



Global Analysis for Jack-Up Rig 400 ft in Transit Condition

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Abstract. In transit condition, Jack-up rig is a type of floating marine structure with large dimensions. The current standards have just regulated calculating in the equivalent models according to the Finite Element Method (FEM), without consideration of structure's simultaneous work as in the overall model. Wave loads included diffracted, radiated wave loads acting on large-sized Jack-up Rig in the transit condition are usually determined by the Boundary Element Method (BEM).

This article indicates general algorithm combining FEM and BEM so as to compute overall Jack-up Rig in the transit condition and apply specifically for a Jack-up Rig be erecting in Vietnamese sea condition.

Keywords: Jack-up rig · Global analysis · Transit condition

1 Introduction

– Jack-up rig 400 ft (Fig. 1) is designed to capable to accommodate 140 people, carry 2,995 tons of goods on average and 6,488 tons at maximum, and have the tonnage of 18,000 tons. Specifications of Jack-up rig 400 ft as:

- Jack-up rig 400ft, capable of operating at a depth of 120 m or 400 ft below water, and is designed with maximum length leg is 167 m including spud can;
- Jack-up rig 400 ft will be able to drill at a depth of 9,000 m or 30,000 ft;
- In operating condition, jack-up rig 400 ft will be able to operate with wind storm up to level 12 and wave height is 22 m corresponding to water depth is 100 m;



Fig. 1. Jack-up rig 400 ft in transit condition

- Jack-up rig can not self-propelled, there are two methods to transit including Wet Tow and dry tow [1];
- Nowadays, the standards to calculate of jack-up rig in transit condition [2, 3] (wet tow, Fig. 2) haven't considered to global model, but only used equivalent model so the local strength of hull has not completed. This article applies the BEM to analyze the interaction between jack-up structure and ocean waves and transfer the wave loads to global model for the structure strength checking.

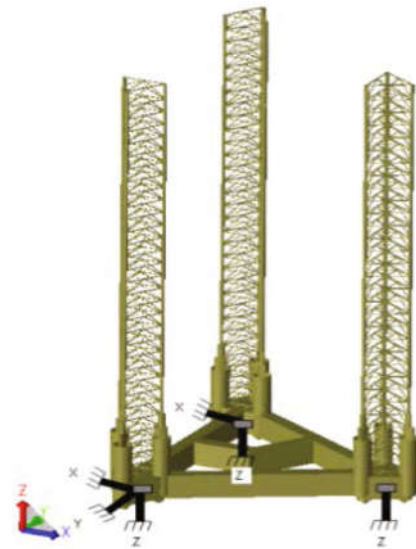


Fig. 2. Equivalent model of jack-up rig in transit condition [2, 3]

2 Methodology of Jack-Up Rig Structural Analysis in Transit Condition

2.1 Wave Loads and Inertial Forces

a. Floating rigid motions

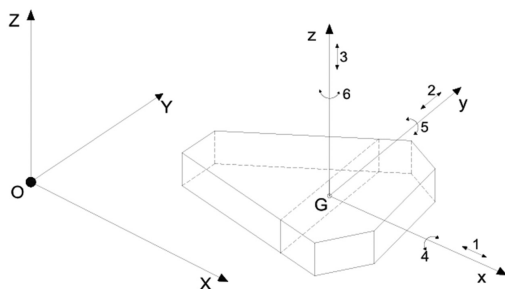


Fig. 3. Definition of axis systems and floating rigid motions

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)

b. The equation of motion

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

Where M: Structure mass matrix in global axis; A is Added mass matrix with the components A_{ij} are determined from radiation wave potential ϕ_{ij} and n_i are the normal vector of dS body on the mean wetted body surface S_o :

$$A_{ij} = Re \left\{ \rho \iint_{S_0} \phi_{ij} n_i dS \right\} \tag{2}$$

C: Damping matrix with the components C_{ij} are determined from radiation wave potential ϕ_{rj} with the assumption viscous damping between structure and environment is ignore:

$$C_{ij} = Im \left\{ \omega \rho \iint_{S_0} \phi_{rj} n_i dS \right\} \quad (3)$$

Where: ω is wave frequency taking into account current velocity caused by Doppler effect depend on current velocity and angle between direct of current and moving direct of structure; ρ is density of environment.

K_{hys} : Hydrostatic Stiffness Matrix, components K_{ij} are determined from hydrostatic pressure affect on wet surface S_0 as [5]:

$$K_{hys} = \begin{matrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & K_{33} & K_{34} & K_{35} & 0 \\ 0 & 0 & K_{43} & K_{44} & K_{45} & K_{46} \\ 0 & 0 & K_{53} & K_{54} & K_{55} & K_{56} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{matrix} \quad (4)$$

\dot{U}, \ddot{U} : vectors of motion velocity and acceleration;

$F(t)$: the vector of wave loads including Incident wave and Diffraction wave. Skipping the second order wave, the j -th (F_j) motion of first order characterized by first order incident wave potential $\phi_I(\bar{X})$ and diffraction wave potential $\phi_d(\bar{X})$ at $\bar{X} = (X, Y, Z)$

c. Determining the velocity potential

By assuming the fluid ideal such that there exists a velocity potential function $\Phi(\bar{X}, t)$ with isolated space dependent term $\varphi(\bar{X})$ and employing linear hydrodynamic theory, accounting for wave radiation and diffraction, the fluid-structure interaction behavior is described by laplace and boundary condition equations [4, 5] in the fixed reference axes (OXYZ, Fig. 3):

To determine the velocity potential, which laplace equation, boundary conditions and Green' function are incorporated together [4, 5], the fluid potential is expressed as:

$$\varphi(\bar{X}) = \frac{1}{4\pi} \int_{S_0} \sigma(\bar{\xi}) G(\bar{X}, \bar{\xi}, \omega) dS \quad (5)$$

Take (6) equation get A_{ij}, C_{ij}, F_j to solve equation of motion (1).

d. Inertial force

Motions at center of gravity are determined from (1) induces inertial forces at i -th mass point of structure can be written as [8] with components inertial in x -direction, centrifugal inertial and tangential inertial forces, inertial in x -direction from acceleration of translation and angular acceleration.

2.2 Jack-Up Rig Structural Analysis Using FEM

The global model includes hull, legs, spudcans structure which are modeled by surface and line body connected together at nodes.

The equation of Finite Element in the global axis is written as:

$$[K] \cdot \{X_N\} = \{P\} \quad (6)$$

Where

$[K]$ - global stiffness matrix of structure;

$\{X_N\}$ - Vector displacement of nodes;

$\{P\}$ - Vector nodes force, includes: wave load, inertial force (determined from BEM), wind load, reaction force of substructures and technical loads.

2.3 Load Transfer from Boundary Element Model to Finite Element Model

Hydrodynamic, hydrostatic and inertial force are determined from BE model. However to analyze structural used again FE model. Step by step to load transfer wave load from BE model to FE model as follows:

Step 1: Panel pressures are extracted from database: $P_1, P_2 \dots P_n$ (Fig. 4a)

Step 2: Nodal values are computed from weighted averaging of pressures of connected panels (Fig. 4b);

Step 3: Finite element nodal pressures computed from weighted averaging of hydrodynamic nodal values (Fig. 4c);

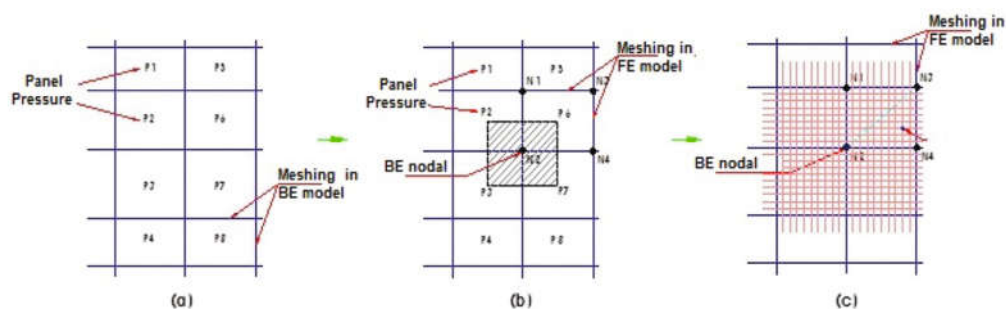


Fig. 4. Illustrating images of load transfer from BEM to FEM

3 The General Algorithm Combining FEM and BEM to Analyze Global Structure in Transit Condition

The Fig. 5 is general algorithm combining FEM and BEM to analyze global structure in transit condition.

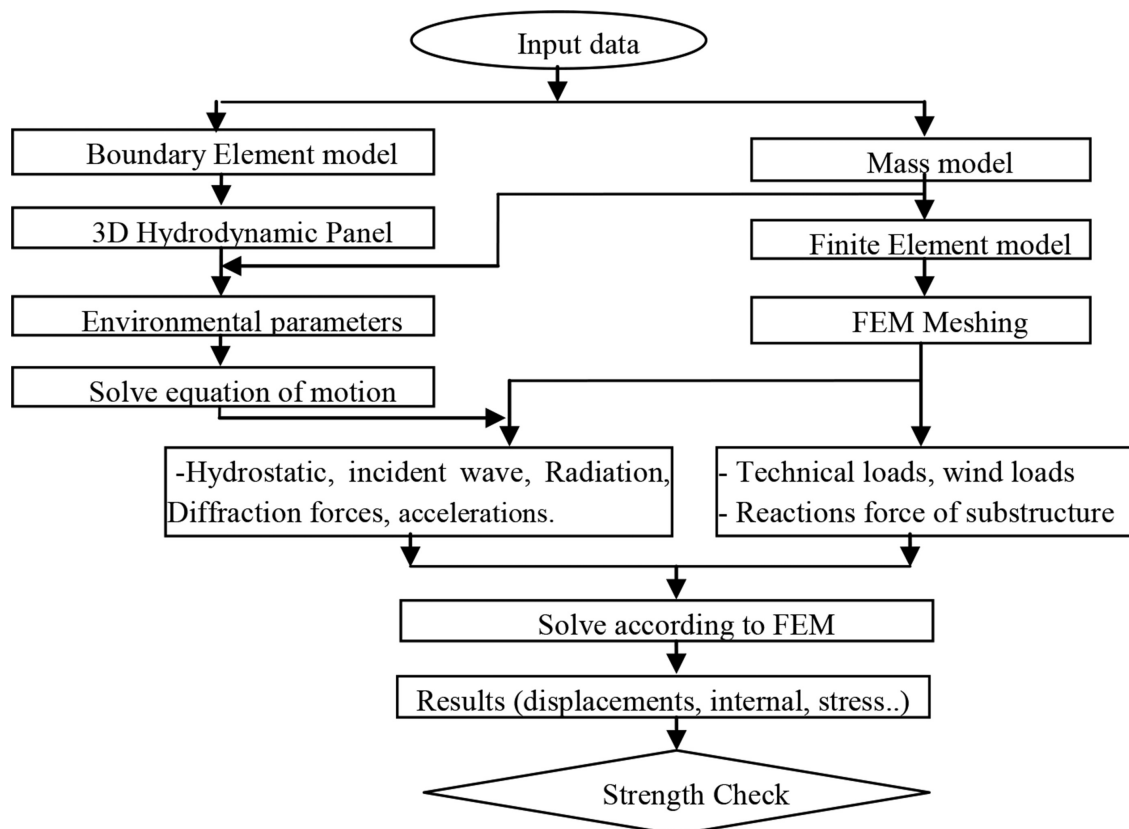


Fig. 5. The general algorithm combining BEM and FEM to strength check jack-up rig structure in transit condition

Additional, the article also clarifies the differences between BE Model and FE model:

- *BE model*: the structure is absolutely rigid and is a particle characterized by total mass, C.O.G and mass inertial moment. So BE model has just side of hull, without consideration stiffener, girder, beam and bulkhead;
- *FE model*: The FE model is offer to calculate for global structure so this model need to be completed and accurate. Normally, the FE model consists of the legs, spudcans, hull and leg-to-hull connections. The remaining substructures are modeled as reaction forces which are put on connection position between them and hull.

4 Application Methodology to Strength Checking for Jack-Up Rig 400 ft Structures in Transit Condition Using ANSYS/AQWA Software

4.1 Input Data

See Table 1.

Table 1. Input data

Parameters of structure	Properties of material	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 tonnes	-Young's Modulus: $E = 20000 \text{ kN/cm}^2$ -Shear modulus: $G = 8000 \text{ kN/cm}^2$ -Yield strength: $F_y = 34,5 \text{ kN/cm}^2$ -Density of steel $\gamma = 7,85 \text{ T/m}^3$	-Loads of technical and equipment according to Weight Control Report (WCR) of Ju-2000 E version; -Environment data: + Wave height: $H = 3 \text{ m}$ + Period: $T = 6 \text{ s}$ + Wind: $v = 75 \text{ knots}$

4.2 Models

The calculation requires three major models as:

- *Mass model*: the mass model to determine properties of structure in transit condition: total mass, center of gravity, mass inertial moment. It is input data of analysis using BEM;
- *Boundary element model*: the boundary element model have just side of hull, it is considered absolute rigid with boundary conditions is performed in Sect. 2.1;
- *Finite element model*: the finite element model is global model include hull, legs, spudcans, leg-to-hull connection structure and all the loads are considered in transit condition.

4.3 Results

Using internal data from FEM solve and spreadsheet according to standard [6, 7], Strength checking results of leg, girder and side as (Table 2):

Table 2. Strength checking results of jack-up rig 400ft

No	Description	UC _{max}	Remark
1	Frame checking	0.364	OK
2	Joint checking	0.190	OK
3	Check for resistance of plate between stiffener (girder)	0.250	OK
4	Check for resistance of stiffened (girder) panels to shear stress	0.250	OK
5	Check for shear force	0.010	OK
6	Check for lateral pressure on plate side	0.340	OK

Comment: Unity check (UC) at around position of leg-to-hull connection are maximum, indicate that in transit condition, legs are fully retracted and bent so internal force at this positions are maximum.

5 Conclusions

The article clarifies the general algorithm combining BEM and FEM to calculate and check Jack-up Rig structures. The results of BEM are wave loads on sides of hull and inertial forces. These results are also input data for the structural checking according to FEM. The global FE model used in the article has replaced the equivalent models. Based on the global FE model, the article were completely solved the strength checking of hull and legs in transit condition.

The combination between BEM and FEM to analyze global jack-up rig 400 ft in transit condition according to algorithm as shown in Fig. 5 of this article has been solved with the helping of the software program ANSYS/AQWA [5], the copyrighted software program of the ICOFFSHORE.

These result are also product of national research project No. SPQG02b.01-01 which performed the research team of ICOFFSHORE.

The next studies will be analyzed for jack-up rig 400 ft in operating, Installation and Retrieval conditions to concludes about the safety of the jack-up rig 400 ft Vietnam sea conditions.

References

1. F&G JU-2000E: Jackup drilling rig. In: JU200E Construction Specifications. Friede and Goldman LTD, Houston, TX (2013)
2. Det Norske Veritas (DnV)–RP-C104: Self-elevating Units (2012)
3. American Bureau of Shipping (ABS): ABS Rules for Building and Classing Mobile Offshore Drilling Units (2001)
4. Newman, J.N.: The theory of ship motions. *Adv. Appl. Mech.* **18**, 221–283 (1980)
5. ANSYS, Inc: Aqwa Theory Manual. Release 15.0 (2013)
6. American Petroleum Institute (API)–RP-2A-WSD: Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms–Working stress Design, 22nd edn. (2014)
7. Det Norske Veritas (DnV)–RP-C201: Buckling Strength of Plated Structures (2010)
8. SACS (Structure Analysis Computer System) User Manual