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RESEARCH ARTICLE

Time History Dynamic Analysis of a New Constructed Offshore Jacket Platform in Persian Gulf Due to Random Waves

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Abstract

API RP2A WSD is a design code in practice for design of jacket platforms in the Persian Gulf but is based on the Gulf of Mexico environmental condition. So for the sake of using this code for the Persian Gulf, it is better to perform a calibration based on this specific region. Analysis and design of jacket platforms based on API code are performed in a static manner and dynamic analysis is not recommended for such structures. Regarding the fact that the real behavior of the offshore jacket platforms is a dynamic behavior, so in this research, dynamic analysis for an offshore jacket platform in the Persian Gulf under extreme environmental condition is performed using random time domain method. Therefore, a new constructed offshore jacket platform in the Persian Gulf is selected and analyzed. Fifteen, 1-h storm, simulations for the water surface elevation is produced to capture the statistical properties of extreme sea condition. Time series of base shear and overturning moment are derived from both dynamic and static responses. By calculating the maximum dynamic amplification factor (DAF) from each simulation and fitting the collected data to Weibull distribution, the most probable maximum extreme (MPME) value for the DAF is achieved. Results show that a realistic value for DAF for this specific platform is 1.06, which is a notable value and is recommended to take into practice in design of fixed jacket platform in the Persian Gulf.

Keywords Offshore platforms · Weibull distribution · Water surface simulation · Time history analysis · Dynamic amplification factor · Persian Gulf

1 Introduction

Offshore platforms have many usages including oil and gas exploration and production, ship loading and discharging, and extracting energy from wind. Offshore oil production is one of the most applications and represents a significant challenge to the design engineer. These offshore structures must perform safely for design lifetimes about 25 years or more when subjected to very harsh marine environments (Sadeghi 2007). Offshore platforms are a significant part in the oil and gas industry and the failure of these structures can lead to enormous catastrophic in national level.

Dynamic response of offshore platforms subjected to harsh environmental condition is of substantial importance in the analysis and design of such structures. The main reason for performing this analysis is wave loading which varies with time and produces dynamic effects on structures. Dynamic analysis can be performed in either frequency or time domain analysis, but regarding the fact that using frequency domain spectral analysis technique requires the response of structures to be linearized, so random time domain simulation is considered for accounting nonlinearities in the analysis (Greeves et al. 1996).

A time domain solution based on approximating structural velocities in Morison's equation with their values at the previous time step was discussed by Anagnostopoulos (1982). A Ritz mode superposition method which computes the

Article Highlights
• Dynamic response of a jacket type offshore platform in the Persian Gulf is investigated by using the random time domain analysis.
• In order to perform dynamic analysis, fifteen 1-hour storm, simulations for the water surface elevation are produced to capture the statistical properties of extreme sea condition.
• Results show that a realistic value for DAF is a noticeable value and can be extended to other platforms with similar dynamic characteristics of this region.

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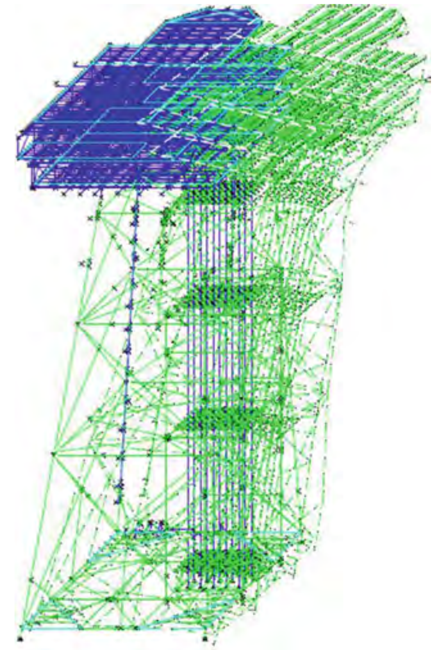
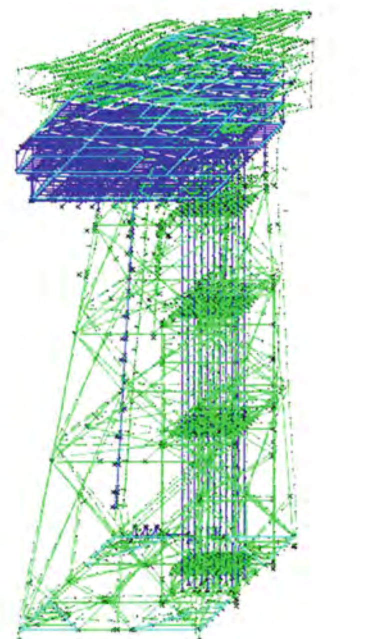
Fig. 1 Platform SACS model



(a) First mode shape



(b) Second mode shape

Fig. 2 Mode shapes. **a** First mode shape. **b** Second mode shape

response by the superposition the lower eigenvectors was presented by Lima et al. (1985). A simplified approximation method with the assumption of narrow-banded waves and using linear Gaussian waves for calculating the dynamic response of offshore structure to wave loading was developed by Chang and Tung (1990). Inertial load set and frequency domain method technique were used for evaluating extreme levels of global dynamic response of a jack-up platform by Greeves et al. (1996). Nonlinear time domain simulation was used to calculate the dynamic response of the jacket platform by Karunakaran et al. (1998). A novel approach for evaluating the extreme response statistics of a drag dominated offshore jacket platform based on Monte Carlo simulation was described by Naess et al. (2007). Azarhoushang and Nikraz (2010) used a procedure, known as pseudo-excitation method, to evaluate the dynamic response of an offshore jacket platform. Aarland (2014) investigated and used a different method to convert a wave spectrum into a surface elevation profile. The accuracy of these different methods of producing random sea simulations is investigated for different offshore structures with different natural periods. Abu Husain et al. (2016) used the Monte Carlo simulation technique to predict the extreme response of the fixed offshore structures by utilizing a simplified model of offshore platforms. A simplified method for evaluating the response of the jacket offshore platform with consideration of lumped mass model which provides a fast way for obtaining platform's response was discussed by Asgarian et al. (2004). Hafez et al. (2012) investigate

Table 1 Natural periods and frequencies for the first four modes

Mode	Period (s)	Frequency (Hz)
1	2.54	0.39
2	2.47	0.4
3	1.78	0.55
4	0.94	1.05

numerically the dynamic response of a jacket offshore structure, which is installed in South China, using both deterministic and spectral design wave approach. Baarholm et al. (2013) perform a time domain irregular wave simulation for a jacket platform located in the North Sea, which is installed in 190-m water depth to estimate the dynamic amplification factor.

The main objective of this paper is to perform a dynamic time domain analysis to investigate the dynamic behavior of the offshore jacket platforms in the Persian Gulf. For this purpose, one of the offshore jacket platforms in the Persian Gulf is selected and is modeled with SACS program. At first, modal analysis is performed for calculating the eigenvalues (natural periods) and eigenvectors (mode shape). Finally, the dynamic analysis in time domain is performed and the demanded outputs, including time histories of global base shear and global overturning moment, are derived and the results are discussed to the better application of the relevant design codes.

2 Modeling

For this study, a real four-legged jacket platform in the Persian Gulf is selected as a case study. A general configuration of jacket platform is displayed in Fig. 1. This jacket is located at 64 m water depth and is fixed to the ground by four through leg grouted piles. The dimensions between the legs at the working point elevation are 24 m × 13.7 m and overall size of the deck is approximately 32.5 m × 27.5 m. Appurtenances of jacket such as boat landing, conductors, risers, launch truss, barge bumper, and j tube are considered in modeling. The platform contains 15 conductors which are guarded by conductor guide. The topside is composed of the upper deck, upper mezzanine deck, lower mezzanine deck, lower deck, and a drain deck. The deck is modeled with all details.

To perform structural analysis, finite element program SACS (Structural Analysis Computer System) is selected.

Significant wave height for 100 year return period is 6.2 (m) with 11.1 (s) peak energy period for *X* and 4.8 (m) with

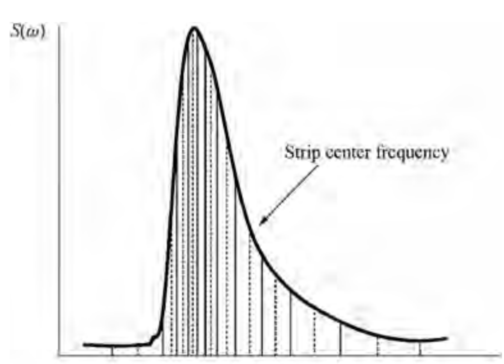


Fig. 3 Splitting the input spectrum into separate strips

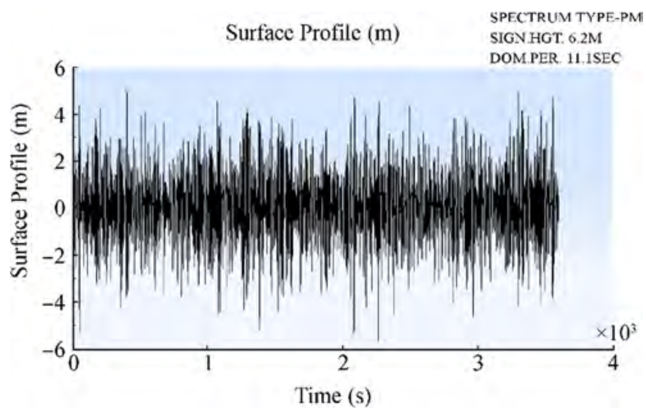


Fig. 4 Water surface elevation due to wave in *X* direction

9.8 (s) peak energy period for *Y* direction. These data are extracted from available site data documents.

3 Time History Dynamic Analysis

For an offshore platform, many different methods are recommended to perform the dynamic analysis. Time domain methods are the most comprehensive and acceptable methods for calculating the response of an offshore platform to random wave loading and also regarding the fact that frequency domain spectral analysis is limited to using linearized response behavior of the structure, so time domain simulation is selected to account for nonlinearities. A primary step for performing a dynamic analysis is the modal analysis to extract eigenvalues (natural periods) and eigenvectors (mode shape). In calculating the response of the structures with dynamic behavior and considering the random nature of wave loading, it is necessary to reflect the stochastic nature of the environmental loads. For this purpose, time histories of water surface elevation are produced from standardized wave spectrums and statistical properties of sea condition must be incorporated in this profile.

With using water surface elevations, the time histories of loads and subsequently the structural response are calculated. The results of a random time domain analysis are time series

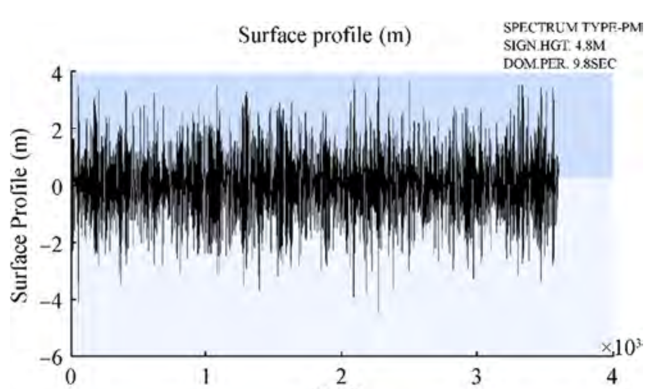


Fig. 5 Water surface elevation due to wave in *Y* direction

Table 2 Max wave height for each surface profile simulations

No. of simulation	*X* direction		*Y* direction	
	Max wave height (m)	Time (s)	Max wave height (m)	Time (s)
1	10.32	2265.25	8.36	2265.25
2	10.22	2262.25	8.26	2262.25
3	10.47	2263.50	8.28	2263.50
4	10.62	2264.50	8.39	2264.50
5	10.3	2265.50	8.29	2265.25
6	10.44	2085.00	8.16	2262.25
7	10.57	2263.50	8.31	2263.50
8	10.64	2264.50	8.37	2264.50
9	10.3	2265.50	8.17	2265.50
10	10.31	2262.50	8.14	2262.75
11	10.57	2263.50	8.26	2263.50
12	10.57	2264.75	8.33	2264.75
13	10.27	2085.00	8.13	52.00
14	10.3	2262.50	8.22	2262.75
15	10.59	2263.75	8.15	2263.75

responses which must be interpreted suitably to be a reliable representation of extreme values. The maximum response of a random procedure is itself a random variable which can be characterized by a probability distribution function. For the estimation of extreme levels of response, the concept of most probable maximum response is utilized which is the mode or the highest point in the probability distribution function.

In the following sections, random time domain analysis procedures for the specified jacket platform are explained and performed.

3.1 Modal Analysis

A primary step before performing any type of dynamic analyses is modal analysis to extract the dynamic characteristic such as natural periods and mode shapes. The analysis is performed through the DYNPAC module of SACS and the results for the first four natural periods and the first two mode shapes are presented in Table 1 and Fig. 2, respectively.

3.2 Simulation of Irregular Sea

In the present research, sea state realization process is simulated for 1-h storm with 15 different simulations to produce numerous random surface elevations.

In random time domain simulation, a specific wave spectrum is chosen and the water surface profile is generated based on this spectrum. An infinite number of simulations can be done with one single spectrum. Each simulation is represented as one realization of the spectrum and is considered one of an

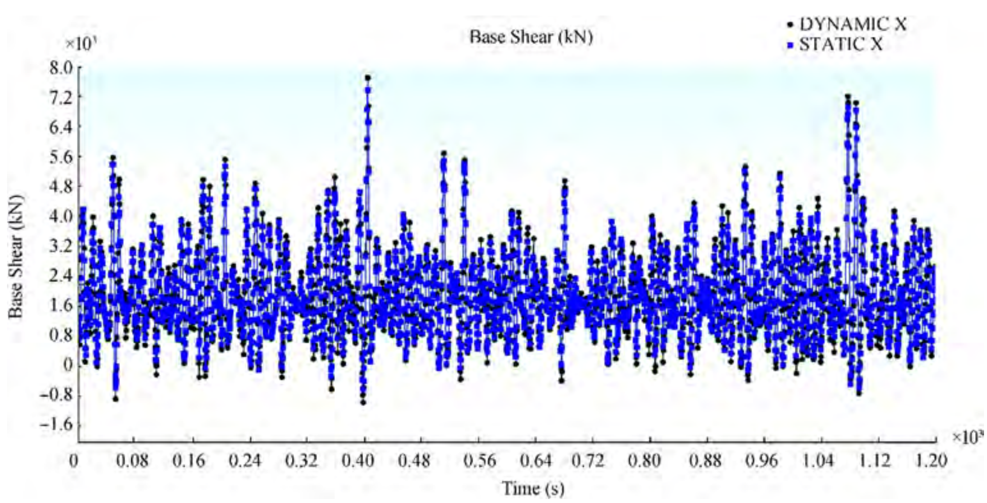


Fig. 6 Time history for base shear in *X* direction

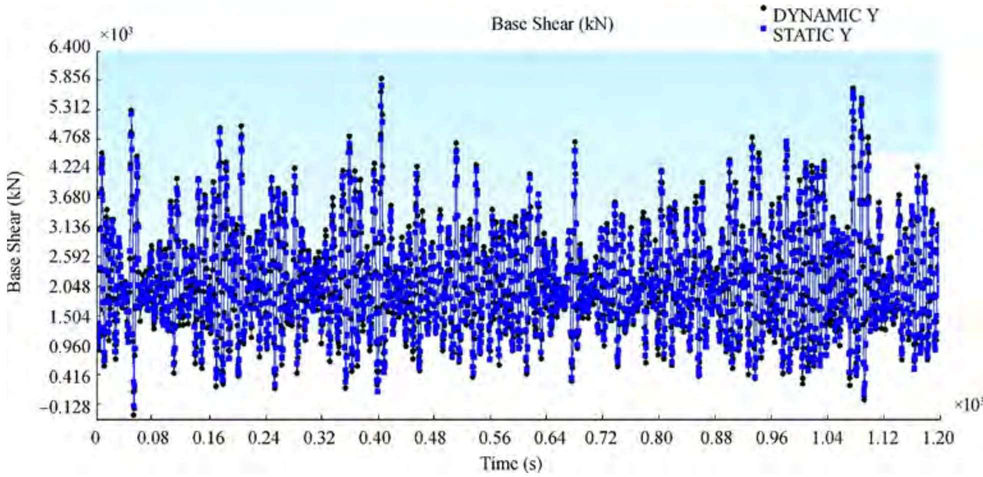


Fig. 7 Time history for base shear in *Y* direction

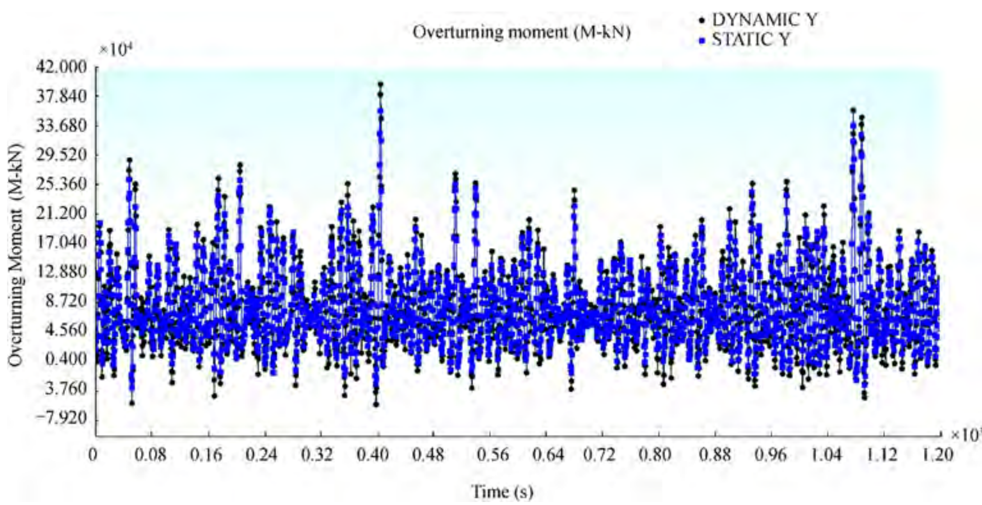


Fig. 8 Time history for overturning moment in *X* direction

infinite number of possible water surface profile which could result from a storm that caused the spectrum of interest (Dean and Dalrymple 1991).

A single realization of the spectrum produces only one of the infinite numbers of simulations. In order to acquire more statistical confidence in the results, it is necessary to perform

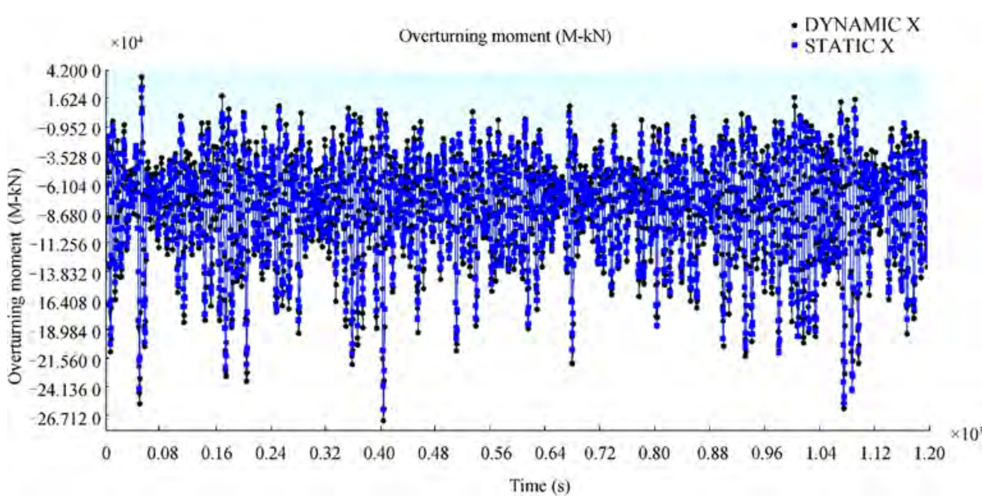


Fig. 9 Time history for overturning moment in *Y* direction

Table 3 DAF for base shear (BS)

Number of simulation	X direction				Y direction			
	Max dynamic BS (kN)	Max static BS (kN)	Time (s)	DAF	Max dynamic BS (kN)	Max static BS (kN)	Time (s)	DAF
1	7622	7417	403	1.027	6070	5805	2267	1.045
2	7929	7714	2264	1.027	6939	6619	2264	1.048
3	7912	7550	1387	1.047	6387	5948	2261	1.073
4	7770	7297	2085	1.064	6392	6009	2085	1.063
5	7905	7510	2263	1.052	6698	6644	2263	1.008
6	7359	6641	2086	1.108	6040	5789	2086	1.043
7	7942	7744	2265	1.025	6770	6442	2265	1.050
8	7984	7533	1387	1.059	6671	6473	2262	1.030
9	7488	6906	2085	1.084	6268	5802	2084	1.080
10	8017	7844	2264	1.022	6935	6680	2264	1.038
11	7764	7115	2086	1.09	6506	6115	2261	1.063
12	7665	7269	2267	1.054	6105	6049	2266	1.009
13	7954	7672	2263	1.036	6683	6668	2263	1.002
14	7084	7016	3301	1.009	6062	5799	1291	1.045
15	8126	7787	2266	1.043	6575	6306	2265	1.042

the simulation process for several, i.e., 10 to 20, sea state realization (Greeves et al. 1996).

Pierson-Moskowitz spectrum is considered in this research to characterize the sea elevation process. Its general form is formulated in Eq. (1).

$$s_\eta(\omega) = 0.0081\frac{g^2}{\omega^5}e^{-0.74\left(\frac{g}{V.\omega}\right)^4} \quad (1)$$

where g is the acceleration due to gravity and V is the wind speed at a height of 19.5 m above the still water level.

After determination of the wave spectrum, the spectrum is broken into airy wave components. SACS program uses Eq. (2) to produce the periods of the wave components.

$$T_n = \frac{T_D}{n}\sqrt{a^2+b^2} \qquad n = 1, 2, 3, \ldots, n_{\max} \quad (2)$$

Table 4 DAF for overturning moment (OTM)

Number of simulation	X direction				Y direction			
	Max dynamic OTM (kN)	Max static OTM (kN)	Time (s)	DAF	Max dynamic OTM (kN)	Max static OTM (kN)	Time (s)	DAF
1	372 535	341 868	3556	1.089	− 291 762	− 273 478	2267	1.066
2	412 838	398 755	2264	1.035	− 341 719	− 319 091	2264	1.070
3	391 288	366 003	1387	1.069	− 319 300	− 286 423	2261	1.114
4	401 824	367 112	2085	1.094	− 316 697	− 288 037	2085	1.099
5	417 205	387 990	2263	1.075	− 323 183	− 321 184	2263	1.006
6	383 424	329 342	2086	1.164	− 294 741	− 276 981	2086	1.064
7	409 663	396 081	2265	1.034	− 332 114	− 307 968	2265	1.078
8	405 340	358 502	2262	1.130	− 325 787	− 312 462	2262	1.042
9	393 239	350 744	2085	1.121	− 313 299	− 278 627	2084	1.124
10	413 475	401 477	2264	1.029	− 340 045	− 322 070	2264	1.055
11	406 578	358 171	2086	1.135	− 322 686	− 292 875	2261	1.101
12	396 557	368 175	2267	1.077	− 296 031	− 281 642	2266	1.051
13	413 065	392 009	2263	1.053	− 333 293	− 313 132	2263	1.064
14	357 560	329 951	2084	1.083	− 292 588	− 265 229	2260	1.103
15	423 010	398 683	2266	1.061	− 321 033	− 300 844	2265	1.067

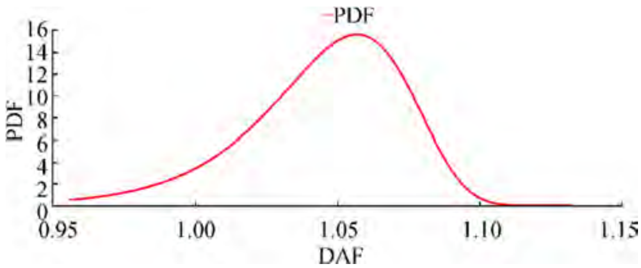


Fig. 10 Weibull fitted PDF for DAF for base shear in *X* direction

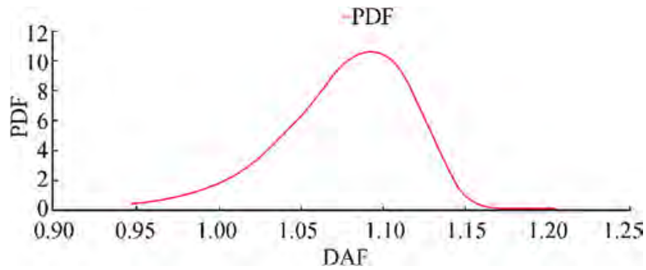


Fig. 12 Weibull fitted PDF for DAF for overturning moment in *X* direction

where T_n is the period of the n_{th} component, T_D is the analysis time duration (3600 s), and n_{max} is the last significant component, which is here 3599. So the first component has the period of 3600 s, the second is 1800 s, and the last one is approximately 1 s. Wave spectrum is partitioned into strips, in such a way each strip having a center frequency corresponding to each wave component (Fig. 3). So amplitude spectrum can be calculated based on this method and surface profile will be generated subsequently.

Input data related to spectrum, which are significant wave height and peak period, are given then the 15 1-h surface elevation simulations for each *X* and *Y* directions are produced. The first surface elevation simulation is presented in Figs. 4 and 5 for *X* and *Y* directions, and the maximum wave height and its associated occurring time are also given in Table 2.

4 Results and Discussions

After simulation of irregular sea and making surface elevations, time histories of the applied hydrodynamic loads can be obtained. Time histories of the structural response are achieved by using the numerical time domain integration of equation of motion by application of the time histories of the applying load. To this end, random wave module of SACS program is used and structural responses are calculated at each 0.5 s interval. For each direction (*X* and *Y*), fifteen graphs for base shear and the overturning moment are derived which each of them is related to one of the surface elevation simulations. Static response as well as dynamic response is calculated in each time step, which is shown in the graphs. Time history results for base shear and overturning moments are depicted in Figs. 6, 7, 8, and 9.

In order to calculate the dynamic amplification factor, maximum dynamic base shear and its associated static value are extracted from each simulation and the same procedure is done for overturning moment. These results are presented in Tables 3 and 4. For calculating the most probable maximum extreme value for DAF, its probability distribution function (PDF) is calculated. In order to interpret of data and calculating the most probable maximum extreme value for DAF, its derived PDF must be fitted to an extreme value distribution. By performing a comparison with extreme distributions, i.e., Weibull, Gumbel, and Fretchet, the Weibull distribution is best fitted and chosen as the extreme distribution function.

To calculate the most probable maximum extreme value, an extreme value distribution is needed to fit the data and Weibull distribution is chosen for this purpose. Weibull distribution is an extreme value distribution and is used to capture the variability of extreme events which might occur once during the return period. Weibull cumulative distribution function for the variable x is formulated in Eq. (3).

$$F(X;a,b) = 1-\exp\left[-\left(\frac{x}{a}\right)^b\right] \tag{3}$$

where a is the scale and b is the shape parameter which can be estimated by interpolation of existing data. By determining the scale and shape factor and drawing the distribution graph for concerning extreme variable, the most probable maximum extreme can be obtained. Weibull fitted to PDF graphs for base shear and overturning moment for both *X* and *Y*

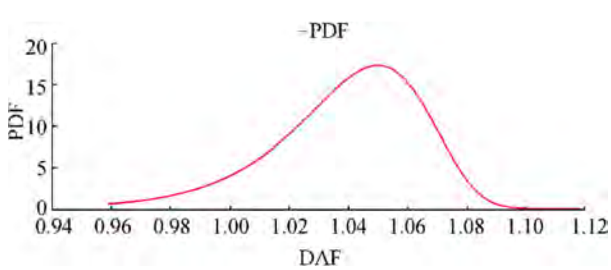


Fig. 11 Weibull fitted PDF for DAF for base shear in *Y* direction

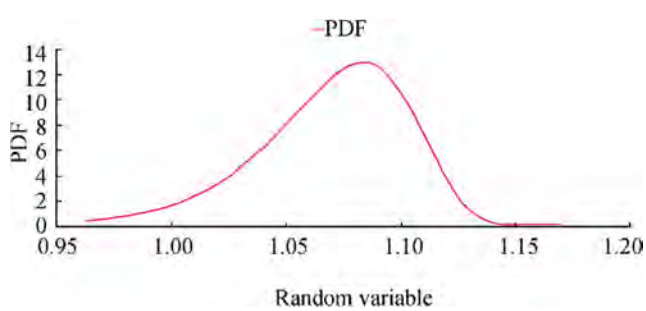


Fig. 13 Weibull fitted PDF for DAF for overturning moment in *Y* direction

Table 5 Most probable maximum extreme value of DAF

DAF	Base shear	Overturning moment
X	1.06	1.09
Y	1.05	1.08

directions are plotted in Figs. 10, 11, 12, and 13 and the most probable maximum value or mode is computed and presented at Table 5.

5 Conclusion

In this paper, dynamic response of the offshore structures is investigated by using the random time domain analysis. In this regard, a new constructed jacket platform in the Persian Gulf is selected. Fifteen, 1-h storm, simulations for the water surface elevation are produced to capture the statistical properties of extreme sea condition. Time series of base shear and overturning moment are derived from both dynamic and static responses. Twenty modes are considered for the analysis and random wave module of SACS program is used to calculate the structural responses at each 0.5 s interval. Dynamic amplification factors are extracted from all simulations. Then by fitting them to Weibull distribution function, the most probable maximum extreme value for DAF in extreme sea condition is computed.

Regarding the fact that API RP2A WSD does not recommend using DAF for structures with natural period less than three seconds, the results showed that the estimated DAF values are not ignorable and it is more realistic to incorporate this value in the static analysis. Results show that a realistic value for DAF for this specific platform is 1.06, which is a noticeable value and can be extended to other platforms with similar dynamic characteristics of this region.

References

Aarland Y (2014) Time-domain simulation of marine structures in irregular seas. MSc thesis. Norwegian University of Science and Technology

Abu Husain MK, Mohd Zaki NI, Johari MB, Najafian G (2016) Extreme response prediction for fixed offshore structures by Monte Carlo time simulation technique. 35th International Conference on Ocean, Offshore and Arctic Engineering, Busan, Korea. https://doi.org/10.1115/OMAE2016-54200

American Petroleum Institute (API) (2000) Recommended practice for planning, designing and constructing fixed offshore platforms-working stress design. 21st edn. In: API-RP-2A-WSD. Washington DC

Anagnostopoulos SA (1982) Dynamic response of offshore platforms to extreme waves including fluid-structure interaction. Eng Struct 4(3): 179–185. https://doi.org/10.1016/0141-0296(82)90007-4

Asgarian B, Mohebbinejad A, Soltani RH (2004) Simplified method to assess dynamic response of jacket type offshore platforms subjected to wave loading. 23rd International Conference on Offshore Mechanics and Arctic Engineering, 685–692. https://doi.org/10.1115/OMAE2004-51383

Azarhoushang A, Nikraz H (2010) Nonlinear water-structure interaction of fixed offshore platform in extreme storm. 20rd International Offshore and Polar Engineering Conference

Baarholm GS, Johansen A, Birknes J, Haver S (2013) Estimation of equivalent dynamic amplification factor (EDAF) on a jacket structure. 32nd International Conference on Ocean, Offshore and Arctic Engineering. https://doi.org/10.1115/OMAE2013-10085

Chang MT, Tung CC (1990) An approximate method for dynamic analysis of offshore structures to wave action. Eng Struct 12(2):120–123. https://doi.org/10.1016/0141-0296(90)90017-M

Dean RG, Dalrymple RA (1991) Water wave mechanics for engineers and scientists. World Scientific Publishing Co Pte Ltd, Singapore

Greeves EJ, Jukui BH, Sliggers PGF (1996) Evaluating jack-up dynamic response using frequency domain methods and the inertial load set technique. Mar Struct 9(1):101–128. https://doi.org/10.1016/0951-8339(95)00006-R

Hafez KA, Aboul-Fadl W, Leheta HW (2012) Comparative dynamic response analysis of a fixed offshore platform using deterministic and spectral wave approaches. 31st International Conference on Ocean, Offshore and Arctic Engineering, Rio de Janeiro, Brazil, 525–533. https://doi.org/10.1115/OMAE2012-83845

Karunakaran D, Baerheim M, Spidsore N (1998) Measure and simulated dynamic response of a jacket and a large jack-up platform in North Sea. Offshore Technology Conference, Houston, Texas. https://doi.org/10.4043/8827-MS

Lima ECP, Landau L, Ebecken NFF, Ellwanger GB, Federal U, De Janeiro R (1985) Nonlinear dynamic analysis of a jacket-type platform by Ritz mode superposition method. Offshore Technology Conference, Houston, Texas https://doi.org/10.4043/5030-MS

Naess A, Gaidai O, Haver S (2007) Efficient estimation of extreme response of drag-dominated offshore structures by Monte Carlo simulation. Ocean Eng 34(16):2188–2197. https://doi.org/10.1016/j.oceaneng.2007.03.006

Sadeghi K (2007) An overview of design, analysis, construction and installation of offshore petroleum platforms suitable for Cyprus oil / gas fields. J Soc Appl Sci 2(4):1–16