Stress state reassessment of Romanian offshore structures taking into account corrosion influence

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Abstract. Progressive degradation analysis for extraction or exploration offshore structure, with appraisal of failure potential and the causes that can be correlated with the service age, depends on the various sources of uncertainty that require particular attention in design, construction and exploitation phases. Romanian self erecting platforms are spatial lattice structures consist of tubular steel joints, forming a continuous system with an infinite number of dynamic degrees of freedom. Reassessment of a structure at fixed intervals of time, re-correlation of initial design elements with the actual situation encountered in location and with structural behaviour represents a major asset in lowering vulnerabilities of offshore structure. This paper proposes a comparative reassessment of the stress state for an offshore structure Gloria type, when leaving the shipyard and at the end of that interval corresponding to capital revision, taking into account sectional changes due to marine environment corrosion. The calculation was done using Newmark integration method on a 3D model, assess of the dynamic loads was made through probabilistic spectral method.

1. Introduction

1.1. Structural modeling of the self erected platform

Evaluation of offshore structures are associated with major uncertainties related to long-term statistics of the sea, hydrodynamic forces, structural modeling and soil - structure interaction modeling, stress concentration factors and fatigue degradation. Structural safety is not conditioned by structure age or loads (environmental or operational) to which it has been or is subject so long as the features and functions for which it was built are maintain. Various processes that lead to risk increasing of an offshore structure, works cumulative and interdependent and involve environmental factors (temperature, wave and wind loads, the chemical composition of water and atmosphere), material (corrosion, wear, material fatigue leading to crack initiation and brittle fracture) and also human (calculation methods used in design, the structural model chosen, choice of materials, analysis of conditions in situ, overhaul periods, evaluation of operating conditions). The human factor is obviously the most flexible of all [1].

Structural modeling can be done with a wide variety of FEM programs [3] in order to increase accuracy while reducing calculation time. This paper presents a spatial modeling of a self erecting
Symmetrical steel platform of Gloria type using finite element program – FEAT, specialized in construction works modeling.

Steel structure is idealized as a spatial lattice girder made of tubular elements rigidly connected, structure feet is made of eight segments connected by welding.

Each section is constituted by a lattice of three vertical bars connected by horizontal bars, reinforced horizontally by means of intermediate elements and vertically by means of diagonal elements. The cross section of the platform’s foot is defined by an equilateral triangle with sides of 6068mm.

The first section of each leg is a system of ballast tanks with structural purpose in the stability of the platform and also to facilitate the foot transition in rock foundation.

The weight of the superstructure is 8400 tons.

Due to special loads that structure is subject to, for the steel used, certain values on the chemical composition and mechanical characteristics are imposed: a low carbon content (<20%) to ensure good weldability with alloying elements that enhance the mechanical strength characteristics without diminishing the characteristics of plasticity and toughness (Mn, Ni, Cr, Mo, Al, V, Ti, Nb) tempering - recovery or normalization treatment, characteristics of high strength (Rm>490 MPa, Rc>355 MPa), toughness at low temperatures, good plasticity, good fatigue, wear and corrosion resistance.

For Romanian platforms imported steel (Gloria and Horizon) and Romanian steel (Prometheus, Fortuna, Atlas, Jupiter and Saturn) was used, both alternatives having optimum operational behavior.

Figure 1. Elements identifying.  
Figure 2. Foot section of the platform and its cross section.

For determining the structural response are taken into account structural weight and hydrodynamic forces associated with beam elements. Structure height is 120m and the water depth at the site (measured from quiet water level) is 50m. A parallel study is done comparing efforts generated by hydrodynamic loads on the new born structure with the ones on corroded structure, using data regarding reducing elements size found by RNR during the overhaul. Establish the real insurance for platforms already in operation makes necessary the study of corroded structure model approach.

1.2. Degradation analysis due to corrosion for self erecting steel offshore structure
Inspections of immersed leg is performed with a frequency of twice in five years for the assessment of structural damage related to: deformations of the pipes due to simultaneous action of marine environment, deck installations and collision with ships, elements and connections corrosion, cracks occurring in welded joints and elements, wear of the means of corrosion protection.
Aggressive characteristics of the water in the western basin of the Black Sea (with a high content of dissolved oxygen, pH = 6.6 - 8.8, salinity 13 - 19%) emphasize the corrosion of structural elements.

Statistical analysis of the corrosion ultrasonic checked data obtained on periodic inspection, carried out in collaboration with experts from the Naval Academy "Mircea cel Batran", revealed a difference of evolution of elements corrosion, the most affected being the intermediate elements. It has also been found that the wear is higher in the end region towards the center of the elements, due to the phenomenon of structural and chemical homogeneity [7].

An interesting aspect noticed in the data processing relating to corrosion structural is a third point of maximum corrosion situated between peak generated in the breaking waves line and the mud line, the maximum that does not appear to platforms located in the Gulf of Mexico and the North Sea.

1.3. Structural response evaluation
Probabilistic spectral method is used to evaluate marine platform degradation due to dynamic loads. Probabilistic method, taking into account a larger amount of parameters ensures a better adaptation of the theoretical model to the real situation.

In assessing sea states histograms by spectral analysis, Black Sea spectrum was used. Directional spectra defined by compass points, each sea state being considered according to the specific direction, were used to increase the accuracy of calculation.

To calculate velocities and accelerations of water particles is adopted Airy linear wave theory.

Fluid loads on the structure are calculated using Morison equation modified by strength term linearization using Penzien's formulation and are considered to have linear variation along the element axis. Inertia and strength coefficients are considered constant $C_M = 1.5; C_D = 0.6$.

It also takes into account the variation in the length of the submerged elements near the sea surface by varying the level of the free surface of the water. Unit weight of Black Sea water is $1,011 \times 10^3 \text{kg/m}^3$. 

**Figure 3.** Areas where stress is measured and corrosion pattern.
Dumping matrix and additional mass matrix associated with submerged structural elements are generated assuming interaction fluid - structure.

Local tensions in offshore structure joints subjected to random loads wave - current are produced from nominal stress response of structural elements using stress concentration factors.

Equations of motion in generalized coordinates for offshore platform are solved in time domain by Newmark integration method (using a step 0.02s).

If acceleration $u(t)$ varies between $t$ and $t + \Delta t$; with substitution $\tau = t - t$ so $\tau = 0$ for $t_i = t$ and $\tau = \Delta t$ for $t_i = t + \Delta t$ and giving a function $f(\tau)$ nil for $\tau = 0$ and 1 for $\tau = \Delta t$, response acceleration vector at a time $\tau \leq \Delta t$ is expressed by the variation law:

$$\ddot{u}(\tau) = \ddot{u}_i + \dot{f}(\tau)(\ddot{u}_{i+\Delta t} - \ddot{u}_i)$$

(1)

identical for all degrees of freedom on $(t_i, \Delta t)$.

Velocity and displacement expressions are obtained by integrating acceleration expression

$$\dot{u}(\tau) = \ddot{u}_i + \int_0^\tau \ddot{u}(\tau) d\tau = \ddot{u}_i + \int_0^\tau (\ddot{u}_{i+\Delta t} - \ddot{u}_i) f(\tau) d\tau = \ddot{u}_i + \tau \ddot{u}_i + (\ddot{u}_{i+\Delta t} - \ddot{u}_i) \int_0^\tau f(\tau) d\tau$$

$$u_{i+\Delta t} = u_i + \dot{u}_i \Delta t + \left[ \frac{1}{2} - \beta \right] \ddot{u}_i + \beta \ddot{u}_{i+\Delta t} \right] \Delta t^2$$

(2)

using substitutions:

$$g(\tau) = \int_0^\tau f(\tau) d\tau$$

end $\gamma \Delta t = \int_0^\Delta t f(\tau) d\tau$

and

$$\tau = \Delta t$$

end $\beta = \frac{1}{\Delta t^2} \int_0^\tau g(\tau) d\tau$

(4)

Together with the equation of motion, these equations allow to determining acceleration, velocity and displacement vectors values at time $t + \Delta t$ according to values at time $t$. $M\ddot{u}_{i+\Delta t} + C\dot{u}_{i+\Delta t} + k u_{i+\Delta t} = F_{i+\Delta t}$

(5)

it can be written as:

$$\left( K + \frac{1}{\beta M} M + \frac{\gamma}{\beta^2 M} C \right) u_{i+\Delta t} = F_{i+\Delta t} + M \left[ \frac{1}{\beta M} u_i + \frac{1}{\beta M} \dot{u}_i + \left( \frac{1}{2 \beta} - 1 \right) \ddot{u}_i \right] + C \left[ \frac{\gamma}{\beta^2 M} u_i + \left( \frac{\gamma}{2 \beta} - 1 \right) \dot{u}_i + \left( \frac{\gamma}{2 \beta} - 1 \right) \ddot{u}_i \right]$$

(6)

by solving it, displacements values for time $t + \Delta t$ is obtained, then speeds and accelerations, depending on the displacements values, velocities and accelerations at an earlier time $t$ and exciter forces values at the same time $t + \Delta t$.

Parameters taken into account have the usual values $\gamma = 0.5$ and $\beta = 0.26 \ [11]$.

The analysis is focused on the estimation of the stress state on joints subject to the hydrodynamic loads and affected mostly from marine corrosion (according to inspection RNR). Points to be considered are the splash area N1 and mud line area N2. Maximum stress points are assumed to be located in the structural nodes.

To aloud evaluation of differentiated loadings depending on the wavelength, the calculation is performed separately on each leg, overlapping effects for each time step.

Obtained results are presented for wave heights of 1-7 m on compass directions. Also stress diagrams are presented (due to the space limitation only for the wave height of 7m (Figure 1), for E-W direction).
The global distribution of stress states on compass directions is presented below for the areas with highest probability of fatigue degradation.

Stress corresponding to hydrodynamic pressure due to the wave crest and wave trough for 7m wave high, E-W direction – case of new structure (daN/cm²)

Stress values in N1 area are presented in lower part of the diagram (in red) while stress in N2 area is presented in upper side of the diagram (in blue).
1.4. Corroded structure (according with RNR measurements) subjected to wave loads

Stress corresponding to hydrodynamical pressure due to wave crest and wave trough for 7m wave high – case of corroded structure (daN/cm²)

A1A2  A3B3  D1D2  D3
Considering N-S direction, for element A1 it can be observe on corroded structure a stress field redistribution with increase between 24-31% on N1 area and decline between 3-18% on N2 area, the highest values corresponding to mean sea states (Beaufort 7: wind up to 33 knots and wave height of 4-5m).
For element A3, stress increase of 14-31% appear in both studied areas with highest values for low sea states (Beaufort 5: wind up to 21 knots and wave height of 1-3m).

In E-W direction, for element A1 increases stress values occur in the range of 25-32% in N1 area and 3-24% in N2 area respectively.

For A3 element increases are between 4-31% in the N1 area and 5-27% in N2 area.

Highest value correspond to storm and severe storm states (Beaufort 8-9 wind up to 41 knots and wave height of 6-7m).

On NW-SE and NE-SW directions for A1 element, stress field redistribution also appears but different from the first situation (N-S, A1) in sense that for N1 area, stress values corresponding to the wave crest decrease 2-12% and that corresponding to wave trough increase 3-9%; and for the N2 area stress increase for the wave crest with 4-16% and decrease for wave trough with 3-9%.

For A3 element stress values increase for N1 area with 2-16% for wave trough and 18-32% for wave crest, and drops with 5-18% for both situations on N2 area.

It is also important to note that changing of the value of stress variation (the difference between the stress generated by the wave crest and that generated by the wave trough), although generally follows the stress values can have, for certain load cases, values significantly different. For A1 element, NW-SE direction, N2 area case, corroded structure stress for wave crest have increased by 4-16% while those for wave trough decrease by 3-9%; in exchange stress variation change has 23-35% increase due to stress redistribution.

In the same sense, for A3 element and E-W and NW-SE direction, for N1 area, although tensions have increased for corroded structure by 28-31% for wave crest and by 4-16% for wave trough respectively, stress variation intervals are lower in the corroded structure case in a range between 19-33%. This is particularly important in the calculation of structural fatigue.

2. Conclusions

Although the average corrosion values fall between 3-6% with tops in the splash zone - segments 15-17, mud line - segment 3 and the central area - segments 8-10 (not exceeding the 10%, RNR maximum allowable value), this phenomenon in conjunction with hydro-meteorological regime change detected recently, significantly affecting the behavior of the structure. It also occurs a maximum of efforts (shown only on charts EW) in the insertion leg-platform, due to blockage of self erected system that can generate, through the mechanism of fatigue, a forth corrosion top (as found in the case of platform Prometheus) but that is not the subject of this study. Stress changes goes around the value of 30%, with the higher values and stress redistribution more pronounced for A1 external element. For diagonal directions (considered NW-SE compass point), stress changes are more uniform both for the two measuring areas and for the sea states, because of the higher rigidity of the platform in this direction. As was noted, it should be taken into account both the stress modification magnitude due to corrosion as well as range of variation of the difference between maximum and minimum stress values. The unevenness of variation occur both due to structural rigidity and the fact that different sectional reduction was not applied evenly throughout the platform body but differentiated on elements, taking into account the measured values.

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