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Performance of Axially Loaded Pile Group in Oil Contaminated Kanhan Sand

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Abstract: The ground is being contaminated by petrochemical activities, oil spills, and pipeline or reservoir leakage everyday. This contamination has been proven to alter the geotechnical properties of soil, and researchers have extensively studied the properties of contaminated granular soils. But the effect of oil contamination on the geotechnical properties of sandy soils has not yet been well evaluated. Hence, a comprehensive set of laboratory pile load tests has been conducted in contaminated sand. This paper presents an experimental investigation aimed for understanding the performance of pile group in oil-contaminated sand. The model parameter are varied, namely thickness of contaminated layer and percentage of oil contamination. The tests were performed with an oil content of 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 % with respect to dry soil to match the field condition. This is an extensive program of work, done on single pile in oil content of 0 to 3.0 % which was published earlier. From the results, it is observed that the maximum pile capacity in all percentages of oil contamination was found in the range of L_C/L_P = 0.50 to 1.0. Pile Capacity Ratio (PCR) is affected remarkably by the thickness of the contaminated-sand layer with respect to the length of pile. PCR is also affected by percentage of oil contamination.
Keywords: Soil pollution; Kanhan Sand; Pile capacity; oil contaminated sand; Length of pile to length of contamination ratio (L_c/L_p); Pile Capacity Ratio (PCR).

I. INTRODUCTION

As we know that gas and oils are the most significant sources of energy worldwide. Also, their importance rise because of increasing global demand for energy. But, the main drawback with this type of energy is the damage they caused to the environment because of oil spills and leakage during their production. Industrial, petrochemical, construction, and sanitary activities contaminate water, air, and land for their short-term benefits. This pollution is usually caused by vandalism, wars, theft, and terrorism, but can also be caused by transporting petroleum, accidental leakage, corroding pipelines, oil spillage, and human error during production and separation process. The physical and chemical properties of the surrounding sand are impacted by oil spill contamination intentionally or unintentionally [17].

Due to rapid industrialization, large quantities of industrial disposal are being discharged in the surrounding areas causing contamination of soil. In addition to environmental concerns for ground water pollution and other possible effects, the geotechnical properties of the contaminated soil and bearing capacity of soil are also altered. In these cases, major tasks are needed for remediation and reclamation of the contaminated sites. Oil spills during transportation on the land or during oil drilling processes happen by accidents in most cases. When oil spills, soils might be contaminated by the leakage. Land contamination is not only harmful for the subsurface water aquifers but is also a detriment to the buildings and structures on it. Any change in the engineering properties and behaviour of the soil strata may lead to a loss in the bearing capacity and an increase in the total or differential settlements of the foundation systems of structures [3].

Although scientists have evaluated the geotechnical properties of contaminated granular soils through comprehensive studies, few researchers have studied the effects of oil contamination on the geotechnical properties of fine-grained soils. Meegoda and Ratnaweera in 1994 examined the compressibility of contaminated fine-grained soils by performing consolidation tests. Their finite-element analysis showed that the settlement of the foundation increases due to oil contamination. Al-Sanad et al. in 1995 and Al-Sanad and Ismael in 1997 found that oil contamination leads to decrease permeability and strength. Vesic in 1973 found that the the angle of friction and bearing capacity factor N_Y got reduced due to oil contamination. Ghaly (2001) performed direct shear tests on oil-contaminated sands which showed a reduction in angle of friction with an increase in the oil percentage. Shin et al. (2002) reported a significant reduction in angle of friction with oil contamination. According to Ratnaweera and Meegoda (2006), the shear strength of granular soil decreases with an increase in pore fluid viscosity. Mashalah et al. (2007) carried an extensive laboratory testing program which shows that oil contamination induces a reduction in the permeability and strength of all soil samples. Sanket

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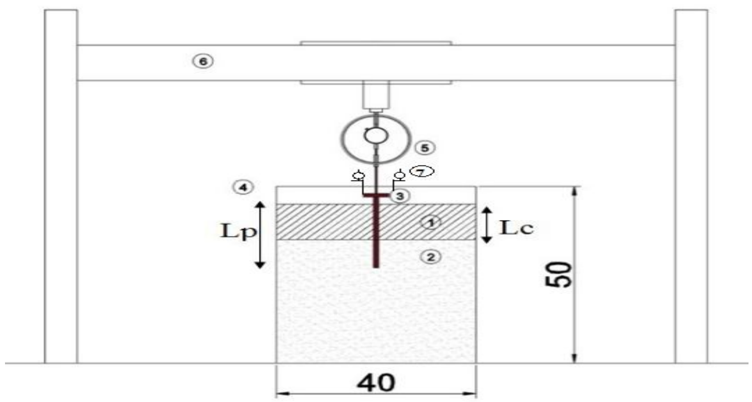
Sabale et al. in 2017 carried out a laboratory investigation on single pile in oil contaminated sand by taking oil content as 0, 0.5, 1.0 and 1.5 %. The results showed increase in cohesion with increase in percentage of oil content and decrease in value of internal angle of friction with increase in percentage of oil content. The range of L_C/L_P where pile capacity observed to be maximum was 0.5 to 1.0 [18]. Sanket Sabale et al. in 2017 carried out a laboratory investigation on single pile in oil contaminated sand by taking oil content as 2.0, 2.5 and 3.0 %. The results showed increase in cohesion with increase in percentage of oil content and decrease in value of internal angle of friction with increase in percentage of oil content. Remarkable changes were observed in Pile Capacity Ratio [4]. The investigation work presented in this paper is the extension of the work mensioned in above two literatures which were published by author.

The knowledge about the behaviour of axially loaded pile groups embedded in oil-contaminated sand is very limited. However, the objective of the current study is investigating performance of pile groups embedded in oil-contaminated by performing laboratory model pile load test. Based on the results, the effect of various parameters influencing the performance of pile group such as the percentage of oil content and thickness of contaminated sand layer were investigated. In addition, the comparison between uncontaminated and oil-contaminated sandy soil were studied.

II. MATERIALS AND METHODS

A. Test Tank and Loading Frame

The experimental setup consist of the loading frame used as a reaction frame, load measuring unit, a test tank, hydraulic jack, and vertical displacement measuring unit. Fig. 1 shows schematic diagram of the testing arrangement. Hydraulic jack consisting of loading unit and pumping unit was used to apply the load. Loading was recorded by using a proving ring (2.5 kN capacity) connected to a long screw from the upper direction and to the pile cap from the lower direction by using an eye bolt. The vertical displacements were measured using two dial gauges accurate to 0.01 mm.



1- Contaminated Sand Layer; 2-Clean Sand; 3-Pile Attached with Pile Cap; 4-Model Tank; 5-Proving Ring; 6-Reaction Frame; 7-Dial Gauge Fig.1 Schematic View of Test Configuration

The tank used in experimental work was square in shape and made up of steel with inner dimensions 400 mm long X 400 mm wide X 500 mm high. 3-mm-thick steel plate was used to fabricate the tank. The vertical and bottom edges of the tank were stiffened using steel angle sections. The inside walls of the tank were smoothly polished to reduce the friction with the sand as much as possible. The tank was designed to be large enough so that there will be no interference between the walls of the tank and the failure zone around the piles [1].

B. Sand Properties

For the experimental study, cohesionless, dry and clean Kanhan sand was used as the foundation soil. This type of sand is available in Nagpur region of Vidarbha, Maharashtra. The test sand has angular shape, uniform yellow colour with small proportion of flint stone of black colour. The particle size of sand decided for the test was passing through 2 mm IS sieve. 40 % relative density was maintained in all the tests. The various laboratory tests were performed to determine the different engineering properties of sand in accordance with the relevant IS codes. The grain size distribution of the sand is shown in Fig. 2. The sand is poorly graded sand (SP) according to the IS Soil Classification System. The properties of clean and oil contaminated sand used are as shown in Table I.

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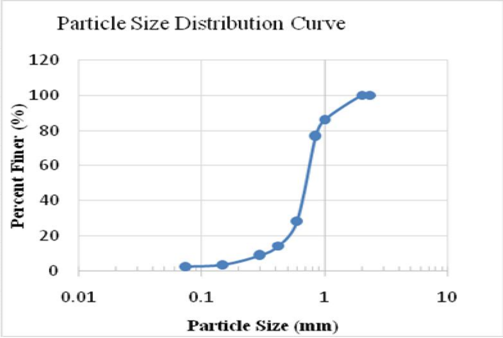

Fig.2 Grain Size Distribution Curve for Sand

TABLE I
PROPERTIES OF SAND USED

Properties	% of oil contamination						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0
Specific gravity (G)	2.71	2.62	2.59	2.57	2.55	2.50	2.44
$\Upsilon_{max\ (kN/m^3)}$	17.16	-	-	-	-	-	-
$\Upsilon_{min\ (kN/m^3)}$	15.86	-	-	-	-	-	-
Angle of internal friction, Ø	45	40	34	30	24	22	18
Cohesion $_{(kN/m^2)}$	0.0	9	17	25	30	33	36
Average grain size (D_{60}) (mm)	0.82	-	-	-	-	-	-
Effective grain size (D_{10})(mm)	0.35	-	-	-	-	-	-
Coefficient of uniformity (C_u)	2.343	-	-	-	-	-	-
Coefficient of curvature (C_c)	1.472	-	-	-	-	-	-
I. S. Classification	SP	-	-	-	-	-	-
Relative density (%)	40	40	40	40	40	40	40

C. Model Pile Foundation

The model pile group for experimental investigation was made from mild steel rods. The piles were provided with threads at one end for attachment of pile cap for ease of applying vertical load. Clean sand was applied to the model pile with the help of epoxy glue to make it friction pile. The groove at centre of the pile cap was provided for applying the loads. Pile cap of size 10 X 10 cm in plan was used in investigation for pile group respectively. Thickness of pile cap for model pile and pile group was taken as 3 mm to be able to fix it to the proving ring, which is attached to the long screw. L- Shaped angles were welded to the pile cap to place the dial gauge. Table 2 shows the details of model pile. Fig 3 shows the model pile used in investigation.

Mazurkiewicz (1968) reported that the pile length/pile diameter ratio (L/D) of 10:1 is a good ratio for model pile tests. Consequently, the length of the model pile was set to be 100 mm and the diameter to 10 mm [1].

Fig.3 Four Pile Group

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TABLE II
MODEL PILE FOUNDATION USED IN TESTING

Sr. No.	Number of piles in group	Shaft diameter	Pile length	Self weight
1	4	10 m	100 mm	0.25 kN

D. Oil properties and preparation of contaminated sand

In proposed experimental study, waste engine oil collected from locally available garage was used to contaminate the sand bed in the model tests. Oil added for contamination of sand worked as a softener which caused decrease or sometimes increase in the friction between sand particles and piles. The properties of oil use in the experiments are shown in the Table III.

For contaminated sand, the amount of oil was calculated as a percent by weight of the dry sand. Oil contaminated sand layers were prepared by mixing the sand with an Oil Content (O.C.) of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 %. The mixed oil contaminated sand was put into closed bags for 2 days for aging and equilibrium, allowing possible reactions between sand and oil [1].

TABLE III
OIL PROPERTIES

Type of oil	Kinematics Viscosity (m^2/s)	Density (kN/m^3)	Specific gravity
Waste Engine Oil	45×10^{-6}	8.3	0.83

III. METHODOLOGY

A. Installation of model pile in sand

Pile installation method used in this investigation was the jacking method. Jacked piles are basically displacement piles pushed into the ground by static load. According to Li et al. (2003), in Hong Kong, the jacking process is often taken as an installation method. Jacked piles have the advantage that they cause little pollution to the environment in the form of noise, air, and vibration. In the investigation, the pile was pushed into the sand manually upto the required depth. After the pile has reached the final penetration depth, the proving ring and dial gauges were fixed and tests were conducted [1].

B. Experimental procedure

The procedure for these experimental tests consisted of the placement of clean and contaminated sand, placement of a pile group, applying the axial load and recording of load and displacement. The empty tank first of all was filled up with required level of uncontaminated sand. While testing on uncontaminated sand, sand rainfall technique was used to fill the tank. The height of fall to achieve the desired relative density was determined prior by performing a series of trials with different height of fall. The sand was poured in the tank by sand rainfall technique keeping the height of fall as 50 cm to maintain the constant relative density 40% corresponding bulk density 16.31 kN/m^3 throughout the test.

In case of contaminated sand a raining technique (pluviation) for soil placement in the test tank was not suitable and did not provide uniform compaction. Therefore, the sand unit weight was controlled by pouring the precalculated weight of contaminated sand into the box for each layer separately, then the sand was placed and surface was leveled [1]. Centering of the tank was done to locate the centre of the tank and pile group was embedded at that centre into the sand bed upto a pile length manually.

Finally, the dial gauges were placed on welded portion opposite sides across the center of the pile cap, and load was applied incrementally. The pile loading was carried out with approximately (0.015 kN) incremental steps, and the pile group was permitted to stabilize. Each load increment was maintained constant until the pile group vertical displacement was stabilized. The axial load was recorded with the help of the proving ring, whereas the vertical displacements of the pile were recorded by the dial gauges. After completing the test, the whole tank had to be emptied, and then, the preparation for the next set had to be made. Experimental setup used in investigation is shown in Fig. 4.

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Fig. 4: Experimental Setup Used for Experimental Investigation

C. Test Program

The model testing program included a parametric study that investigated different variables. Table IV shows a summary of model test parameters and their values. To study the effect of contaminated sand, the test on pile group embedded in uncontaminated sand was also carried out as a reference. A total of 22 tests were conducted to study the effect of oil contamination on performance of pile group under axial load in oil contaminated sand.

TABLE IV
MODEL TEST PROGRAM

Series	Constant parameter	Varying Parameter
I	OC = 0 %	-
II	OC = 0.5 %	L_c/L_p=0.50,0.75,1.0
III	OC = 1.0 %	L_c/L_p=0.25,0.50,0.75,1.0,1.25,1.50
IV	OC = 1.5 %	L_c/L_p=0.50,0.75,1.0
V	OC =2.0 %	L_c/L_p=0.50,0.75,1.0
VI	OC =2.5 %	L_c/L_p=0.50,0.75,1.0
VII	OC =3.0 %	L_c/L_p=0.50,0.75,1.0

IV. EXPERIMENTAL RESULTS

In this research, laboratory studies were conducted on model pile foundation. The laboratory study would give an idea about the behaviour of pile group on oil contaminated sand bed with various oil content and depths of contamination. During the experimental investigations, depth of contamination and percentage of contamination are augmented whereas the other parameters viz., diameter of pile, length of pile, type of soil, type of oil and density of sand were kept constant. The model pile load tests were conducted on pile group in uncontaminated and contaminated sandy soil bed and the load settlement curves were plotted for each test from which pile capacities were calculated. Then pile capacities of pile group in oil contaminated sand were compared with that of pile group in uncontaminated sand in terms of Pile Capacity Ratio.

A. Performance of pile group on Uncontaminated Sand

Initially, test on pile group in uncontaminated sand was conducted so that the results could be compared with pile group in oil contaminated sand. Load settlement curve for four pile group in uncontaminated sand is as shown in Fig. 5. The pile capacity of pile group in uncontaminated sand was obtained as 0.22 kN.

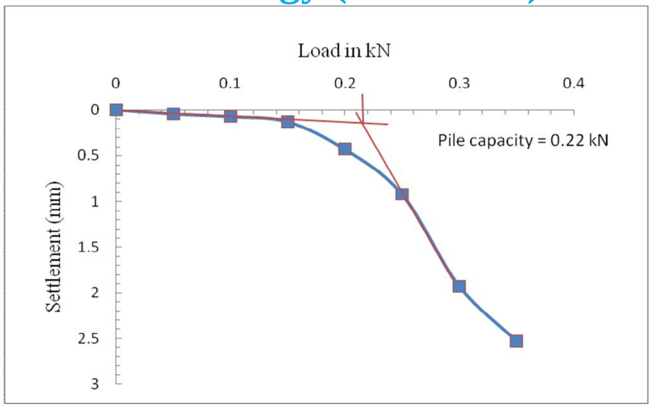

Fig.5: Load Settlement Curve for Four Pile Group in Uncontaminated Sand

B. Performance of pile group in Oil Contaminated Sand

The load settlement curves for various depths of contamination and percentage of contamination of sand for pile group are drawn and pile capacities are determined. Fig. 6 shows load settlement curves for pile in 1.0 % of oil contamination for all L_c/L_p ratios. The variation of Pile Capacity with L_C/L_P for pile group in 1.0 % oil contamination is shown in Fig. 7. Only one curve for each parameter is included in paper and for remaining curves, values are shown in Table V. Table V shows tests results for pile group embedded in uncontaminated and contaminated sand for L_c/L_p= 0.25 to 1.50.

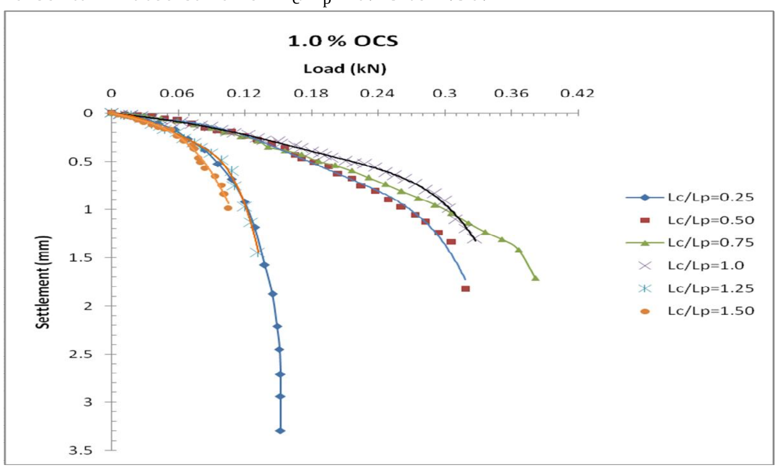

Fig.6 Load Settlement Curves for Pile Group in 1.0 % Oil Contaminated Sand Bed

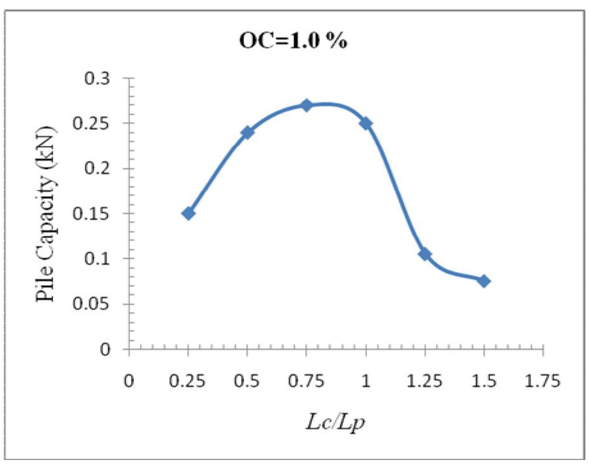

Fig.7 Variation of Pile Capacity with L_C/L_P in 1.0 % O. C

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TABLE V

PILE CAPACITIES OF PILE GROUP EMBEDDED IN UNCONTAMINATED AND CONTAMINATED SAND BED

% O C	Pile Capacities for Various L_c/L_p (kN)					
	0.25	0.50	0.75	1.0	1.25	1.50
0	0.22					
0.5	-	0.195	0.27	0.21	-	-
1	0.15	0.24	0.27	0.25	0.105	0.075
1.5	-	0.235	0.27	0.24	-	-
2	-	0.26	0.21	0.16	-	-
2.5	-	0.195	0.22	0.18	-	-
3	-	0.18	0.21	0.145	-	-

C. Summary and Discussion

The model pile load tests were carried out on pile group and the pile capacities were calculated from the load versus settlement curves. One of the most important objectives of the present experimental study was to investigate the influence of the depth of oil contamination on the behaviour of pile group under axial loading. Therefore, a series of tests were conducted with various percentages of oil content (O.C.) viz., 0, 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 % and for various L_C/L_P ratios viz., 0.25, 0.50, 0.75, 1.0, 1.25, and 1.50. For comparing the test data, the term Pile Capacity Ratio (PCR) is used and is defined as

$$PCR = \frac{P_{U,oil}}{P_{U,uncontaminated}}$$

where,

$P_{U,oil}$ = Pile Capacity of the pile group embedded in oil-contaminated sand from experimental tests; and

$P_{U,uncontaminated}$ = Pile Capacity of the pile group embedded in uncontaminated sand from experimental tests.

Summary of PCR values for pile group in uncontaminated and oil contaminated sand for different percentages of oil and depths of contamination is given in Table VI.

TABLE VI

PCR VALUES OF PILE GROUP FOR DIFFERENT DEPTHS OF CONTAMINATION AND PERCENTAGE OF OIL CONTAMINATION

% O C	PCR for various L_C/L_P ratios					
	0.25	0.5	0.75	1	1.25	1.5
0	-	1	1	1	-	-
0.5	-	0.89	1.23	0.95	-	-
1	0.68	1.09	1.23	1.13	0.47	0.34
1.5	-	1.07	1.23	1.09	-	-
2	-	1.18	0.95	0.73	-	-
2.5	-	0.88	1	0.82	-	-
3	-	0.82	0.95	0.66	-	-

D. Effect of Oil Contamination on Soil Properties

As pile shaft resistance is highly dependent on the friction angle of granular soil, direct shear tests were performed on uncontaminated and oil contaminated sands to examine the effect of percentage of O.C. on the angle of shearing resistance values of sand. Variation of peak friction angle with oil content is shown in Fig. 8 and variation of cohesion with oil content is shown in Fig. 9.

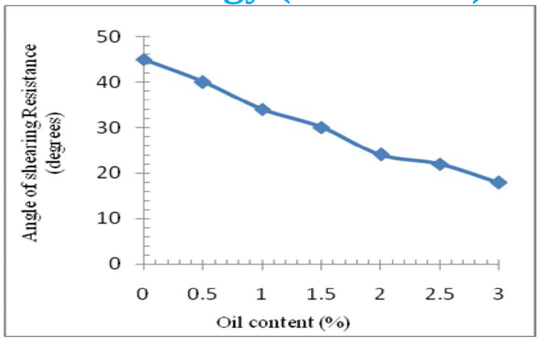

Fig.8 Variation of Friction Angle with O.C.

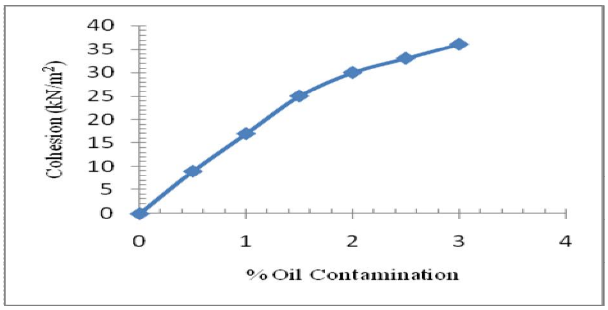

Fig.9 Variation of Cohesion with O.C.

From Fig. 8 it is observed that the angle of internal friction is significantly influenced by oil contamination and it decreases with increase in percentage of oil contamination. From Fig. 9, it is observed that the cohesion of sand increases with increase in the percentage of oil contamination.

E. Effect of Depth of Contamination

In the present study, six different depths of contamination were adopted and model pile load test was carried out on pile group embedded in contaminated sand bed. Variation of PCR with depth of contamination (L_C/L_P) was studied for various percentages of oil contamination. The variation of PCR with L_C/L_P for pile group in 1.0 % of oil contaminated sand is shown in Fig. 10.

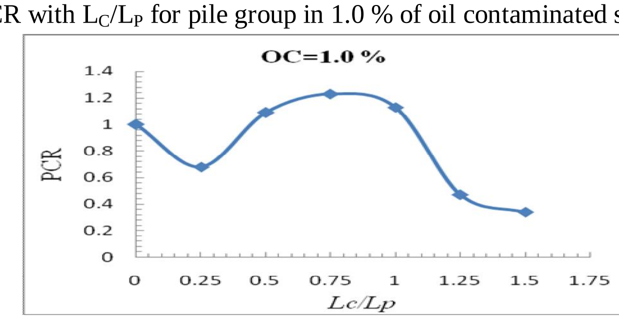

Fig 10: Variation of PCR with L_C/L_P for Pile Group in 1.0 % O. C.

From figure 10, it is observed that the PCR is affected remarkably by the thickness of the contaminated-sand layer with respect to the length of pile. However, this variation is neither of increasing or decreasing trends, and is non uniform in nature. It decreases initially and then increases upto a certain value of L_C/L_P depending upon percentage of oil contamination. With further increase in L_C/L_P, PCR decreases.

F. Effect of Percentage of oil contamination

From the determined values of PCR, variation of PCR with depth of contamination was plotted as well as variation of PCR with percentage of contamination was also plotted to see the change in trend of curves. Fig. 11 shows variation of PCR with percentage of oil contamination for L_C/L_P = 0.50 in pile group. From Fig. 11 it is observed that the variation of PCR with percentage oil

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contamination is very haphazard in nature and is very difficult to interprete any conclusion. There are certain decrease and increases in value of PCR as percentage of oil changes.

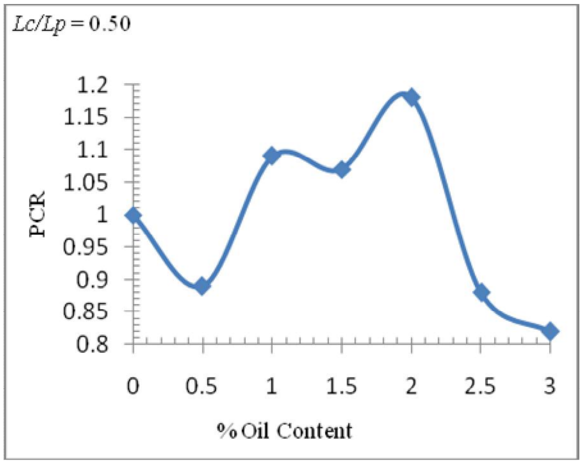

Fig.11: Variation of PCR with Percentage of Oil Contamination for L_C/L_P =0.50 in Pile Group

V. CONCLUSIONS

The knowledge about the behaviour of axially loaded pile and pile groups embedded in oil-contaminated sand is very limited. Therefore, the capacities of pile groups embedded in oil-contaminated sand were investigated using laboratory model pile load test. Based on the results, the effect of various parameters influencing the performance of pile group such as the percentage of oil content and thickness of contaminated sand layer were investigated. Within the framework of the present investigation, the following conclusions are drawn.

A. The angle of internal friction is significantly influenced by the oil contamination. It decreases with the increase in percentage of oil contamination.

B. The cohesion of the sand increases with increase in percentage of oil contamination.

C. For single pile and pile group, pile capacity increases with increase in depth of contamination (L_C/L_P) upto a certain depth. With the further increase in the depth of contamination, the pile capacity decreases drastically. The range of L_C/L_P for which the pile capacity is maximum is 0.5 to 1.0.

D. PCR is affected remarkably by the thickness of the contaminated-sand layer with respect to the length of pile. However, this variation is neither of increasing or decreasing trends, and is non uniform in nature. It decreases initially and then increases upto a certain value of L_C/L_P, depending upon percentage of oil contamination. With further increase in percentage of oil contamination, PCR decreases.

E. PCR is affected remarkably by the percentage of the contamination. However, this variation is very fluctuating and haphazard in nature and therefore is difficult to interprete. It decreases initially and then increases upto a certain value of percentage of oil contamination depending upon depth of contamination. With further increase in percentage of oil contamination, PCR decreases.

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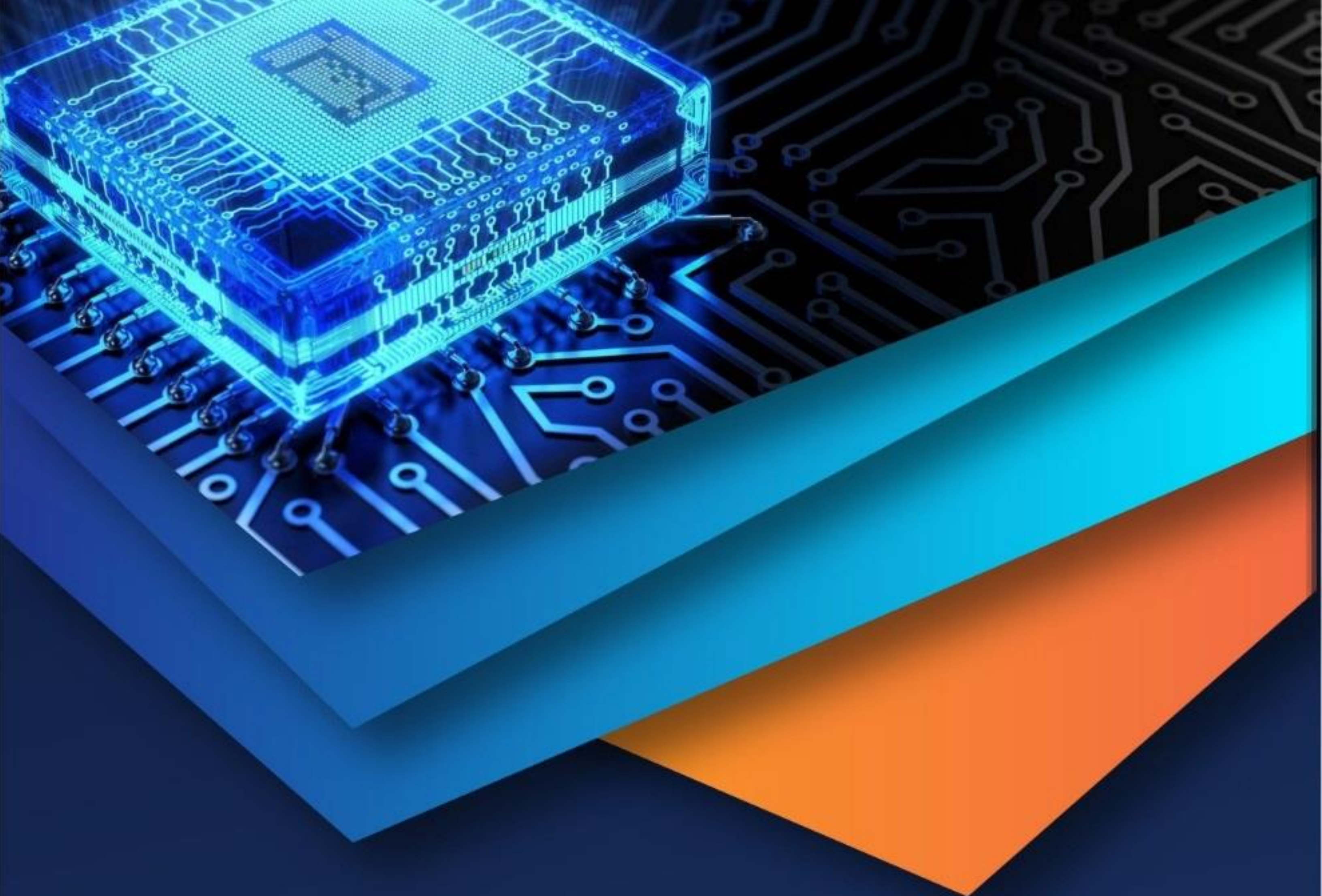

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