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ANALYSIS AND DESIGN OF TAPERED PILES WITH CORRUGATIONS IN SANDY SOIL CONDITION

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Abstract- Our main motive under this topic is to investigate behaviour of tapered piles under various soil conditions and examine their feasibility. We have added another feature into the tapered piles, and that is of corrugated surfaces. The corrugation can be either semi-circular or square in shape. The advantages of using corrugated surface is that the cylindrical surface area of piles is increased which further leads to an increase in skin friction, thus the load carrying capacity of the piles.

Keywords- Corrugations, group pile, skin friction. tapered pile, square tapered piles

I INTRODUCTION

Our main motive with this research work is to investigate the behaviour of tapered piles under various soil conditions and examine their feasibility. "Corrugated surfaces" have been added to the tapered piles which can be either semi-circular or square in shape. This addition leads to an increase in the cylindrical surface area of piles further causing an increase in skin friction, thereby enhancing the load carrying capacity of the piles.

Based on the shape tapered piles can be classified as:-

- ○ Circularly tapered piles
- ○ Square tapered piles
- Based on the shape of corrugations, the tapered piles are divided as:-
- ○ Tapered piles with circular corrugations
- ○ Tapered piles with square corrugations
- Based on technique of construction we have -
- ○ Normal tapered piles
- ○ Step tapered piles

Our aim is to analyze tapered piles and calculate their area and circumference followed by computation of load bearing capacities both as individual and group piles. A detailed design including the amount of reinforcement, pile cap group piles followed by cost assessment and feasibility analysis is done. Thus, we have decided to introduce a system of corrugations on the surface of tapered piles along its length to let its cylindrical surface area increase that would lead to enhancement in load carrying capacity of piles. Two basic types of corrugations will be introduced "semi-circular and square followed by computation of the base and cylindrical areas of the foundation. Some advantage of using tapered piles :-

- Tapered piles are easy to drive into the soil due to their changing cross sections, low at bottom and high at top.
- Tapered piles offer high amount of frictional resistance for same base area due to increased cylindrical surface area.
- Tapered piles enhance the load carrying capacity and strength of piles.
- Tapered piles compact soils in the vicinity to enhance its strength.
- Tapered piles are efficient in operation.
- The number of tapered piles as a group is reduced for the same area and same amount of load to be resisted as compared to normal vertical piles.
- Tapered piles are cost effective.

II METHODOLOGY

Tapered piles corrugated length: -

These corrugation enhance the surface area have the skin friction also increases leading to an increased capacity of tapered piles we consider these corrugations a semicircular in shape.

- Let us assume that 10 corrugations are present in 1 cm so the length of 1 cm changes to

$$= [9.090 \text{ x } 10^{-4} \text{ x } 6 + 5 \times \frac{TL}{2} \times 9.090 \text{ x } 10^{-4}]\text{m}$$

i.e. Semi-circular and b plain areas in 10 corrugations

1 cm = 0.012595 m

Thus in 1m = 100 m = 1.2595 m

Thus for a surface with corrugations

1 = 1.2595 m

Thus corrugated surface increase the cylindrical surface area of piles, thus its skin friction resistance.

Tapered Piles - Corrugated Semicircular

Circular Vertical Piles	***Square vertical piles***	***Circularly tapered piles***	Square tapered piles	Step tapered piles
Diameter d= 0.3m	Width = 0.3 m, thickness = 0.3 m	Top diameter = 0.6 m (d_1) Bottom diameter = 0.3 m (d_2)	Top width = 0.6 m (a) Top thickness = 0.6 m (t1) Bottom width = 0.3 m (b) Bottom thickness = 0.3 m (t2)	Divided into 6 parts of 2 m each Bottom dia (d_2) = 0.20 m Top dia (d_1) = 0.35 m
Length = 12 m	Length = 12 m	Length = 12 m. (l)	Length (l) = 12 m	Length = 18 m
At each part the diameter in areas by 2.5 cm				

Assumed data in the analysis

Analysis of tapered sections

1. Circularly tapered sections

Let, d_1 = top diameter, d_2 = bottom diameter, L = length of pile

Consider any section of length dx let dia be D_x at this point

So, $D_x = D_1 - \left(\frac{D_1 - D_2}{L}\right) x$

$D_x = D1 - K_x$

Where $K = \left(\frac{D_1 - D_2}{L}\right)$

- To calculate the volume we need to integrate the area of each such strips throughout the length

Total volume

$$v = \int_0^l \frac{\pi}{4}\, dDx^2 = \frac{\pi}{4}\int_0^l (D_1 - kx)^2\, dx$$

$$v = \frac{\pi}{4}\left[D_1^2\, x + K^2\frac{x^3}{3} - 2D_1 K_{\frac{x^2}{1}}\right]_0^l$$

$$v = \frac{\pi}{4}\left[D_1^2\, l + K^2\frac{l^3}{3} - 2D_1 K_{\frac{l^2}{1}}\right]$$

Now, $A = \frac{V}{L}$

For Example: As per Our assumptions

d_1=0.6 m, d_2=0.6 m, l=12 m

$$K = \frac{d_1 - d_2}{l} = \frac{0.6 - 0.3}{12} = 0.025$$

Now,

$$v = \frac{\pi}{4}\left[(0.6)^{\,2} \times 12 + \frac{0.025^2 \times 12^3}{3} - \frac{2 \times 0.6 \times 0.025 \times 12^2}{2}\right]$$

$$v = \frac{\pi}{4}[4.32 + 0.36 - 2.16]$$

$$v = 1.979\, m^3$$

$$A = \frac{1.979}{12} = 0.165\, m^3$$

Now we read to calculate cylindrical surface area of the square tapered piles

Perimeter of section X-x= πDx

$=\pi\, [D_1 - K_x]$

For the length l of pile

Slanting length = $l_s = \sqrt{P^2 + B^2}$

$=\sqrt{12^2 + 0.15^2}$ =12.00093 m

Cylindrical as= $\int_0^l \pi\, D_x = \int_0^l \pi (D_1 - Kx)\, dx$

Surface area = $As = \pi\left[D_1\, x + K\frac{x^2}{2}\right]_0^l$

Top perimeters $= \pi d_1$; $As = \pi\left[D_1\, l + K\frac{l^2}{2}\right]$

Bottom perimeters$= \pi d_2$; $As = \pi(d_1 + d_2) \times l_5^2$

Average$=\frac{\pi}{2}(d_1 + d_2)$

d_1=0.6m, d_2=0.3m, l_s = 12.00093 m

For corrugated surfaces,

1 m=1.2595 m ; 12.00093 m= 15.1152 m

Now, As= $\frac{\pi}{2}(d_1 + d_2) \times l_s = \frac{\pi}{2}(0.6 + 0.4) \times 15.1152 = 23.74\, m^2$

Let a= top width; b== bottom width; t_1= top thickness; t_2= Bottom thickness

At section x-x the width

Wx= (a-k_1x)

Where; $K_1 = \frac{a-b}{L}$; thickness t_x=(t_1-k_2x); $K_2=\frac{t_1-t_2}{2}$

Now we used to calculate is volume by integrating area of each strip of width Wx and thickness bx, throughout the length

$A_x=W_x$ x t_x= (a-k_1x) (t_1-k_2x) =at_1- ak_2x - k_1t_1x + $k_1k_2x^2$

Now volume ,

$$v = \int_0^l [at_1 - ak_2x - k_1t_1x + k_1\, k_2x^2]$$

$$v = [at_1x - ak_2\frac{x^2}{2} - k_1t_1\frac{x^2}{2} + k_1k_2\frac{x^3}{3}]$$

$$v = at_1l - ak_2\frac{l^2}{2} - k_1t_1\frac{l^2}{2} + k_1k_2\frac{l^3}{3}$$

now $A = \frac{V}{L}$

assuming the data a=0.6 m, b=0.3m, t_1=0.6m, t_2=0.3m, l=12m

so, $k_1 = \frac{a-b}{L} = \frac{0.6-0.3}{12} = 0.025$; $k_2 = \frac{t_1-t_2}{L} = \frac{0.6-0.3}{12} = 0.025$

$$v = 0.6 \times 0.6 \times 12 - 0.6 \times 0.025 \times \frac{12^2}{2} - 0.025 \times 0.6 \times \frac{12^2}{2} + 0.025 \times 0.025 \times \frac{12^3}{3}$$

$$v = (4.32 - 1.08 - 1.08 + 0.36)m^3; v = 2.52\, m^2$$

Now $A = \frac{V}{L} = 0.21\ m^2$

Now we read to calculate cylindrical surface area of the square tapered piles

Top perimeter = 2(a + t_1); Bottom perimeter = 2 (b + t_2)

Average of the two = $\frac{1}{2}$ x2(a + b + t_1 + t_2)

= (a + b + t_1 + t_2)

Now cylindrical surface area = (a + b + t_1 + t_2) x ls

where; Ls = slanting length of tapered pile;

ls=slanting length of tapered pile= $\sqrt{P^2 + B^2}$ =$\sqrt{12^2 + 0.15^2}$ =12.00093 m

Now assuming corrugated surface

Ls = 12.00093 m = 15.1152 m ; a = 0.6 m, b = 0.4 m, t_1 = 0.6 m, t_2 = 0.4 m

So As = (a + b + t_1 + t_2) x Ls

= (0.6 + 0.4 +0.6 + 0.4) x 15.1152 =30.2304 m^2

Thus we have effectively calculated the area, and cylindrical surface area of two main types of tapered piles.

1. Circularly tapered piles
2. Square tapered piles

Now we need to compute load bearing capacities or each.

INDIVIDUAL TAPERED PILES

LOAD BEARING CAPACITY

For any pile type or soil conditions the basis formula to calculate bearing capacity is

$Q_f = q_f A_b$ + Fs As

Where,

Q_f = ultimate load bearing capacity of pile

A_b = area of pile at base

q_f= ultimate laoad capacity of strata on which piles is supported

F_s = average ultimate friction of shearing resistance of soil per unit area

A_s = cylindrical surface area of pile (perimeter x length)

I. ***In sand***

Method 1 : we have $Q_f = q_f A_b$ + fs As

Where ; q_f= ˊYD_fNq;

D_f = depth of pile embedded in sand ;

ˊY = Effective overburden pressure at bottom or base of pile

N_q = values of N_q for drivers pile vary as **-** :

Φ in degree	Value of Nq	
	$\frac{Df}{B}$= 25	$\frac{Df}{B}$= 50
28	12	9
30	7	14
32	25	22
34	40	37
36	58	56
38	89	88
40	137	136

$F_s = k_s\overline{q_0}$ tan δ

$\overline{q_0}$ = Average effective over burden pressure acting along Embedded length; $\overline{q_0} = \frac{rDf}{2}$

δ = friction angle b/w pile surface and surrounding sand

value of δ = 0.75 for concrete pill

= 20 for steel pile

K_s = average coefficient of lateral Earth pressure acting along any embedded length D_f

= 1.0 for loose sands

= 2.0 for dense sands

Method 2 :

Computing ultimate Bearing of pile by SPT-N value method

O_f = qfAb + Fs As

Now, $q_F = 40\ N\,\frac{Df}{B}$ [Limited to 400 N]

where, N is SPT-N value in visibility of pile base

Fs = 2 N where $\bar{N}$ is SPT N value averaged rear embedded depth of pile

(i) ***Circulatory tapered piles***

Problem: - We need to calculate the ultimate load bearing capacity of circularly tapered piles with varying diameter in sands and compare the same with ultimate load bearing capacity of normal vertical circular piles.

Assumptions: - As per the practical observations we assume the following data

Tap dia of tapered pile = d_1 = 0.6 m

Bottom dia of tapered pile = d_2 = 0.3 m

Dia of normal vertical pile	0.3 m
Length of pile	12 m
Corrugated length of pile	5.1152 m
Friction angle of sand	40^o
K - value of dense	2.0
Dry unit weight of sand	8 KN/M^3

Solution : (a) For vertical circular pile ultimate load carrying capacity

$$Q_f = q_F A_b + F_s As$$

where; $q_F = rDfN_q$; Nq_r = B.C. facture; $N_q = \tan^2(45 + \frac{\phi}{2})\, e^{\pi} \operatorname{Tan} \phi$

So; $N_q = \tan^2\left(45 + \frac{40}{2}\right) e^{\pi} \tan 40^o = 64.194$

Hence, qF = rDfNq = 18 x 12 x 64.194 = 13865.904 KN/m^2

Also, $F_s = K_s \overline{qo} \tan \delta$

where $K_s = K = 2$

$\delta = 0.75\, \phi$ (ascrete pile) = 30^o , 20^o (still corrugators)

$$\overline{q_0} = \frac{r\,Df}{2}$$

So; $F_s = 2 \text{ x} \frac{1}{2} \text{ x } 18 \text{ x } 12 \text{ x } \tan 20^o = 78.62\ KN/m^2$

Now, A_b = area of base = $\frac{\pi}{4}(0.3)^2 = 0.07068\ m^2$; As = πd x D_f = π x 0.3 x 12 = 11.3097 m^2

Q_f= qfAb+Fs As

Q_f= 13865.904 x 0.07068+78.62 x 11.30 = 1869.128 KN

Now using Fos =2.5, So safe load $Q = \frac{Qf}{FOS} = \frac{1869.128}{2.5} = 747.652\ KN$

(b) For circularly tapered piles

Value of q_f=13865.904 KN/m^2 ; Value of Fs=78.62 KN/m^2

Now, for circularly appeared piles, as use now already calculated.

$A_b = \frac{\pi}{4}(0.3)^2 = 0.07068\ m^2$ and As (for corrugated surface)= 23.74 m^2

now $Q_f = q_F A_b + F_s A_s$, Q_f=13865.904 x 0.07068+78.62 x 23.74 = 2846.480 KN

Now using Fos =2.5

So safe load $Q = \frac{Qf}{FOS} = \frac{2846.480}{2.5} = 1138.592\ KN$

(c) Comprising of normal vertical circular pile and circularly tapered pile.

$$= \frac{Safe\ load\ for\ tapered\ pile}{Safe\ load\ for\ vertical\ pile} = \frac{1138.592\ KN}{747.652\ KN} = 1.523$$

Result: Thus circular tapered piles can bear loads about 1.523 times higher than normal vertical piles, thus are more effective in use.

(ii) *Square tapered piles*

***Problem*: -** We need to calculate the ultimate load bearing capacity of square tapered pile with varying width and thickness in sands and compare the same with ultimate load bearing capacity of normal vertical square piles.

Assumptions: As per the practical observations we assume the following data:-

1	Top width of square pile (a)		0.6 m
2	Bottom width of square pile (b)		0.3 m
3	Top thickness of square pile (t_1)		0.6 m
4	Bottom thickness of square pile (t_2)		0.3 m
5	Length of piles		12 m
6	Corrugated length of piles		15.115 m
7	Friction angle of dense sand		40^o
8	Dry unit weight of sand		$18KN/m^3$
9	K - value of dense sand		2.0

Solution :

(a) For vertical square pile ultimate load carrying capacity

$Q_F = q_F A_b + f_s As$

For sands with same value of friction angle and piles of same length (12m), the

value of qF = 13865.904 KN/m^2; Fs = 78.62 KN/m^2

$A_b = (0.3 \times 0.3) = 0.09\ m^2$; $A_s = 4 \times 0.3 \times 12 = 14.4\ m^2$

So, QF = $q_f A_b$ + Fs As= 13865.904 x 0.09 +14.4 x 78.62 = 2380.06 KN

Using FOS = 2.5 ; So safe load Q = $\frac{Qf}{FOS} = \frac{2380.06}{2.5}$ KN

Q = 952.024 KN

(b) ***For tapered square pile***

Ultimate load carrying capacity

$Q_F = qFA_bFsAs$

Value of Fs = 78.62 KN/m^2

Now, for tapered square piles, as we have calculated

Ab = $(0.3)^2 = 0.09\ m^2$ and As (corrugated length) = 30.2304 m^2

Now Q_F = 13865.904 x 0.09 + 30.2304 x 78.62 = 3624.645 KN

using FOS = 2.5, Safe load Q = $\frac{QF}{FOS} = \frac{3624.645}{2.5}$ = 1449.86 KN

(c) Comparision of normal vertical square pile and tapered square pile

$\frac{Safe\ load\ for\ tapered\ pile}{Safe\ load\ for\ vertical\ pile} = \frac{1449.86\ KN}{952.024\ KN}$ =1.523

Result **:** Thus square tapered piles with varying width and thickness can bear to ads about 1.523 times higher than normal vertical care, hence are more effective in use.

III CONCLUSION

With all the noted advantages of using tapered piles our observations include a major finding that the cylindrical surface area is prominent factor in enhancing the load carrying capacity of tapered piles. The tapered piles hold immense potential to bring a revolution in the construction industry and should be tested for other medias also.

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