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FEM Simulation of Elasto-Plastic Tube Indentation Comparison with Experiment

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Abstract. Paper provides the summary of the FEM simulation of elasto-plastic strains and stresses in the course of the local indentation of a steel pipe by a spherical indenter. Series of 65 FE parametric studies of the elasto-plastic state of the indented tubes was performed to describe the influence of tube diameter, wall thickness, indenter diameter and the depth of indentation. The numerical results were compared with the experimental results.

Introduction

Mechanical damage is one of the most severe forms of damage that is found in pipelines. The most common defects that reduce both the static and cyclic strength of a pipeline are dents which are caused by a collision of the tube with external rigid objects. A dent in a pipeline is a permanent plastic deformation of the circular cross section of the pipe. Dent depth is defined as the maximum reduction in the diameter of the pipe compared to the original diameter. A dent causes a local stress and strain concentration. The severity of a dent depends on its size and shape and on a number of other factors, for instance whether it affects the curvature of a girth or seam weld and whether it contains other defects, such as a gouge or a crack [1]. In many cases it is necessary to repair such damage. However, in some cases, a combination of detailed inspection and assessment can result in conclusion that the damage is acceptable [2].

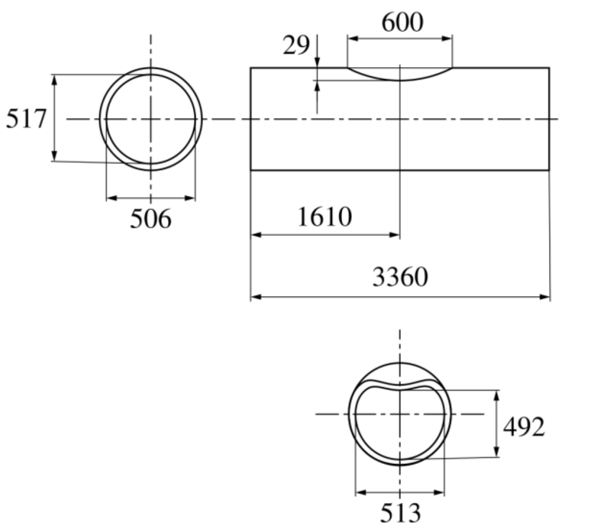

Fig. 1. Dent caused by the experimental indentation

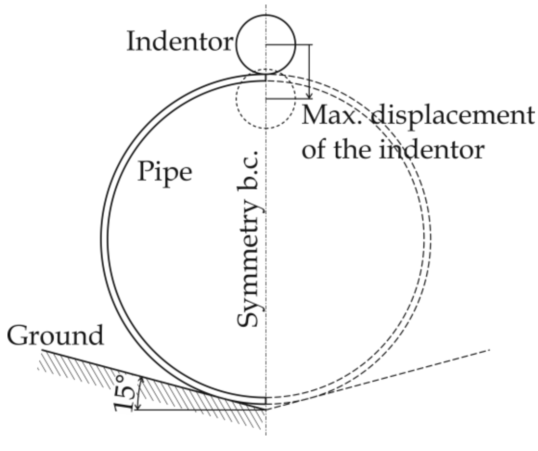

Fig. 2. FE ¼ model of indentation

FE simulation of the tube indentation

The FEM calculation was performed according to the recommendation of API 579-1 / ASME FFS-1 2007 [3] for Level 3 Dent Assessment. The configuration of the experimental loading of the indented tube has two planes of symmetry see Fig. 1. FE simulation model was adjusted as ¼ of the whole with appropriate symmetrical boundary conditions see Fig. 2. The FE model of tube was supported equally as in the experiment i.e. the support was modeled as the rigid plane with the inclination of 15 degrees. The contacts were defined between the tube and the rigid spherical indenter and between the tube and the rigid support. The loading was controlled by the displacement of the indenter. Series of 65 FE calculations of the elasto-plastic state of the indented tubes was performed. The combination of three tube diameters D=508, 920 and 1420 mm with the ratios between the diameter and the wall thickness D/h= 91, 76, 64, 51 and 37 resp. were used. The diameters of the spherical rigid indenters were 100 and 200 mm, the depth of the indent varied gradually from 75 to 150 mm. The residual stresses and strains in the vicinity of the dent after the relieving of load were determined together with the depth and length of the resulting dent. The elasto-plastic material properties were obtained from the tensile test curve of pipe material which was converted to True Stress – True (Logarithmic) Strain curve for the FE calculation purpose. FE mesh was created using 8-node hexahedron elements which allow the local adaptability of mesh that is necessary in large strains. Each single FE model from a series of 65 cases was created using a Python script which comprised the combinations of the tube diameter *D*, the wall thickness *w*, the indenter diameter *di* and the immersion depth of indenter *h*.

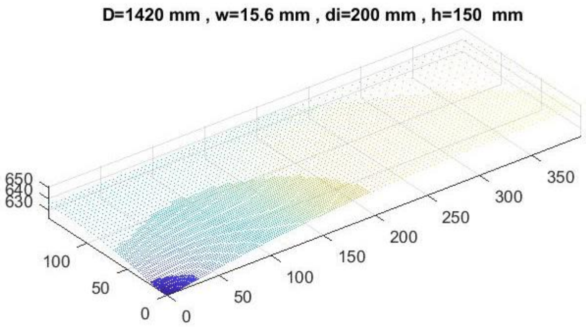

Fig. 3. Shape of tube under the indenter

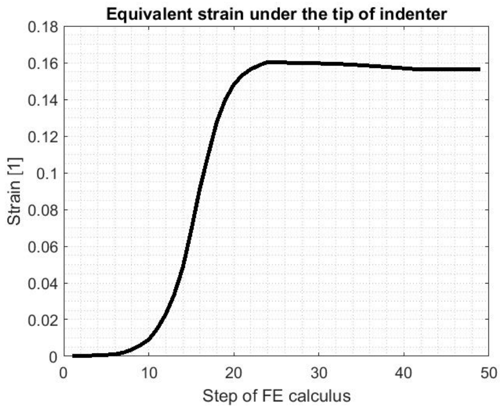

Fig. 4. Equivalent strain

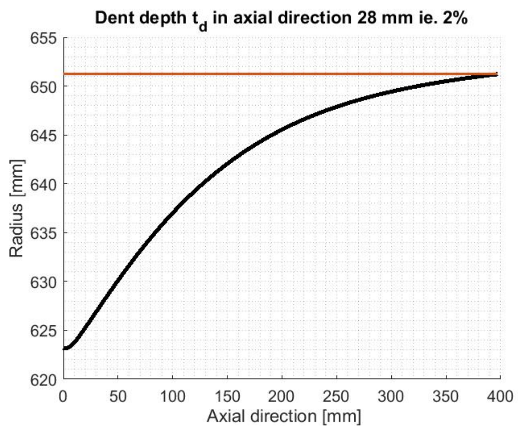

Fig. 5. Depth of the dent - axial direction

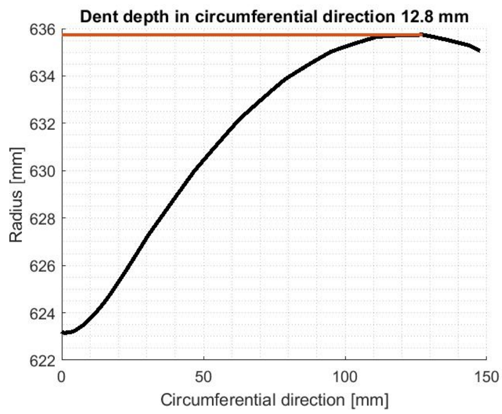

Fig. 6. Depth of the dent - circumf. direction

Results of FEA

The evaluation of the FE results and the graphic processing were performed in Matlab. Some results for a particular configuration (the tube diameter *D*=1420 mm, the wall thickness *w*=15.6 mm, the indenter diameter *di*=200mm and the immersion depth of indenter *h*=150mm) are shown in the Fig. 3 to 6 where the deformed shape of the tube is captured together with the evolution of equivalent strain inside the tube under the indenter in course of loading and the final value of the residual equivalent strain (around 15%) after the unloading. The shapes of dent in axial and circumferential directions are shown in Fig. 5 and 6. The depths of dent in these principal directions can be determined as the distances between the tangent lines (red lines) and the bottom of dent. One of the parameters characterizing the dent is the ratio between the axial depth of dent (28 mm) and the diameter of the tube (2%).

The contours of central cross-section at the different steps of loading are captured in Fig. 7 for the configuration (*D*=508, *w*=13.8, *di*=100 and *h*=25mm). The displacement of the point A located inside the tube under the indenter is in Fig. 8. The ovalization of the tube cross-section is also noticeable. The successive equivalent strain and principal stresses at this point are shown in Fig. 9 and 10. The residual deformation of the tube and the residual strain and stresses are also apparent in these figures.

It is therefore possible to establish through the FEA all the necessary parameters that US and British standards require for the assessment of safety of the pipeline with the defects of dent type.

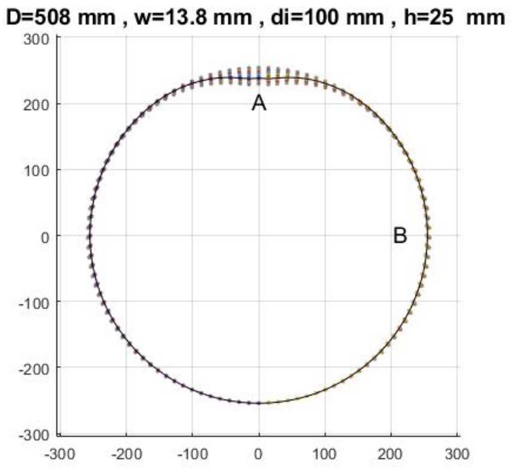

Fig. 7. Tube contour in course of indentation

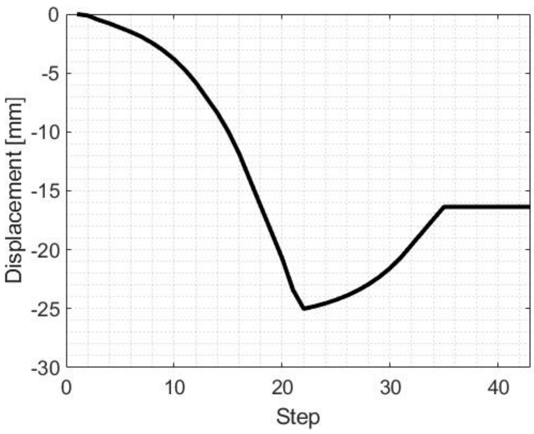

Fig. 8. Displacement of the point A

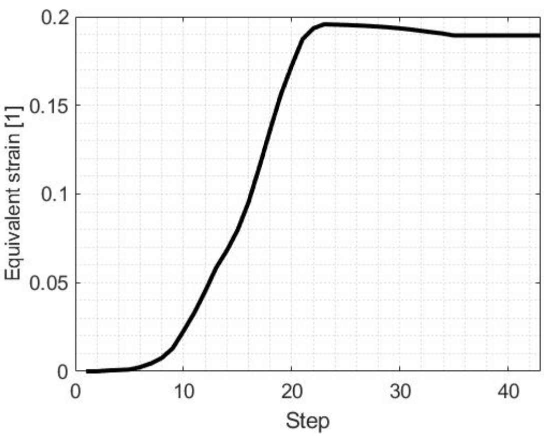

Fig. 9. Equivalent strain in point A

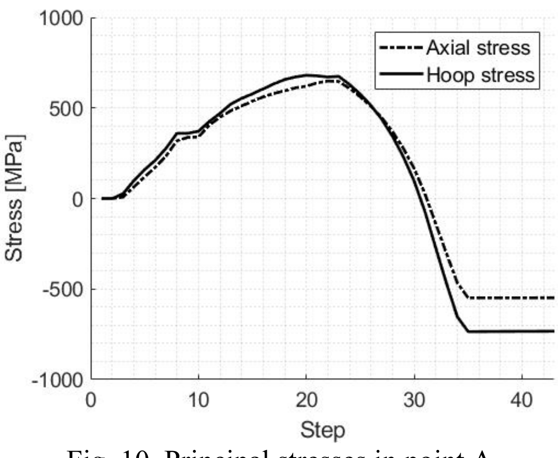

Fig. 10. Principal stresses in point A

Conclusions

In this paper, the residual stresses and strains in a series of numerical simulations of steel pipes subjected to indentation were quantitatively investigated based on nonlinear FEM. A numerical model has been developed and validated by test results, capable of predicting residual strength of dented pipe. The effects of tube and indentation variable parameters including the indentation depth, the diameters of tube and indenter and the tube thickness have been identified. The results of FEA were compared with experimental measurements [4] and they were found in good agreement.

References

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