

VARIATION OF STRESS CREATED BY WAVES AND MARINE CURRENTS IN A LEG OF OFFSHORE PLATFORM

DOBROT OANA-MIRELA¹*, MOCANU COSTEL IULIAN¹

¹University of Dunarea de Jos, Galati, 47 Domneasca Street, 800001, Romania.

¹Department of Naval Structure, Faculty of "Naval Architecture", Stiintei Street, 800146, Galati, Romania

Abstract: The offshore platform have usually leg for sustaining on sea deep. The calculus of the legs is very complicated because of the variation of the loads in time. In this paper is present the numerical results for charging of a leg with forces caused by waves and marine currents. The software for calculation of force induced by water use Airy theory (for regular waves). The structure has been analyzed numerically using the program Solid Works-COSMOS/M (stress and displacements), and FORHID (loads).

Keywords: stress, wave, FEM, offshore platform

1. INTRODUCTION

The offshore structures have been divided into following categories [1]:

1. Fixed Platforms: steel template structures and concrete gravity structures. The platforms are built on concrete or steel legs fixed directly onto the seabed. The platforms have legs which supporting a deck with space for drilling rigs and crew quarters.
2. Compliant tower: compliant tower, guyed tower, articulated tower, tension leg platform.
3. Floating Structures: floating production system; floating production, storage and offloading system

2. TYPES OF LOADS

Loads on offshore structures are classified into two major categories gravity loads and environmental loads. Categories by gravity loads are determinate from deadweight of structure and facilities. Environmental loads governing the design of offshore structures. Various environmental loads acting on the offshore platform are [1]:

1. Gravity Loads: structural dead loads, facility dead loads, fluid loads, live loads, drilling loads.
2. Environmental Loads: wind loads, wave loads, current loads, buoyancy loads, ice loads, mud loads.
3. Seismic Loads.

2.1. Environmental Loads on Offshore Structures

The Environmental loads include: wind, wave, current, ice and snow, earthquake, temperature, marine growth, sea bed movement, and tide generated loads. Loads induce by wind, waves and earthquake are present in this paper.

*Corresponding author, email: ana.dobrot@ugal.ro

2.1.1 Wind loads

The environmental load caused by wind acting only on the portion of a offshore structure above sea level, as well as on any equipment, etc. located on the deck [2]. Wind induced loads acting on offshore platforms on a derrick is defined by fundamental equation of aerodynamic forces:

$$F_D(T) = \frac{1}{2} \rho C_D A U^2(t) \quad (1)$$

The terms are following signification:

- ρ - air density;
- C_D - drag coefficient of drag ;
- A - projection area of a structure
- $U(t)$ - wind speed

2.1.2 Wave loads

The waves are assumed to be long-ridge. The wave can be described by the parameters: period (T), wave height (H), and water depth (d) as present in Figure 1.

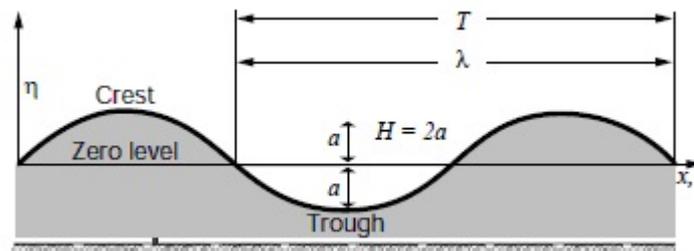


Fig.1.A wave structure.

A wave is defined by the following characteristic:

- λ - is wave length is the horizontal distance (in meters) between two successive crests;
- T - the period is the time interval (in seconds) between the passages of successive crests passed a fixed point;
- f - the frequency is the number of crests which pass a fixed point in 1 second (Hertz) and is the same as $1/T$, represent the reciprocal of the period;
- h_w - wave height, for a simple sinusoidal wave $h_w = 2a_w$;
- a_w - the amplitude, is the magnitude of the maximum displacement from mean sea-level. (meters or feet);
- $c = \lambda/T$ - the rate of propagation which represents the propagation speed of the wave crest;
- $\omega = 2\pi/T$ - pulse wave;
- $k = 2\pi/\lambda$ - wave number.

2.1.3 Speed and length wave

Based on expression pulsation ω resulting speed and wave length [3], [4]:

$$\lambda = \frac{2\pi}{k}; \quad \omega = \frac{2\pi}{T}; \quad c = \frac{\lambda}{T} = \frac{\omega}{k} \Rightarrow c = \sqrt{\frac{g}{k} \cdot th(kH)}; \quad \lambda = \frac{gT^2}{2\pi} \cdot th\left(\frac{2\pi H}{\lambda}\right) \quad (2)$$

Where c_g propagation speed wave with same length and amplitude is:

$$c_g = \frac{d\omega}{dk} \Rightarrow c_g = \frac{c}{2} \cdot \left(1 + \frac{2kH}{sh2kH} \right) \quad (3)$$

2.1.4 Pressure wave

The hydrodynamic additional pressure resulting from wave is:

$$p_w = -\rho \frac{\partial \phi}{\partial t} - \frac{1}{2} (\vec{v})^2; \quad \frac{1}{2} (\vec{v})^2 \approx 0 \Rightarrow p_w(x, z, t) = \rho g \frac{ch[k(z+H)]}{ch(kH)} \cdot \zeta_v(x, t) \quad (4)$$

2.2 Morison's Equation

The inertia and added mass effect and the damping effect of the drag force on the slow drift motion, for the slender cylindrical floating structure, can be evaluated by using Morison's equation. Morison et al. (1950) proposed that the total force is the sum of drag force and inertia force. The total force is result from the wave and current loading can be calculated by Morison equation [5].

Morison equation per unit length is:

$$\frac{dF_x(t)}{dz} = \frac{dF_{I_x}(t)}{dz} + \frac{dF_{D_x}(t)}{dz} = c_M \rho \frac{\pi D_c^2}{4} \frac{\partial u(t)}{\partial t} + \frac{1}{2} c_D \rho D |u(t)| u(t) \quad (5)$$

Where:

- F_x is the total force;
- ρ - is the density of the sea water;
- c_M - is the added mass coefficient;
- c_D - is the drag (resistance) coefficient;
- u - is the water particle velocity relative to the member normal to the member axis;
- D - is diameter of the beam exposed to the sea.

The first term in the equation is inertia component and the second term is the drag component. This can be expressed as:

$$F_x = F_{I_x} + F_{D_x} \quad (6)$$

The diffraction model is presented in Figure 2.

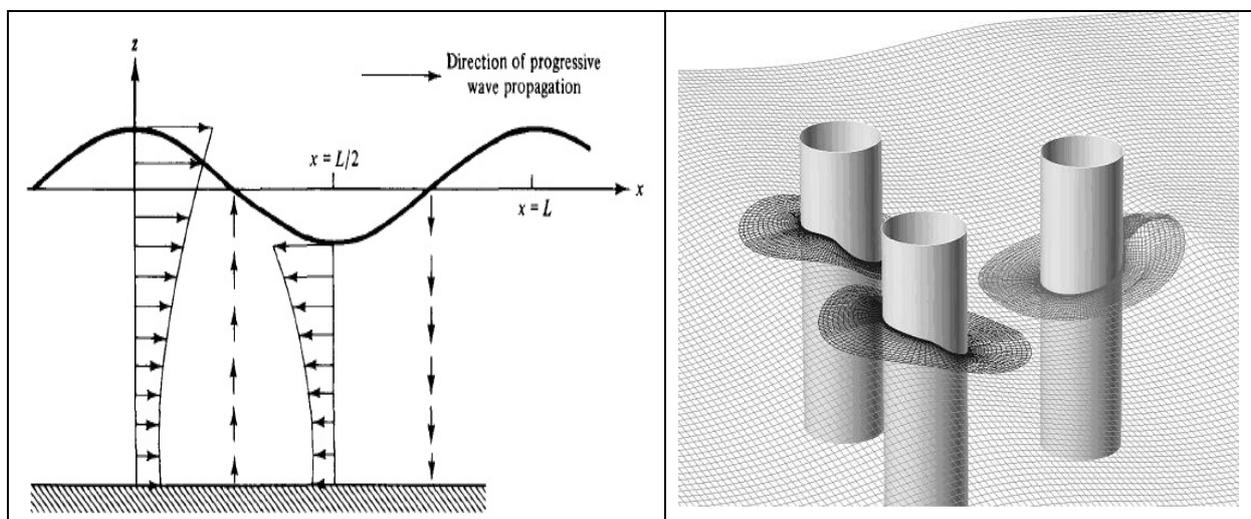


Fig. 2. Diffraction Model (Wu & Eatock-Taylor, 1999) [6].

3. LOADS CALCULATION

3.1 Hydrodynamic forces generated by wave action

In this sentence are mentioned theoretical results obtained with the program "FORHID". "FORHID" program solved the calculation of hydrodynamic forces and moments given by marine currents and wave action on structures composed of bar networks. Using the Morison-O'Brien equation result the moments MF_x and MF_y of forces F_x and F_y from the basic of fixed structure (see Figure 3).

The necessary dates for to run the program is defined in Table 1 [7].

Table 1. Data entry.

Symbol	Explanation	Value
N	Number of curves;	303
ρ	Density of the sea water	1.013 [t/m ³]
C_M	Added mass coefficient.	2
C_D	Resistance coefficient.	1
DELTD	Diameter growth due to the deposition phenomenon	0 [m]
ANIU	Cinematic viscosity	0.00000101 [m ² *s]
C_{R1}	Current velocity to the seabed	0.6 [m/s]
C_{R2}	Current velocity at free surface	1.2 [m/s]
x_i, y_i, z_i	Node coordinates bar	[m]
D	Diameter of the beam exposed to the sea	[m]
PERT	Wave period	10.2 [s]
HVAL	Wave height	14.3 [m]
ADINC	Water depth	33 [m]
ZBAZA	Distance from the base structure	0 [m]
UMIU1	Wave angle	0 [degrees]

The program delivers results, Table 2:

Table 2. Results „FORHID”.

Symbol	Explanation
F_i	hydrodynamic load for bar „i”
FXI, FYI, FZI	hydrodynamic force components on the bar „i”
XFI, YFI, ZFI	coordinates of the point of application of hydrodynamic force calculated on the bar „i”
FI1	hydrodynamic force of the bar „i”; of a node 1
FXI1, FYI1, FZI1	hydrodynamic force components of the node "1" of the bar "i"
F_x, F_y, F_z	total hydrodynamic force components structure
F	the total hydrodynamic force structure
MF_x, MF_y	moments of total forces, F_x and F_y in relation to the basic plan structure

3.2 Loading. Structural analysis results

Were adopted resulting hydrodynamic forces and moments resulting on the program "FORHID". Forces and moments given by summed of wave and marine currents action are the results for each node. Loads were imposed for each node separately.

4. NUMERICAL ANALYSIS

The Finite Element Method (FEM) knew a quick development in tandem with the increase of the computational capacities and it has enforced as a general numerical method of solving engineering problems from different areas, inclusively the naval domain [8].

The structural analysis through the finite element method requires using the same equations of the elasticity theory. MEF fundamental equation is:

$$\{P_k\} = [K]\{u_k\} \quad (12)$$

Where $\{P_k\}$ - is the vector of nodal forces, $[K]$ - is the rigidity matrix and $\{u_k\}$ is displacement vector.

In this paper is presented an numerical (using FEM) test for the model to see the distribution of stress. To determine by calculation the stress was used the Solid Works-COSMOS/M software.

Most steel offshore support structures are three-dimensional frames fabricated from tubular steel members. This gives the best compromise in satisfying the requirements of low drag coefficient, high buoyancy and high strength to weight ratio [3]. The most common used offshore geometry is a jacket structure, which comprises a prefabricated steel support structure (jacket) extended from the sea bed (connected with piles at the sea bed) to some height above the water surface level, and a steel deck on the top of the jacket.

The main leg loads are given by: own weight, body platform weight, wave loads acting on leg structure and wind loads acting on lateral surface of platform body.

The platform model considered in this paper is the “Gloria” platform. The Gloria substructure has four legs supported by vertical steel piles grouped symmetrically around each corner leg. The substructure is a piled steel jacket. The jacket’s lower part is 47.68 m high and is connected to the pile foundation. At the bottom, to simulate connection leg – bottom water has built a very rigid structure that simulates fixity. Discredited model is constructed of 156 nodes and 303 curves, is present in Figure 3.

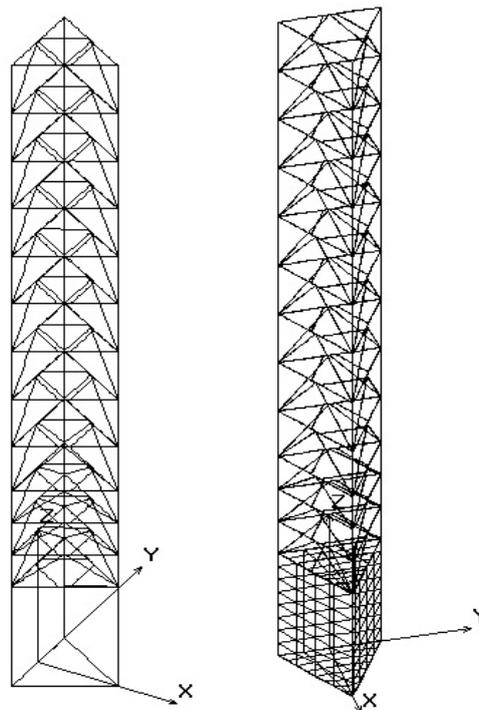


Fig. 3. Leg's structure model.

The diameter and thickness beam of which is build the jacket structure is present in Table 3.

Table 3. The diameter and thickness of beam.

Diameter [m]	Thickness [m]
0.914	0.050
0.460	0.032
0.340	0.016
0.220	0.008

Was considerate for loads:
 Case I – just own weight of leg;
 Case II - own weight and waves leg.

The displacement and stress distribution for initial model structure charged with own weight and body platform weight is present in Figure 4 and Figure 5.



Fig. 4. Stress distribution for structure leg model.



Fig. 5. Displacement for structure leg model .

In Table 4 and Table 5 is presented stress and displacements variation on node number 160 at z=47,68.m.

Table 4. Stress variation.

Time [s]	Stress variation [MPa]	
	Case I	Case II
0	7.39E+01	1.43E+02
0.851		1.00E+02
1.702		9.71E+01
2.552		9.24E+01
3.403		8.80E+01
4.254		9.22E+01
5.105		8.77E+01
5.956		9.21E+01
6.806		9.74E+01
7.657		9.89E+01

Table 5. Displacement variation.

Time [s]	Displacement variation [mm]	
	Case I	Case II
0	0.805	1.1
0.851		2.7
1.702		2.5
2.552		2.5
3.403		2.5
4.254		2.5
5.105		2.5
5.956		2.5
6.806		2.5
7.657		2.5

8.508		1.17E+02
9.359		1.26E+02
10.21		1.43E+02

8.508		2.5
9.359		2.5
10.21		2.5

In Figure 6 is presented normal stress variation which appear on the leg from wave action at an angle of incidence 0 degrees.

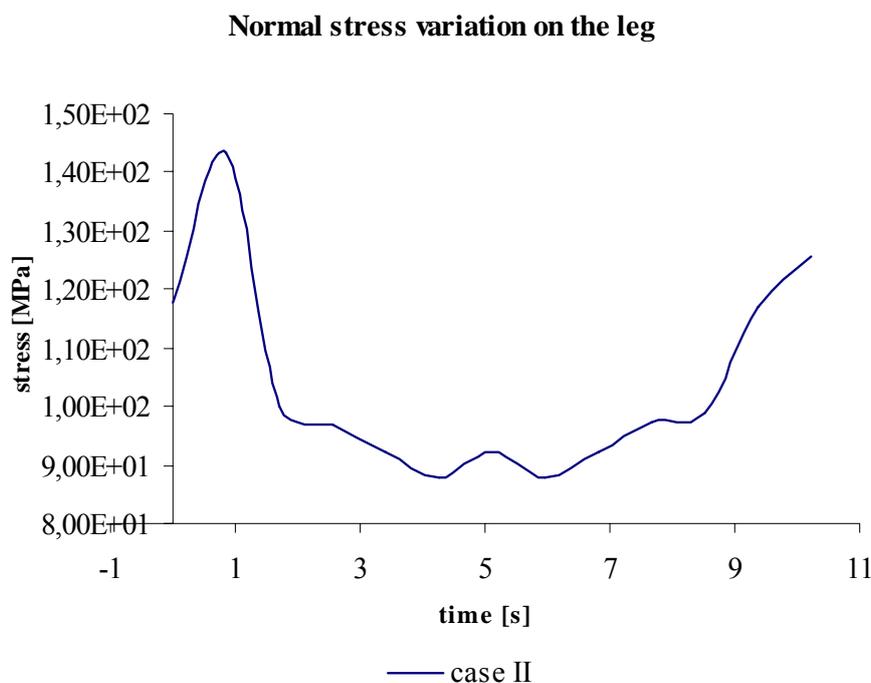


Fig. 6 Variation stress.

5. CONCLUSIONS

After numerical study made can draw the following conclusions:

1. As can be seen from Table 2, wave influence on normal stress variation is 41.2% compared with his own weight. Maximum stress from node considered value of 1.43e+02 MPa is with 58% smaller than the the admissible material which is made leg (360 MPa).
2. As can be seen from Table 2, wave influence on displacement variation is 70% compared only with his own weight.
3. Having in consideration points 1 and 2 results that the wave and sea currents have a major influence on the stresses and displacements which appear in the structure leg of an offshore platform. From this we can conclude that it is necessary to consider these influences on the dimensioning of such structures.
4. For the future is interesting to have in view also wind influence on the stress and displacements variation on platform legs. This was not taken in consideration in this study because usually wind influence is not considered.

ACKNOWLEDGEMENT

The authors gratefully acknowledge POSDRU project -“Improving the business cycle students in doctoral studies” – 61445 ID 88/1.5/S acronym EFFICIENT for financial support, grant of the University “Dunarea de Jos” of Galati, 2011

REFERENCES

- [1] Nallayarasu, Dr.S., Offshore Structures Analysis and Design, Department of Ocean Engineering Indian Institute of Technology Madras, Chennai - 600036, India.
- [2] Jang, J.J., Guo, J.S., Analysis of maximum wind force for offshore structure design, Journal of Marine Science and Technology, Vol. 7, No. 1, 1999, p. 43-51.
- [3] Domnisoru, L., Dinamica navei, Oscilații și vibrații ale corpului navei, Editura Tehnică, București, 2001.
- [4] Domnisoru, L., Modelarea fenomenelor de springing și whipping. Hidroelasticitatea navei, Editura Evrika, Brăila, 1997.
- [5] Young-Bok, K., Dynamic analysis of multiple-body floating platforms coupled with mooring lines and risers, Submitted to the Office of Graduate Studies of Texas A&M University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, May 2003.
- [6] Rahman, M., Heaps, S., Wave Forces on Offshore Structures: Nonlinear Wave Diffraction By Large Cylinders, Canada, 1983.
- [7] Crudu, L. Contribuții teoretice și experimentale privind hidrodinamica sistemelor plutitoare ancorate de exploatare petrolieră marină, Teză Doctorat Universitatea “ Dunarea de Jos “ din Galati, Facultatea de Nave, Iulie 2008.
- [8] Domnisoru, L., Finite element method in shipbuilding, Engineering Publisher, Bucharest, 2001.