Initial ovality effect on the maximum shear stress in offshore deep sea pipe

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Abstract
The effect of initial ovality on the stress increase, especially shear stresses, in deep sea and ultra-deep sea pipes was investigated. Von Mises shear was used for comparative analysis. The pipes were modeled with initial ovality of 0.0, 3.0 and 5.0%. No thermal loading was considered in this study. The shear stresses increased linearly with the increase of initial ovality in the pipe.

Introduction
Since new hydrocarbon reserve discoveries are more and more rare in the conventional offshore, the industry is looking into new hydrocarbon reserve perspectives located in deep sea (between 500 and 1500 m) and ultra-deep sea (between 1500 and 3000 m) as underlined by Robertson et al. (2005). Thus, one of the currently most challenging projects in the petroleum industry consists of exploiting oil resources at great depths, where production infrastructures are submitted to high hydrostatic pressures (up to 300 bar) and to low external temperatures (about 4 °C at 3000 m), (Bouchonneau et al. 2010).
Under these extreme thermo-mechanical conditions: high pressure and low external temperature plus high internal temperature (the oil flowing inside the pipe can be up to 100 ^{o}C, (Collins 1989)), an initial ovality of the pipe can induce high stresses in the pipes. And as stated by Castello et al. (2007), it is well known that during the collapse of pipes by external pressure shell bending in the circumferential direction occurs caused by the increasing ovality. Consequently any initial ovality of the pipe will accelerate the failure and hence needed to be assessed and quantified.

Objective
The objective of this study was to investigate the effect of initial ovality on the maximum shear stresses induced in deep offshore pipelines under increasing hydrostatic pressure representing the depth of sea bed.

Model
ABAQUS was used for the analysis. A deep sea steel pipe was modeled without the thermal insulation. The pipe had an inner diameter of 140 mm and the outer diameter of 200 mm. The pipe model length was 2 meters to reduce the effect of boundary condition on the stresses.
In all the models the mesh was generated using three-dimensional quadratic reduced-integration solid elements C3D20R. A linear elastic model was used for the steel since the stresses in the pipe are expected to be lower than the yield stress f_y : E = 200 GPa and $\nu = 0.3$
The initial ovality Δ_o is defined as follow (Castello et al. 2007):

$$\Delta_o = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}},$$

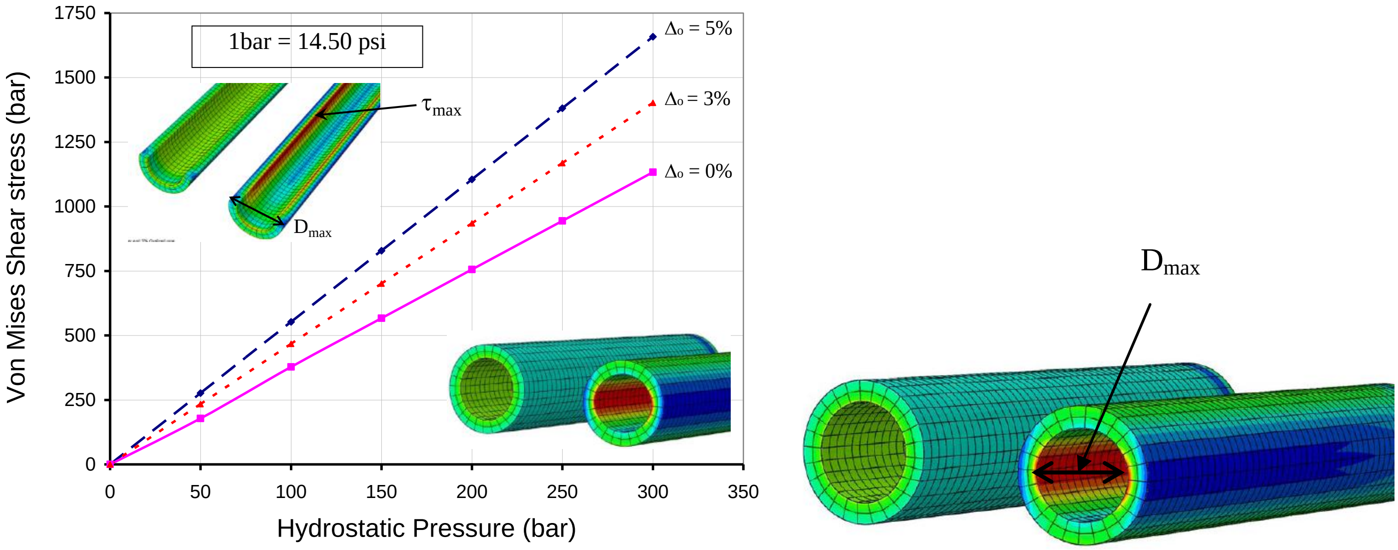
where D_{max} and D_{min} are maximum and minimum diameter, respectively. Von Mises yield criterion, also known as the maximum octahedral shear stress criterion is expressed as follow:

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2},$$

where σ_1, σ_2 and σ_3 are the principal stresses.

Result and Discussion

As shown in Fig. 1 (a.) the maximum octahedral shear stress increased linearly with the hydrostatic pressure (meaning with increase of the sea depth). Also τ_{max} increased with higher initial ovality of the pipe. At a depth of 500 m (beginning of deep sea) there is an increase of 56 and 98 bars for 3 and 5% initial ovality, respectively; these stresses went up to 269 and 525 bar at 3000 m deep. This variation represented an increase of 24 % and 46 %, of the octahedral shear stress for 3 % and 5 % initial ovality respectively.



a.) b.)

Fig. 1 a.) Maximum octahedral shear stress vs. Applied hydrostatic pressure. b.) ABAQUS models for the pipes.

The maximum shear stress in the ovalized pipes are located at the inner face of the pipe in the direction of the maximum diameter as shown on Fig. (a.) and (b.). This study is interested in the stress concentration due to the initial ovality and subsequent failures. The linear elastic properties of the materials will also influence the results.

Conclusion

The effect of initial ovality on maximum shear in offshore deep sea pipelines was investigated. The maximum octahedral shear stress, parameter of Von Mises yield criteria, increases linearly with the initial ovality and the hydrostatic pressure. Any initial ovality, consequently, induces a shear stress concentration in the pipelines. This effect needs to be considered in the analysis of the deep sea pipelines.

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