Evaluation of Ultimate Strength of Jacket Type Structures under Marine Loading

S.A. Kheiri[1] and M.R. Bahaari[2]

Abstract: An existing platform should undergo the assessment process if one or more of the following conditions exist: 1) Addition of personnel 2) Increased loading on Structure 3) Damage found during inspection and etc.

A structure should be evaluated based on its current status, accounting for any damage, repair, or other factors affecting its performance. Analyses consist of both design level analysis and ultimate strength analysis. The latter is more desired and common in offshore work. Push-over and nonlinear time-domain analysis methods are acceptable in ultimate strength analysis. The main result of such analysis is Reserve Strength Ratio (RSR). Acceptance or rejection of structure fitness is dependant on this ratio. In conventional push-over analysis, wave dynamic loading is simulated by equivalent quasi static load and dynamic affects such as added mass, damping and inertial force are neglected. However, in time-domain analysis, dynamic effects are considered and subsequently ultimate strength can be estimated better with more precision.

In this current study, two platforms were selected for case study analysis. Push-over analyses and nonlinear dynamic analyses were applied to both platforms and the relevant results were compared to each other. "ABAQUS" software was used for modeling and analysis. Pile-soil interaction is modeled by nonlinear springs and in the meantime analyses took into account the effect of large displacement, plasticity and strain hardening, as well.

In the course of limited investigation, it was concluded that in nonlinear dynamic analysis, reserve strength of jacket structures was estimated to be higher than that of static push-over and that structures can bear more partial failure before global failure.

Keywords: platform, assessment, push-over, nonlinear time-domain analysis, ABAQUS, RSR, failure

1. Introduction

When designers want to ensure the existing structure can withstand new condition after changes in jacket structure, for example, increasing design load or inspection reveals some damages in structure and etc; assessment process is performed [1].

The strength of existing structure under lateral loading can be controlled by appropriate methods. One can be design level analysis where after linear analysis, design criteria should be checked. Another would be ultimate strength analysis. Here, through nonlinear analysis, ultimate strength of structure is estimated and compared to strength of structure in design level [1, 2 and 3]. Static push-over or nonlinear time-domain analysis can be selected as a nonlinear analysis [1]. The main result of ultimate strength analysis method is reserve strength factor introduced by Lloyd and Clawson [4]. Reserve strength ratio (RSR) with same definition is described as follows by Bea et al [5]:

$$RSR = \frac{F_{ult}}{F_D}$$

[1] Ms Graduate of Marine Structure, Faculty of Civil Engineering, University of Tehran
[2] Associate Professor of Civil Engineering, School of Civil Engineering, University of Tehran

F_{ult} is ultimate lateral loading tolerable by structure and F_D is lateral loading pertaining to design condition. Lateral loading consists of wave and pertinent current load [1]. Structure will pass assessment if this ratio is grater than that indicated in codes like API [1] or ISO [6].

Focus in this paper is on ultimate strength analysis. Both of static push-over and nonlinear time-domain analysis are utilized to determine reserve strength and behavior of jacket structures. Then results of these two analyses are compared to each other.

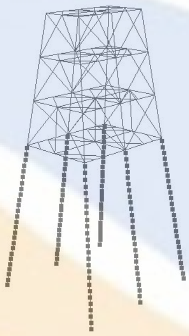
2. Modeling

2.1- Software: ABAQUS is a suite of powerful engineering simulation programs and was used in the investigation for modeling and analysis.

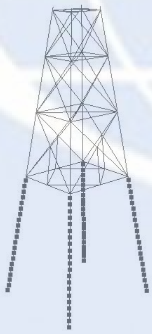
ABAQUS/Aqua is a set of optional capabilities that can be added to ABAQUS/Standard. It is intended for the simulation of offshore structures, such as oil platforms. Some of the optional capabilities include the effects of wave and wind loading and buoyancy [7].

2.2- Structural Members Model: Frame element was selected for modeling of structural pipe members. Main reasons were nonlinearity characteristic, buckling behavior modeling in nonlinear analyses, and capability of use in AQUA analysis and possibility of use in both dynamic and static analysis. This type of elements can be used to solve a wide variety of civil engineering design applications, such as truss structures, bridges, internal frame structures of buildings, off-shore platforms, and jackets, etc [7].

Figures 2-1 represents 3-D schematic of two investigated jackets named in this study as jacket "A" and jacket "B".



Jacket A



Jacket B

Figure 2-1: 3-D representation of 2 investigated jackets

2.2- Pile and Soil Model: piles same as structural members were modeled by frame3D elements. Soil surrounding of piles was modeled by nonlinear springs. P-Y, T-Z and Q-Z that indicate property of these springs corresponds to lateral resistant vs. lateral deflection, skin friction resistant vs. vertical deflection and tip resistant vs. vertical tip deflection, respectively [1, 8]. These curves for various layers can be obtained by tests directly or as a function of soil specification C, cohesion, and φ, friction angle, recommended in codes like API [1]. Buried length of piles in jacket "A" and "B" are 42 m and 54 m, respectively. These lengths are divided to 2m segments and nonlinear springs were used in any segments.

2.3- Pile and Leg Connection: In design and construction of jackets there are two methods for connection between pile and leg. First is grouting the gap and second is leaving this gap without any grout. The latter case of non-grouted is assumed in this study, where there is no constraint between pile and leg in pile axial direction, but there is constraint in lateral direction. Suitable element for this type of connection is cylindrical connector element that is used in every joint level. At top level of piles, pile and leg are welded to each other via crown pieces so weld connector element was used at that level, as well.

3. Loading and Analysis

3.1- Loading: The main lateral loading for this analysis consist of wave and current. ABAQUS/AQUA is capable to exert wave load statically or dynamically. Drag and inertia factor for wave and current loading were assumed to be 1.05 and 1.2, respectively. Marine loads property are selected as typical for Persian Gulf region and together with other gravitational loads applied for structures. Design wave height and its period assumed to be 11.8m and 12sec, respectively, while the relevant current velocity is 1.29 m/s^2

3.2- Analysis: static push-over and nonlinear dynamic analysis were performed for structures. In earlier analysis, static loads corresponding to design condition are applied to structure, then step by step with increasing of load intensity the structure is analyzed to determine its response. This type of analysis is known as RIKS analysis in ABAQUS software and used for push-over analysis.

In nonlinear dynamic analysis for the first time, design loads was exerted to structure dynamically during of 1 period of wave. and structure was analyzed and response was recorded. After that, maximum loading tolerable by structure dynamically was determined with trial and error method. It means maximum loading that was not known at first can be found by increasing loads until load magnitude causes global failure in the course of analysis. Load has been increased by scale factor or load factor. It other words intensity of wave dynamic loading was multiplied by load factor.

4. Results

4.1-Static push-over analysis results:

4.1.1- Jacket A: In figure 4-1 results of push-over analysis on this jacket is shown. Table 4-1 depicts sequence and type of failures while in figure 4-2 locations of failure are indicated.

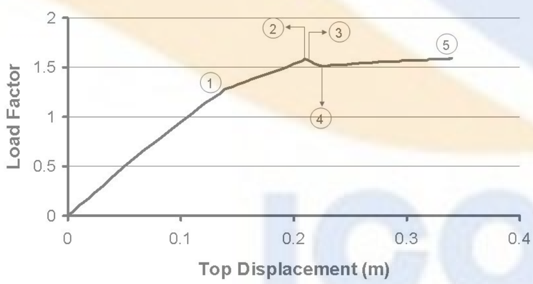


Figure 4-1: push-over graph of jacket A

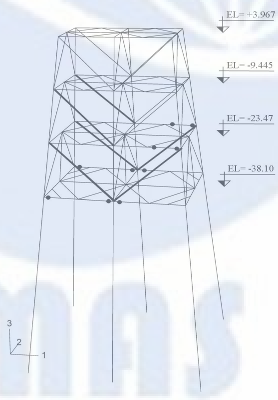


Figure 4-2: Locations of failure in jacket A

Sequence	Load Factor	Lateral top deflection(m)	Failure type
1	1.275	0.139	buckling of two braces between level of -22.37 and -28.10
2	1.576	0.21	buckling of two braces between level of -9.445 and -23.47
3	1.565	0.214	bending yielding of two elements in level of -23.47
4	1.533	0.268	yielding of tension bracing between level of -23.47 and -38.10
5	1.58	0.339	forming of some plastic hinges in level of -38.10 and collapse

Table 4-1: sequence and type of failures in jacket A

Reserve strength ratio (RSR) of this jacket is equal to 1.576 and it showed semi-ductile behavior as per Ref [9].

4.1.2- Jacket B: Table 4-2 presents sequence and type of failures. For more details of results refer to Ref [10].Reserve strength ratio (RSR) of this jacket is equal to 2.73 and it showed semi-ductile behavior as per Ref [9].

Sequence	Load Factor	Lateral top deflection(m)	Failure type
1	1.175	0.167	buckling of braces between level of -28.00and -49.10
2	2.376	0.250	Yielding of compressive piles near sea bottom
3	2.73	0.291	Yielding of tension piles near sea bottom and collapse

Table 4-2: sequence and type of failures in jacket B

4.2-Nonlinear time-domain analysis results:

4.2.1- Jacket A: three stages performed to indicate maximum tolerable lateral load of jacket structure. Response of this jacket in design level (load factor=1) and three stages mentioned above are illustrated in figure 4-4. Locations of partial failure are showed in figure 4-5. In table 4-3 sequences and types of failure at load factor 1.64 is described:

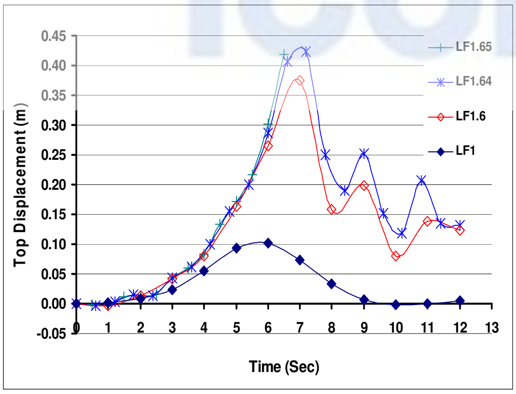


Figure 4-4: response of jacket A in various load factors in nonlinear time-domain analysis

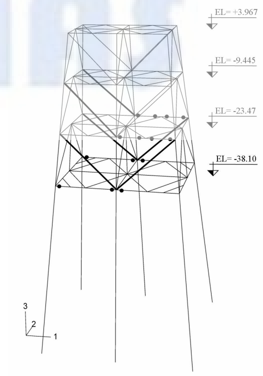


Figure 4-5: places of failure in jacket A at load factor 1.64

Load Factor= 1.64		
Sequence	)SEC(time	Failure type
1	4.6	buckling of two braces between level of -22.37 and -28.10
2	5.47	buckling of two braces between level of -9.445 and -23.47
3	5.53	bending yielding of two elements in level of -23.47
4	6.17	yielding of tension bracing between level of -23.47 and -38.10
5	6.82	forming of some plastic hinges in level of -38.10

Table 4-3: sequence and type of failures in jacket A at load factor 1.64

With respect to the said results, ultimate load factor resisted dynamically by structure is estimated to be 1.64; therefore, reserve strength ratio of jacket A is 1.64. The corresponding maximum lateral deflection appears to be 424 mm.

4.2.2- Jacket B: According to the results, ultimate load factor dynamically resisted by structure appears to be 3.03 i.e. reserve strength ratio of jacket B is 3.03. The corresponding maximum lateral deflection seems to be 503 mm. Table 4-4 contains sequences and type of failures at load factor 3.03:

Load Factor= 3.03		
Sequence	)SEC(time	Failure type
1	2.92	buckling of braces between level of -28.00and -49.10
2	4.48	Yielding of compressive piles near sea bottom
3	4.56	Yielding of tension piles near sea bottom and collapse
4	5.04	yielding of tension bracing between level of -28.00 and -49.10
5	5.28	forming of two plastic hinges in level of -49.10
6	5.64	buckling of braces between level of -28.00and -10.70
7	5.88	forming of plastic hinges in vertical members connected braces in level of -49.10

Table 4-4: sequence and type of failures in jacket B in load factor 3.03

.

5. Summery & Conclusions

By doing static push-over and nonlinear time-domain analysis for evaluation of two typical piled jackets in Persian Gulf region and comparison of results, followings are concluded, in order:

- Reserve strength ratio for jackets A and B in nonlinear time-domain analysis shows an increase of 4% and 11%, respectively, compared to those factors derived from static push-over analysis.
- Maximum lateral deflection of structures increased under dynamical loading, as well.
- In nonlinear time-domain analysis more partial failures can be borne by structure. In other words structure seems to be stable dynamically, while it behaves unstable statically.

  In general it can be concluded that static method for evaluation of jacket structure against marine loading is a conservative one. For achieving more reliable results it is necessary to consider more variety of jackets with different geometry and properties against special environmental load levels and the parameters effect on dynamic behavior be examined.

6. References

[1] American Petroleum Institute.; *Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms-Working Stress Design,* API-RP2A, Washington, DC 20th Edition, 1996.

[2] *Recommended seismic design criteria for new steel moment-frame buildings,* Report No. FEMA-350, SAC Joint Venture, Federal Emergency Management Agency, Washington DC,2000.

[3] *Seismic evaluation and retrofit of concrete buildings,* Report No. ATC-40, Advanced Technology Council, Redwood City, California, 1996.

[4] Lloyd, J.R. and Clawson, W.C, "Reserve *and Residual Strength of Pile Founded Offshore platforms*", The Role of Design, Inspection and Redundancy in Marine Structural Reliability, Proc. National Academy Press, Washington DC, 1984.

[5] Bea, R. G. et al: "Development *of ATM (Assessment, Inspection, Maintenance) Programs for Fixed and Mobile Platforms"* Poc. 20th Annual OTC, Paper 5703, Houston, 1988.

[6] ISO, *"Petroleum and Natural Gas Industries — Fixed Steel Offshore Structures"*. 2001

[7] ABAQUS Version 6.4 Documentation; *"ABAQUS Analysis User's Manual"*, 2004.

[8] Poulos,H.G., Davis,E.H., *"Pile Foundation Analysis And Design."* John Wiley &Sons, Inc., 1980.

[9] Schmucker,D.G.;*"Near-failure behavior of jacket-type offshore platforms in the extreme wave environment",* PHD Thesis , Reliability of Marine Structures Program, Report RMS-21, Dept. Civil Eng., Stanford university CA, USA, 1996.

[10] خيري جلودار، سيد عباس؛ تحليل پوش‌اور ديناميكي سكوهاي دريايي، پايان نامه كارشناسي ارشد، دانشكده عمران، دانشگاه تهران، 1384.