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STUDY ON THE STRESS VARIATION IN THE COMPONENTS OF OFFSHORE RIG LEGS IN VARIOUS COLLISION SITUATIONS

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ABSTRACT

The offshore rigs are designed for oil and gas drilling and extraction in the seabed. Generally speaking, an offshore structure consists of its body and support elements (legs). As a result of the interaction of the legs with the environment, or the collision with various floating objects, some damage may affect the components. In this case, a methodology should be found, in order to determine the strains occurring in such situations. The paper studies the behavior of offshore rig legs' elements in various cases of damage to the components.

The Finite Element Method is used to determine the strain state in various damage scenarios. As offshore structures operate in the marine environment, which displays a dynamic behavior, calculations were performed to detect the alterations of the rig's own pulsations. It is important for the operators of the drilling installations as it avoids the overlap of the rig's own vibration modes.

KEYWORDS: collision, stress, offshore, Finite Element Method

1. INTRODUCTION

Starting with the mid-20th century, oil and especially gas consumption have continuously increased (8-10 per cent annually on the average), thus leading to a series of prospection operations, also covering lakes, seas and oceans.

In the post-70s era, maritime commerce has developed tremendously in point of liquefied gas transportation, also extending oil exploitation from seabeds, by means of offshore rigs.

According to a report of the UN Secretary, about 27% of the total crude oil and gas extracted all over the world comes from exploiting marine resources [2].

Producing oil and gas from offshore rigs by means of fixed platforms has gained a tremendous momentum in the energy industry in the past ten years. Design of such structures is dependent upon lateral forces applied by environmental conditions such as waves, currents, impacts as well as seismically-induced excitations.

Severe lateral forces may cause considerable damage to load carrying members and endanger overall stability of the structure.

Designing offshore structures mainly depends on environmental loads, especially waves, and loads occurring in the various stages of erection and assembly. In order to analyse an offshore structure, certain functional data and environmental information should be known [4].

Considering as main loads the wave, wind, and marine currents loads, the strain occurring in the rig leg is of the bending type. Adding this strain to the axial one, generated by the rig's own weight and structure, it may be concluded that the support legs are subjected to a complex type of strain.

Offshore rig legs, due to their length, are sensitive to the dynamic action of waves, winds, and marine currents. The vibrations occurring due to these environmental factors result in the increase of bar efforts, causing fatigue damage to these elements in the course of time [3].

2. OVERVIEW OF THE ANALYZED STRUCTURE

The analysis of the resilience of the metallic structure of the offshore rig legs is performed by means of the Finite Element Method.

The overall calculation uses standard programs based on the finite element method, consisting in loading the discrete model, with the existing node forces, in certain loading hypotheses, and obtaining the structure's response (deformations and efforts), in the case of the linear elastic behaviour of the structure [38].

Static response is obtained by solving the static equilibrium equation [1]:

$$[K]\{U\}=\{Q\} \qquad (1)$$

Where

- [K] represent the rigidity matrix
- {U} is the displacement vector.
- {Q} is the element nodal forces vector;

Due to the structure complexity, certain conventions are to be adopted in constructing the models for global analysis. Thus, a series of constructive details will not be considered, such as brackets, relief holes, rigidity ribs, and junctures.

The platform model taken into consideration is the self lifting “Gloria” platform, Fig.1. The dimensional characteristics of the model are:

- body length L=52.5m, width B=40.84m, construction height D=6.4m;

- leg length l_p = 121.9 m. It has a number of 4 legs, arranged symmetrically against the center line (C.L).

Environmental conditions: medium water depth h=90 m, maximum water depth h_{max} = 94m, maximum wave height H_{max} = 12m, wave period T = 10.2s, maximum wind speed v=45m/s.

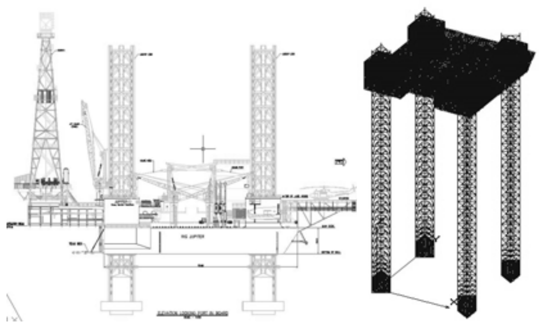


Fig. 1. *FEM model*

Shaping by means of the finite element consists in the structure meshing by means of the SolidWorks - COSMOS/M program, the meshing taking place after defining the geometry, viz. the point and the curves. After the geometry definition, the “Beam3D” elements and the material characteristics are defined for steel: Young’s modul E=2.1*10^{11} N/m^2, Poisson’s ratio ρ=7850 kg/m^3 [1].

The last step consists in defining the relation of the structure with the environment. The structure – soil relation consists in the prohibition of movement in nodes 1,2 and 3, on the directions x, y, z, and the circles around these axes, thus resulting in restraints.

In order to determine the sum of the stress and displacements that occur when a leg is subjected to strains, the structure was rendered discrete into bar elements with 6 degrees of liberty per node. The connections between the bar elements were made through rigid nodes, and the bottom leg connections were limited. The mesh of the platform body was simplified, as it does not constitute the object of the present work.

Because of a large amount of nodes and elements obtained, the structure was shaped with circular section bar elements.

A leg consists of 399 points and 786 lines. The shape of a leg is an equilateral triangle with the side of 6.096 m.

The legs structure sum up 8 sections, meaning 33 storeys. In table 1 is given each floor height.

Table 1. *Floor height*

The geometry of the offshore legs is given in Fig.2.

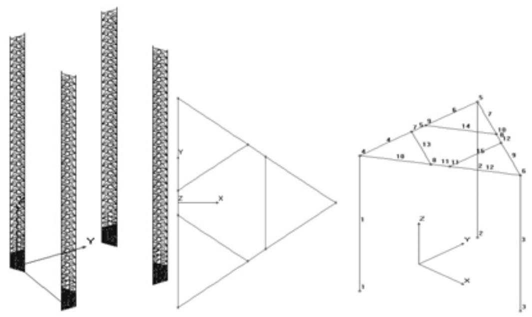


Fig. 2. *The geometry of the offshore legs*

After making the legs geometry, are defined the specific material properties of the studied platform legs, consisting in diameters with specific thickness of the bars from which are made the platform legs. From the definition of the four types of diameters, with specific thickness from which the structure is built, results four types of group elements shown in table 2.

Table 2. *Diameters types*

Type	Diameter [mm]	t [mm]
1 - cordes	915	50
2 - horizontals	460	32
3 - diagonales	340	16
4 - intermediate	220	11

The whole shaping of the platform body was made with plane elements. In Fig. 3 is shown the shaping of the body and its positioning towards the platform legs. The platform exterior shield, the deckhouse structure and the girder structure are integrated into the platform exterior shield.

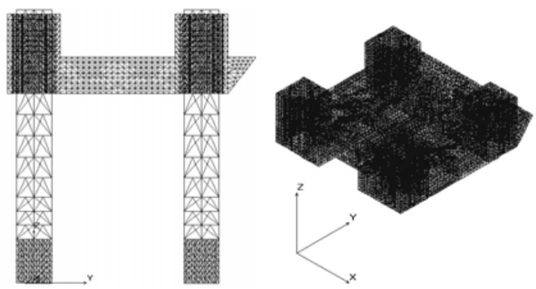


Fig. 3. *Offshore body geometry*

In the body shaping were defined four group elements "SHELL3T" typed. After the making of the body geometry, are defined the material properties, consisting in tin thickness specific to each platform construction.

Table 3. *Tin thickness types*

Group element	Thickness [mm]
V- reinforcements of the platform legs	50
VI – roof metal sheet	50
VII – exterior shield	25
VIII – upper and lower shell	25
IX – cross bar	15

Ten group elements resulted from the structure shaping. The last group element has the purpose of making the connection between the legs and the body of the platform.

3. NUMERIC RESULTS

The stress and displacements distribution for the model structure charged only with the own weight of the body and leg are shown in Fig 4.

The maximum stress results are:

- stress in the body $\sigma_{\max} = 123.45\, MPa$;
- stress in the legs $\sigma_{\max} = 38.416\, MPa$.

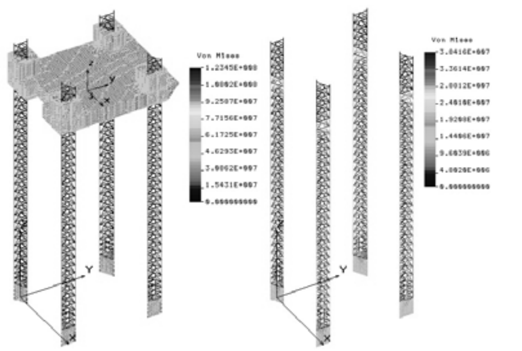


Fig. 4. *Stress distribution on the elements for the model*

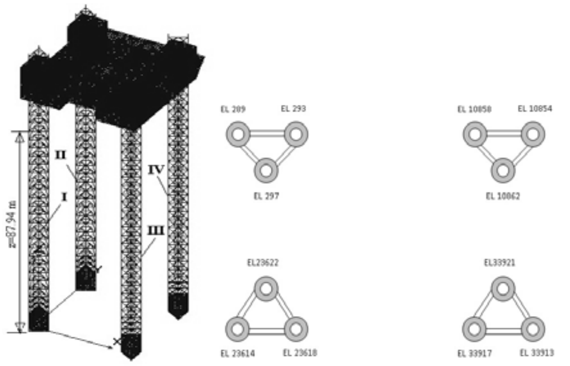


Fig. 5. *Location of elements analyzed*

Stress variation was analyzed using elements located at z=87,94 m, elements within the 4 legs, one 3 – legs, elements within the largest diameter beams, D=915 mm, represented in Fig.5.

In Table 4 are shown the corresponding elements of each leg.

Table 4. *Elements analyzed for each leg*

Legs	Elements		
Legs I	289	293	297
Legs II	10854	10858	10862
Legs III	23614	23618	23622
Legs IV	33913	33917	33921

The stress distribution for the model structure charged only with the own weight of the body and leg is shown in Table 5.

Table 5. *Initial stress*

Element	Stress [MPa]	Element	Stress [MPa]
289	14.3	23614	14.3
293	17.81	23618	17.81
297	18.52	23622	18.52
10854	18.64	33913	18.64
10858	19.73	33917	19.73
10862	21.24	33921	21.24

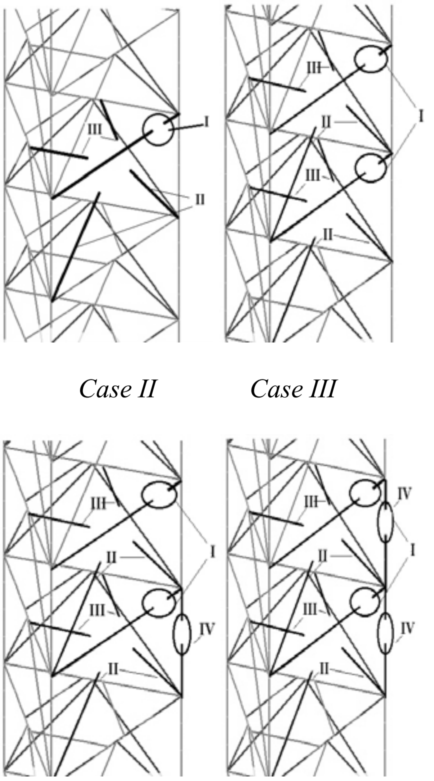
4. THE INFLUENCE OF LINKING ELEMENTS' DAMAGE ON THE STRAIN STATE IN THE OFFSHORE LEG STRUCTURE

As a result of collisions with other floating bodies (especially supply ships), the leg structure may undergo alterations by damage to the components.

To perform the numerical analysis, the case considered was the damage to elements on one leg, thus taking into account the following cases:

- Case I - with no destroyed element.
- Case II - is considered destroyed an horizontal bar (tube B) from cote z = 80,62m, having further the damage of the two middle bars from the same floor and damage of the two diagonals (tube B), shown in Fig. 6(a).

- Case III – in comparison with the first case, the destroyed of the horizontal bar from cote z = 84.28.
- Case IV – it is to be considered the destruction of the curve located between z = 80,62 m and z=84,28m, meaning the destruction of a bar with the largest diameter of the leg structure D=0.915m (tube A).
- Case V- it is to be considered the destruction of the curve located between z=84,28 m to z = 87,94 m.

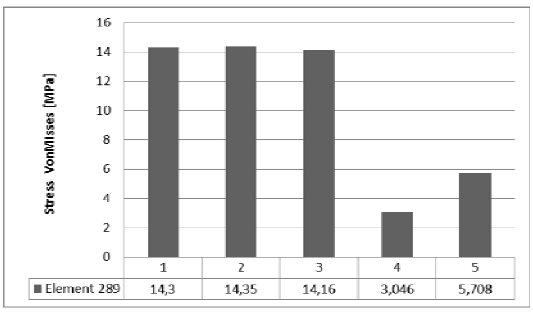


Case II *Case III*

Case IV *Case V*

Fig. 6. *Cases of bar elements destroyed*

In Fig. 7 is presented the distribution of the Von misses stress values for the chosen elements which belong to the damaged leg, the platform being charged only by its own weight.



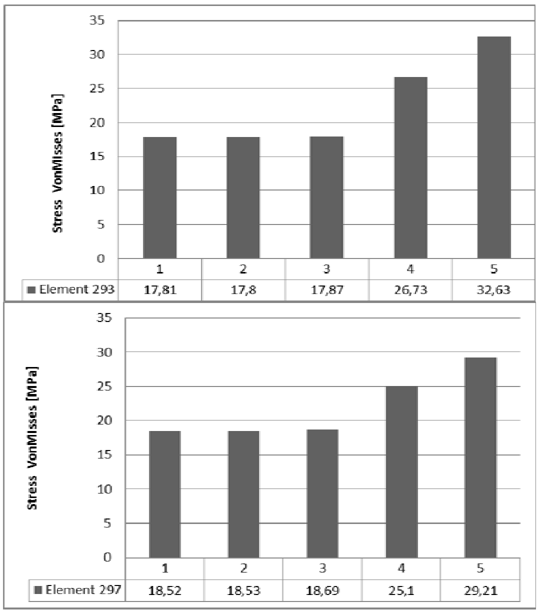


Fig. 7. *Stress variation depending on the damaged elements for the first leg*

Fig. 8 shows the distribution of the VonMisses strain for the elements selected in the second leg, the offshore rig being loaded only with its own weight.

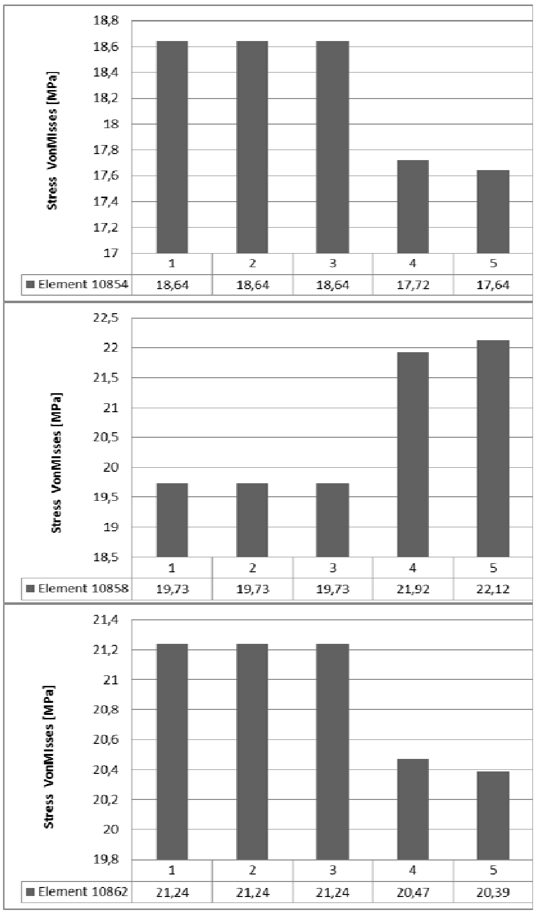


Fig. 8. *Stress variation depending on the damaged elements for the second leg*

Fig. 9 shows the distribution of the VonMisses strain for the elements selected for the third leg, the offshore rig being loaded only with its own weight.

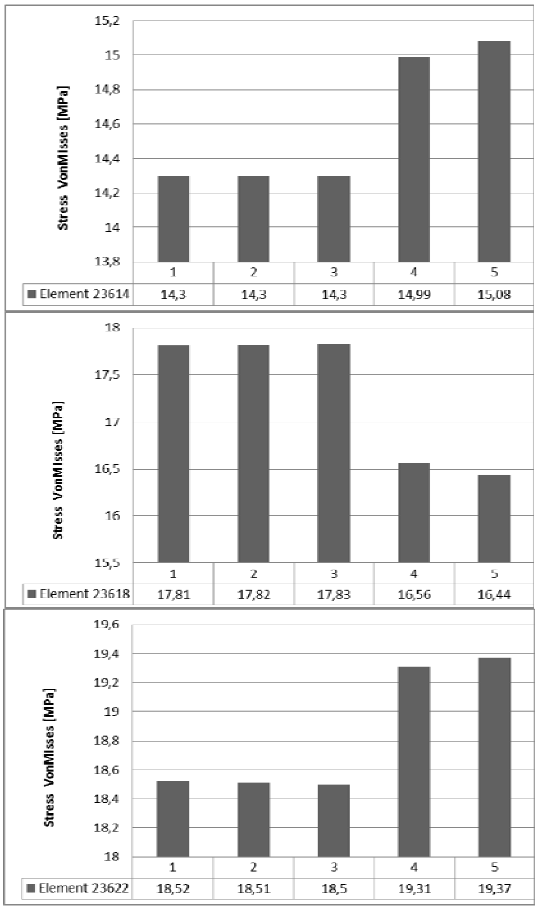
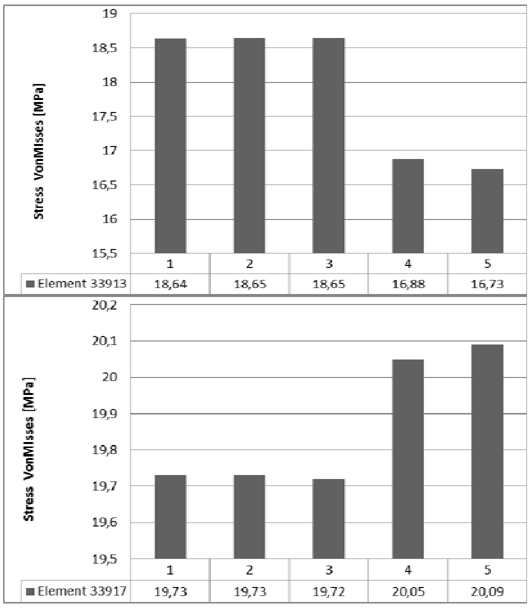


Fig. 9. *Stress variation depending on the damaged elements for the third leg*

Fig. 10 shows the distribution of the VonMisses strain for the elements selected for the fourth leg, the offshore rig being loaded only with its own weight.



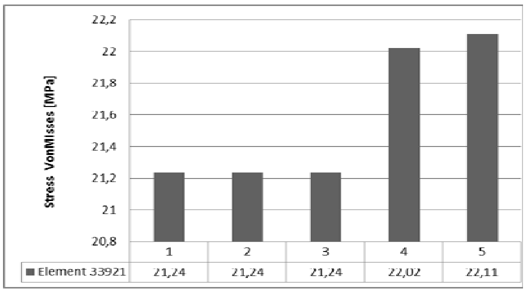
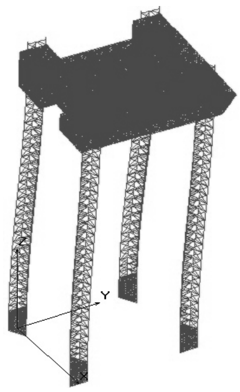


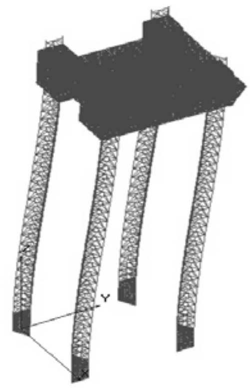
Fig. 10. *Stress variation depending on the damaged elements for the fourth leg*

5. CALCULUS OF THE RIG'S OWN PULSATIONS

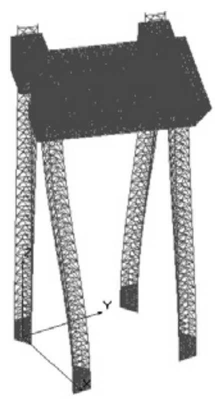
As a result of the analysis by the finite element method, the rig's own pulsayions were calculated, resulting the rig's own vibration modes. The first four vibration modes are shown in Fig. 11 [5].



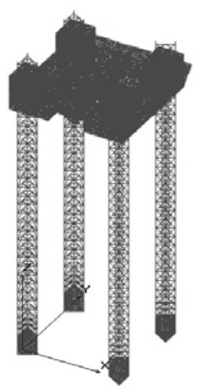
Mode I
Fz=0,345364(cyc/s)



Mode II
Fz=0,350555 (cyc/s)



Mode III
Fz= 0,423275 (cyc/s)



Mode IV
Fz= 1,93098 (cyc/s)

Fig. 11. *The first four vibration modes*

6. THE INFLUENCE OF ELEMENT DAMAGE ON THE RIG'S OWN PULSATION MODES

As a result of damage to elements in the structure of leg I, scenarios detailed in chapter 4, an analysis was carried out to show the influence of the leg element damage on the rig's own pulsation modes. Table 6 shows the frequency variation according to the damage cases considered for the first four pulsation modes.

Table 6. *Frequency variation according to the damage cases considered*

Caz	Frecquency [cyc/s]			
	Mode I	Mode II	Mode III	Mode IV
Initial	0,34536	0,35056	0,42328	1,93098
I	0,34523	0,35051	0,42301	1,93098
II	0,34494	0,3504	0,42243	1,93098
III	0,34139	0,34718	0,42054	1,93098
IV	0,34002	0,34695	0,42032	1,93098

7. CONCLUSIONS

The analysis of the strains resulting from the numerical models in the four cases of damage to the leg leads to the following conclusions:

1 The resulting strains in tube A when several elements are damaged (cases IV and V) – the strains decrease. A possible explanation is the fact that this tube has virtually lost all connection to the rest of the tubes.

2. The resulting strains in tubes B and C increase, as expected, as they are elements no longer contributing to taking over the load.

3. The analysis of the rig's own pulsations shows a decrease of these pulsations. It is an indication to the offshore rig's operator to avoid the overlap of the calculated pulsation to the pulsations of the drilling machines.

4. The numerical analysis performed is useful in taking into account the various collision scenarios.

Acknowledgements

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