Ultimate Pullout Capacity of Pile

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Abstract— From the review, it was seen that systematic investigations on the quantitative influence of the parameters such as length to-diameter ratio, pile friction angle and behavior of the pile under pulling load. In this current study represents experimental method to predict pullout capacity of pile such as field testing. However, the high cost measured both in time and money for obtaining high quality data from full-scale field tests and considering the large number of variable involved to determine if accurate data could be obtained by conducting model tests in the field. In the absence of resources and high cost of testing model, small-scale machine is made to test piles by using this machine we can predict behavior of pile, embedded in soil. Field model testes have been carried out on single concrete pile of same cross-sectional area with different surface area. In which piles having length 600 mm, 800 mm and 1000 mm with 180 mm diameter, with L/D ratio 3.33, 4.44, 5.55. Semi-empirical approaches based on the experimental observations would be helpful for predicting the ultimate resistance of piles. This Study presents a summary of soil conditions, experimental model to predict pull out capacity, results of the cast in situ tests, a description of the installation and uplift testing of pile and comparison between predicted and experimentally found ultimate uplift capacity. From the analysis of piles embedded in homogeneous soil.

Key words: Pullout Capacity, Pile, Vertical Displacement, Shaft Friction, L/D Ratio

I. Introduction

Extensive theoretical and experimental investigations have been carried out over the last few decades to study the behavior of piles subjected to axial pullout loads.

Structures such as transmission towers, mooring system for ocean surface or submerged platforms, tall chimneys, jetty structures are subjected to uplift loads. If structures are constructed under water then uplift forces are applied on the basement of the structures. The types of foundations to be adopted for these structures vary per the suitability of the site conditions. When poor soil at shallow depth or problem of caving or water table arises, the geotechnical engineers are compelled to adopt deep foundation in the form of piles. Similarly, lateral forces act on, the foundations of quay and harbor structures due to the impact of ship during berthing and wave action, offshore structures subjected to wind and wave action, earth retaining structures and lock structures. Large loads act on the foundations of retaining wall, anchors for bulk heads, bridge apartments, piers, anchorage for guyed structures and offshore structures which are generally supported on piles.

Generally ultimate capacity of piles under pulling load depends on the embedded length, pile diameter, pile-soil friction angle and inclination of load, shear strength parameters and density of foundation medium. Pullout capacity is evaluated in terms of the shearing resistance along the perimeter shaft. This is in contrast to a shallow conical soil failure which may occur with short, stubby member

II. Literature

A. *Theoretical Analysis*

The failure surface was assumed curved and passing through the surrounding soil mass. The lateral horizontal extent of the failure surface was dependent on the angle of shearing resistance ϕ of the surrounding soil, soil-pile friction angle ɗ, and aspect ratio L/d.

1) Chattopadhyay & Pise (1987) [8]:

a) Assumptions Made

1) For a particular slenderness (aspect) ratio the lateral horizontal extent of the failure surface from the axis of the pile was maximum for $\delta = \phi$.
2) For $\delta = 0$, the failure surface coincides with the interfacial plane between the pile and soil.
3) For piles with soil-pile friction angle $\delta \geq 0$, under ultimate uplift force, P_u the resulting failure surface initiates tangentially to the pile surface at the tip of the pile and moves through the surrounding soil.
4) For $\delta > 0$, the inclination of the failure surface with the horizontal at the ground surface approaches (45°- ϕ /2).

On account of his theory friction increases in a linear way with increasing depth based on his test.

$$(L/d)_{er}=0.156D_r=3.58, D_r\leq 0.7, \quad (1)$$

$$(L/d)_{er}=14.5, D_r\geq 0.7, \quad (2)$$

Ultimate capacity of uplift pile in sand was determined by the following:

$$P_U=0.5\pi d\, \gamma\, L^2\, K_u \tan(\delta),\ (L/d)\leq (L/d)_{cr} \quad (3)$$

$$P_U=0.5\pi d\, \gamma\, L_{cr}^2\, K_u \tan(\delta)+\pi d\, \gamma\, L_{cr}\, (L_{cr}- L)K_u \tan(\delta),\ (L/d)\geq (L/d)_{cr} \quad (4)$$

2) Deshmukh et al. (2010) [14]:

Proposed semi-analytical method was simple and provides a closed-form solution for the net uplift capacity of a pile anchor for the depths up to critical embedment ratio.

In the proposed method, Kotters equation was employed to evaluate vertical soil reaction R_v in which failure surface was an inverted truncated cone, on the failure surface. This equation that was valid for plane strain condition was successfully used for the analysis of a retaining wall. Author considered the sum of vertical soil pressure at failure surface and the weight of the pile and soil in failure zone equal to uplift capacity of the pile.

3) Tran-Vo-Nhiem (1971) [30]

Tran-Vo-Nhiem developed an equation for uplift capacity of piles on the assumption that the passive pressures act on the side of the pile. It considered that the passive pressures on the side of the pile are proportional to the square of the depth. By integrating the vertical component of these passive pressures on the shaft of the pile he developed the following expression

$$Q_u=A_s(\gamma LM\phi_R+CM_{CR}) \quad (4)$$

A_s = Embedded surface area of the pile,

γ = Unit weight of soil
$M\phi_R, M_{CR}$ = Dimensionlecss coefficients depending on ϕ and D/L ratio

B. Model Test

1) Krishna et al. (2004) [22]:

Krishna did laboratory model tests on single steel model pile of cross-sectional 20mm X 20mm with length 400mm & 600mm. It was observed that the axial displacement depends on the normal components of thee pull and also the normal displacement depends on the axial components of the pull. Oblique capacity of piles decreases with increase in % of compressive load. On account of paper pullout capacity depend on embedment length, compressive load applied on pile, oblique pullout load.

2) Srirama Rao et al. (2007) [3]:

This paper presents the results of field scale test of GPA (granular Pile anchors) of varying diameter and a length with aspect ratio varies from 2.5 to 10, piles where embedded in clay. The uplift load i.e. pullout capacity increased with the increasing diameter of the GPA. This was because the resistance to uplift increased with increasing surface area of the pile-soil interface consequent upon increase in the diameter. Pullout capacity also increases with increasing in length of pile. When the length of the GPA was increased from 500 to 750 and 1000 mm, the percentage increase in the uplift load required for an upward movement of 25 mm was 33.3 and 55.5% respectively.

3) Sivakumar et al. (2012) [34]:

A new method of analysis for the determination of the ultimate pullout capacity has been presented and verified experimentally. This paper has presented the construction, testing, and performance of granular anchors in old filled deposits (QUB site) and an intact lodgement till deposit (TCD site). Granular anchors with $L/D > 7$ principally failed by bulging whereas short granular anchors failed on shaft resistance. In analogue to the ultimate pullout capacity of a rigid pile, the ultimate resistance of the granular anchor in shaft resistance, including its self-weight contribution, was given by:

$$T_F = \pi D L \alpha C_u + \frac{\pi D^2 L\, \gamma}{4} \qquad \text{....... (5)}$$

Where D and L are anchor diameter and length, respectively; α was an adhesion factor; Cu was the un-drained shear strength of the surrounding soil; and γ_g was the unit weight of the granular backfill. The study has also demonstrated that the pullout capacity can be increased significantly using a multiple-plate anchor system, provided the L/D ratio of individual column segments was greater than the critical value.

4) Kotal et al. (2015) [2]:

Anchors of solid wooden pile having diameter of 40mm diameter and 600mm length. The truncated cone model was considered to predict the net uplift capacity of single pile anchor. In the truncated cone model, the uplift force was resisted by:

- The weight of the soil in the truncated cone
- Shearing resistance of the soil along the failure surface
- Weight of the pile and pile anchor.

So, from the analytical analysis for cohessionless soil (c=0). We get the final expression as:

$$Q_u = 2\, \gamma\, K_b\, (L^2/2) \tan(\delta) + W \qquad \text{.............(6)}$$

Kotal did Experimental and theoretical investigations on model single pile anchor and pile group. Pile anchors having more embedment depth offer more resistance capacity than pile anchors having less embedment depth. It was also observed that ultimate capacity increases with B/d ratio i.e. the ratio of anchor to shaft width increase was more for long pile anchors.

5) Kulhawy Formula (1985) [21]:

Axial load carrying capacity of the pile was initially determined by calculating resistance from end bearing at toe/tip or wall friction/skin friction along pile surface or both, based on the soil data. From considered pile dimensions, all piles categories under short pile, hence pullout capacity of piles mainly governed by shaft friction.

III. Analysis of Literature

- Based on the literature survey it was observed that:
- Meyerhof (1973) method ignores the self-weight of pile, thus making the calculation value smaller than the test value.
- Chattopadhyay and Pise (1986) method can predict the uplift capacity of pile in sand, but the process is complicated.
- Vesic (1970) theory cannot use length that beyond a critical value of 10D in loose sand and 20D in dense sand.
- Dash and Pise (2003) conducted only laboratory tests on model tabular steel piles. The result indicated that the compressive load effect decreases the net uplift capacity of pile.
- The conclusions of some studies were limited by the facts that only property of soil influence on pile foundation.
- It has been seen from the literature that only model tests were carried out and there were no field tests carried out to obtain pullout capacity of pile.

A. Theoretical Pull-Out Capacity of Pile

Analytical model based on effective stress method presented by Kulhawy (1985) of predicting the ultimate resistance of short- piles. [21]

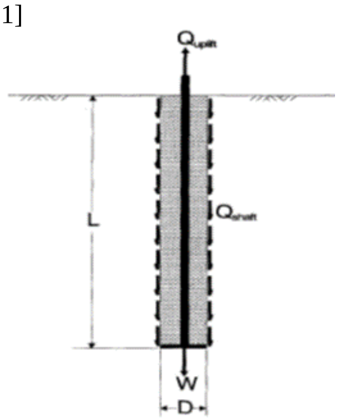

Fig. 1: Perimeter Shear Model for Pile Pullout Capacity (1985)

$$Q_u = Q_{shaft} + Ws$$

$$Q_u = K_p \times P_{dia} \times \tan(\delta)\, A_s + Ws \qquad \text{..................(7)}$$

Where,

K_p = Coefficient of earth pressure
P_{dia}= Effective overburden pressure in kg/cm^2 along the embedment of pile
(δ) =Angle of wall friction between pile and soil in degrees. It may be taken equal to angle of internal friction of soil
As = Surface area of pile shaft in cm^2
While evaluating effective overburden pressure, total and submerged weight of soil shall be considered above and below water table respectively.

B. *Experimental Property of Soil*

Pile was tested in pre-defined (selected area where pile was casted and whole experiment was performed) area. As from IRC 78:2014 code pullout capacity of pile was depending on soil parameters, hence to predict pullout capacity of pile it was necessary to find parameter of soil. Following table shows parameter of soil, where pile was casted and checked its UPC

Sr. No.	Properties	Symbol	Values
1.	Specific Gravity	G	2.41
2.	Natural Water Content	W	27.50%
3.	Maximum Dry Density (MDD) (gm/cc)	$(\rho_d)_{max}$	1.745
4.	Optimum Moisture Content	OMC	11.23%
5.	Cc Coefficient of curvature	Cc	1.28
6.	Cu Uniformity Coefficient	Cu	10.52
7.	Unconfined Compressive Strength (UCS) (Kg/cm^2)	c'	1.6
8.	Direct Shear Test (Unconsolidated Un-drained)	ϕ	41.24^0
9.	Liquid Limit %	LL	40.12%
10.	Plastic Limit %	PL	16.28%
11.	Angle of friction between pile and soil	δ	41.24^0
12.	Adhesion Factor	α	0.4
13.	Unit weight of soil (kN/m³)	γ	17.36

Table 1: Experimental Properties of Soil

IV. EXPERIMENTAL MODEL

On account of maximum load and as per tests specifications accordance with ASTM standards D-3689 following system is designed. The model considered in the present study consist of following components

A. *Base Plate*

Base plate was used to hold the RCC pile, base plate assembly contain upper plate made by ISMB-100x75, ISA- 50x50x5 and bottom plate made by ISMC- 75x50, ISA- 50x50x5 these two plates connected by four numbers of ISA 50x50x5. Bottom plate having four number 20 mm diameter hole. As shown in below Fig. 2

B. *High Strength Rod*

Further base plate was connected to the system by high strength rod which having 16 mm diameter.

C. *Compressive Proving Ring*

Proving ring was provided between middle plate and lower plate. Compressive proving ring will help to calculate applied pulling load on pile

D. *Middle Plate*

Middle plate was made of 4 number of ISMC- 75x50 and 5 mm plate placed over it which was fixed on ISMC by bolt.

E. *Vertical Member*

These whole systems supported by 4 numbers ISMB- 100x75 and 5 mm square plate welded at the bottom to resist uneven settlement and to provide firm support.

F. *Hydraulic Jack*

Hydraulic jack was placed on middle plate; hydraulic was used to apply pulling load and which will transfer to the pile through upper plate, upper plate is connected to high strength rod then finally to the pile by lower plate.

Proving ring was provided in between middle plate and at the upper plate of anchorage plate which was used find out the load taken by the pile.

G. *Dial Gauge*

This was provided to measure vertical uplift displacement of pile with respect to applied load.

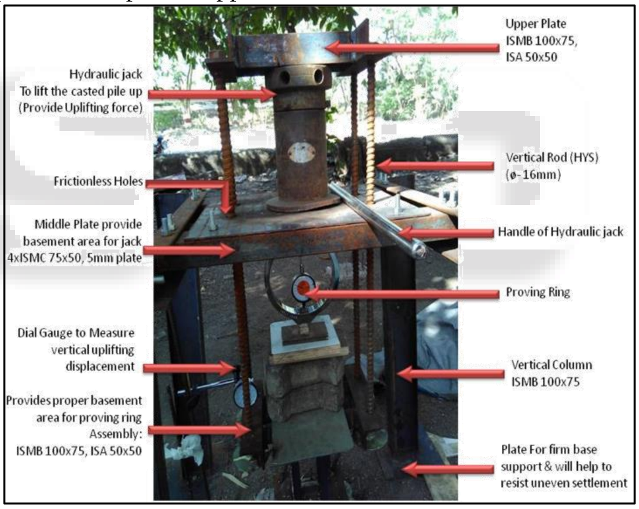

Fig. 2: Snap of working Model

Compressive Proving ring was used to measure applied load on pile which was fixed in between middle plate and lower plate, load was noted (recorded) an interval of 0.2 mm of deflection. There were four base plates provided to give firm support to the vertical column. Pile was anchored to the base plate with the help of dowel bar removed from the pile. Actual pictorial views shown in Snap of Working Model.

V. RESULTS & DISCUSSIONS

A. *Pull Out Test Results*

Test Pile Set -1 (Diameter= 180mm, Length= 600)

1) Test Specimen A_1

(1) TA18L600

Test Specimen A_1, with Diameter of pile= 180 mm and Length= 600mm

The uplift loads of the pile have been plotted against the axial displacement as shown Fig 3 and it was observed that the load displacement responses of pile are non- linear in nature. To plot these graphs, readings has been taken on field in which the axial displacement of pile has been measured by using dial gauge and load was measured by using proving ring. The load has been observed at an interval of 0.2 mm displacement i.e. (at interval of 20 unit of dial gauge reading).

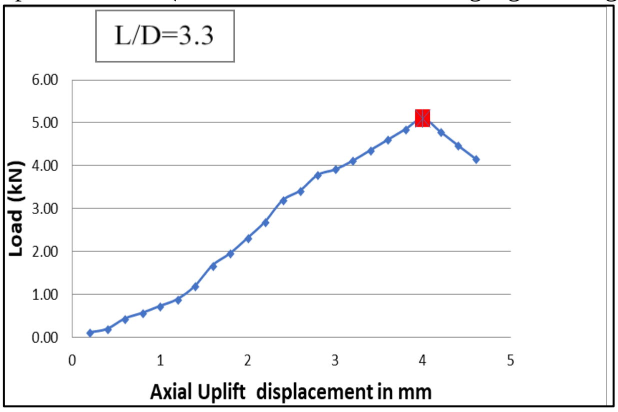

Fig. 3: Load vs Axial Uplift Displacement for Sample TA18L600

Axial failure was considered when the pile moves out of soil and load start decreasing. Ultimate pullout capacity of piles will be maximum load taken to uplift the piles before decreasing in load, was find out from graph and also noted axial displacement of pile at maximum load. Permissible axial displacement of pile was 15 mm as given in IRC 78 2014. It has been observed that for all piles, the maximum displacement at which piles required maximum load to uplift was varying from 3 mm to 5 mm.

Based on soil data ultimate uplift capacity of pile given by Kulhawy (1985)

$$Q_u = K_P P_{dia} \tan(\delta) A_S + W_s$$

K_P = 1.8

$P_{dia} = \gamma$ D =17.36 x 0.5= 8.68

tan(δ)= tan(41.24) =0.876

$A_S = \pi$DL =3.14 x 0.18 x 0.6=0.339

$W_S = \gamma V = \frac{\pi x\, 0.18^2}{4}$ x 0.6 x25=0.382

Q_u = 5.029 kN

2) Test Specimen B₁

a) TB18L600

Test Specimen B, with Diameter of pile= 180 mm and Length= 600mm

As from graph shown in Fig 4 it has been seen that initial behaviour of pile under uplift load was linear, after 1.5 mm displacement load get increased with large interval. From graph and observation table it was concluded that pile loses its frictional resistance when it reaches to displacement 3.4mm beyond which uplift capacity of pile decrease.

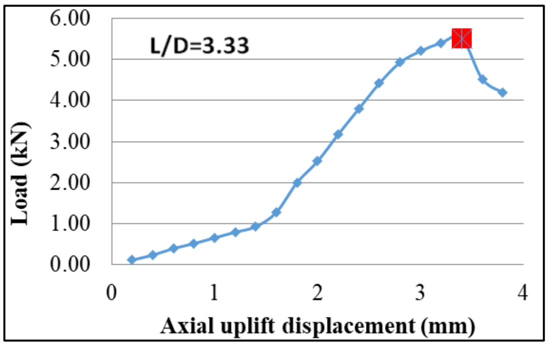

Fig. 4: Load vs Axial Uplift Displacement for Sample TB18L600

B. *Results*

For L/D=3.33,

TA18L600; Load= 5.10 kN, Displacement= 4mm

TB18L600; Load= 5.52 kN, Displacement= 3.4mm.

Theoretical ultimate pullout capacity of pile was 5.029 kN

Fig. 5: Failure Due To Loss of Frictional Resistance

1) Failure Pattern

During experiment as the pullout load increases it lead to increase the deflection of pile. At certain point the pullout load reaches to its maximum value and beyond this it started decreasing. The pullout load was decreased due to decreased in frictional resistance between pile and surrounding soil (shaft resistance).

Test Pile Set -2 (Diameter = 180 mm, Length = 800)

2) Test Specimen A₂

a) TA18L800

Test Specimen A₂, with Diameter of pile= 180 mm and Length= 800 mm

The uplift loads of the pile have been plotted against the axial displacement as shown in Fig. 6 It was observed that the load displacement response of pile was linear in nature up to ultimate load. The maximum uplift capacity of pile was obtained of an axial vertical displacement 4.6 mm.

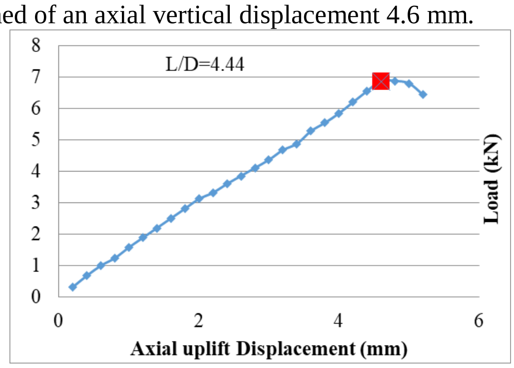

Fig. 6: Load vs Axial Uplift Displacement for Sample TA18L800

3) Test Specimen B_2

a) TB18L800

Test Specimen B_2, with Diameter of pile= 180 mm and Length= 800 mm

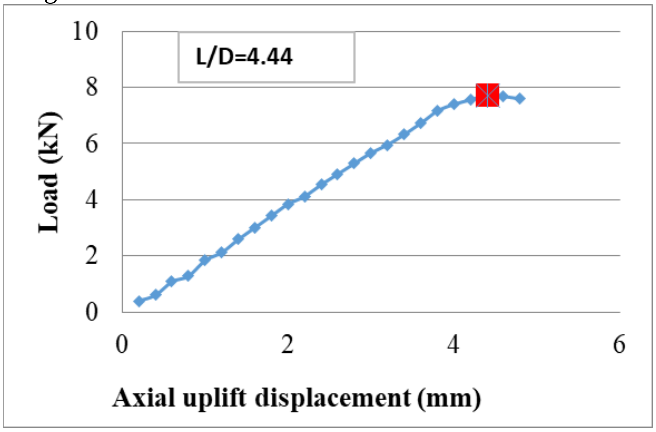

Fig. 7: Load vs Axial Uplift Displacement for sample TB18L800

C. Results

For L/D=4.44,

TA18L800; Load= 6.88 kN, Displacement= 4.6 mm

TB18L800; Load= 7.72 kN, Displacement= 4.4 mm

Based on found soil data theoretical ultimate pullout capacity of pile was 6.66 kN

Test Pile Set - 3 (Diameter= 180 mm, Length= 1000)

1) Test Specimen A_3

a) TA18L1000

Test Specimen A_3, with Diameter of pile= 180 mm and Length= 1000 mm

The uplift loads of the pile have been plotted against the axial displacement as shown in Fig.8 From Fig. 8, it was observed that the variation of load to displacement of pile was non-linear up to ultimate load of 4mm of vertical displacement. Beyond ultimate load, pile start losing shaft friction and sudden decrease in load has been observed.

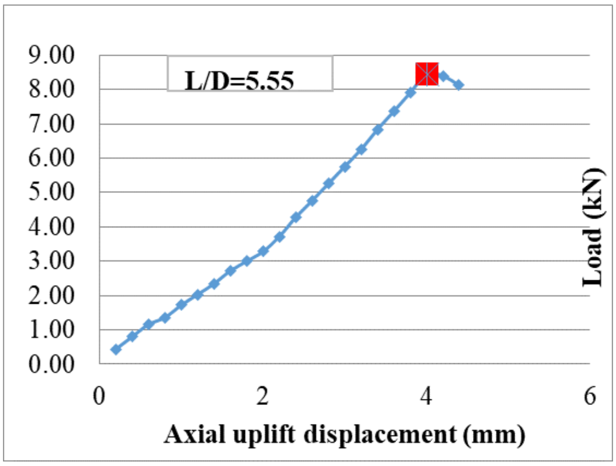

Fig. 8: load vs Axial Uplift Displacement for Sample TA18L1000

2) Test Specimen B_3

a) TB18L1000

Test Specimen B_3, with Diameter of pile= 180 mm and Length= 1000 mm

The uplift loads of the pile have been plotted against the axial displacement as shown in Fig. 9 and observed that the load displacement response of pile was non-linear up to ultimate load. The maximum load taken by pile was 8.66kN at 4 mm vertical displacement. It observed after maximum load pile start losing its shaft friction, there was abrupt change in load taken by pile has been seen under further loading.

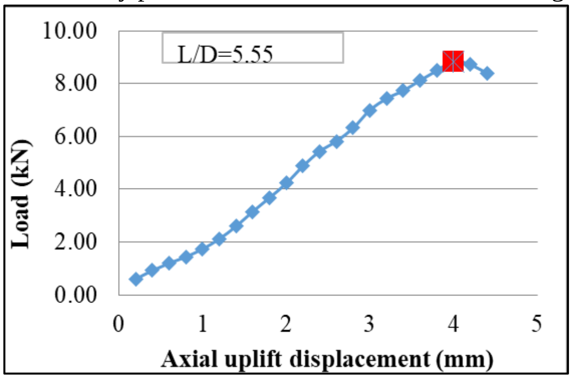

Fig. 9: Load Vs Axial Uplift Displacement for Sample TB18L1000

D. Results

For L/D= 5.55,

TA18L1000; Load= 8.45 kN, Displacement= 4 mm

TB18L1000; Load= 8.86 kN, Displacement= 4 mm

Based on found soil data theoretical ultimate pull out capacity of pile was 8.33 kN

1) Variation of Ultimate Pull out Capacity with L/D Ratio

a) Change in Ultimate Pull out Capacity Due to Change in Embedded Pile Length

(1) Constant Diameter (D= 180mm) with Length= 600mm, 800mm, 1000mm.

EXA180 represents experimental ultimate pullout capacity of sample (A) with diameter 180 mm and length 600 mm, 800 mm, 1000 mm respectively. (L/D: 3.33, 4.44, 5.55)

EXB180 represents experimental ultimate pullout capacity of sample (B) with diameter 180 mm and length 600 mm, 800 mm, 1000 mm respectively. (L/D: 3.33, 4.44, 5.55)

Ultimate Pullout Capacity						
L/D	EXA 180 UPC (1)	EXB 180 UPC (2)	Theoretical UPC (B)	Mean 1+2 =(A)	Difference UPC (A-B)	Percentage Change (A-B) %
3.33	5.10	5.52	5.029	5.31	0.281	5.58
4.44	6.88	7.72	6.66	7.30	0.64	9.61
5.56	8.45	8.86	8.33	8.655	0.325	3.90

Table 2: Percentage Change in Theoretical & Experimental Pullout Capacity with L/D ratio (D=180mm)

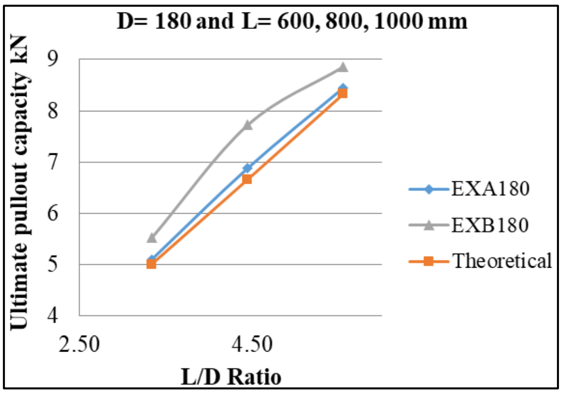

Fig. 10: Experimental and theoretical pullout capacity of pile with respect to change in L/D Ratio for constant diameter D=180 mm

From Fig. 10 one can see that as mean ultimate pullout capacity of pile increase with increase in L/D ratio. It is indicated that pullout capacity of pile gets increased due to increase in embedded length of piles. It was observed that from Fig. 10 and Table 2 the increase in mean ultimate pullout capacity was about 37% and 19% for L/D increase from 3.33 to 4.44 and 4.44 to 5.56 respectively. Diameter of both piles were 180mm and embedded lengths of piles as 600 and 800mm, 33.33% increase in A_1 and A_2 length of pile shows increased in mean ultimate pullout capacity about 37%. Similarly, 25% increase in length of pile of 800mm to 1000mm in A_2 and A_3 and diameter of both pile were 180mm, which shows 19% increase in mean ultimate pullout capacity.

VI. Conclusions

1) The soil sample found from the pit is soft rock i.e. Murum soil (in between organic soil and sandy soil)
2) Pile having more embedment depth offer more resistance capacity than pile having less embedment depth.
3) The resistance offered by the pile at any Vertical displacement (Pullout) increases significantly with increase in L/D ratio.
4) The load-displacement curves are found to be linear and non-linear in nature for single pile
5) The theoretical results of Ultimate capacity of pile compared reasonably with the experimental results. In general, almost all the cases, the theoretical result shows close to the agreement with experimental result.
6) It is seen from experimental observation, Pullout Capacity of Pile also increase within increase L/D ratio.
7) Analytical model based on effective stress method presented by Kulhawy (1985) of predicting the ultimate resistance of short piles proposed in this study and the theoretical results compare reasonably well with the experimental results. In general, almost all the cases, the theoretical result is close to observed result.

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