

“EFFECT OF CHANGE OF LENGTH ON SKIN FRICTION OF PILES”

MAJOR REPORT

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Submitted by

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Contents

Contents	1
Acknowledgement	3
Certificate	4
Abstract	5
List of Figures	6
List of tables	8
List of graphs	9
Chapter 1 Introduction	10
Chapter 2 Literature review	11
2.0 Torsion of circular shafts	11
2.1 Definition of Torsion	11
2.2 Effects of Torsion	11
2.3 Generation of shear stresses	12
2.4 Twisting Moment	13
2.5 Shearing Strain	13
2.6 Modulus of Elasticity in shear	13
2.7 Angle of Twist	13
2.8 Relationship in Torsion	14
2.9 Torsional resistance of single pile in layered soil	14
2.10 Numerical solution of single pile subjected to simultaneous Torsional and axial loads	15
2.10.1 Numerical analysis	15

Chapter 3 Experimental Setup

3.0 Construction of Pit	18
3.1 Drying and Filling of Sand	19
3.2 Placing of Girders and inclined pulley	19
3.3 Manufacturing of Single Pile	23
3.4 Arrangement to apply pure torsional force on the pile	24
3.5 Experimental procedure	25

Chapter-4 Result and discussion

4.0 Sieve analysis	27
4.1 Experimental study of single pile	28

Chapter 5 Conclusion

References	42
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Date: 19/06/2017

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CERTIFICATE

This is to certify that major project report entitled “Effect of change of diameter on skin friction of piles of varying length” is an authentic record of my own work carried out in fulfillment of the requirements for the award of Master of Engineering (Geotechnical Engineering), department of Civil Engineering, Delhi Technological University, Delhi under the guidance of Dr. Naresh Kumar.

Dated: 19/06/2017

Ombir Tomar

Roll no: 2K15/GTE/12

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

Dr. Naresh Kumar

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Delhi Technological University,
Delhi.

ABSTRACT

Tall buildings play a key role in current urban strategies and regeneration. Development of these building presents several problems related to the design and assessment of pile foundations. Among these combinations of vertical, lateral and torsional forces to the piles due to the eccentricity of wind action on vertical projections of multistoried tall buildings is of particular interest.

. Torsional forces are also acting on the pile and IS 2911 for pile foundation has not been considered torsional forces for pile designing but it should be considered.

Therefore, objectives of the present work are:

- (1) Mechanism of applying torque to piles.
- (2) Experimentally to examine basic pile-soil interactions in the modal pile subjected to torque in the context of study of torque Vs angle of twist.

A mechanism of applying torque to a single pile was thought upon and worked out accordingly. Experiments on single pile were performed. Torque on a single pile was applied using the above said mechanism. Experiments were performed by increasing the embedded depth of a modal pile. When we increased the embedded depth of pile at regular intervals with the different torques for increasing angle of twist till the failure angle of twist is achieved.

FIG. NO.	DESCRIPTION	PAGE. NO.
FIG2.0	Torsional force acting on circular shaft	11
FIG.2.1	Here the cylindrical member or a shaft is in static equilibrium where T is the resultant external torque acting on the member. Let the member be imagined to be cut by some imaginary plane 'mn'.	12
FIG.2.2	When the plane 'mn' cuts remove the portion on R.H.S. and we get a fig2.2. Now since the entire member is in equilibrium, therefore, each portion must be in equilibrium. Thus, the member is in equilibrium under the action of resultant external torque T and developed resisting Torque T_r .	12
FIG.2.3	The Figure shows that how the resisting torque T_r is developed. The resisting torque T_r is produced by virtue of an infinitesimal shear forces acting on the plane perpendicular to the axis of the shaft. Obviously such shear forces would be developed by virtue of shear stresses.	12
FIG.2.4	shaft under torsion showing shearing strain	13
FIG.2.5	shaft under torsional force	14
FIG 2.6	Idealized problem: determination of base resistance (Basack and Sankhasubhra Sen 2014)	15
FIG 2.7	Theoretical considerations :(a) pile under combined loading ;(b) pile element with stresses on surface ;(c) typical soil element (Basack and Sankhasubhra Sen 2014)	16

FIG 3.1	Real image of pit on left and plan view, side view of pit on right	18
FIG 3.2	Yamuna sand specimen	19
FIG 3.3	Girders with pulley welded together	19
FIG 3.4	Girder fixed on top of brick wall and pulley inclined at 45° with vertical	20
FIG 3.5	drilling hole in wall to insert a part of girder	22
FIG 3.6	Pulley making an angle of 45 degree with vertical	22
FIG 3.7	Chain in high tension carrying heavy load to apply torque on pile	22
FIG 3.8	Steel modal pile of 90cm length	23
FIG 3.9	Manufacturing of pile	23
FIG 3.10	Complete view of apparatus	24
FIG 3.11	Calculation of angle of twist	25
FIG 3.12	Complete upper view of mechanism	26
FIG 3.13	Elevation view of mechanism producing torque in pile	26
FIG 4.1	Pile inserted inside sand to 50cm of depth	28
FIG 4.2	Pile inserted inside sand to 55cm of depth	32

LISTS OF TABLES

TAB. NO.	DESCRIPTION	PAGE NO.
TABLE.4.1	Sieve Analysis	27
TABLE.4.2	Torque applied and twist angle for depth 45cm of modal pile	29
TABLE.4.3	Torque applied and twist angle for depth 50cm of modal pile	31
TABLE.4.4	Torque applied and twist angle for depth 55cm of modal pile	33
TABLE.4.5	Torque applied and twist angle for depth 45cm of modal pile	35
TABLE.4.6	Torque applied and twist angle for depth 50cm of modal pile	36
TABLE.4.7	Torque applied and twist angle for depth 55cm of modal pile	37

LIST OF GRAPHS

GRAPH. NO.	DESCRIPTION	PAGE NO.
GRAPH.4.0	Sieve analysis	27
GRAPH.4.1	Measured torque-twist angle curve for modal pile depth 50cm in sand	37
GRAPH.4.2	Measured torque-twist angle curve for modal pile depth 55cm in sand	37
GRAPH.4.3	Measured torque-twist angle curve for modal pile depth 60cm in sand	38
GRAPH.4.4	Measured torque-twist angle curve for modal pile depth 55cm in sand	38
GRAPH.4.5	Torque-twist angle relation for different depth of modal pile	39
GRAPH.4.6	Strain energy and twist angle relation for different depth of modal pile	39

INTRODUCTION

Some structures such as offshore platforms, tall buildings, electric transmission towers and bridge bents are subjected to lateral loads of significant magnitude due to wave and wind actions, high speed vehicles, or ship impacts. Considerable torsional forces can be transferred to the foundation piles by action of eccentric lateral loading. Insufficient design of the piles against these loads can result in catastrophic consequences. At least four multi-storey buildings have suffered permanent breakage due to wind actions and marked permanent deformations from torsion (Vickery 1979).

Large diameter bored piles are usually used to support bridges and tall buildings, because such piles can sustain large loads. However, various deformity can be left in a pile even though care is taken during pile construction. Wong (2004) conducted a real survey on quality assurance for bored pile built in Hong Kong. Among these all types of pile defects, cavities in the pile shaft, and soft toes (eg, soil inclusions and unbound aggregate), and short piles that are not founded at the deputed rock level are reported to occur sometimes. Poulos (1997, 2005) suggested that defects in bored piles can be divided into two categories: geotechnical defects and structural defects. Structural defects are those related to the strength, size and stiffness of the completed piles being less than assumed in design, such as honeycombs, necking, soil seams, and cracks along the shaft. Geotechnical defects are related to either construction related problems such as short piles, toe debris, and over break cavities or misassessment of in situ conditions during design.

Piers are key of bridges, which are commonly subjected to eccentrically horizontal loads from high speed vehicles, wind or even ship impacts. Therefore, torsional resistances of their foundations are very important for bridges. Insufficient design of the foundations against these loads leads to disastrous consequences.

Chapter 2

Literature Review

2.0 Torsion of circular shafts

2.1 Definition of Torsion: Consider a shaft rigidly clamped at one end and twisted at the other end by a torque $T = F.d$ applied in a plane perpendicular to the axis of the bar such a shaft is said to be in torsion. SI unit of torque is N-m.

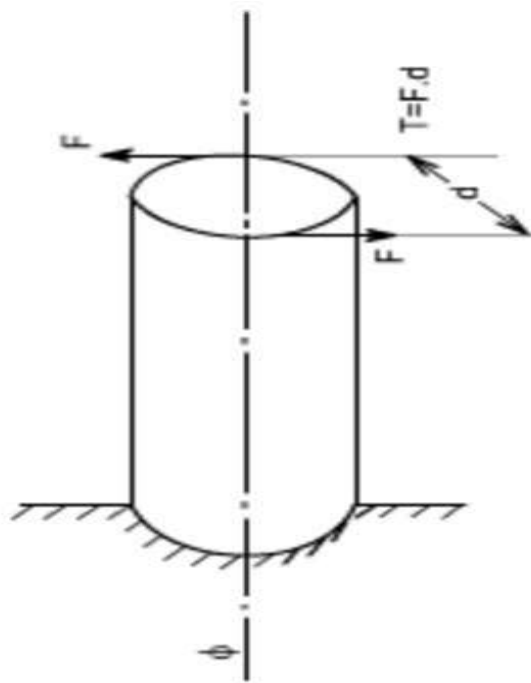


Fig2.0: Torsional force acting on circular shaft

2.2 Effects of Torsion: The effects of a torsional load applied to a bar are

- (i) To impart an angular displacement of one end cross-section with respect to the other end.
- (ii) To setup shear stresses on any cross section of the bar perpendicular to its axis.
- (iii)

2.3 Generation of shear stresses

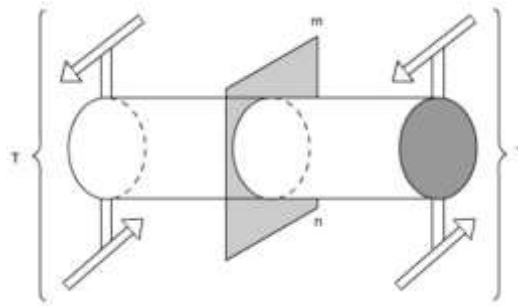


Fig2.1: Here the cylindrical member or a shaft is in static equilibrium where T is the resultant external torque acting on the member. Let the member be imagined to be cut by some imaginary plane ' mn '.

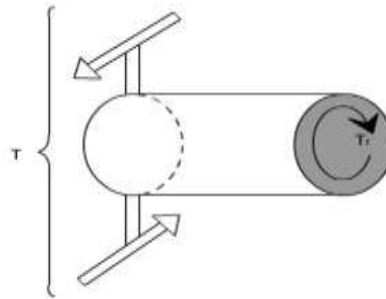


Fig2.2: When the plane ' mn ' cuts remove the portion on R.H.S. and we get a fig2.2. Now since the entire member is in equilibrium, therefore, each portion must be in equilibrium. Thus, the member is in equilibrium under the action of resultant external torque T and developed resisting Torque T_r .

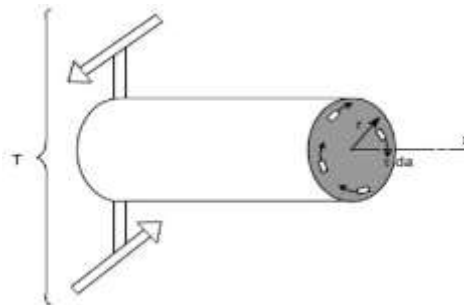


Fig2.3: The Figure shows that how the resisting torque T_r is developed. The resisting torque T_r is produced by virtue of an infinitesimal shear forces acting on the plane perpendicular to the axis of the shaft. Obviously such shear forces would be developed by virtue of shear stresses.

Therefore we can say that when a particular member (say shaft in this case) is subjected to a torque, the result would be that on any element there will be shear stresses acting. While on other faces the complementary shear forces come into picture. Thus, we can say that when a member is subjected to torque, an element of this member will be subjected to a state of pure shear.

2.4 Twisting Moment

The twisting moment for any section along the bar / shaft is defined to be the algebraic sum of the moments of the applied couples that lie to one side of the section under consideration. The choice of the side in any case is of course arbitrary.

2.5 Shearing Strain

If a generator $a - b$ is marked on the surface of the unloaded bar, then after the twisting moment 'T' has been applied this line moves to ab' . The angle ' γ ' measured in radians, between the final and original positions of the generators is defined as the shearing strain at the surface of the bar or shaft. The same definition will hold at any interior point of the bar.

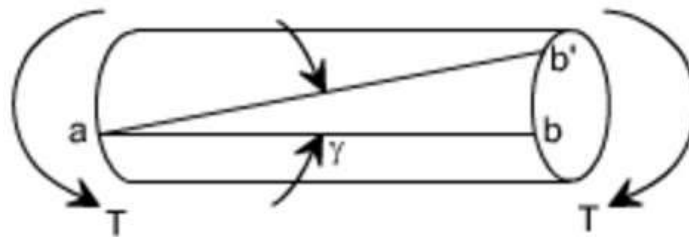


Fig2.4: shaft under torsion showing shearing strain

2.6 Modulus of Elasticity in shear

The ratio of the shear stress to the shear strain is called the modulus of elasticity in shear OR Modulus of Rigidity and is represented by the symbol G . SI unit is pascal (Pa).

$$G = \frac{\tau}{\epsilon}$$

2.7 Angle of Twist

If a shaft of length L is subjected to a constant twisting moment T along its length, then the angle through which one end of the bar will twist relative to the other is known as the angle of twist. Θ in radian.

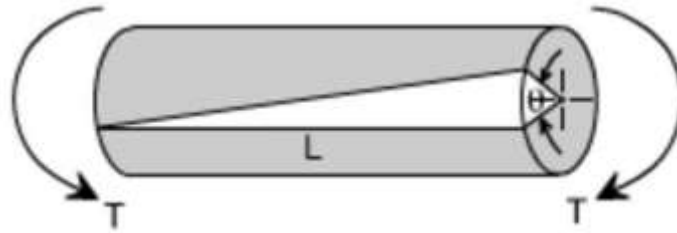


Fig2.5: shaft under torsional force

2.8 Relationship in Torsion

T = Torsion force (N-m)

J = Polar moment of inertia (m^4)

Polar moment of inertia for hollow cylindrical shaft =

R = Radius of cross-section of circular shaft (m)

τ = Shear stress (MPa)

G = shear modulus (GPa)

Θ = Angle of twist (radian) $\{ 1 \text{ radian} = \frac{180}{\pi} \text{ degree} \}$

L = Length of shaft (m)

$$\frac{\tau}{R} = \frac{T}{J} = \frac{G\theta}{L}$$

$$J = \frac{\pi}{32} (D^4 - d^4)$$

D = external diameter

d = internal diameter

Strain energy (U) of the modal cylindrical pile is equal to the work done by the load, provided no energy is gained or lost in the form of heat. (Joules)

$$U = \frac{1}{2} T \Theta \text{ (joules)}$$

2.9 Torsional resistance of single pile in layered soil

The analysis and solutions presented are based on Randolph's (1981) simplified elastic model of a beam on elastic foundation using the Winkler approximation.

2.10 Numerical solution of single pile subjected to simultaneous torsional and axial loads

The application of eccentric horizontal forces on the structures causes torsional forces on the pile foundation, apart from other complex loading conditions such as pullout loads, moments, and so on. Examples of such loading includes bridge piers, high rise buildings, electric transmission towers and offshore structures subjected to wave forces and wind, ship impacts and high speed vehicles (Azadi et al. 2008).

When group of pile is subjected to torsion, the piles undergo lateral displacement along with twisting and thus the applied load is transmitted to the pile head in the form of torsional and lateral force components (Basile 2010).

Piles can be loaded to failure more simply by torsional loading compared to other modes of loadings, which necessitates the significance of analyzing pile-soil-pile interactive performance under torsion (Zhang and Kong 2006; Zhang 2010).

2.10.1 Numerical analysis

Idealized problem is presented in fig.2.8a,b,c. A single vertical floating cylindrical pile having internal diameter D_i and external diameter D .

Young's modulus E_p , torsional rigidity $J_P G_P$ is fix in a elastoplastic subsoil medium up to depth L below the ground surface. Under the simultaneous actions of axial load V_t and torque T_t , the vertical shear stresses $\tau_v(z)$ and interface horizontal $\tau(z)$,

Base stresses $\bar{\tau}$ and $\bar{\sigma}$ are developed on vertical surface and the pile base. The primary objective is to assess the distribution of these stresses on the interface and then to compute displacements and other admissible parameters.

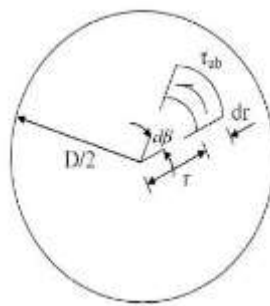


Fig 2.6: Idealized problem: determination of base resistance (Basack and Sankhasubhra Sen 2014)

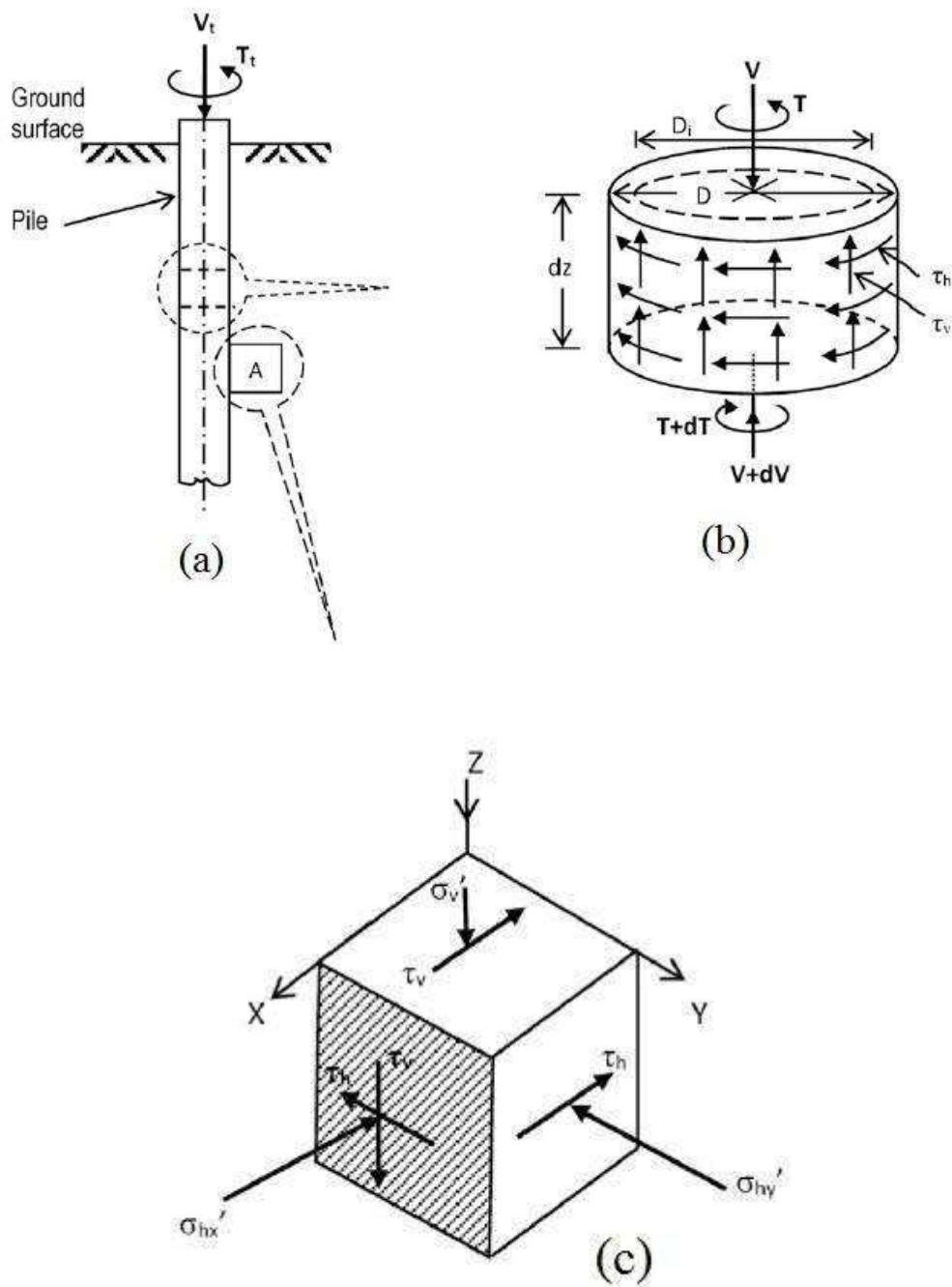


Fig 2.7: Theoretical considerations :(a) pile under combined loading ;(b) pile element with stresses on surface ;(c) typical soil element (Basack and Sankhasubhra Sen 2014)

Boundary element solution for pile-soil interactive performance under simultaneous axial loads and torsion has been developed, considering soil nonlinearity and effect of pile soil slippage. Comparison of BEM results with experimental data available and existing solutions justifies the power of the proposed model. From selected parameter study, the ultimate torsional pile capacity is found to be affected by axial load.

The ground line torque twist response has been observed as hyperbolic and continuously degrading with increase in the axial load.

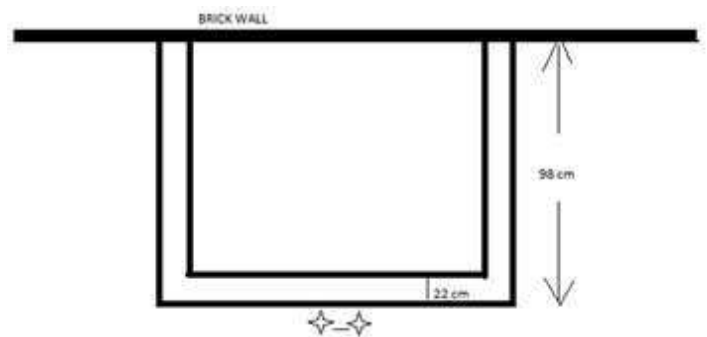
In cases of clay and sand, the horizontal and resultant shear stresses increases linearly with depth until a peak value is attained, following a sharp curvilinear decrement. The vertical shear-stress profiles are curvilinear and decrease with depth. Profile for twist angle is parabolic.

Chapter 3

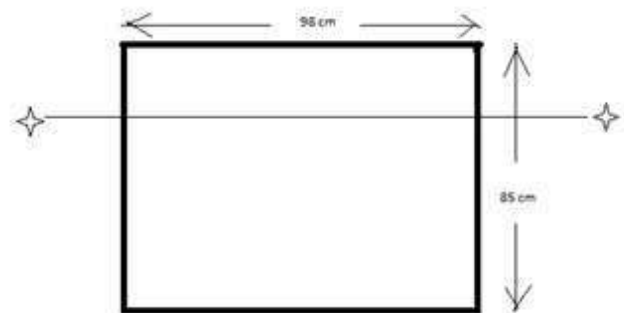
Experimental Setup

3.0 Construction of pit

Suitable site was selected, in the soil mechanics laboratory. Fig shows the construction of pit. Construction of pit was done by myself and my cousin brother Er. Prashant Kumar.



Cross section plan view of pit



Side view of brick pit

fig 3.1: real image of pit on left and plan view, side view of pit on right

Pit has length, breadth and depth of 98cm, 98cm, and 85cm respectively. Local building material such as cement, fine aggregates and coarse aggregates were transported to the site. Approximately 1 cubic meter of Yamuna sand was transported to the site of interest. Transported Yamuna sand was laid on the dry floor in layers. Then sand was dried under sun for a week.

3.1 Drying and filling of Yamuna sand

Approximately, 1 cubic meter of Yamuna sand was filled in the pit. It was transported to the site in polypropylene bags from building materials shop near DTU College. I have filled the pit in three layers. On the first day 3 bags of sand was transported to the site and then dried up for next 7 days and after drying it was filled in the pit. Similarly in next filling of 3 bags of sand it was firstly dried for one week and then filled in the pit. Then at last pit was filled with 4 dried sand bags ,total 10 Yamuna sand bags was filled in the pit to complete nearly 1 cubic meter sand volume.

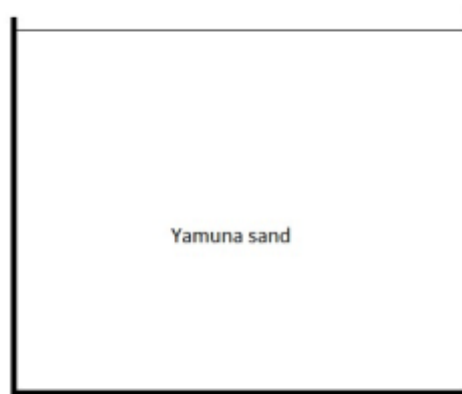


Fig 3.2 yamuna sand specimen

3.2 Placing of girders and inclined pulley

After filling the sand in the pit, the girders were transported to the site. I have used two T shaped steel channel sections which are 1.10 m in length each. They were fixed on the brick wall pit and each girder was hold fasted about 10 cm inside the laboratory wall.

Fig3.3: girders with pulley welded together





Fig3.4: girder fixed on top of brick wall and pulley inclined at 45° with vertical





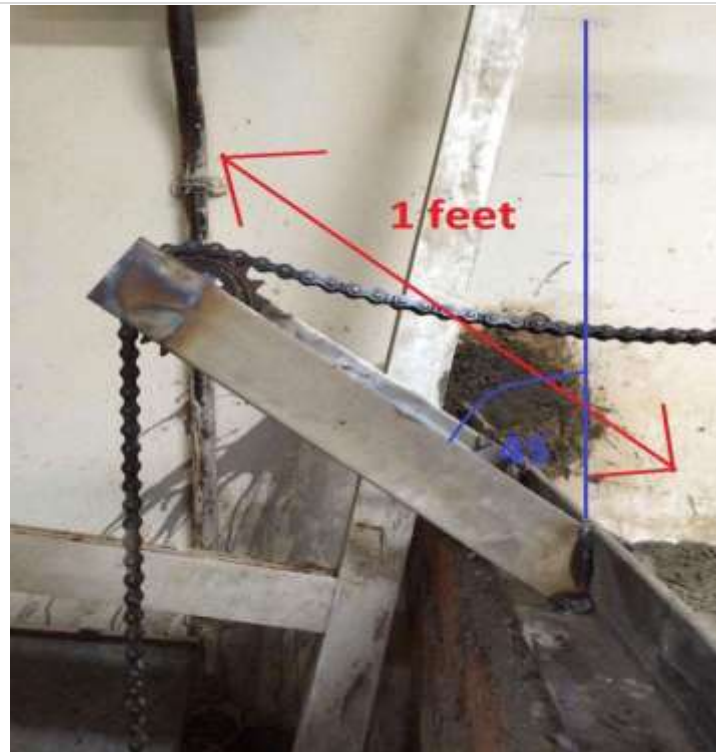


Fig3.6: pulley making an angle of 45° with vertical



Fig3.7: chain in high tension carrying heavy load to apply torque on pile

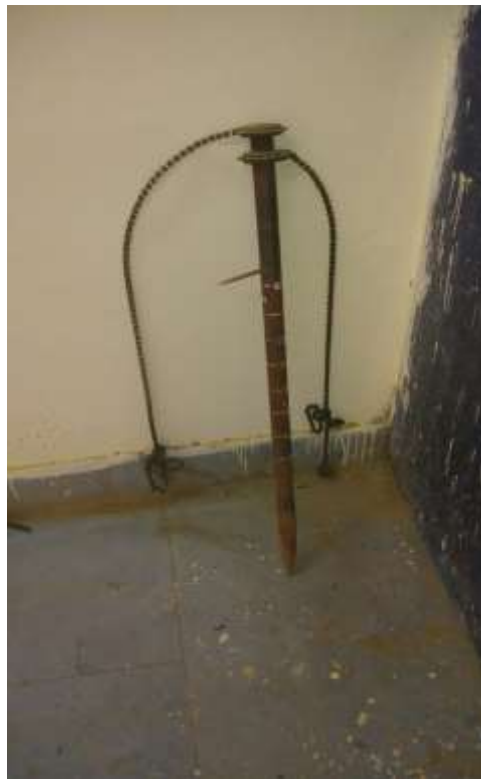
3.3 Manufacturing of single pile

Single pile was manufactured. Mild steel pile was used for manufacturing of the pile. Steel pile used is hollow of 30 mm diameter and 90 cm length.



Fig3.8: steel modal pile of 90cm length

A solid cone of mild steel is attached to the end of the hollow pile. Cone is provided so it can be driven into the soil easily. Solid cone is made with the help of cutter and lathe machine as shown in fig 3.9.



3.4 Arrangement to apply pure torsional force on the pile

Two sprockets are welded on the top most end of the steel pile .they are welded up and down in horizontal and chain is wrapped around each sprocket. Mechanism is made in such a manner that when both chains are pulled together by same force they will produce combined additive torsional force acting on the pile and steel pile will rotate.



Fig3.10: complete view of apparatus.

When loads are hanged on both the opposite sides of the chain, chain will be in tension and as per increasing load, torque acting on the pile also increases simultaneously. While torque acting on the pile, pile rotates on its longitudinal axis and angle of twist is calculated as shown in fig 3.13.



Fig3.11: calculation of angle of twist

3.5 Experimental procedure

Arrangement was also made so that standard weights may be loaded with the help of pulley and high tensile chains. Photo shows the arrangement of pile. Experiment is done on loose Yamuna sand. each day one set of experiment were performed, which included tests results and showing in graphical manner how angle of twist varies with defined loads while increasing the depth of the pile.

For each addition of weight on a hanger, angle of twist was noted in a field book.

Mathematically,

$$F = m \times g \text{ (N)}$$

$$T = 2 \times F \times r \text{ (N-m)}$$

Where, F = Applied force (N)

m = Mass loaded on hanger (kg)

g = Acceleration due to gravity (9.81 m/s^2)

T = torque applied (N-m)

$$r = \frac{1}{2}[\text{External pile diameter}] + [\text{thickness of the sprocket} + \frac{1}{2}\text{thickness of the chain}] = 3.5\text{cm}$$



Fig3.12: complete upper view of mechanism



Fig3.13: elevation view of mechanism producing torque in pile

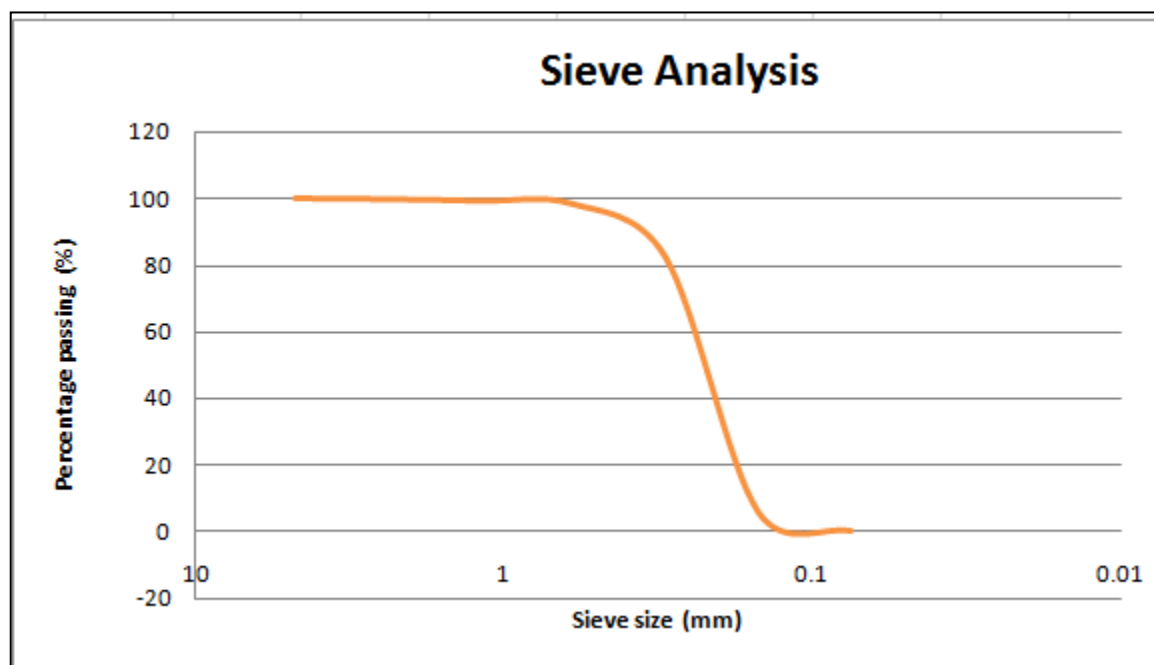
Chapter 4

Results and discussion**4.0 Sieve analysis**

Sieve analysis was performed in the laboratory of the sand sample taken from the site of interest and observation sheet is prepared as follows:-

S.No.	IS Sieve	Particle size D(mm)	Mass retained(g)	%Retained	Cumulative% retained	Cumulative% finer(N)
1.	4.75mm	4.75mm	0	0	0.00	100.00
2.	2.36mm	2.36mm	2.6	0.26	0.26	99.74
3.	1.18mm	1.18mm	4.70	0.47	0.76	99.24
4.	600 μ	0.600mm	8.75	0.88	1.67	98.33
5.	300 μ	0.300mm	154.25	15.43	17.64	82.36
6.	150 μ	0.150mm	740.80	74.08	94.34	5.66
7.	75 μ	0.075mm	54.60	5.46	100.00	0.00

Table 4.1: Sieve analysis



Graph 4.0: sieve analysis

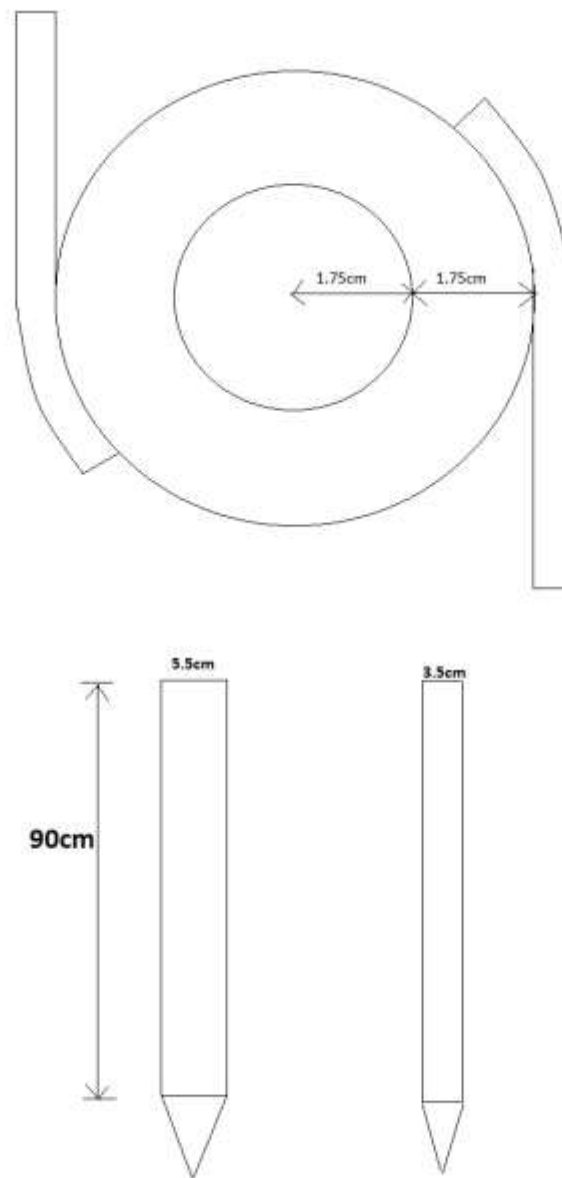


Fig 4.1

4.1 Experimental study of single pile

1. External pile diameter = 3.5 cm
2. Pile length = 90 cm
3. Pile depth inside Yamuna sand = 45 cm
4. Pile material = stainless steel
5. Pile thickness = 3 mm
6. Length of the spoke for measuring angle = 8 cm
7. Thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain} = 1.75 cm

$$8. r = \frac{1}{2}[\text{External pile diameter}] + [\text{thickness of the sprocket} + \frac{1}{2}(\text{thickness of the chain})] = 3.5\text{cm}$$

S no.	Mass (kg)	Force = mg (N)	Torque = 2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	3.87	0	0.017453	0.01693
2	7.13	69.95	5.92	2	0.034907	0.085521
3	10.11	99.18	5.97	3	0.043633	0.151407
4	12.17	119.39	9.14	7	0.069813	0.291819
5	12.74	124.98	9.53	8	0.10472	0.458149
6	14.45	141.75	10.51	10	0.122173	0.605978
7	15.58	152.84	11.08	12.5	0.15708	0.840376
8	16.31	160.00	11.32	16	0.226893	1.2706

Table4.2: torque applied and twist angle for depth 45cm of modal pile

1. External pile diameter = 3.5 cm
2. Pile length = 90 cm
3. Pile depth inside Yamuna sand = 50 cm
4. Pile material = stainless steel
5. Pile thickness = 3 mm
6. Length of the spoke for measuring angle = 8cm
7. Thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain} = 1.75 cm
8. $r = \frac{1}{2}$ [External pile diameter] + [thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain}] = 3.5cm

S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T \Theta$ (joule)
1	2.82	27.66	3.87	0	0.017453	0.01693
2	7.13	69.95	5.92	1	0.034907	0.085521
3	10.1	99.18	5.97	1.5	0.034907	0.121126
4	12.1	119.3	9.14	3	0.05236	0.218864
5	12.7	124.9	9.53	7	0.087266	0.381791
6	14.4	141.7	10.51	9	0.122173	0.605978
7	15.5	152.8	11.08	11	0.165806	0.887064
8	16.3	160.0	11.32	13	0.174533	0.977384

Table4.3: torque applied and twist angle for depth 50cm of modal pile

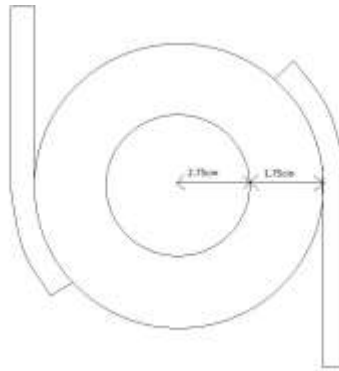
Fig4.2: pile interested
inside sand to 55cm of
depth



1. External pile diameter = 3.5 cm
2. Pile length = 90 cm
3. Pile depth inside Yamuna sand = 55 cm
4. Pile material = stainless steel
5. Pile thickness = 3 mm
6. Length of the spoke for measuring angle = 8cm
7. Thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain} = 1.75 cm
8. $r = \frac{1}{2}$ [External pile diameter] + [thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain}] = 3.5cm

S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist θ	Angle of twist θ (radian)	Strain energy $U = \frac{1}{2}T\theta$ (joule)
1	2.82	27.66	3.87	0	0.017453	0.01693
2	7.13	69.95	5.92	1	0.017453	0.042761
3	10.11	99.18	5.97	1	0.034907	0.121126
4	12.17	119.39	9.14	2	0.043633	0.182387
5	12.74	124.98	9.53	3	0.069813	0.305433
6	14.45	141.75	10.51	7	0.10472	0.51941
7	15.58	152.84	11.08	8	0.122173	0.653626
8	16.31	160.00	11.32	10	0.139626	0.781908

Table4.4: torque applied and twist angle for depth 55cm of modal pile



1. External pile diameter = 5.5 cm
2. Pile length = 90 cm
3. Pile depth inside Yamuna sand = 45 cm
4. Pile material = stainless steel
5. Pile thickness = 3 mm
6. Length of the spoke for measuring angle = 8cm
7. Thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain} = 1.75 cm
8. $r = \frac{1}{2}$ [External pile diameter] + [thickness of the sprocket + $\frac{1}{2}$ {thickness of the chain}] = 4.5cm

S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	4.98	0	0	0
2	7.13	69.95	7.6	1.5	0.008727	0.033588
3	10.11	99.18	10.2	4	0.017453	0.095144
4	12.17	119.39	11.7	8	0.034907	0.229224
5	12.74	124.98	12.2	9	0.043633	0.299897
6	14.45	141.75	13.45	10.5	0.07854	0.611995
7	15.58	152.84	14.18	11	0.10472	0.880154
8	16.31	160.00	14.49	13	0.122173	1.07483

Table4.5: torque applied and twist angle for depth 55 cm of modal pile

9. External pile diameter = 5.5 cm
10. Pile length = 90 cm
11. Pile depth inside Yamuna sand = 50 cm
12. Pile material = stainless steel
13. Pile thickness = 3 mm
14. Length of the spoke for measuring angle = 8cm
15. Thickness of the sprocket¹₂ + {thickness of the chain} = 1.75 cm
16. $\frac{1}{2}r = [\text{External pile diameter}] + [\text{thickness of the sprocket}^1_2 + \{\text{thickness of the chain}\}] = 4.5\text{cm}$

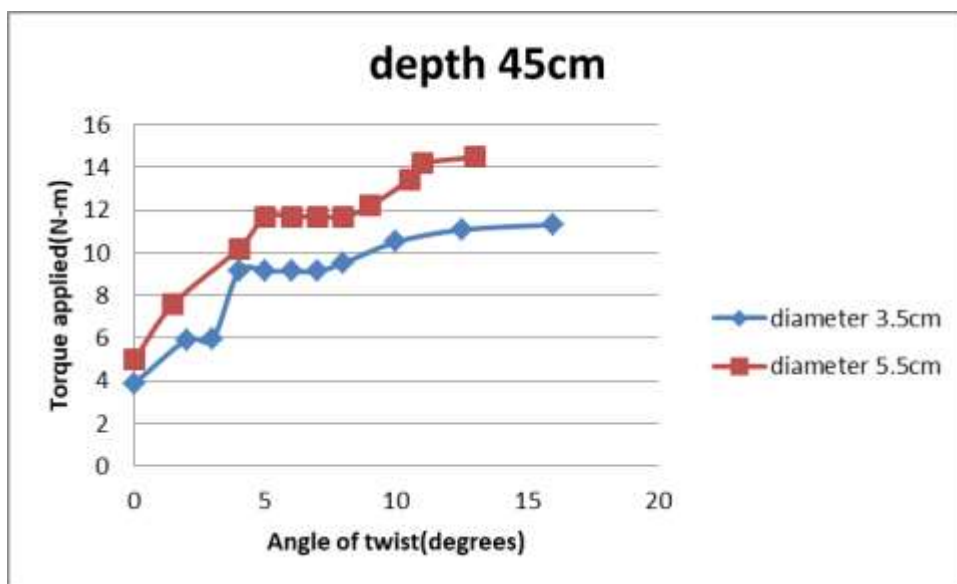
S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	4.98	0	0	0
2	7.13	69.95	7.6	0.5	0	0
3	10.11	99.18	10.2	1	0.008727	0.047572
4	12.17	119.39	11.7	4	0.017453	0.114612
5	12.74	124.98	12.2	8	0.034907	0.239917
6	14.45	141.75	13.45	10	0.05236	0.407997
7	15.58	152.84	14.18	11	0.061087	0.513423
8	16.31	160.00	14.49	12	0.069813	0.614188

Table4.6: torque applied and twist angle for depth 50 cm of modal pile

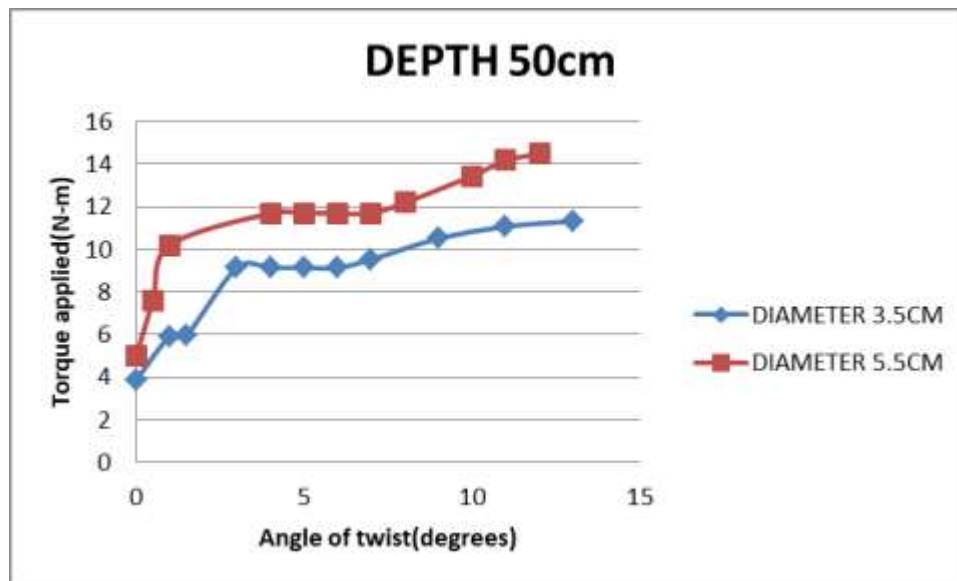
17. External pile diameter = 5.5 cm
18. Pile length = 90 cm
19. Pile depth inside Yamuna sand = 55 cm
20. Pile material = stainless steel
21. Pile thickness = 3 mm
22. Length of the spoke for measuring angle = 8cm
23. Thickness of the sprocket₂ + {thickness of the chain} = 1.75 cm
24. $\frac{1}{2}r$ = [External pile diameter] + [thickness of the sprocket₂ + {thickness of the chain}] = 4.5cm

S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	4.98	0	0	0
2	7.13	69.95	7.6	0	0	0
3	10.11	99.18	10.2	0.5	0.017453	0.095144
4	12.17	119.39	11.7	2	0.05236	0.343836
5	12.74	124.98	12.2	4	0.061087	0.419855
6	14.45	141.75	13.45	8	0.069813	0.543995
7	15.58	152.84	14.18	9	0.087266	0.733462
8	16.31	160.00	14.49	11	0.10472	0.921283

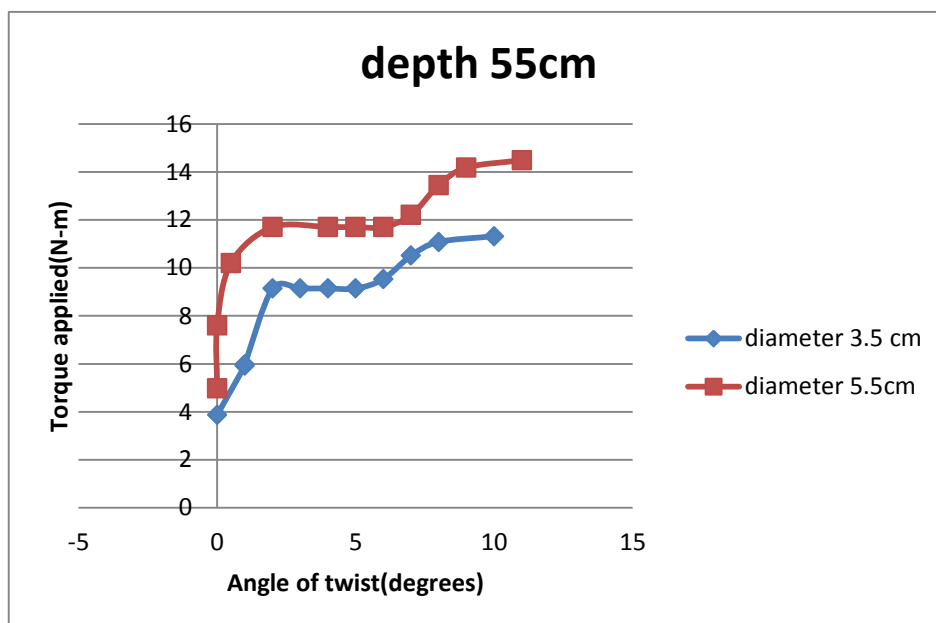
Table4.7: torque applied and twist angle for depth 55 cm of modal pile



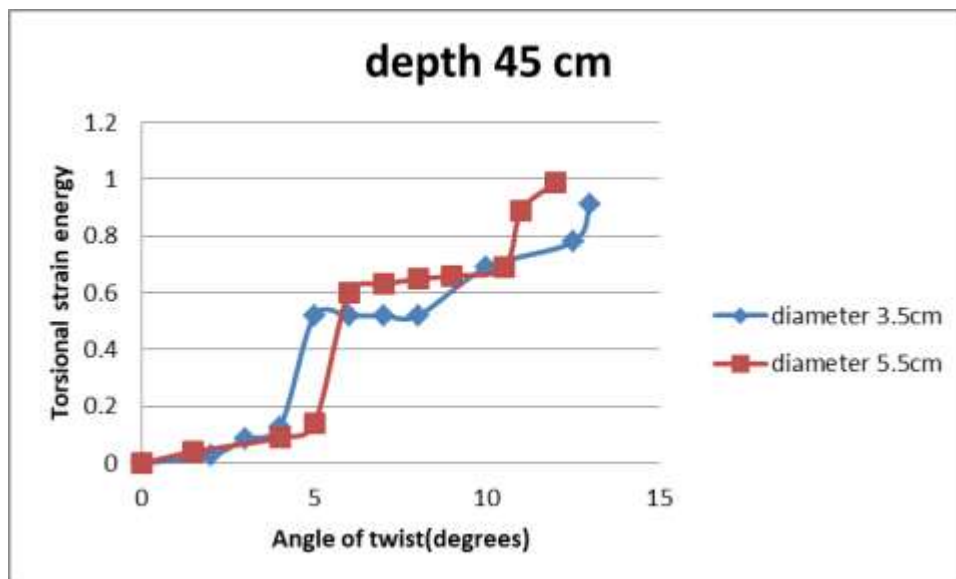
Graph .2: comparison of angle of twist of two different diameter piles at depth 45 cm



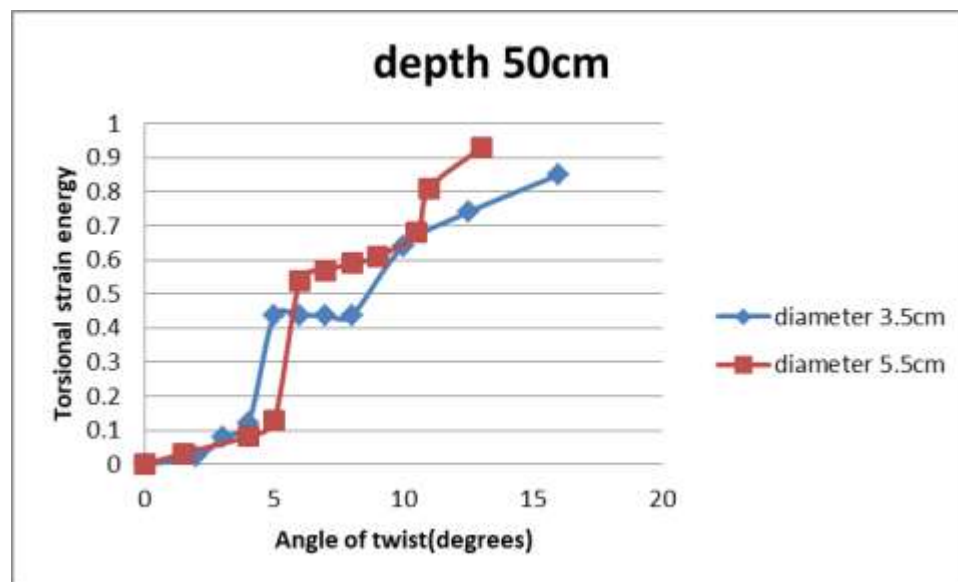
Graph .3: comparison of angle of twist of two different diameter piles at depth 50 cm



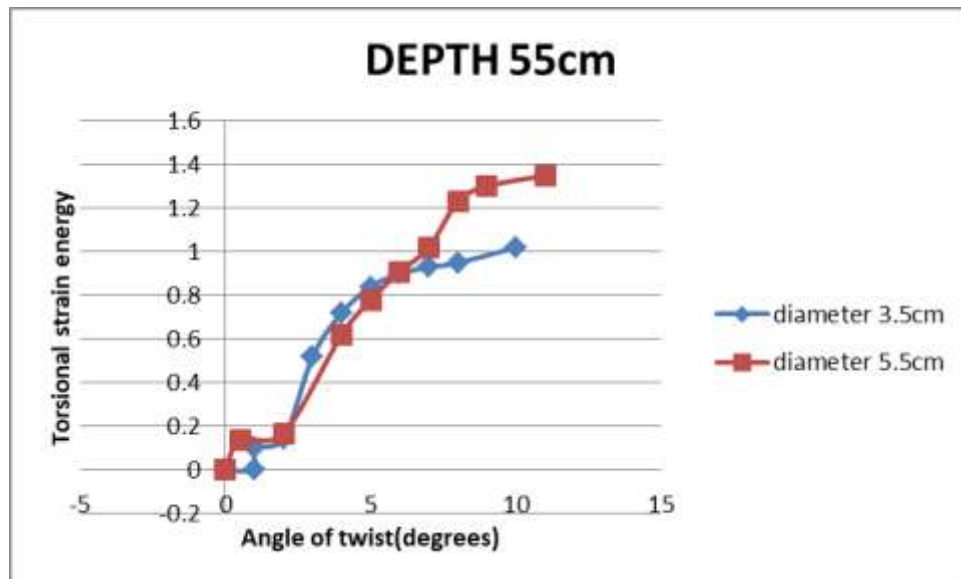
Graph 4: comparison of angle of twist of two different diameter piles at depth 55 cm



Graph 5: comparison of torsional strain energy of two different dia. Piles at depth 45cm



Graph 6: comparison of torsional strain energy of two different dia. Piles at depth 50cm



Graph 7: comparison of torsional strain energy of two different dia. Piles at depth 55cm

Conclusion

1. It is investigated that resistance of steel pile subjected to torque, increases with increase in angle of twist.
2. It has been observed that in working model cylindrical steel pile is resisted to rotating because of skin friction when torque is applied and critical angle is nearly 3.5 degree for 3.5 cm diameter pile
3. It has been observed that in working model, steel pile is resisted to rotating because of skin friction when torque is applied and critical angle is nearly 4.5 degree for 5.5 cm diameter pile
4. It has been observed as we increase the diameter of the pile strain energy increases results in increase in skin friction.
5. Angle of twist is minimum at largest depth and at largest diameter.

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