"EFFECT OF TAPERING ON SKIN FRICTION OF PILE OF VARYING LENGTH"

A DISSERTATION

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In partial fulfillment of the requirement for the award of the degree of

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In

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Submitted by

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Contents

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Finally I express gratitude to my family for their love and encouragement. I have received so much personal support from family and friends.

Date:04/07/2017 (Yogesh kumar saharan)

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CERTIFICATE

This is to certify that major project report entitled "Effect of tapering 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: 04/07/2017

Yogesh kumar saharan

Roll no: 2K15/GTE/20

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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ABSTRACT

Development of building presents several problems related to the design and assessment of pile foundations. Specially tall buildingsbplay a key rolenin current urban strategies and regeneration. 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.

The Design and analysis of pile foundation present a complex problem to the engineers because of several factors that affect the foundation behaviour. Such factors include mode of loading, soil properties, pile geometry, placement and method of construction .The mode and magnitude of loads transferred from the super structures will influence the selection of pile foundation to resist the imposed loads. Torsional forces are also acting on the pile and IS 2911 for pile foundation has not 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) Comparison of angle of twist and torsional strain energy between tapered pile and cylindrical pile of same diameter

(3)Experimentally to examine basic pile–soil interactions in the modal pile subjected to torque in the context of study torque/angle of twist.

A mechanism of applying torque to a single pile was fabricated. Experiments on two piles were performed. Torque on piles was applied using the above said mechanism. Experiments were performed by increasing the depth of piles. When we increased the depth of pile at regular intervals with the different torques for increasing angle of twist till the failure angle of twist is achieved.

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Chapter 1

INTRODUCTION

Torsional forces can be transferred to the foundation piles by action of eccentric lateral loading.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. 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).

Bored piles of large diameter 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 either construction related problems such as short piles, toe debris, and over break cavities or misassessment of in situ conditions during design.

Key of bridges are known as piers, 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.

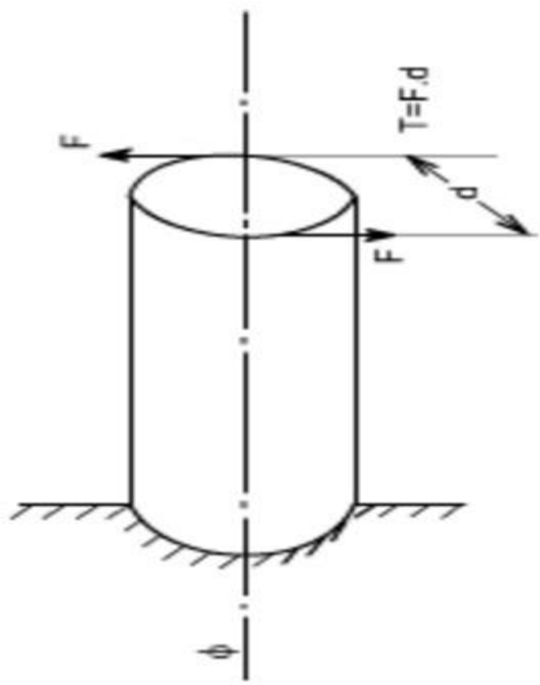


Fig2.0: Torsional force acting on circular shaft

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.

2.3 **Generation of shear stresses**

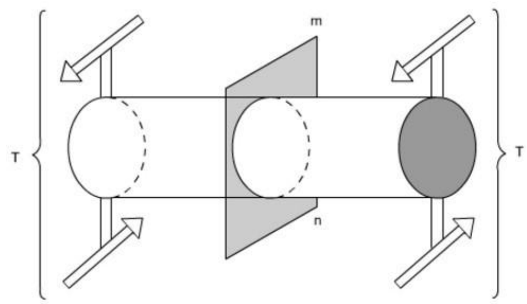


Fig2.1: Here the cylindrical member or a shaft is in static equilibrium where T is the resultant external torque acting on the member. Let the member be imagined to be cut by some imaginary plane 'mn'.

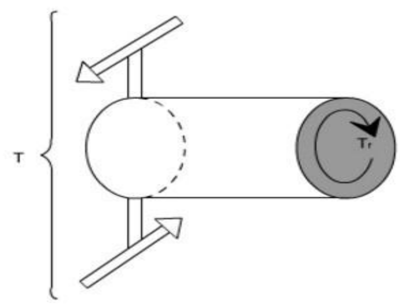


Fig2.2: When the plane 'mn' cuts remove the portion on R.H.S. and we get a fig2.2. Now since the entire member is in equilibrium, therefore, each portion must be in equilibrium. Thus, the member is in equilibrium under the action of resultant external torque T and developed resisting Torque T_r.

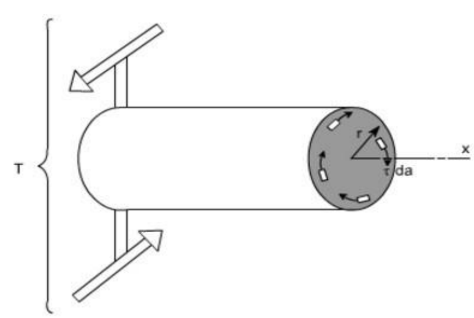


Fig2.3: The Figure shows that how the resisting torque T_r is developed. The resisting torque T_r is produced by virtue of an infinites mal shear forces acting on the plane perpendicular to the axis of the shaft. Obviously such shear forces would be developed by virtue of sheer stresses.

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 sheer 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.

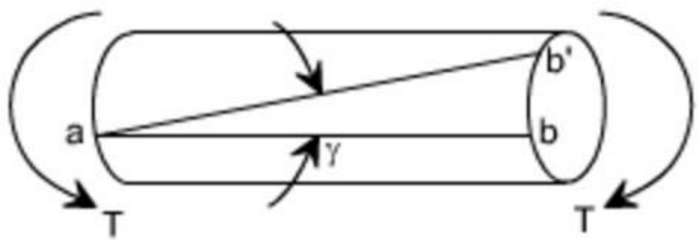


Fig2.4: shaft under torsion showing shearing strain

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, than the angle θ through which one end of the bar will twist relative to the other is known is the angle of twist. θ in radian.

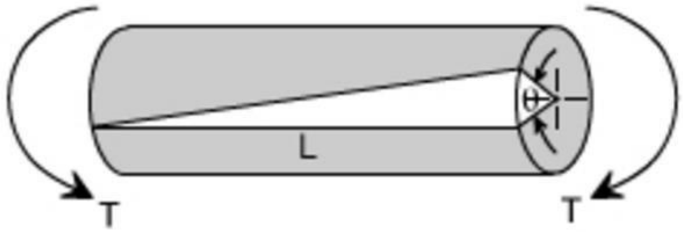


Fig2.5: shaft under torsional force

2.8 **Relationship in Torsion**

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

T = Torsion force (N-m)

J = Polar moment of inertia (m^4)

Polar moment of inertia for hollow cylindrical shaft = $J = \frac{\pi}{32}\left(D^4 - d^4\right)$

D= external diameter

d= internal diameter

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

τ = Shear stress (MPa)

G = shear modulus (GPa)

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

L = Length of shaft (m)

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

2.9 **Torsional resistance of single pile in layered soil**

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

2.10 **Numerical solution of 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 $\tau_t(z)$,

Base stresses τ_b and σ_b 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.

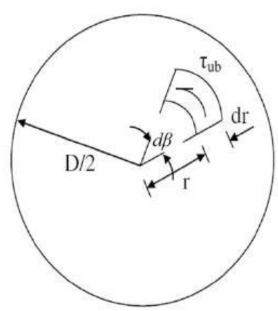


Fig 2.6: Idealized problem: determination of base resistance (Basack and Sankhasubhra Sen 2014)

Boundary element solution for picture 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.

TAPERED PILES

If a friction pile subjected to a downward vertical load, has its sides parallel, the transfer of load to the surrounding soil is entirely by the shear at the interface. However, if such a pile is provided with a *taper* a part of the downward load is transferred by direct bearing on the sides over the area shown in the figure. This bearing results in an increased normal pressure when compared to the pile without taper, which consequently increases the frictional component of the hearing resistance. Tapered piles are therefore very effective in frictional soils such as sand. On the other hand, in clay, the difference between the capacities of prismatic and tapered piles will be marginal or nil, since the adhesion component of shearing resistance is independent of the normal pressure. On the side of tension, however, the advantage in compression is lost as can be realised from (in which the pile width is exaggerated by compressing its length), where heavy resistance is encountered in compression, but virtually no resistance in tension. A *wedge* which is difficult to drive in the face of increasing resistance, but easy to pull out, is another *analogy* for explaining the behaviour of a tapered pile.

A tapered pile actually represents a more equitable distribution of material in the pile than a uniform pile, in the frictional mode of resisting a compressive load and also in resisting a horizontal load at the top. If the friction generated on the pile surface is uniform or uniformly increasing with depth, the *axial force* diagram increases *uniformly* (triangular) or *parabolically* towards the top, respectively. In either case , a *tapered pile* with its cross section increasing towards the top makes for a more *efficient* utilisation of the pile material. In the same way, under a horizontal load at the top, the flexural effects of deformation, bending moment and shear force are maximum at the top and decreases in a *periodic* form very fast with depth. Hence from the point of view of bending also, a *tapered pile* represents a more optimum distribution of the pile material.

Extensive studies involving both theoretical (by the finite element method) and experimental investigations on tapered piles with different geometrical shapes of cross section, such as *square*, *circular* and *triangular*, by Kurian and Srinivas (1995) have shown that for the same material input, he performance of the *tapered pile* is much *superior* in terms of both bearing capacity and settlement, to the corresponding piles of uniform cross section, under compressive axial load, in sand. In each case, piles

in the *displacement* mode presented much better performance than *replacement* piles. A significant finding has been that *triangular piles* outperform the other shapes. These studies have been extended for horizontal loads, where tapered displacement piles again revealed their superiority, thanks to the more equitable distribution of pile material at the top where bending effects are the highest.

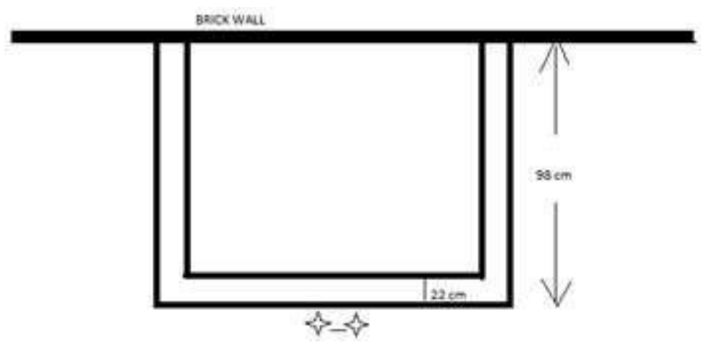
For a quantitative picture of the findings from these investigations reference is invited to Kurian (2013: Sec.2.1.1).

Chapter 3

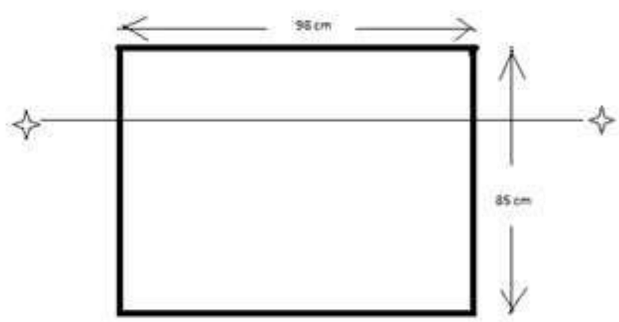
Experimental Setup

- **DIMENSION OF PPPP P PIT**

Suitable site was selected, in the soil mechanics laboratory. Fig shows the dimension of pit.



Cross section plan view of pit

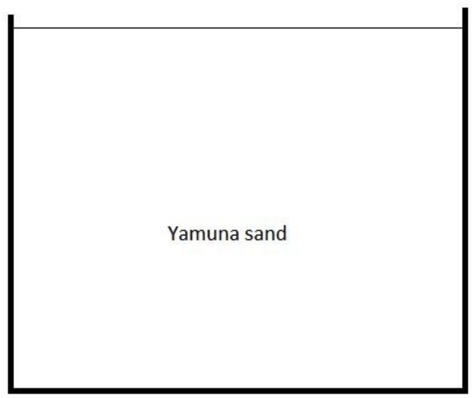


Side view of brick pit fig 3.1: real image of pit on left and plan view, side view of pit on right

Pit has length, breadth and depth of 98cm, 98cm, and 85cmrespectively. 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 weak.

- ## 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 weak 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.



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.

Fig3.2: girder fixed on top of brick wall and pulley inclined at 45° with vertical

Fig 3.3:view of tapered pile inserted in
The pit

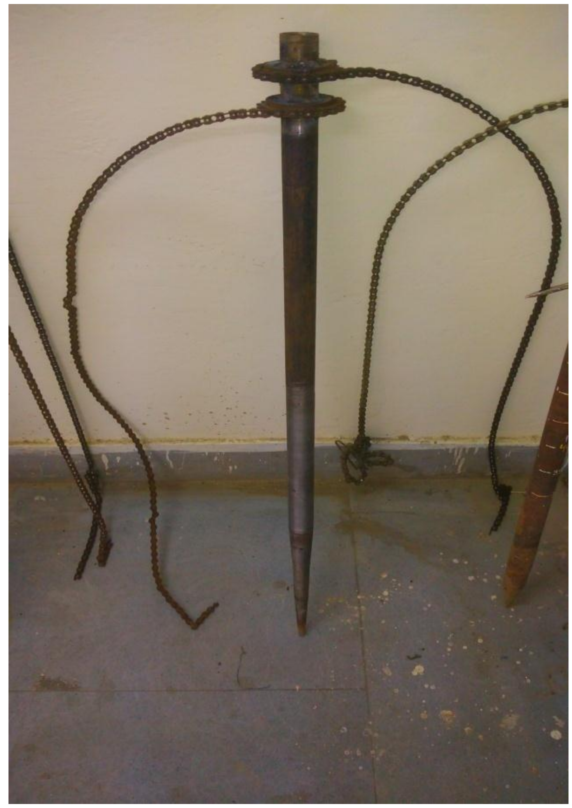


Fig.3.4: Tapered pile

Fig 3.5: view of cylindrical
Pile in pit

Fig 3.6 : Myself putting load on piles

Fig 3.7: myself noting down the angle of twist

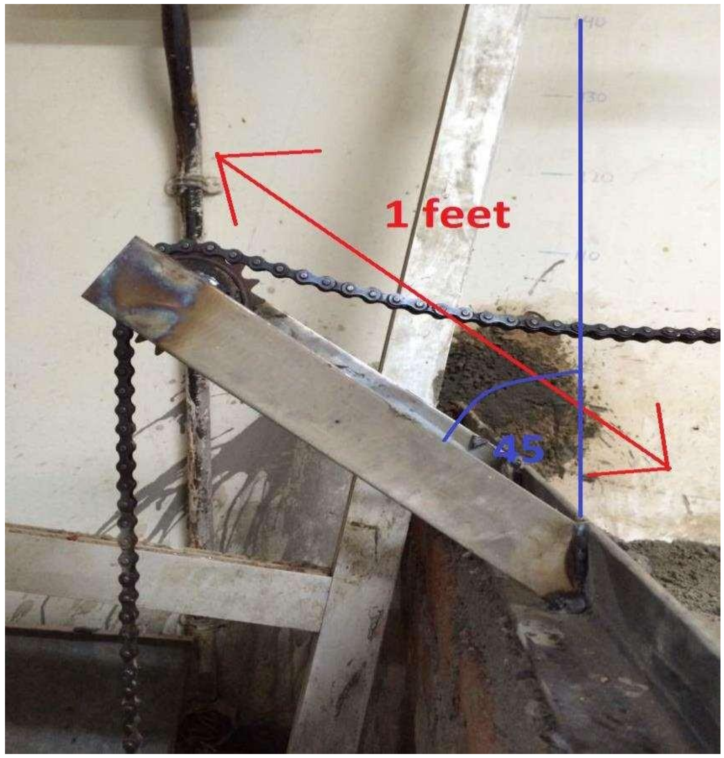


Fig3.8: pulley making an angle of 45° with vertical

Fig3.9: chain in high tension carrying heavy load to apply torque on pile

- ## Manufacturing of 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.

Fig 3.10: Lathe machine on which pile is fabricated

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.

- ## 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.

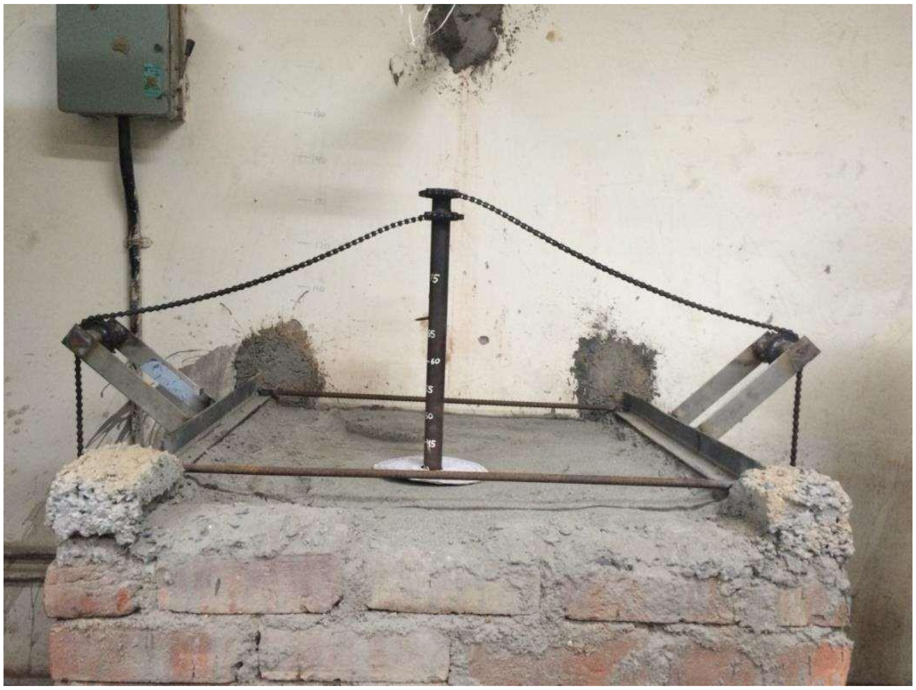


Fig3.11: complete view of apparatus.

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.

Fig3.12: calculation of angle of twist

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

Fig3.13: complete upper view of mechanism

Fig3.14: elevation view of mechanism producing torque in pile

Chapter 4

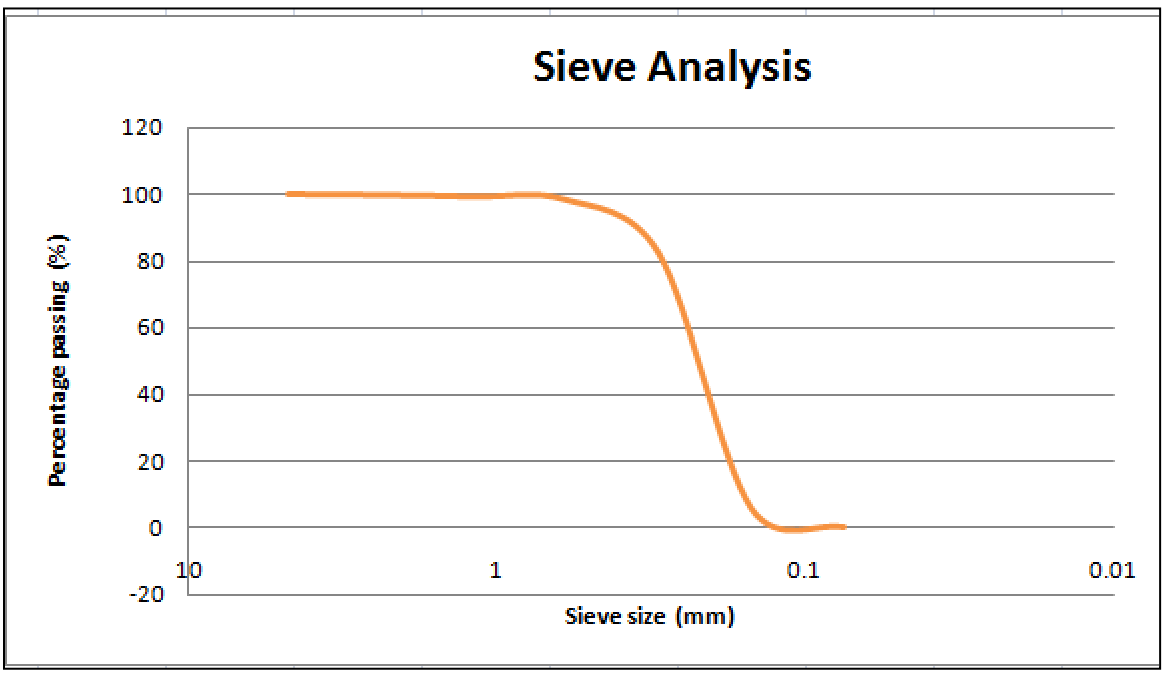
Results and discussion

4.0 **Sieve analysis a**

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.	600µ	0.600mm	8.75	0.88	1.67	98.33
5.	300µ	0.300mm	154.25	15.43	17.64	82.36
6.	150µ	0.150mm	740.80	74.08	94.34	5.66
7.	75µ	0.075mm	54.60	5.46	100.00	0.00

Table 4.1: Sieve analysis



Graph 4.0: sieve analysis

4.1 Experimental study of pile

1. External tapered 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 = 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

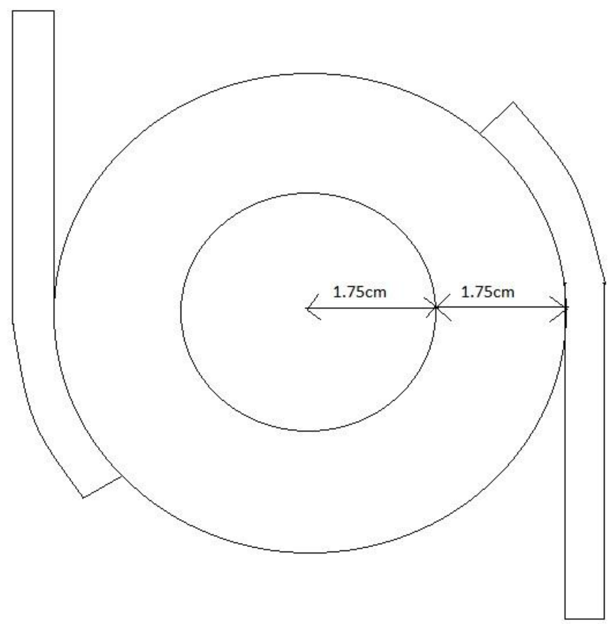


Figure 4.1: elevation of tapered pile

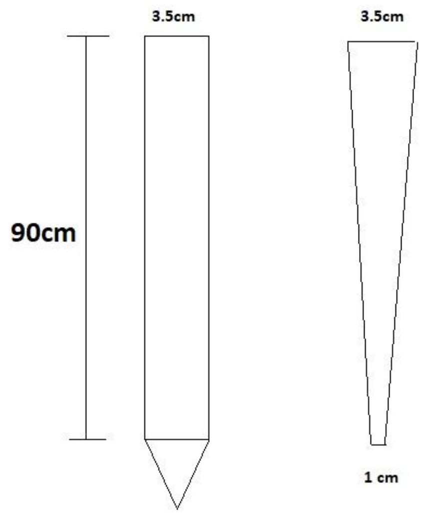


Figure 4.2 : dimension of cylindrical pile and tapered pile

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 1/2Tϴ (joule)
1	2.82	27.66	1.94	0	0	0
2	5.64	55.33	3.87	1	0.0174	0.0515
3	7.13	69.95	4.90	2.5	0.0348	0.1038
4	8.62	84.567	5.92	3	0.1046	0.4780
5	10.111	99.186	6.94	9	0.1395	0.6647
6	11.67	113.899	7.97	11	0.1482	0.7787
7	12.17	119.333	8.36	12	0.1918	1.0625
8	13.38	130.57	9.14	12.5	0.2267	1.2831

Table4.2: Torque applied and twist angle for depth 50 cm of tapered pile of 3.5 cm dia.

–

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 1/2Tϴ (joule)
1	2.82	27.66	1.94	0	0	0
2	5.64	55.33	3.87	2	0.0173	0.102662
3	7.13	69.95	4.90	3	0.0261	0.155294
4	8.62	84.56	5.92	3.5	0.0348	0.046
5	10.1	99.18	6.94	4	0.1217	0.582155
6	11.6	113.8	7.97	10	0.1558	0.825453
7	12.1	119.3	8.36	10	0.1746	1.063604
8	13.3	130.5	9.14	13	0.1919	1.481785

Table4.3: Torque applied and twist angle for depth 55 cm of tapered pile of 3.5 cm dia.

S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Ø	Angle of twist Ø (radian)	Strain energy U = 1/2 TØ (joule)
1	2.82	27.66	1.94	0	0	0
2	5.64	55.33	3.87	.5	0	0
3	7.13	69.95	4.90	1	0.069907	0.204196
4	8.62	84.567	5.92	2	0.078087	0.359165
5	10.111	99.186	6.94	2.5	0.097738	0.465724
6	11.67	113.899	7.97	3	0.143117	0.75208
7	12.17	119.333	8.36	8	0.15708	0.870221
8	13.38	130.57	9.14	11	0.18326	1.037249

Table4.4: Torque applied and twist angle for depth 60 cm of tapered pile of 3.5 cm dia.

1. External cylindrical 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 = 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 (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	1.94	1	0.017453	0.043459
2	5.64	55.33	3.87	3.5	0.061087	0.232129
3	7.13	69.95	4.90	6.4	0.111701	0.569675
4	8.62	84.567	5.92	8.2	0.143117	0.837234
5	10.111	99.186	6.94	9.5	0.165806	1.011418
6	11.67	113.899	7.97	13	0.226893	1.525854
7	12.17	119.333	8.36	16.4	0.286234	2.029399
8	13.38	130.57	9.14	19.5	0.340339	2.465758

Table4.5: torque applied and twist angle for depth 50cm on cylindrical pile.

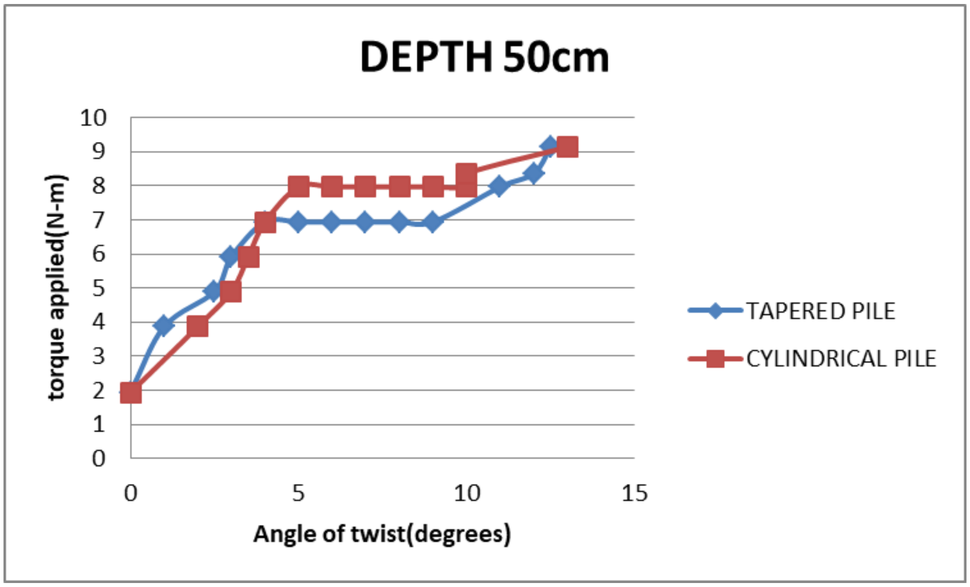
S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy U = 1/2 TΘ(joule
1	2.82	27.66	1.94	0.5	0.008727	0.013298
2	5.64	55.33	3.87	2	0.034907	0.134354
3	7.13	69.95	4.90	3.5	0.061087	0.333005
4	8.62	84.567	5.92	4.5	0.07854	0.515754
5	10.111	99.186	6.94	7	0.122173	0.839711
6	11.67	113.899	7.97	10.5	0.18326	1.427988
7	12.17	119.333	8.36	12.5	0.218166	1.833654
8	13.38	130.57	9.14	14.5	0.253073	2.226433

Table4.6: torque applied and twist angle for depth 55cm on cylindrical pile.

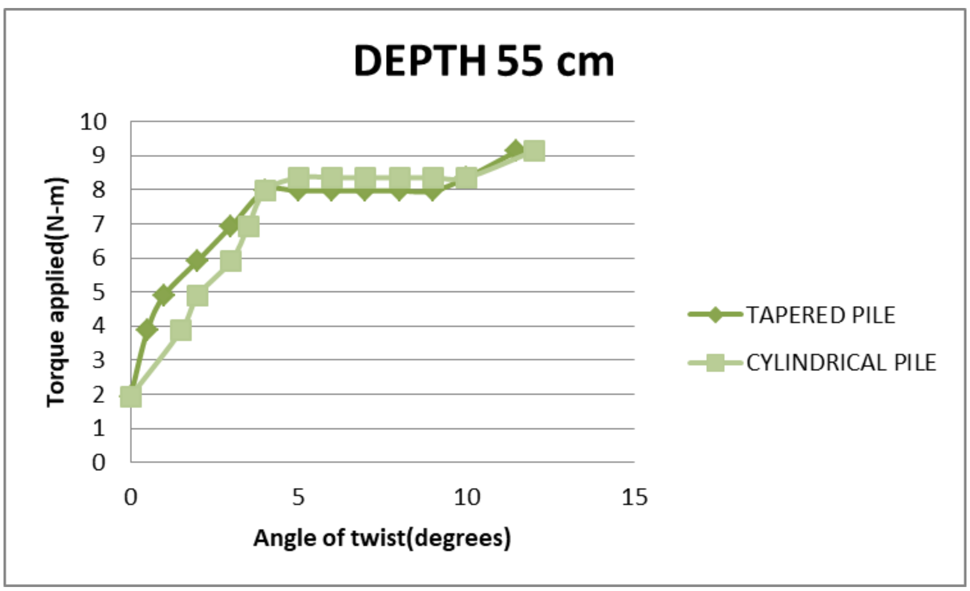
S no.	Mass (kg)	Force = mg (N)	Torque =2 x F x r (N-m)	Angle of twist Θ (degree)	Angle of twist Θ (radian)	Strain energy $U = \frac{1}{2}T\Theta$ (joule)
1	2.82	27.66	1.94	0	0	0
2	5.64	55.33	3.87	1	0.017453	0.066323
3	7.13	69.95	4.90	2.5	0.043633	0.222529
4	8.62	84.567	5.92	4	0.069813	0.408407
5	10.111	99.186	6.94	5.5	0.095993	0.585558
6	11.67	113.899	7.97	6	0.10472	0.70424
7	12.17	119.333	8.36	9	0.15708	1.113695
8	13.38	130.57	9.14	10	0.174533	1.264491

Table4.7: torque applied and twist angle for depth 60cm on cylindrical pile.

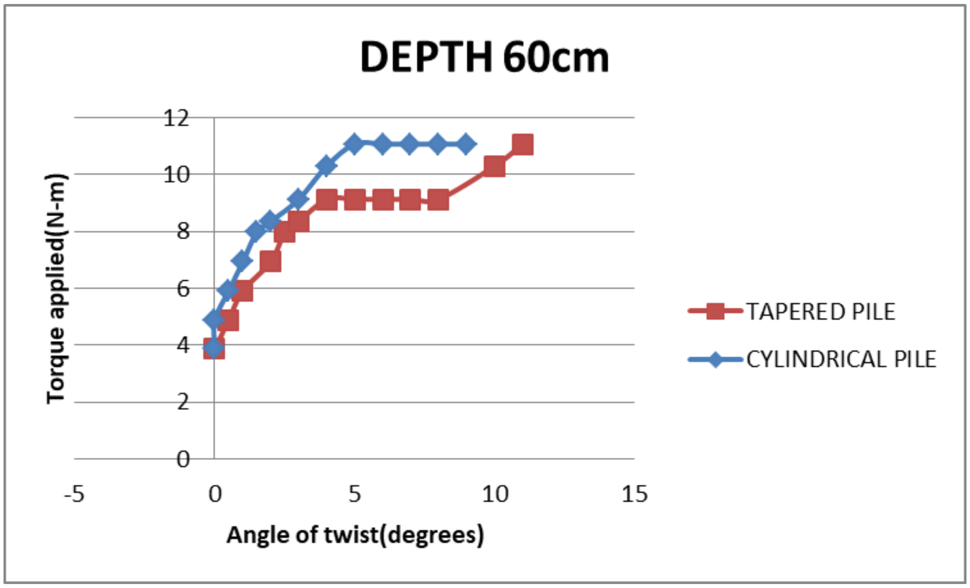
GRAPHS



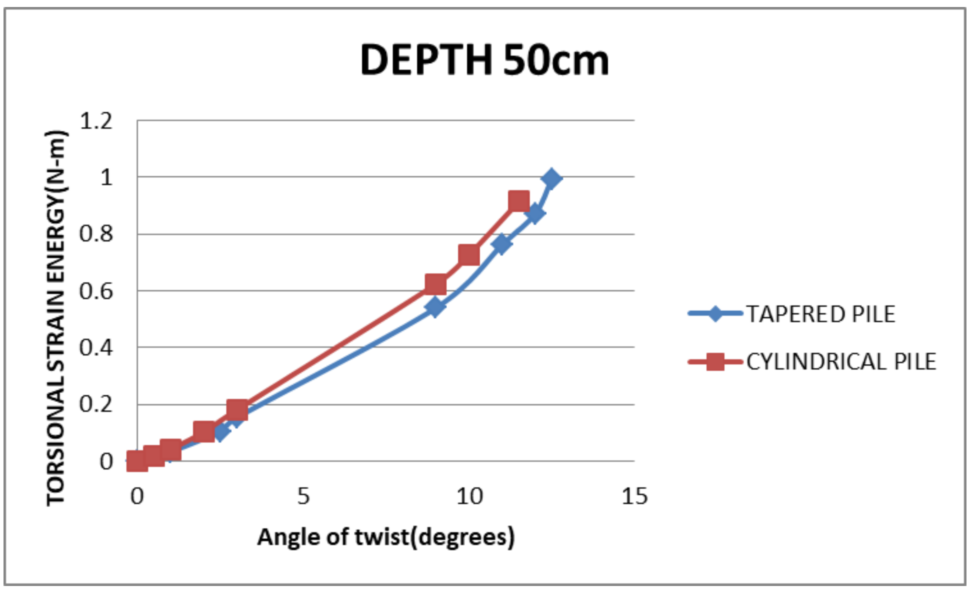
Graph 4.1: comparison of angle of twist in tapered and cylindrical pile at depth 50cm



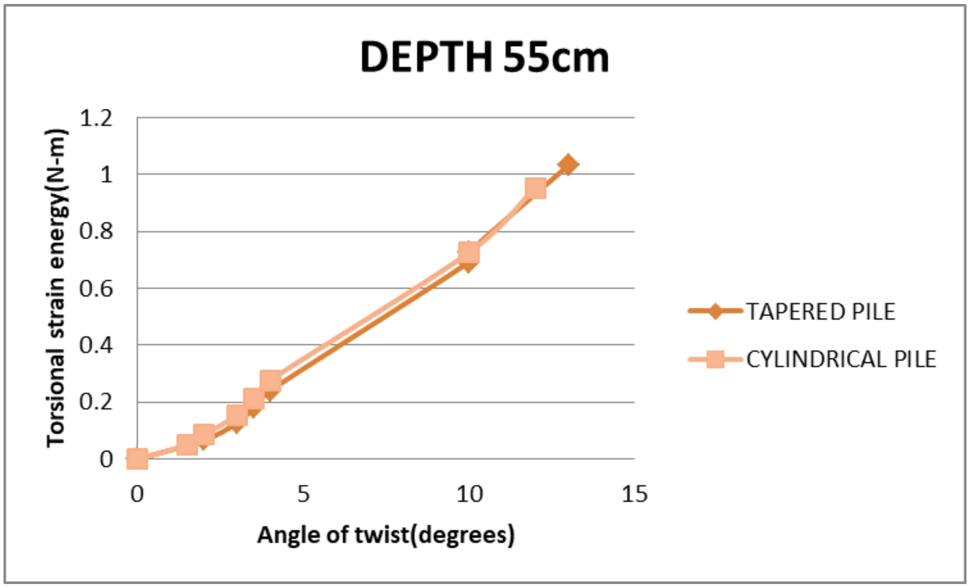
Graph4. 2: comparison of angle of twist in tapered and cylindrical pile at depth 55cm



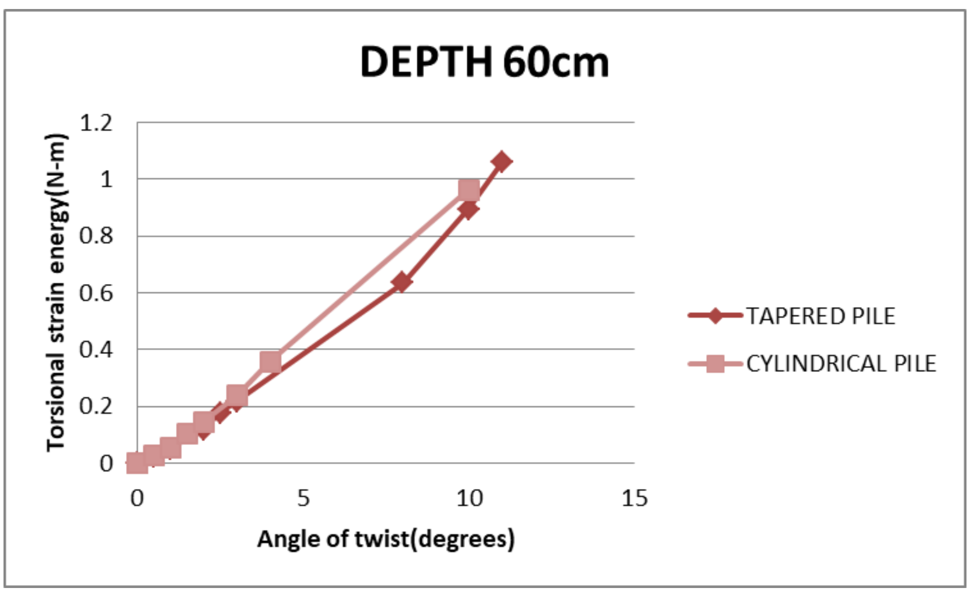
Graph4. 3: comparison of angle of twist in tapered and cylindrical pile at depth 60cm



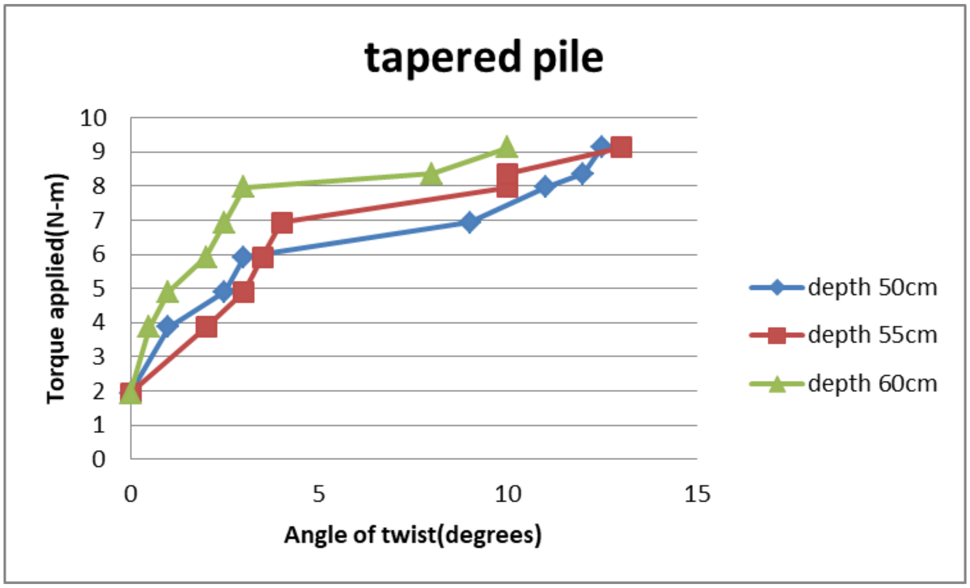
Graph4. 4: comparison of strain energy of cylindrical and tapered piles



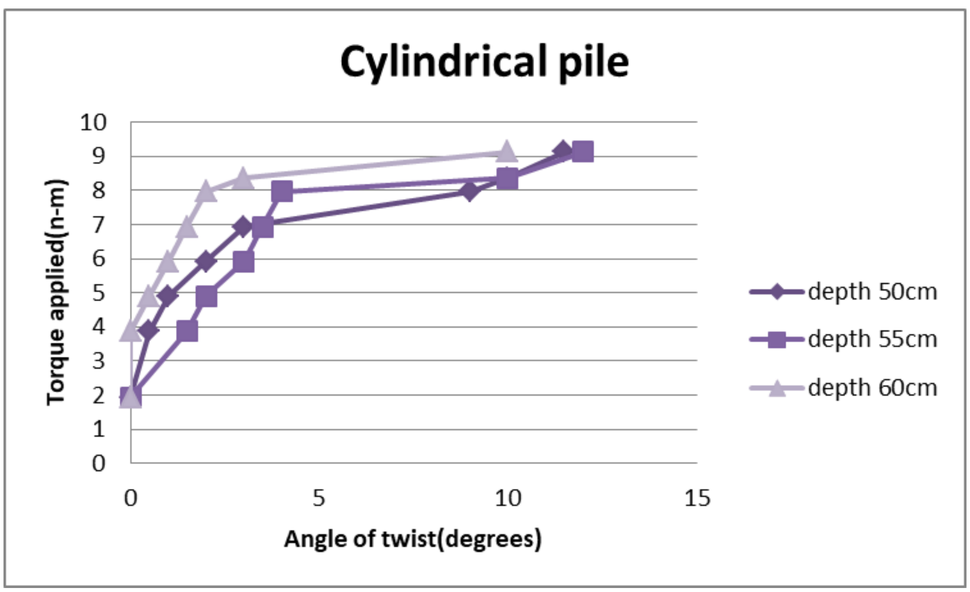
Graph 4.5: comparison of torsional strain energy between tapered and cylindrical piles at depth 55cm



Graph4. 6 : comparison of torsional strain energy between tapered and cylindrical piles at depth 60cm



Graph 4.7: comparison of angle of twist of tapered pile at different depth



Graph4. 8: comparison of angle of twist of cylindrical pile at different depth

CHAPTER 5

conclusion

1. It is investigated that resistance of steel pile subjected to torque, increases with increase in angle of twist
2. Critical angle of twist is less in tapered pile as compare to cylindrical pile.
3. Critical angle of twist is 3 degree in tapered pile and 4 degree in cylindrical pile
4. As we increases length of piles in soil angle of twist decreases and also torsional strain energy

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