

Experimental measurement of dynamic loading and numerical analysis of gas pipeline damaged by corrosion

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Abstract. The paper presents the results of the expert works in the area of diagnostics, repair, and reconstruction of the steel pipelines of the transit gas pipeline (TP) on Slovak territory. One part of our work included dynamic measurements of a steel casing pipe located under the railway. This pipeline was damaged by corrosion and it was necessary to evaluate its safety.

Introduction

Department of steel and timber structures of SUT in Bratislava has provided designs and experimental measurements on transit gas pipelines from 1998 until today. In these years methodology of short and long term measuring of strains has been developed. The behaviour of pipeline in landslides was examined and measures in case of sudden landslide were proposed. The influence of the dynamic effects of the load on the pipeline is currently being investigated. The pipeline is effected by various dynamic loads as technical seismicity [1, 2], traffic [3] and stochastic loads [4]. Fatigue damage estimation by dynamic load was studied in [5, 6]. Interaction of buried pipeline with Soil under different loading cases was examined in [7]. The previous works focused on maintenance procedures and reparations of gas pipeline components were published in [8, 9].

The paper describes the experimental measurements and numerical FEM analyses performed on the steel casing pipe and gas pipeline at the intersection of TP and rails of Railways of Slovak Republic (ZSR). The aim of the work was to theoretically determine the additional stresses arising in the pipeline damaged by corrosion. Destruction patterns of steel sample, possessing cracks of corrosion-mechanical origin, under cyclic loading were examined by Nasibullina in [10]. Zhu et al investigated dynamic failure behavior of buried cast iron gas pipeline with local external corrosion subjected to blasting vibration [11]. Blast effects on steel structures was described in [12, 13]. Assessment of Corrosion Risk in Slovak Pipeline Transmission Network was studied by Kadukova [14] and comprehension diagnostic of pipelines were reported in [15].

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1 In-situ dynamic measurement of the gas-pipeline in the crossing with rails of ŽSR

There are three railway tracks at the intersection – the double-track railway line Košice - Čierna nad Tisou, and the wide gauge line (1520mm) Haniská – Mál'ovce. It is located near Slánské Nové Mesto. The crossing of the gas pipeline with the railway is at the stationing 65,045 km of normal and 58,260 km of wide-gauge line. Stationing of the pipeline underway, with a total length of 107.0 m, is 49,957 to 50,064 km.

A pipeline DN1200 in steel casing is placed directly in the railway embankment. The 38m long casing pipe consists of an outer steel pipe DN 1800 mm, and an inner steel pipe DN 1500 mm. The outer pipe was added in the 70's, driven into the embankment by means of jacking (ramming) technology. Then the smaller pipe was pulled inside the bigger and the space between these two pipes was filled with concrete B 15 (C12/15), which was made by grouting.

The pipe jacking was made at a slope of 3.37% from a starting shaft of 6 x 7.5 m area with sloping side walls. The retaining wall (perpendicular to the casing) for hydraulic press consisted of 10 pieces of 15 m long steel pipes DN 500 mm, and wooden sleepers measuring 200 x 200 x 3000 mm (a total of 13 pieces).

According to the results of diagnostics of pipeline operator employees, the current state of the gas pipeline was unsatisfactory and repair works were required. Repairing, as well as verification of the actual damage to the pipeline, was impossible due to the cramped conditions between the casing and gas pipeline. There was a free space of only about 200 mm.

1.1 In-situ experimental measurements

At the pipeline operators' request, the experimental measurements of stresses and dynamic vibration values were performed on exposed parts of the casing and pipeline.

Excavations were carried out for the purpose of performing measurement on both sides of the casing. From the Kalša side, the height of the cover layer of soil above the pipeline was 5.0 m.

On the other side (Slánské Nové Mesto), where the measurements were performed, the height of the cover layer above the pipeline was approximately 2.5 m (Fig. 1). There were significant cracks in waterproofing found on both sides. The values of vibrations and stresses were measured in three places - on the outer tube of the casing, on the inner tube of the casing and on the gas pipeline. The measuring points are shown in the Figure 2.

The measurements were taken between 9:00 AM and 6:00 PM.



Fig. 1. Excavation at the measuring point



Fig. 2. Measuring points



Fig. 3 Strain gages

1.2 Results experimental measurements

Gradually, 15 train sets (passenger trains, express trains, and cargo trains) moving along the normal gauge were monitored. Trains on the wide gauge were registered after 4:00 p.m. The strains measured by passing on a normal gauge train were in the minimum ranges (0 - 1MPa). The total maximum vibration values ranged from of 0.08 to 0.1 mm. Measurements were performed at the lower limits of sensor sensitivity. The fact that the pipe stress state also changed during the train's passage is a proof that the load is transferred from the guard to the pipe via the centring rings.



Fig 3. Strains measurement results

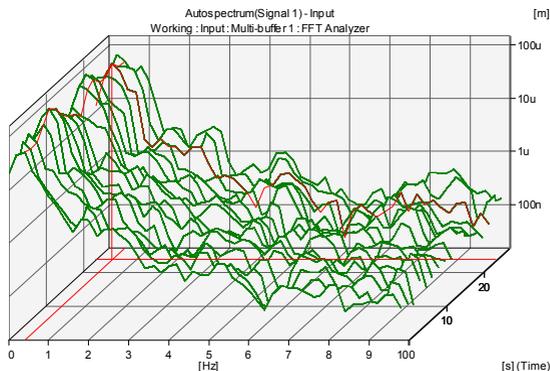


Fig 5. 8th Measurement - autospectrum (cascade) passing of cargo train on a wide gauge line

The results of strains measurements during the passage of a cargo train (4000t) on a wide gauge line are shown in the Figure 4 and the frequency measurements are shown in the Figure 5. The maximum displacement of the pipeline caused by a cargo train passing through the wide gauge railway amounted to 125 μm . This data was then used in the theoretical analysis.

2 Numerical FEM analysis of railway and pipeline crossing

Due to the inaccessibility of the pipeline in the casing (it was not possible to provide experimental measurements), the only way to find out the stress level on the pipe in the middle of the casing was numerical calculation. In the first step, the load distribution from the train (UIC -71 and a heavy cargo train) through the embankment body was analysed, because the pipeline was in the depth from 3.9m (normal gauge) to 5.35m (wide gauge). In the next step, this load was applied to the FEM model of the pipeline (Fig 6). Calculated stresses were compared with the stresses measured in-situ approximately on the same place (end of the casing) (Fig 7.). After calibration of the calculation model, the change of stress state of the pipe was analysed on a model with reduced wall thickness as a means of simulating the corrosion effects. Maximal depth of corrosion loss was 3.5mm at pipe \varnothing 1220/18.9mm from material X70.

The achieved calculated stress increments were compared with the stresses from the internal maximal gas pressure of 7.35 MPa. Gas pressure creates tension at the level 233.55 MPa, where the design resistance of the pipe is 242.50 MPa (leaving only 8.95MPa as a reserve).

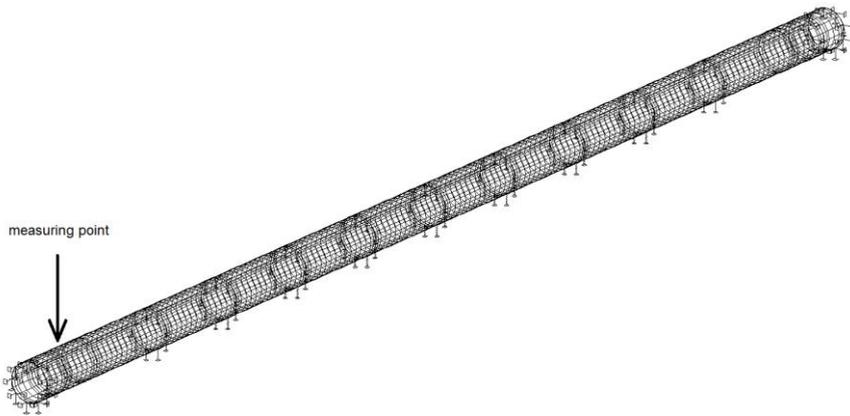


Fig 6. FEM model.

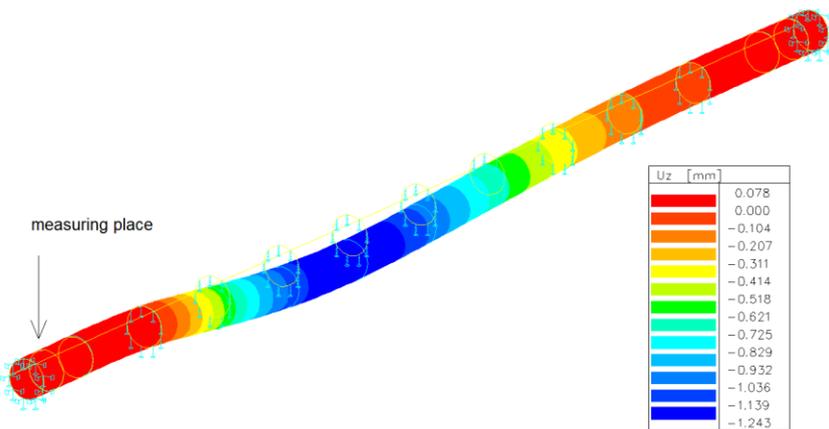


Fig 7. Displacements by passing of heavy cargo train.

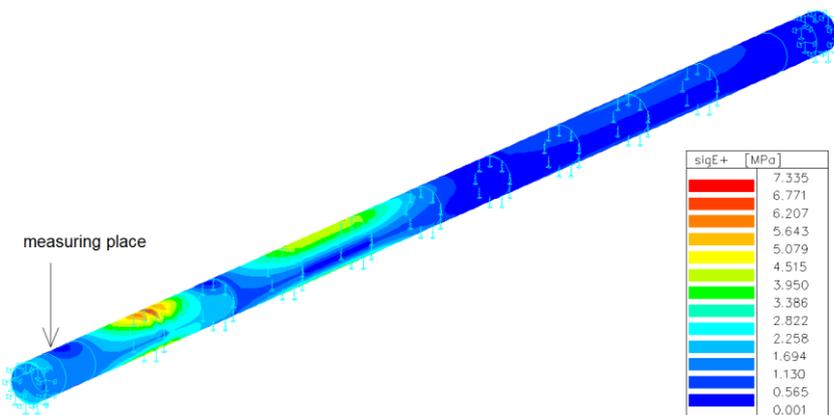


Fig 8. Stresses by passing of heavy cargo train.

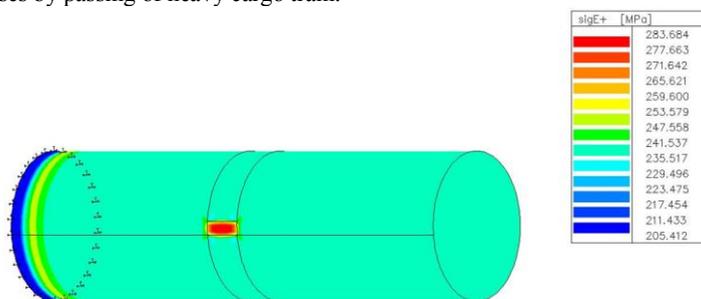


Fig 9. Stresses by local corrosion loss of 3,1mm and internal gas pressure 7,35MPa.

The results show that if the stress at the end of the casing at the in-situ measuring point is 1MPa (as measured), the calculated stress caused by the passing heavy cargo train on the pipe inside the casing ranges between 7 and 10MPa.

The second calculation shows that local weakening of the pipeline by corrosion will cause an increase of stress by more than 40MPa.

3 Discussion

The experimental measurement of dynamic loading of gas pipeline and its casing was used as a basis for preparing and calibrating a numerical FEM model. This model was used for stress level analysis of a pipeline damaged by corrosion. Calculations and measurement show that passing train creates a cyclic stress change ranging between 1 and 10MPa. The main problem of the pipe is corrosion loss of 3.2mm. Corrosion increases the stress level by 40MPa. The combination of these two factors (train / more trains at once + corrosion) with high internal pressure of gas can significantly decrease the safety of the pipe.

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