International Journal of Civil, Structural and Concrete Engineering
Volume 1 Issue 2

An Experimental Study on Vertical Piles under Axial and Lateral Loads in Loose Sand Medium

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Abstract

When vertical piles are installed beneath buoyant structures such as dry docks, basements, and pumping stations they are required to resist uplift loads. Although the loads applied on piles are usually a combination of both vertical and lateral loads, very limited experimental research has been done on the response of pile groups subjected to combined loads. Due to pile–soil–pile interaction in pile groups, the response of a pile group may differ substantially from that of a single pile. This difference depends on soil state and pile spacing. This paper presents results of experiments designed to investigate pile interaction effects on the response of pile groups subjected to 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 loose sand is detrimental to their lateral capacity.

Keywords*: - Vertical Pile, axial loads, lateral loads, loose medium sand.*

INTRODUCTION

The occurrence of uplift and lateral loading: When vertical piles are installed beneath buoyant structures such as dry docks, basements, and pumping stations they are required to resist uplift loads. Where the hydrostatic pressure always exceeds the downward loading, as in the

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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 un watered 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. Cable anchors might not then be suitable if the dock floor was underlain by soft or loose soil. **See Figure: 1**

Vertical piles are used to restrain buildings against uplift caused by the swelling of clay soils. Swelling can occur, for example, when mature trees are removed from a building site. The desiccated soil in the root zone of the trees gradually absorbs water from the surrounding clay, and the consequent swelling of the clay may amount to an uplift of 50 to 100mm of the ground surface, causing severe damage to buildings sited over the root zone. In sub-tropical countries where there is a wide difference in seasonal climatic conditions, i.e. a hot dry summer and a cool wet winter, the soil zone affected by seasonal moisture changes can extend to a depth of several metres below the ground surface.

In clay soils these changes cause the ground surface to alternately rise and fall with a differential movement of 50mm or more. The depth to which these swelling (or alternate swelling and shrinkage) movements can occur, usually makes the use of piled foundations taken below the zone of soil movements more economical and technically more suitable than deep strip or pad foundations.

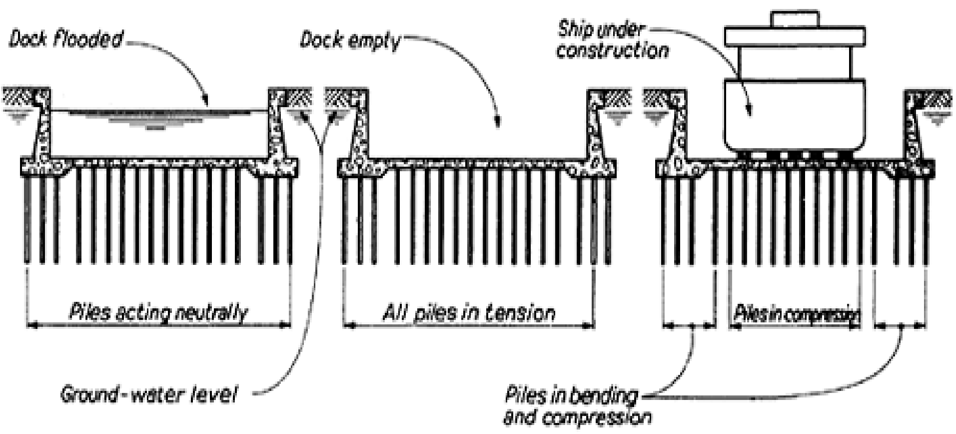

Fig. 1 Tension/compression piles beneath floor of shipbuilding dock

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Vertical piles must have a sufficient depth of penetration to resist uplift forces by the development of skin friction in the soil beneath the zone of soil movements (Figure 1.2). Uplift on bored piles can be reduced by casting the concrete in the upper part of the pile within a smooth polyvinylchloride (pvc) sleeve, or by coating a precast concrete or steel tubular pile with soft bitumen. Uplift can be further reduced by supporting the superstructure clear of the ground surface, or by providing a compressible layer beneath pile caps and ground beams. Piles in large groups may also be lifted due to ground heave. (***See Figure:-2)***

Single vertical piles subjected to lateral loads: The ultimate resistance of a vertical pile to a lateral load and the deflection of the pile as the load builds up to its ultimate value are complex matters involving the interaction between a semi-rigid structural element and the soil, which deforms partly elastically and partly plastically. Taking the case of a vertical pile unrestrained at the head, the lateral loading on the pile head is initially carried by the soil close to the ground surface. At a low loading the soil compresses elastically but the movement is sufficient to transfer some pressure from the pile to the soil at a greater depth.

A short rigid pile unrestrained at the top and having a length to width ratio of less than 10 to 12 **(Figure 3)** tends to rotate and passive resistance develops above the toe on the opposite face to add to the resistance of the soil near the ground surface.

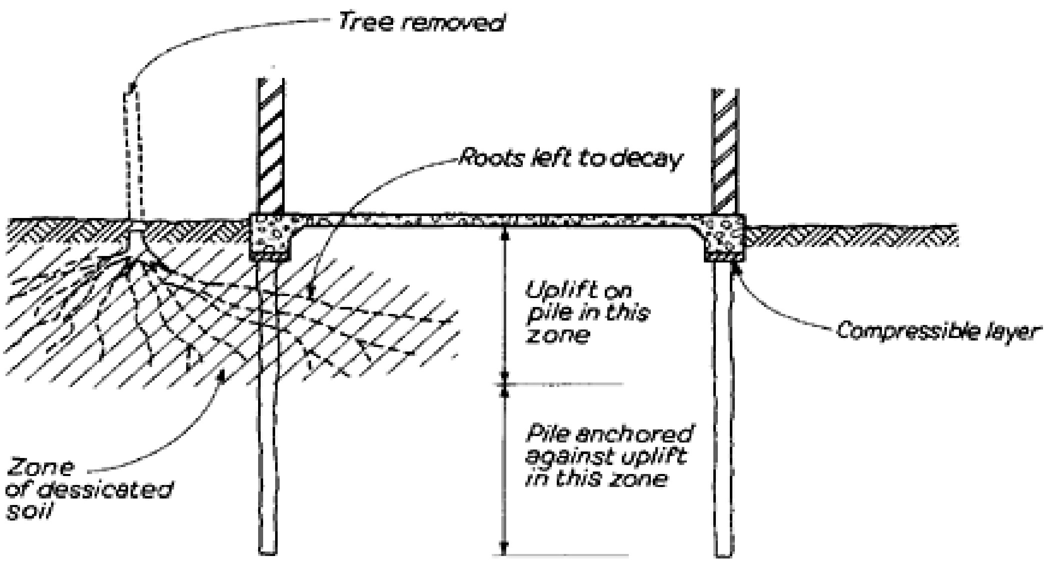

Fig:-2 Uplift on pile due to swelling of soil after removal of mature tree

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Eventually the rigid pile will fail by rotation when the passive resistance of the soil at the head and toe are exceeded. The short rigid pile restrained at the head by a cap or bracing will fail by translation in a similar manner to an anchor block which fails to restrain the movement of a retaining wall transmitted through a horizontal tied rod **(Figure 1.3)**.

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. When the applied horizontal load per pile exceeds the value suitable for the sand vertical piles, inclined piles called batter piles or raker piles, are used in combination with vertical piles. The degree of batter, that is the angle made by the pile with the vertical, may be as high as 30o.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.

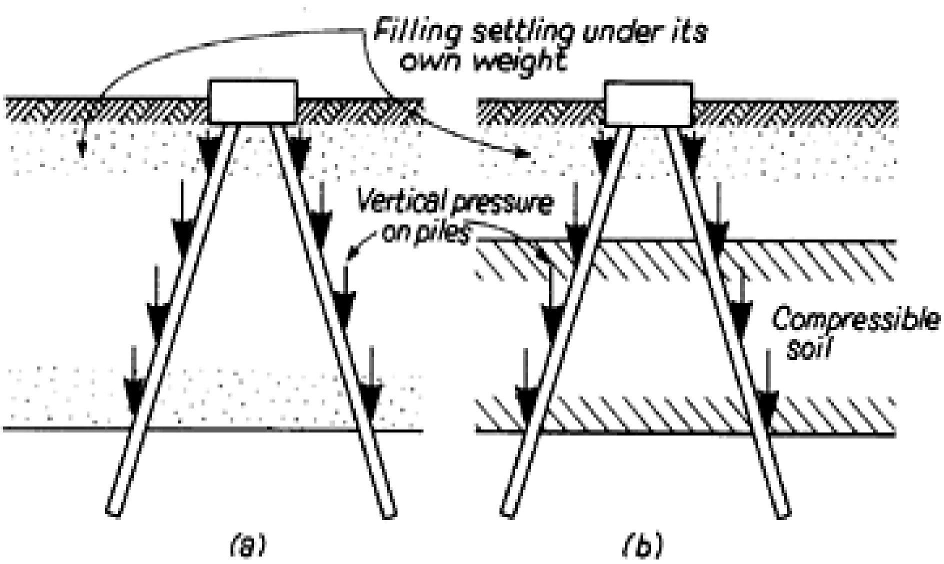

Fig:-3 Bending of slender raking piles due to loading from soil subsidence: (a) Fill settling under own weight and (b) Fill overlying compressible soil

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

EXPERIMENTAL INVESTIGATION

Pile foundations are most popular form of deep foundations used for onshore and offshore structures. They are often used to transfer large loads from superstructures into deeper competent soil layers particularly when the structure is to be located on shallow weak soil layers. 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

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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

Initially steel was considered as a pile material, but to simulate the elastic pile behaviour, the pile length required was too long because of higher stiffness. For equal cross sectional properties, wooden has stiffness value equal to only (1/3)rd of that for steel. Furthermore, wooden material is flexible enough to allow reasonably accurate measurement of strain even under small load levels for measuring the bending behaviour of piles. 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. However, due to difficulty in fabrication of the scaled down size of model pile for a fixed size of prototype, the size of model is fixed in the present investigation based on available sized in the market. The range of prototype dimensions represented by the model pile is 1 in 15.

Prototype pile is assumed as steel pile. In the present study, for the prototype pile diameter of 360 mm, a scaling factor of 15 is obtained. 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)

In general, the dimensions of model test tank are decided based on the effectively stressed zone of soil mass from the edge of the foundation. For laterally loaded single pile, it is inferred from the literature that the boundary effect is more predominant within 10 times the pile diameter from the pile periphery (Narasimha Rao et al. 1998). In the present study, mode pile diameter is

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25 mm and hence the size of the tank in plan should be larger than 240mm for single pile. For piles subjected to uplift load, zone of influence is 3 to 8 times of pile diameter from the edge of the pile at ground surface (Kishida, 1963). Hence the minimum size of the tank should be 425mm (8d + 8d + d = 17 d). Accordingly, the dimensions of the model steel tank are fixed as 630 mm ×630 mm× 750 mm (depth) to avoid the boundary effects while testing the model pile under lateral loads.

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:-4 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,

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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 up to 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 each case was decided up to 10mm maximum deflection in several incremental loads, and readings wear taken by Linear Varying Differential Transducer (LVDT).

Fig:-5 Unloading of sand sample

RESULTS AND DISCUSSIONS:

Table:-1 Lateral loads and lateral displacements

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	0.00	0.00	0.00

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2	36.30	0.02	0.01	0.03	0.08	0.02	0.03	33.33	0.00
3	58.66	0.03	0.02	0.13	0.13	0.04	0.06	69.23	53.84
4	80.54	0.04	0.03	0.20	0.16	0.05	0.09	75.00	55.00
5	102.32	0.12	0.05	0.23	0.20	0.06	0.15	73.91	34.78
6	123.80	0.13	0.06	0.28	0.27	0.08	0.18	71.43	35.71
7	144.99	0.14	0.07	0.33	0.32	0.09	0.24	72.72	27.27
8	164.51	0.15	0.08	0.36	0.34	0.11	0.28	69.44	22.22
9	184.43	0.17	0.09	0.40	0.39	0.14	0.31	65.00	22.50
10	203.46	0.19	0.10	0.43	0.42	0.16	0.34	62.79	20.93
11	222.39	0.21	0.12	0.44	0.45	0.17	0.37	61.36	15.90
12	241.13	0.23	0.14	0.49	0.47	0.18	0.39	63.26	20.40
13	259.87	0.24	0.16	0.53	0.49	0.21	0.45	60.37	15.09
14	278.60	0.25	0.18	0.55	0.52	0.23	0.49	58.18	10.90
15	297.24	0.27	0.19	0.60	0.54	0.25	0.55	58.33	8.33
16	315.88	0.29	0.21	0.61	0.57	0.26	0.59	57.37	3.27
17	334.52	0.30	0.23	0.63	0.62	0.28	0.62	55.55	1.58
18	353.06	0.31	0.24	0.66	0.70	0.3	0.67	54.54	-1.51
19	371.50	0.34	0.25	0.73	0.75	0.34	0.72	53.42	1.36
20	389.85	0.36	0.26	0.79	0.81	0.42	0.78	46.83	1.26
21	408.29	0.38	0.29	0.83	0.87	0.44	0.86	46.98	-3.61
22	426.44	0.39	0.35	0.85	0.90	0.47	0.91	44.70	-7.05
23	444.69	0.42	0.39	0.91	0.94	0.48	0.95	47.25	-4.39
24	462.64	0.48	0.43	0.93	1.00	0.49	0.98	47.31	-5.37
25	480.40	0.52	0.46	1.03	1.04	0.51	1.02	50.48	0.97

Of Steel piles in loose sand medium

Table:-2 Lateral loads and lateral displacements

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	0	0	0.00	0	0.00	0	0.00
2	36.30	0.02	0.04	0.12	0.03	0.02	0.03	83.33	75.00
3	58.66	0.06	0.12	0.15	0.08	0.05	0.06	66.66	60.00
4	80.54	0.08	0.17	0.22	0.10	0.07	0.09	68.18	59.09
5	102.32	0.13	0.21	0.24	0.17	0.11	0.11	54.16	54.16
6	123.80	0.16	0.24	0.29	0.21	0.13	0.16	55.17	44.82
7	144.99	0.19	0.27	0.35	0.24	0.15	0.22	57.14	37.14
8	164.51	0.23	0.29	0.41	0.26	0.16	0.25	60.97	39.02
9	184.43	0.26	0.31	0.46	0.33	0.18	0.27	60.86	41.30

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10	203.46	0.29	0.34	0.5	0.38	0.24	0.30	52.00	40.00
11	222.39	0.36	0.35	0.54	0.40	0.28	0.33	48.15	38.88
12	241.13	0.42	0.4	0.58	0.47	0.31	0.40	46.55	31.03
13	259.87	0.49	0.42	0.65	0.53	0.35	0.43	46.15	33.84
14	278.60	0.52	0.43	0.69	0.58	0.37	0.44	46.37	36.23
15	297.24	0.54	0.47	0.74	0.62	0.39	0.46	47.30	37.83
16	315.88	0.59	0.51	0.76	0.64	0.42	0.53	44.73	30.26
17	334.52	0.63	0.52	0.81	0.65	0.43	0.59	46.91	27.16
18	353.06	0.65	0.53	0.85	0.70	0.47	0.65	44.70	23.52
19	371.50	0.69	0.57	0.89	0.72	0.49	0.70	44.94	21.34
20	389.85	0.73	0.62	0.97	0.74	0.53	0.73	45.36	21.64
21	408.29	0.76	0.65	1.08	0.75	0.61	0.75	45.52	30.55
22	426.44	0.83	0.67	1.16	0.78	0.71	0.76	38.79	34.48
23	444.69	0.89	0.69	1.24	0.80	0.76	0.83	33.06	33.06
24	462.64	0.93	0.73	1.33	0.83	0.82	0.85	38.34	36.09
25	480.40	0.96	0.75	1.36	0.88	0.85	0.87	37.50	36.02

Of Wooden piles in loose sand medium

List of Graphs in Loose Sand Medium

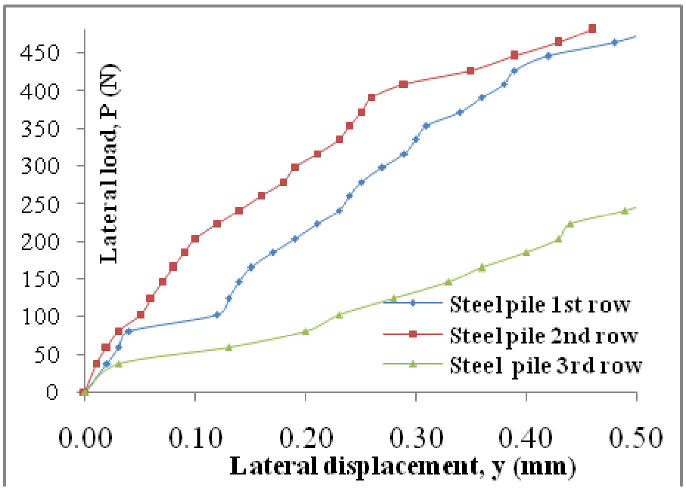

Figure: 6 - Lateral load Vs lateral displacement curve of steel pile for different rows in loose sand medium

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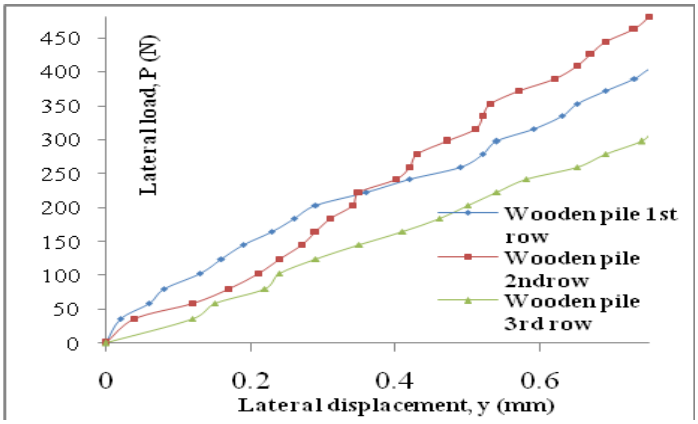

Figure: 7- Lateral load Vs lateral displacement curve of wooden pile for different rows in loose sand medium

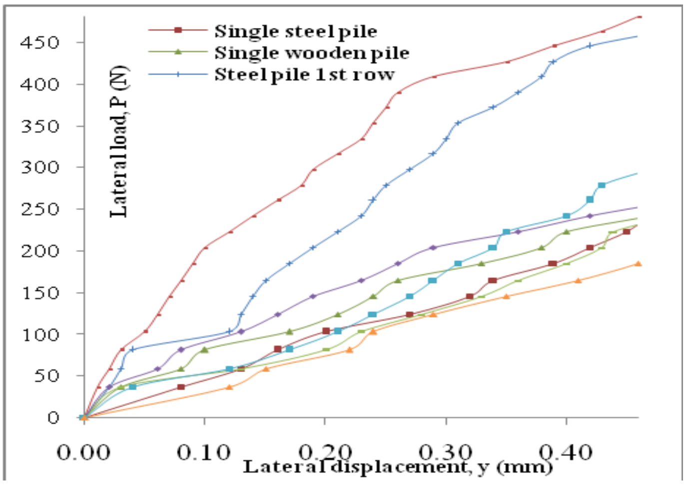

Figure: 8 - Lateral load Vs lateral displacement curve of all single and group pile materials in loose sand medium

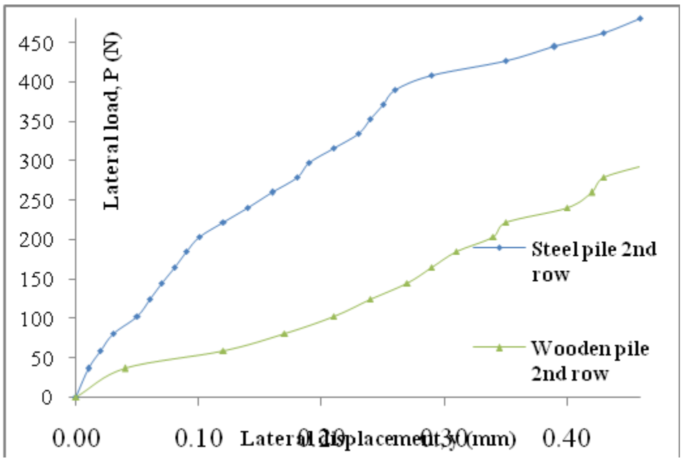

Figure: 9 - Lateral load Vs lateral displacement curve of all group pile materials 2nd row in loose sand medium

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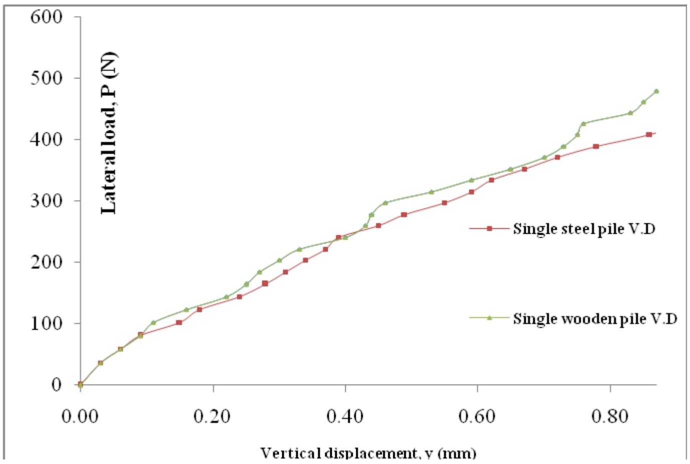

Figure: 10- Lateral load Vs lateral displacement curve of different single piles in loose sand medium

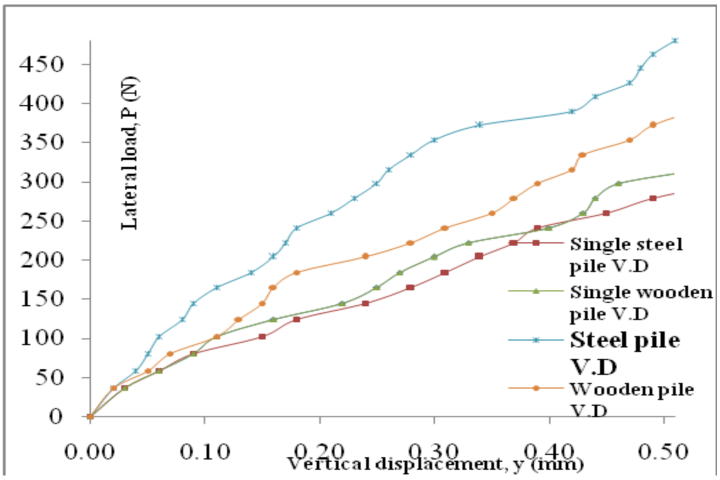

Figure: 11- Lateral load Vs lateral displacement curve of all single and group pile materials in loose sand medium

From figure 8, for the constant displacement the lateral load increases for steel pile when compared with wooden piles in loose sand medium. Similarly wooden pile take less lateral load comparing to steel piles in loose sand medium. Steel pile takes more lateral load because of its flexural rigidity is more than the wooden piles. However ultimate lateral load capacity carried less by steel piles in loose sand medium maintained in model tank.

Figure 11 shows that single steel pile carried less lateral load with a constant vertical displacement in loose sand medium. As the vertical displacement increases by wooden pile compared to steel pile because achieving more density. Vertical displacement decreases by steel group piles when comparing to wooden pile

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materials while doing the 95% dense sand medium in experimentally. Based on experimental observation, steel model piles have more group efficiency than wooden model piles in both loose and dense sand medium.

Efficiency of Piles in Loose Sand Medium

Table: 3 Efficiency of steel pile group in loose 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	-	-	297.24	16.23
2		-	2	-	259.87	14.19
3		-	-	3	203.46	11.11

Table: 4 Efficiency of wooden pile group in loose 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	-	-	241.13	11.11
2		-	2	-	259.87	11.97
3		-	-	3	184.43	8.49

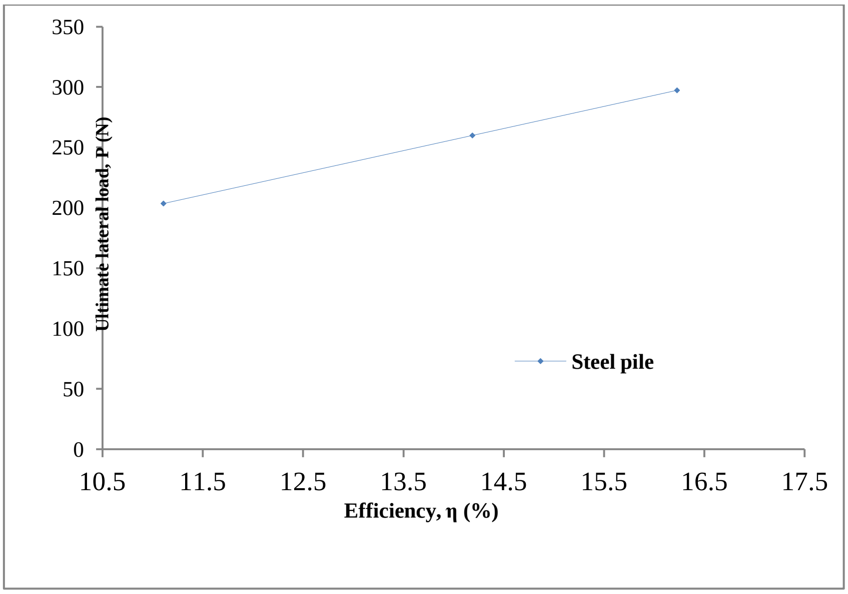

Figure: 12- Ultimate lateral load Vs efficiency of different group pile material in loose sand medium

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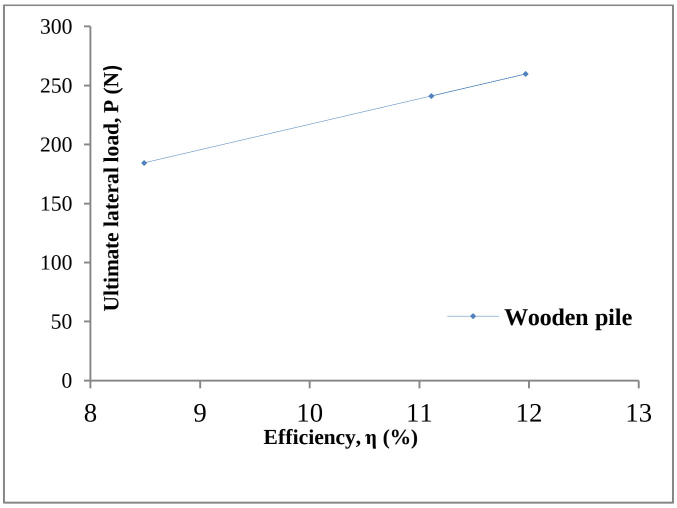

Figure: 13 Ultimate lateral load Vs efficiency of different group pile material in loose sand medium

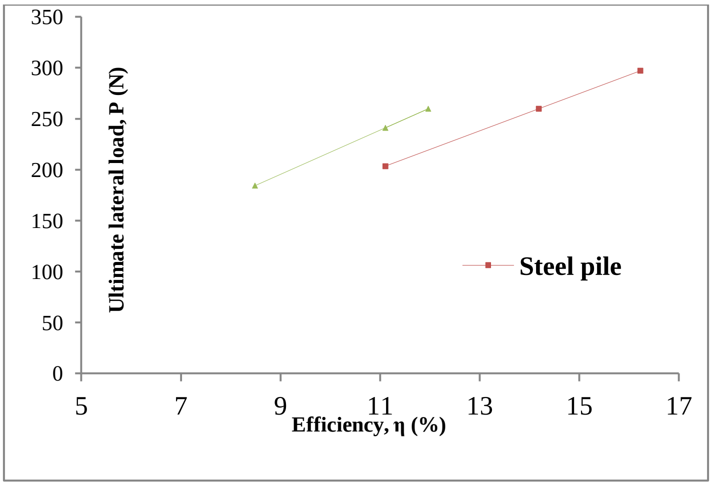

Figure: 14 Ultimate lateral load Vs efficiency of different group pile material in loose sand layer

Based on experimental observation, steel model piles have more group efficiency than wooden model piles in both loose and dense sand medium.

CONCLUSION

- The ultimate lateral displacement occurred more by wooden group of piles in fully loose sand medium.
- The ultimate lateral displacement occurred more by single steel piles in fully loose sand medium.
- For the constant displacement the lateral load increases for steel pile when compared with wooden piles in loose sand medium.

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- Wooden pile take less lateral load comparing to steel piles in loose sand medium.

- Steel pile takes more lateral load because of its flexural rigidity is more than the wooden piles.

- For single steel model pile material is carried less lateral load with respect to single wooden and single steel pile in loose sand medium.

- Wooden pile in loose sand medium carry less lateral load when comparing the steel piles in loose sand medium.

- The increase in the density of sand leads to increase in load carrying capacity of single and group piles.

- The steel piles have more uplift resistance in loose sand medium.

- The steel model piles have more group efficiency than wooden model piles in loose sand medium.

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