STRENGTH CONSEQUENCE MINIMIZATION OF DIGGING OFF BURIED GAS PIPELINE AT ISOLATION COAT RENOVATION REALIZED DURING OPERATION

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Abstract. Because of economic reasons many of the maintenance and repair activities at the buried gas pipeline are performed during its operation. By digging off the earth from the sides of the pipeline in certain length there is a possibility that additional bending loading of the pipe occur due to its deflection. This is caused by the additional compressive force which originates in the buried pipeline as a result of a detained strain, when the longitudinal strain in the pipeline due to service condition (internal pressure and heating) cannot be realized. In the paper a numerical simulation (using of program ANSYS) of buried gas pipeline elbow at backfill removal due to repair of isolation coast and following filling will be presented.

Keywords: buried pipeline elbow, additional loading after filling excavation, non-compacted ground, gravel pipe bed

1. Introduction

Many of maintenance activities and repairs of gas pipelines are carried out during their operation for economic reasons. High-pressure gas pipeline from strength aspect can be considered a closed cylindrical shell with axis represented by a 3D curve, which is consisted of straight parts and large radius elbows with small bending angle.

A pipeline buried in the earth is loaded by a pressure of the transported gas, thermal expansion, gravity forces of the pipeline and the earth over it, reaction forces between the earth and pipeline and friction forces respectively. Friction forces acting on relatively short part of the pipeline (some hundreds meters), are capable to retain longitudinal deformation of the pipe originating from internal pressure and temperature change; as a result considerable compression axial force originates in the pipeline. In the straight parts of the pipeline this force causes only compressive load, while in the elbows additional bending load is created as well. The bending load is negligible since the elbows are supported by the naturally compacted earth on its sides and at the bottom. We used Tresca's hypothesis in strength assessment of the resultant mutiaxial strain. In the pipeline there are principal stresses in tangential, axial and radial directions. They are given by equations

$$\sigma_t = \frac{p\ \mathrm{d_S}}{2\ \mathrm{h}},$$
$$\sigma_a = \frac{p\ \mathrm{d_S}}{4\ \mathrm{h}} + \sigma_N = \frac{p\ \mathrm{d_S}}{4\ \mathrm{h}} - \left[\frac{p\ \mathrm{d_S}}{4\ \mathrm{h}}\left(1-2\mu\right) + E\alpha\Delta T\right], \qquad (1)$$
$$\sigma_r = -p \cong 0,$$

where $\mathrm{d_S}$, h ... are the mean diameter of the pipe, and wall thickness,

μ, α ... are Young's modulus, Poisson's ratio, and thermal expansion coefficient of the pipe material,

p, ΔT ... are operating pressure and temperature increment with respect to the reference temperature of the pipeline during its assembly.

As the biggest principal stress is $\sigma_1 = \sigma_t$ and the smallest one is $\sigma_3 = \sigma_r = 0$ then stress intensity is given by $\sigma_i = \sigma_1 - \sigma_3 = \sigma_t$.

We can conclude, that compressive force from retained axial strain does not affect the stress intensity either in straight parts or in elbows of buried pipeline.

If we dig off a longer part of an operating pipeline, i.e. we remove aside supporting effect of the compacted earth and reactions from the bottom respectively, the loading of that pipeline part is affected due to compressive force from retained axial strain.

A straight pipeline, which is digged off in sufficient length, can move aside and as a result additional bending loading might occur. In the deflected part the compressive force slightly decreases and its decrease must be compensated by friction forces of the earth near the edges of the excavation. This problem was theoretically solved in [1], [2], [6].

If the pipeline elbow is digged off significant additional bending loading originates in it, where bending loading is determined by the geometrical shape of the elbow and is practically independent on the pipe deflection, see [3]. If we denote $\Delta\sigma_N$ the axial compressive stress decrease and $\sigma_{o,max}$ the stresses, corresponding to the additional bending moment, than the principal stress in axial direction will be given by

$$\sigma_a = \frac{p\ d_S}{4\ h} + (\sigma_N - \Delta\sigma_N) \pm \sigma_{o,\max} . \qquad (2)$$

Consequently the axial stress becomes the smallest one on the side where compressive bending stresses act, i.e. $\sigma_3 = \sigma_a$, and the stress intensity increases.

Significant additional loading of gas pipeline occurs at earthwork during renovation of isolation coat of convex elbow (in valley), situated in a vertical plane. Two technological procedures of earthwork, evaluated by the factor of safety at the critical place of the pipeline after renovation, are presented in this paper.

2. Stress-strain analysis of elbow after isolation coat renovation

In this part we determine additional loading of the convex buried gas pipeline elbow at single phases of new isolation coat creation during its operation, i.e. in the digged off state and after following backfilling. We evaluate the state, when filling is done without earth compacting as well as when the gravel bearing bed is created.

Numerical analysis has been made by finite element method using the ANSYS program. For gas pipeline modeling we used the PIPE16 element, which enables realization of overpressure in pipe, outer unit loading along the pipeline and temperature loading as well. The compressive axial force from restrained longitudinal deformation was realized by fixing the pipe model at the ends. The CONTAC52 element was used for modeling the contact between the earth and the pipeline, which simulates compressive normal reaction force of the earth and friction force in the opposite direction to the displacement of pipe element. The element enables to realize a gap as well, i.e. displacement of the pipe element in the normal direction, for which contact does not still occur.

A numerical analysis was performed for a pipeline dimension DN 1200 (d_S = 1200 mm, h = 13,6 mm), where pressure and temperature of transported gas were p = 6,6 MPa, T = 38°C (i.e. ΔT = 23°C). Parameters of elbow are: radius ρ_0 = 203,6 m, bending angle α = 9°; the slopes of straight parts of the pipeline from both sides of the elbow are the same. We assume, that isolation coat renovation was realized along the whole length of the elbow, i.e. 32 m. The height of the earth layer covering the pipeline is 1,2 m, see [4], [5], [6]. Two technological procedures of the earthwork during repair are evaluated in the following parts.

2.1 Excavation backfilling with earth without compacting

Let us have a case of the elbow, which is sapped along its whole length. On this part (between points 1 and 2 in Fig. 1) the pipeline creates a bridge and straight parts lay on the compacted ground with normal stiffness KN = 10.10^6 N/m^2 and friction coefficient f = 0,4. The deflection curve of the pipe axis is given in Fig.1 with maximum value of radial displacement u_{max} = 10,6 cm. Due to deflection the axial compressive stress decreases by $\Delta\sigma_N$ = -20,7 MPa, related to its original value from retained axial strain σ_N = -115,5 MPa. The corresponding additional bending moment diagram is shown in Fig.2 with maximal stress value $\sigma_{o,max}$ = 125 MPa in the middle of the elbow, and $\sigma_{o,max}$ = 123 MPa (with opposite orientation) in the cross-sections above bearing bed near the edges of excavation (points 1,2). In these sections on the side of compressive bending stresses the stress intensity values are σ_i = 366 MPa, and σ_i = 364 MPa, respectively; for comparison the value of stress intensity before sapping of the elbow was only σ_i = 286 MPa.

If we backfill the excavation with earth without compacting of the pipe bed after renovation, the pipe loading will worsen due to the gravity force of covering earth; this ground bed is not bearing, i.e. by increasing the deflection of the pipe axis about another 10 ÷ 15 cm the bed is not able to bear practically any normal loading. Maximum value of

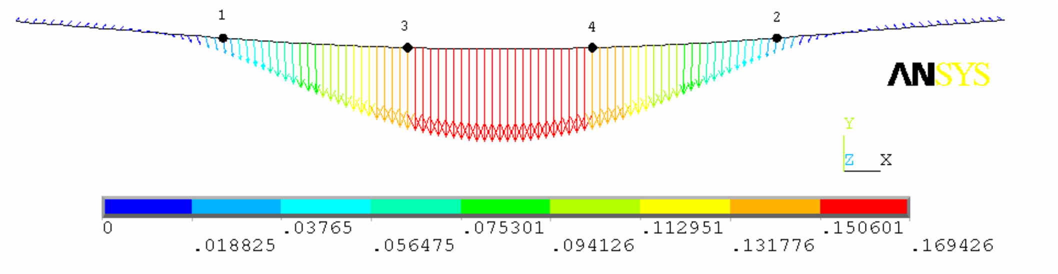

Fig. 1Deflection diagram of pipe axis [m] at sapping elbow along the whole length

radial displacement increases to u_{max} = 16,9 cm; due to deflection of the pipe axis the axial compressive stress decreases by $\Delta\sigma_N$ = -25,7 MPa and in cross-sections with extreme values of bending moment the corresponding stresses will reach $\sigma_{o,max}$ = 199,9 MPa (at the middle of the elbow) and $\sigma_{o,max}$ = = 189,5 MPa (near the edges of the hollow). The stress intensity diagram is shown in Fig. 3 with the maximum value σ_i = 433 MPa. This 1,51-multiple increase of stress intensity with respect to the value before renovation, is evidently inadmissible, because in the same rate decreases the factor of safety of the pipeline part.

The same result we would obtain, if the sapping and following excavation backfilling would be done on shorter length and repeated several-times (e.a. on twice, three-times), incidentally with some break, too (e.a. one-two years); after some time the freely filled earth will naturally compact, and a hollow will be created under the pipeline. It is clear, that the quality of the new bearing bed created after renovation has significant influence on additional loading of the pipeline.

2.2 Successive sapping of pipeline and bearing gravel bed creation

Because the compacting of the earth under the pipeline is practically impossible, the creation of new gravel bearing bed has to be considered. The deformation characteristic of gravel with grain size at about 10 mm mixed with sand, valid for experimental model is shown in Fig.4. In the experiment this mixture was situated in a steel pipe of inner diameter ϕ145 mm and length h = 150 mm and it was compressed by piston. We can substitute (for higher pressure) this strongly non-linear characteristic by the straight line, shifted from the coordinate system origin by initial non-resistance displacement denoted by Δ.

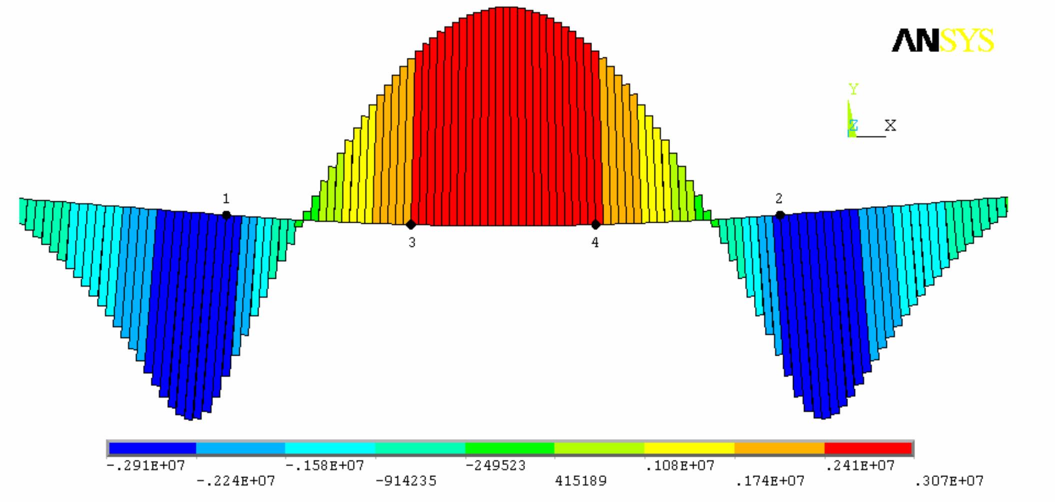

Fig. 2 Additional bending moment diagram [Nm] at sapping elbow along the whole length

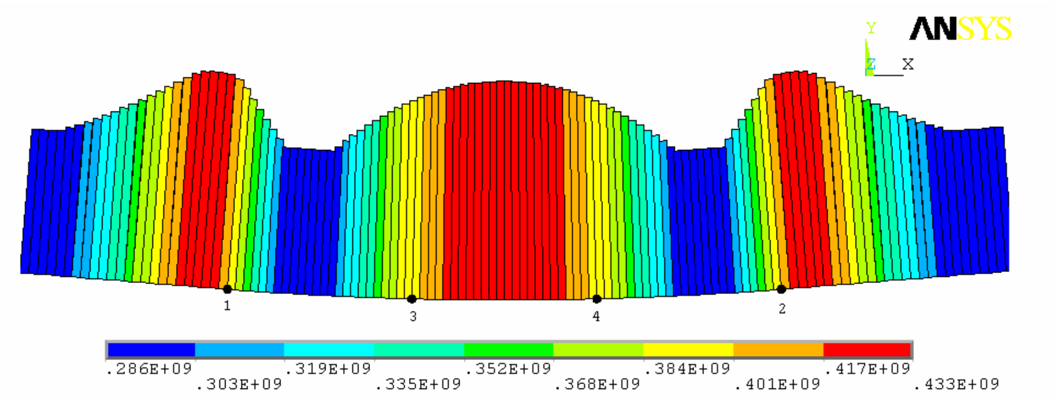

Fig.3 Stress intensity diagram [N/m^2] after backfilling hollow without processing of pipe bed

In order to use the above mentioned characteristic for description of the deformation characteristic of the new bearing bed at the earthwork during isolation coat renovation, it is necessary to ensure the deformation state of the gravel to be similar as it was in the experiment, i.e. compression in quasi-closed space. That can by done in the following way: gravel is heaped up under the pipeline as long as a contact with the pipe occurs in the width equal approximately to the half of the pipe diameter; downwards the gravel width can increase, e.a. due to a pouring angle. This gravel layer (with a height about 0,6m) is closed by layer of compacted earth, which top reaches at least the pipe axis. Then for the deformation characteristic of gravel bed a normal stiffness KP = 5.10^6 N/m^2 and non-resistance displacement up to Δ = 0,025 m can be used.

Let us evaluate the strength consequence of digging off convex elbow realized by the following technological procedure at the earthwork:

- In the first phase the pipeline covering earth is removed and its sides are digged off along the whole length of the elbow, so the pipe still lying on the compacted earth.
- In the second phase the earth is removed from under the pipe along some part its of length, e.a. along one third (see Fig. 5a, between points 1,3). After isolation coat repair the new bearing gravel bed is created in the way mentioned above. Due to subsequent sapping off the pipe it is necessary to create a supporting wall from bags filled with gravel. In the figure a non-resistance displacement Δ of gravel bed is also drawn. This procedure is still twice repeated, see Fig. 5b, c. In Fig. 5b we can see, that the deflected pipeline is supported by the gravel bed part on the left to the point 3 at sapping the second third of elbow (3,4), and therefore the values of radial displacement are small.
- In the third phase the pipeline elbow is burried with soil along its whole length.

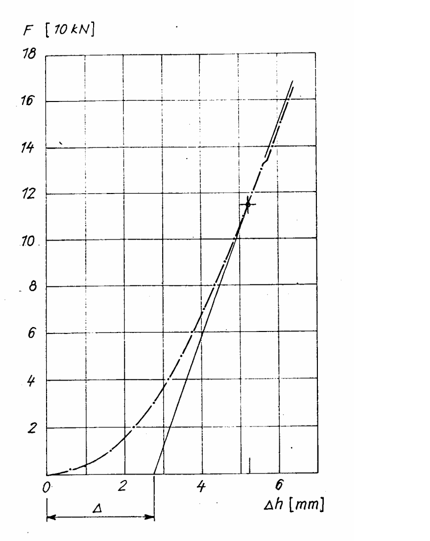

Fig. 4 Deformation characteristic of gravel bearing bed model

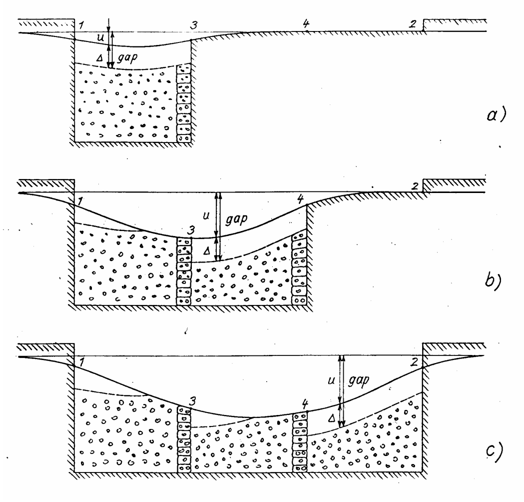

Fig. 5 Demonstration of single phases of successive pipe sapping and simultaneous creation of bearing gravel bed

We remark, that CONTAC52 element requests to measure the gap value from the original position of the pipeline elbow axis (before renovation, when pipe lays on compacted ground). For simulation of stress-strain state after renovation the gap value in general place given with co-ordinate x is expressed by

$$gap(x) = u_i(x) + \Delta ,$$

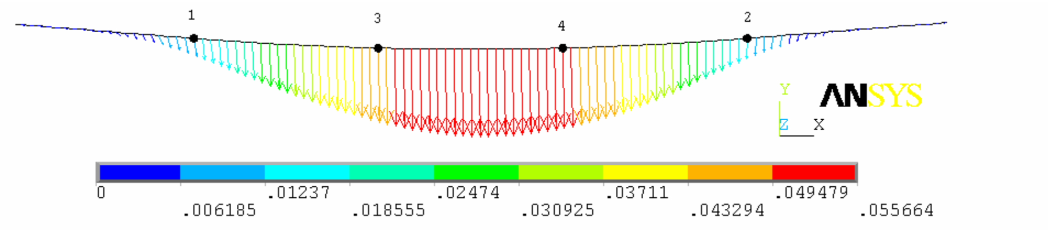

Fig. 6 Deflection diagram of pipe elbow axis [m] after repair at sapping and creation of gravel bed on three-times

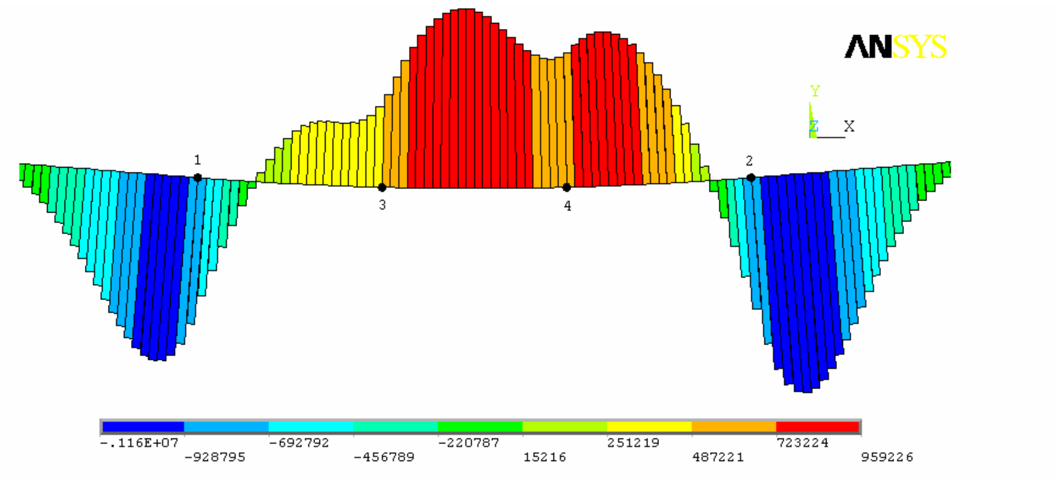

Fig. 7 Additional bending moment diagram [Nm] after repair at sapping and creation of gravel bed on three-times

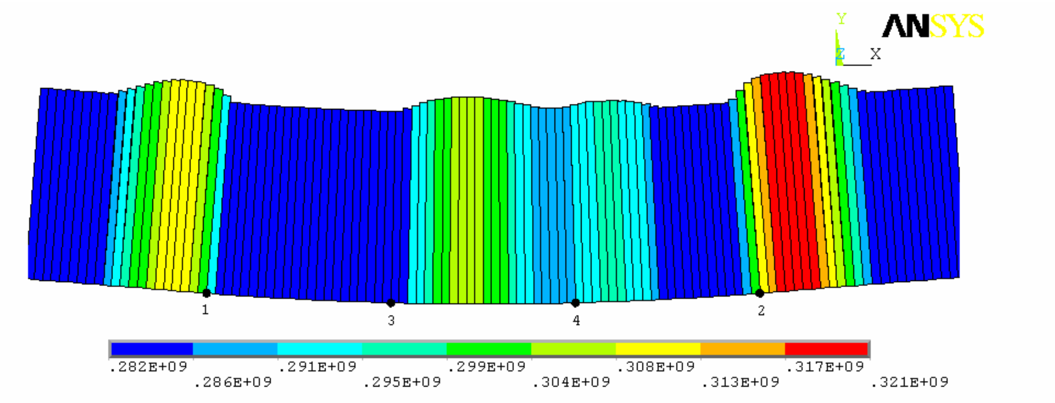

Fig. 8 Stress intensity diagram [N/m^2] after repair at sapping and creation of gravel bed on three-times

where $u_i(x)$ is radial displacement of the elbow axis in general place of the same elbow part, which is just sapped. Therefore it was necessary to determine the deflection curve at every step of successive sapping the pipe and gravel bed creation.

The results of numerical stress-strain analysis of the convex elbow after renovation, realized in the above mentioned way of successive pipe sapping and simultaneous gravel bed creation on three-times, are shown in the following figures. Fig. 6 presents the deflection curve of the pipeline axis; maximum value reaches u_{max} = 5,6 cm. Due to deflection the axial compressive stress decreases by the value $\Delta\sigma_N$ = -14,4 MPa, related to its original value from retained longitudinal strain σ_N = -115,4 MPa. The corresponding additional bending moment diagram is shown in Fig. 7 with maximum stress value $\sigma_{o,max}$ = 75,5 MPa in the cross-section above the bearing ground bed near the edge (2) of the excavation. The diagram of stress intensity at critical point of every cross-section is given in Fig. 8. The maximum value is σ_i = 321 MPa, that is 1,14-times higher than it was before renovation (σ_i = 282 MPa). We can conclude, that the evaluated technological procedure of gravel bed creation is applicable.

3. Conclusion

Considering the numerical results of stress-strain state of buried gas pipeline after the repair (at which the pipe is sapped during operation) it is necessary to create a new bearing pipe bed at the earthwork. Because the earth compacting under the pipeline is practically impossible, the creation of bearing bed from gravel has to be considered. Using the technological procedure, in which the sapping of pipe elbow and following gravel bearing bed creation is performed successively (on the three-times), we can reduce the value of the stress intensity in critical place (1,14-multiple of the value referring to the state before renovation). For comparison we used the same elbow, where the excavation backfilling after renovation was done with the non-compacted earth; the value of the stress intensity in critical place was 1,51-times higher than its original value. As the factor of safety of this pipe part decreases in the same rate, this earthwork technology is evidently inadmissible.

References

[1] Jančo, R.: Numerical analysis of buried gas pipeline during operatiom. Habilitation thesis, SjF STU Bratislava, 2010

[2] Poděbradský, J.: Change of stress-strain state of buried gas pipeline at backfill removal during operation. In: *Proceedings of conference Maintenance and repair of gas pipelines,* High Tatras, 2000, Paper 34, 7 p.

[3] Poděbradský, J., Benča, S.: Additional loading of buried gas pipeline elbow at backfill removal during operation., In: *Proceedings of conference Strojné inžinierstvo'2001*, STU Bratislava, 2001, Section No. 9, p. 602-607

[4] Poděbradský, J., Jančo, R., Benča, S., Elesztős, P.: *Resultant stress state at critical locality of a pipeline laid in hilly terrain caused by its digging off during operation.*, In: Technical report of SjF STU Bratislava, 2002, Part I, 44 p.

[5] Jančo, R., Poděbradský, J.: Numerical simulation of loading of buried gas pipeline elbow after renovation of isolation coat during operation, In: *Proceedings of conference „Applied Mechanics 2003"*, Gliwice, Poland, 2003, p. 101-106

[6] Jančo, R.: FEM approach of solution of beams on elastic foundation. In NÁHLÍK, L. -- A KOL. *Applied Mechanics 2011 : Conference Proceedings. 13th conference. Velké Bílovice, April 18-20, 2011.* Brno: Academy of Sciences of the Czech Republic, 2011, s. 71--74. ISBN 978-80-87434-03-1.