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An estimation of total fatigue life of jack-up leg structures induced by wave loading

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ABSTRACT: Jack-up platforms operate in three conditions: Transit, Preloading and Operating. Fatigue life of the jack-up platforms in operating condition will be determined as similar as for offshore fixed steel structures. In Preloading condition, the fatigue damages are usually ignored. Up to now, the fatigue damages in transit condition have been calculated approximately by 20% of design life of jack-up platforms, the calculation method is usually accepted by Consultants and Register agencies.The article will present a method to estimate total fatigue life of jack-up leg structures induced by wave loading while considering fatigue damages in operating conditions and transit conditions.

1 INTRODUCTION

Jack-up structures include 3 main parts: Hull, legs and spudcans structures. In operating conditions (Figure 1a), the platform structures are working as the same as fixed offshore structures. In wet tow conditions (Figure 1b) the structures are working as the same as floating structures.

According to current standards, Safety conditions of jack-up legs structures are usually evaluated in ULS and FLS and considered in operating and transit cases. In ULS, jack-up structures assessments methods for operating and transit conditions are detailed in Det Norske Veritas (2012), American Bureau of Shipping (2014)… In FLS, the safety methods for operating conditions are detailed in Det Norske Veritas (2012), American Bureau of Shipping (2002). In Dinh Quang Cuong, Vu Dan Chinh (2019), authors clarified a method to evaluate fatigue life of the structures in transit conditions.

The article will present some ideas to estimate total fatigue life of jack-up leg structures induced by wave loading in combinations of operating conditions and transit conditions.

2 PREDICTION OF FATIGUE LIFE OF JACK-UP LEG STRUCTURES

2.1 *Operating conditions*

In operating duration, jack-up leg structures are impacted directly by wave loading of different environmental conditions and at different locations. So, in the life time, any point of the structures is always bear many stress groups Generally, a hotspot of a jack-up structure is assumed to resist m group of stresses ranges Si induced by short- term sea-states which specified by significant wave heights Hsi and number of cycles n_i ($i=1\div m$). Whereas, the stresses ranges are calculated by multiplication of nominal stresses and stress concentration factors (Barltrop, N. D. P., Adams, A. J, 1991). According to Palmgren-Miner rule (Barltrop, N. D. P., Adams, A. J, 1991), fatigue cumulative damage ratio of the hotspot is expressed by formula as below:

$$D = \sum_{i=1}^{m} \frac{n_i}{N} \tag{1}$$

Commonly, jack-up legs are made of high strength steels with yield limits large than 500MPa, so fatigue limit cycles N_i can be determined based on S_i (MPa) by the S-N curve in DnV RP-C203, (2005) as below:

$$LogN_i = 17.446 - 4.7LogS_i \tag{2}$$

Fatigue life of the hot spot can be determined by the formula (1), with a safety factor γ_f. The factor value depends on standards (API RP 2A, 2007, DnV RP-C203, 2005) .

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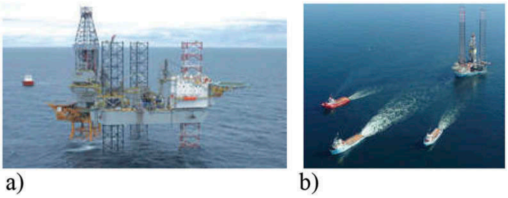
a) b)

Figure 1. Illustrations of Jack-up platform in operating and transit conditions.

$$T = \frac{1}{\gamma_f D} \tag{3}$$

As mentioned above, jack-up platforms must be worked in different locations with various water depths. To analyze fatigue damage in a whole life time, the structures should be simulated by corresponding models. According to basis theories, authors suggested a procedure of fatigue analysis of jack-up structures in operating conditions in the Figure 2 as below.

2.2 *Transit conditions*

Generally, fatigue analysis of jack-up legs structures in transit conditions are performed as the same as operating conditions. However, due to the legs were elevated so fatigue loading are not wave loading, but are inertia forces induced by wave during transit durations. Normaly, in many projects, default fatigue life of the structures in transit conditions are 20% of the design life. Besides, there are some references mentioned about how to calculate fatigue damage in the conditions (Lloyd's Register of Shipping, 1992, HSE 2003). In Dinh Quang Cuong, Vu Dan Chinh (2019), the authors proposed a procedure to estimate fatigue damages of the legs structures during transit. The general algorithm can be expressed in Figure 3.

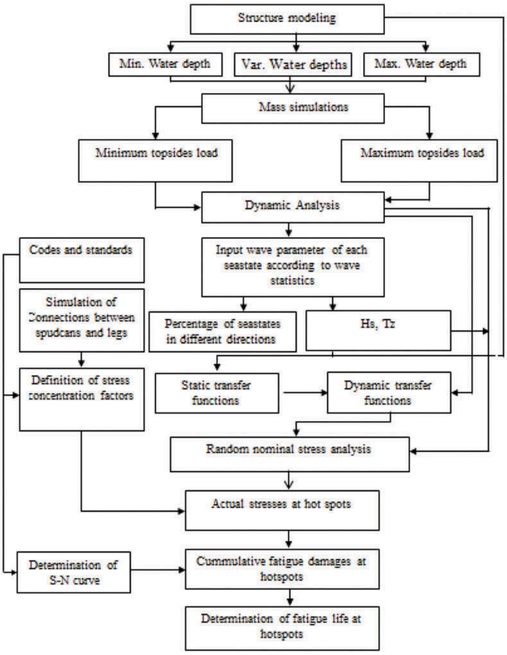

Figure 2. Procedure of Fatigue Analysis of Jack-up Structures in Operating Conditions.

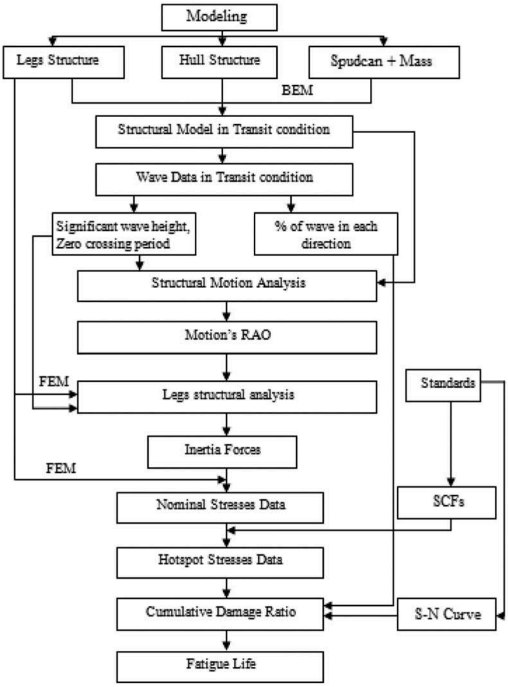

Figure 3. Procedure of Fatigue Analysis of Jack-up Structures in Transit Conditions.

Herein, $RAO(\omega)$ is Response Amplitude Operator of the structural response u(t). It is depended on masses of jack-up platforms, hydrostatic stiffness matrixes, dampings (Newman, J.N., 1980). The results of finite element analysis will be used to determine the stress spectrums $S_{\sigma\sigma}(\omega)$ at hotspot of the structures including stress concentration factors (American Bureau of Shipping, 2002).

3 ESTIMATION OF TOTAL FATIGUE LIFE OF JACK-UP LEG STRUCTURES

To call fatigue cumulative damage of a hotspot of jack-up leg structures in operating conditions and transit conditions in a year are D_{op} and D_{ts}, respectly. The damage in operating duration with n of different water depths can be expressed by the formula as below:

$$D_{op} = \sum_{i=1}^{n} \alpha_i D_{opi} \tag{4}$$

And the total damage of the hotspot, D_{tot}, is calculated:

$$D_{tot} = D_{op} + \beta D_{ts} \tag{5}$$

Whereas, α_i is fraction of fatigue life at i^{th} water depth condition ($i=1 \div n$) and β is average fraction of fatigue life of transit condition in a year. Due to the damages are independence and to have a linear relationship, so with safety factor is equal 1, α_i and β are satisfied the equation:

$$\sum_{i=1}^{n} \alpha_i + \beta = 1 \tag{6}$$

The total fatigue life of the hotspot in a year can be calculated as:

$$T_{tot} = \frac{1}{D_{tot}} = \frac{1}{D_{op} + \beta D_{ts}} = \frac{1}{\sum_{i=1}^{n} \alpha_i D_{opi} + \beta D_{ts}} \tag{7}$$

The suggested formulas will be used to estimate total fatigue life of a jack-up leg structures in Vietnamese conditions as below.

4 A VIETNAMESE CASE STUDY

In the case study, we perform fatigue analysis of jack-up platform Tam Dao 05 which is operating in Thien Ung field. Input data are summarized in section 4.1 as below.

4.1 *Input data*

Structural Data

Fatigue Wave Data

Statistic wave data for fatigue analysis in operating conditions:

Wave scattering diagram is follow report "Metocean criteria and statistics 8 to 9°N, 107 to 109°E, Offshore South Vietnam. V1.0 for the Thien Ung Project Feed Design" .(Vietsovpetro J.V, 2010).

The distribution of wave in accordance to the directions is given below (Table 2, Figure 4):

In transit conditions, wave data for all directions can be assumed:

+ Wave height: H = 3m

+ Period: T = 6s

Table 1. Summary of structural data.

Main parameters	Values
Water depth (m)	122
Length of Legs (m)	167
Hull dimensions (LxBxD), (m)	70.4 x 76.0 x 9.4
Distance between legs (vertical x horizontal), (m)	47.6 x 45.7
Total live load of hull in operating condition (mton)	3766
Weight of hull in operation (ton)	8500
Weight of Spudcan (ton)	1082.56
Total tonnage, cargo and ballast in transit condition (ton)	24642
Trasit Draft (m)	7.320

Table 2. Fatigue wave scatter.

Wave Direction (from)	Percentage distribution (%)
North	0.45
Northeast	44.53
East	9.28
Southeast	0.95
South	1.79
Southwest	29.21
West	13.35
Northwest	0.43

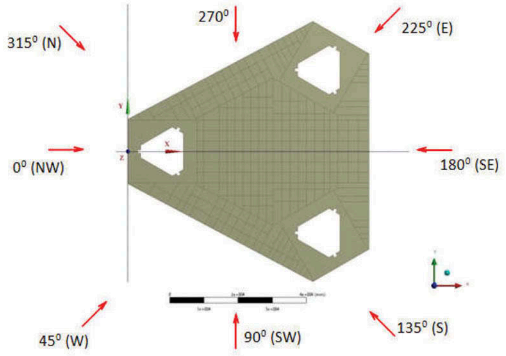

Figure 4. Illustration of wave scatter.

4.2 *Modeling*

TD-05 jack-up platform structure for legs fatigue analysis can be modeled by SACS software, includes: Mass, Hull and Legs models. There are two models corresponding to operating conditions (Figure 5) and transit conditions (Figure 6). In operating conditions, hull structures are modeled by an equivalent system with equivalent stiffness according to Det Norske Veritas (2012). The structure is

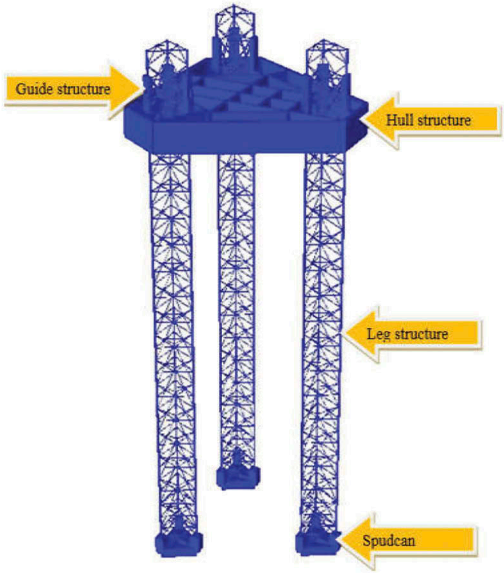

Figure 5. Jack-up structure model in operating conditions.

analyzed by Finite Element Method. In transit conditions, hull structures are modeled by an absolutely stiffness body with similar geometry to analyze the interaction between waves and large bodies. The structural motions are determined by Boundary Element Method. Then the motions are used as input data to analyze jack-up leg structures by Finite Element Method.

4.3 *Fatigue analysis and results*

Fatigue damage of the structural hotspots are analyzed by SACS software. In operating condition, wave data is given in section 4.1 with Pierson Moskowitz Spectrum. Joints with the most damages are shown in Figure 7. Typical hotspot stress spectrum and maximum damage of joint 0283 of member 0275-0283 is presented in Figure 8.

In transit condition, wave data is given in section 4.1 as above with Pierson Moskowitz Spectrum. Joints with the most damages are shown in Figure 9. Typical hotspot stress spectrum and maximum damage of joint 1009 of member 1009-1031 is presented in Figure 10.

Herein, we will choose 6 typical joints to analyze total fatigue life: 3 joints with maximum damages in operating condition and 3 joints with maximum damages in transit condition fatigue life. The results are listed in Table 2, 3 as below.

4.4 *Total fatigue life estimation*

Total fatigue lifes of above hotspots of the leg structures will be determined depended on different fraction factor scenarios in 5 cases as below.

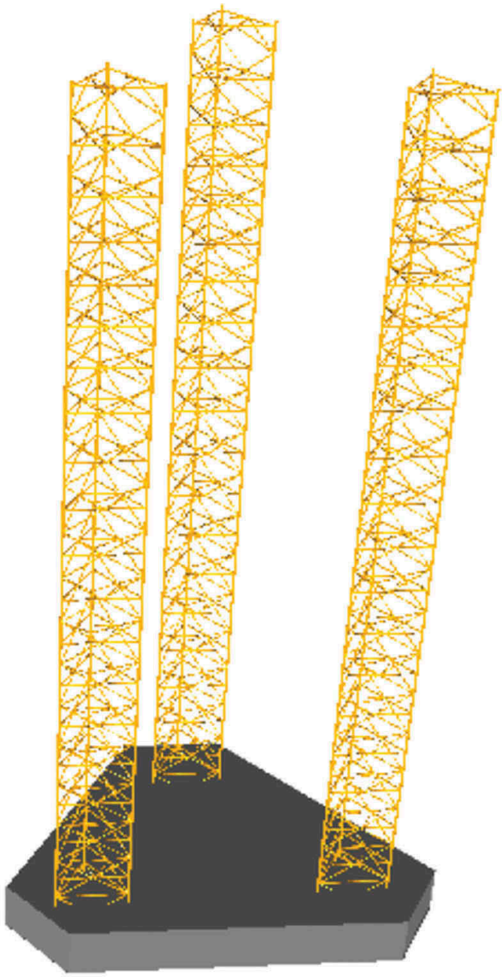

Figure 6. Jack-up structure model in transit conditions.

Case 1: Fraction of fatigue life in a year for operating conditions at 100m, 107m, 122m of water depth and in transit condition are 0.25, 0.25, 0.3 and 0.2, respectively.

Case 2: Fraction of fatigue life in a year for operating conditions at 100m, 107m, 122m of water depth and in transit condition are 0.8, 0.0, 0.0 and 0.2, respectively.

Case 3: Fraction of fatigue life in a year for operating conditions at 100m, 107m, 122m of water depth and in transit condition are 0.0, 0.8, 0.0 and 0.2, respectively.

Case 4: Fraction of fatigue life in a year for operating conditions at 100m, 107m, 122m of water depth and in transit condition are 0.0, 0.0, 0.8 and 0.2, respectively.

Case 5: Fraction of fatigue life in a year for operating conditions at 100m, 107m, 122m of water depth and in transit condition are 0.2, 0.2, 0.3 and 0.3, respectively.

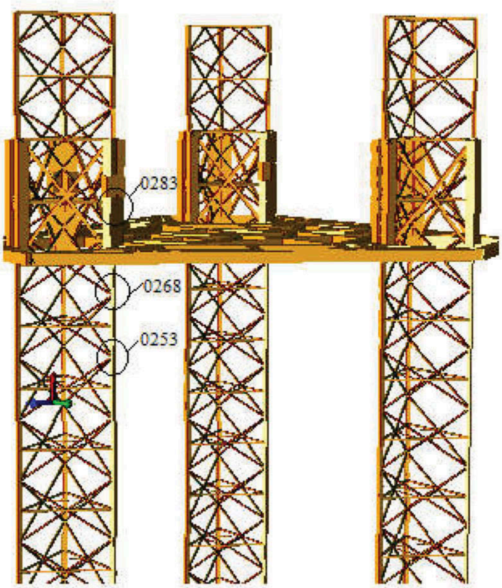

Figure 7. Location of joints with maximum fatigue damages in Operating conditions.

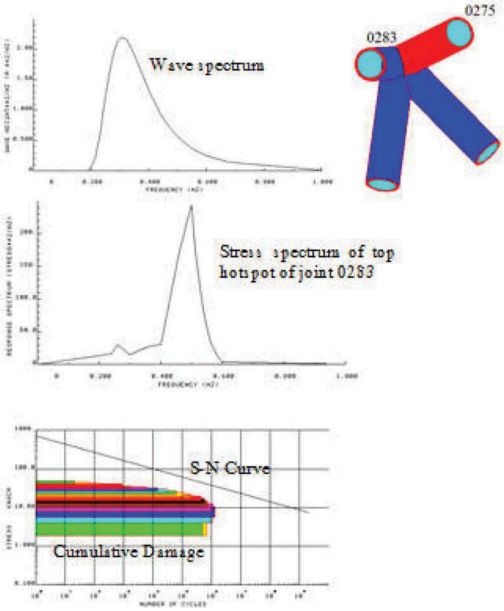

Figure 8. Fatigue damages results of a typical joints in Operating conditions.

4.5 *Recomendations*

Based on the analysis results, we draw diagrams to expression the variation of fatigue life of joints in each case (Figure 11) and the variation of fatigue life of each joint in 5 cases (Figure 12).

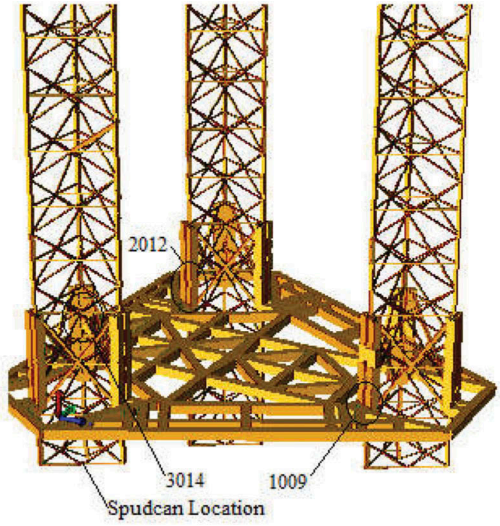

Figure 9. Location of joints with maximum fatigue damages in Transit conditions.

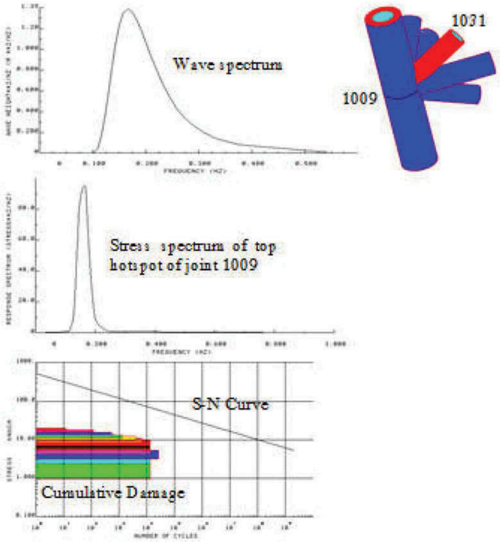

Figure 10. Fatigue damages results of a typical joints in Transit conditions.

According to results in tables and Figure 11, 12, there are some recomendations:

- Fatigue damages are almost maximum at connecting joints between legs and guides;
- Joints 0283, 0268, 0253 are almost not affected by fatigue in transit conditions. It can be explained that in the conditions, they are on the top level of the legs, so internal forces are small. Whereas, fatigue damages of joints below such as 1009, 3014, 2012 in transit conditions are significants.

Table 3. Summary of fatigue damages of typical joints in operating condition per year.

Joint	Member	Location in section	Damage (100m of W.D)	Damage (107m of W.D)	Damage (122m of W.D)
0283	0275-0283	Top point	0.031	0.032	0.051
0268	0260-0268	Top point	0.026	0.028	0.050
0253	0245-0253	Top point	0.024	0.027	0.048
1009	1009-1031	Top point	0.009	0.01	0.014
3014	3014-3025	Top point	0.0006	0.0007	0.0007
2012	2012-2026	Top point	0.001	0.0015	0.0016

Table 4. Summary of fatigue damages of the structure in transit condition per year.

Joint	Member	Location in section	Damage
1009	1009-1031	Top point	0.028
3014	3014-3025	Top point	0.0266
2012	2012-2026	Top point	0.024
0283	0275-0283	Top point	Infinitive
0268	0260-0268	Top point	Infinitive
0253	0245-0253	Top point	Infinive

Table 5. Summary of fatigue life of the structure in transit condition.

Joint	Member	Location in section	Average Damage per year	Total Fatigue Life	Design Life
0283	0275-0283	Top point	0.031	32.52	25
0268	0260-0268	Top point	0.029	35.09	25
0253	0245-0253	Top point	0.027	36.83	25
1009	1009-1031	Top point	0.015	68.73	25
3014	3014-3025	Top point	0.006	168.49	25
2012	2012-2026	Top point	0.006	169.35	25

Table 6. Summary of fatigue life of the structure in transit condition.

Joint	Member	Location in section	Average Damage per year	Total Fatigue Life	Design Life
0283	0275-0283	Top point	0.0248	40.32	25
0268	0260-0268	Top point	0.0224	44.64	25
0253	0245-0253	Top point	0.0216	46.30	25
1009	1009-1031	Top point	0.0136	73.53	25
3014	3014-3025	Top point	0.0060	167.79	25
2012	2012-2026	Top point	0.0060	166.67	25

Table 7. Summary of fatigue life of the structure in transit condition.

Joint	Member	Location in section	Average Damage per year	Total Fatigue Life	Design Life
0283	0275-0283	Top point	0.0256	39.06	25
0268	0260-0268	Top point	0.0208	48.08	25
0253	0245-0253	Top point	0.0192	52.08	25
1009	1009-1031	Top point	0.0128	78.13	25
3014	3014-3025	Top point	0.0059	170.07	25
2012	2012-2026	Top point	0.0056	178.57	25

Table 8. Summary of fatigue life of the structure in transit condition.

Joint	Member	Location in section	Average Damage per year	Total Fatigue Life	Design Life
0283	0275-0283	Top point	0.0400	25.00	25
0268	0260-0268	Top point	0.0400	25.00	25
0253	0245-0253	Top point	0.0384	26.04	25
1009	1009-1031	Top point	0.0168	59.52	25
3014	3014-3025	Top point	0.0060	167.79	25
2012	2012-2026	Top point	0.0061	164.47	25

Table 9. Summary of fatigue life of the structure in transit condition.

Joint	Member	Location in section	Average Damage per year	Total Fatigue Life	Design Life
0283	0275-0283	Top point	0.0276	36.23	25
0268	0260-0268	Top point	0.0258	38.76	25
0253	0245-0253	Top point	0.0246	40.65	25
1009	1009-1031	Top point	0.0164	60.98	25
3014	3014-3025	Top point	0.0086	116.69	25
2012	2012-2026	Top point	0.0082	122.25	25

– In operating duration, jack-up platforms may be worked in some areas with different water depths, so total fatigue damages are depended on locations and percentage of exploitation at each location. The fatigue damages tend to increase accordingly water depths.

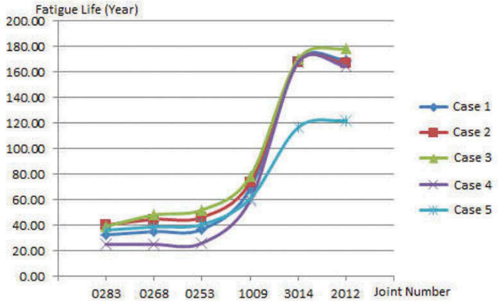

Figure 11. Total fatigue life chart of considered joints.

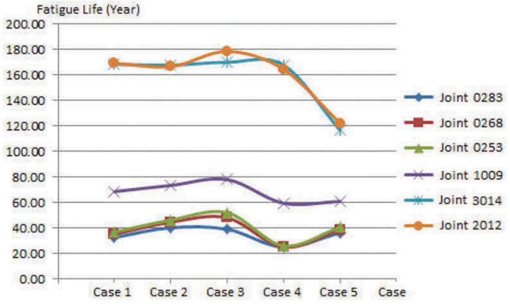

Figure 12. Total fatigue life chart of considered joints in 5 cases.

5 CONCLUSIONS

There are some conclusions as below:

- Fatigue damages of jack-up structural legs in transit conditions are significant and depended on environmental conditions in the moving area. So the use of 20% of total life for fatigue life in transit condition is only a reference value in design.
- The fatigue damages in operating conditions and transit conditions usually change in opposite directions along leg structures. So it is necessary to calculate total fatigue damages at every hotspots of the structures in total of operating and transit durations. Based on the calculation results, the hotspot with maximum damage will be found.
- The fraction factors of different working conditions in formulas (1), (2) and (3) have a significant influence to total fatigue life of jack-up legs structures. So it is necessary to study about the sensitivity of them to make the best operating plans for jack-up platforms in their life in the next time.
- However, due to jack-up leg strusctures can be elevated, the results of total fatigue damages analysis can be used to make plans to survey and repair at annual maintainance stages.
- The paper will be used as a reference and a guide for designs or assessments of jack-up legs structures in Vietnam in the future.

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