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Numerical assessment of the behaviour of a fixed offshore platform subjected to ship collision

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Abstract

According to the International Association of Oil and Gas Producers Report [1] one of the main accidental situations endangering offshore Jacket platforms is a ship collision. Such scenario may induce severe damage level and is therefore addressed in the Norwegian standards, Norsok N-003 and N-004 [2,3], which provide a series of guidelines and methodologies to establish the resistance and ductility of framed structures.

The ship-platform collision is characterized by the ship's kinetic energy, due to its carrying mass and velocity, and also by the deformation capacity of both structure and ship. As two bodies collide their deformation stiffness can lead to different responses: a near elastic collision (in which case the two bodies travel in opposite directions after the collision), a perfectly inelastic (both bodies travel together), or a situation in-between. The Norsok standards establish three different design cases: *strength design*, in which the energy is dissipated by the ship; *ductile design* in which the energy is dissipated by the structure; or a halfway compromise *shared-energy design*, which is rather troublesome to quantify.

In this way, the main purpose of this paper is to perform a sensible numerical analysis of the behaviour of a steel offshore platform based on the Merluza-1, located in Bacia de Santos, São Paulo, Brazil, under an impact loading of a stiff and a soft 5000 ton ships, traveling at a speed of 0.5 m/s and, as prescribed in the standards, at a speed of 2 m/s. The finite element software ABAQUS is used to determine the deformation and dissipated energy in both the ship and the structure during the local collision.

Keywords: offshore, ship collisions; numerical simulation; Jacket structure; impact loading

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1 Introduction

The design of offshore structures requires accidental load cases to be considered; one particular event is the collision of heavy ships to the platform's supporting elements. According to recommendations of Norsok N-003 and N-004 [2,3], the structure ought to resist the damage caused by a given accidental scenario and avoid its progressive collapse, allowing for safe evacuation of the platform. The methodology put into practice for the last three decades considers ships with a mass of 5000 metric tonnes traveling at a velocity of 2 m/s. According to recent research [4,5] a revision of Norsok N-003 is expected in the upcoming years to account for the higher capacity modern ships, and to replace the force/displacement curves taking into account new ship configurations. References [6,7,8] have studied the effects of ship and structure configurations in the case of their impact and have concluded that the ship's stiffness and the dimensions of the contact area will play an important role in the structural strength resistance.

1.1 *Design principles*

The evaluation of offshore structures subjected to the impact of ships relies in the kinetic energy carried by the ship, and therefore in its mass and velocity. at the moment of collision. Depending on the ship and the structure's stiffness, this kinetic energy may be dissipated through the deformation of either i) the ship, ii) the structure, or even iii) a combination of both. Each of these three situations are covered by Norsok N-004 [3], Fig. 1, which are characterized by:

i) Strength design – the structural element suffering the collision is strong enough to remain within the elastic range during the whole impact, thus with reduced capacity to absorb kinetic energy; this approach requires the ship to dissipate the energy, with elevated damage. This design strategy will also require an immensely conservative design of the platform, which may be extremely expensive;

ii) Ductile design – as opposed to the previous design technique, in this case, the kinetic energy is solely absorbed by the structure, which may render the element's supporting capacity useless and trigger a progressive collapse mechanism if unchecked.

iii) Shared-energy design – the shared-energy design is a middle ground situation, when both the ship and the structure deform and dissipate the kinetic energy; however, this method is harder to quantify by means of simple methods, since two different elements are dissipating energy [3].

Bearing in mind the difficulties in establishing a shared-energy design situation, this paper looks forward to study a fixed offshore jacket subjected to the impact of a ship, by building a finite element model accounting for the geometric and material non-linear behaviours. The analysis takes into consideration two velocities, 2m/s and 0.5 m/s, and two different stiffness conditions for the ship. The model is built with the general purpose software Abaqus [9].

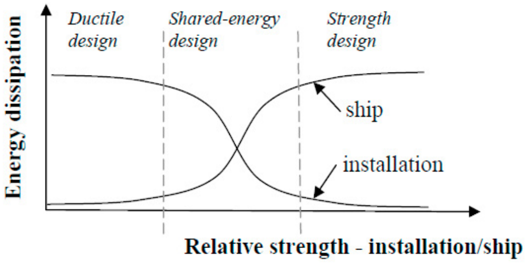


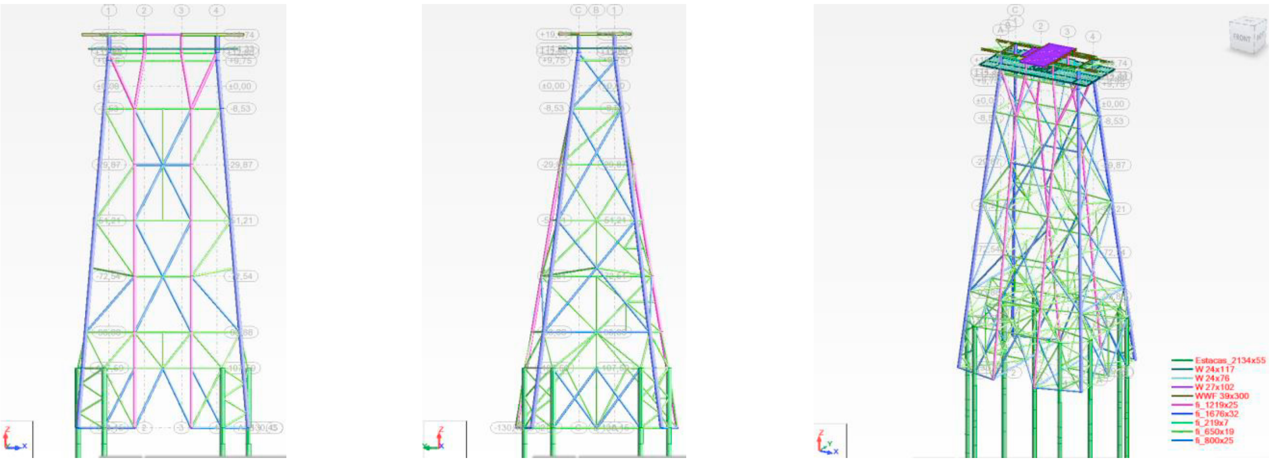
Fig. 1. Characterization of the three design strategies [7]

1.2 *Platform description*

The platform chosen for the analysis is an existing platform located in Bacia de Santos, in the state of São Paulo, Brazil, also known as Merluza-1. The platform is fixed at a depth of 134 m. Fig. 2 shows the working platforms' *Topside* level and the inferior supporting structure, also designated by *Jacket*.

Fig. 2. General view of the Merluza-1 platform [8].

The *Topside* has a total operating area of 1915 m^2; it's in this area that all the operations related to extraction, storage and processing of crude oil are made. The *Jacket*, the supporting structure, is defined by a spacial truss structure using tubular cross-sections in S355 steel. The structure's foundation is achieved by tubular piles. Further description of the platform may be found in [10,11]. Fig 3 provides a view of the *stick model* of the jacket structure.



a) Side view. b) Front view. c) Perspective.

Fig. 3. Stick model of the Merluza-1 platform, [10].

2 Finite element model description

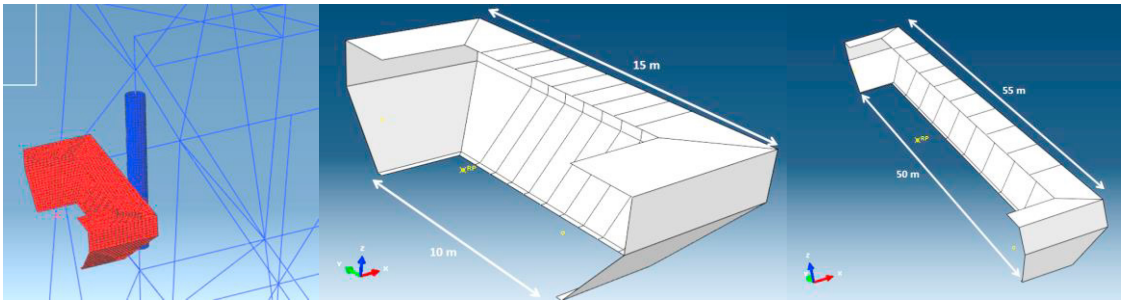
2.1 *General considerations*

The numerical model is built with the general purpose software ABAQUS [9], using the *dynamic/Implicit* solver which follows the HHT algorithm. The model uses both beam and shell finite elements, S4R; beam elements are used to model the majority of the jacket truss structure, and shell finite elements are used to model both the ship and the impacted leg element. The impacted leg has a circular cross-section with 1676 mm of diameter and 32 mm of thickness; its elements are linked to the beam structure by coupling the shell edge on the beam's node. The mesh size for the beam and shell elements has been limited in order to meet the relation $5<l_e/t<10$, where t is the structural element's thickness and l_e is the width of the finite element; an $l_e = 220$ mm is used. The contact interactions are modelled with "Hard-contact", ensuring that pressure is transmitted upon contact and released if the surfaces are separated.

The ship is considered with a mass of 5000 tonnes and it is assumed that the platform carries five localized masses of 5 tonnes. From the main numerical model, several analyses are developed in this paper:

i) the effects of the kinetic energy of the ship are addressed by considering two different initial velocities of 2.0 m/s and 0.5 m/s stiff ship impacting the jacket's leg Fig 4 a);

ii) two different models of ships: a stiff (Fig 4 b)) and a soft one (Fig 4 c)) traveling at 2m/s, are idealized to explore the structural response and strain energy dissipation.



a) view of the jacket model b) stiff ship geometry c) soft ship geometry

Fig. 4. a) View of the finite element model and detail of the b) stiff and c) soft ship geometries. [12]

2.2 *Material model*

The material is assumed the same for both the jacket and ship. The non-linear elasto-plastic behavior for the S355 steel considered is represented in Fig. 5 and is specified in Norsok N-004 [3] following Eq. (1). The material parameters considered are: material density of 7850 kg/m^3; Elastic modulus of 210 GPa, except for the stiff ship in which an increased value is considered ($E_{stiff\_Ship} = E_{soft\_Ship}$ *100); Poisson coefficient of 0.3; yield strength of 355 MPa and critical strain (ε_{cr}) of 15%, corresponding an H = 0.0034, see Eq. (1).

$$H = \frac{E_p}{E} = \frac{1}{E}\left(\frac{\sigma_{cr} - f_y}{\varepsilon_{cr} - \varepsilon_y}\right) \quad (1)$$

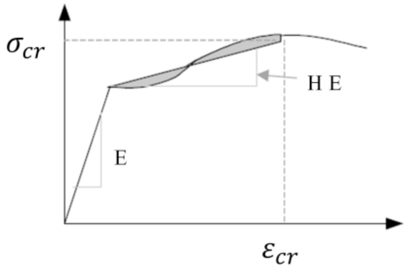


Fig. 5. Material model definition [8].

3 Collision Scenarios

3.1 *Stiff ship: 2 m/s vs. 0.5 m/s*

The first analyses consider a ship with 5000 tonnes traveling with two different velocities, one of them is the recommended velocity by the standard for member verification, 2 m/s, and a slower one at 0.5 m/s. Fig. 6 presents the evolution of the velocity for both analysis; it can be observed that up to the first second of time the velocity remains null, since this first step is used to apply a vertical load of 125 MN modelling the weight on the platform; then the velocities remain constant as the ship travels a distance of 900 mm which was initially defined as a standoff distance; at a given point, when impact occurs, the velocity starts to decrease as the kinetic energy is transferred to the jacket structure; once the velocity crosses the 'x' axis corresponds to the ship's reverse traveling direction. This reversal point corresponds to the maximum deformation of both the Leg and Jacket observed in Fig. 7. From Fig 7 and Fig.8 it can be observed that the ship traveling at 0.5 m/s does not create permanent damage on the jacket (notice the zero deformation on Fig 7) while the ship travelling at 2 m/s, which carries 16 times the kinetic energy ($E_k = 0.5\,m * v^2$), creates a final dent on the leg of 1000 mm. Despite this dent on the leg, the jacket itself recovers most of the deformation, as shown by the dotted blue line in Fig. 7.

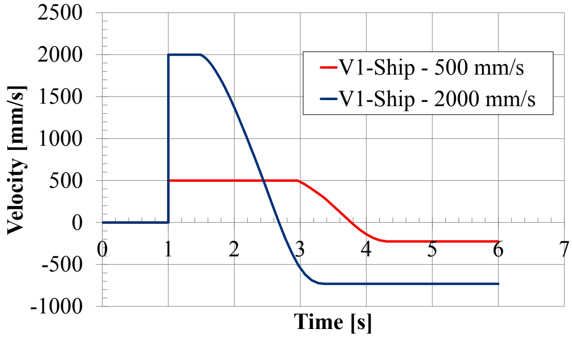


Fig. 6. Ship velocity throughout the analyses.

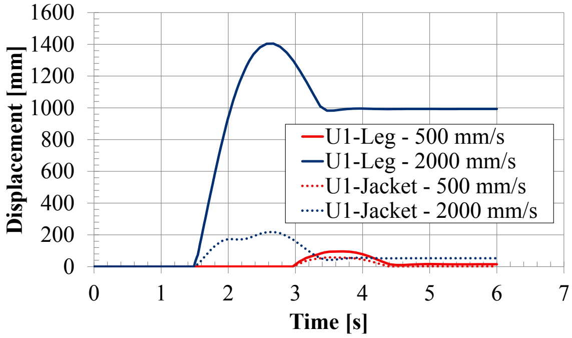


Fig. 7. Leg and jacket deformation

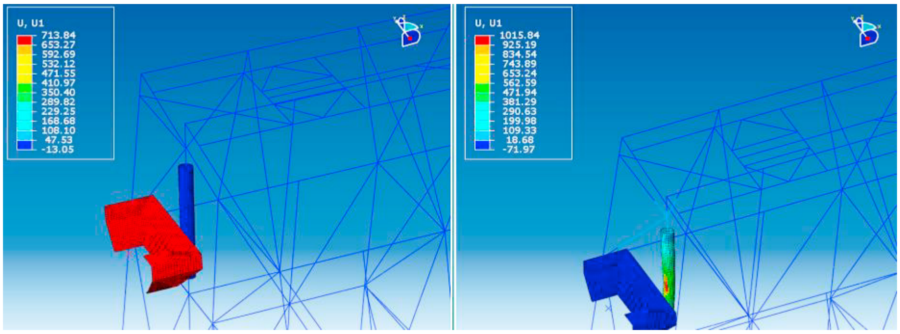


Fig. 8. Final deformation of the model for 0.5 m/s and 2 m/s.

3.2 *Stiff vs. Soft ship*

The previous analysis has demonstrated that a 5000 ton stiff ship travelling at 2 m/s can create serious damage on the jacket's leg; the following analysis looks forward to access the benefits (to the structure) of having a softer ship that would be able to dissipate a share of the kinetic energy, in line with a *Shared-design* situation. Two types of ships are considered, stiff ship and soft ship according to Fig. 4 b) and Fig. 4 c).

Fig. 9 presents the evolution of the strain energy (ALLSE) released upon the impact at the 1 second mark; Fig. 9 b) provides the same representation but focusing on the ship and leg.

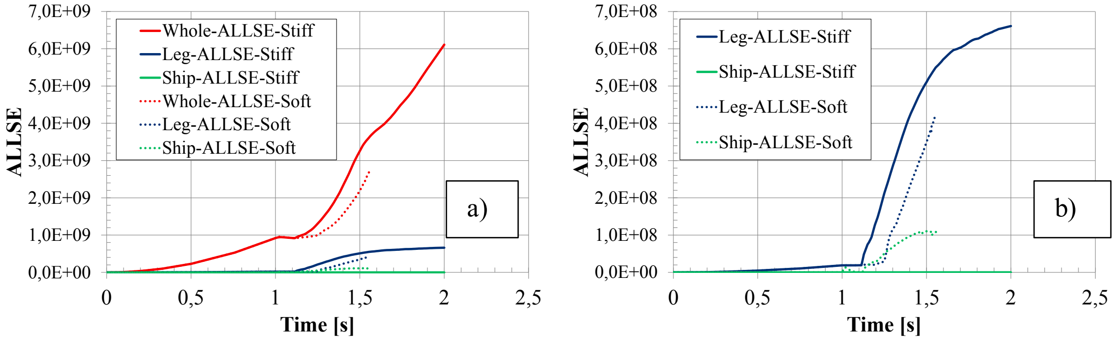


Fig. 9. Evolution of the strain energy dissipated along the analysis a) Whole model; b) Leg and Ship only.

One of the main observations is that the energy dissipated by the whole model (although also accounting for the leg, ship and initial ship energy) is an order of magnitude higher that what's dissipated by the ship or the leg. While the stiff ship does not provide any strain energy release, the soft ship is able to dissipate 1/4 of the energy dissipated by leg, thus reducing the damage to the leg. The final deformations are shown in Fig. 10 where it can be observed the increased leg damage from the stiff ship and the shared damaged from the soft ship impact.

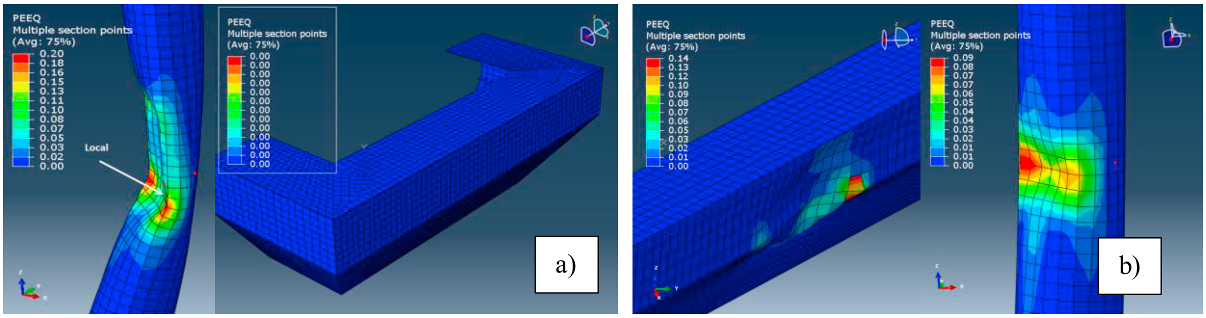


Fig. 10 Leg and ship final deformations: a) stiff ship, b) soft ship

4 Conclusions

One of the main hazards to offshore platform's integrity is a ship collision. This accidental scenario may endanger the load carrying capacity of the impacted elements thus limiting the robustness of the whole structure, with potentially catastrophic consequences. Hence, this paper discusses a finite element model to assess the behavior of an offshore platform subjected to a ship collision; from four different analyses focusing on i) a stiff ship travelling at 0.5 and 2.0 m/s and ii) a stiff and soft ship travelling at 2m/s it could be observed that:

i) the 2 m/s recommended velocity may cause severe damage on the jacket's legs; this is very pronounced particularly when compared to a velocity 0.5 m/s, as the 2 m/s ship carries 16 times the kinetic energy of the same ship travelling at 0.5 m/s (assuming constant mass);

ii) in both impacts due to soft or stiff ships (*Shared design* situation vs. a *Ductile - design* one), the energy dissipated by the remaining structure is much higher than that from the sum of the leg and ship;

iii) by considering a shared design situation the damage to the jacket structure is reduced.

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