Collapse of steel pipes under external pressure and axial tension

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IT IS WELL KNOWN that, when steel pipes are subjected to axial tensile loads, their external collapse pressure diminishes. When calculating the collapse pressure of casings using the standard API 5C3, even though the formulas are not applicable for axial tensile stresses up to the material yield stress, it is clear that the predicted collapse pressure tends to zero when the applied axial tensile stress tends to the material yield stress (see Figs 1 to 3). When calculating the collapse pressure of subsea pipeline systems using the standard DNV OS-F101, the external collapse pressure is zero when the applied axial tensile stress equals the material yield stress.

However, it has been observed that even when the applied axial tensile stress matches the material yield stress, there is still a remaining capacity in the pipes for carrying external pressure [1]. In this paper we investigate the above assertion and quantify, using finite-element models, the collapse of steel pipes that are first subjected to axial tensile load and afterwards to external pressure.

The finite-element analyses that we present here confirm that, even when the applied axial tensile load matches the material yield load, there still remains a not-negligible capacity in the pipes for carrying external pressure.

Numerical analyses

In this paper, we consider pipe samples with a length (L) to diameter (D) ratio equal to 10, and for two different load cases:

(a) the sample is loaded by axial tension and afterwards, keeping the applied axial load constant, it is loaded with external pressure up to collapse;

(b) the sample is loaded by axial tension and afterwards, keeping the axial displacement of the sample ends constant, it is loaded with external pressure up to collapse.

Even though the hardening of the material does not have any influence on the external collapse pressure of the pipes when the applied load is only external pressure [2], in this case [axial tensile load + external pressure] we also investigated the effect of the material hardening (E_t) on the results.

For our analyses we considered a 7-in diameter pipe and two material grades: Grade 55 and Grade 80. We included in our models a constant ovality of 0.5%.

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The finite-element models were developed using the shell element MITC4 [3-5] which incorporates shear deformation, while the ADINA [6] code was used for the analyses. We considered a simple bilinear material model with hardening modulus E_t. The reliability of these models was established via several validations that are discussed in Refs. 2 and 7-10. Regarding the boundary conditions, one of the sample ends was modelled as fixed and the other one was given one axial degree of freedom.

Collapse of the 7-in Grade 55 pipe

In this analysis we considered two hardening cases:

$$E_t = E/100$$
$$E_t = E/10{,}000$$

where E is the Young's modulus of the steel.

In Fig.1 we show the results for the case in which the axial load is kept constant during the external pressure loading: it is clear that for the analysed case, when both hardenings are considered, the pipe remains with a not insignificant capacity for carrying external pressure after it yields in axial tension. The figure also shows that the hardening effect is only significant for axial loads close to the yield load.

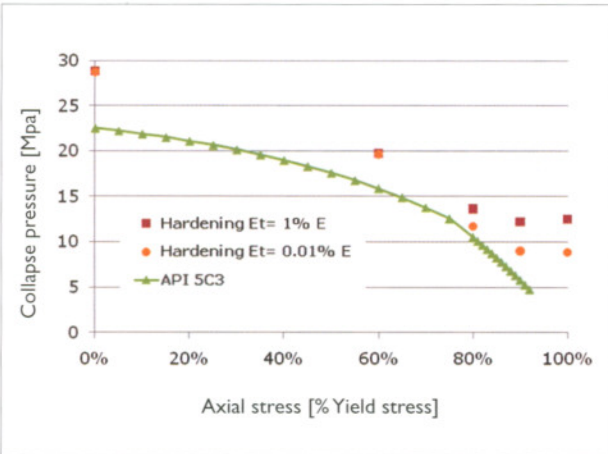

Fig.1. Grade 55 with the axial load being kept constant during the pressure loading.

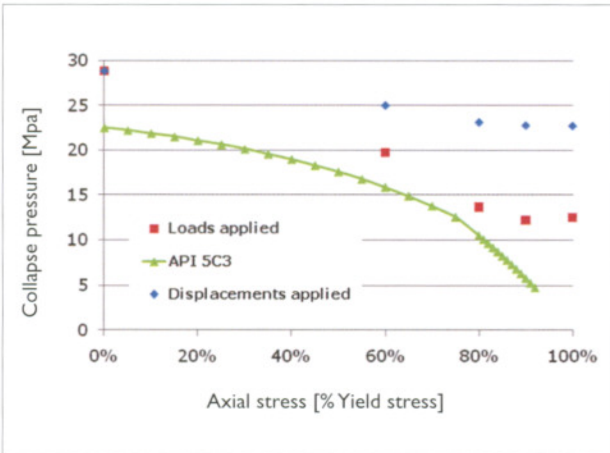

Fig.2. Grade 55 with the axial load / axial displacement being kept constant during the pressure loading.

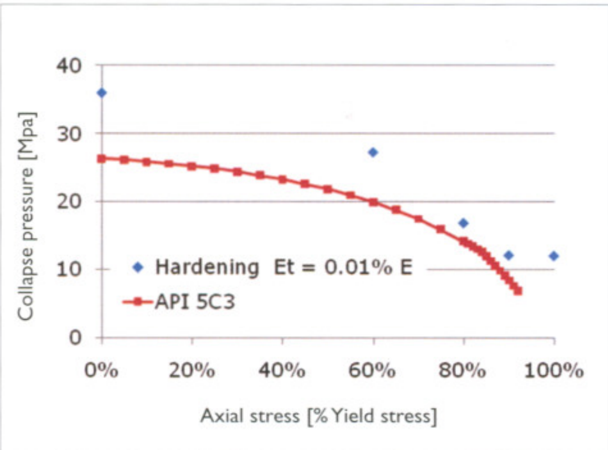

Fig.3. Grade 80 with the axial load being kept constant during the pressure loading.

In Fig.2 we show the results for the case in which the axial displacement of the sample ends is kept constant during the external pressure loading. The results show that the collapse pressure is higher than when the axial load is kept constant.

Collapse of the 7-in Grade 80 pipe

Figure 3 shows the effect of axially loading the Grade 80 pipe, considering only the more detrimental cases: the smallest hardening, and the axial load being kept constant during the pressure loading. The results for this case show the same tendencies as those observed for the Grade 55 case.

Conclusions

The finite-element analyses that are discussed in this paper confirm that even when the applied axial tensile load matches the material yield load, there still remains a capacity in pipes for carrying external pressure. The existing standards do not show this extra collapse strength, and therefore underestimate a pipe's collapse resistance.

The case in which the axial load is kept constant during external pressurization has a larger detrimental effect on a pipe's external collapse pressure than the case in which the axial displacement is kept constant.

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