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# Local and global assessments of a subsea riser-spool connection under dropped impact loads

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**Abstract.** Subsea riser tube and spool is often used together to connect the riser of jacket to flowline or pipeline. Due to its limited size (less than 200 m), the location is within the lifting zones of the platform. Consequently, the dropped object hazard has potential high risk and needs to be checked. This paper presents a numerical study on accessing the structural dynamics of a subsea riser connection under the dropped container impact loads. De-coupled local and global models were established. The impact impulse was obtained from local impact analysis by Abaqus Explicit solver, in which deformations from container and pipeline are both captured. The impact energy level is in line with the risk assessment. The global model was built by ANSYS APDL macros. A simple input file is only needed for end users. The nonlinear pipe and soil interaction are included in a simplified manner. The model comprises of static and dynamic analysis parts. The static analysis captures the in-place configuration and the functional loads. The dynamic analysis is a restart with inherited stress state from static analysis. The impact impulse was applied by point loads in a certain time range. The nonlinear soil stiffness was approached by spring elements (compression only). The dynamic analysis was done in a longer time, ensuring to capture any dynamic effects. The interface loads at the riser stick-out and riser anchor are both extracted and discussed. It is shown that present structure design can withstand the dropped loads at the input energy level.

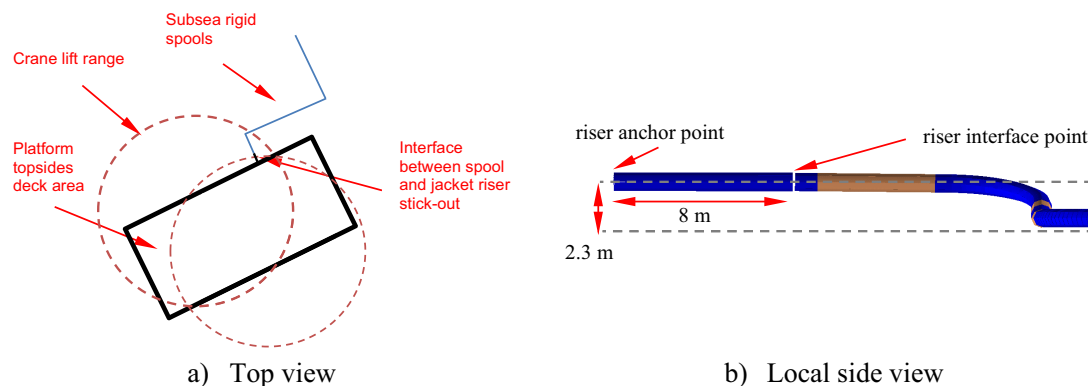
## 1. Introduction

A subsea rigid spool is often used to do the connections between riser, pipeline, or other subsea structures. Due to its limited size (less than 200 m), the location is normally within the lifting zones of the platform, as seen from Figure 1(a). A connection scenario, as shown in Figure 1(b), is quite vulnerable to external impact loads due to the freespan from the riser anchor point to the first touchdown point of subsea spool.

The damage caused may lead to severe environmental and economic consequences. Risk assessment to dropped object loads towards the subsea spools are required, proper measure has to be taken if the risk level exceeds acceptable limit, for example, subsea protection structure might be needed (GRP cover or other protections, see the discussion by Zhang et al. (2019) [1]). The total risk (R) is the summation of the product of each event's probability (Pi) and its corresponding consequence (Ci) as expressed in equation (1).

$$R = \sum_i^N C_i \times P_i \quad (1)$$



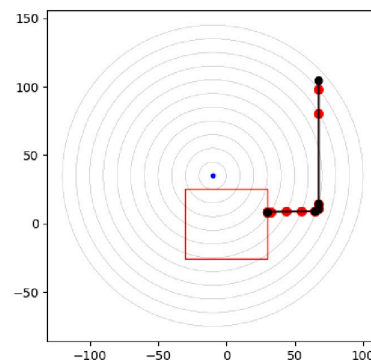


**Figure 1:** a) An illustration of a platform crane lift range and subsea spool layout. b) a local side view of the connection between the riser tube end and the subsea spool.

The probability level check could be done according to DNVGL-RP-F107 (2019) [1]. As shown in Figure 2, the total hit probability along the spool can be calculated by summing up the corresponding probability level at each ring. The hit probability on general is linked to the water entry angle, water depth, the shape of dropped object etc. as discussed in by Aanesland (1987) [3] and Yasseri (1997) [4] and the recent work by Fossan et al. (2016) [5]. The impact energy associated with hit probability shall be established before the consequence analyses. This paper mainly focuses on the consequence (C) check to the interface loads at the riser stick-out by doing nonlinear finite element analyses. The probability level calculation is not covered. The concluded design accidental loads to consider in consequence analysis was 400 kJ (initial kinetic energy) in operation. This load is with  $10^{-6}$  annual hit frequency on the spool.

The consequence of the dropped object to subsea rigid spools is twofold. The local damage to the pipeline and the global damage to the jacket riser connection. The local damage is similar to subsea pipeline under dropped object impacts. The energy sharing between the pipeline, its supporting seabed and the global pipeline system shall be well considered to get the non-overconservative results. Nevertheless, the local damage could be first conservatively assessed by assuming the seabed and the dropped objects are both rigid and all energy goes to the pipeline, see Wiezbicki and Suh (1988) [12] and a recent work by Yu et al. (2016) [8]. Zeinoddini et al. (2013) [9] demonstrated that the seabed flexibility and internal pressure play an import role on the local damage of the pipeline under impacts from dropped objects. Bruschi et al. (2018) [5] presented a summary work regarding on the external interference towards offshore pipelines by the dropped and dragged anchors. A review of state-of-the-art tools was included. Selker et al. (2018) [7] analyzed the impact of dropped objects and anchor dragging on pipeline by including the pipe-soil interaction and transient dynamic effects. The soil was modelled as a continuum with Mohr-Coulomb failure model. Zhao et al. (2018) performed the impact analysis of dropped objects and trawl board on submarine pipelines by using non-explicit finite elements. Drucker-Prager model was used to analyze the elastic-plastic properties of soil under impact. Alsos et al. (2012) [10] found that the global deformations might be triggered, and it will lower the dissipated energy into the local damage. However, the freespan during the impact scenario is not often considered. On the other side, the connection between riser and spool could be largely influenced in such high impact loads.

In this paper, a de-coupled approach was adopted to check the integrity of the interface between riser stick-out and spool under dropped container impact loads. The local model is an explicit analysis in Abaqus (2019) [12] while the global model is a transient dynamic analysis in ANSYS 19 [14] with pre-stressed state (static operational loadings). The soil and concrete mattress stiffness are simplified by nonlinear compression only springs, which are normally only available as engineering inputs. Nonlinear material properties with temperature derating are included to capture the plastic deformations if there are any, especially for the high energy impact case.



**Figure 2:** An example of probability calculation model according to DNVGL-RP-F107 (2019).

## 2. Methodology

### 2.1 Local model

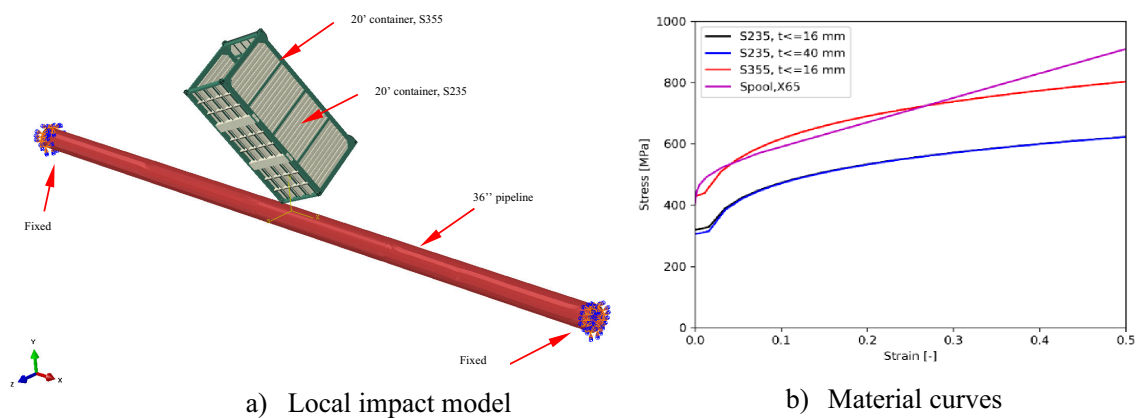
A typical 20' container (2440 mm x 2900 mm x 6100 mm) is modeled in detail as seen in Figure 3(a). It is made of material S235 and S355, the material properties are obtained based on DNVGL-RP-C208 (2019) [16]. To be conservative, the mean value of the corresponding material class has been used for the container. Figure 3(b) shows the material curves used in the simulation. There is no need to include damage in the material properties in this study for both pipeline and container. The first reason is that only marginal deformation observed from the pipeline side, and the container represents a conservative load to the pipeline by not invoking crack or fracture damage.

The container is rotated in a way that the eccentricity is minimized during the impact, aiming for the most conservative impact scenario. The pipeline is fixed at both ends without supports below, simulating a freespan situation for the impact loads, similar as the spool case. Contact pairs are defined to capture the interactions between container and pipeline, and possible contacts within deformed structures. No fracture model was implemented into the container, so the impact force is conservative. The pipe is made of X65 material (yield stress 455 MPa) with internal diameter 859.0 mm and the wall thickness ( $t$ ) is 40 mm (outer diameter  $D$  is 939 mm).

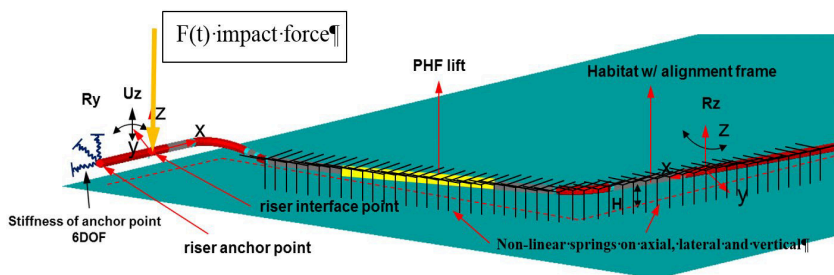
### 2.2 Global model

The global model was built in ANSYS 19 [14] via the APDL macros. It includes uneven seabed, tie-in process (with combination of misalignment at tie-in ends), dynamic analysis, rock-cover simulation, and modal analysis etc. Python scripts [17] are used to do pre- and post- processing of the inputs or results, such as the combination of tie-in tolerances and various code checks according to DNVGL or ASME regulations etc.

In this model, a static model was first built, normal installation and operational loads have been simulated. The impact simulation is a restart from the operation step. To simulate the dynamic behaviours, the transient analysis feature has been activated after the static spool in-place configuration is finished (operation with end expansion, internal pressure 17.5 MPa). Nonlinear springs (axial, lateral and vertical) have been included in the model. The springs will not be activated in the static analysis, in which a flat seabed was used. The flat seabed is not activated, and the springs are activated in the transient analysis. A duration of 3 seconds after impact has been simulated to catch dynamic amplifications if there are any. The impact force history is obtained from local damage analysis from Abaqus Explicit solver (2019) [13]. Figure 4 shows the general arrangement of the finite element model in ANSYS [14]. The stiffness of the anchor point has also been included by using 6DOF stiffness matrix, this is to lower the conservatism of the interface loads during tie-in and dynamic impact loads.



**Figure 3:** a) Impact model in Abaqus 2019 [13]. The color presents different material types used in the model. b) Material curves for container and spool according to DNVGL-RP-C208 (2019) [16]. The mean values of material properties are used for container.



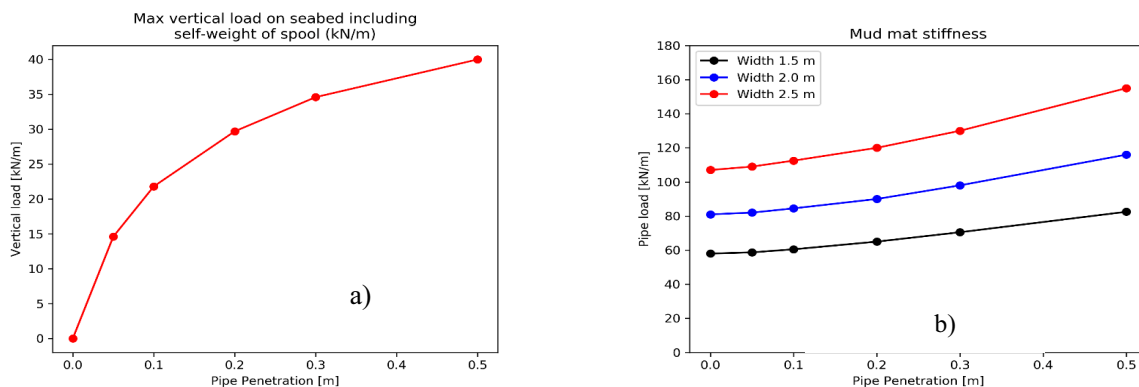
**Figure 4:** Illustration of the global finite element model in ANSYS 19 [14] (PHF means pipeline handling frame).

Prior the impact analysis, geotechnical assessment has been performed for checking the soil stiffness under impact loads. The concluded results were used here. The vertical soil stiffness between spool/pipeline and the seabed is presented in Figure 5 (a). In the touchdown area, 2 m along spool, a heavy-duty polyurethane support mattress (Mudmat®30, see [15]) was installed before spool was lowered after tie-in. The corresponding stiffness is shown in Figure 5 (b). The vertical springs are only with compression stiffness.

### 3. Results

#### 3.1 Local results

Figure 6 shows the screenshots of the simulations. It is seen that part of the kinetic energy is remained after impact due to the rotation of the container. The container corner undergoes large deformation, local buckling of the beams is observed as shown in Figure 7(b). The deflection of the mid-span can reach as high as 34 mm ( $\Delta$ ) and the local dent is only up to 8 mm ( $\delta$ ) depth as shown in Table 1.



**Figure 5:** a) Nonlinear vertical soil stiffness curve for the seabed. b) Nonlinear vertical soil stiffness for section with mattress, pipe-load versus further penetration from as-installed condition (The width 1.5 m for equivalent bearing width is used).

Figure 7(a) shows the local dent. Only minor damage is observed. The local dent obtained is far less than the analytical equation, which is calculated as 103 mm, see Eq. (2) (DNVGL-RP-F107, 2019 [2]). This equation assumes that the ends can move freely, without considering axial force.

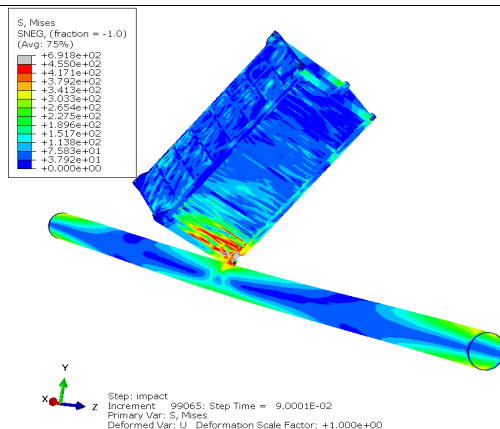
$$E = 16 \cdot \left(\frac{2\pi}{9}\right)^{\frac{1}{2}} \cdot m_p \cdot \left(\frac{D}{t}\right)^{\frac{1}{2}} \cdot D \cdot \left(\frac{\delta}{D}\right)^{\frac{1}{2}} \tag{2}$$

where  $E$  is the dissipated energy,  $m_p$  is the plastic bending moment,  $D$  is the outer diameter,  $t$  is pipe wall thickness,  $\delta$  is local denting distance.

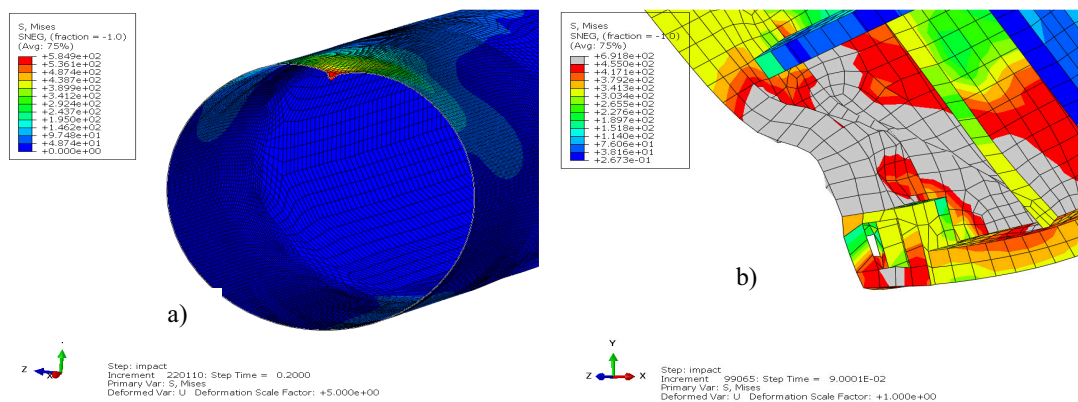
The main reason is due to the shared energy between pipe and container and as well as the freespan flexibility boundary conditions. Figure 8 shows the impact forces during the impact simulation (up to 0.2 s). They will be used in the global model for a dynamic analysis.

**Table 1:** Damage size and damage categories based on local impact analyses and analytical solution in DNVGL-RP-F107 (2019) [2].

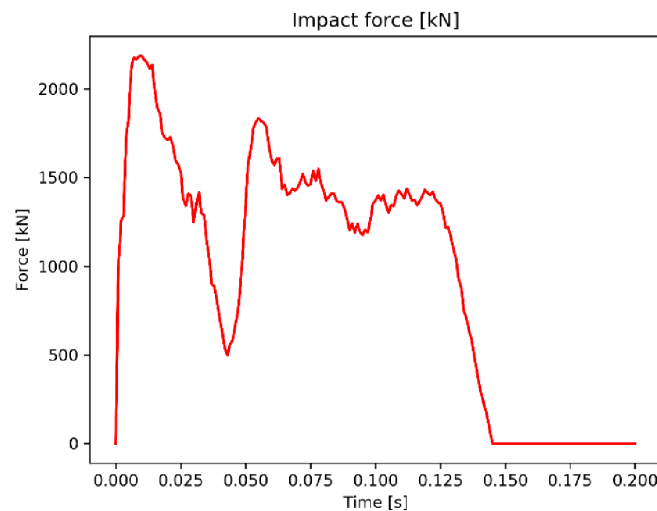
Cases	Deflection $\Delta$ [mm]	Local Dent $\delta$ [mm]	Normalized dent [%]	Damage level
Numeric	-34.0	8	0.8	Minor damage D1
Analytical	0	103	11	Major damage D3



**Figure 6:** von Mises contour plot of simulation results with initial kinetic energy  $E_{int} = 400$  kJ. Detailed deformations at impact place are shown in Figure 11 and Figure 12.



**Figure 7:** a) Local dent plot due to impact with initial kinetic energy  $E_{int} = 400$  kJ with scale factor 5. b) Local deformation of the container corner (von Mises contour plot, grey color shows stress level larger than 455 MPa).

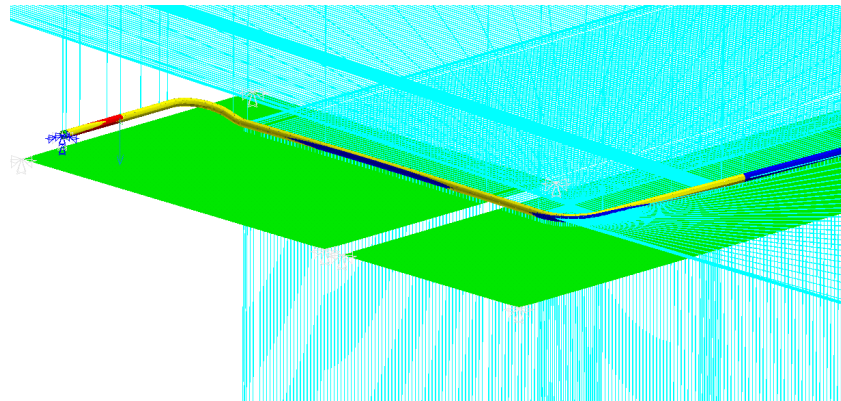


**Figure 8:** Impact force with impact duration with initial  $E_{int} = 400$  kJ.

### 3.2 Global model results

The impact force from local FE impact analysis as seen from Figure 8 is applied as point forces at the interface point (see Figure 4). The impact force is applied after the spool is under operational loads ( $T=12$  s). The impact force vanishes at time approx. 12.20 seconds and the simulation continues to time 15.0 seconds. Figure 9 shows a screenshot of the FE model. The spring elements are with length 100 m (light blue lines in Figure 9). The spring elements are made long enough to eliminate the influences of the strain/displacements caused during the static analysis procedures.

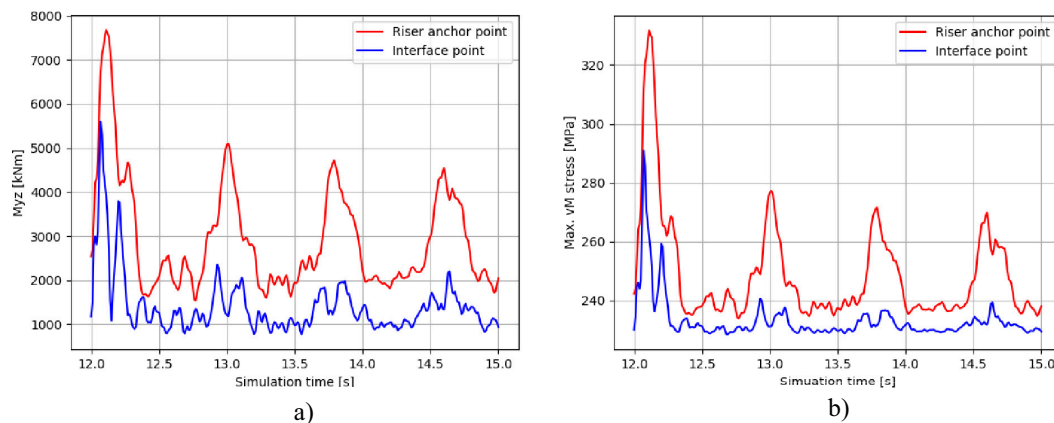




**Figure 9:** Screenshot of finite element model in ANSYS 19 [14] at time 12.01 s. The soil spring elements are represented by light blue lines.

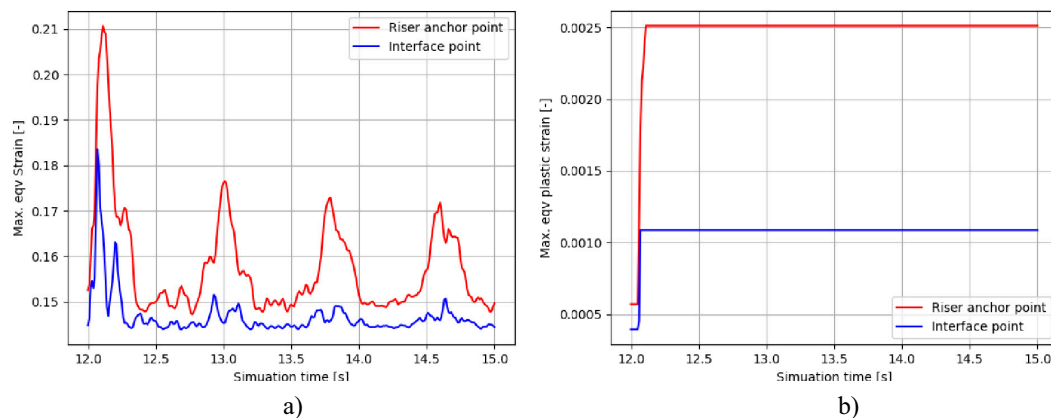
The resultant bending moment and von Mises stress are presented in Figure 10(a, b) respectively. It is seen that the resultant bending moment is as high as 7800 kNm and the maximum von Mises stress is 330 MPa, which is less than the factorized yield strength (432 MPa), see DNVGL-ST-F101 (2017) [17]. Thus, the stress level under such impact is acceptable. Note that the limit value used in (345.6 MPa) is with safety factor 0.80 and not applicable here.

Additionally, Figure 11(a) show the maximum equivalent strain at riser anchor and interface point during the simulation period (in percentage). It is seen that the maximum strain is less than 0.4% at riser anchor, which may indicate that fracture won't initiated. Note that, the local stress concentration due to material or geometry non-continuity is not included in the global model. And additionally, the low-cycle fatigue is not checked here, the allowable cycles might be limited under such high plastic strains. In this respect, separate engineering checks shall be performed to the welding sleeve. Figure 12 presents the dynamic soil forces during the simulated duration, in which the force transfers along the subsea pipelines. As seen from these results, similar patterns are observed, it may be an indication of elastic behaviours are only activated during the impact, for example the equivalent plastic strain as shown in Figure 11(b) is very small.

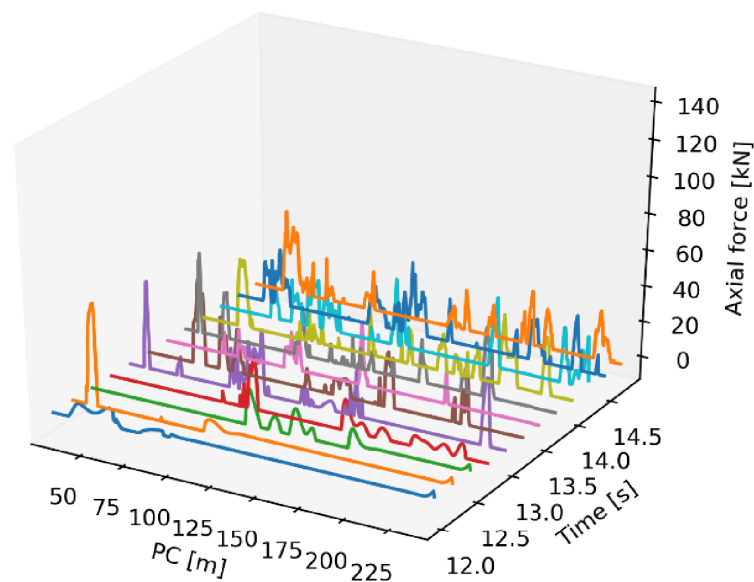


**Figure 10:** a) Total bending moment at interface and riser anchor. b) Max. von Mises stress at interface and riser anchor.





**Figure 11:** a) Max. equivalent strain [%] at interface and riser anchor. b) Equivalent plastic strain [%] at interface and riser anchor.



**Figure 12:** Soil force during the dynamic analysis at time interval 0.5s. PC is the accumulated pipeline coordinates along the spool.

#### 4. Conclusions

Following conclusions are made:

- A framework of local and global numerical models has been successfully set-up for analyzing the dropped container impact to subsea rigid spools.
- The local model is based on Abaqus explicit solver and can capture the local damage due to the high level of impact energy.
- The global model is built based on static and dynamic analysis. The static analysis was used to capture the in-place and pre-stress states for spool in operations. The dynamic analysis was used to capture the dynamic amplification effects if there are any.

- Nonlinear material properties of steel and the nonlinear spring elements were used to approach the nonlinear effects of steel, and penetration into soil successfully.
- In the scenarios analysed, the spool has minor damage, and the riser anchor has marginal plastic deformation with initial kinetic energy 400 kJ.

It is noticed that less conservative results might be achieved if a coupled analysis model is used, for example the combination of global and local model in one program platform, either Abaqus or ANSYS. However, this has not been investigated in this paper.

### Acknowledgements

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