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Composite Repair of Through-Wall Defects in Pipework

Analytical and Numerical Models with respect to ISO/TS 24817

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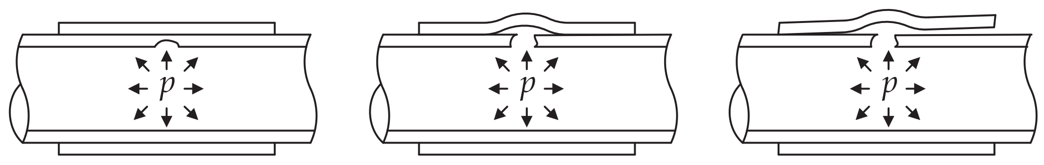
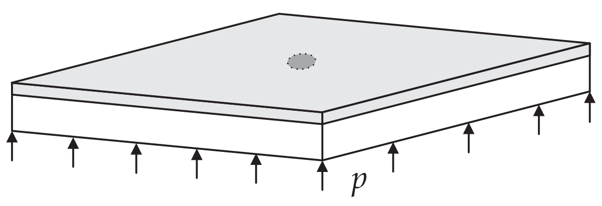
1. Introduction

Operating in harsh environmental conditions, steel pipelines often suffer from corrosion. To extend the life of affected pipelines, the use of *Fibre-Reinforced Plastic* (FRP) overwrap repairs which can be applied on an operating pipeline has been considered as a promising solution. Generally, the worst scenario to be considered is that internal corrosion leads to a through-wall defect in the pipe. Thus, the fluid pressure acts on the FRP/steel interface and a blister in the overwrap occurs. If the detachment of the overwrap from the steel substrate propagates this can even result in an external leakage.



This case of damage is considered in the Code ISO/TS 24817, providing a theoretically based solution to determine the released energy in case of FRP/steel interface fracture. To verify the code's approach, representative flat plate test samples are widely investigated.



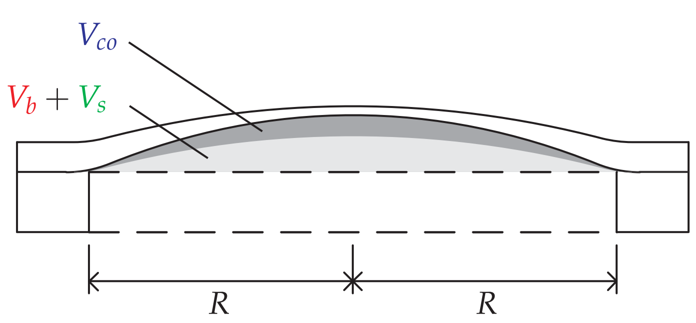
Provided that the adhesion between the substrate and the repair is only given by brittle resin, the principles of linear elastic fracture mechanics can be applied. Accordingly, fracture is only initiated if the energy release rate G is greater than or equal to the crack resistance G_C. In the case of linear elasticity it follows

$$G = \frac{p\,dV}{2\,dA} \geq G_C \tag{1}$$

where p is the applied pressure, and dV equals the change of blister volume during an infinitesimal crack advance dA. Obviously, the only unknown term in Eq. (1) is the function of dV. Therefore, an analytical fracture mechanics model has to be developed.

2. Analytical Analysis

In order to determine the blister volume V, it is assumed that the behaviour of the pressurised repair, hole radius R, is equivalent to the one of a clamped circular plate under uniform load p. It is found that the total volume is a sum of three deflection modes: bending (V_b), transverse shear (V_s) and through-thickness compression (V_{co}).



Based on the analytically derived term for dV and Eq. (1), an expression for the energy release rate G can be determined.

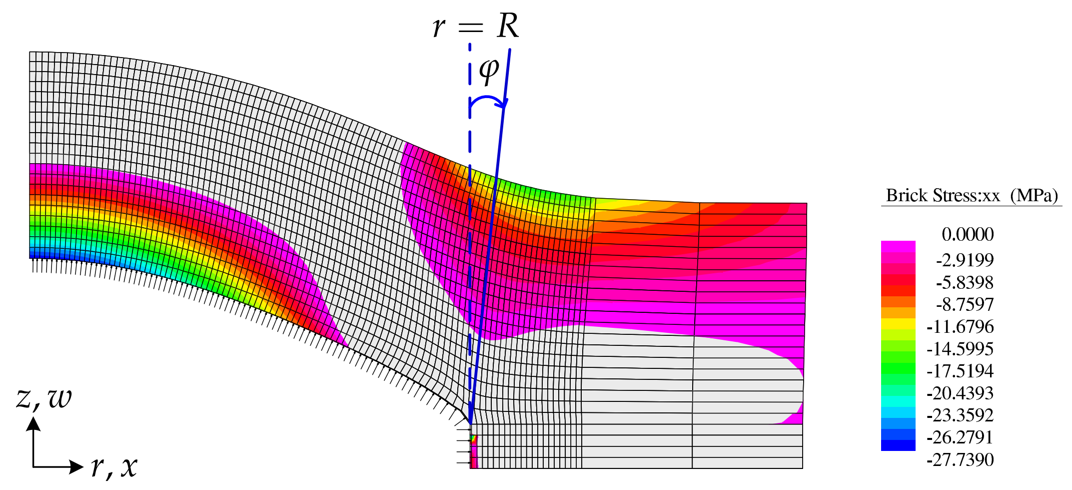
$$G = p^2 \left[\frac{3(1-\nu^2)}{32Et^3} R^4 + \frac{3}{20Gt} R^2 + \frac{2(1-\nu_{31}^2)}{E_{33}\pi} R \right] \tag{2}$$

A comparison of Eq. (2) with the one given in the ISO-Code shows that the code is overestimating the influence of transverse shear due to a neglect of a parabolic shear stress distribution over the plate thickness. Further, the in-plane Young's Modulus $E_{11} (= E_{22})$ is erroneously used instead of E_{33} to consider transverse compression.

3. Numerical Analysis

A finite element analysis of a clamped circular plate under uniform load (Model I) shows that the terms for bending and transverse shear deflection show a high accuracy to the numerical results. However, it is found that the consideration of through-thickness compression is only reasonable if the plate is sufficiently thick.

The second major assumption of the analytical model to be verified is the reduction of the problem to the one of a clamped plate. Therefore, the more realistic model of a continuous plate, consisting of a rigid steel substrate and a FRP repair is applied (Model II). A contour plot of the stress σ_{rr}, like given in the Figure below, shows that there is a high concentration of compression stress along the edge $r = R$ due to a rotation of the pressurised repair against the substrate.



Evidently, neither the bending slope $\varphi(r)$ nor the vertical deflection $w(r)$ is zero at $r = R$ as it was assumed for Model I.

4. Summary

The separation of the total deflection into its single modes provides a workable solution, although several inaccuracies implemented in the code were found. The most critical one is the underestimation of blister volume due to the assumption of a clamped support. Hence, the use of compliant springs is highly recommended instead.

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