DYNAMIC ANALYSIS OF JACKET TYPE OFFSHORE PLATFORMS CONSIDERING CONNECTIONS FLEXIBILITY

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Abstract- Offshore steel jacket structures consist of tubular members and associated joints. For simplified computer analysis, connections between the elements are assumed to be rigid, which means that there would be no axial rotational or deflection at the end of the secondary member against the main member's axis. Nevertheless, the tubular joints have remarkable amount of flexibility in the elastic–perfectly plastic region. In this study, two models of a 3D frame of a fixed steel platform SPD7 existing in the Persian Gulf are made. Nonlinear static and dynamic analyses with respect of joint flexibility are performed and compared to platform with rigid connections to investigate the effect of joint flexibility on natural frequency of the structure. The results show that the natural frequency of platform without flexibility has been increased even though the effect of increasing the ductility to the Platform's frequency was predictable. Besides, by performing dynamic history analysis and investigating the exact effect of connection flexibility, the results show that the base shear values are reduced compared to the rigid model. It proved that local joint flexibility has considerable effect on nonlinear static and dynamic behavior of offshore structures.

Keywords- Tubular Joint, Jacket Type Offshore, Dynamic Analysis.

I. INTRODUCTION

Tubular elements have many applications in engineering structures. These elements with rounded and rectangular sections are used in on-shore and offshore structures, space trusses, telecommunication and power transmission towers, load carrying structure of cranes, and steel elevated tanks. The tubular sections are very economical and are considered superior to other sections for different reasons, some of which are: a high rotational strength (resistance), symmetry of section properties, the possibility of welding their connections, simplicity of shape, reduced painting area, attractiveness and reduction of the area exposed to corrosion. Moreover, the tubular sections show the best behavior against hydrodynamic and drag forces compared to other existing sections.

The rounded (circular) sections not only have a high torsional stiffness, they also show a similar buckling strength in all section axes, and from structural point of view are the most appropriate sections to form the spatial frame elements.

After the World War II and the expansion of oil industry offshore, the need to use the tubular sections as the best option in building offshore structures, especially offshore platforms increased. By then, there existed no knowledge about the role and performance of welded tubes as a structural connection. Thus several studies were carried out on tubular structures and their connections (joints), most of which were based on offshore platform design requirements. Meanwhile, one of the aspects that were taken into consideration was the flexibility of tubular joints. In computer analyses of the structures with tubular elements like offshore oil platforms, the connections between the elements are considered rigid using conventional methods. In fact, the joint is assumed as a dimensionless point on which the elements are connected together rigidly and is not modeled as a structural member. This assumption means that there would be no axial or rotational deflection (deformation) at the end of the secondary member against the main member's axis. However, in real conditions, some local deflections are created in the rounded section of the main member under the imposed loads from the secondary member. This indicates that the tubular joints have remarkable amount of flexibility in the elastic-perfectly plastic range. So the results of analyses based on joint rigidness differ to a great extent from the actual behavior of the structure. These differences are observable in structure deformation, distribution of inner forces, buckling forces of the members, and also the natural frequency of a structure, especially in case of 3D structures. Therefore, taking the flexibility effects into account seems to be very crucial in the overall analysis of a structure. As the high effect of joint flexibility on the results of tubular structure analysis was specified, it attracted the attention of many researchers and various studies and tests were carried out on tubular joints.

One of the earliest investigations of the effects of local joint flexibility on the response of offshore installations dates back to 1980, when Bouwkamp[1] conducted research on the analytical techniques used to develop the joint flexibility model and to find some procedures to incorporate these effects into the overall structural response. They provided joint analysis models which were assembled from the component branch and chord substructures using a consistent multilevel substructure technique. Later, Ueda [2] provided an improved joint model and equations for

the flexibility of tubular joints. The accuracy of their models was confirmed through comparisons with results from finite element analysis. They concluded that their models are capable of representing the nonlinear behavior of actual joints accurately. Fessler and Spooner [3] and Fessler [4] presented improved equations for the flexibility coefficients in terms of joint parameters in Y-, X- and gap K-joints. Billington [5] provided new formulae which describe the ultimate limit state of tubular joints. They conducted extensive research on over 200 carefully screened static test results. Karamanos [6] investigated the fatigue design of K-joint tubular girders. Skallerud [7] performed experimental investigations of the cyclic inelastic behavior of tubular joints, and provided researchers with valuable test data. van der Vegte [8] studied the ultimate strength of uniplanar X- and T-joints, and developed limit state equations through regression analyses over the results of carefully verified finite element models. Dier [9] described the recent developments that have taken place in offshore tubular joint technology. The static loading performance of tubular joints in multi-column composite bridge piers was studied by Lee [10]. Lee and Parry [11] conducted research on strength prediction for ring-stiffened DT-joints in offshore jacket structures. Wang and Chen [12] examined the cyclic performance of circular hollow section joints used in steel tubular structures, and performed quasi-static experimental tests to study the response of eight T-joint specimens. Honarvar [13] studied the cyclic behavior of two small-scale models, representative of a jacket type offshore platform located in the Persian Gulf, with two different pile leg interactions. They also presented the analytical modeling of pile–leg interactions as well as brittle joint behavior, and concluded that joint rupture is encountered in the grouted model prior to the ungrouted frame due to the greater stiffness and strength of grouted legs. Alanjari [14] developed an analytical model which made use of uniaxial fiber elements to model a fracturing tubular joint, and presented a discussion on the energy dissipation of offshore platforms. However, their models lacked joint local biaxial and triaxial effects, as they did not take local joint flexibility into account.

Although, several studies and experiments have been done on pipe connections platforms in 2-Dimensional states, limited studies were found on offshore platform considering the joint flexibility in 3-Dimensional.

This paper presents on modeling of 3-D frame of a fixed steel platform SPD7 existing in the Persian Gulf. Nonlinear static and dynamic analyses with respect of joint flexibility are performed and compared to platform with rigid connections to investigate the effect of joint flexibility on natural frequency of the structure. The effect of joint-can is also investigated for 3 types of connection.

II. MATERIALS AND METHOD

The steel used in modeling has the following characteristics [15]:

Specifications: API-5L-B
Yield Stress: 36 kg/mm^2
Elastic Module: 20000 kg/mm^2
Poisson's Ratio: 0.3
Strain hardening Ratio: 0.0034

The Grout used in the model has the following characteristics:

Elastic Module: 12 * 10 kg/mm^2
Poisson's Ratio: 0.25
Bond Strength: 15 * 10 Pascal

The parametric finite element model of tubular joints has been created using APDL software programming capability. All geometrical and mechanical properties of the materials are considered as variables in this model. Due to the creation of high plastic strain in the interface of the connection of two tubes, the meshing of this section has been done finer than other parts. SHELL43 elements with four nodes (each node with six degrees of freedom) and the function type 1 which are suitable for analyzing the issues related to the final displacement and elastic-perfectly plastic, have been used for modeling the connection components. In this instance, the main connecting pipe diameter is 1727 mm with thickness of 32mm and secondary pipe diameter and thickness of 610 mm and 19.1 mm respectively, which is the characteristic of a sample platform connection. In the distance of 2500 mm from the junction of the axes, the load is imported as push-over. Since the members of connection in the platform model also include axial force, a vertical stress in different forms of tensile and pressure is imported along the axis of secondary member.

III. FINITE ELEMENT MODEL

Two finite element models of a SPD7 platform's frame are designed in 3D. The SPD7 platform with the overall height of 80.50m consists of four bases, two of which have slight slope of 12.27% on two plates and two other bases, one on a vertical (upright) plate, and the other one has a slope of 6.99 % respectively. The jacket section is located between -60 m and +4.5 m levels to the LAT. The deck section has been built in four levels between +5.30m and +20.5m levels.

The first platform was modeled by means of uniaxial beam-column elements having tubular members rigidly interconnected to each other at nodal points. The brace is extended to intersect with the chord central axis.

The second model is generated by using 3D shell element for the platform's joints and pipe element for the members to account the joint flexibility automatically.

IV. RESULTS AND DISCUSSIONS

A. Nonlinear Static Analysis (Push Over)

In this analysis, a loading model (pattern) is considered on the nodes of the platform, and then this model is increased steadily until when the platform is not able to tolerate its gravity loads (or in many cases to reach the extent of displacement that the numerical analysis of the platform structure becomes unstable). Figure 1 and 2show the diagram for push-over analysis of SPD7 platform, obtained from the nonlinear static analysis done by ANSYS11 software.

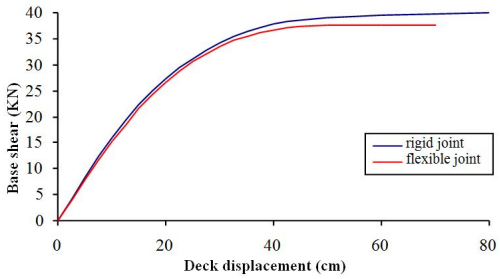


Figure 1: Deck displacement in X-direction for rigid and flexible SPD7 platform

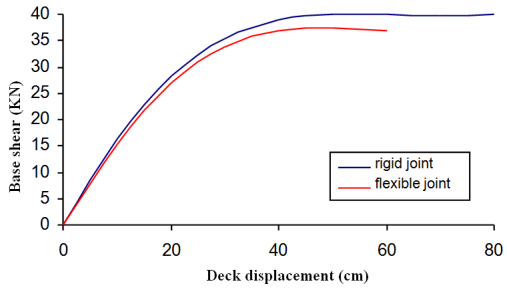


Figure 2: Deck displacement in Y-direction for rigid and flexible SPD7 platform

It can be seen that there is little difference between the graphs obtained for the model with rigid joints and the one with flexible joints. However, this difference increases with increasing load and entering the nonlinear range.

Failure in the model with rigid joints starts with buckling of the bracings between second- third and third-fourth levels, and with increasing levels of load, buckling of bracings at other levels occurs successively. Finally, the structure collapses with these bracing failures.

In the model with flexible joints, failure starts with the buckling of bracings at second- third and third- fourth levels. With increasing load, other braces and the joints attached to them start flowing, and ultimately what causes the structure to collapse is the buckling of relative braces and the failure of joints connected to them. The responses of the two different models differ slightly because of the lower level of joint flexibility in the platform due to using Joint-cans.

B. Modal Analysis

Modal analysis was performed on both platforms. The modal response of the structure in flexible joint case is different from its modal response in structure with rigid joints. Also, the vibration modes and modal mass participation rate had significant changes.

Table 1: Comparison of structural vibration periods for two models

Mode no.	Model with flexibility	Model without flexibility	Percentage of discrepancy
1	2.271	2.050	9.721
2	2.055	1.929	6.166
3	1.956	1.807	7.642
4	0.444	0.462	4.241
5	0.424	0.412	2.804
6	0.383	0.383	0.000
7	0.375	0.382	1.847
8	0.363	0.373	2.725
9	0.356	0.351	1.389
10	0.345	0.336	2.586
11	0.329	0.326	0.904
12	0.312	0.298	4.444
13	0.306	0.287	6.149
14	0.290	0.286	1.365
15	0.289	0.285	1.370
16	0.287	0.270	5.862
17	0.268	0.257	4.059
18	0.248	0.235	5.200
19	0.228	0.232	1.739
20	0.217	0.224	3.196

C. Dynamic Analysis

Using the Macro software programming capability, the models were analyzed dynamically. Thus, the first acceleration of gravity was applied on the structure, followed by applying the acceleration to all nodes of the structure in each time step. Each time step also is divided into five parts or sub-steps.

Nonlinear dynamic analysis was implemented on both models using Tabas earthquake. Acceleration mapping were taken from data from PEER Strong Motion Database website. Figure 3 shows the Tabas earthquake record.

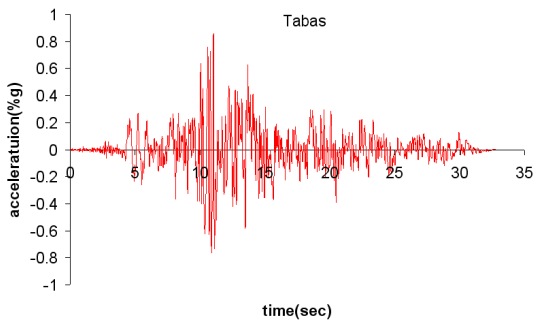


Figure 3: Record of Tabas earthquake in Iran -1978

The values for base shear and relative peak drift of the levels have been shown in Figures 4, 5, and 6.

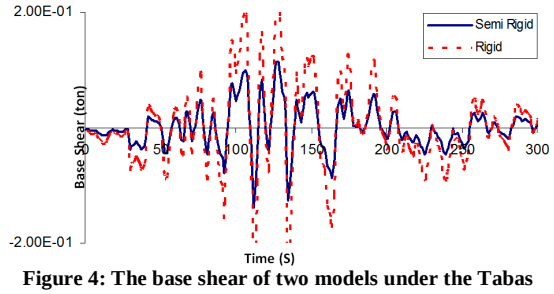


Figure 4: The base shear of two models under the Tabas earthquake

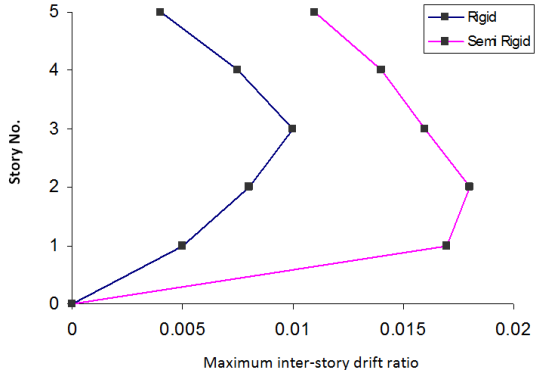


Figure 5: Maximum inter- story drift ratio in the X-direction

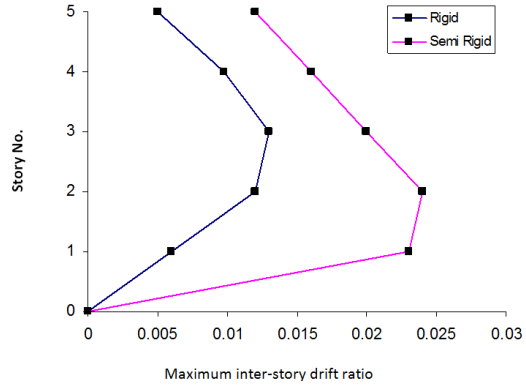


Figure 6: Maximum inter- story drift ratio in the Y-direction

Comparing the obtained results, it can be seen that in the flexible model, the base shear value is reduced compared to the rigid model. Also, the comparison of the relative drift values of the lower levels shows that the flexible structure with joint can, despite lower base shear force, experienced more lateral displacement which is different in direction of X and Y, so that displacement in direction of X is lower.

CONCLUSION

Based on this study, the effects of joint flexibility on the local and global behaviour of the jacket type offshore platform were investigated. Knowing the fact tubular connections are flexible and they can dissipate energy when subjected to cyclic forces, one can conclude that disregarding the joint flexibility in the estimation of overall energy dissipation, presents inaccurate results By running the non-linear static analysis, it was found that the static response of the structure changes with respect to the joints flexibility. These changes increase significantly upon the nonlinear range. In the platform SPD7, the deck displacement of the flexible model increases by a maximum of 10% in linear range and up to 40% in non-linear range compared to the rigid model. By comparing the base shear and deck displacement graphs of two platforms can conclude that the platform with rigid joints is considerably stiffer and over-strength and stiffness would be more significant when the inelastic responses are encountered.

Modal characteristics of the structure with flexible joints have significant differences to those of the structures with rigid joints. The percentage of difference in the vibration period in the first mode for the two platforms is approximately 10%. Also, significant changes in the form of vibration modes and the effective modal mass were observed. Based on the dynamic time-history analysis and investigation of the effect of flexibility, it was shown that the base shear values have reduced in flexible joints model by about 30% compared to the rigid joints model which define that the rigid joints platform is stiffer compared with flexible joints model. Also, the comparison of the values of the inter-story drifts shows that the flexible structure despite the lower base shear force, experiences a greater lateral displacement and inter-story drifts compared to the rigid joints model due to less stiffness and strength of the jacket structure. However, the displacement values of the flexible structure are at an acceptable level.

REFERENCES

[1] Bouwkamp, J. G., & Hollings, J. P. (1980). Effects of Joint Flexibility on The Response of Offshore Towers. Offshore Technology, 455–464.

[2] Ueda Y, Rashed SMH, Nakacho K. An improved joint model and equations for flexibility of tubular joints. J Offshore MechArctEng 1990;112:157–68.

[3] Fessler, H., & Spooner, H. (1981). Experimental determination of stiffness of tubular joints. Symposium Integrity of Offshore Structures.

[4] Fessler, H., Mockford, P., & Webster, J. (1986b). Parametric Equations For The Flexibility Matrices Of Single Brace Tubular Joints In Offshore Structures. ICE Proceedings, 81, 659–673.

[5] Billington, C., Lalani, M., &Tebbetl, I. (1982). Background to new formulae for the ultimate limit state of tubular joints. In Offshore Technology Conference.

[6] Karamanos SA, Romeijn A, Wardenier J. On the fatigue design of K-joint tubular girders. International Journal of Offshore and Polar Engineering 2000;10(1).

[7] Skallerud BH, Eide O, Amdahl J, Johansen A. On the cyclic capacity of tubular joints subjected to extreme cyclic loads. In: 14th Int. Conf. on Offshore Mech. and Arctic Eng., 1995. p. 19–22.

[8] Van der Vegte, G. J., Koning, C. H. M. de, Puthli, R. S., &Wardenier, J. (1991). The static strength of multiplanar tubular steel X-joints. In 1st International O shore and Polar Engineering Conference (pp. 42–52).

[9] Dier, A. (2005). Tubular joint technology for offshore structures. Steel Structure 5(2005), 495–502.

[10] Lee, J. H., Hino, S., Ohta, T., &Seo, S. T. (2002). Static loading performance of tubular joint in multi-column composite bridge piers. Memoirs of the Faculty of Engineering, Kyushu University, 62(3), 129–137.

[11] Lee, M. M. K., & Llewelyn-Parry, A. (2004). Strength prediction for ring-stiffened DT-joints in offshore jacket structures. Engineering Structures, 27(3), 421–430.

[12] Wang, W., & Chen, Y. (2007). Hysteretic behaviour of tubular joints under cyclic loading. Journal of Constructional Steel Research, 63(10), 1384–1395.

[13] Honarvar MR, Bahari MR, Asgarian B, Alanjari P. Cyclic inelastic behavior and analytical modeling of pile–leg interaction in jacket type offshore platform. Applied Ocean Research 2008; doi:10.1016/j.apor.2008.02.001.

[14] Alanjari P, Asgarian B, Bahari MR, Honarvar MR. On the energy dissipation of jacket type offshore platforms with different pile–leg interactions. Applied Ocean Research 2009; doi:10.1016/j.apor.2009.07.002.

[15] American Petroleum Institute, API. Recommended practice for planning, designing and constructing fixed offshore platforms. Working Stress Design. API RP2A-WSD, Edition 22nd. December; 2005.

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