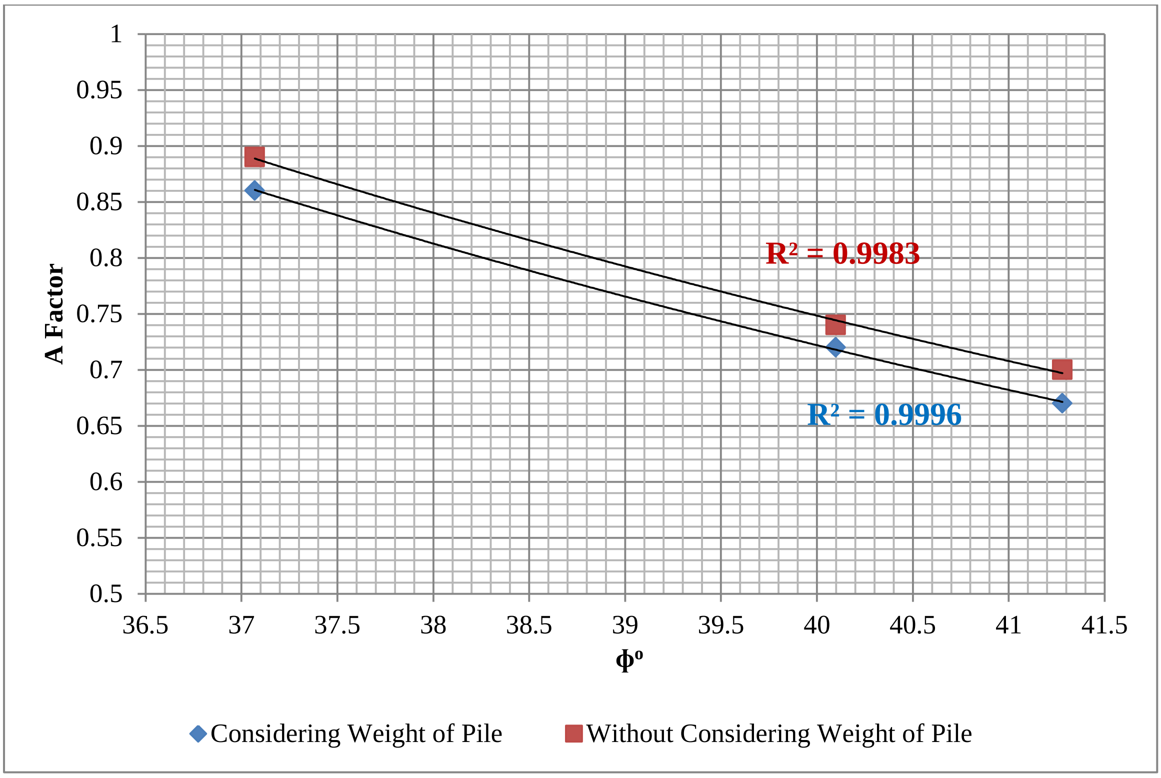


Fig. 6.20 Proposed of A_i-factor for different ϕ values

The values of A_1 and A_4 differs from the values of A_2 and A_3, as in order to calculate the frictional resistance of pile, weight of pile has to be deducted from the uplift capacity for IS code and Ismael's method (for A_1). The variation thus suggests that factors can be considered for only two cases i.e. one for the case when weight of the pile was considered and the second one being without considering the weight of the pile.

Table 6.28, tabulates the A-factors calculated for different cases as given depending on the ϕ values. The A-factors can be obtained using Fig. 6.20, depending on the case whether the weight of the pile is deducted from the uplift capacity or not such as for IS code and N.F. Ismael's method, weight of the pile is required to be considered but as per Meyerhof and Kulhawy et al. method the frictional resistance of pile shaft is equal to the predicted uplift capacity i.e. without considering the weight of the pile. This A-factor can be multiplied with respective passive earth pressure coefficient to give K-factor value for particular angle of internal friction and can be used in different theoretical equations to obtain higher accuracy in determining the frictional resistance offered by pile shafts.

CHAPTER 7

CONCLUSIONS

The main objective of this dissertation was to determine the effect of polymer fluid on frictional resistance of pile through experimental work. In the laboratory experiments influence of various parameters such as polymer concentration, silt content, increase in pH etc. were determined to optimize the rheological properties of polymer fluid. The effect of different polymer concentration fluid on physical model pile was studied through field work in a fabricated pull out test setup and the theoretical and experimental results were compared to help in developing a better understanding of the topic. The conclusions drawn from the comparison of theoretical and experimental results have been as follows:

1. Addition of even small concentration of polymer crystals, 0.006%, with proper mixing techinique, can increase the Marsh viscosity of water significantly (from about 35 s to nearby 60 s) and with addition of sodium hydroxide (NaOH), the pH of drilling fluid rises but the Marsh viscosity of both low (0.006%) and high (0.1%) polymer concentration drilling fluid rises upto a limiting pH (9.7-10.3) and thereafter decreases on further increment thus these two concentrations with pH value in above range were used for the determination of uplift capacity using pull out test.
2. The pH of the drilling fluid does not show significant change with the passage of time, i.e. remains in the range 8.3-8.6 whereas a small increase in the Marsh viscosity of low concentration polymer fluid can be observed for the first two hours in comparison to high concentration polymer but thereafter it decreases with the passage of time and the rate being higher for high concentration polymer fluid.
3. The silt particles, 5% amount, settles within 2h after mixing irrespective of the concentration of polymer (low or high). The pH of the fluid decreases from 8.3 to 8.1 by the addition of silt and the Marsh viscosity of the top fuid (fluid portion on top of the settled particles of silt) also decreases as the silt content settles in both low as well as high concentration polymer fluids.
4. Bleaching powder (hypochlorite) was added to study its environmental benefit and results shows that it increases the pH value of the drilling fluid and coagulates with polymer molecules, which, with passage of time (about 2h) settles at the bottom and reducing the Marsh viscosity of top fluid significantly.

5. The layer of polymer fluid reduces the internal angle of friction of soil from 41.28^{o} to 37.07^{o} at the contact surface, with increasing polymer concentration from 0-0.1% thus reducing the shear strength of the soil and the decrement being significant with increase in the polymer concentrations.
6. The uplift capacity of the cast in-situ concrete pile, determined by performing a pull out test on physically modeled pile, have shown that it decreases with the formation of layer of polymer fluid (required for stabilization of borehole) between soil and pile shaft with the affect being significant with increase of polymer concentration in drilling fluid. The reduction was being about 3.37% and 9.5% on using low (0.006%) and high (0.1%) concentration polymer fluid
7. Different theories underestimate the uplift capacity of the bored cast in-situ concrete piles. The frictional resistance of the pile obtained from the experimental results were found more approximate to the theoretical values determined using Kulhawy et al. method as compared to IS code method and Meyerhof and N.F. Ismael's method.
8. From the comparison between theoretical and experimental results, the K-factor has been found approximate to the passive earth pressure coefficient k_p multiplied by a constant, A-factor (varying from 0.67-0.9 for different angle of internal friction). The use of this K-factor, in the theoretical equations will help to determine the actual frictional resistance offered by the pile shaft.

REFERENCES

1. A. Ata, M. O'Neill: 2000, "The physiochemical interaction between PHPA polymer slurry and cement mortar", *Geotechnical Testing Journal*, GTJODJ, Vol. 23,pp: 231-241.
2. A. Sil, K. Wakadikar: 2012, "Toxicity characteristics of drilling mud and its effect on Aquatic Fish Populations", *Journals of Hazardous, Toxic and Radioactive Waste,* Vol. 16
3. B. C. Chattopadhayay, P. J. Pise,1986, "Uplift capacity of piles in sand". *Journals of Geotechnical Engineering*, Vol.112 Paper No. 20919.
4. C. Lam, V. Troughton, S. Jefferis, T. Suckling: 2010, "Effect of support fluids on pile performance- a fiel trial in East London", *Ground Engineering Technical Paper*.
5. C. Lam, S. Jefferis, T. Suckling, 2013, "Construction techniques for bored piling in sand using polymer fluids". *ICE Publishing*.
6. C. Lam, S. A. Jefferis,: 2013, "Polymer support fluids: use and misuse of innovative fluids in geotechnical works", *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris*
7. C. Lam, S. Jefferis, C.M. Martin: 2014, Effect of polymer and bentonite support fluids on concrete sand interface shear strength, *Journals of Geotechnique*, pp: 28-39.
8. C. Lam, P.J. Martin, S.A. Jefferis, K.G. Goodhue: 2014, Determination of residual concentration of active polymer in a polymeric support fluid, Geotechnical Testing Journal, Vol. 37, No. 1, pp: 1-14.
9. C. Lam, V. Troughton, S. Jefferis, T. Suckling: 2015, "Performance of bored piles constructed using polymer fluids: Lessons from European experience", *Journal of Performance of Constructed Fascilities*, ISSN 0887-3828.
10. D. R. Levacher, J.G. Sieffert, 1985, "Tests on model tension piles". *Journals of Geotechnical Engineering*, Vol.110 Paper No. 19338.
11. D. Brown: 2002, Effect of construction on axial capacity of drilled foundations in piedmont soils, *Journal of Geotechnical and Geoenvironmental Engineering*, pp. 128: 967-973.
12. D. Brown: 2012, "Recent advances in the selection and use of drilled foundations".
13. J.R. Omer, "The use of polymer support fluids in the construction of drilled shafts*", International Symposium of Deep Foundations, Civil Engineers School of Mexico*, 2011

14. K. E. Gaaver, 2013, "Uplift capacity of single pile and pile group embedded in cohesionless soil". *Alexandria Engineering Journals*, Pp.365-372.
15. K. Ilampruthi, V.K. Kumar: 2011, "Effect of filtercake on interfacial friction-an experimental study", *Proceedings of Indian Geotechnical Conference*, paper no. D-117, Kochi
16. Nabil F. Ismael, T.W. Klym, 1979, "Uplift and bearing capacity of short piers in sand". *Journals of Geotechnical Engineering*, Vol.105.
17. R.E. Majano, M.W. O'Neill, K.M. Hassan: 1994, Perimeter load transfer in model drilled shafts formed under slurry, *Journal of Geotechnical Engineering*, Vol. 120, pp: 2136-2154.
18. R.P. Frizzi, M.E. Meyer, L. Zhou: 2004, Full scale field performance of drilled shafts constructed utilizing bentonite and polymer slurries, *GEOSUPPORT*, pp: 573-583
19. W. C. Oye, N. Marumdee, 2012, "Estimation of uplift pile capacity in the sand layers". *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, Vol.4, ISSN 2228-9860.
20. IS1498:1970, "Classification and Identification of soils for general engineering purposes".
21. IS 2720 (Part 3/sec2): 1980, "Method of test of soils- Determination of specific gravity".
22. IS 2720 (Part 4): 1985, "Method of test of soils- Grain size analysis".
23. IS 2911 (Part 4): 1985, "Code of practice for design and construction of pile foundations- Load test on piles".
24. IS 2720 (Part 13): 1986, "Method of test of soils- Direct shear test".
25. IS 3177:1999, "Code of practice for electric overhead travelling".
26. IS 456: 2000, "Plain and reinforced concrete - code of practice".
27. IS 2911 (Part 1/sec2): 2010, "Code of practice for design and construction of pile foundation".