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Experimental Investigation on Vertical Piles in Dense Sand Medium under Axial and Lateral Loads

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Abstract

Vertical piles are used in such structures which receive the heavy loads especially the structures like dry docks, basements and like pumping stations to resist the uplift loads. The loads which are coming on piles are the combination of both vertical and lateral loads, a very few number of researches has been done on this response of pile groups subjected to the combination of both loads. Here the interaction of pile-soil-pile in the structure is to be observed. In this paper we are discussing and presenting the experiments on different piles in dense sand medium, and the behavior of vertical piles under both axial and lateral loads. The combined load test results showed that the resistance, lateral displacement and efficiency at the head of the piles increased substantially for tests performed in the presence of axial loads, suggesting that the presence of axial loads on individual and groups of piles driven in dense sand is detrimental to their lateral capacity.

Keywords: *Dense sand medium, Vertical Pile, Axial loads, Lateral loads*

INTRODUCTION

The occurrence of uplift and lateral loading: vertical piles are used in the structures to resist the uplift loads. Where the hydrostatic pressure always exceeds the downward loading, as in the case of some underground tanks and pumping stations, the anchorages are permanently under tension and cable anchors may be preferred to piles. However, in the case of the shipbuilding dock floor in figure1, for example, the anchorages may be under tension only when the dock is unwatered before the commencement of shipbuilding. As the loading on the floor from ship construction increases to the stage at which the uplift pressure is exceeded, the anchor piles are required to carry compressive loads. **See Figure: 1**

Vertical piles are used to restrain buildings against uplift caused by the swelling of clay soils. **See Figure: 2**

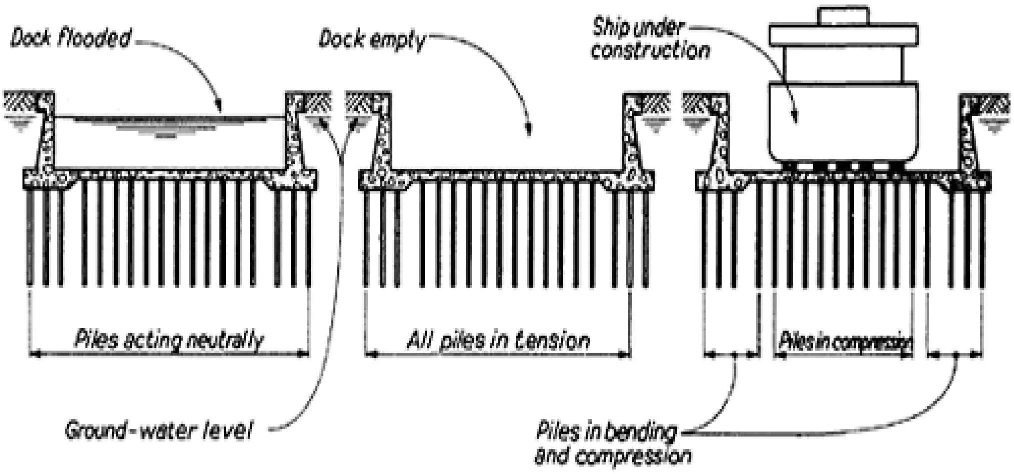

Fig. 1 Tension/compression piles beneath floor of shipbuilding dock

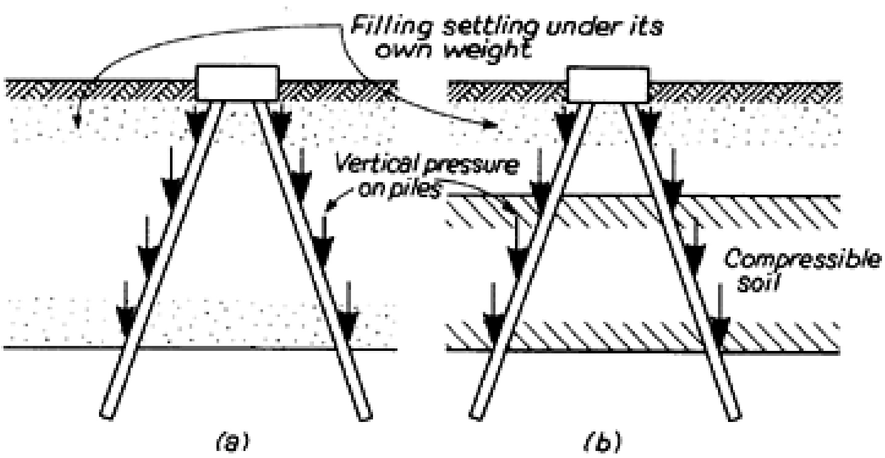

Fig. 2 Bending of slender raking piles due to loading from soil subsidence: (a) Fill settling under own weight and (b) Fill overlying compressible soil

Laterally loaded piles: Vertical piles are generally used in foundations to withstand vertical loads, which may induce loads and moments in axial compression. Vertical piles have, conventionally, not been used for taking up any lateral loads, although they are capable to withstand small lateral loads. Since lateral loads may quite possibly be caused on pile foundation due to wind and seismic forces in buildings, earth pressures in earth retaining structures, sures in water front structures, etc.

In order to understand the capability of individual vertical piles to withstand lateral loads, an analysis is usually carried out, based on the plastic theory for short rigid piles; while the elastic theory is used for analyzing the behaviour of long piles.
Brinch Hansen (1951), and Meyer and Ranjan (1973) have developed an analysis for small rigid piles based on plastic theory, where in it is assumed that the limiting or maximum soil resistance acts against the pile, when it is subjected to ultimate load. The pile deflects to such an extent that full soil resistance along the pile length, develops though it is not true for small deflections.

Objectives

- To study the behavior of laterally loaded single pile in dense cohesion less soil medium.
- To study the behaviour of lateral pile groups experiment in dense cohesion less soil medium.
- To study uplift loads by different pile material in dense cohesion less soil medium.
- To study the behaviour of lateral displacement of wooden piles in dense soil medium
- To study steel piles and wooden piles behaviour in dense sand medium.
- To study uplift resistance different single pile in dense cohesion less soil medium.
- To study lateral load and uplift load relation in dense cohesion less soil medium.

EXPERIMENTAL INVESTIGATION

Pile foundations are one of the types of deep foundations which are to be used for the structures with heavy loads which are built on weak or loose soil. Hence the study behaviour and failure of flexible pile under lateral loads at certain eccentricities in different soil medium is quite complex. In this chapter details of experimental set up, testing procedure and loading conditions under which model studies are conducted are discussed.

The experimental set up consists of the following

1) Sand medium
2) Model Piles and pile caps
3) Foundation (Model Steel Tank)
4) Stone platform
5) Device for pouring Sand (Hopper)
6) Set up for applying horizontal load

Sand Medium: The required uniform sand was prepared from the local sand by sieving. Before sieving, collected sand was dried in open area. For achieving desired uniform material, sand was sieved through 1.18mm and 90 μ sieve. Material passing through 1.18mm sieve and retaining on 90 μ sieve was tested for determining engineering properties. Sand was choosen as soil medium in the present investigation as its behavior is free from time effects. Sand was used in dry condition for the tests which has uniformity coefficient 3.63, Co-efficient of curvature is 0.73. The sand is sub granular with specific gravity 2.66. This test was conducted in loose medium and dense medium. The sand density is 1.46gm/cm3 in loose condition medium and 1.65gm/cm3 in dense condition medium. The sand was prepared by 60cm freefall for dense condition medium using the rainfall technique.

Model Piles and Model Pile Caps

Before the steel material was used to be considered as pile material, but to achieve the higher stiffness the length required is more. For equal cross sectional properties, wooden has stiffness value equal to only (1/3)rd of that for steel.. Therefore, wooden material was selected as a model pile material. Size of model piles should be properly scaled down from the size of the prototype. The range of prototype dimensions represented by the model pile is 1 in 15.

Here we assumed the steel pile of dia meter 360mm with scaling factor of 15 in the present work. The slenderness of pile (l/d ratio) of pile: 20 is used in the present investigation. For the sand used in the present study and pile properties, the pile length l/d = 20 behave as long and flexible pile under lateral loading.

Foundation (Model Steel Tank)

The dimensions of tank are to be decided based on stress zone of soil mass at the edge of the foundation. In this work we have used 25mm diameter pileand hence the tank used to be in plan is 240mm for single pile. Hence the minimum size of the tank should be 425mm (8d + 8d + d = 17 d). The steel tank dimensions are taken as 630*630*750mm.

A model steel tank 12 gauge thickness of steel material sheet of size 630mm X 630mm X 750mm was selected. The size of the tank was sufficient to conduct one test in one filling. The edge distance of the box is two times the longest pile length (500mm) and depth around. The box consists of one slits at the bottom edge.

Stone platform

Steel tank was placed on the rigid Stone Platform of size 3535mm X 2926mm and thickness is 366mm. The steel tank is placed on the rigid concrete platform.

Device for pouring sand

Preparing the soil medium is very important of any model study in sand. Because the height of pouring sand controls the density of sand, the sand was poured by rainfall technique using the hopper of size 305mm 180mm 75mm to the bottom, 230mm 180mm 75mm to the top, and steeper to the front of size180mm 90mm at 15mm slit which sand is made to fall uniformly. The sand was poured from a constant height of 1cm to get soil medium in loose state and from 60cm to get dense State.

To get the loose and dense sand layer of H/D ratio 0.5, first the sand is poured from the height of 60cm from bottom of tank to get dense state and the middle layer is filled with the sand of height of fall 1cm to get loose state, remaining top layer of sand is poured from the height of 60cm to get dense state.

Fig.3 Device for pouring sand

Setup for applying horizontal load

For applying horizontal load the entire setup is made within the box and it consists of loading arm support, loading hanger along with flexible extension wire rope, eccentricity maintained at 115mm at centre of the pile cap to above the ground level.

TESTING PROCEDURE

The height of the tank is dived into several numbers of layers, for the desired density of soil, the weight of soil to be filled in each layer (30cm) is calculated and the same is filled uniformly. The sand is compacted using steel plate hammer for accommodating the weight of sand (27cm) in each layer. Sand bed with a relative density of 95% is prepared.

Initially, the sand is filled upto the pile tip, and then the pile is kept in its position vertically. After that sand is filled again. During this process, it is ensured that the pile remains vertical with the help of proper support system. After each test whole soil and piles are removed from the tank and the process is repeated for conducting the next test.

The piles were tested under horizontal load at constant eccentricity. The failure of load in every case is decided up to maximum deflection of 10mm and the readings are taken in Linear Varying Differential Transducer (LVDT).

RESULTS AND DISCUSSIONS

Table-1 Lateral loads and lateral displacements of Steel piles in dense sand medium

Sl. No	Lateral load in N	Lateral displacements in mm				Vertical displacement in mm		% Variations with 3rd row and V D	% Variations with 3rd row and V D (SP)
		1st row	2nd row	3rd row	Single pile	group	single		
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	36.30	0.05	0.09	0.03	0.03	0.03	0.04	0.00	-33.33
3	58.66	0.08	0.13	0.05	0.07	0.02	0.06	60.00	-20.00
4	80.54	0.11	0.21	0.08	0.10	0.05	0.09	37.50	-12.50
5	102.32	0.14	0.25	0.10	0.13	0.06	0.12	40.00	20.00
6	123.80	0.16	0.28	0.12	0.15	0.10	0.16	16.66	-33.33

7	144.99	0.18	0.29	0.15	0.17	0.12	0.18	20.00	-20.00
8	164.51	0.21	0.31	0.17	0.21	0.15	0.21	11.76	-23.52
9	184.43	0.24	0.32	0.19	0.25	0.16	0.22	15.78	-15.78
10	203.46	0.28	0.35	0.21	0.27	0.19	0.24	9.52	-14.28
11	222.39	0.32	0.37	0.25	0.31	0.22	0.28	12.00	-12.00
12	241.13	0.34	0.41	0.27	0.33	0.25	0.30	7.40	-11.11
13	259.87	0.37	0.44	0.29	0.35	0.26	0.32	10.34	-10.34
14	278.60	0.38	0.45	0.31	0.37	0.29	0.34	6.45	-9.67
15	297.24	0.42	0.47	0.35	0.39	0.30	0.38	14.28	-8.57
16	315.88	0.44	0.51	0.38	0.41	0.32	0.39	15.78	-2.63
17	334.52	0.45	0.53	0.39	0.45	0.36	0.42	7.69	-7.69
18	353.06	0.47	0.54	0.41	0.47	0.38	0.45	7.31	-9.75
19	371.50	0.48	0.55	0.42	0.49	0.40	0.46	4.76	-9.52
20	389.85	0.50	0.58	0.43	0.50	0.44	0.47	2.27	-9.30
21	408.29	0.51	0.59	0.45	0.51	0.46	0.48	2.17	-6.66
22	426.44	0.52	0.65	0.48	0.52	0.48	0.50	0.00	-4.16
23	444.69	0.54	0.67	0.51	0.54	0.49	0.51	3.92	0.00
24	462.64	0.55	0.69	0.52	0.57	0.50	0.52	3.84	0.00
25	480.40	0.56	0.70	0.53	0.60	0.51	0.54	41.50	-1.88

From table 1 observed that, the percentage variation of 3rd row and vertical displacement of steel pile in dense sand medium from 2.17% to 60% observed by experimentally.

Table- 2 Lateral loads and lateral displacements of wooden piles in dense sand

Sl. No	Lateral load in N	Lateral displacements in mm				Vertical displacement in mm		% Variations with 3rd row and V D	% Variations with 3rd row and V D (SP)
		1st row	2nd row	3rd row	Single pile	group	single		
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	36.30	0.04	0.03	0.08	0.02	0.02	0.04	75.00	50.00
3	58.66	0.10	0.04	0.09	0.05	0.05	0.06	44.44	33.33
4	80.54	0.12	0.08	0.12	0.07	0.08	0.09	0.33	25.00
5	102.32	0.14	0.12	0.15	0.09	0.11	0.12	26.66	20.00
6	123.80	0.15	0.13	0.18	0.11	0.13	0.16	27.77	11.11
7	144.99	0.17	0.14	0.19	0.13	0.17	0.18	10.52	5.26
8	164.51	0.18	0.21	0.22	0.14	0.19	0.21	13.63	4.54
9	184.43	0.19	0.23	0.24	0.17	0.20	0.22	16.66	8.33
10	203.46	0.22	0.27	0.25	0.28	0.21	0.24	16.00	4.00
11	222.39	0.23	0.28	0.26	0.32	0.23	0.28	11.53	-7.69
12	241.13	0.25	0.29	0.29	0.34	0.26	0.30	10.34	-3.44
13	259.87	0.26	0.31	0.32	0.36	0.27	0.32	15.62	0.00
14	278.60	0.28	0.33	0.34	0.37	0.29	0.34	14.70	0.00
15	297.24	0.30	0.35	0.35	0.39	0.31	0.38	11.42	-8.57
16	315.88	0.32	0.37	0.38	0.41	0.32	0.39	15.78	-2.63
17	334.52	0.34	0.38	0.39	0.43	0.35	0.42	10.25	-7.69
18	353.06	0.35	0.40	0.43	0.44	0.36	0.45	16.27	-4.65

19	371.50	0.36	0.43	0.45	0.46	0.38	0.46	15.55	-2.22
20	389.85	0.38	0.44	0.48	0.49	0.39	0.47	18.75	2.08
21	408.29	0.40	0.45	0.49	0.51	0.40	0.48	18.36	-2.04
22	426.44	0.42	0.47	0.50	0.53	0.41	0.50	18.00	0.00
23	444.69	0.43	0.49	0.52	0.56	0.43	0.51	17.30	1.92
24	462.64	0.46	0.52	0.53	0.59	0.44	0.52	16.98	1.88
25	480.40	0.47	0.53	0.55	0.61	0.45	0.54	18.18	1.81

From table 2 observed that, the percentage variation of 3rd row and vertical displacement of wooden pile in dense sand medium from 0.33% to 75% observed by experimentally.

List of graphs in dense sand medium

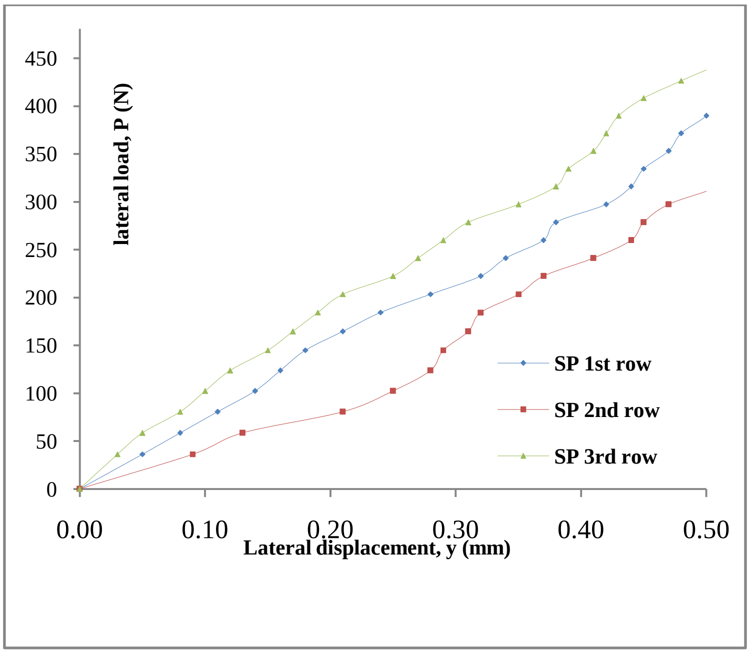

Fig 4 lateral load Vs lateral displacement curve of steel pile for different rows in dense sand medium.

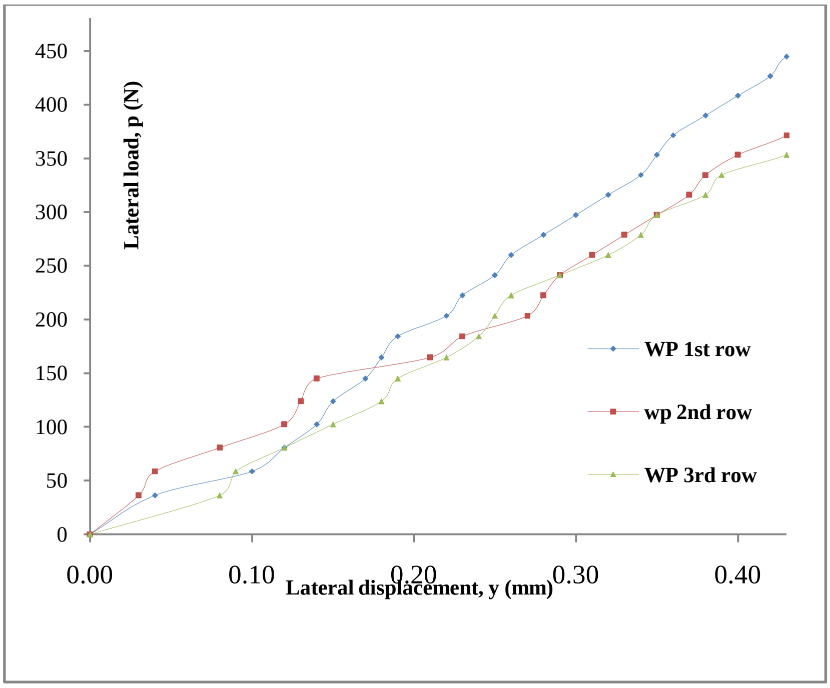

Fig 5 Lateral load Vs lateral displacement curve of wooden pile for different rows in dense sand medium

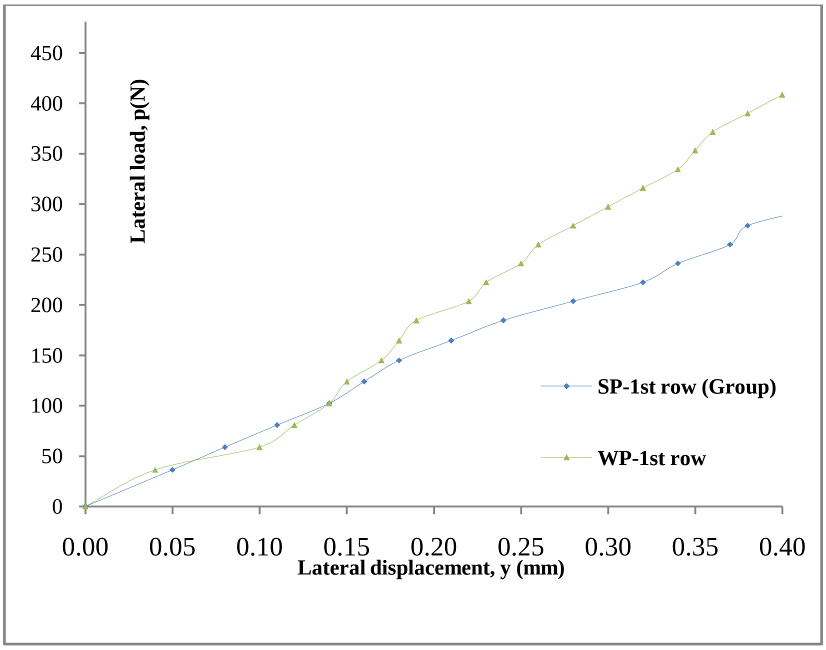

Fig 6 Lateral load Vs lateral displacement curve 1st row of different group piles in dense sand medium.

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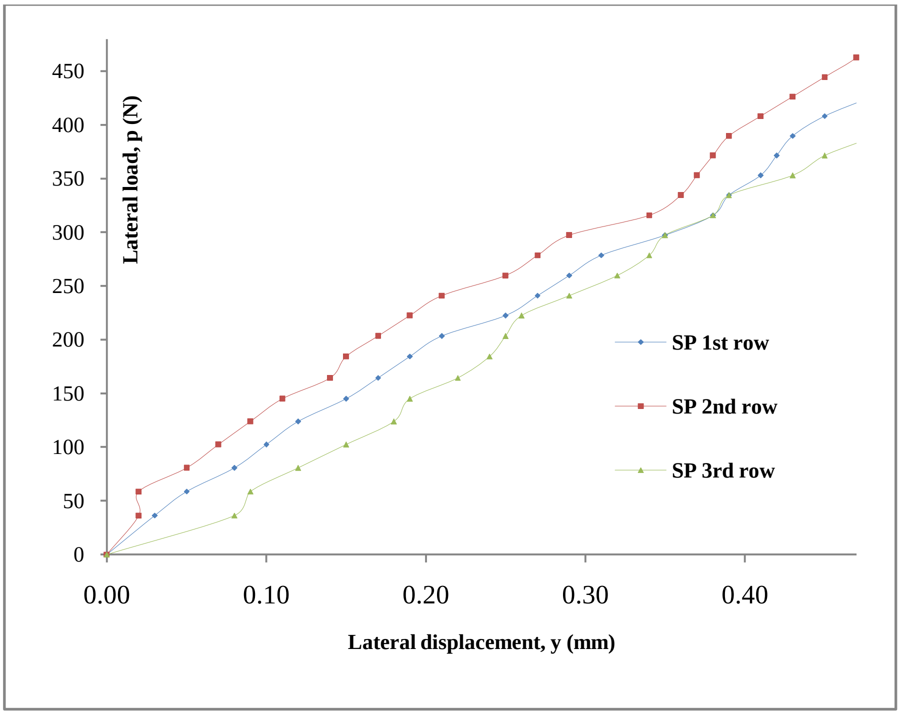

Fig 7 Lateral load Vs lateral displacement curve for steel pile of different rows in dense sand medium

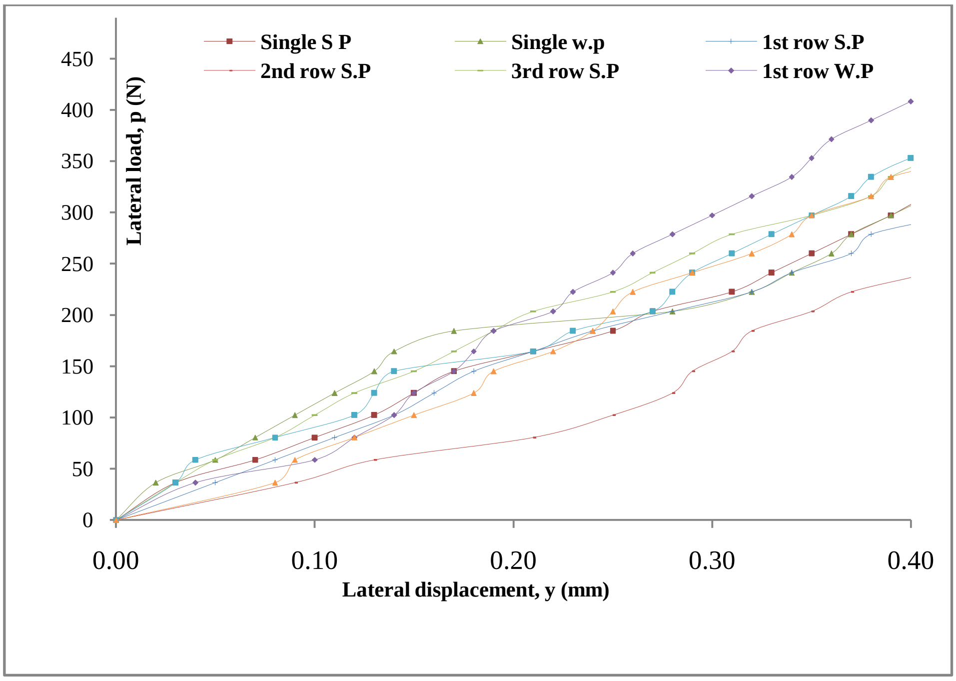

Fig 8 Lateral load Vs lateral displacement curve of all single and group pile materials in dense sand medium

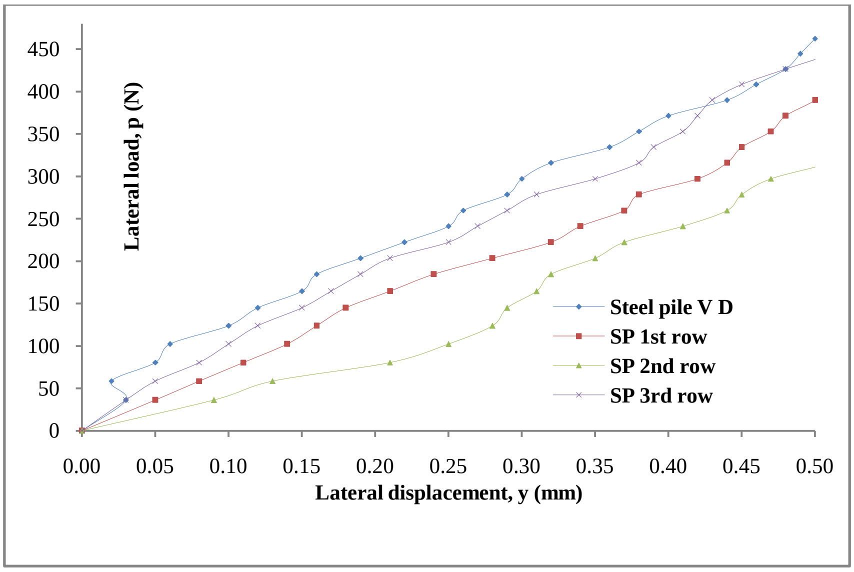

Fig 9 Lateral load Vs vertical displacement curve of Steel pile of different rows in dense sand medium

Figure 9 shows that steel pile carried more lateral load by experimentally in dense sand medium while maintaining fully dense sand medium.

With respect to steel pile, wooden pile carry more lateral load experimentally.

The single wooden pile will take the less lateral load by comparing with single steel pile in dense sand medium

Wooden pile in dense sand medium occurred less lateral load than the steel pile when comparing with wooden pile in the dense sand medium.

Efficiency of piles in dense sand medium

Table 3 Efficiency of steel pile group in dense sand medium

Sl.No	Type of pile	Type of rows			Ultimate Lateral load (P) in N	Efficiency of group pile (η) in %
		1	2	3		
1	Steel	1	-	-	444.69	14.7
2		-	2	-	462.64	15.36
3		-	-	3	371.5	12.33

Table4 Efficiency of wooden pile group in dense sand medium

Sl. No	**Type of pile**	**Type of rows**			Ultimate Lateral load (P) in N	Efficiency of group pile (η) in %
		1	**2**	**3**		
1	Wooden	1	-	-	426.44	14.16
2		-	2	-	371.5	12.33
3		-	-	3	353.06	11.72

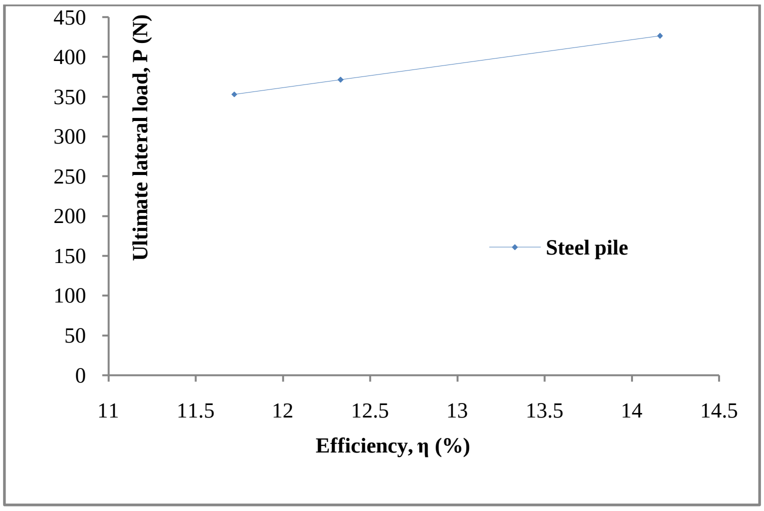

Fig. 10 Ultimate lateral load Vs efficiency of different group pile material in dense sand medium

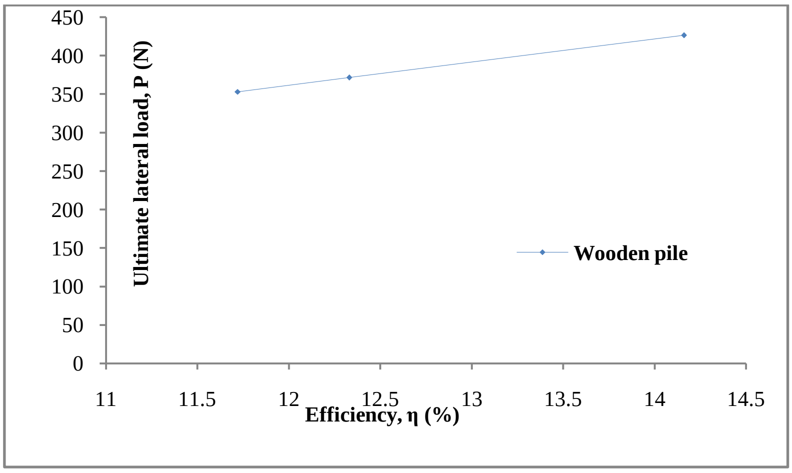

Fig.11 Ultimate lateral load Vs efficiency of different group pile material in dense sand medium

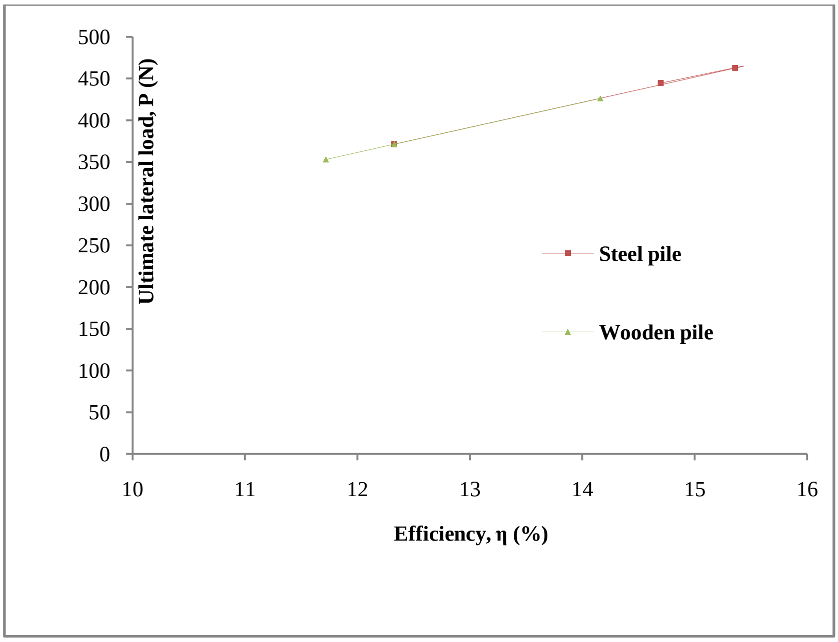

Fig.12 Ultimate lateral load Vs efficiency of different group pile material in dense sand medium

Based on experimental observation, steel model pile has more group efficiency than wooden model piles in dense sand medium.

CONCLUSIONS

- Comparing to single pile and group piles, the group piles occurred less lateral displacement in dense sand medium.
- Steel pile takes more lateral load because of its flexural rigidity is more than the wooden piles.
- Steel pile carried less lateral load by experimentally in dense sand medium while maintaining fully dense medium.
- Wooden pile carry less lateral load when comparing the steel piles in dense sand medium.
- The steel piles have more uplift resistance in dense sand medium.
- The steel model pile has more group efficiency than wooden model piles in dense sand medium.

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