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Effect of Size of Model Pile Group Subjected to Eccentric and Inclined Loading

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***Abstract*— Pile foundation is used in many important structures and offshore structures. As we know, we normally design piles for axial forces but in some scenario we come across inclined or eccentric loads, for analysis which the current practice is to convert them in horizontal and vertical components or vertical load and moment. But from experiments we can see that this practice not exactly perfect solution. So in this investigation an effort is made to discover the effect of size of model pile group subjected to eccentric and inclined loading.**

***Keywords*—Pile, Pile Group, Eccentricity of load, Inclination of load, Model study, Pile head displacement in direction of load, ultimate load, Ultimate Moment, Efficiency of Pile Group**

I. INTRODUCTION

The purpose of a pile foundation is to transmit the loads of a superstructure to the competent soft soil without excessive structural deformations. The capacity of the pile foundation is dependent on the material and geometry of each individual pile, the pile spacing -pile group effect, the strength and type of the surrounding soil, the method of pile installation, and the direction of applied loading-axial tension or compression, lateral shear and moment, inclined compression or tension ,or combinations.

Evaluation of pile bearing capacity is still a subject of many researchers. Generally, the ultimate load carrying capacity of pile is given by the sum of end bearing or point or tip resistance and the frictional resistance along the embedded length of pile shaft. And for inclined loading or eccentric loading the loads are divided into horizontal and vertical component or vertical load with moment. But the research shows the different results than the well established theories.

In this work the effect of size of model pile group is studied for different eccentric and inclined loading. For this purpose single pile of diameter 16mm and embedded length of 24cm was used and for pile groups same pile configuration is used with 3d spacing. Different eccentricities were taken as 0, 0.05L, 0.1L, 0.2L (L= Embedded length) and different load inclinations were taken as 0° (Vertical load) , 30°, 60°, 90°(Lateral Load). Study of effect of these eccentricities and inclination on different pile group (2x2, 2x3) is studied in this work.

II. MATERIAL OF INVESTIGATION

The sand used in the present investigation is brought from Bahadarpur near Sankheda, situated in Gujarat (India). The tests were performed on dry sand. The various engineering properties of the sand are tabulated in Table I. Grain size distribution characteristics of Bahadarpur sand are shown in fig I.

TABLE I

ENGINEERING PROPERTIES OF SAND USED

Sr. No.	Properties of sand	Value
1	D_{10}, mm	0.32
2	D_{30}, mm	0.51
3	D_{60}, mm	0.71
4	Coefficient of Uniformity, C_u	2.22
5	Coefficient of Curvature, C_c	1.14
6	Fine Sand	19.00%
7	Medium Sand	74.10%
8	Coarse Sand	6.90%
9	I.S Soil Classification	SP
10	Specific Gravity	2.61
11	Angle of Soil-Pile Friction (δ) Mild Steel Pile	22.00°
12	Maximum Density, $\gamma_{d\ max}$	1.95 g/cc
13	Minimum Density, $\gamma_{d\ min}$	1.48 g/cc
14	Sand Density, γ_d	1.73 g/cc

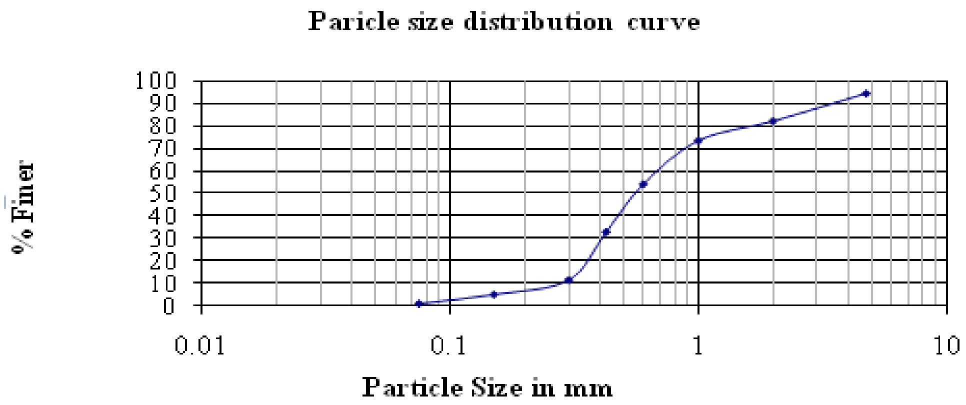

Fig. 1 Grain size characteristics of bahadarpur sand

III. **EXPERIMENTAL STUDY**

In present study the load carrying capacity of single pile with different eccentricities and inclination of load is carried out and these data is compared with the load carrying capacity of the pile groups. For model testing, circular tank of size 90cm diameter and 60cm height is fabricated with mild steel. The model tank was placed centrally in reaction frame fabricated from anglr section and channel section. Different proving ring of capacity 2000kgf, 1000kgf, 250kgf & 25kgf were used depending on loading requirement.

TABLE III

DETAILS OF MODEL PILE TESTED

Details of Pile	Value
Pile diameter (mm)	16
Single Pile embedded length L (mm)	240
Pile Group embedded length (mm)	240
Modulus of Elasticity 'E' (N/mm²)	2.1×10^5
Moment of Inertia 'I' (mm^4)	3.215×10^3
Flexural Rigidity 'EI' (N.mm²)	6.752×10^8

A. Single pile

Single pile of diameter 16mm and total length of 29cm with embedded length of 24cm was bolted with pile cap of 20mm thickness and 300mm x 90mm size.

B. Pile groups (2x2 & 2x3)

Pile groups of identical pile with c/c distance of 3d (48mm) were used for the investigation. Diameter of which were 16mm and embedded length of the piles were 24cm.

C. Model tank and test procedure

The 90cm diameter tank was filled in three layers of 20cm with vibration of 30s, 45s & 60s for respectively bottom, middle and top layer by small vibrator. After compaction of the middle layer, the centring is done with plumb bob and the model is so adjusted that the line of action of load intersects the centre at top of soil after filling of top layer. The dial gauges and the proving ring is placed such that the dial gauge gives displacement in the direction of load and in case of vertical eccentric loading, two dial gauge at different end at same distance from load of action are placed and average displacement is taken into consideration.

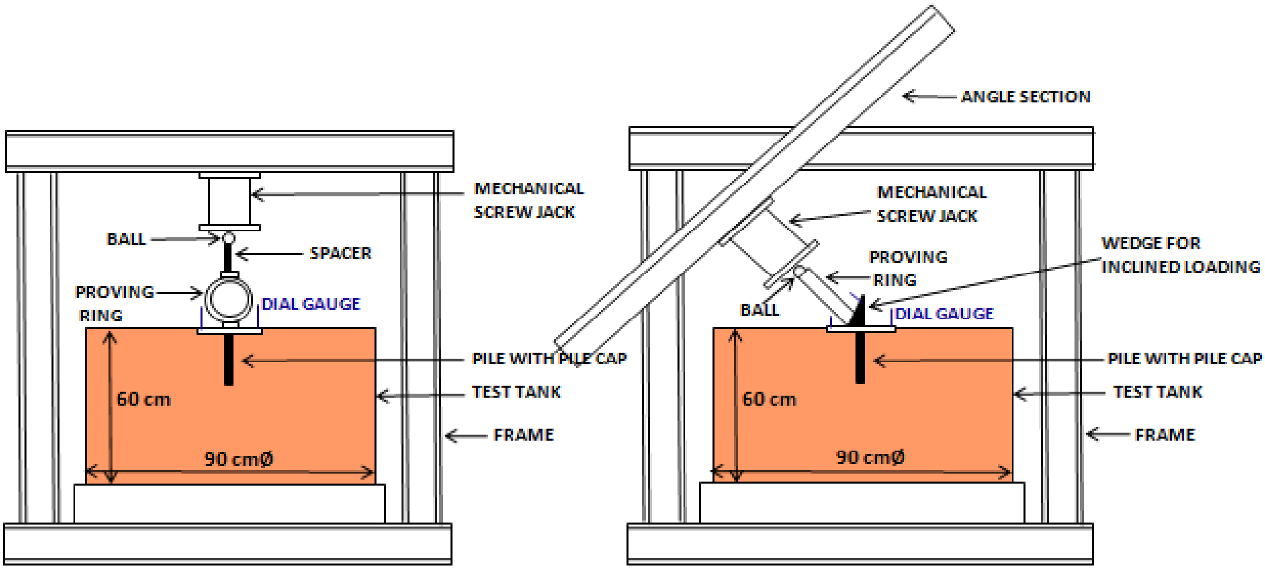

Fig. 2 Loading arrangement of single pile foe vertical and inclined loading

Same arrangement is done foe 2x2 and 2x3 pile groups with great care as the readings in the dial gauge are very sensitive with disturbance to tank and/or model. The load is applied until the proving ring shows the reading. Than the dial gauges are set to zero and load is applied at regular interval and the reading is taken when the fluctuation in the proving ring and dial gauge stops. In other word the displacement at a specific load doesn't changes.

IV. RESULT AND ANALYSIS

In the present investigation the tests were carried out on single pile as well as on group of piles till ultimate load is reached, which subsequently shows decreasing proving ring reading accompanying with substantial increasing settlement reading. For vertical loading, IS 2911 (part-4) suggests that,the initial load displacement curve is curvelinear from beginnig with convex upward and after it becomes a straight. The failure load was taken to be that load at which the displacement curve passes into steep and fairly straight tangent.

By performing more than than 48 tests for this investigation the Displacement in the direction of load vs. Load diagram were drawn for each test and ultimate load carrying capacity was found for single pile and pile group for different cases. These ultimate load are shown in the Table III. With them the ultimate moment are also shown which are obtained from the ultimate load and leverarm for that ultimate load in different cases. The efficiency of the pile group is calculated by taking referance of single pile loaded in same manner as that of the pile group for perticular case.

On comparing these ultimate load, ultimate moment and efficiency with different eccentricities and inclinations, we can get clear idea about hoe they behave. For that we have plotted different graphs foe ultimate load, ultimate moment and efficiency of pile group.

A. Ultimate Load carrying capacity characteristics

Fig. 3 to 5 show us the behavioue of ultimate load with eccentricity. Here for load inclination of 90° the ultimate load doesn't change because the horizontal eccentricity doesnt change the line of action of load and the pile group doesn't show any change in ultimate load with the eccentricity at 90° load inclination however there is a little change in ultimate load carrying capacity of single pile at 90° load inclination with different eccentricity. Fig. 6 to 8 show overlap of curves of different eccentricities at 90° load inclination, which shows the same thing.

B. Ultimate Moment characteristics

The common behaviour noticed in these tests is that the ultimate moment increases as the ultimate load reduces. Fig.9 shows the increasing behaviour of ultimate moment with the eccentricity. The reason behind this nature is the increase in the leverarm with more eccentricity, but in case of 90° load inclination the leverarm remains the same and ultimate load for single pile reduces, which causes the reduction in the ultimate moment. Fig 10 & 11 shows no change in ultimate moment for 90° load inclination as the ultimate load and the leverarm doed not change. Fig 12 shows higher moment foe lower eccentricities at 90° load inclination as a reflection of the reason discussed for Fig. 9.

C. Efficiency of Groupings

Here, for calculation of efficiency the ultimate load carrying capacity of the grouping is devided by product of number of piles in group and ultimate load carrying capacity of single pile for the same loading condition. From these efficiency results, we can conclude that the pile groups of taken dimentions and spacing acts as a block.

TABLE IIIII

RESULTS OF ULTIMATE LOAD, ULTIMATE MOMENT AND EFFICIENCY FROM THE INVESTIGATION FOR DIFFERENT ECCENTRICITY AND INCLINATION

Eccentricity	Inclination	Ultimate Load (N)			Ultimate Moment (Nm)			Efficiency	
		Single Pile	2x2	2x3	Single Pile	2x2	2x3	2x2	2x3
Centre	0°	81.7	1755	2925	0	0	0	5.37	5.97
	30°	55.8	1315	2050	0	0	0	5.89	6.12
	60°	35.4	350	585	0	0	0	2.47	2.75
	90°	21.78	150	260	1.524	10.5	18.2	1.72	1.99
E = 12mm	0°	73.53	1610	2630	0.882	19.32	31.56	5.47	5.96
	30°	54.46	1170	1900	0.762	12.16	19.745	5.37	5.81
	60°	32.67	320	525	0.196	1.92	3.15	2.45	2.68
	90°	19.06	150	260	1.33	10.5	18.2	1.97	2.27
E = 24mm	0°	60	1315	2190	1.44	31.65	52.56	5.48	6.08
	30°	43.57	950	1610	0.906	19.745	33.46	5.45	6.16
	60°	25.87	265	440	0.31	3.18	5.28	2.65	2.83
	90°	16.34	150	260	1.14	10.5	18.2	2.295	2.65
E = 48mm	0°	45	1025	1755	2.16	49.2	84.24	5.69	6.5
	30°	32.67	730	1255	1.36	30.345	52.17	5.59	6.4
	60°	19.06	205	350	0.46	4.92	8.4	2.69	3.06
	90°	13.6	150	260	0.952	10.5	18.2	2.76	3.19

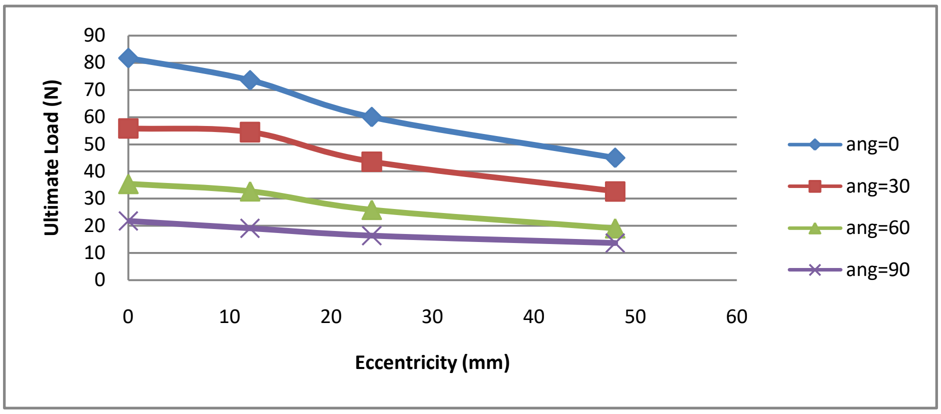

Fig.3Ultimate Load (N) vs. Eccentricity (mm) for single pile

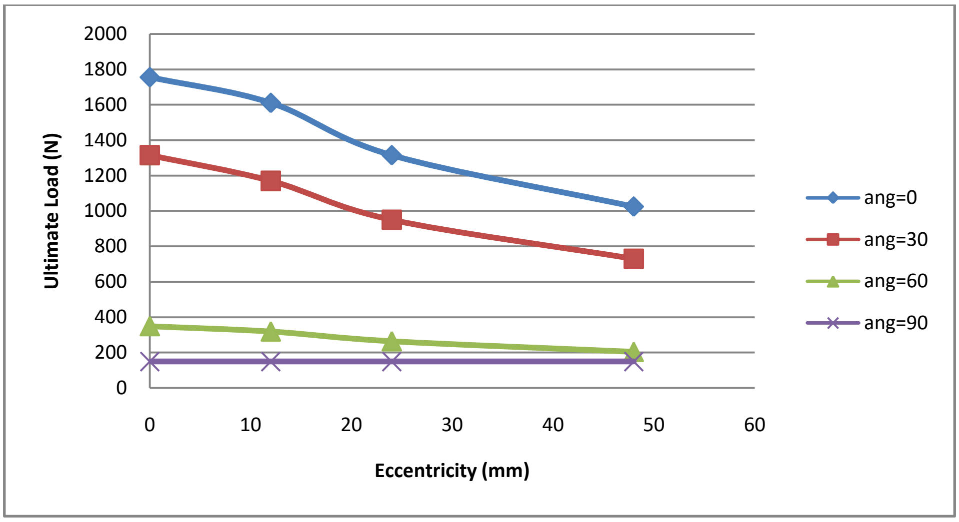

Fig.4Ultimate Load (N) vs. Eccentricity (mm) for 2x2 pile group

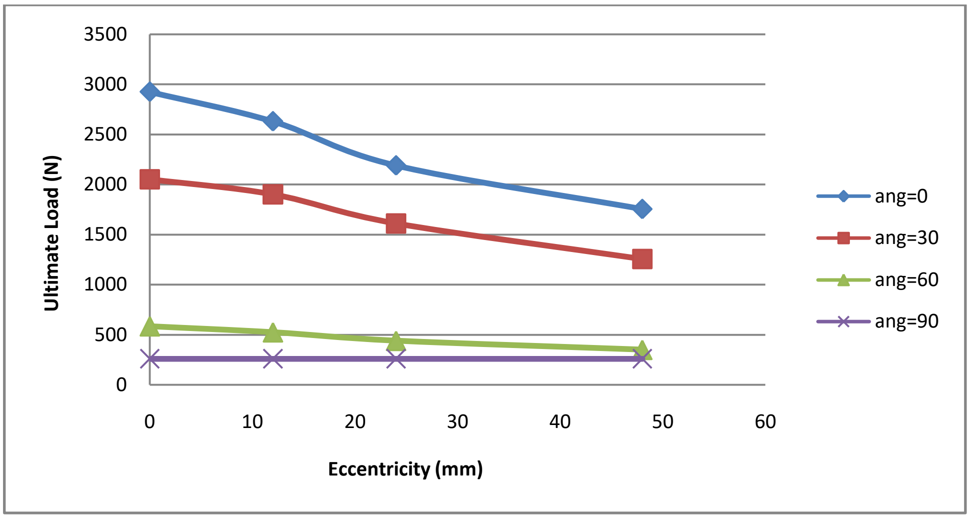

Fig. 5 Ultimate Load (N) vs. Eccentricity (mm) for 2x3 pile group

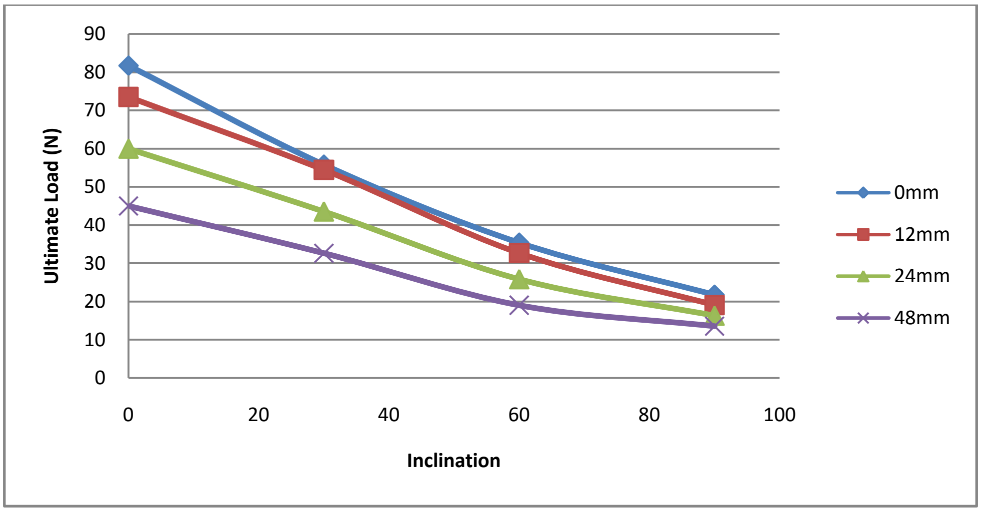

Fig. 6 Ultimate Load (N) vs. Inclination for single pile

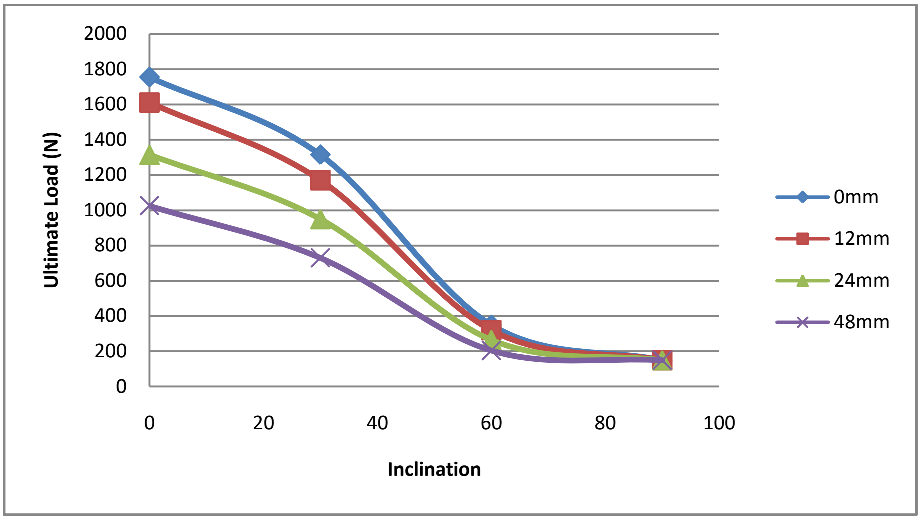

Fig. 7 Ultimate Load (N) vs. Inclination for 2x2 pile group

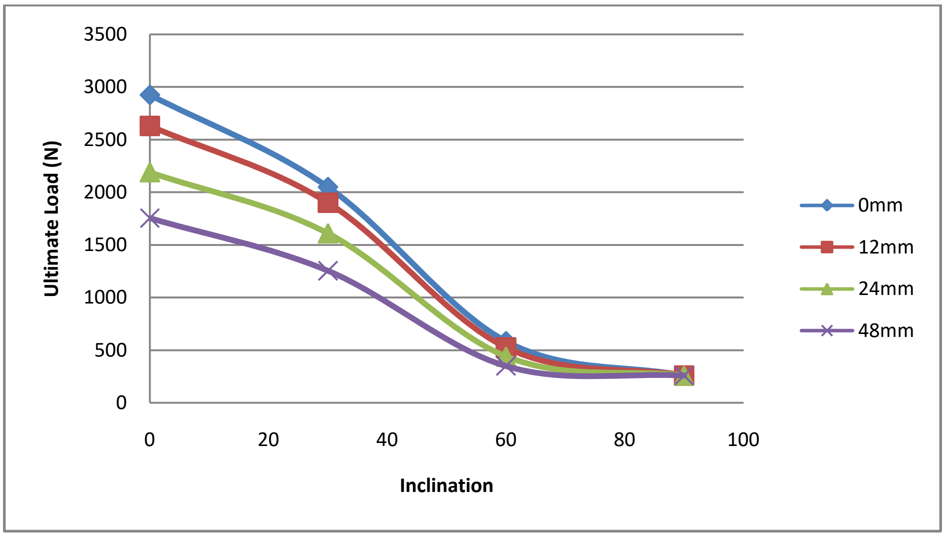

Fig. 8 Ultimate Load (N) vs. Inclination for 2x3 pile group

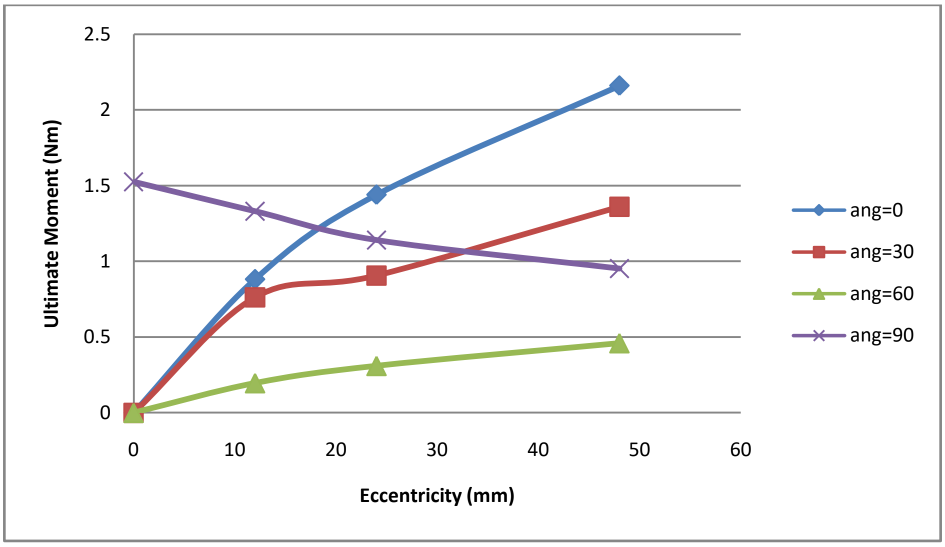

Fig.9 Ultimate Moment (Nm) vs. Eccentricity (mm) for single pile

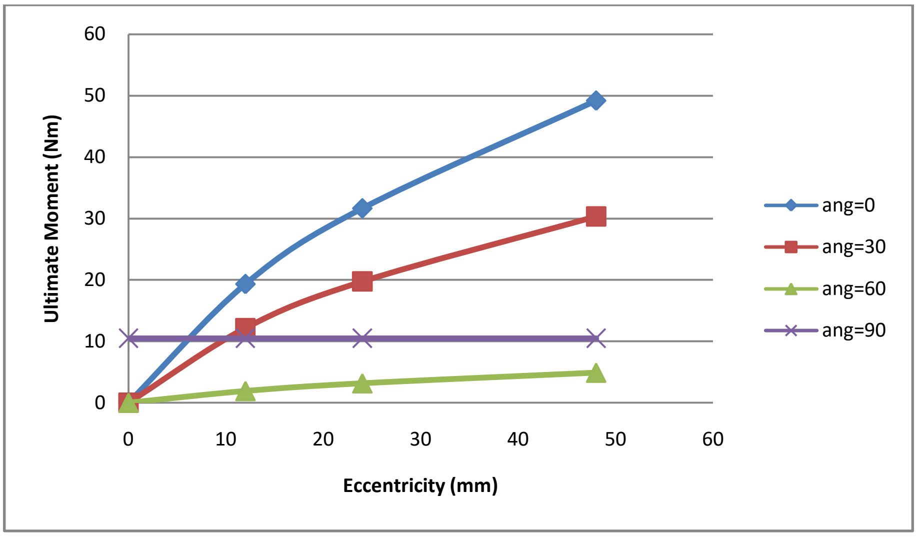

Fig.10 Ultimate Moment (Nm) vs. Eccentricity (mm) for 2x2 pile group

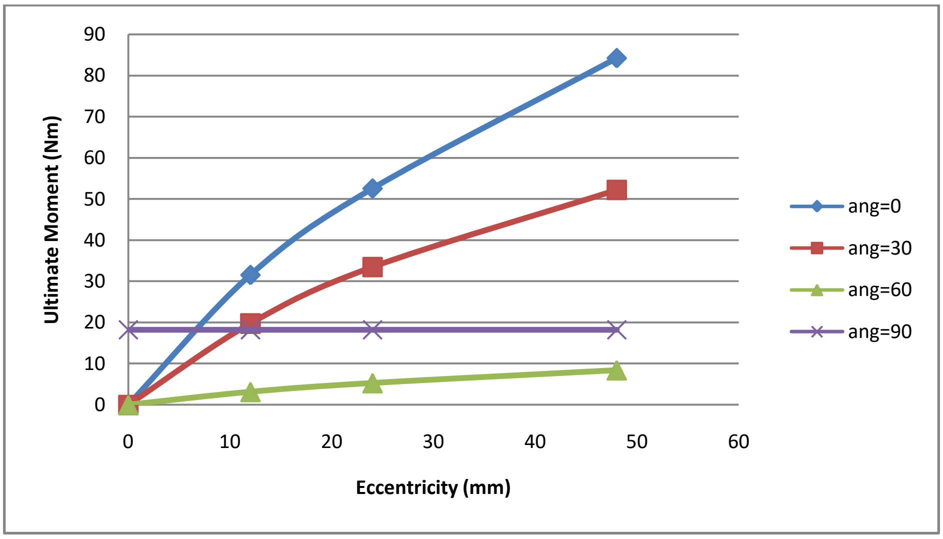

Fig.11 Ultimate Moment (Nm) vs. Eccentricity (mm) for 2x3 pile group

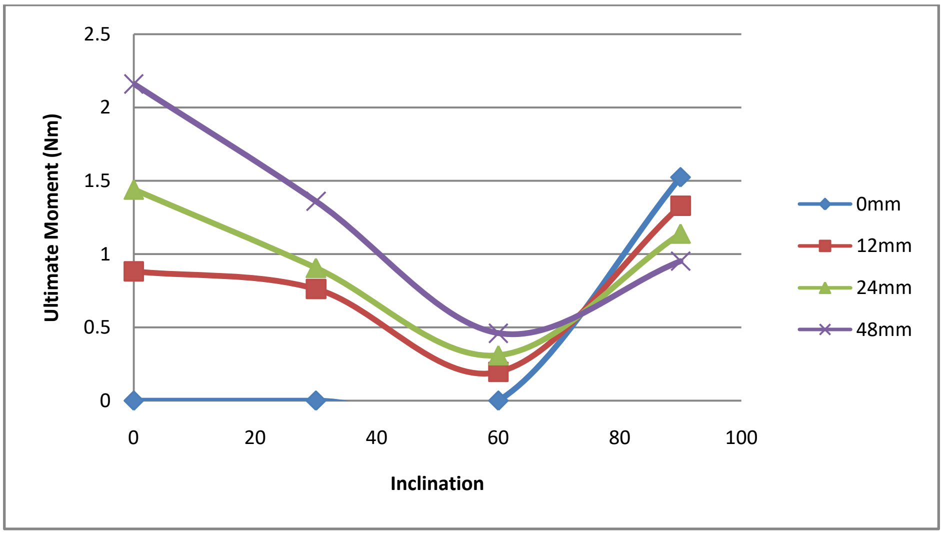

Fig.12 Ultimate Moment (Nm) vs. Inclination for single pile

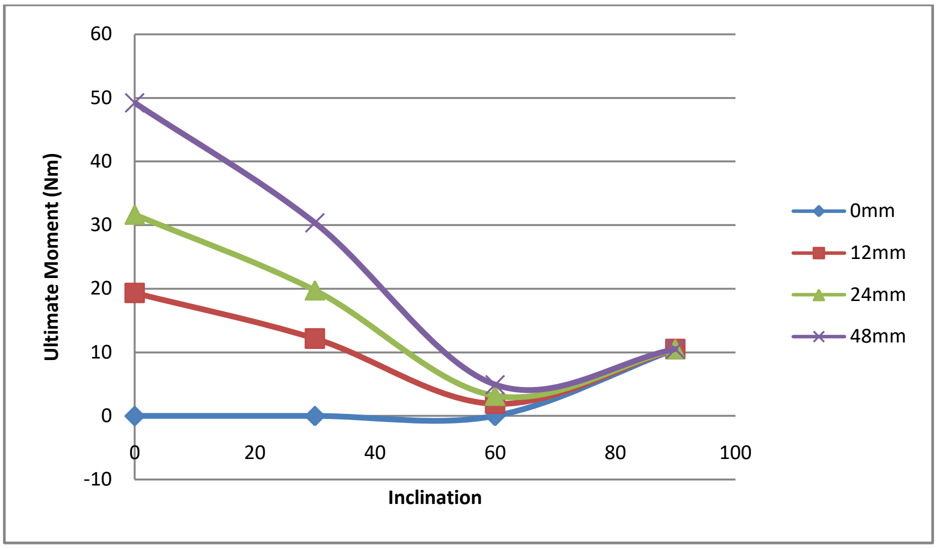

Fig.13 Ultimate Moment (Nm) vs. Inclination for 2x2 pile group

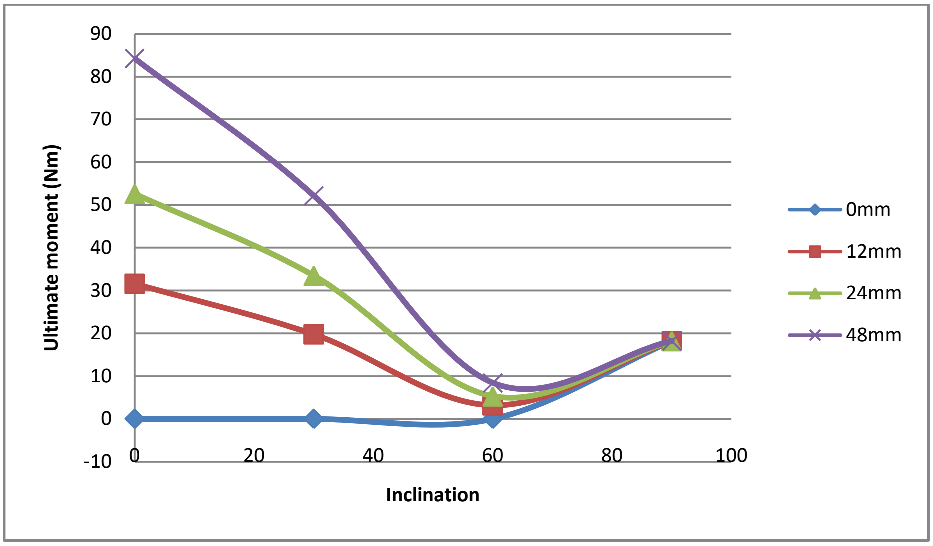

Fig.14 Ultimate Moment (Nm) vs. Inclination for 2x3 pile group

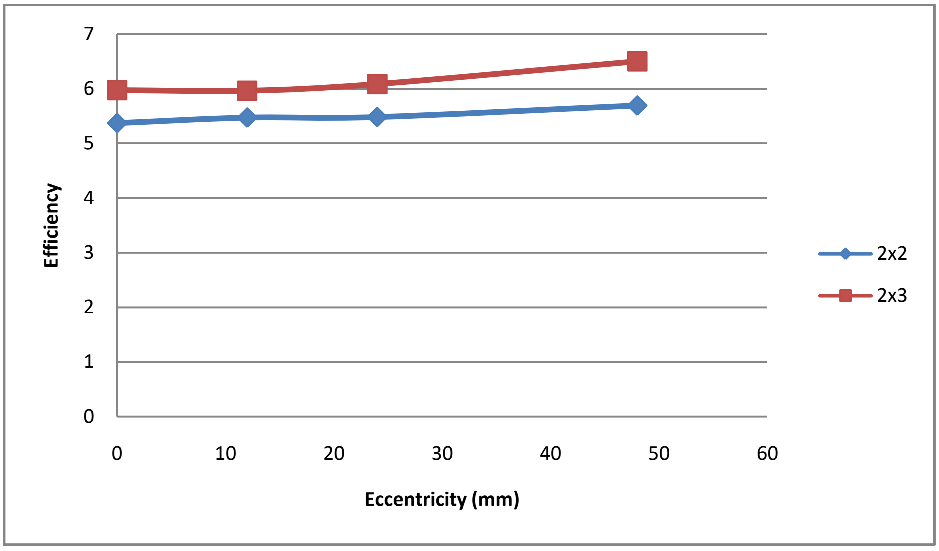

Fig.15 Efficiency vs. Eccentricity (mm) for vertically loaded pile groups

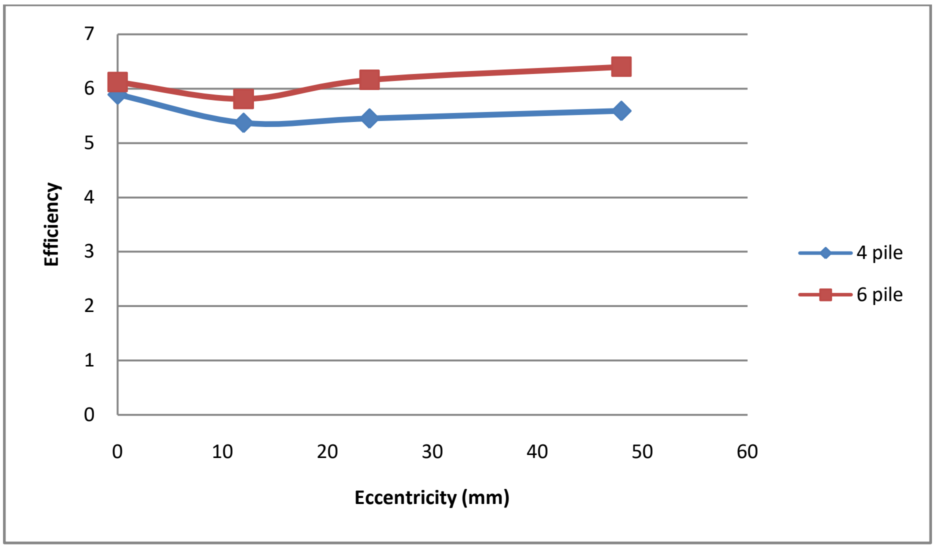

Fig.16 Efficiency vs. Eccentricity (mm) for pile groups at 30° load inclination

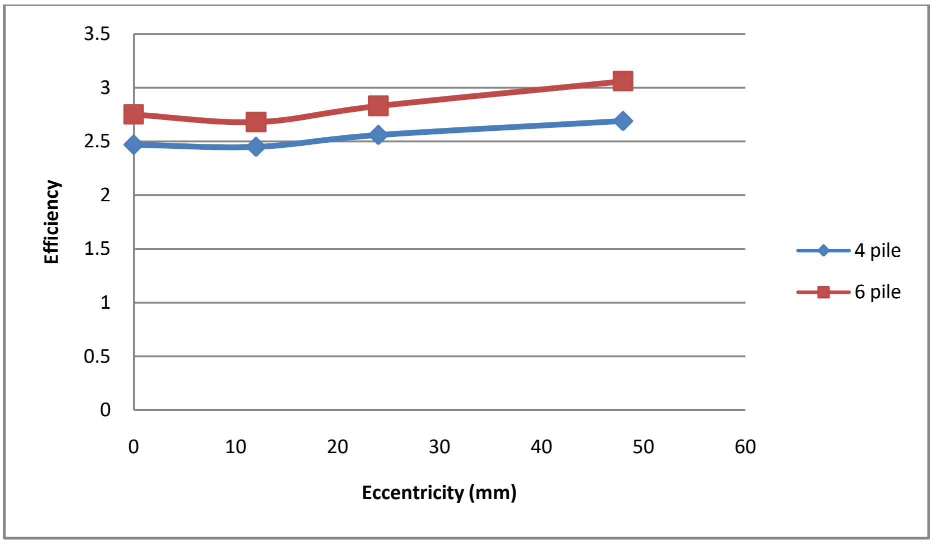

Fig.17 Efficiency vs. Eccentricity (mm) for pile groups at 60° load inclination

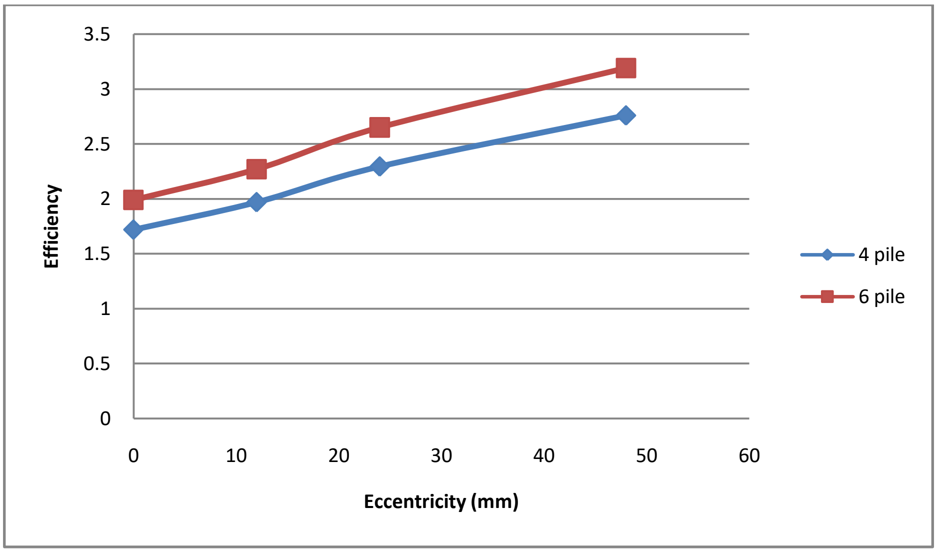

Fig.18 Efficiency vs. Eccentricity (mm) for pile groups at 90° load inclination

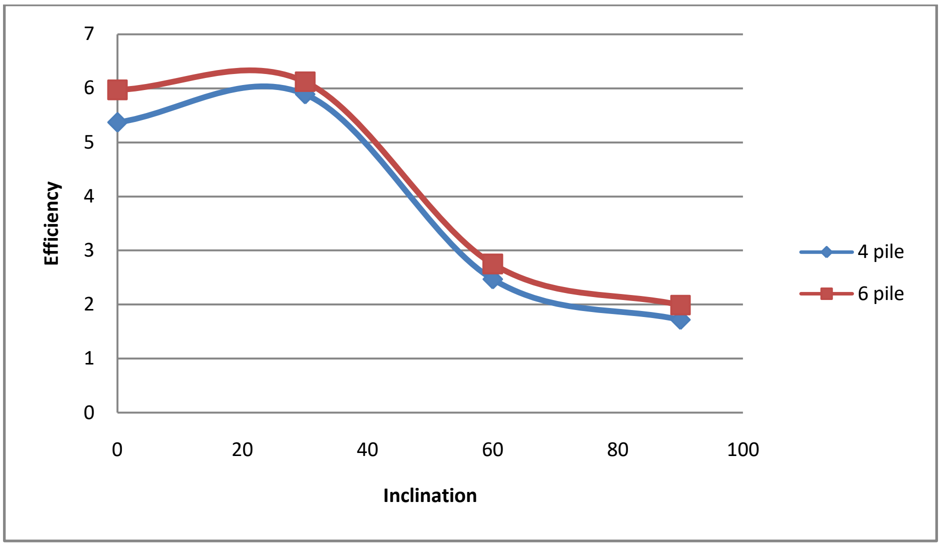

Fig.19 Efficiency vs. Inclination for Centrally loaded pile groups

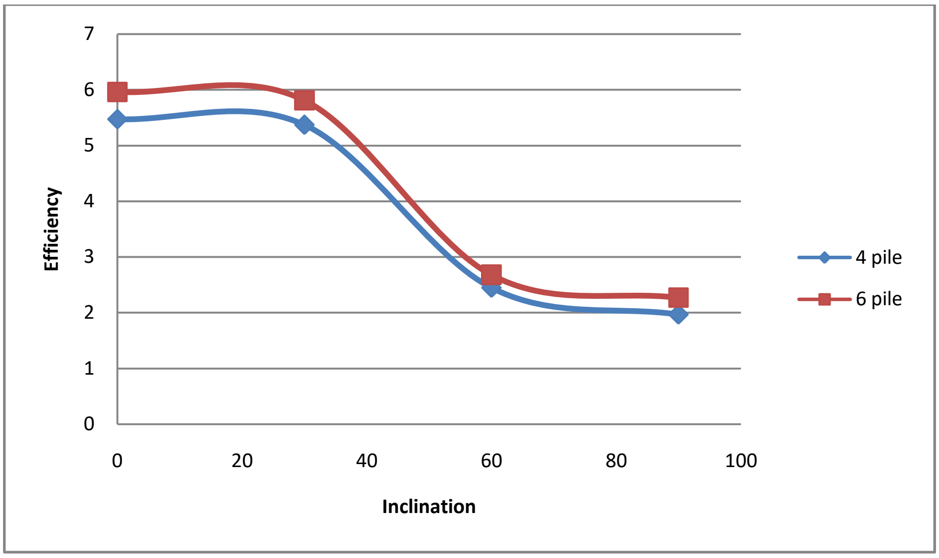

Fig.20 Efficiency vs. Inclination for pile groups at load eccentricity of 12mm

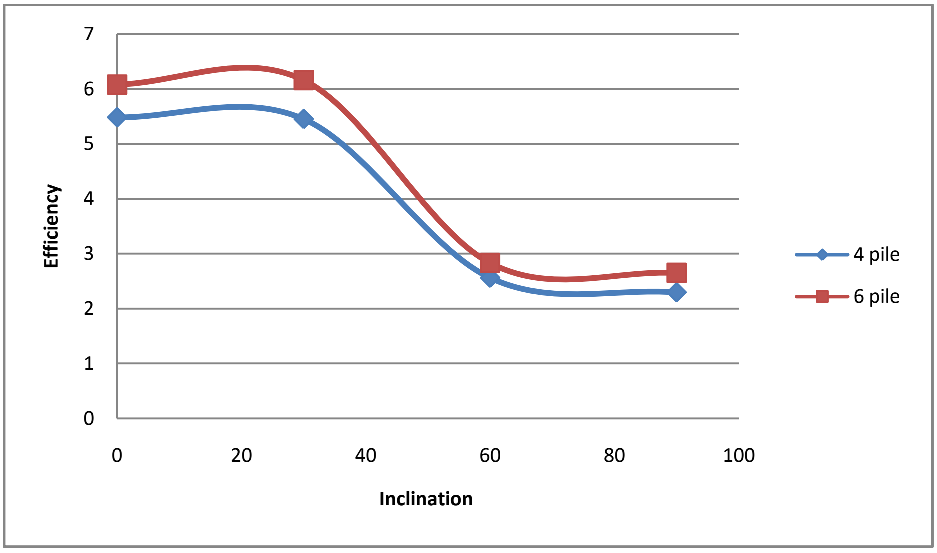

Fig.21 Efficiency vs. Inclination for pile groups at load eccentricity of 24mm

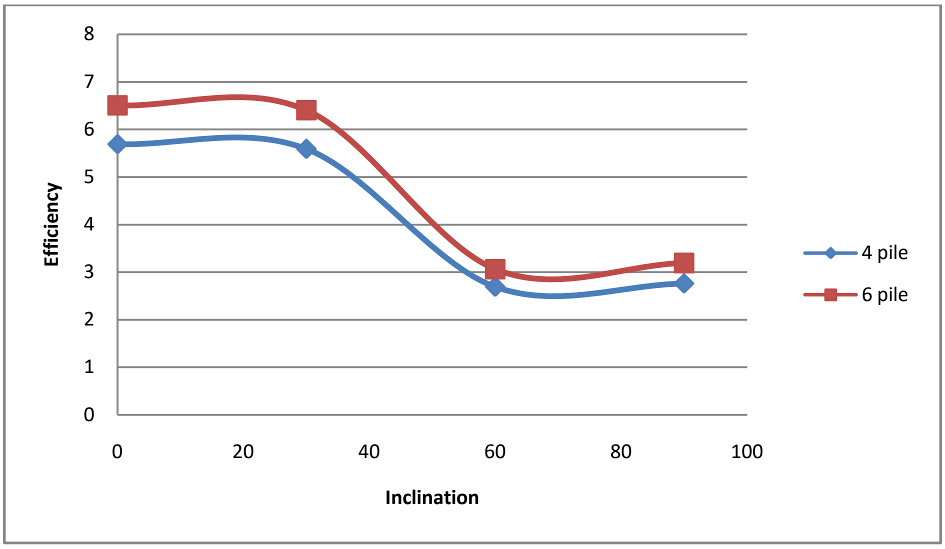

Fig.22 Efficiency vs. Inclination for pile groups at load eccentricity of 48mm

V. CONCLUSIONS

1. The load vs pile head displacement characteristics are typically non-linear in nature. Initially this increase in the displacement is at very slow rate with progress of loading which is curvilinear with convex upward. With further progress of loading turns into straight line higher progressive settlement. As the eccentricity of load increases the load carrying capacity decreases and the curve falling down towards the displacement axis.
2. The ultimate load vs. eccentricity for different inclination shows as the eccentricity increases its load carrying capacity decreases. From 0.05L to 0.1L eccentricity, rate of reduction is more whereas from 0 to 0.05L and from 0.1L to 0.2L eccentricity, rate of reduction of ultimate load is less.
3. The ultimate load vs. inclination for different eccentricities shows as the load inclination with vertical increases from 0° to 90°, the load carrying capacity of single vertical piles subjected to eccentric inclined load decreases. From 30° to 60°, rate of reduction is more whereas from 0° to 30° and 60° to 90° inclination, rate of reduction of ultimate load is less.
4. As the eccentricity of load increases, the ultimate moment increases. All the ultimate moment vs. eccentricity characteristics are curvilinear in beginning with convex upward which fall in to straight line thereafter except for 90° load inclination.
5. The Efficiency vs. Eccentricity and Efficiency vs. Inclination graphs clearly shows the 3x2 pile group as more efficient than 2x2 pile group.

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