Dynamic Effects of Wave Loads in Analysis to Check Strength and Fatigue for Fixed Steel Jacket Structure

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Abstract. The problems of analyses to check strength (ULS) and fatigue (FLS) are two paramount in the steps of designing the structure of the Fixed Steel Jacket structure. Currently, based on the principle of dynamic effects of wave loads are evaluated when the natural period of the structure $-T_{max}$ closes to the period of wave, the current standards (API, DNV, ISO, ABS, PTS,…) base on the natural period of structure $-T_{max}$ that provisions allowing the analysis by the Quasi-Static method or the Dynamic method. This article analyses and performs evaluating the dynamic effects of wave loads through analyses the structure of the Fixed Steel Jacket structure by the Quasi-Static method and Dynamic method in Ultimate Limit State and Fatigue Limit State for the Vietnamese continental shelf condition.

Keywords: Dynamic effects · Jacket · Quasi-Static · Dynamic method

1 Introduction

In general dynamics, the dynamic effects of dynamic load is determined by the ratio of the dynamic response to the static response [1–3], as follows:

$$DAF = \frac{Dynamic\ response\ at\ level\ p}{Static\ response\ at\ level\ p} \quad (1)$$

where response at level p possible values is the displacement, moment, shear force, stress, UC,… when analyzing the structure by static method or dynamic method.

For jacket structures, it is possible to evaluate the dynamic effect of wave load through structural analysis in the quasi-static or dynamic method. The problems of analysis to check strength (ULS) and fatigue (FLS) are two paramount in the steps of designing the structure of the fixed steel template jacket platform. In this paper, the author will present the evaluation on the dynamic effect for strength and fatigue of steel fixed structure jackets in the quasi-static or dynamic method for the Vietnamese continental shelf condition.

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2 One Degree of Freedom and Dynamic Effect

The general equation of the one degree of freedom [4–7]:

$$M\ddot{u} + C\dot{u} + Ku = F(t) \tag{2}$$

where M, C and K are the mass, damping and stiffness for the structure; F(t) is the load; u = u(t) is the displacement of structure.

The dynamic effect of the one degree of freedom is evaluated based on the dynamic response determined from Eq. (2) compare to the static response as determined from the following Eq. (3):

$$Ku = F \tag{3}$$

From which defined to the dynamic effect of the one degree of freedom through dynamic application factor - DAF as follows:

$$DAF = \frac{1}{\sqrt{\left(1 - \Omega^2\right)^2 + \left(2\xi\Omega\right)^2}} \tag{4}$$

where $\Omega = \frac{\omega}{\omega_1}$, ω is the wave frequency, ω_1 is the first frequency of the structure; ξ is the structural damping; DAF is the dynamic amplification factors = $DAF_{Q\text{-}S}$ is the dynamic effect when analyses by the Quasi-Static method.

3 Multi Degree of Freedom and Dynamic Effect

The general equation of the multi degree of freedom [4–7]:

$$M\ddot{U} + C\dot{U} + KU = F(t) \tag{5}$$

where M, C, K are the mass, damping and stiffness matrices for the structure; F (t) is the load vector; U is the displacement vector of structure.

The dynamic effect of the multi degree of freedom is evaluated based on the dynamic response determined from Eq. (5) compare to the static response as determined from the following Eq. (6):

$$KU = F \tag{6}$$

From which defined to the dynamic effect of the multi degree of freedom through DAF_D (dynamic effect when analyses by the Dynamic method) as follows:

$$DAF_D = \frac{Maximum\ base\ shear\ in\ dynamic\ response}{Maximum\ base\ shear\ in\ static\ response} \tag{7}$$

4 Dynamic Effect for Check Fatigue

Conditions to check fatigue as follow [2, 8]:

$$D \leq [D] \tag{8}$$

where D is the fatigue damage at any time of exploitation; [D] is the allowable fatigue damage.

As shown in Eqs. (4) and (7), find: $\sigma_D = DAF_i\sigma = (DAF \vee DAF_D)\sigma$. Therefore, for each wave parameter (H_i, T_i, n_i), we can determine the fatigue damage as follows:

$$D_D = \frac{n}{N} = \frac{n}{a}S_D^m = \frac{n}{a}(S * DAF_i)^m = D(DAF_i)^m \tag{9}$$

where D_D is the fatigue damage for dynamic method; D is the fatigue damage for static method; n is the number of cycles for a given stress range i; N is the number of cycles before failure for the stress range i; a, m are dependent material parameters, determined based on SN-curve; $S = \Delta\sigma = (\sigma_{max} - \sigma_{min})$, see details at [2, 5, 8].

Therefore, dynamic effect for check fatigue (DAF_F) is defined as follows:

$$DAF_F = \frac{D_D}{D} = (DAF_i)^m = (DAF \vee DAF_D)^m \tag{10}$$

The above analysis that: the dynamic effects for check fatigue (DAF_F) and dynamic effects for check strength (DAF or DAF_D) are different.

5 Application for Practical Analysis

5.1 Input Data

We will analysis the jacket structure of Dong Do wellhead (Water depth = 64.9 m; Jacket weight = 1681 MT; Deck weight = 904 MT) in the Vietnamese continental shelf condition by Sacs software, the main input data are shown in Tables 1, 2 and Fig. 1.

Based on the [2, 5] and Sacs software [10], built schematic diagram for analysis jacket structure as follows (Figs. 2, 3):

Fig. 1. Model of Dong Do wellhead

Table 1. Wave conditions data for check strength [9]

As. Wave Directions From	Degree	Wave Parameters			
		H_{max} (m)	Tass (s)	H_s (m)	T_P (s)
One-year Return Period					
North	225	4.7	7.4	2.5	7.4
North-East	180	9.9	10.4	5.3	10.4
East	135	5.2	7.8	2.8	7.7
South-East	90	4.0	11.9	2.1	11.9
South	45	3.9	11.8	2.1	11.8
South-West	0	5.3	7.8	2.9	7.8
West	315	4.5	7.3	2.4	7.3
North-West	270	3.2	6.3	1.7	6.2
Omni Directional		9.9	10.4	5.3	10.4
One Hundred-year Return Period					
North	225	7.1	8.9	3.8	8.9
North-East	180	14.9	12.6	8.0	12.5
East	135	7.8	9.4	4.2	9.3
South-East	90	6.0	13.8	3.2	13.7
South	45	5.8	13.6	3.1	13.6
South-West	0	8.0	9.5	4.3	9.4
West	315	6.8	8.8	3.7	8.7
North-West	270	4.9	7.5	2.6	7.5
Omni Directional		14.9	12.6	8.0	12.5

Table 2. Value DAF and DAF_D for check fatigue

	Wave Period - T_i (s)															TOTAL
Wave height - $H_{i(m)}$	1.41	4.23	7.05	9.87	12.69	15.51	18.33	21.15	23.97	26.79	29.61	32.43	35.25	38.07	40.89	
13.875					2											2
13.875				4	14											18
13.125				16	14											30
12.375				26	35											61
11.625				51	73	4										128
10.875				128	154	17										299
10.125				248	253	35										536
9.375				458	453	76										987
8.625			4	1080	811	168	9									2072
7.875			20	2296	1462	279	14									4071
7.125			33	4430	2361	496	38									7358
6.375			233	9401	3758	878	93	7								14370
5.625			1075	17621	7007	1806	165	22		1						27697
4.875		55	6359	30805	12454	2571	254	16	2							52516
4.125		760	21350	49586	22417	3547	513	31	7							98211
3.375		542	62761	89090	33803	4621	685	66	13							191581
2.625		5394	185551	142843	44927	5023	594	49	7							384388
1.875		66818	501774	226962	49734	5752	789	28	3							851860
1.125		582153	1144851	308320	44789	7935	630	25	2							2088705
0.375	50630	1610646	981617	166819	14672	2334	892	315	67	31	10	7	2	1		2828043
TOTAL	50630	2266368	2905628	1050184	239193	35542	4676	559	101	32	10	7	2	1		6552933

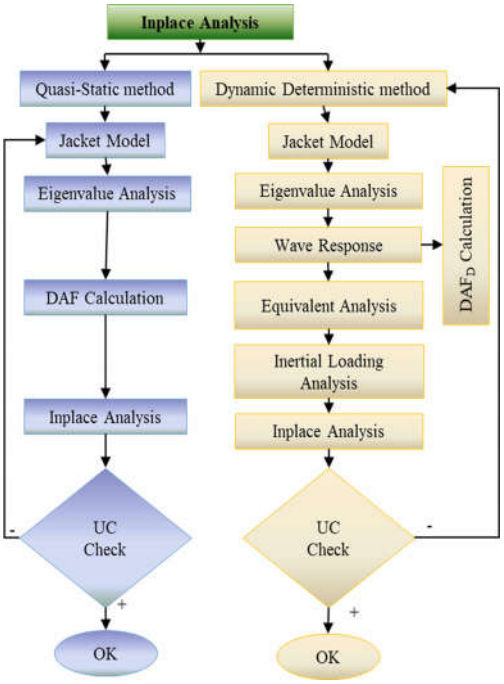

Fig. 2. Schematic diagram for analysis to check strength

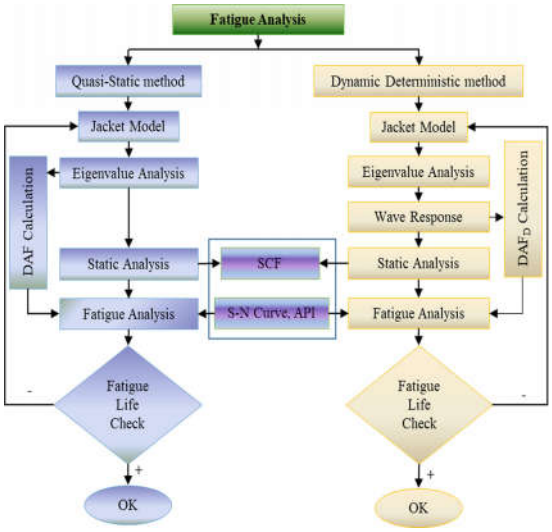

Fig. 3. Schematic diagram for analysis to check fatigue

5.2 Analysis Results

The outputs in this report will include: DAF, DAF$_D$, DAF$_F$ and Fatigue life. The details are shown in Tables 3, 4 and Figs. 4, 5 and 6 below.

a. **With wave conditions for check strength**

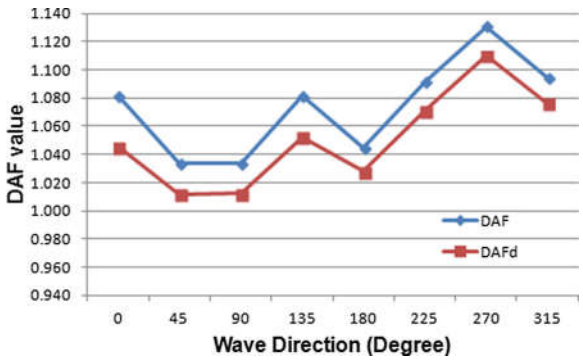

Fig. 4. Value DAF & DAF$_D$ Operating conditions

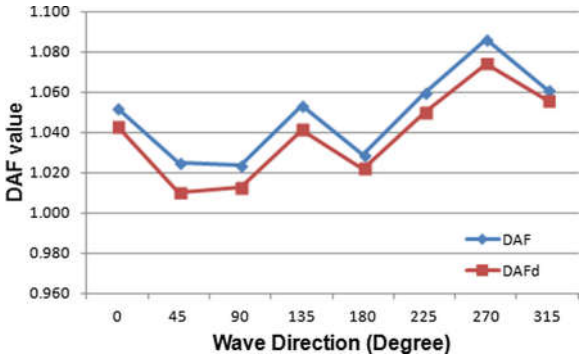

Fig. 5. Value DAF & DAF$_D$ Storm conditions

b. **With wave conditions for check fatigue**

Table 3. Value DAF and DAF_D for check fatigue

Direction	DAF (Average)	DAF_D (Average)
0	1.091	1.086
45	1.109	1.099
90	1.127	1.110
135	1.108	1.100
180	1.090	1.087
225	1.108	1.106
270	1.127	1.120
315	1.108	1.103

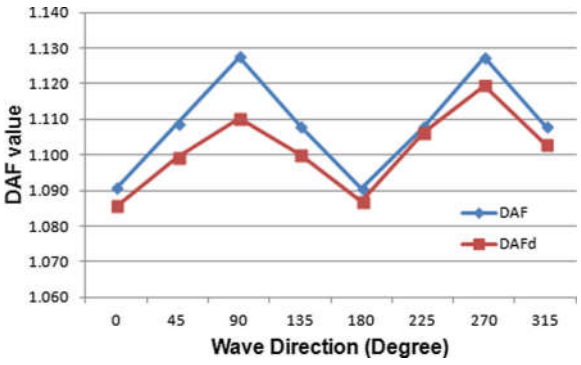

Fig. 6. Value DAF & DAF_D for check fatigue

Table 4. Fatigue life check and DAF_F (SN-curve according to the API [8], m = 3; [D] = 0.5)

Joint	Quasi-static (Q-S)		Dynamic		Quasi-static DAF = 1		DAF_F	
	Damage	Fatigue Life (year)	Damage	Fatigue Life (year)	Damage	Fatigue Life (year)	DAF_F (Q-S)	DAF_F (Dynamic)
L501	0.946	21	0.852	23	0.609	33	1.6	1.4
L503	0.683	29	0.609	33	0.438	46	1.6	1.4
L503	0.683	29	0.609	33	0.438	46	1.6	1.4
L504	0.463	43	0.419	48	0.300	67	1.5	1.4
L301	0.452	44	0.402	50	0.247	81	1.8	1.6
L304	0.417	48	0.372	54	0.230	87	1.8	1.6
L301	0.452	44	0.402	50	0.247	81	1.8	1.6
L501	0.946	21	0.852	23	0.609	33	1.6	1.4
L502	0.360	56	0.315	63	0.221	90	1.6	1.4
L304	0.417	48	0.372	54	0.230	87	1.8	1.6

6 Conclusion

Based on the above analysis and the example, we found that dynamic effects for quasi-static (DAF) and dynamics effects for dynamic method (DAF_D) are different. For Dong Do wellhead have water depth 64,9 m then DAF value is greater than DAF_D.

For the check fatigue, when evaluating the dynamic effect, it is necessary to evaluate through the fatigue damage because the conditions for analysis to check fatigue are small and short waves, DAF_F is much bigger than DAF and DAF_D.

In addition to previous studies by authors [11, 12], as well as studies by other authors,… authors will continue studying more fully the dynamic effects of the wave on the jacket structure with deeper sea water to give advice for practical analysis when applied to Vietnamese continental shelf condition.

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