# IMPACT AGAINST OFFSHORE PIPELINES

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*Summary* Offshore pipelines subjected to accidental impact loads from trawl gear or anchors may experience large global deformation and large local strains, creating a complex stress and strain history that may lead to fracture during the rebound phase after the impact event. In this study experiments and numerical simulations have been carried out to predict the behaviour of a pipeline which is first impacted by an anchor and subsequently hooked and released due to fracture of the anchor chain.

## INTRODUCTION

Transportation of oil and gas is an essential part of the offshore industry. To this end pipelines are under widespread use, often under high pressures and temperatures. Impact from trawl gear and anchors are known to cause problems, especially if the pipeline is hooked and dragged far from its initial position. An impact with hooking and following release of the pipeline produce a complex stress and strain history which is not well covered in the current guidelines and design codes [1].

The present study investigates impact against a typical offshore pipeline using a pendulum accelerator. After the impact, the pipelines are straightened in a tension rig. Albeit simplified, this load sequence is thought to capture the main physics of an actual impact event including the hooking and release of the pipeline. A number of material tests were conducted to calibrate a constitutive relation and a fracture criterion for use in the numerical simulations. The global response of the simulations was in excellent agreement with the experiments, but the force level at fracture was overestimated. To be able to rely on results from numerical analyses of a complex problem requiring a high degree of accuracy, laboratory tests are indispensable.

## MATERIAL TESTING AND MODEL CALIBRATION

The material is in steel grade X65 which is commonly found in offshore pipelines. It has a nominal yield stress of 450 MPa, an ultimate tensile strength of 535 MPa and a Young's modulus of 208000 MPa. Tensile tests on smooth axisymmetric specimens were carried out to investigate cross-section homogeneity and anisotropy. Strain rate sensitivity tests were conducted in a split Hopkinson tension bar. Notched axisymmetric specimens were used to determine the fracture strain as a function of stress triaxiality. As isothermal conditions were assumed, no temperature softening was accounted for.

From the tension tests it was evident that the material was indeed homogenous and isotropic. Some typical stress-strain curves are shown in Figure 1 (taken from different directions with respect to the pipeline's longitudinal direction). The tensile data, along with the strain rate sensitivity data, was used to calibrate the Johnson-Cook (JC) constitutive relation [2], relating the equivalent stress $\sigma_{eq}$ to the equivalent plastic strain $\varepsilon_{eq}$ and the equivalent strain rate $\dot{\varepsilon}_{eq}$, while omitting temperature dependence. The JC fracture strain $\varepsilon_f$ is a function of stress triaxiality $\sigma^*$ and was calibrated using axisymmetric tensile specimens with three different notch radii: smooth, 0.8 mm, 2.0 mm.

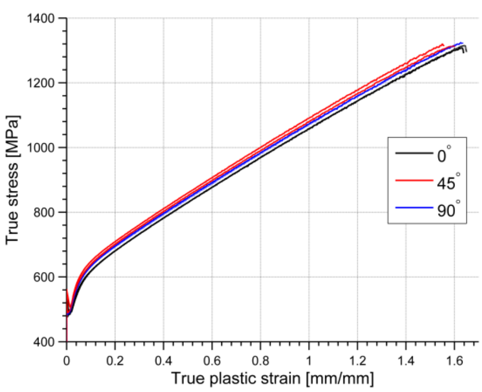


**Figure 2**: *True stress-true strain relations from tensile tests from different directions.*

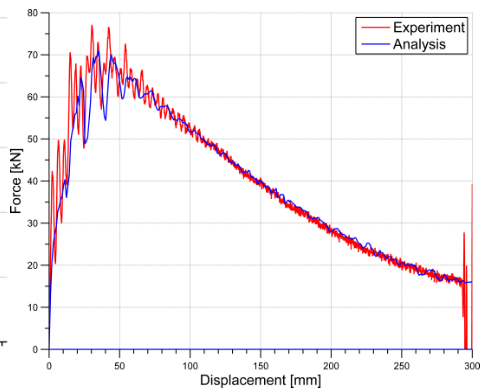


**Figure 1**: *Force-displacement curves for experiment and simulation from impact step.*

## COMPONENT TESTING AND ANALYSES

A simply supported pipeline (span = 1 m) with an inner diameter of 123 mm and wall thickness of 4 mm was struck by a trolley weighing 1472 kg at velocities in the range 2-5 m/s, and the event was captured using a high-speed camera. After impact, the pipelines were pulled straight quasi-statically in a tension rig and inspected for fracture as the axial load increased. Fracture was detected on the impact side of the pipeline shortly after the tensile load was applied. Numerical analyses were run using 8-node volume elements in Abaqus [3]. Results show that the global response of the pipeline was captured very well, particularly the impact step as seen in Figure 2 and Figure 3. Localization of the strains was also well described, but the onset of fracture was not captured properly as the load level at this stage in the analysis was somewhat overestimated compared to the test. Figure 4 shows the equivalent plastic strain in the simulation when fracture has occurred in the experiment.
From the experiments and analyses it is clear that the critical zone undergoes a complex strain history. Looking at the principal stresses in the critical element on the outer surface of the pipeline (see Figure 5), the analyses suggest that it first experiences tension (states 1-2) before being compressed (states 2-7) and then unloaded (states 7-8). The stretch step (states 8-11) changes the stress state towards uniaxial tension, which is reasonable. Using a fracture criterion not only dependent on stress triaxiality may improve the results regarding prediction of fracture.

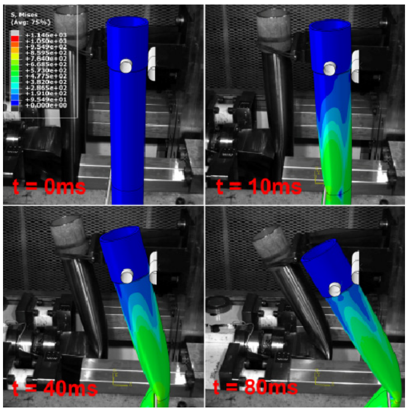


**Figure 3**: *Images from high-speed camera and simulations ($v_0$ = 5.13 m/s).*

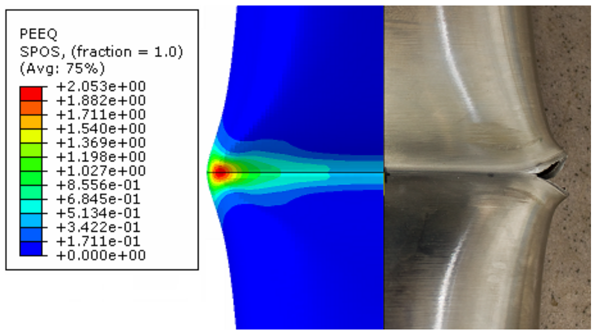


**Figure 4**: S*imulation with equivalent plastic strain (left side) and photo of impacted and stretched pipe with fracture ($v_0$ = 5.13 m/s).*

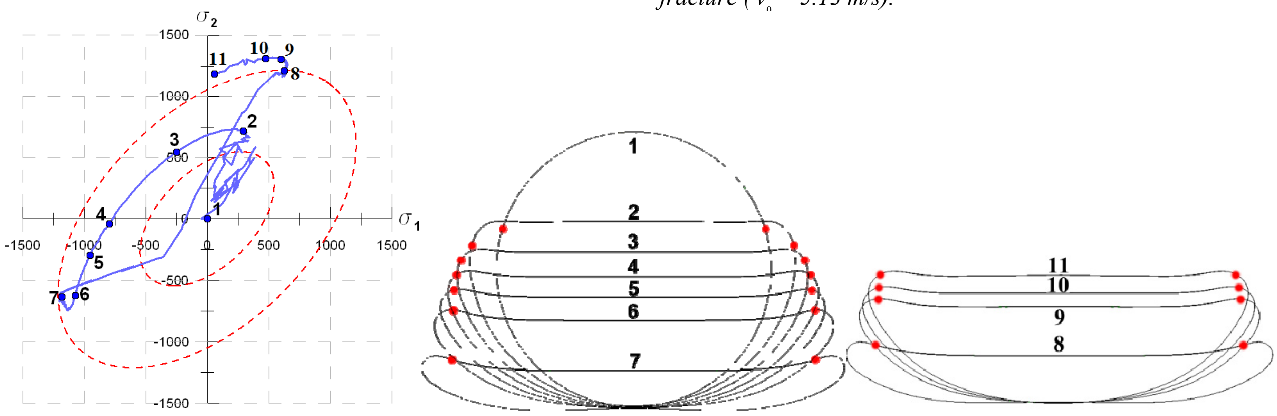


**Figure 5**: *History of principal stresses during entire load sequence (left) and corresponding states of deformation during impact (centre) and during stretching (right).*

## CONCLUSIONS AND FURTHER WORK

The main conclusion from the study so far is that both the strain localization and the overall global response are captured well by the chosen numerical model using the JC constitutive relation. However, refinement with respect to the prediction of fracture needs to be carried out. The JC fracture model predicted fracture too late; a larger axial displacement was required to produce fracture in the analysis compared to the experiments. As the JC constitutive relation only accounts for isotropic hardening, a properly calibrated model which also takes potential kinematic hardening of the material into account may further improve the simulation results.

### References

[1] Det Norske Veritas (DNV). Recommended practice DNV-OS-F111: Interference between trawl gear and pipelines, 2006.
[2] Johnson GR, Cook WH. A constitutive model and data for metals subjected to large strain, high strain rates and high temperatures. Proceedings of the 7th International Symposium on Ballistics 1983, p. 541-547.
[3] SIMULIA. Abaqus Analysis User's Manual Version 6.10, 2010.