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Stress and Strain State Analysis of Defective Pipeline Portion

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Abstract. The paper presents computer simulation results of the pipeline having defects in a welded joint. Autodesk Inventor software is used for simulation of the stress and strain state of the pipeline. Places of the possible failure and stress concentrators are predicted on the defective portion of the pipeline.

Introduction

After the construction of the main pipeline, the process of its long-term operation begins. A safe operation of a commercial construction built even in compliance with a perfect engineering design (with the use of advanced CAD systems) is impossible without its periodical inspection, technical diagnostics, estimation of its actual state, timely repair, and replacement of worn-out parts.

Unfortunately, the actual state of commercial constructions in operation is analyzed after the technical diagnostics often not only without the use of computer simulation techniques, but also without any appropriate engineering estimates at all. In these cases, they use tables with results of model tests created dozens years ago or, at most, the simplest semiempirical formulas for calculation of one or another defect allowance.

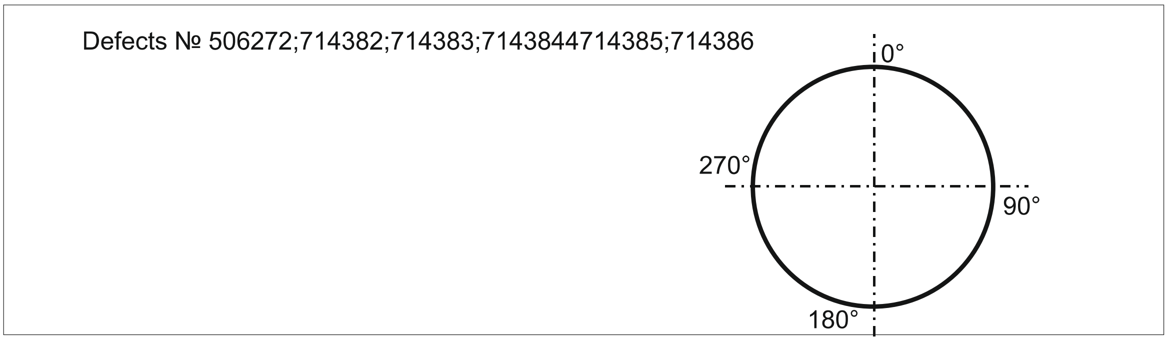
A non-destructive testing (NDT) of industrial pipelines included in the main oil transportation objects, often poses a problem of their technical diagnostics and further operation. Thus, such defect as displacement was discovered in the weld-affected zone of the pipeline. The static strength and the allowable lifecycle (service life) of welded joints with defects are calculated in accordance with the Standard ‘Main pipelines. Circular, longitudinal, and spiral welds with defects and pipes with ripples. As preliminary estimates have shown, there is no a combination of external service loads capable to induce the limit state in the pipeline portion. It was decided to support by calculations the possibility of further operation of the pipeline portion with defect, and replace it at the next major repair.

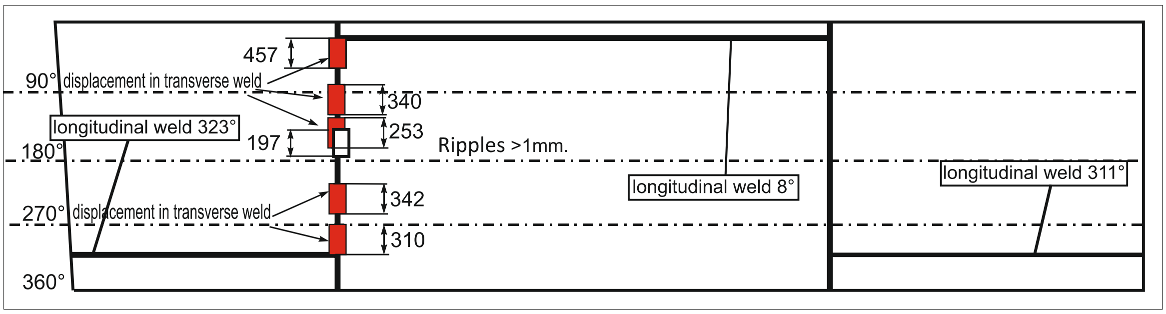
The aim of this paper is to define the possibility of further operation of the pipeline by means of ascertaining the values of internal forces applied to the defective portion. The values obtained for maximum stresses and theoretical values of the pipeline material strength are to be compared. The stress values and the pattern in the defective portion are suggested to determine by the simulation model of stress and strain state of the pipeline with defect and the finite element method. Autodesk

Inventor, 3D mechanical CAD software allowing to design and study the stress and strain state of different pipelines is used for this simulation. In works [1-10], the authors describe the individuality and complexity of this software.

2. Results and discussion
The internal changes in metal lead to its fracture and are called a limit stress state. The structural reliability is provided by the comparison of maximum stresses which appear at the most dangerous point and admissible limit values of the given material. The limit stress state of a structure is just the limit beyond which its operation is impermissible. The structural reliability is higher when the level of actual internal stresses is farther from the limit state. Autodesk Inventor software allows the strain-stress computation of the pipeline wall and obtaining output data in the form of three values of primary stresses which are presented by roots of a cubic equation defined by the stress vector components.

The strain-stress computation is based on the calculation methodology of allowable elastic stresses. The stress and strain state of the displacement type defect located on a cylindrical pipe casing is determined by a three-dimensional design model subjected to combined service loads. Since the aim of this work is to study stresses occurring within the defective portion of the pipeline, the design model can be reduced to its defective portion. The internal excessive stress is the service load applied to the pipeline. The dead load of the pipeline portion, wind and snow/ice loads also should be taken into account. In order to provide a static determinability of the model, the boundary conditions include a pin-edge fixing of the pipeline portion to prevent linear motions. Schematic view of defect locations on the pipeline portion N 82140 is given below.





3. Defective portion simulation model
The length of the pipeline casing is selected such that to exclude the possible effect of end connections on the defect area. The displacement type defect is simulated in conformity with the measurement results obtained during technical diagnostics (Fig. 1a,b,c). Loads distributed across the casing area are

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applied to its defect area. Welded joints are neglected. The finite element model contains five casing objects unified with each other by the bonded contact, i.e. the complete dependence of displacements is provided in all assemblies. Cartesian system is used for this model. The finite element mesh reproduces the surface curvature and is superimposed automatically. The minimum mesh size was obtained at mash condensation within the defect area and equals to 0,6 mm. Mesh size of 10 mm was accepted for all other structural elements. The non-linear model simulation was carried out using the iteration technique. The values of the equivalent stresses are distributed in the sectional area of casing under the maximum load, i.e. in its outer surface. The graphic imaging of stress field distribution in the pipeline wall is depicted in Figures 2 - 6.

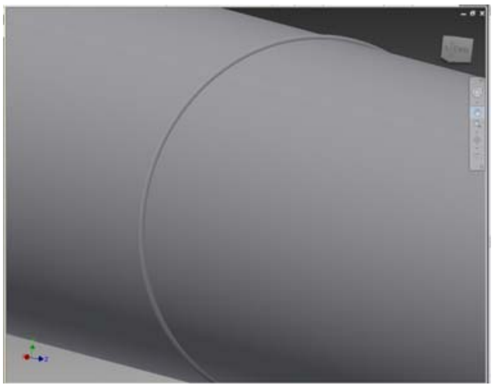

Figure 1a. Pipe the weld.

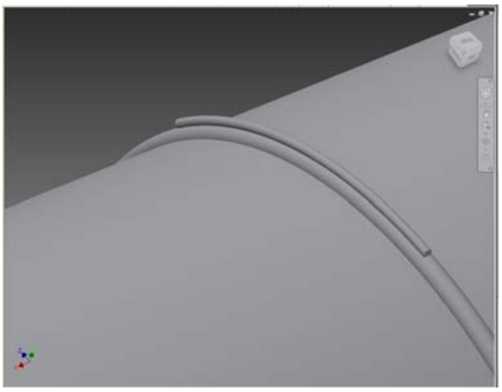

Figure 1b. Defect

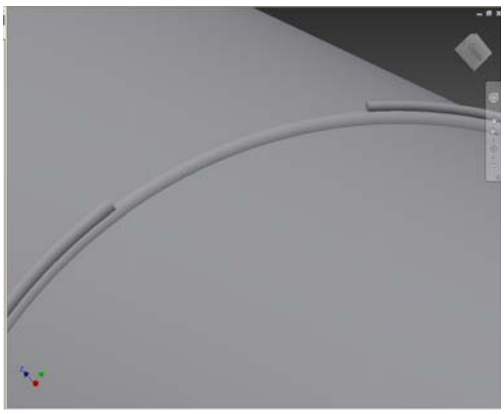

Figure 1c. Finite element model of pipeline with the displacement type defect.

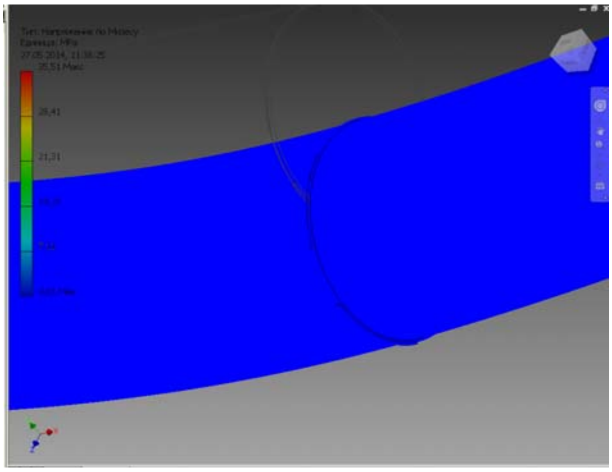

Figure 2. Equivalent stress distribution in the sectional area of casing

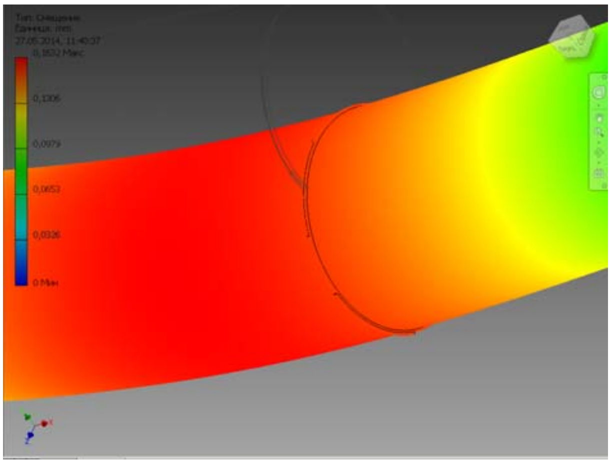

Figure 3. Bending in defect area

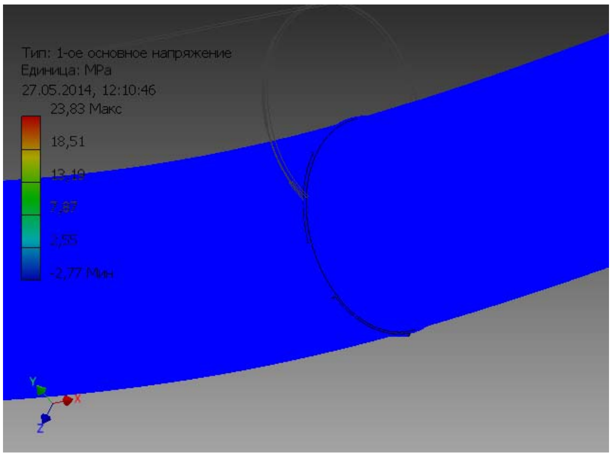

Figure 4. The first main stress

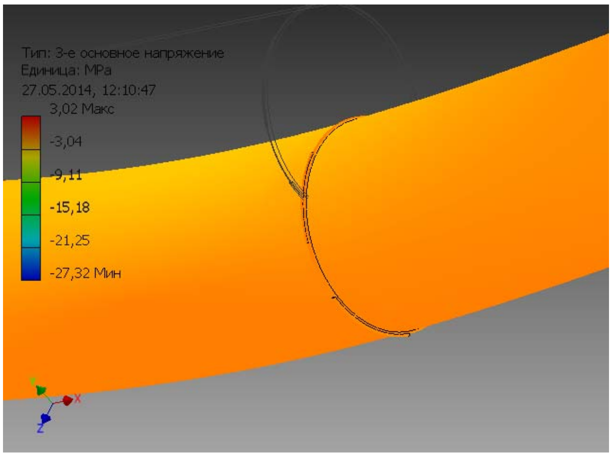

Figure 5. The third main stress

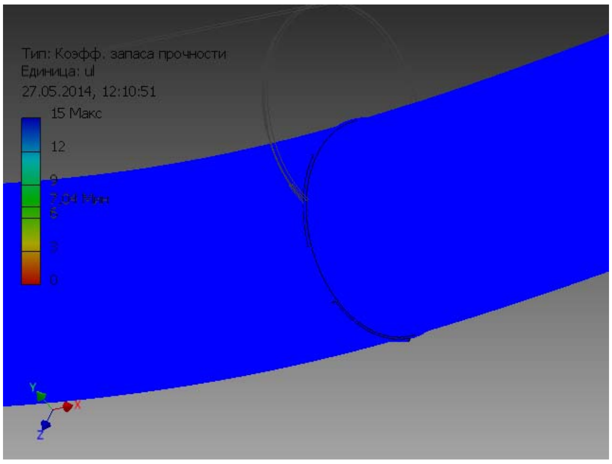

Figure 6. The factor of safety

As a result of this study the following parameters are obtained: von Mises stress (min = 0,00505 MPa; max = 35,51 MPa); safety factor (min = 7,04; max = 15); basic deformation (min=-0,00000093; max = 0,000131). These values were compared with those presented in SNiP 36.13330.2012 ‘Main pipelines’ and no deviations were found.

4. Conclusions

The use of Autodesk Inventor software for the stress and strain state analysis of the pipeline portion in protective steel casing showed that the universal CAD system allows solving a variety of difficult problems.

For example, computer simulation of welded joints allowed detecting the effect of non-metal inclusions on stresses in welded joints of the pipeline. Stresses on the interface between those inclusions and the steel matrix increased due to the physical properties of the both. The linear portion of the pipeline with circular joints was characterized by a non-uniform stress and strain state. Maximum stress values were observed on the interface between the base metal and weld root.

The simulation of the stress and strain state showed that the finite element model of the pipeline portion with the defective metal wall is adequate to the NDT results. The pipeline displacement enabled local stresses. Thus, the increase of the equivalent stresses nearby the maximum displacement depth was 1,4%. The maximum values of membrane, shear, and equivalent stresses do not exceed the theoretical resistance of 35,51 MPa. Thus, in observing the theoretical pressure inside the pipe having the wall thickness corresponding to the actual strength, the displacement type defect has no a significant effect on strength and reliability of the pipe portion.

5. References

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