Behaviour of piles supported berthing structure under lateral loads

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ABSTRACT
A series of laboratory experimental setup is designed with a single row of instrumented piles in a berthing structure reduced to a model scale. The experiments were carried out by applying both berthing and mooring forces, with and without considering the seabed slope angle. Tie rods are introduced in the frame of the berthing structure and its effect is studied. This paper describes the analysis of experimental results obtained from the laboratory test. The load vs deflection behaviour of piles, distribution of load among the piles and tie rod, and the behaviour of the structure with the effect of tie rod on the structure are discussed in this paper.

Résumé
Une série de montage de laboratoire expérimental est conçu avec une seule rangée de pieux instrumentés dans une structure d'accostage réduite à une échelle de modèle. Les expériences ont été réalisées en appliquant à la fois l'accostage et l'amarrage des forces, avec et sans tenir compte de l'angle de la pente des fonds marins. Les tirants sont introduits dans le cadre de la structure d'accostage et de son effet est étudié. Cet article décrit l'analyse des résultats expérimentaux obtenus sur le test de laboratoire. Le comportement en flexion des pieux vs charge, répartition de la charge entre les pieux et les tirants, et le comportement de la structure avec l'effet de la tige sur la structure sont discutés dans le présent document

1 INTRODUCTION

Berthing structures are constructed in ports and harbours to provide facilities for berthing and mooring of vessels, loading and unloading of cargo and for embarking and disembarking of passengers and vehicles. In berthing structures, lateral forces are caused by impact of berthing ships, pull from mooring ropes and pressure of wind, current, wave and floating ice, seismic force, active earth pressure and differential water pressure, in addition to self-weight of the structure and live load.

Tie rod anchors may be provided in order to strengthen the structure and to resist these lateral loads and reduce the deflection to a large extent. The effect of tie rod anchors on a berthing structure is studied by carrying out experiments on a single frame of the berthing structure reduced to a model scale. In this study a tie rod is connected which anchors the structure to a deadman wall. The use of tie rod anchors in berthing structures will reduce the bending moment and lateral deflection and thus the required cross sectional area of the pile and the amount of reinforcement can be reduced resulting in an economical design of the structure.

Raju et al. (1985) analysed alternative systems for a berthing structure considering a combination of diaphragm wall and piles and revealed that by marginally increasing the diameter of the pile the lateral capacity of the pile is increased rather than providing tie rod anchors. But this is a case of closed type berthing structure which contains the diaphragm wall at sea side.

Sundaravadivelu et al. (1990), conducted a tie rod force measurements in a Cargo Berth at Paradeep Port, India and the design of another berth in the vicinity was modified to retain the vertical piles and eliminate the deadman diaphragm wall and tie rods. Both the researchers concluded that tie rod anchors were not effective. But this aspect purely depends on the type of berthing structure (open type or closed type). Hence an in-depth analysis is essential for finding out the effect of anchors on an open type berthing structure.

Muthukkumaran et al (2003) studied the behaviour of berthing structure in sloped ground under seismic load. Muthukkumaran and Sundaravadivelu, (2007) studied the effect of dredging on piles and diaphragm wall-supported berthing structures. The lateral load arised due to horizontal movement of soil during dredging operation is considered as primary force in their study.

Prakash and Kumar (1996), Gandhi and Selvam (1997), Kim et al. (2004) and Almas Begum et al. (2008 and 2009) conducted experiments on single and group of piles. Most of the studies were on model scale piles by using the principles of similitude which gives a general guidance on conducting the experiments.

2 EXPERIMENTAL WORK

2.1 Test setup

Figure 1 shows the experimental setup. The test setup consists of 5 numbers of piles connected rigidly at top by a rectangular wooden beam. The dimensions of the model pile, wooden beam, tie rod, deadman wall etc were arrived using Buckingham's-pi theorem. Solid aluminium rod is used as tie rod which is anchored to a wooden deadman wall. The piles are placed as preinstalled piles with a minimum bottom clearance of 4 times the pile diameter.

The loading pulley is placed at a height of 50mm above the tank surface. The pulley transferring the load is properly greased to avoid any frictional loss of the lateral load. Lateral load is applied using static weight at a constant interval of time. The horizontal displacement of the pile cap was measured using mechanical dial gauges. In case of sloping ground, the horizontal displacement was measured at the pile cap and also at 50mm, 200mm and 350mm below the pile cap. Each load increment was maintained for about 10min in order to stabilise the displacement without any movement. Strain along the length of the pile was measured with the help of 48 channels Data Acquisition System. Tie rod was pasted with 3 strain gauges along its length in order to obtain the force transmitted to the anchor. For applying the berthing force, the load is applied on the other end of the wooden beam and the piles are rotated such that the strain gauges are always on the tension side.

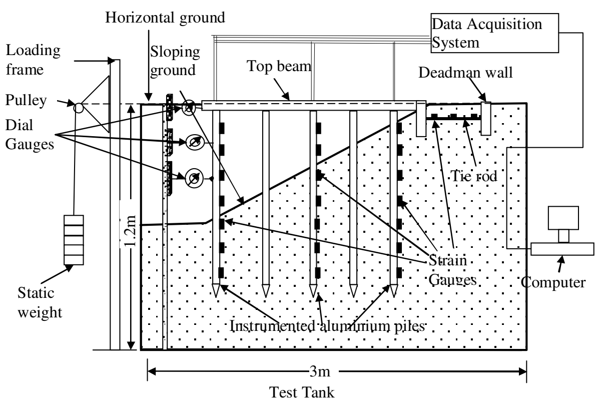

Figure 1. Experimental set up

2.2 Soil Description:

The soil sample used for the present study was collected from Cauvery river bed in South India. The physical and engineering properties of the sand were determined through laboratory tests as per relevant Indian Standards. The specific gravity of the sand is determined as per IS-2720 part III Sec 2 (1980). The sieve analysis is done as per IS 2720-part IV (1980). Based on the particle size distribution, the sand is found to be poorly graded sandy soil. Relative density is determined as per IS 2720 part 14 (1983). A summary of index properties and engineering properties determined for the sand is presented in Table 1.

Table 1: Properties of soil.

Description	Value
Specific Gravity G_s	2.67
Effective size D_{10}	0.27mm
D_{30}	0.42mm
D_{60}	0.7mm
Co-efficient of Uniformity, C_u	2.592
Co-efficient of curvature, C_c	0.933
Max unit weight, γ_{max}	17.63 kN/m^3
Min unit weight, γ_{min}	14.363 kN/m^3
Relative density, R_D	30%

Sand was filled in the tank with a relative density of 30% for all the tests. To achieve uniform density, sand raining device with a pipe and cone is designed as per Gandhi and Selvam (1997). The sand poured through a hopper was dispersed at the bottom of the pipe by a 60 °inverted cone. The density was varied by varying the free fall of sand particles. The height of fall is maintained as 5 cm which corresponds to achieve a 30% relative density as obtained from the density calibration chart. A slope of 1V:2H is maintained while filling the sand in tank.

2.3 Pile and tie rod Instrumentation

Aluminium piles having an outer diameter (D_o) of 25.4 mm with 1 mm wall thickness were used as the model piles. Among the five piles, the front, intermediate and rear piles are instrumented with the strain gauges. Second and fourth piles were not pasted with strain gauges and the results can be calibrated from the instrumented pile readings. However the strain gauge readings and the bending moment were not discussed in this paper.

Tie rod was pasted with 3 strain gauges at a distance of 15 cm apart. The magnitude of the load which is resisted by the anchor can be obtained by knowing the axial strain of the tie rod. In order to obtain the tie force constant, a simple tensile and compression tests were done on the aluminium tie rod. The force constant is an average value of the result of the tensile and compression test. The strain calibration is shown in figure 2.

The strain response was found to be linear for the increase in load. From the slope of the trend line, the force constant is obtained as 1 micro strain = 0.1732 N for both tensile and compressive loading.

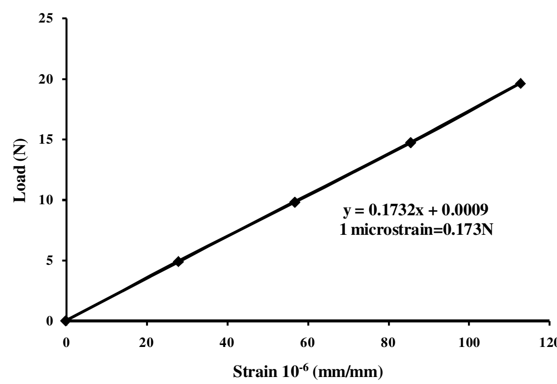

Figure 2. Calibration of strain measuring device for a single strain gauge

3. RESULTS AND DISCUSSIONS

The notations used in the graphs and tables are as follows:

i. SG-WOT-MF: Sloping ground – without tie – mooring force
ii. SG-WT-MF: Sloping ground – with tie – mooring force
iii. SG-WOT-BF: Sloping ground – without tie – berthing force

iv. SG-WT-BF: Sloping ground – with tie - berthing force
v. HG-WOT-MF/BF: Horizontal ground – without tie – mooring force
vi. HG-WT-MF: Horizontal ground – with tie – mooring force
vii. HG-WT-BF: Horizontal ground – without tie – berthing force

3.1 Lateral Load Behaviour:

The allowable lateral deflection of the pile is taken as 20% of the pile diameter (Narasimha Rao et al., 1998) and hence the load corresponding to 5mm deflection, in this case, is taken as the lateral load capacity of the piles. Figure 3 shows the lateral load deflection response of the structure for various loading conditions in 1V:2H sloping ground. It is observed that the addition of tie rod connected anchor significantly increases the lateral load carrying capacity of the structure irrespective of the loading direction. When the structure is subjected to mooring force, the lateral load capacity is increased from 150 N to 250 N in the presence of tie rod anchor whereas in berthing force the capacity is increased from 200 N to 390 N. It is observed that when the structure is subjected to mooring force with tie rod, it carries almost a load equivalent to the structure subjected to berthing force without tie rod. Which implies that tie rod strengthens the structure in mooring condition equivalent to the passive soil resistance in berthing condition without tie rod.

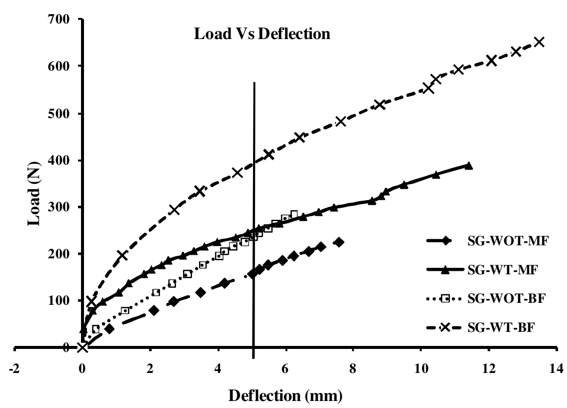

Figure 3. Load Vs Deflection for various cases in Sloping Ground

From Figure 4, it is observed that providing anchor in horizontal ground also significantly increases the lateral load capacity of the structure by 1.7 times. However, in the presence of tie rod, the lateral load vs deflection behaviour for both berthing force and mooring force is similar until 5 mm deflection of the pile.

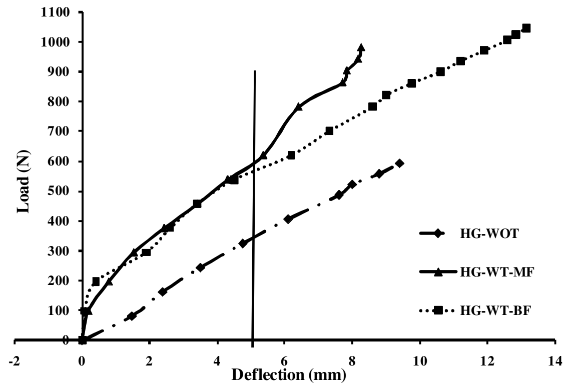

Figure 4. Load Vs Deflection for various cases in Horizontal Ground

Figure 5 shows the magnitude of lateral capacity of the berthing structure for different loading and ground condition. It can be clearly seen that the lateral capacity of the pile in sloping ground is increased by 70 % when tie rods are provided. Whereas in horizontal ground, the lateral capacity of the pile is increased by 65%.

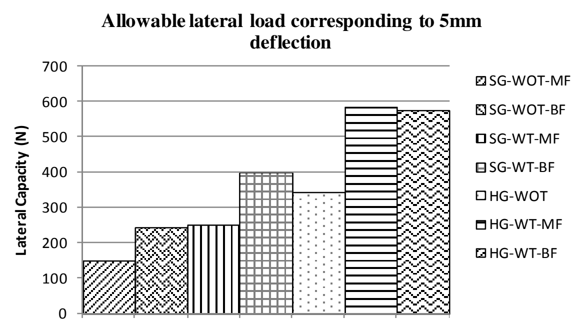

Figure 5. Lateral Capacity of pile

3.2 Tie Force Measurement:

When the structure is connected with an anchor, part of the applied lateral load will be resisted by the anchor.

The tie force variation is shown in Figure 6. It can be observed that in sloping ground, the anchor takes more force compared to horizontal ground. Providing tie rod anchors is more effective for mooring force when compared to berthing force. In sloping ground the force in tie rod get mobilised faster and takes up a lot of load that comes to the berthing structure. In horizontal ground since soil is up to the top of the pile, the force in the tie rod gets mobilised slowly or in other words most of the applied loads is resisted by the piles rather than transferred to the anchor. Tie rod when provided in a sloping ground is observed to take about 15% of the load transferred to the structure in mooring condition. While in berthing condition it takes approximately 2.8% of an applied lateral load of 225N.

In horizontal ground, under mooring condition, tie rod takes about 3.75% and about 1.25% for berthing force. It is also observed that when the applied lateral load goes beyond 800N, the lateral load transferred to tie rod reaches its ultimate and is almost constant beyond that.

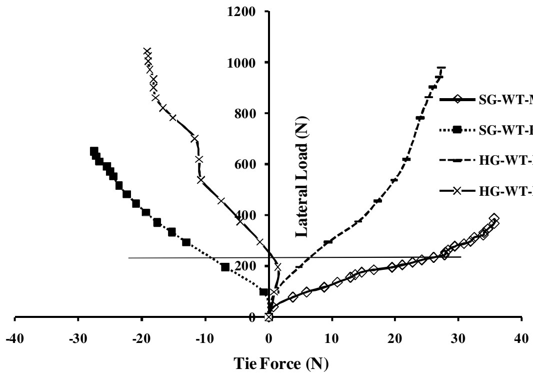

Figure 6. Distribution of Force in Tie rod

Table 2 shows the comparison of maximum deflection for various cases corresponding to a load of 225N. It also shows the lateral load capacity of the pile corresponding to 5mm deflection (20% of pile diameter)

Table 2: comparison of various cases for a common deflection and common load.

Experimental Details	Max Deflection for 225Nmm	Lateral Load corresponding to 5mm deflection in N
SG-WOT-MF	7.59	150
SG-WOT-BF	4.79	200
SG-WT-MF	3.98	250
SG-WT-BF	1.5	390
HG-WOT-MF/BF	3.2	325
HG-WT-MF	1	590
HG-WT-BF	0.9	585

Figure 7 and Figure 8 shows the deflection measured in sloping ground along the length of pile at three different locations using dial gauges for mooring force and berthing force respectively. The deflection is measured for the front pile where the soil is at a depth of 475 mm from the top. The deflection profile is observed to be linear for mooring force and the provision of anchor reduces the deflection to a large extent in both berthing as well as mooring conditions.

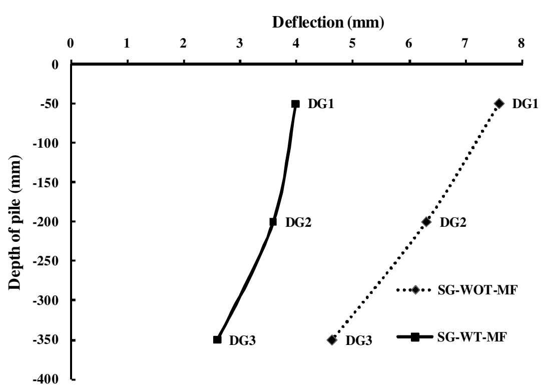

Figure 7. Deflection against depth (dial gauge readings) for mooring force

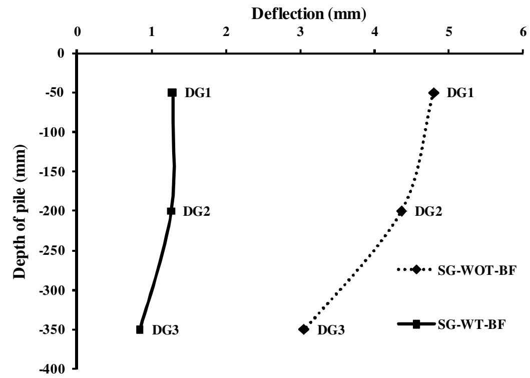

Figure 8. Deflection against depth (dial gauge readings) for berthing force

4 CONCLUSIONS

A berthing structure is analysed for both berthing force and mooring force in sloping ground and horizontal ground, with and without the provision of tie rod anchor. Mooring force is much critical compared to the other lateral loads acting on the structure.

The lateral capacity of the pile when subjected to mooring force in sloping ground is increased by 70% when tie rods are provided and in horizontal ground, it is increased by 65%.

Tie rod when provided in sloping ground takes about 15% of the load transferred to the structure in mooring condition, while berthing it takes approximately 2.8%.

In horizontal ground, tie rod takes less than 5% of the load but the lateral capacity of the pile is significantly increased for higher load cases.

Hence, in an open type berthing structure, tie rod is effective in reducing the deflection of the structure and thereby controlling the forces that goes to the piles. As a result of which the required cross sectional area of the pile and the amount of reinforcement used in them is reduced resulting in an economical design of the structure.

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