11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

THE LOADINGS WHICH ACT ON A ROMANIAN JACK-UP STRUCTURE IN THE BLACK SEA

Georgică Slămnoiu, Associate Prof. Ph. D.
Research Center for Navy
4 Stefanita Voda Street, Constanta
Romania

Niculae Alexe, Senior Researcher Ph. D.
Research Center for Navy
4 Stefanita Voda Street, Constanta
Romania

Gabriel Vladu, Senior Researcher Ph. D.
Research Center for Navy
4 Stefanita Voda Street, Constanta
Romania

ABSTRACT
On a jack-up structure acts static loads (own weight, machines, installations and materials weight) and dynamic loads (waves, wind, marine currents, earthquake, operating installations).
The authors led their analysis on the determining the dynamic loads produced by waves, wind and marine currents, in the Black Sea, because these are the main source in collapse of the structure.
The structural model of the Romanian jack-up is proposed by the authors and respects strictly the geometrical and mechanical characteristics of the real structure.
For the evaluation of the hydrodynamic loads on the Romanian jack-up cylindrical beams, the authors used the MIRAF program which calculates the wave loads together with the action of the currents.
For the evaluation of the wind loads on the Romanian jack-up model the authors used deterministic relation based on Morison formula.
Keywords: static loads, dynamic loads, wave loads

1. INTRODUCTION

Over a jack-up structure in exploitation acts: 1. static loads: the dead load, the weights of installations, equipments and materials situated on deck; 2. dynamic loads: waves, wind, marine currents, earthquake and the operation of drilling and auxiliary equipments.
The way in which the jack-up reacts to the act of the enumerated loads represents *the jack-up answer.*
The answer is composed by the ensemble of the mechanical sizes (tensions, deformations, displacements) that appear simultaneously in the elements of the legs and body, when jack-up is submitted to a certain type of loading. The analyses of the jack-up's behavior in exploitation can be approached in three aspects: static, dynamic, fatigue resistance.
The static calculus of the jack-up is accomplished in two stages: 1. the global calculus, achieved for the tension determination from the tubular elements of the legs (but not in the zones in which exist tensional concentrators); 2. the local calculus, that consists in the determination of the local stresses allocation (in knots) departing from the global calculus results.
The global calculus utilizes the standard programs based on finite elements method FEM (RDM, SAP 90, ALGOR, COSMOS, FRAN, STRUDL, MARCH-MENTAT etc.) and consists in the discreet model's loading, with the forces to the existing knots at the moment „t", in the framework of some loading hypothesis, and obtains the structures answer (deformations and tensions), in the conditions of the structure's linear elastic behavior.

The static answer is obtained through the solution of the equations of static equilibrium:

$$[K]\{\delta\} = \{F\} \tag{1}$$

where: [K] = matrix of structure's rigidity, {δ} = the vector of nodal displacements, {F} = the vector forces to knots.

In case of loading hypotheses with forces from waves, the vector {F} is defined by the Morison relation [1],[2]:

$$\{F\}=0,5\ \rho\ [C_D][A]\{v\}\{v\}+\ \rho\ [C_M][V]\{\dot{v}\} \tag{2}$$

where: $\{v\}$, $\{\dot{v}\}$ = speed and acceleration vectors of the fluid to the static knots of the structure; ρ = the water density; $[C_D]$,$[C_M]$ = the diagonal matrix of the hydrodynamic coefficients C_D and C_M; [A],[V] = the matrices of the areas and volumes of the structure's bars.

Speeds v and the accelerations $\dot{v}$, are established with the utilization of a proper wave theory.

For hypothesis of load with forces generated by wind, the vector {F} may be determined with the relation [3],[4],[5]:

$$\{F\} = 0,5\ \rho_a\,[C_d][A]\{v^2\} \tag{3}$$

where: ρ_a = air density; $[C_d]$= the matrix of the training coefficient; [A] = the matrix of the exposed areas; {v} = the wind speed vector on the structure's knots level established in the recommended conditions [3],[4],[5] or based on the local measurements.

The global static calculus permits tensions determination in the elements of the legs, away from the singular points like the tubular joints (knots). Tensions distribution in this area is complicated especially because of the specific geometry of the tubular joint. In the vicinity of the welding, in some points called hot-spots, are signaled tension peaks that can be up to 20 times higher than the medium level of the tension from the tubular elements of the blending [1].

The purpose of *the local static calculus* is determining the tensions distribution in the most stressed tubular blending, and the peaks of these tensions. This calculus can be done in three modes: the finite element method; the margin element method; the method of stresses concentration factors.

The resistance structures of the jack-up can be shaped with straight beam type elements with axial stiffness, inflection, shearing and torsion [1]. Therefore: 1.the jack-up's body (with a rigid, cassette structure) is shaped by a spatial network of straight beams adequate to its shape and stiffness; 2. the jack-up's legs may be meshed: spatial, with straight beam type elements, with the shape, dimensions and stiffness of the leg's tubular elements; by equivalence with straight beam type elements, disposed in extension, every element having the same height as the equivalent panel and the stiffness and geometric characteristics are calculated with specific equivalence relations that exist in literature. Modeling the link between the jack-up's body and legs may be done by: "joint" type links at the bolts attachment level; „master – slave" type links at the guiders level.

2. STRUCTURAL MODEL PROPOSED BY THE AUTHORS

For F.E.M analysis of jack-up, the authors proposed a spatial model characterized by: parallelepiped body in framework form with very high stiffness ($E=2\cdot10^{20}$ N/m^2), made of beam 3D elastic elements, loaded with the real mass of the jack-up's body; spatial beams legs with railings to which the elements are stiffly connected in knots; legs built-in the marine soil and stiffly connected with the body.

The stiff built-in model of the legs in the marine soil was accepted by the authors having in mind the fact that after a certain wile of anchoring, the soil around the legs yields and the elasticity module of the soil is approx. six times smaller then that of the steel. About the stiff connection between the legs and the body the authors consider that the effect of these modeling is materialized in a tension concentrator whose effect vanishes a few cm from the connection.

The model used to mesh the legs uses 7776 beam 3D elastic elements and 6568 knots and has the following advantages: 1. follows the exact geometric and mechanical characteristics of the real pipes: lengths, diameters, masses, inertial moments; 2. offers a better calculus precision than the models used by: Pitulice [7] – equivalent beam type model with masses concentrated at the horizontal landing level; Dima [6] –hybrid model, with 3 legs meshed with straight beam type elements disposed in extension and 1 leg spatially meshed in accordance with the real composition; Spatoulas [8] – spatial model with 3648 beam 3D elements and 2635 knots.

In figure 1 is presented the structural model of the jack-up, and in figure 2, the model of a leg section. The following notations where used: 1-vertical tube; 2-horizontal pipe; 3-diagonal pipe; 4-

intermediary pipe; 5-body. We distinguish the following: the horizontal pipes are made of six beam 3D elastic elements; the diagonal pipes are made of four beam 3D elastic elements; the intermediary pipes are made of two beam 3D elastic elements; the portion of the vertical tube between two horizontals is made of fuor beam 3D elastic elements.
The modeling of the jack-up's structure was made with the help of the COSMOS/M program.
The purpose that the authors chose for the spatial modeling of the platform was to give the application a form as close to reality as possible, proving the righteousness of the F.E.M. utilization at the complex structure study, whatever its gauge is.

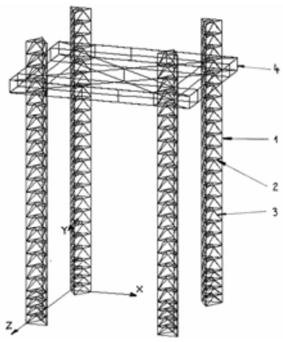

Figure 1. The structural model of the jack - up

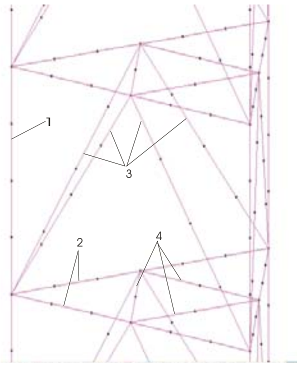

Figure 2. The model of a leg section

3. ESTABLISHING THE LOADINGS PRODUCED BY THE WIND AND WAVE THAT ACTS ON THE JACK-UP

The calculus of the forces provided by the wind that is presented in the international rules [3], [4], [5], uses deterministic relations based on the Morison type formula (3):

- API-RP-2 rules [4]: $F_v = 0{,}0473\ v^2\ C_s\ A$, N (4)
- A.B.S. rules [3]: $F_v = 0{,}0623\ v_k^2\ C_h\ C_s\ A$, daN (5)
- D.N.V. rules [5]: $F_v = 0{,}5\rho\ v_{yt}^2\ C_s\ A\ \sin\alpha$, daN (6)

where: F_v = the force generated by the wind; $v = \overline{v_{10}}(y/10)^x$, in km/h; $\overline{v_{10}}$ = medium speed of the wind measured at 10 m above the water; y = element height relative to the water surface, in m; x = 1/8, for continuous wind and x = 1/13, for wind blasts; C_s = shape coefficient ; A = wind exposed surface, in m^2; v_k = wind speed, in m/s; C_h = height dependent coefficient; ρ = air density, in kg/m^3; $v_{yt} = \alpha' \ \overline{v_{10}}\ (y/10)^{\beta}$; α' = burst factor; β = exponent, depends on the action time of the wind.

Because the first Romanian jack-up was built under surveillance of American Bureau of Shipping, for determining the wind force the relation (5) was used, and resulted: F_v = 2500 kN .

For the calculus of the hydrodynamic loadings on the tubular elements of the legs was used MIRAF program [9], developed by the authors in collaboration with specialists from the „Ovidius" University Constanta, Romania. The MIRAF program has two important branches (fig. 3): 1. force distribution over height – study of the wave force depending on depth; the graphic permits comparison of the evaluated forces in two ways: F_S – force calculated considering the spectral characteristics, F_d – force calculated in determinist manner; also, may count, the current influence by determining the current speed depending on the wind speed and depth; 2. graphic specter – spectral energy representation for a wave with certain characteristics (H,T), same as speeds, accelerations and forces specters that varies with depth for the same wave. Entry dates are grouped in two categories: the ones related to the characteristics of the studied structure of jack-up (water depth; length, diameter and the number of modules of the legs's vertical tubes) and the ones that describe a state of the sea (wind speed, wave period and height). For the coefficients C_M and C_D of the Morison relation (see relation 2) one of the following variants: user inserted constants; analytic determination of the coefficients. In the program are implemented spectral models: Black Sea, Pierson-Moskovitz, JONSWAP. The wave theory used is the one of the Airy wave, specific to the Black Sea [6], [10]. These theory is the most simple approximation in modeling the real wave and is based on the presumption that the wave height is much smaller than it's length and water depth. By applying the MIRAF program, was determined that the vertical distribution of the hydrodynamic force corresponding to the cylindrical modules of the vertical tubes with the diameter of 914 mm and height of 900 mm, in determinist manner, for the projection wave's parameters (H_{max}=12 m and T =10 s) and accepting C_M= 1,5 and C_D= 0,6 (fig. 4).

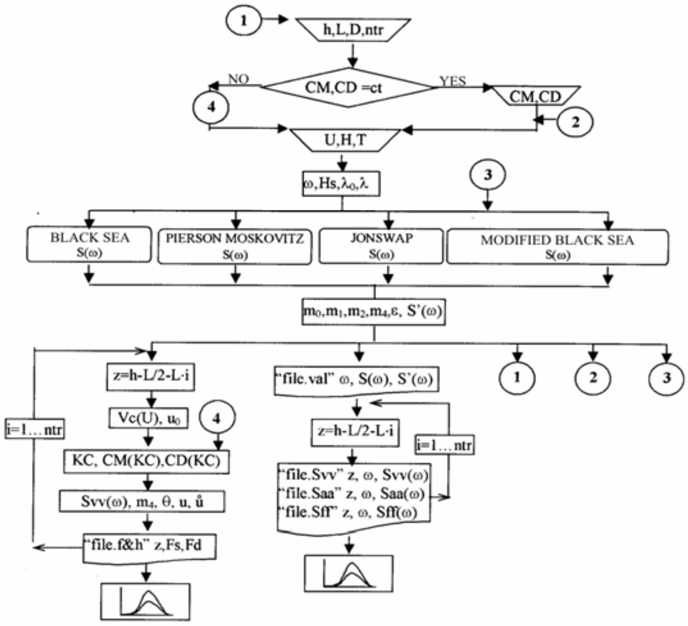

Figure 3. Block diagram of the MIRAF Program

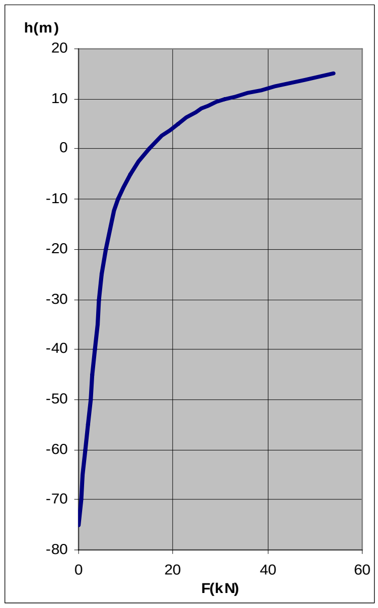

Figure 4. The vertical distribution of the hydrodynamic force

4. CONCLUSIONS

The discrete spatial model developed by the authors for the Romanian jack-up respects the geometric and mechanical characteristics of the real pipes and tubes and because of the high number of beam 3D elastic elements (7776) and of a very high number of knots (6568) it offers a big calculus precision.
The calculus program realized for the loading of the jack-up's structure with the load produced by the wave, permits a very realistic determination of the hydrodynamic loads on the cylindrical bars of the legs, having in mind the fact that beside the wave's action, the program considers the action of the marine currents over the structure, in Black Sea conditions.

5. REFERENCES

[1] Mc CLELLAND, B., REIFEL, M. Planning and design of fixed offshore platforms, Van Nostrand Reinhold Company, New York, 1986.
[2] SARPKAYA, T., DALTON, C. Analysis of wave plus current-induced forces on Cylinders. OTC 6815, Houston, Texas, 1992.
[3] xxx Mobile Offshore Drilling Units. American Bureau of Shipping, New-York, 1980.
[4] xxx Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms. American Petroleum Institute, Washington D.C., 1980.
[5] xxx Rules for the Design, Construction and Inspection of Offshore Structures. Det Norske Veritas, 1981.
[6] DIMA, A. Contributions to the calculus and design work of the marine metallic platforms. Doctorate thesis, Construction Institute, Bucharest, 1993.
[7] PITULICE, D. Study of the behavior in waves, of the moving and stationary fixed platforms, Doctorate thesis. University „ Dunărea de Jos", Galati, 1998.
[8] SPATOULAS, G. Contributions to the dynamic calculus of the metallic structures of the marine platform type, and the pipes system. Doctorate thesis, University „Petrol-Gaze", Ploieşti, 2000.
[9] JOAVINĂ, R., SLĂMNOIU, G., POPA, M. The effect of marine currents on the wave forces acting on thin elements. The 17th International Symposium on Naval and Marine Education, Naval Academy „Mircea cel Bătrân", Constanta, Romania, 24-26 Mai, 2001.
[10] xxx Rules for classification and construction of the marine platforms. Romanian Register of Shipping, Bucharest, Romania, 1992.