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ACCURACY OF OFFSHORE RISER-GUARDS COLLISION MODELS USING BEAM OR SHELL ELEMENTS

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Abstract. *In order to protect risers of offshore structures against possible ship collisions, a structure composed of steel tubular members, namely riser-guard, may be installed on offshore platforms. These structures are designed to absorb energy of a typical supply vessel collision, possibly avoiding an environmental disaster due to oil spill. Generally, riser-guard structures are designed using finite element models with beam or shell elements. A typical structural model with beam elements requires less computational effort than when shell elements are used. When some geometrical conditions are met, though, energy dissipation by local effects is increased and in order to capture these effects, shell elements are needed. In this work, a parametric study is performed to explore the differences in response of a structure modeled with beams and shell elements. A typical riser-guard structure is simulated against a vessel collision event and its response in terms of a set of design parameters is compared for the different modeling approaches.*

Keywords: *Ship collision; Offshore structures; Riser-guard; Explicit finite element analysis*

INTRODUCTION

With the continuous development of offshore oil fields an increased number of offshore platforms are being installed. To ensure operations, a large number of supply and service vessels are required. Risk of collision is increased and mitigations might be necessary to avoid environmental releases as well as substantial structural damage and its possible escalating effects on personal life. Mitigations might be focused on risk by decreasing collision frequency or reducing the consequence of a collision incident.

Steel riser-guards are among the possible mitigations that are being used in offshore structures to protect the risers and also the structure itself against typical supply vessel collision. The riser-guards are framed structures, typically composed of tubular members, designed to withstand collision loads and absorb energy through plastic strains.

A significant number of works have already been performed to evaluate structural strength of dented and impacted steel cylindrical tubes by experimental testing and numerical simulations (Sharp et al.,1996, Walker and MacCall, 1998 and Zeinoddini et al., 2008). Sadowski and Roter (2013) studied the use of solid or shell elements to model thick cylindrical tubes and shells under global bending. It is presented that both thin and thick (shear flexible) shell elements may give a reasonable accuracy prediction of the buckling moment under global uniform bending for cylindrical tubes as thick as R/t = 10.

There are a few publications involving collision in riser-guards. Palaniandy et al. (2013) explored the use of commercially available high strength steel wire mesh to replace the conventional steel riser-guard. Palaniandy et al. (2014) studied an estimation of vessel stopping time during a collision event against riser-guard of a jacked platform using finite element model. Syed et al. (2015) proposed a damage assessment of offshore riser-guards under accidental vessel impact where systematic numerical investigations were performed using a nonlinear finite element analysis.

This paper deals with the different modelling techniques for steel structures subjected to accidental collision loads. The specific case to be studied is a typical riser-guard structure, designed to withstand collision load by deformation and plastic strains. The riser-guard structure is composed of structural elements with tubular sections. The structural behavior is assessed with the use of two different modelling techniques, with the tubular structure modelled using beam elements and shell elements.

Although riser-guards published works are found, their structural design information are not easily found in literature, probably because of industry secrecy.

1 SHIP COLLISION MECHANISM

The ship collision mechanism can be simulated using several approaches, with changes in how to handle the energy balance of the collision incident. The energy of a collision incident can be classified as external or internal energy. The external energy is related to the kinetic energy before and after the collision while the internal energy consists in strain energy by the means of structural deformation. The external energy, initially the kinetic energy of the colliding vessel, is transformed to internal energy or even kinetic energy of the facility, depending on the fidelity of the model used to simulate the collision.

ABS on its Guidance Notes on Accidental Load Analysis and Design for Offshore Structures (2013) describes three alternative approaches for the modelling of collision incidents in terms of conservation and transformation of energy.

In method A, the most conservative approach, all the colliding vessel kinetic energy is assumed to be absorbed by the structural deformation of the facility. In this method the colliding vessel is modeled as a rigid body.

In method B, two different analyses are performed, one with the colliding vessel modeled as a rigid body and the facility as flexible body and the second analysis with the colliding vessel modeled as a flexible body and the facility as a rigid body. The total energy is based on the uncoupled structural deformation of the colliding vessel and the facility.

The third method, method C, the total energy balance is evaluated with a coupled analysis with both colliding vessel and facility modeled as flexible bodies.

In Figure 1 the energy balance of a collision event between a vessel (subscript v) and a facility (subscript f) is represented. The colliding force vs. displacement curves are shown for the different modeling approaches. It can be seen that the choice of the method will have an impact on the level of colliding forces as well as in the deformation and consequent damage suffered by the structure. As the entire system energy will be absorbed by the facility structure, method A will result in the higher colliding forces.

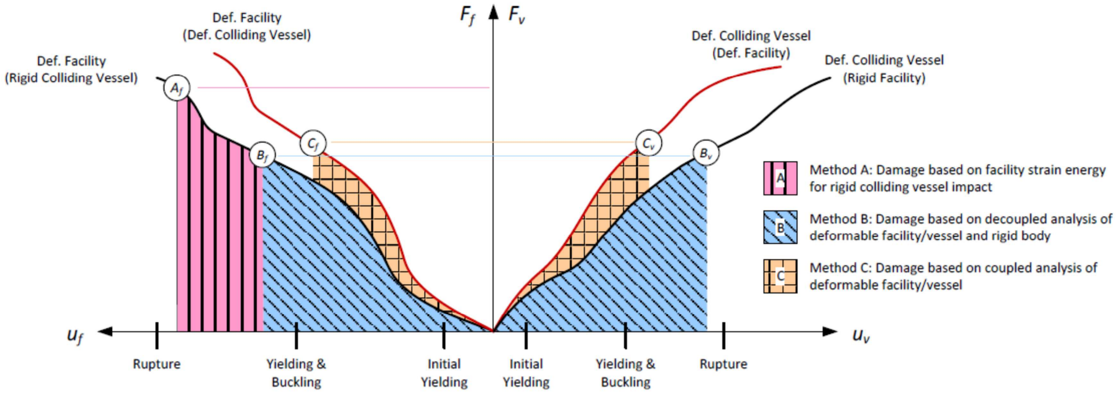

Figure 1. Alternative approaches to predicting facility and colliding vessel strain energy (ABS, 2013)

1.1 Structural design against collision

This paper focuses on modeling a vessel collision incident on a framed steel structure composed of members with tubular cross-section, riser-guard. As method A is employed in the collision analyses, the entire kinetic energy is assumed to be dissipated by the strain energy of the riser-guard structure.

Among the approaches to design structures against accidental collision loads are the use of explicit dynamic nonlinear analysis with the finite element method. Some commercial finite element software packages with explicit dynamic capabilities are Ansys and Abaqus, for example. The finite element model for a riser-guard is usually composed of the tubular members modeled as beam elements with tubular cross-section properties or as shell elements with thickness properties.

The structural design of a steel structure against collision loads are based on energy absorption through plastic strains. The structural response governing the design, besides total energy absorption, are usually the reaction forces, vessel stop time and clearance from the colliding vessel to the protected elements of the platform.

The energy absorption mechanism for steel structure with tubular members have three main components: local denting, bending of the tubular member, and global deformation of the structure. The local denting energy formulation or any joint flexibility effects is not taken into account when modeling beam elements using aforementioned software. In this way, the finite element model using beam elements will not take into account the energy absorption by the means of local denting and its influence on the stiffness and response of the structure.

One alternative is to model the structure as shell elements with enough mesh discretization so that the local denting is captured by the model. This alternative increases the computational cost but is expected to capture with greater fidelity the energy transformation mechanism of a collision with such kind of structure.

2 FINITE ELEMENT MODELS FOR TUBULAR STEEL PIPES UNDER COLLISION

Riser-guards are structures usually made of steel members with tubular cross-section designed to protect risers from possible impacts from collisions on the outer side of fixed platforms. To better understand the structural behavior of those structures when subject to collision loads two models are used in this paper, one with beam elements and the other with shell elements. A simple case was initially simulated in order to check local denting influence on the total energy absorbed. This simple model consists in a simply supported steel pipe subject to a mid-span collision, as presented in Figure 2.

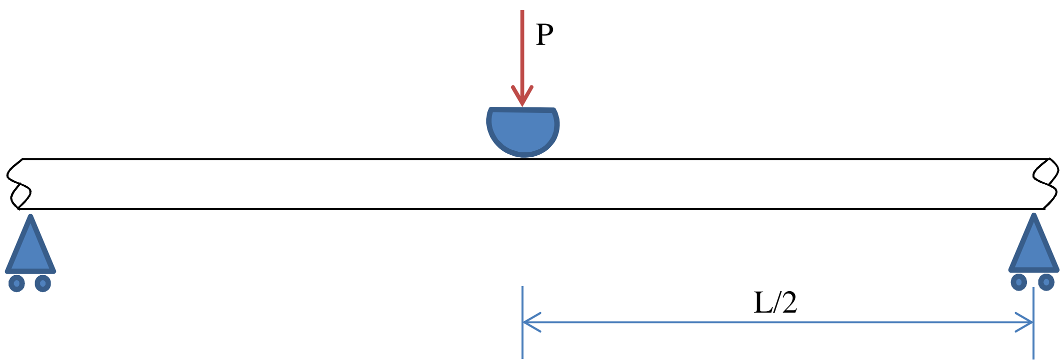

Figure 2. Simply supported pipe with collision object

The general purpose finite element (FE) package Abaqus (2011) is employed for modeling the structure considering material and geometrical nonlinearities. The impact object is considered an analytical rigid surface with the same radius of the pipe. An elastic-perfectly plastic material model is used for the tubular structure. The geometrical properties defined are: i) external radius, R = 50 mm, ii) thickness, t = 5 mm and iii) three lengths L are applied:

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L/R = 10, 12.5 and 15. The material parameters required are given by: i) E = 210 GPa, ii) Poisson ratio, ν = 0.3, iii) yield strength σ_y = 355 MPa and iv) density, ρ = 7.8 ton/m³.

Impulsive force equivalent to a collision of a 10 ton object with an impact velocity of 2 m/s is applied to the model. A failure strain of 0.15 m/m was chosen to describe the ultimate strain limit defining the rupture of the material.

As it is a simple case, analytical formulations for beams can be easily found in the literature and for convenience, the results will be normalized according to these formulations. The ultimate reaction force can be obtained with Eq (1):

$$P_u = \frac{4\,\sigma_y\,Z_p}{L} \tag{1}$$

where the plastic section modulus Z_p is given by:

$$Z_p = \frac{D^3}{6}\left[1 - \left(1 - \frac{2\,t}{D}\right)^3\right]. \tag{2}$$

The elastic strain energy is given by Eq. (3):

$$U_e = \frac{P_m^2\,L^3}{96\,EI} \tag{3}$$

where the maximum elastic reaction force is taken as:

$$P_m = \frac{4\,\sigma_y\,I}{L\,R}. \tag{4}$$

2.1 Beam model

A nonlinear FE model using beam elements for collision into a simply supported tube is detailed in this section. The beam model is simulated by a static analysis and an explicit dynamic analysis for initial verification. The Timoshenko´s beam element, B31 (2-node beam element with linear interpolation formulations in three-dimensional space), is employed in the analyses. For comparison the relation L/R = 15 was considered. The dynamic method contains a tool (called *shear failure) that can be associated with deletion elements to simulate the structural member failure. On the other hand, in the static method procedure, this modeling approach is not easy to be applied. However, the ultimate reaction force must be the same in both analyses.

It is important to mention that, in the static analysis, the reaction force response after structural failure tends to be a constant value because, in fact, the member failure is not represented in the model. In the dynamic procedure, the reaction force falls to zero after reaching the ultimate plastic strain. The reaction force (P) versus the central displacement (δ) of the static and dynamic analysis are presented in Figure 3. As expected, in both models, the structural failure is predicted at the same level of reaction force. In Figure 4a and Figure 4b, are presented the envelope of the equivalent stresses for the static and dynamic models. Note that with the dynamic model the mid-span member failure is simulated.

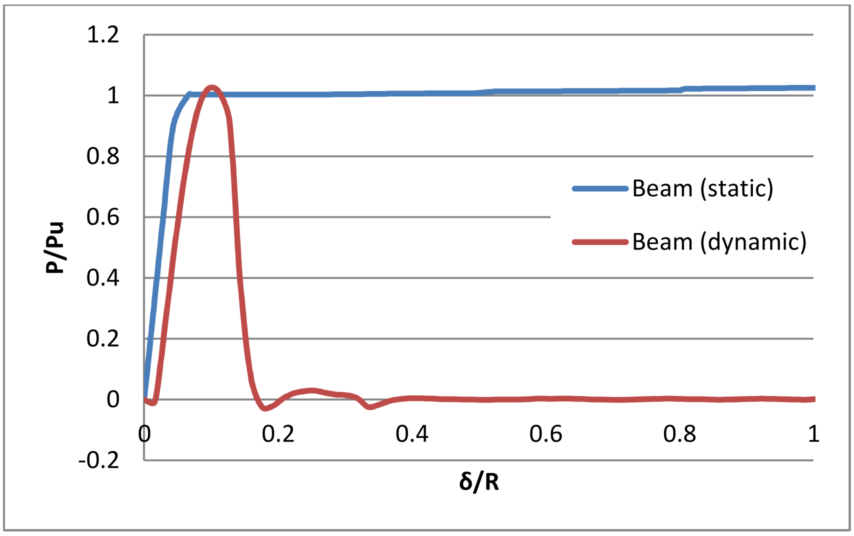

Figure 3. Simply supported pipe mid-span collision reaction forces for static and dynamic analyses

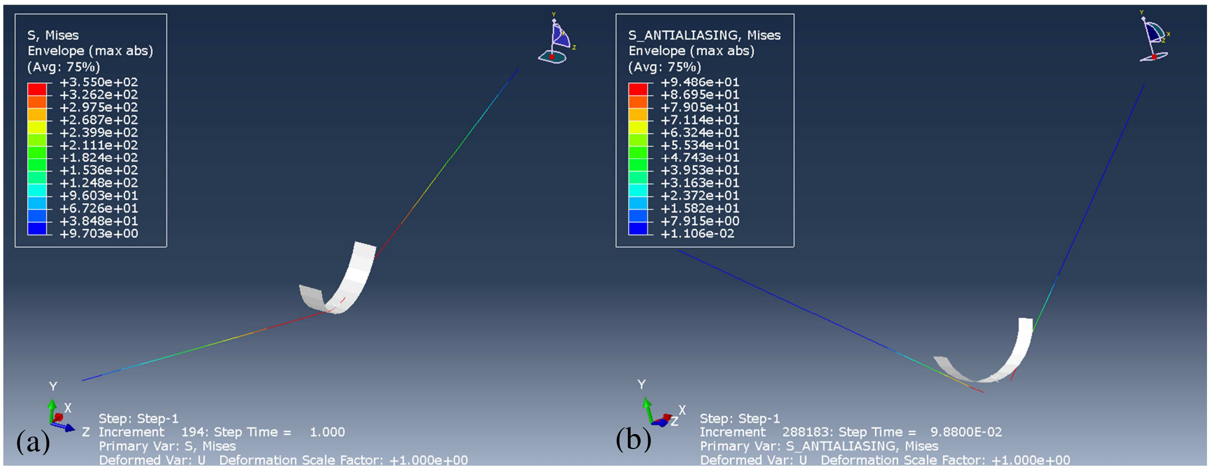

Figure 4. Equivalent stresses for static (a) and explicit dynamic (b) analyses

2.2 Shell model

The analyses with the shell model are performed to verify the influence of the local denting on the total energy absorbed by the collision until the member failure. A 4-node general-purpose curved thick shell element, with reduced integration, hourglass control and finite membrane strain, named SR4, is employed in the analyses. As in the beam dynamic model, this analysis was carried out using Abaqus/Explicit package. In order to compare the results from beam and shell dynamic models three pipe lengths were considered (L/R = 10, 12.5 and 15).

The most important result and governing criteria used in the design of a structure against collision is the total energy absorbed by the structure. In Figure 5, the total energy - normalized by the elastic energy for L/R =15 - versus the external pipe surface central displacement is presented. It can be noted that there is a big difference between the absorbed energy simulated by the beam and shell models for all cases analyzed. The energy absorbed with shell model is approximately 15 times higher than with the beam model simulation. It can be concluded that using beam elements to estimate the rupture energy absorbed of a simply supported tube under mid-span collision, leads to very conservative results. The local effects, for the simple supported tube, are shown to be an important factor into the total strain energy. The equivalent plastic strain envelope distribution of the shell model as well as the after collision structural configuration is presented in Figure 6 for L/R=15 and U/Ue=60.

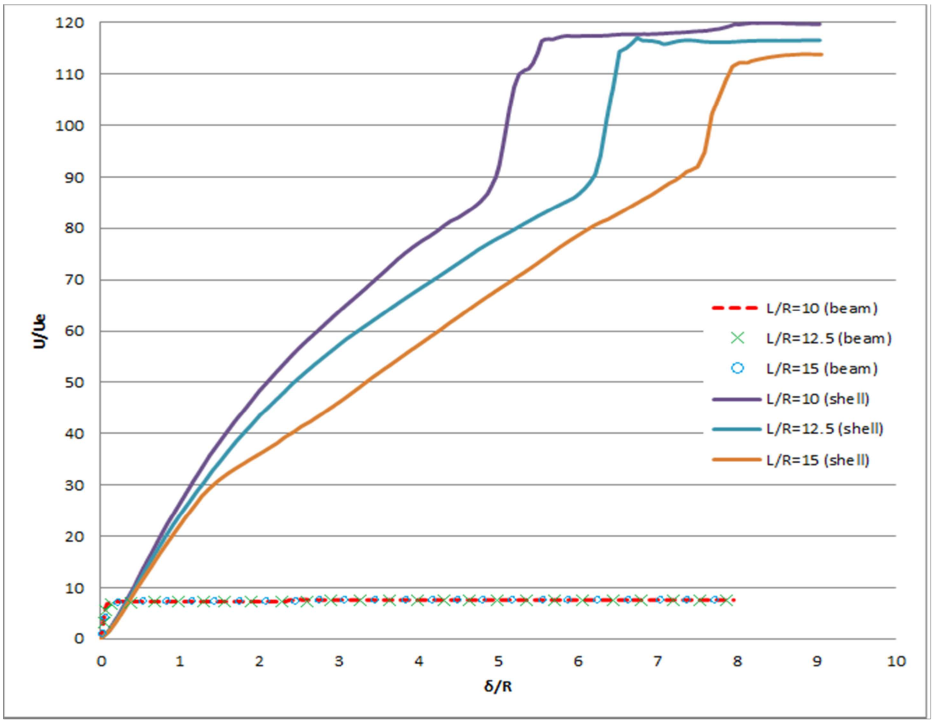

Figure 5. Energy absorption for shell and beam models

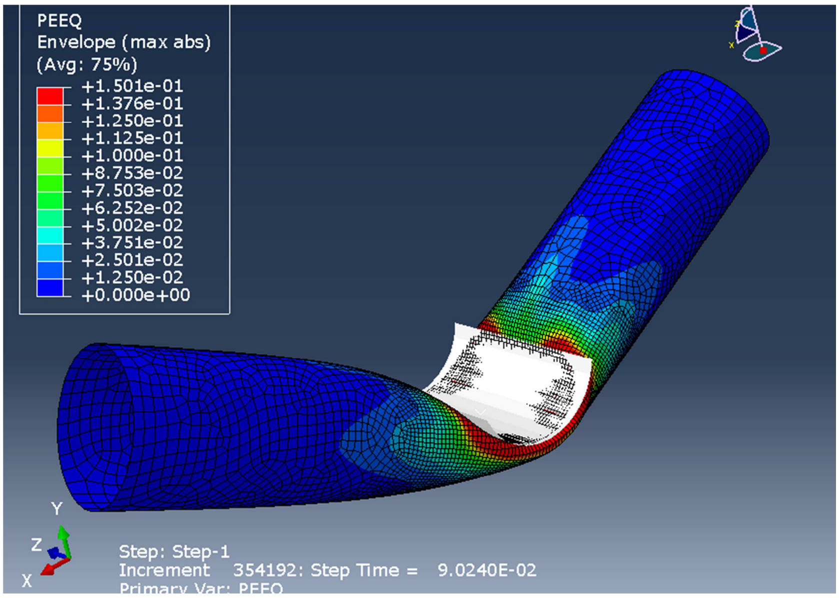

Figure 6. Equivalent plastic strains for a shell model

In Figure 7, the reaction forces vs. central displacement curves comparing the beam and shell models are shown. These curves are built with the explicit dynamic analyses results. It can be seen that with the beam models, ultimate strain is reached and the member rupture is represented by the model. With the shell models, due to local conformation of the pipe in the collision region, the failure of the structural member as a whole is not reached. It can also be noted that the predicted reaction forces are higher when modeling the structure as beams when compared to shells. In terms of geometry, longer tubes yields lower reaction forces when compared to shorter tubes with the same sectional characteristics, while absorbing the same rupture collision energy.

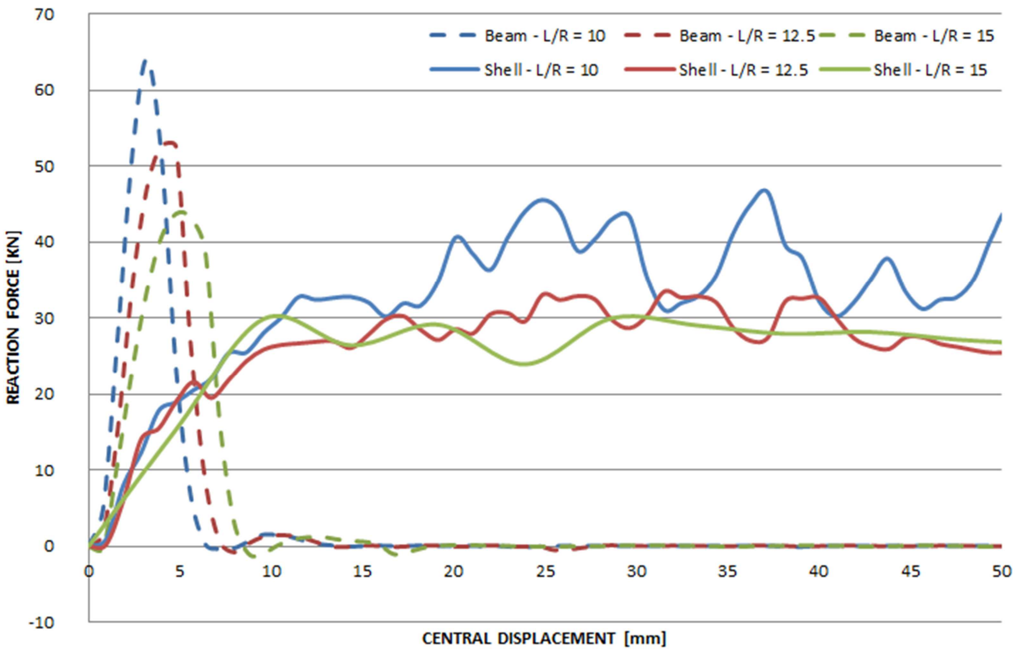

Figure 7. Reaction forces vs central displacement curves for beam and shell models

3 RISER-GUARD FINITE ELEMENT MODELS

While riser-guard structures are not vastly found in literature due to its specific applications or even industrial secrecy, some work have been published where riser-guards structures were analyzed. A typical riser-guard structure is composed of steel members with tubular cross-section welded in a way to form a grid or framing structure.

The design criteria for such structures are not explicitly given in any design rules or guides. Usually the design of riser-guards are driven by design parameters like clearance between the colliding vessel and the protected structure during a collision event, total energy absorption and reaction forces at the riser-guard foundations. The structure should be able to withstand a collision event, absorbing energy by plastic strains and maintaining a clearance between a colliding vessel and the protected structure. The platform structure should be able to withstand the riser-guard reaction forces due to a collision event.

In this section the structural analyses for the riser-guard under collision are presented. In the same way as in the previous section, the structural models used are based on beam and shell elements. Explicit dynamic analyses are performed.

3.1 Characteristics of the models

The riser-guard model proposed and studied in the present work is based on the few information exposed by Palaniandy et al. (2013), i.e.:

- Dimensions - 14 x 10 m;
- Numbers of tubes in the longitudinal and transversal direction are, respectively, 15 and 10;
- Material – yield strength of 240 MPa, ultimate strength of 430 MPa and ultimate strain of 0.2;
- Impact energy – colliding vessel mass of 2500 tons at a velocity of 1.5 m/s.

Some additional considerations were taken into account to predict the analysis:

- The pipe radius suggested are presented in Figure 8;
- The thicknesses for all pipes respect the relation R/t = 10;
- A rigid sphere with a diameter of 3 m was used as the impact object placed at the center of the models;
- The general surface to surface contact formulation with no friction was used for both models;
- The analyses were carried out using Abaqus/Explicit package;
- The only difference between the two models was, as expected, the elements, B31 for beam and SR4 for the shell model.

The general views of the beam and shell models are shown, respectively, in Figures 9 and 10.

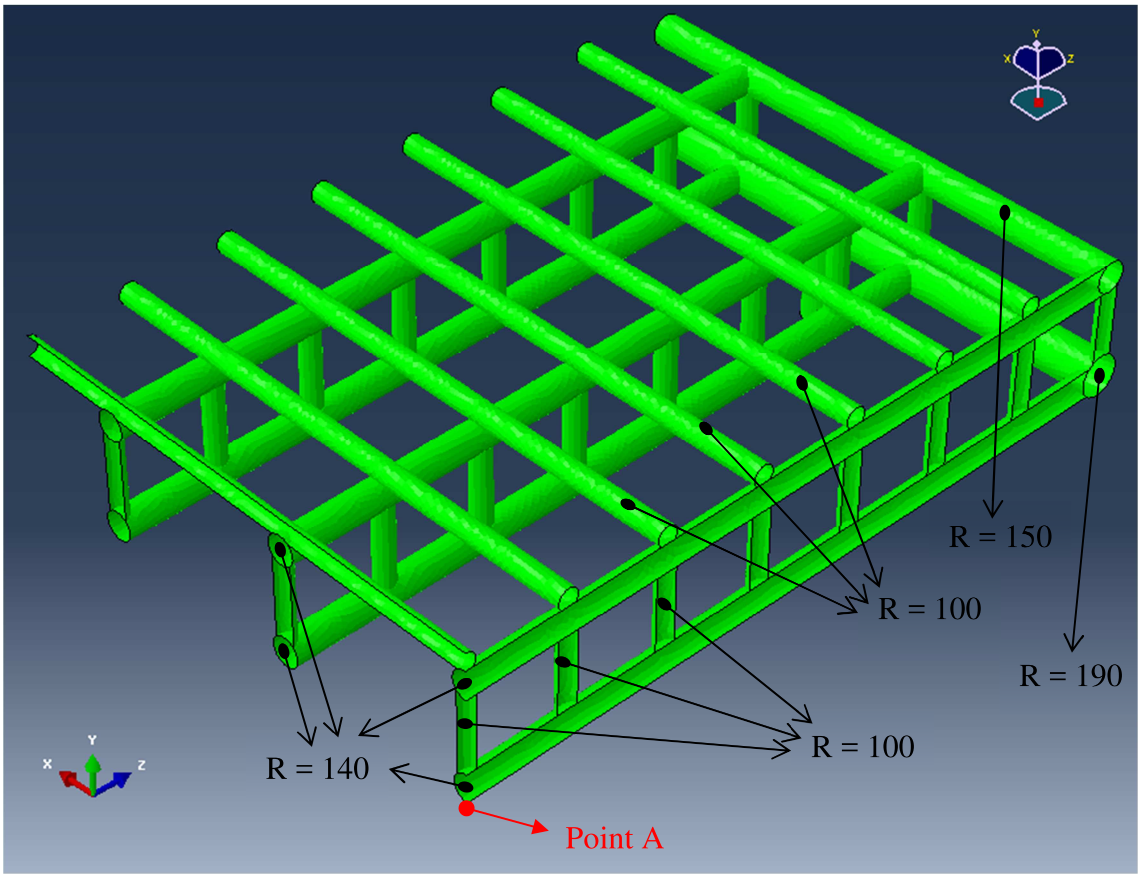

Figure 8. Riser-guard geometry

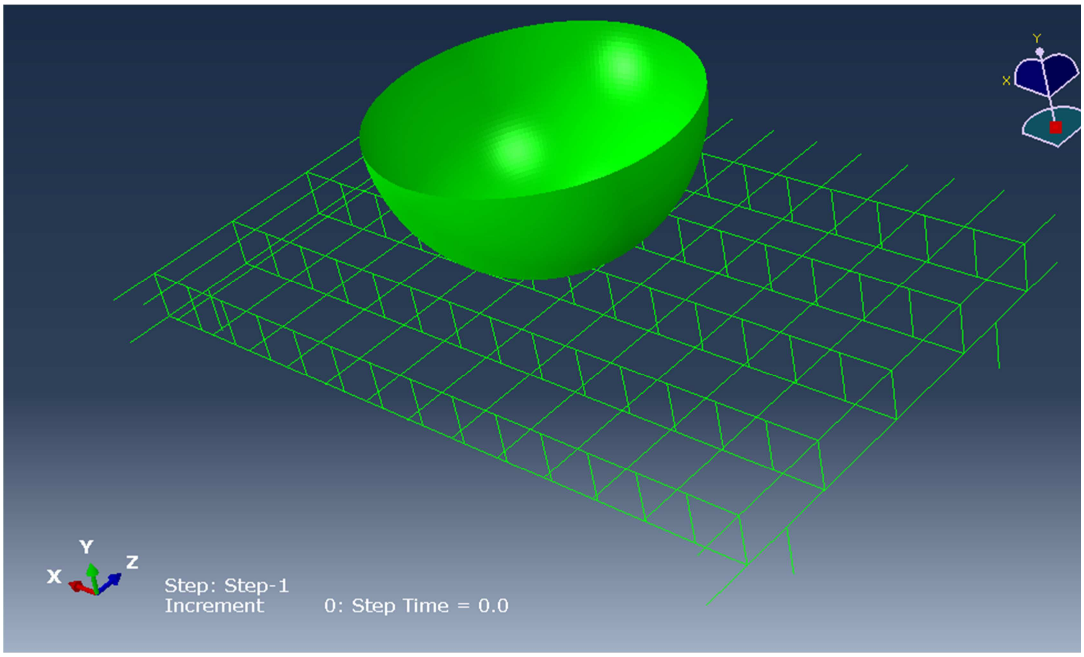

Figure 9. Riser-guard beam model

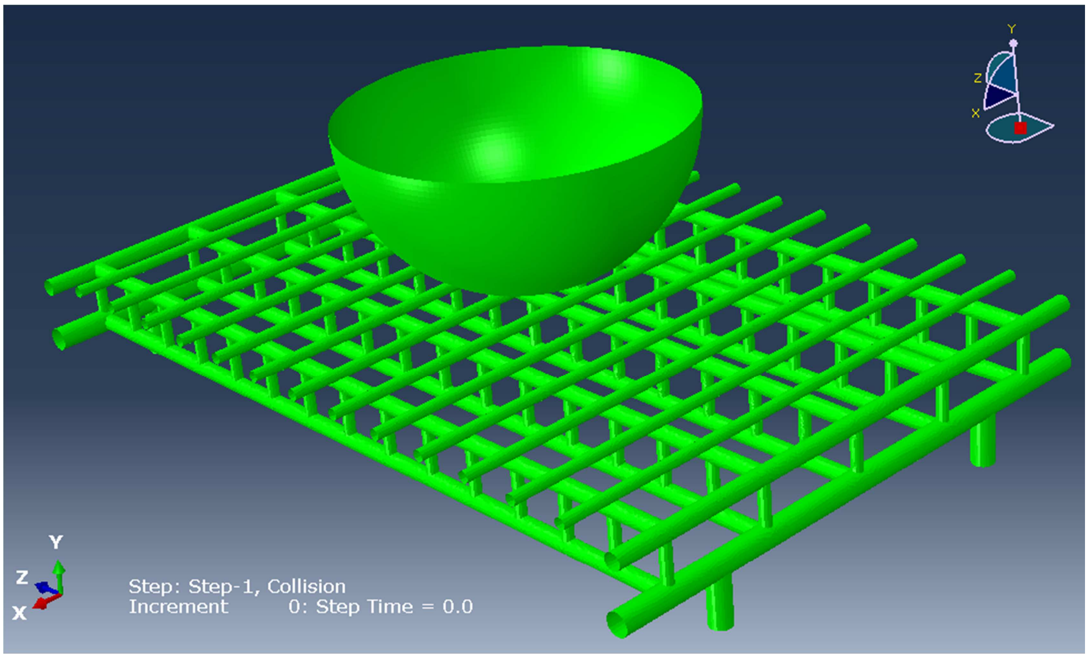

Figure 10. Riser-guard shell model

3.2 Results

The final deformed configuration, with displacements in the Y-direction are presented in Figures 11 and 12 (units in millimeters), for beam and shell models respectively. It can be noted that the displacement at the collision region are similar for both models. However, in Figures 13 and 14 it can be seen the equivalent plastic strain distribution obtained with both models are very different. Moreover, it is noted that local deformation is captured using shell elements while this effect is neglected when using beam elements. It can also be observed that in the two models no member rupture occurs.

The total energy versus the riser-guard central displacement at its most internal point (called as point A in Figure 8) is plotted in Figure 15. It can be observed that the shell model presents lower point A displacement than beam model for the same energy, leading to a conclusion that more energy is being absorbed by the shell model at the same level of displacement. Furthermore, this difference tends to be higher as the energy increases. This is explained due to the local effects that are being captured by the shell model. In order to absorb the same amount of energy, disregarding the local effects, a higher global deformation is needed by the beam model resulting in a lower clearance of the damaged riser-guard and the protected structure.

The time-history of the reaction force of each support is shown in Figure 16. It is noted that a much lower reaction force is obtained using shell model than using the beam model. The model using shell elements is capturing global and local strains while the model of beam

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elements is capturing only global strains. Furthermore, plastic strains are developed in more regions with the shell model due to local effects, therefore, the reaction force is lower in comparison with the predicted with the beam model. Thus, it can be concluded that riser-guards modeled with shell elements will yield more realistic results in terms of structural clearance and foundation loads. When modelling such a structure with beam elements, a higher clearance will be necessary and higher foundation loads will be obtained.

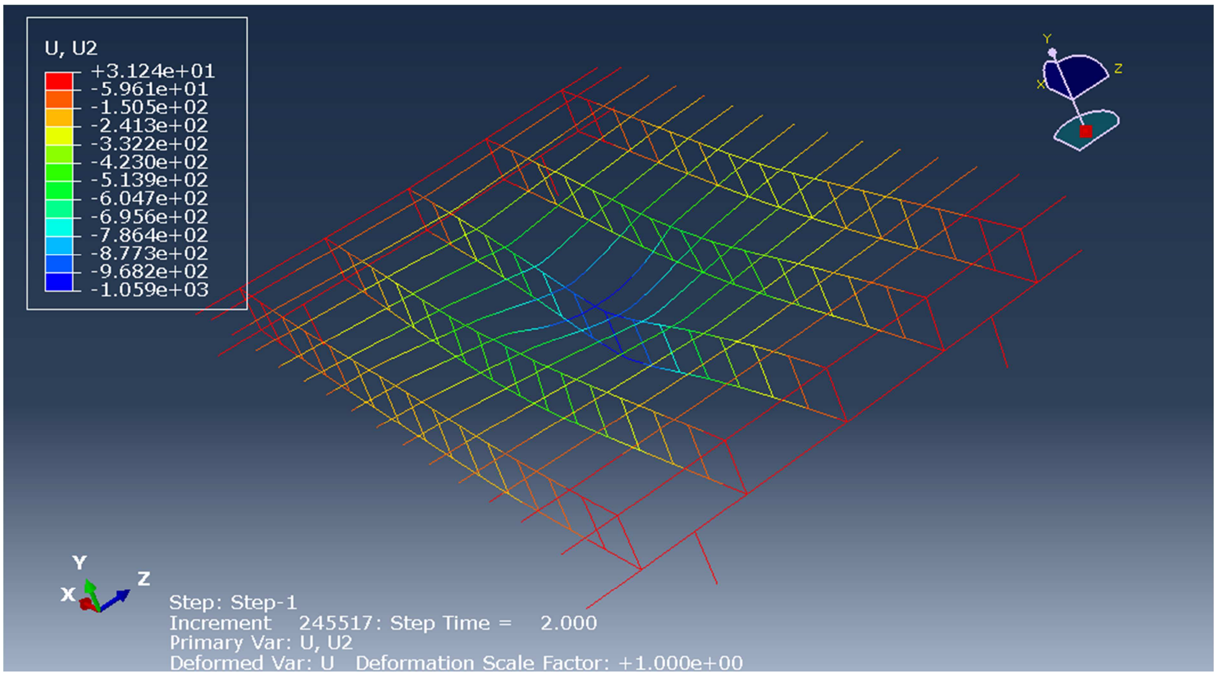

Figure 11. Y-direction displacement [mm] - beam model

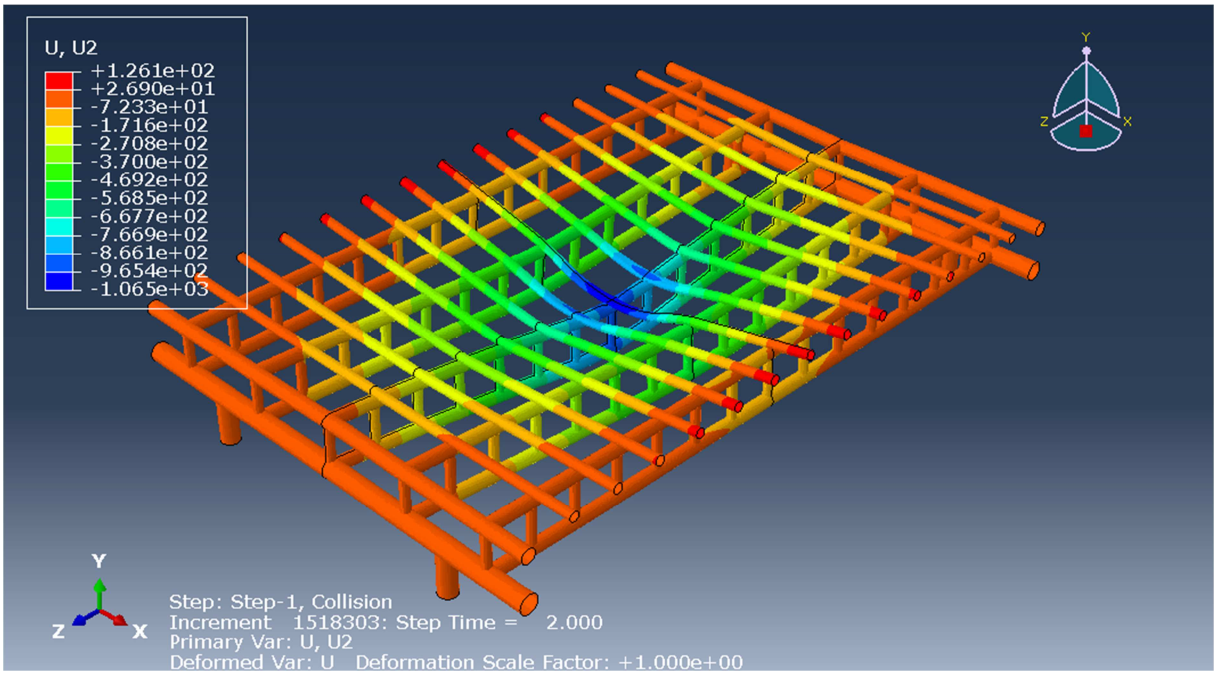

Figure 12. Y-direction displacement [mm] - shell model

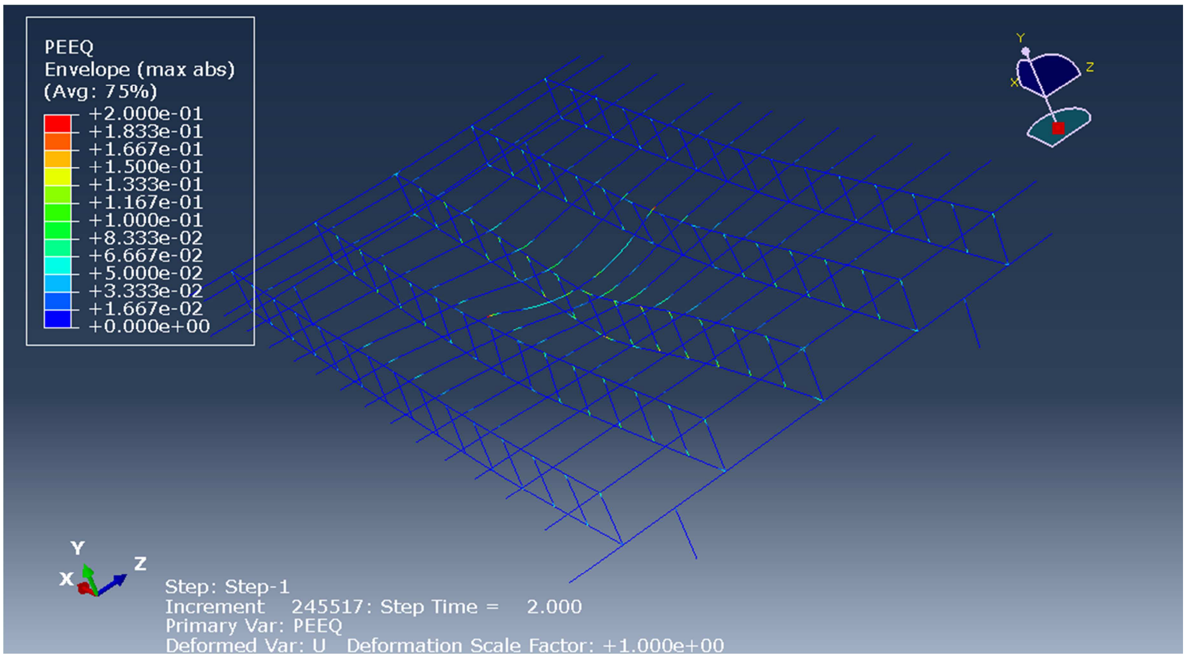

Figure 13. Equivalent plastic strain - beam model

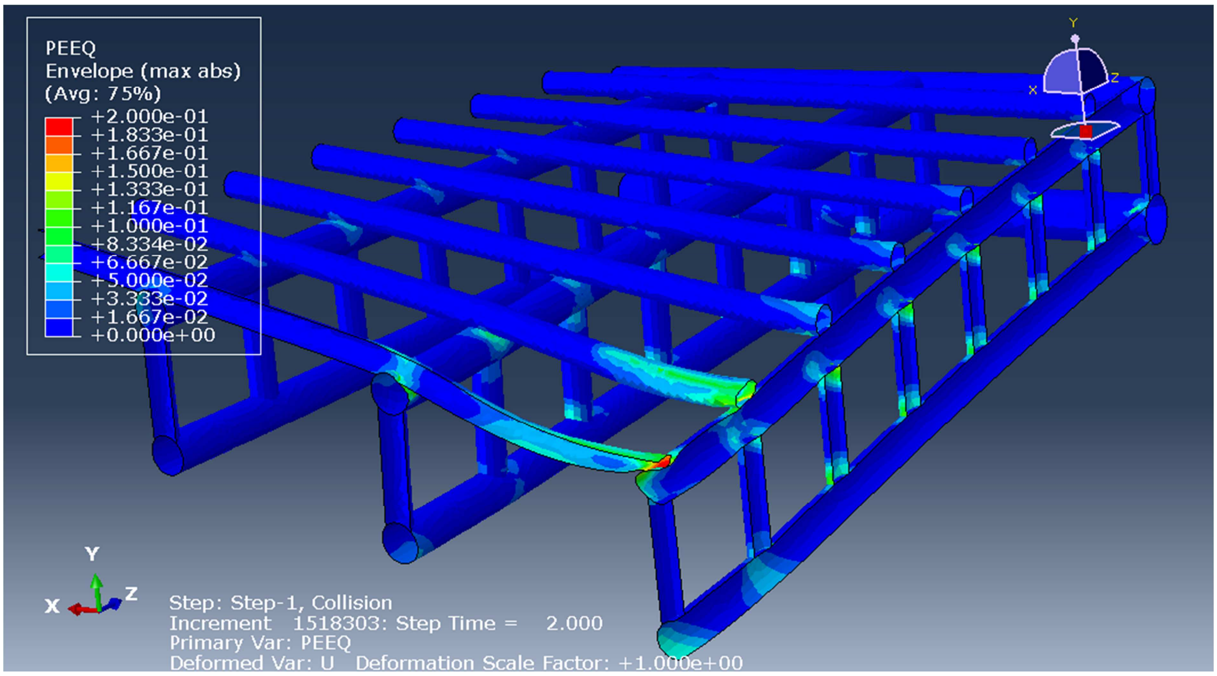

Figure 14. Equivalent plastic strain - shell model

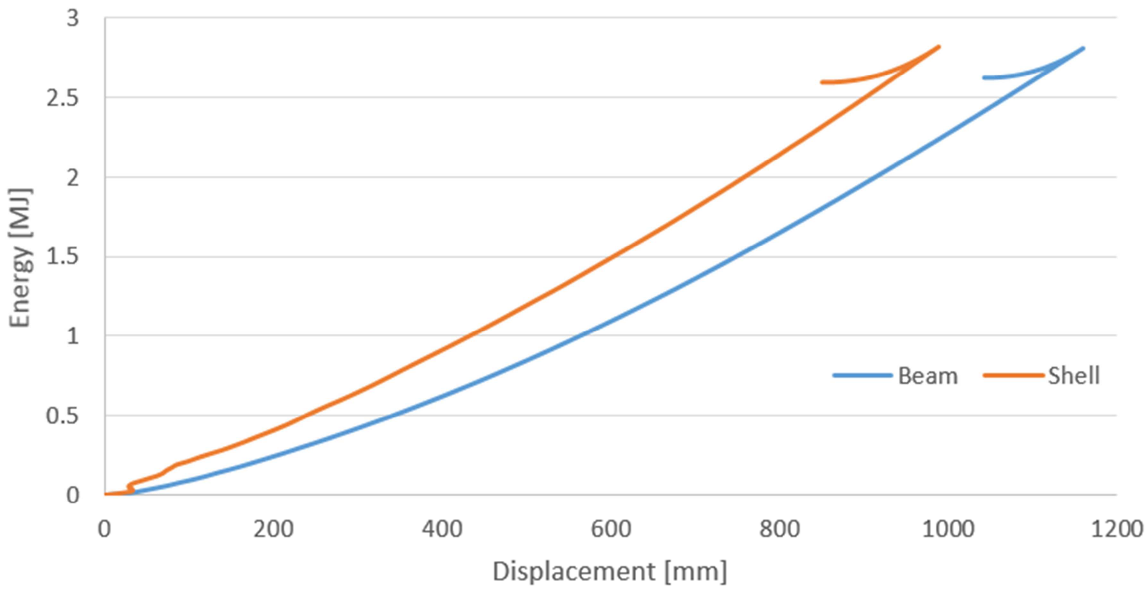

Figure 15. Total energy versus riser-guard central displacement

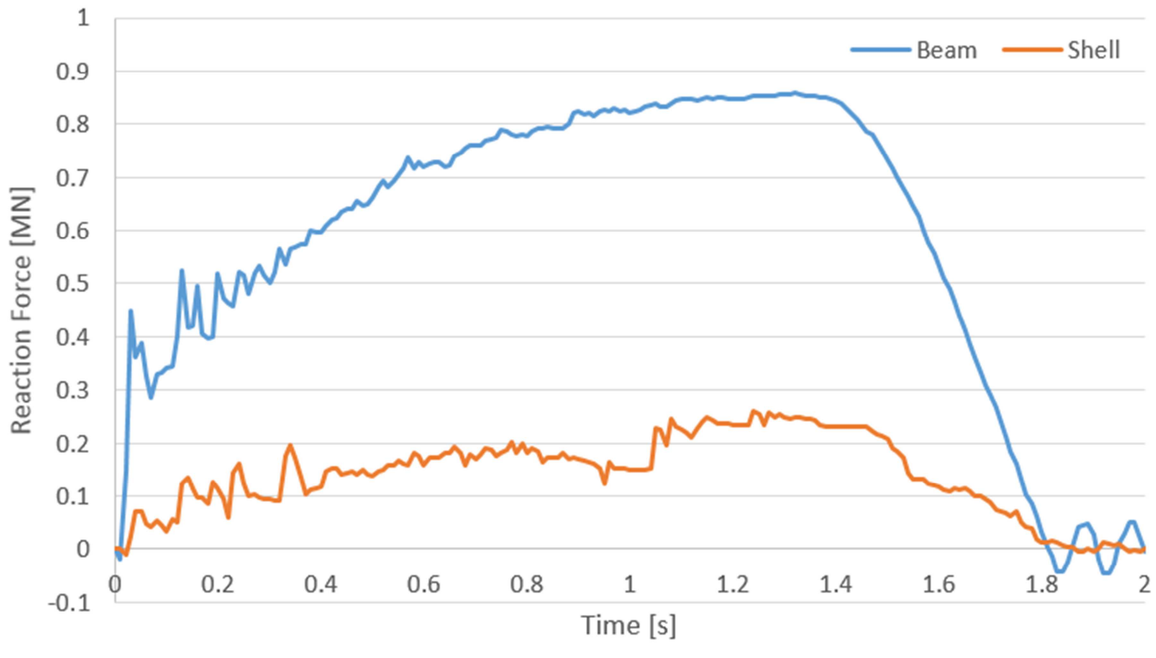

Figure 16. Time-history of the support reaction force

4 CONCLUSIONS

This paper focused in two different modeling techniques to verify the structural behavior of a riser-guard collision event. The idea was to model this structure using beam and shell elements and find out how close or far the results are from each other. The analyses were carried out with material and geometrical nonlinearities using the explicit dynamic method.

Riser-guards are structures usually made of steel members with tubular cross-section designed to protect risers from possible impacts. Thus, initially, a simply supported steel pipe subjected to a mid-span collision was proposed, using beam and shell elements, in order to verify the rupture collision energy of a tubular member. With the results, it was shown that the shell model presents much more energy absorption capability when compared to the beam model until the rupture of the member occurs. So, the use of beam model to design tubes under collision may lead to an oversized structure.

A complete model of a riser-guard structure was also proposed using beam and shell elements. Little information on these structures is found in the literature and then some considerations were estimated to perform the analyses. In these simulations, the impact energy was fixed for both models. No member rupture was captured by either model. It was shown that with the same energy, a higher displacement was predicted with the beam model. In terms of reaction forces, lower reaction forces were obtained with the shell model during the impact event. Both differences are justified by the fact that the shell model is able to account for local strains while the beam model is not.

Finally, once two important design criteria of riser-guards (structure clearance in a collision event and foundation loads) are better estimated with the use of shell elements, it can be concluded that riser-guards should be modeled with shell elements to take advantage of more realistic results. Conservative results are obtained when modelling such structures with beam elements: a higher clearance will be necessary and higher foundation loads will be found.

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