Fatigue Analysis of Jack-up Leg Structures in Transit condition

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Abstract. In transit condition, jack-up platform is a type of floating structures with large dimension. In towing duration, legs of the self-elevating unit are elevated, so they do not directly subject to wave and current loads but only resist inertia loads due to motion induced wave and other loads. Actually, fatigue damages of the jack-up legs structure in transit condition have not been studied clearly yet. However, Registers and Consultancy have been used 20% of total fatigue life for transit life time in the analyses and designs [1]. The percentage is approximately value, which has not accurately reflected the fatigue life in transit condition. To have the more accurately results, it is necessary to solve two important problems which are motions analysis and determination of inertia forces on the legs structure induced by the motions. These problems will be made clearly in the article and applied for 400ft jack-up platform fabricated in Viet Nam.

Keywords: Jack-up structures; Transit condition; Fatigue analysis.

1 Introduction

In transit condition, Jack-up platforms can be towed by ships (Wet tow) or be carried by barge (Dry Tow). Although only moving in a short time and in a mild sea-state, but they still have cumulative damages induced by fatigue which has effects on the total design life. Nowadays, the problems are mentioned in some researches and standards [2], [3]. The article aims to clarify basic aspects of fatigue analysis of jack-up leg structures in transit condition and its applications for Vietnamese conditions.

2 Determination of Hotspot Stresses of Jack-up Leg Structures

2.1 Wave loads and inertial forces

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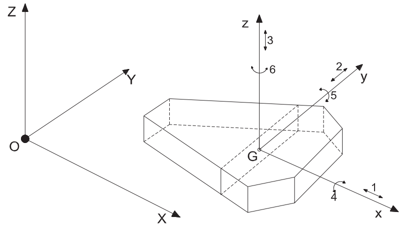
Floating structural motion components (Fig. 1)



Translations	**Rotations**
1. Surge (along X)	4. Roll (about X)
2. Sway (along Y)	5. Pitch (about Y)
3. Heave (along Z)	6. Yaw (about Z)

Fig. 1. Definition of Axis Systems and Floating Rigid Motions

The equation of motion

$$(M + A)\ddot{U} + C\dot{U} + K_{hys}U = F(t) \tag{1}$$

where: M is structural mass matrix in global axis; A is added mass matrix determined from radiation wave potential on the mean wetted body surface of hull; Damping matrix C is determined from radiation wave potential; Hydrostatic Stiffness Matrix K_{hys} is determined from hydrostatic pressure effect on wet surface of hull [4]; $\dot{U}, \ddot{U}$: vectors of motion velocities and accelerations; F(t): the vector of wave loads based on incident wave potentials and diffraction wave potentials.

Inertial force

Motions at center of gravity of a jack-up platform are determined from (1) induces inertial forces at i^{th} mass point of the structure. The forces [5] include components of inertial in translations, centrifugal inertial and tangential inertial forces.

2.2 Hotspot stresses determination

Assuming that incident waves are stationary random processes specified by spectrum density functions $S_{\eta\eta}(\omega)$, the response spectrums of the structures in equation (1) can be expressed in formula as below:

$$S_{uu}(\omega) = RAO(\omega)^2.S_{\eta\eta}(\omega) \tag{2}$$

where $RAO(\omega)$ is Response Amplitude Operator of the structural response u(t).
According to [5], based on $S_{uu}(\omega)$, the inertial force spectrums at mass m_i can be determined depending on response accelerations of the structural central of gravity, roll and pitch angles, distances from m_i to the central of gravity. The structures will be analyzed by finite element method, the stress spectrums $S_{\sigma\sigma}(\omega)$ are determined at hotspot of the structures including stress concentration factors [6]. Finally, the stress ranges and number of cycles are determined by formula in [7]. Actually, joints of jack-up legs are complicated, so the hotspot stress concentration factors (SCF) are commonly determined by analysis of local FE models [5], [6].

3 Fatigue Analysis of Jack-up Leg Structures in Transit Conditions

Assuming a hotspot of a jack-up structure resist m group of stresses ranges S_i with number of cycles n_i. According to Palmgren-Miner rule [6], [7], fatigue cumulative damage ratio of the hotspot is expressed by formula as below:

$$D = \sum_{i=1}^{m} \frac{n_i}{N_i} \tag{3}$$

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 [8] as below:

$$Log\ N_i = 17.446 - 4.7 Log S_i$$

(4)

Fatigue life of the hot spot can be determined by the formula (5), with a safety factor γ_f. The factor value depends on standards [5], [6].

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

(5)

This article establishes the general algorithm for fatigue analysis of Jack-up legs structures in transit condition in Fig. 2.

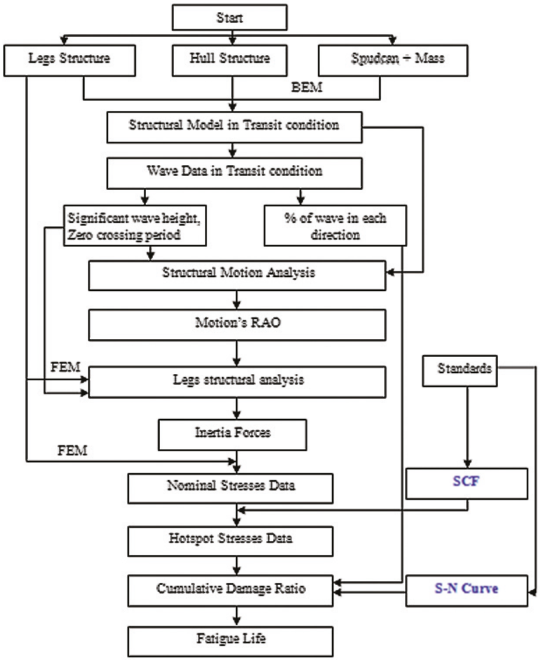


Fig. 2. Fatigue analysis algorithm for jack-up leg structures in transit condition

4 A Vietnamese Case Study

In this article, Tam Dao 05 Jack-up platform [9] is considered to analyze fatigue of the leg structures in transit condition, using SACS software version 5.6.

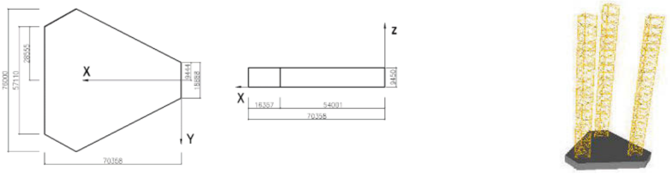
4.1 Input data

Table 1. Input data [9]

Parameters of structure	Material Properties	Loading condition
- Length of hull: 70,4 m - Width of hull: 76 m - Height of hull: 9,5 m - Draft: 7320 mm - Total tonnage, cargo and ballast: 24642 tons	- Young's Modulus: $E = 20000\ kN/cm^2$ - Yield strength: $Fy = 54,5\ kN/cm^2$ - Density of steel $\gamma = 7,85\ T/m^3$	- Platform weights are given in Weight Control Report of Ju-2000E version; - Environment data for all directions in transit condition: + Wave height: H = 3m + Period: T = 6s

4.2 Models

SACS model of TD-05 jack-up platform structure for legs fatigue analysis includes: Mass, Hull and Legs models. Fatigue loading will be calculated based on wave data in transit conditions (Fig. 3).



a) Equivalent hull model b) Jack up structural model

Fig. 3. Jack-up structural model in transit condition

4.3 Results

Motion's RAO: Motion's RAO of the structure are determined in 8 directions corresponding to wave directions in transit condition. The typical RAOs corresponding to 45^{o} wave direction are expressed in Fig. 4.

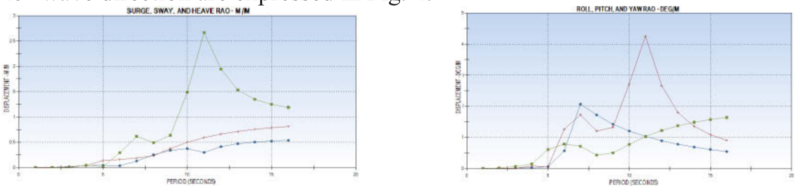


Fig. 4. Motion's RAO of TD-05 Platform corresponding to 45^{o} wave direction

Joint SCF Calculation

SCFs of joints of the leg structures can be determined based on Local finite element models using Ansys version 17 (Fig. 5). The maximum SCF corresponding to axial force, in-plane bending and out-plane bending are **2.55**, **2.43** and **2.33**, respectively.

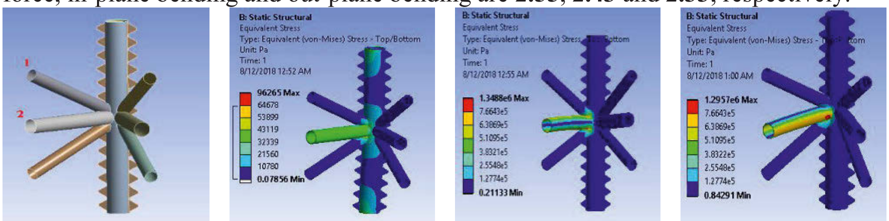


Fig. 5. Joint modeling and the local stresses due to axial force, in-plane bending moment, out-plane bending moment of a brace

Stresses Spectrum and Fatigue Cumulative Damage

In transit condition, wave data is given in table 1 with Pierson Moskowitz Spectrum. Fatigue damage of the structural hotspots are analyzed by SACS software. The maximum damage of joint 1009 of member 1009-1031 is presented in Fig. 6 as below.

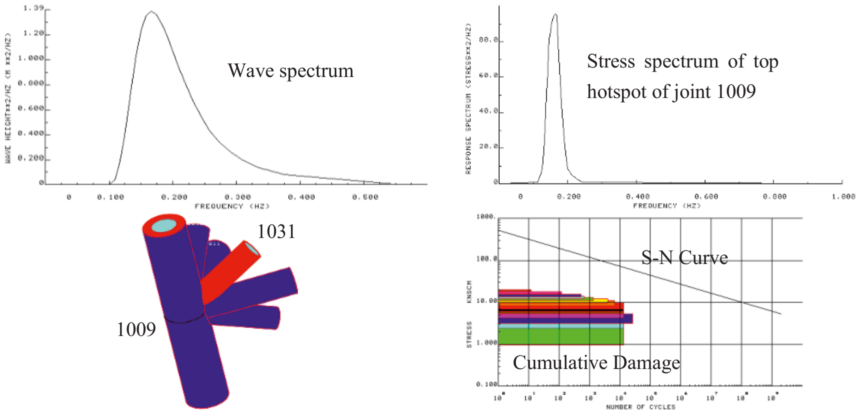


Fig. 6. Stress Spectrum and Fatigue Cumulative Damage Results of joint 1009

Fatigue Life Results in transit condition

Three joints with minimum fatigue life are listed in Table 2. As the results, there are some comments:

- The jack-up structure is safe in transit conditions. However, the damages have a certain influence of the total life of the jack-up structure.
- The fatigue damages per year are significant, but they are limited by short moving duration of jack-up platforms.
- The wave data in Table 1 are only used for fatigue analysis corresponding to field transit condition. In case of ocean transit condition, the fatigue damages will be larger because of the effects of larger wave heights.
- The maximum damages are usually occurred for joints at contiguous locations between jack-up legs and hull. So in the operation condition, fatigue may be happened at high levels. Otherwise, in the transit condition, it may be happened at lower levels because the legs are elevated. So the total fatigue life of the jack-up structure has to be evaluated from the combination of operating condition and transit condition.

Table 2. Summary of fatigue life of the structure in transit condition

Joint	Member	Location in section	Damage per year	TransitFatigue Life	Design Life for transit condition
1009	Brace 1009-1031	Top point	0.028	35.48	5
3014	Brace 3014-3025	Top point	0.0266	37.57	5
2012	Brace 2012-2026	Top point	0.024	41.23	5

5 Conclusions

Based on the research results of the article, there are some discussions as below:

Using 20% of total life for fatigue life in transit condition is only a reference value in design. It is necessary to analyze fatigue damage of existing jack-up structures in transit conditions in case of structural re-use assessment or life extension assessment.

At the present, there are only recommendations in current standards about effects of fatigue of the jack-up platforms in transit condition [2], [3] but there are no detailed guidelines and procedures to evaluate the fatigue damages.

The article establishes the algorithm to analyze fatigue of Jack-up leg structures in transit conditions based on the combination of calculation theories of floating body motions, global and local structural analysis, random fatigue analysis…which are published in standards and textbooks and professional software. The algorithm is the main result of the article. It has been successfully applied for Tam Dao 05 Jack-up platform. It is one of products of national research project No.SPQG02b.01-01 which performed by research team of ICOFFSHORE and verified by Technip FMC Vietnam.

In the next time, the authors will publish a method to assess total fatigue life of jack-up leg structures in combination of operating and transit conditions.

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