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RESEARCH ARTICLE

Strength rehabilitation of a pipeline system at the critical point by mechanical preloading

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Abstract

Computer modelling and numerical FEM analysis of buried preloaded (prestressed) piping of a compressor station is shortly discussed in the present paper. The aim of the preloading is to reduce the stress intensity at the critical point of the piping. The necessary preloading force was computed as a non-linear function of the effects of bearing and friction at the pipe/soil interface. The real magnitude of the force and the unloading bending moment were tensometrically measured during preloading.

Paper also presents brief descriptions of the proposed preloading procedure to be applied as well as the tensometric checks of the preloading force and the necessary relieving bending moment.

The comparison of the FEM results and the evaluation of measurement readings confirmed the efficiency of preloading under service conditions.

Keywords

Buried Pipeline System · Mechanical Preloading · Strength Rehabilitation · FEM Analysis

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Introduction

Friction forces represent a substantial complication to strength analysis of buried pipeline systems. These concentrated (on contact with supports) or distributed (effects of surrounding ground) forces acts against piping motion caused by thermal dilatation, pressure or other axial displacements of the piping. These forces reduce, on the one hand, magnitudes of these displacements, but on the other hand, lead to the axial stress, which is superimposed on stress caused by active loads. Under given circumstances a comprehensive analysis of such a system necessitates a solution of the non-linear contact problem. If the finite element method (FEM) is applied, the computing model of the system features additionally to the piping elements also the contact elements.

This paper presents certain results computed using the FEM for strength analysis of the buried piping system of a transmission gas pipeline within premises of a compressor station, main goal of the study is the calculation of the preloading values in a part of the system necessary during installation aimed at reduction of the inadmissible load at the critical point of the system. The result of the analysis is the necessary preloading force to be achieved during the installation of the piping. Paper also presents brief descriptions of the proposed preloading procedure to be applied as well as the tensometric checks of the preloading force and the necessary relieving bending moment.

1 The purpose of preloading

Fig. 1 shows a part of a FEM computational model of the piping system on newly built premises of the Vežké Kapušany compressor station. The model served for comprehensive strength analysis of the system under service load [2]. All significant loads of the piping were assumed in the checking:

- the internal over-pressure,
  - the load caused by thermal dilatation, assuming also the reactions and friction forces from supports and the ground,
- the weight of the piping proper, the insulation, filling and the gravity of the ground.

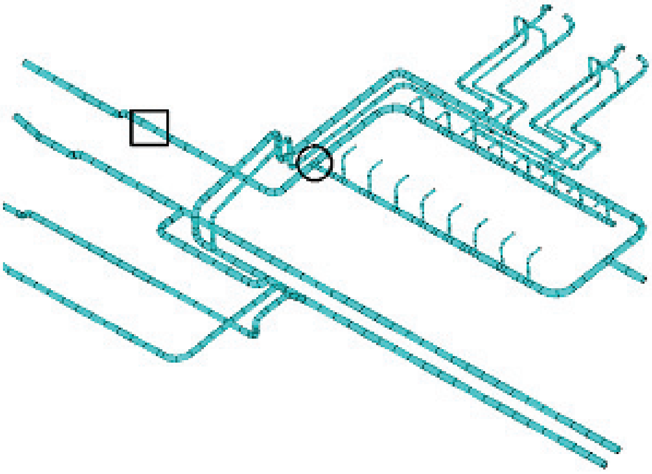

Fig. 1. Part of the piping system computational model in the vicinity of the critical point (T-shaped fitting highlighted in the figure by a circle)

The spatial model of the piping system was based on isometric projection drawings taking into account all its specific parts (bends, valves, flanges, reducers, T-shaped fittings) and their respective material, cross-section and weight specifications. The supports were represented by the contact elements featuring the rigidity and frictional properties of the respective point. The effects of the soil were simulated by the contact elements (vertical direction + friction) as well as by SPAR elements with the normal rigidity of the soil (in lateral direction). The most adverse loading state - putting into operation - was analysed using the following input values:

- Assembling temperature 15 ˚C
- Delivery piping: 7.4 MPa pressure ; 60 ˚C temperature
- Intake, suction and anti-pumpage piping: 5.5 MPa pressure; 23 ˚C temperature
- Output piping: 7.4 MPa pressure; 50 ˚C temperature

The stress intensity on straight portions of the piping, without any more significant bend or twist, is roughly equal to tangential component of the stress, which could be computed from the following relationship $\sigma_t = \frac{pD_s}{2t}$, with p – gas pressure, D_s – average piping diameter, t – piping wall thickness. The estimate for straight portions of the output piping would be as follows:

$$\sigma_t = \sigma_{int} = \frac{pD_s}{2t} = \frac{7.4\,1394.7}{2\,25.3} = 204.0\,\text{MPa}$$

and, for the straight portions of the intake piping this value is smaller, proportionally to the input pressure.

Numerical computations of the piping yard using the FEM under service load have brought the results shown in Fig. 2, presenting stress intensity values. Along with confirmation of the analytical values on straight portions of the piping, we can also identify the point of concentrated stress, reaching the non-permissible extreme of σ_{int} = 623 MPa in the T-shaped fitting, highlighted in Fig. 1 and 2 by circles.

The reason for the occurrence of the critical point in the T-shaped fitting is the additional bending and shearing load caused by the opposite movements of the output piping and the intake collector of coolers under the thermal and pressure load. Based on the designer's proposal it was decided to solve the problem by tensile preloading the output piping at the point highlighted by a square in Fig. 1 during the installation in the direction of gas flow, introducing in this way into the T-shaped fitting the initial bending moment in direction opposite to the adverse moment acting during the service. If the preloading gap is determined correctly or, in other words, if the preloading moment is sufficient, the stress at the critical point does not exceed the range permitted.

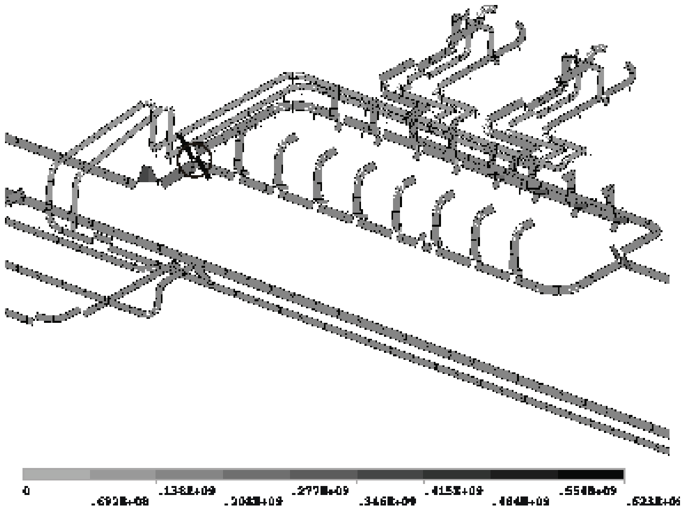

Fig. 2. Maximum stress intensity values at the critical point and its vicinity[Pa]

2 Computation of preloading force and pre-stressing effects

First an approximate analytical computation of the pre-stressed piping portion performed in order to arrive at an estimate of the approximate value of the necessary preloading gap and the preloading force, applying the simplified beam representation shown in Fig. 3. Friction was disregarded and rigid constraint was applied at the critical point. For a given axial displacement of the end point u_A and assuming only the bending effect of the force F, the relationship between this displacement and the force F can be expressed as follows [1]:

$$u_A = \frac{R}{EJ}\int_0^{\pi/2} M(\varphi)\,\frac{\partial M(\varphi)}{\partial F}\mathrm{d}\varphi + \frac{1}{EJ}\int_0^{L} M(x)\,\frac{\partial M(x)}{\partial F}\mathrm{d}x \tag{1}$$

where EJ is the bending rigidity of the pipe and M is the bending moment. After expressing the integrals in (1) and inverting the results we would arrive at the following relationship:

$$F = \frac{u_A\,EJ}{0.356R^3 + R^2L + RL^2 + L^3/3} \tag{2}$$

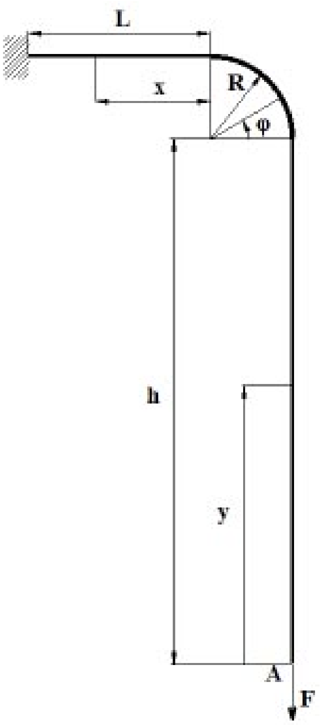

Fig. 3.

The relationship (1) can be used to determine already estimated value of the u_A, leading to a sufficient relieving bending moment in the fixing (in the critical point). The value received in the above described manner was further refined using the FEM. The computational model shown in Fig. 1 was modified, to facilitate the simulation of the preloading efforts. We removed the effects of gas pressure and temperature, the effects of the ground along the excavated portion; and we introduced in the preloading point (square in Fig. 1) the preloading gap. A finite element of the truss type featuring absolute rigidity was applied in this gap, with the initial strain being equal to one. The element has simulated in this manner the retraction of both parts of the piping system by the respective preloading gap, while accounting for the different rigidity of both parts. The result of this numerical analysis was the size of the necessary preloading gap, equal to 42 mm. Application of the latter in the computing model of the piping yard lead to reduction of stress intensity at the critical point to a permitted value of 454 MPa (Fig. 4). The necessary preloading force for the gap specified above is 292 kN. Preloading procedure and preloading jig were both designed according to this value.

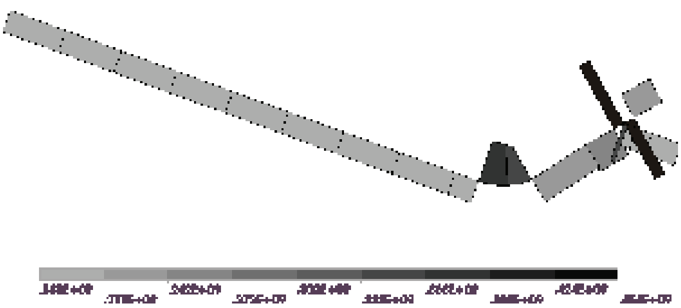

Fig. 4. Stress intensity at the critical point after preloading [Pa]

It might be of interest to note that approximate analytical calculations of the force with the above specified gap resulted in the value of 332 kN. Increased force is logical consequence of bigger than real rigidity of the boundary conditions used in this model: Mechanical compliance of the part connected is neglected on the one hand on the other hand, we have totally rigid fixing.

3 Implementation and checking of preloading

Preloading at the critical point of the system was implemented with minimum costs. The point of tensile preloading (highlighted with a square in Fig. 1 was the assembly joint after pressure test. The assembly piece was made with a 45 mm gap. Using six welded fixtures with screws modified specifically for this purpose both parts were manually tightened with screws, to achieve the 3 mm distance, and welded together in pre-stressed state with a guaranteed welding joint. The effect of preloading in the vicinity of the critical point was studied using the tensometric means (refer to the Figs. 5a - 5d).

Tensometric checks were performed in the course of preloading as well as over the first six months of system service. The check was based on comparison of the data measured against the data calculated from the realistic FEM model. Detailed results of the checks are presented in reports [2, 3] confirming in full the improved strength of the critical point as well as good quality of the computing model. E.g. the bending moment identified with tensometric means at the point of measurement on the critical section following the preloading is 59.9 MPa and the calculated value is 63.8 MPa. Repeated service checks were performed, each time after several months. Resulting forces of the internal forces existing under given service conditions were specified at the point of checking according to [3] using tensometric means. Identical service conditions were entered in the FEM calculation. The comparison of the results and the evaluation of measurement readings confirmed the efficiency of preloading also under service conditions.

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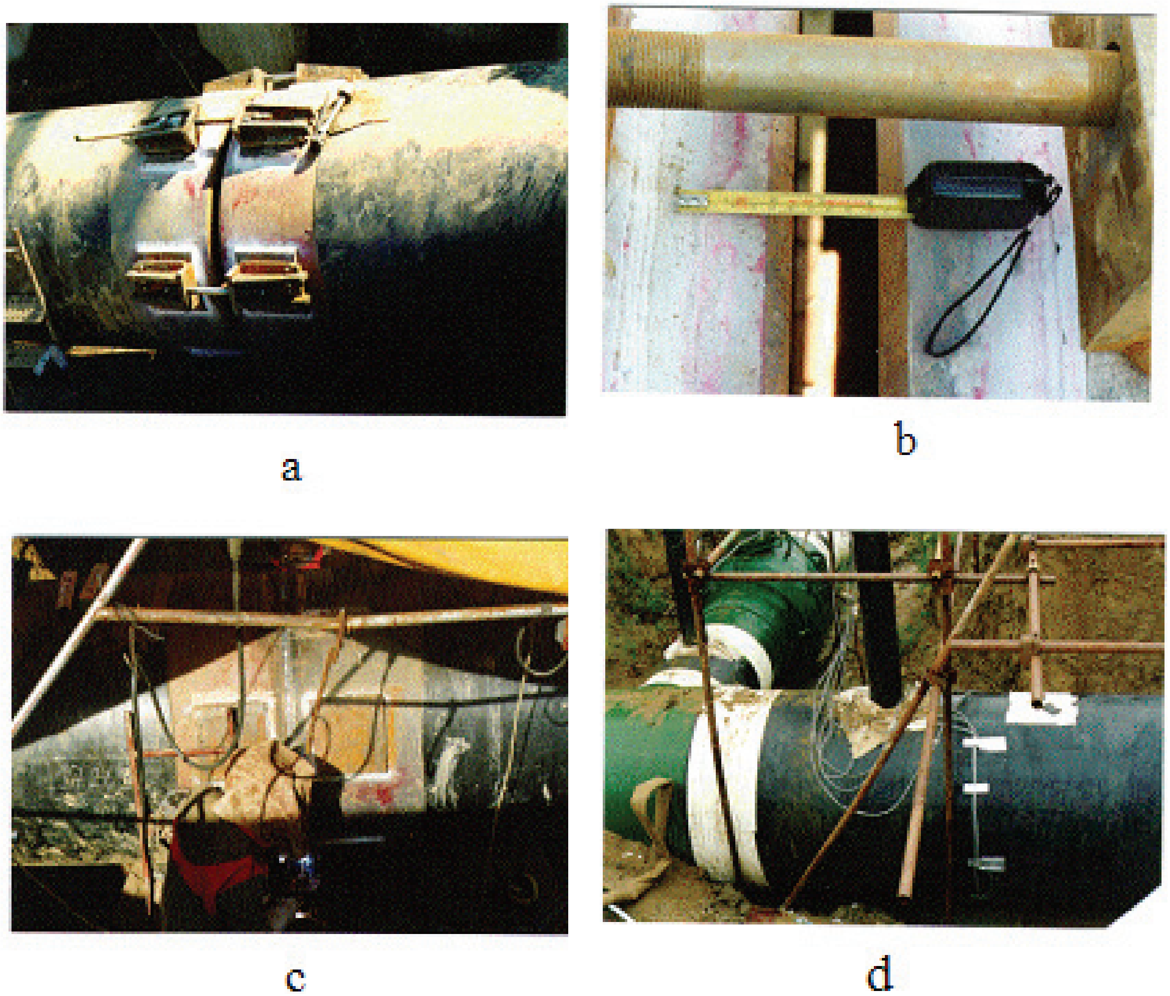

Fig. 5. a. Assembly gap is prepared for preloading
b. Overall size of the assembly gap is 45 mm (42 mm for preloading, 3 mm for welding joint)
c. Assembly joint welded with the pre-stress
d. The point of tensometric monitoring of the effects of preloading