Effect of Seabed Slope on Offshore Pile Lateral Behaviour Under Wave Force

Muthukkumaran, K.  
Assistant Professor  
e-mail: kmk@nitt.edu

Sathyanarayanan, D.  
M. Tech. Student  
e-mail: inspirablesathy@yahoo.co.in

Department of Civil Engineering, National Institute of Technology, Tiruchirappalli

ABSTRACT

Fixed offshore platforms supported by pile foundations are required to resist dynamic lateral loading due to wave forces. The response of a jacket offshore tower is affected by the flexibility and nonlinear behavior of the supporting piles. In this study, a typical fixed offshore platform is chosen, and dynamic wave analysis is performed on it. Analysis has been performed for extreme environmental conditions. For the foundation, the deflections and reactions at regular intervals along the vertical direction from the seabed have been found out from the dynamic analysis, and the results have been compared. The aim of this study is to investigate the effects of the combined lateral and vertical loads on pile group foundation of a fixed offshore structure and the effects of seabed slope on the pile responses. To provide a more accurate and effective design for offshore pile foundation systems under axial structural loads and lateral wave loads, a finite element model which is modelled in FLAC3D is employed herein to determine the soil structure interaction under similar loading conditions. Three dimensional modeling and the analyses are done using FLAC3D. A parametric study has been done by varying the seabed slope to examine the variation in soil-structure interaction. Based on the parametric study, the conclusions are drawn for the effect of seabed slope on the lateral behaviour of the offshore platform piles.

1. INTRODUCTION

An offshore structure has no fixed access to dry land and may be required to stay in position in all weather conditions. Offshore structures may be fixed to the seabed or may be floating. Majority of offshore structures support the exploration and production of oil and gas, other major structures, e.g. for harnessing power from the sea. Offshore Platforms are in general classified as Fixed Platform, Compliant Platform and floating production systems. A Fixed Platform consists of a jacket (a tall vertical section made of tubular steel members supported by piles driven into the seabed) with a deck placed on top. The deck provides space for crew quarters, drilling rigs, and production facilities. The fixed platform is economically feasible for installation in water depths up to about 600 m. Foundation piles have a significant effect on the response of fixed offshore structures.

In this study, the response of the platforms mainly depends on the pile response and pile-soil interaction. Wave forces and forces due to current are the forces which contribute the lateral forces for an offshore structure. The vertical load will be acting on the deck. The literatures on dynamic analysis of an offshore platform are limited. Mostafa and Naggard (2004) have studied the response of fixed offshore platforms to wave and current loading including the soil structure interaction. The soil resistance to the pile movement is modelled using dynamic p–y curves and t–z curves to account for soil nonlinearity and energy dissipation through radiation damping. Eicher et al. (2003), in their study, analysed the deformation of and stresses in a single offshore concrete pile under combined structural and wave loading by the finite element method. Also performed a parametric study due to changing loading conditions. Mostafa and Naggard (2006), has examined the effect of seabed instability on a fixed offshore structure in their study taking into account the soil non-linearity, dynamic soil resistance and pile-soil-pile interaction. The parameters considered in the study are soil movement, sliding layer depth, pile flexibility and axial loading at pile head.

2. PLATFORM DESCRIPTION

The platform considered in this study is the ‘Kvitebjørn’ platform. Water depth at the site is 190 m and the
3. ENVIRONMENTAL DATA

The environmental data are based on STATOIL specifications ‘Metoean Design Criteria for Kvitebjørn’ and are provided by Aker Engineering AS. The maximum directional wave heights for the 100-year return period are given in Table 1, including the mean wave period along with the 90% interval. The thickness of marine growth is considered to be 20 mm below El. +2 m. The average dry density of the marine growth material is considered to be 1300 kg/m³. Morison’s equation is used together with the API wave force guidelines to generate the hydrodynamic forces. Drag and inertia coefficients are assumed to be 0.7 and 2.0, respectively, and the wave kinematics are calculated using the Stoke’s fifth order wave theory.

Table 1: Design Waves versus Return Period

<table>
<thead>
<tr>
<th>Return Period (year)</th>
<th>Wave Height, H (m)</th>
<th>Wave Height Above MSL (m)</th>
<th>Wave Period (s)</th>
<th>Mean Value, T</th>
<th>90% Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (operating condition)</td>
<td>22.5</td>
<td>12.8</td>
<td>13.8</td>
<td>12.2 - 15.5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>25.3</td>
<td>14.2</td>
<td>14.6</td>
<td>13.0 - 16.4</td>
<td></td>
</tr>
<tr>
<td>100 (extreme condition)</td>
<td>28.5</td>
<td>16.1</td>
<td>15.3</td>
<td>13.6 - 17.1</td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>36</td>
<td>20.4</td>
<td>17.1</td>
<td>15.1 - 19.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Properties of Soil

<table>
<thead>
<tr>
<th>Layers</th>
<th>Depth (m)</th>
<th>Type of soil</th>
<th>C_u (kPa)</th>
<th>E (kPa)</th>
<th>φ (°)</th>
<th>c (kPa)</th>
<th>Shear strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.5</td>
<td>very soft to soft silty sandy clay</td>
<td>15</td>
<td>3000</td>
<td>0</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>24.5</td>
<td>sandy, clayey silt</td>
<td>80</td>
<td>40000</td>
<td>0</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>very stiff to hard silty clay</td>
<td>150</td>
<td>180000</td>
<td>0</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>very dense fine sand</td>
<td>-</td>
<td>100000</td>
<td>35</td>
<td>-</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>very stiff to hard clay</td>
<td>290</td>
<td>435000</td>
<td>0</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>very stiff to hard clay</td>
<td>185</td>
<td>277500</td>
<td>0</td>
<td>185</td>
<td>185</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>very stiff to hard clay</td>
<td>195</td>
<td>292500</td>
<td>0</td>
<td>195</td>
<td>195</td>
</tr>
</tbody>
</table>

Fig. 1: 3D View of the Model
5. LOADS ACTING ON PLATFORM

Static Loads
Structural Loading on the deck = 230,000,000 N.
Structural Load is applied as pressure over the deck plate.

Dynamic Loads
In our structure, the wave loads acting on the structure is the dynamic(lateral) load. The wave forces are calculated using stoke’s fifth order wave theory and Morisson’s equation. The wave Particle velocity and acceleration are calculated using the stoke’s fifth order wave theory. The current velocity at the respective depth is summed up to the wave particle velocity found from the stoke’s theory(API RP 2A-WSD) and then applied to the morisson’s equation to find the wave force at a certain depth.

6. ANALYSIS IN FLAC3D

Static Analysis
A static or steady-state solution is reached in FLAC3D when the rate of change of kinetic energy in a model approaches a negligible value. This is accomplished by damping the equations of motion. At the conclusion of the static solution stage, the model will either be at a state of equilibrium or at a state of steady flow of material, if a portion (or all) of the model is unstable under the applied loading conditions. Mechanical ratio is ratio of the maximum unbalanced mechanical force magnitude for all the grid points in the model divided by the average applied mechanical force magnitude for all the grid points in the model. (Default Value is 1×10^5).

Dynamic Analysis
Always a static equilibrium condition precedes a dynamic analysis. The unbalanced force history reduces to about 2% during the static phase of the analysis. This shows structure to be in equilibrium. Then, the dynamic analysis is performed on the structure by varying the load with respect to time. Here, in FLAC3D, the load is varied with respect to the dynamic time and the responses of the pile structural element nodes with respect to dynamic time are stored as histories and can be reviewed. We can then plot responses of the pile along the depth of the pile for the combined action of the structural (vertical) load and the dynamic wave (lateral) load on the offshore platform. The loads in FLAC3D are varied using the fish functions. The dynamic analysis is carried out for one complete wave cycle, taking into account the 100 year return period datas. The responses of a pile in a row are studied. The legend followed for piles and legs are shown in Figure 2. The wave forces are calculated using the stoke’s fifth order wave theory and is applied to the model at various nodes.

7. RESULTS

Model Validation
Figure 3 and 4 shows the deflection and bending moment respectively along the pile length for the finite difference analysis and Mostafa and Nagger (2004). The maximum deflection and bending moment are very well comparable with Mostafa and Nagger (2004).

The deflections of all the piles are shown in Figure 5. The deflection of rear pile of leg2 (L2P3) is found to be more critical than all other piles in the row. The deflection of L1P2 is found to be approximately 62% of deflection of L2P3.

The bending moments for all the piles are shown in Figure 6. The bending moment for the front pile of leg2 (L2P2) is found to be approximately 111.5% of rear pile of leg1 (L1P3)
8. PARAMETRIC STUDY

The seabed slope is varied and the pile responses are studied for various slopes of seabed. The increase in seabed slope increases the displacement of the pile. The variation of displacements for all slope cases is shown in Figure 7. The maximum displacement for a plane seabed case is found to be 26.13mm and it increases gradually with the increase in seabed slope. The value of maximum deflection for 1 in 10 slope case is found to be 107.8mm. The location of maximum displacement remains the same for all the cases.

Figure 8 shows the variation of bending moment for all the slope cases. The maximum bending moment increases with the increase in slope of seabed. The maximum negative bending moment for a plane seabed case is observed to be 9.162MNm and it increases with the increase in seabed slope. The maximum negative bending moment for 1 in 10 slope case is 12.673MNm. The location of the maximum bending moment also varies with respect to slope.

9. CONCLUSION

From the results, it is clear that the maximum lateral deflection among all the piles at seabed level has been occurred in the rear piles of leg1 (which is in tension) and leg2 (which is in compression). The lateral deflection of piles increases with increase in slope of seabed. In the In case of bending moment, the maximum negative bending moment among all the piles has been found to be occurred in the front pile of leg2. Maximum negative bending moment for the pile increases with increase in seabed slope. The maximum negative bending moment of front pile of leg2 (L2P2) when the seabed slope is of 1 in 50 is about 4.2% higher than the maximum negative bending moment of the pile in plane seabed case.

ACKNOWLEDGEMENTS

Funding for these studies was provided by Department of Science and Technology (DST) under Fast Track for Young Scientists Program (SR/FTP/ETA-08/2007), and this support is gratefully acknowledged.

REFERENCES


