146 EFFECT OF SOIL STRUCTURE INTERACTION ANALYSIS ON THE RESPONSE OF FIXED OFFSHORE JACKET STRUCTURE

Seeram Madhuri[1]

M. G. Muni Reddy[2]

Assistant Professor, Department of Civil Engineering, University College of Engineering Kakinada, JNTU Kakinada

Email ID:[1] madhuri.seeram@gmail.com

Assistant Professor, Department of Civil Engineering, University College of Engineering, Andhra University

Email ID: [2] munireddy9@rediffmail.com

Abstract: Offshore jacket platforms are being extensively used for the exploration of oil and natural gas. Now a day's these structures are being suggested for supporting offshore wind turbines. The jacket structures are fixed to sea bed using piles. These piles penetrate into the soil and transfers structural loads to the soil. The soil structure interaction of the piles should be studied for the safety of the structure. In the present study, the soil structure interaction (SSI) of the jacket structure is studied by developing a MATLAB code and performed static analysis using stiffness method. Structural elements are modeled using three dimensional beam elements. The modulus of sub-grade reaction of the surrounding soil is estimated using Vesic equation. The spring stiffness of the surrounding soil along the length of the piles of the jacket is estimated using Newmark distribution. Wave force on the structural elements of the jacket structures is estimated using Morison's equation. The deflection of the topside and at the sea bed is presented in this paper. The effect of the marine growth on the static and dynamic response is also studied and concluded that the response of the structure and the natural period of the structure are increased when the marine growth is present

Keywords: Jacket Structures, soil springs, Morison equation, Finite element analysis, Three dimensional beam element, Response

1 Introduction and brief literature review:

Mainly offshore jacket structures are used for gas and oil exploration, processing and supporting structures for offshore wind turbines etc. Many of the offshore jacket structures are constructed at water depths ranging from 30m to 300m. The jacket structure has to resist different structural, equipment, environmental and accidental loads etc. Among all the loads wave, current and wind loads are continuous throughout the life of the structure. The stability of the jacket structure mainly depends on foundation system. The surrounding soil and soil structure interaction plays major role in the response of the jacket structure. Incremental dynamic analysis of jacket platform including the pile soil interaction was performed under earthquake loading by using Winkler beam foundation technique (Behrouz and Alireza, 2008). Rehman et al. (2012) performed a nonlinear finite element analysis by using two dimensional beam elements for modeling the structural members under wind, wave and combination of wind and wave loads. The results indicated considerable effect of current velocity on the response of the jacket and nonlinear displacement increment was observed. Behrouz et al. (2012) studied the effect of soil-pile-structure interaction on dynamic characteristics of a prototype jacket structure by performing experimental and numerical investigations for hinged and skirt pile boundary conditions using ABAQUS and SACS software's. Soil pile interaction was modeled in SACS using simplified model. Based on the study it was observed that the soil pile interaction had significant effect on the dynamic characteristics of the jacket structure. Wei et al. (2015) performed soil structure interaction study of a jacket type offshore wind turbine by developing flexible foundation, p-y model of the pile groups and fixed foundation. Based on the study it was observed that the flexible foundation system estimated well the loads on the offshore wind turbine and suggested to consider the pile group in the fatigue analysis. Zadeh et al. (2015) studied the nonlinear response of fixed offshore platform under the combined wave, wind and current loading for one year and one hundred year return periods using SAP2000 software. The direction of the wave also studied and concluded that the loading and direction has significant effect on the fixed offshore structure by investigating bending moments, axial forces and shear forces on the members. The marine growth develops on the jacket structure after several months of the installation. Due to marine growth, the mass of the structure and diameter increases. Based on the literature review it is understood that the soil structure interaction analysis of jacket structure with marine growth on the structural elements under environmental loading is limited. Hence the main objective of the present study is to study the effect of soil structure interaction under wave and current loading when the jacket members are having marine growth on the structural members.

2 Analysis of fixed jacket structure:

The present studied four legged jacket structure is having a deck size of 46m x 46m is located at a water depth of 153m. The foundation level of the jacket piles is up to a depth of 84m from the sea bed. The stiffness of the soil springs of the surrounding soil is estimated using Vesic (Bowels, 1974) equation and Newmark (1942) distribution. The soil profile considered in the present study and estimated soil spring stiffness of the piles is given in Table 1. The outer diameter and the wall thickness of the jacket legs and inclined members are about 1.2m x 15mm and 0.8m x 12mm respectively. The foundation of the jacket structure is assumed with steel piles of 1.524m outer diameter and 60mm wall thickness. The thickness of the marine growth is taken as 100mm up to the water depth of 40m and 50mm below 40m water depth to sea bed level. The density of marine growth is considered as 1400kg/m^3. Topside weight of 8.15t/m^2 is considered and applied as nodal loads. The density of steel is assumed as 7850kg/m^3. A MATLAB code is generated to analyze the fixed offshore jacket structure. All the structural members and foundation piles are modeled using three dimensional beam elements with six degrees of freedom at each node (i.e. three translations and three rotations). Coordinates, element connectivity, member properties and constraint details are given as input. A finite element model is developed. Wave (wave height of 8m wave period of 12s) and current (velocity of 1m/s) loading on the structural members is estimated using Morison equation (Eq. 1). The water particle velocity and accelerations along the water depth are estimated using Airy's wave theory. The wave loading is estimated by descritizing the wave into time steps. The wave load at each time step is estimated. The varying wave loads per unit length of structural members below the water line are estimated and converted to nodal loads. The maximum wave loading in the wave cycle is considered for the prediction of the deflections (Eq.2). The soil structure interaction analysis is performed for the considered jacket structure with and without marine growth and wave directions of 0, 45 and 90 degrees. The drag coefficient is taken as 0.6 and 0.7 in the cases of without and with marine growth respectively, where as inertia coefficient is taken as 2.0. The stiffness of the surrounding soil is added to the elemental stiffness matrix of the structural members of the piles of the jacket from sea bed to the foundation level. Global stiffness matrix of the structure and load vector is assembled based on connectivity, orientation of the element with the global axis and constraints. The generated finite element model of the jacket is shown in Fig. 1. A static analysis is performed using stiffness method (Eq. 2). The static analysis of the jacket structure is also performed by considering fixity depth (as per IS 2911 (Part 1/Sec 2):1979). The deflections at sea bed and top of the deck for the considered cases are listed in Table 2. A modal analysis is also performed by considering soil structure interaction and marine growth. The natural period's up-to 6th modes are listed in Table 3 and first mode shapes with and without marine growth are shown in Fig. 2.

$$df = \frac{1}{2}\rho_w D C_d \left(u_f + u_c\right)\left|u_f + u_c\right| + \rho_w A_c C_m \dot{u}_f \qquad (1)$$

$$[K]\{X\} = \{f(t)\} \qquad (2)$$

where,
df force per unit length
C_d Drag coefficient
D Diameter of the element
u_f Fluid velocity along the water depth
u_c Current velocity along the water depth

$\dot{u}_f$ Fluid acceleration along the water depth
C_m Inertia coefficient=C_a+1
C_a Added mass coefficient
A_c Cross sectional area of the tube
ρ_w Fluid density
[K] Global Stiffness matrix of the structure
$\{X\}$ displacement of the structure
$\{f(t)\}$ Wave Force exerted on structure

3 Results and Discussions:

The observed deflections of the topside and at sea bed in all the wave directions considered indicate that the deflection at sea bed is lesser than the deflection at top side indicating the effect of soil. The topside deflection is observed 38% higher when the marine growth is considered than the deflection when marine growth is not considered. The top side deflection is observed lesser in fixity depth method than the SSI. The deflection at sea bed is observed lesser in all the considered cases, indicating the contact of structure with the soil. The dynamic analysis results indicate that the natural period of the jacket structure increases when the marine growth is considered due to the increase in structural mass.

Table 1 Soil profile of the jacket structure

Soil Type	Depth from seabed (m)	Modulus of sub-grade Reaction (kN/m^2)	Soil Spring stiffness (kN/m)
Medium Dense Sand	0 to 2	15000	7027.115
Firm to Stiff Clay	4 to 6	75000	142765.3
Soft to Firm Clay	8 to 12	45000	90235.53
Stiff Clay	14 to 28	80000	157930.1
Very stiff to Hard Clay	30 to 52	85000	183436.5
Medium Dense Sand	52 to 58	68000	132226.8
Hard Clay	58 to 68	68000	127415.8
Strong Limestone	68 to 86	100000	194558.5

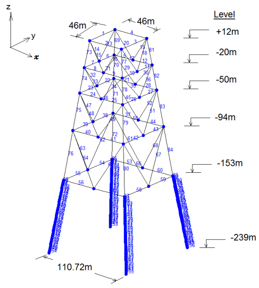

Fig. 1 Finite Element model of Jacket structure with soil structure interaction

Table 2 Deflections at topside and seabed of the jacket structure

	Topside (mm)			Seabed (mm)		
Deflection along	X	Y	Z	X	Y	Z
0 degree wave direction						
SSI	12.1	11.2	-1.8	0.4	0	-1.8
SSI & MG	16.8	12.8	-1.8	0.4	0	-1.7
Fixity & MG	-16.3	14.8	-0.1	-0.03	0.004	- 0.0002
45 degree wave direction						
SSI	-12.2	11.4	-1.9	0.4	0	-1.8
SSI & MG	-17	13	-1.9	0.4	0	-1.7
Fixity & MG	-16.7	14.7	0.1	-0.03	0.004	0.0006
90 degree wave direction						
SSI	-12.1	12	-1.9	0.4	0	-1.8
SSI & MG	-16.8	13.6	-1.9	0.4	0	-1.8
Fixity & MG	-16.8	14.2	0.2	0.03	0.04	0.0007

4 Conclusions:

Based on the present study it is observed that the response of the structure and natural period is increased when marine growth is considered due to the additional structural mass and no significant change in the structural stiffness. The modal analysis without SSI indicated higher natural period than the SSI analysis results. This is observed due to the reduction in the stiffness of the structure when SSI in not considered. The lateral deflections are observed higher when SSI&MG is compared with SSI & Fixity analyses. In order to predict the structural response accurately, the soil structure interaction analysis shall be performed. The difference in deflection is observed at 0 and 90 degree wave direction even though the structure is symmetric. This is due to the change in wave direction.

Table 3 Natural Periods of the jacket structure including soil structure interaction

Mode No	Natural Period (s) (SSI)		Natural Period (s) (without SSI)	
	Without Marine Growth	With Marine growth	Without Marine Growth	With Marine Growth
1	4.8224	5.6683	5.1067	6.0024
2	3.8003	4.6519	5.0345	5.9177
3	3.8003	4.6519	5.0345	5.9177
4	3.0387	3.5891	4.8225	5.6685
5	3.0387	3.3687	3.0541	3.5891
6	3.0541	2.8101	2.2601	2.6872

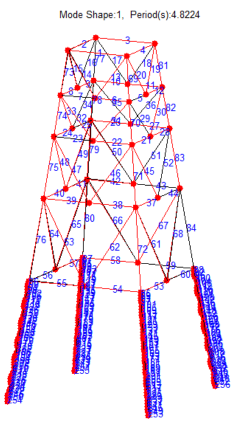

Fig. 2a Mode shape of the jacket structure without marine growth

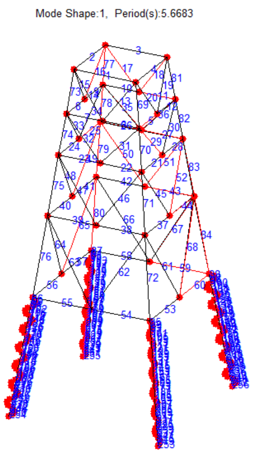

Fig. 2b Mode shape of the jacket structure with marine growth

References:

Behrouz Asgarian and Alireza Flouz (2008) Incremental Dynamic Analysis considering pile soil structure interaction for the jacket type offshore platforms, Proceedings of the ASME 27th International Conference on Offshore Mechanics and Arctic Engineering, OMAE 2008, June 15-20, Estoril, Portugal.

Shehata E. Raheem, Elsayed M. A. Abdel Aal, Aly G. a. Abdel Shafy and Fayez K. Abdel Seed (2012) Nonlinear Analysis of Offshore Structures under Wave Loadings, 15th World Conference on Earthquake Engineering, LISBOA.

Wei Shi, Hyum Chul Park, Chin Wah Chung, Hyun Kyung Shin, Sang Hoon Kim, Sung Soo Lee and Chang Wan Kim (2015) Soil Structure Interaction on the Response of Jacket Type Offshore Wind Turbine, International Journal of Precision Engineering and Manufacturing Technology, Vol. 2, No. 2, pp. 139-148.

Ghassemi Zadeh, S. M., Shojayee B. R., and Vaziri K. O. S. M.S. (2015) Finite Element Numerical Method for Nonlinear Interaction Response Analysis of Offshore Jacket Affected By Environment Marine Forces, Open Journal of Marine Science, 5, pp. 422-442.

IS 2911(Part1/ Sec2)-1979 Indian Standard code of practice for design and construction of pile foundation, Part-1, BIS, New Delhi.

Newmark, N. M (1942) “Numerical procedure for computing deflections, moments and buckling loads*”, Proc. ASCE*, ASCE, New York, N.Y., Vol.68, 679.

Vesic, A. B. (1961) “Bending beam resting on isotropic elastic solid”, *Journal of Engineering Mechanics Division, ASCE,* Vol. 87, EM2,April 35-33.