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INTERACTION OF SURFACE DEFECTS ON HIGH-DIAMETER PIPE LINES

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Resumé: *This paper describes results of research on influence of an interaction between two surface corrosion defects on limit pressure as a function of configuration of these defects. This influence was investigated numerically using finite element method (FEM) and experimentaly using strain-gauges analysis. The results help us to distinguish whether a group of corrosion defect on pipe-line DN 800 is to be considered as a single large defect or as several single local defects. Limit pressure was determined according to ANSI/ASME standards. The new modification of methodology, which predicts limit pressure has significant influence on results accurancy. The resulting error between first evaluation and experimentaly obtained value of limit pressure was lower then 5%.*

Introduction:

The main goal of the research was to describe (experimentaly and numericaly) interaction between large surface corrosion defects on pipe-line surface. These types of corrosion defects usually have form „single cup" (point defects) or a „group of such cups" (surface defect). The parts with nominal wall thicknes called bridges remain between these defects. Pipe DN 800, with three exactly defined artifical defects with bridges, was used as tested body in experimental strain analysis. Nominal thickness of this pipe wall, made of X 60 steel, was 10.6 mm. Three model defects called DEF 1, DEF 2 and DEF 3 and two bridges, called BRIDGE 1-2 and BRIDGE 2-3, with different length in pipe-line axis direction are plotted on Fig. 1. Dimmensions of the defects and bridges are described on the same figure. This model was analysed using FEM and ANSI/ASME standard, too.

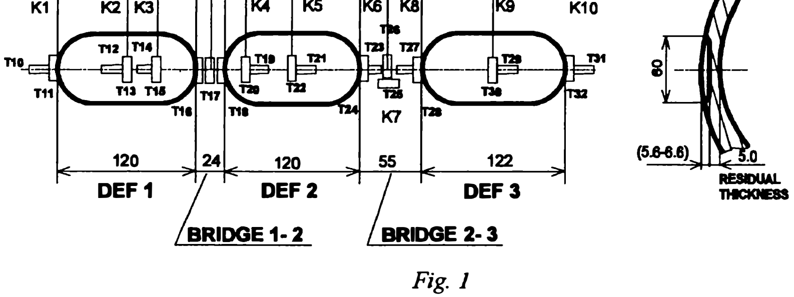

Fig. 1

Experimental strain analysis:

To determine strains inside the defects and bridges 23 strain-gauges were installed (see Fig. 1). Stain-gauges HBM, types 6/120 LD 20 for large strains and 6/120 LY 11 for small strains were used for this analysis. The first level of loading was the nominal operating pressure of 7.25 MPa. At this load level all strain-gauges inside the defects were in plastic state. Only strain-gauges away from defects have not reached yield point. Burst pressure was 12.0 MPa. The point, at which the fracture was initiated, is located at the centre of DEF 2. Fig. 2 presents typical results of strain-gauges measurement (strain gauges K5 in DEF 2) by all pressuring cycles (0 - 7.25 -0, 0 - 8.1 - 0 , 0 - 9.5 - 0 and 0 - 12.0 [burst pressure]) MPa.

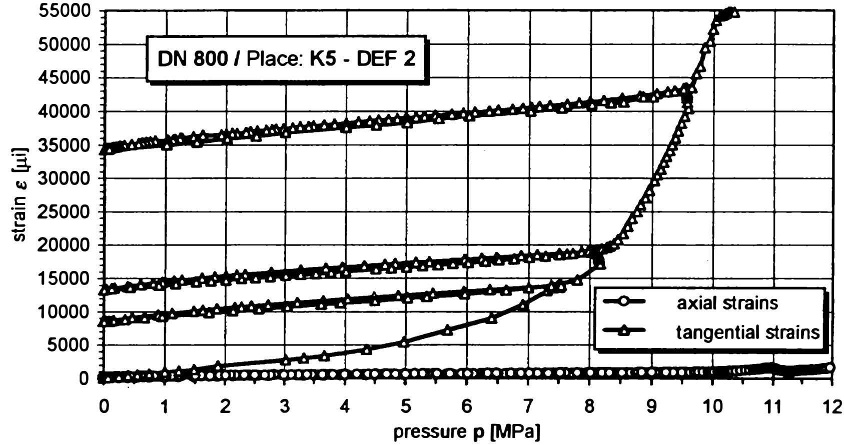

Fig. 2

Single defects affect the pipe surface as concentrators, which may be described by a coefficient α. These coefficients define theoretical maximum value of quantity at a measured location in correlation with the nominal value of the quantity. In elastic-plastic state we evaluated:

- Coefficient of stress concentration α_σ, which defines the relation between elastic-plastic stress and nominal stress.
- Coefficient of strain concentration α_ε, which defines the relation between real strain in elastic-plastic range and nominal strain.
- Coefficient of concentration α

For linear material the following relation must be satisfied:

$$\alpha_\sigma = \alpha_\varepsilon = \alpha$$

In elastic-plastic range we may use Neuber's relation :

$$\alpha_\sigma \cdot \alpha_\varepsilon = \alpha^2$$

Examples of concentration coefficients in some determined locations depending on the pressure are presented in Fig. 3 and Fig. 4.

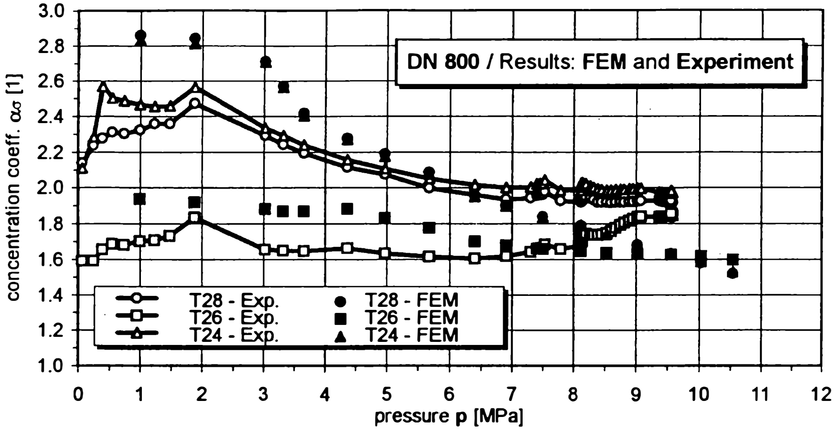

Fig. 3

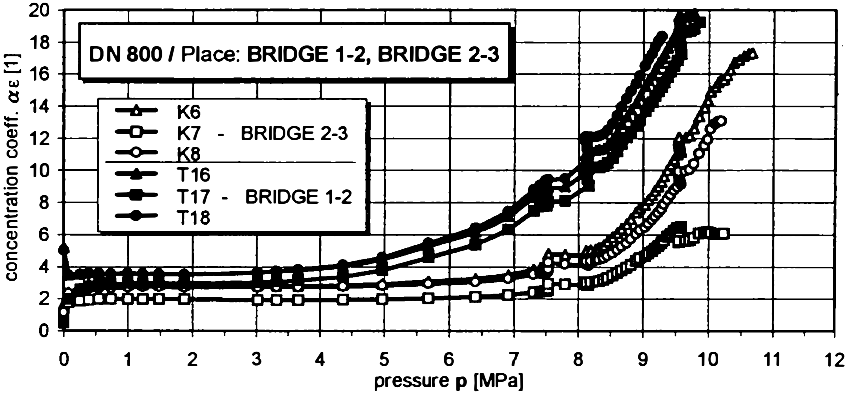

Fig. 4

Numeric stress analysis - FEM approach

Since artifical defects are analyzed, ANSYS Finite Element program's preprocessor was used to generate FE mesh. Computation itself was done through FEM-211 program, developed in Dept. of Elasticity and Strength of Materials, Faculty of Mechanical Engineering, CTU Prague. Both material and geometric non-linearities are included in FE model consisting of 793 quadratic isoparametric elements with 14 007 degrees of freedom. Results are stored in range from 0 to 11 MPa for pressures. Comparison with the experiment is based on about 150 virtual strain gauges which provide meaningfull strains, when large deflection, large strains and updated Lagrangian-Jaumann stress rate tensor analysis scheme is used, by exact simulation of line extension on FE structure surface. Von Mises equivalent stress σ_{HMH} as a function of the longitudinal coordinate **y** is plotted in Fig. 5.

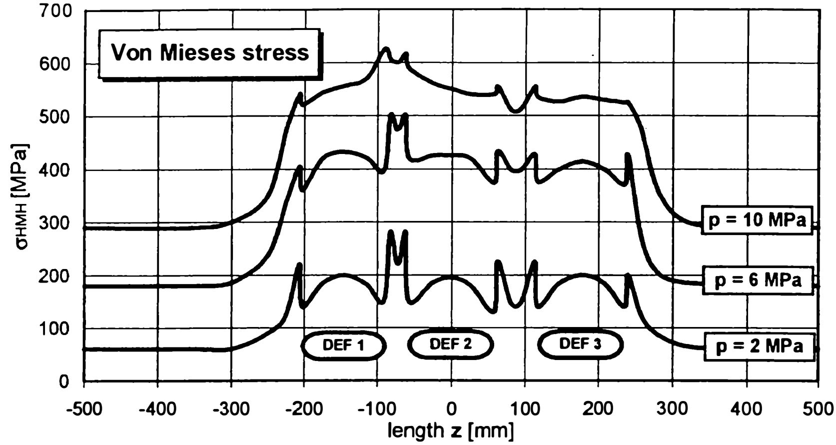

Fig. 5

ANSI/ASME standard application

The investigation of the model defect was evaluated by the ANSI/ASME standard application, see Fig. 6. Various combination of the defects DEF 1, DEF 2 and DEF 3 associated to points V1 - V4 in Fig. 6 were compared with the allowed lengths (using criterion ANSI/ASME B31.G) and with the limit lengths (using the experimental CTU-curves). Its seems, that only one combination of defects (alternative V4 on the Fig. 6) is somewhat above the allowed length in accordance with the B31.G criterion, but it lies bellow the experimental limit lengths. Having considered of the double defect with the narrow BRIDGE 1-2 (alternative V2) behaves, as a consequence plasticity of the bridge, as a single long defect. Double defect with the wide BRIDGE 2-3 (alternative V3) shows the similar behaviour. The plasticity in the bridge appears near the limit pressure, when the nominal stress reaches almost the yield stress (this state is represented by the limit curve CTUP-B). The assesment of the defect as the long defect consisting of all three parts (alternative V1) was found conservative according to the experimental limit curves of CTU. Alternatives V2 and V4 are effective to evaluate limit pressure using ANSI/ASME approach

Limit State

Burst pressure was predicted using the methology explained in [1,2]. It is based on a hypothesis that the limit state of a damaged pipe is determined by the field of plasticity measure in its volume. Conclusion following from the methodology application is: The limit pressure is probably in the range **p** = (12.2 ± 0.3) MPa.

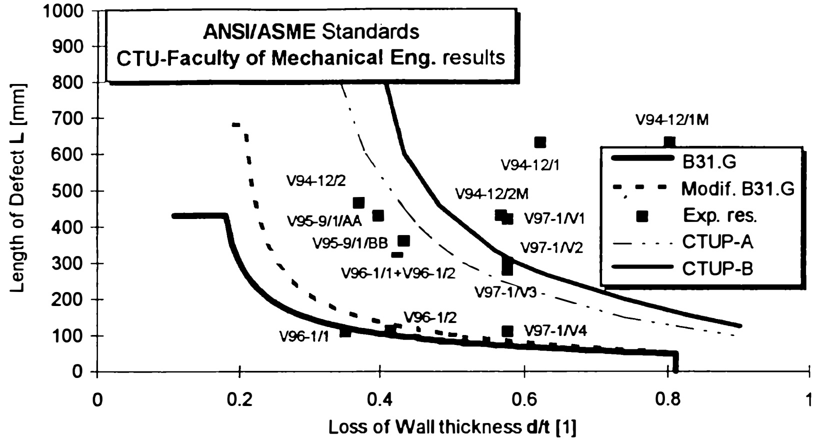

Fig. 6

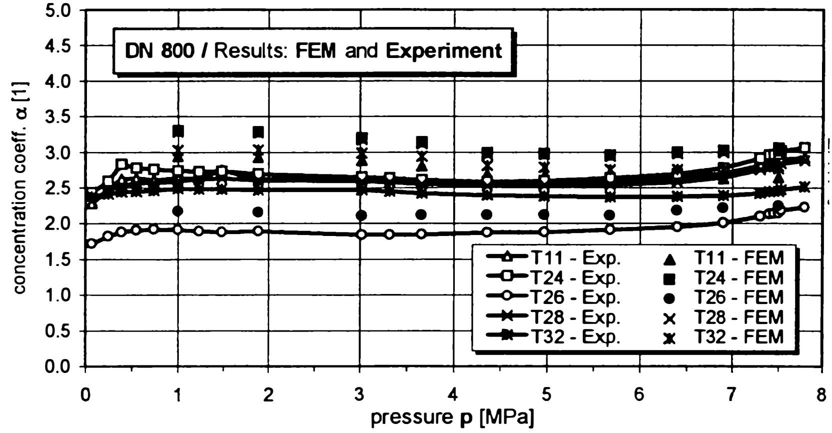

Fig. 7

Conclusions

1. Experimental strain analysis shows that in the stretched localities plastic strain occurs when pressure reaches 3.5 MPa. The correspondence between strains evaluated via strain gauges and FEM is satisfactory. At pressure level 7.5 MPa the coefficient of tangential strains concentration is evaluated as 9 and tangential stress one as 2.8. Depending on the pressure, these coefficients vary and satisfy Neuber's criterion of constant value of its product (see Fig. 7).

2. Burst pressure was determined as 12 MPa, crack propagation started at DEF 2. Pipe body, except defects, remained elastic until limit pressure was reached. Burst pressure prediction using plastic area methodology had 2% error. ANSI/ASME prediction error is about 10-30 %.
3. Bridges with length less than twice the wall-thickness must be included into the defect length. Defects with bridges longer than 4.5 times the wall-thickness may be evaluated as single ones.

References:

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Abstract in Czech:

Předložený referát se týká řešení otázek vlivu sousedních plošných korozních defektů na mezný tlak porušení s různou délkou spojovacích můstků. Vzájemná interakce determinovaných defektů a její vliv na mezní tlak porušení byl řešen numericky metodou konečných prvků (MKP) a experimentálně pomocí odporové tenzometrie. Byly získány základní poznatky, umožňující posoudit pásovou skupinu plošných korozních defektů na potrubí DN 800 s ohledem na délkový rozměr můstku mezi defekty. Mezní destrukční tlak byl rovněž určován pomocí standardů ANSI/ASME. Zdokonalování metodiky určování mezního tlaku porušení se projevilo zpřesněním jeho odhadu, který se lišil od experimentálně zjištěného destrukčního tlaku o méně než 5%.

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