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APPLICATION OF TRENCHLESS METHODS FOR PIPELINES RENOVATION ON MINING AREAS

ZASTOSOWANIE METOD BEZWYKOPOWYCH DO RENOWACJI RUROCIĄGÓW NA TERENACH GÓRNICZYCH

Several trenchless methods are currently applied to repair damaged pipelines of territorial development networks. There exist many technologies of pipelines renovation no always useful to repair pipelines on mining and post-mining areas. In the paper influence of mining exploitation onto pipelines was presented with special regard of pipelines after accomplished renovation with use of trenchless methods. An evaluation of these methods application possibilities to the renovation of pipelines on mining areas was also carried out.

Keywords: trenchless methods, pipelines renovation, mining areas

Obecnie do renowacji uszkodzonych rurociągów sieci uzbrojenia podziemnego stosowane często są metody bezwykopowe. Istnieje wiele technologii renowacji rurociągów, które nie zawsze nadają się do naprawy przewodów na terenach górniczych i pogórniczych. W artykule przedstawiono wpływ eksploatacji górniczej na rurociągi ze szczególnym uwzględnieniem rurociągów po przeprowadzonej renowacji z zastosowaniem metod bezwykopowych. Dokonano także oceny możliwości zastosowania tych metod do naprawy przewodów na terenach górniczych.

Słowa kluczowe: metody bezwykopowe, renowacja rurociągów, tereny górnicze

1. Introduction

For the replacement, renovation and reconstruction of damaged pipelines of technical territorial development networks more and more often trenchless methods are used. Thanks to this fact decreases the range of carrying out of expensive, frequently deep excavations, which in a developed area can cause considerable difficulties relating to the traffic. The trenchless tech-

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nologies of renovation of water, sewerage and gas pipelines allow to restore and in some cases even to improve the usable properties of the pipelines through the introduction of a new pipe into their interior or carrying out of internal lining. Nowadays, these technologies are used also more and more often in mining and post-mining areas, where mining activities contributed in an essential way to the damage of territorial technical development networks. The networks located in mining areas are subject to the influence of strains and curvatures of the ground layer adjacent to the surface and land subsidence (Kowalski, 2001). These impacts causes both changes of natural object loads as well as horizontal and vertical displacements. Land subsidence cause the change of primary pipelines formation line, what is especially significant in the case of sewerage networks with gravitational flow of wastewater and/or rainfall water.

In the paper, influence of mining deformations onto pipelines of technical territorial development network after accomplished repair with the use of trenchless methods was presented. An evaluation of these methods application possibilities to the renovation of pipelines on mining and post-mining areas was also carried out.

2. Trenchless methods of pipelines renovation

Trenchless pipelines renovation can be realised through coating (spraying) of a thin material layer on the internal surface of cleaned pipes and also through the introduction or carrying out of internal lining or pipe.

According to the liner's cooperation with the renovated pipes we can divide the methods of no-dig pipeline renovation into two types (Bontus et al., 2005; Gumbel, 1998; Kuliczkowski, 2005):

- loose-fitting – not closely adjacent to the walls of repaired pipes, with or without filling of the space between the lining and old host pipes (Fig. 1a),
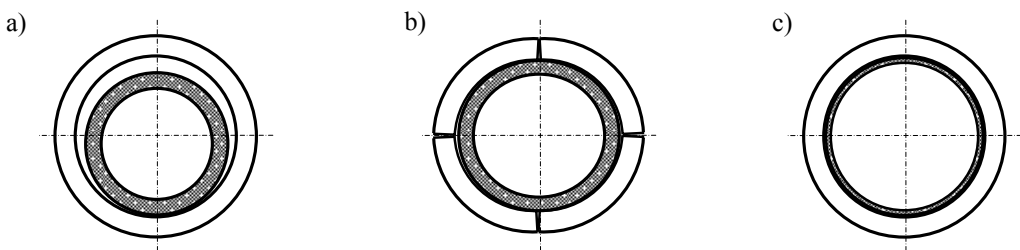- close-fitting – closely adjacent to the h ost pipe walls (Fig. 1b,c).

Fig. 1. Types of liners according to their cooperation with the renovated pipe: a) independent loose-fitting, b) independent close-fitting, c) interactive close-fitting

The renovations of the first type are realised through the introduction into the interior of old pipelines of new pipes with smaller outside diameter, without deformation of their cross-section. The reconstruction of this type can be realised using long pipe sections, joined on the surface and pulled into renovated pipeline. The preparation of the entire pipeline section with considerable length is carried out through joining the pipes on the surface, for instance through welding of

pipe segments made of polyethylene. The space that arose between the introduced pipes and the old pipeline is sometimes filled with a filling material, for example concrete. This filling material stabilizes the new pipe in the old one.

The renovations of the second type are realised through the introduction of an initially deformed pipe into the repaired pipeline and its formation or introduction of a special sleeve saturated with resins and carrying out the pipe on the spot or through coating (spraying) of a thin material layer on the surface of pipes.

Carrying out of the pipeline renovation using an initially deformed continuous pipe made of thermoplastic materials, such as polyethylene or polyvinyl chloride (PVC), consists in its pulling into the pipeline's interior and next suitable formation through heating and internal pressure. The lining closely adheres to the internal surface of the renovated pipeline. These technologies are called Fold and Form Pipe (FFP).

The pipelines renovation through carrying out of the pipe on the spot consists in the introduction into the interior of a sleeve saturated with resins, which under the impact of internal pressure is subject to inversion and is pressed towards the internal surface of repaired pipes. Next the resins are subject to hardening. The hardened lining can be stuck to the surface of renovated pipes or only adhere closely to them without junction. Technologies of this type are called Cured in Place Pipes (CIPP).

The thin coat, received by spraying, overlaid on the internal surface of pipes serves their tightening and repair of small damage. Moreover, it constitutes anticorrosion protection and improves the pipeline's hydraulic properties, and in the case of water supply systems it allows to improve the drinking water quality. The coat usually reaches the thickness of at least a few mm and can consist of one or more layers. These methods are used most often for the renovation of old water pipelines, mainly made of steel, cast-iron or asbestos and cement. The materials used to carry out such coats constitute most often cement mortar, cement mortar with plasticizing additives, as well as epoxy resins, polyurethanes and polyethylene (Bontus et al., 2005; Gumbel, 1998; Kuliczkowski, 2004; Kowalczyk & Kalisz 2002).

The mentioned above methods of no-dig network renovations can be used for the restoration of pressure and non-pressure pipelines. The liners can serve the pipeline tightening without the transfer of loads, which transmit the old pipes. In a situation, when the renovated pipeline is partly or entirely degraded, the liners can also partly or entirely transfer internal and external loads (Falter, 2001; Falter et al., 2002; Thépot, 2004).

3. Impact of underground mining exploitation on renovated pipelines by use of no-dig methods

The horizontal strains of the ground layer adjacent to the surface have decisive unfavourable influence on additional loads and displacement of elements of water, gas and sewerage networks (Hejmanowski et al., 1994; Kwiatek, 1997, 2007; Mokrosz, 1985). In the case of non-pressure sewerage pipelines also changes of ground inclination are important. Moreover, in the case of pipelines with big diameters an essential impact can also have surface curvatures. The influence of underground mining operations on the pipelines was presented in Figure 2.

When determining pipeline loads caused by underground mining exploitation the changes of soil pressure on pipe walls towards the transverse direction to their axis and longitudinal loads
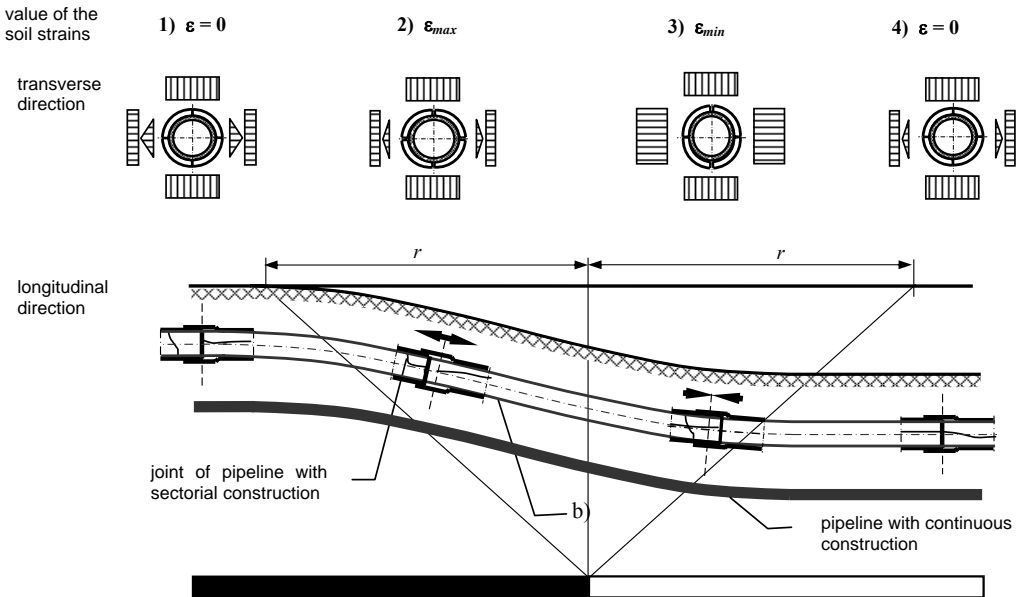
Fig. 2. Influence of underground mining exploitation on different kinds of pipelines: 1) state before
underground extraction, 2) ground lengthening, 3) ground shortening

should be taken into consideration first of all (Kalisz, 2001; Mokrosz, 1985). Longitudinal loads
are caused by the friction of soil grains against the external surface of pipes.

The loads of external host pipes are generally transferred to the lining and internal new
pipes, carried out using of no-dig methods of renovation. This impact is also considered in the
longitudinal and transverse direction towards their axis.

3.1. Impact of mining exploitation in the longitudinal direction towards the pipeline axis

The deformed ground layer influences the pipelines through the forces of friction of displaced
grains against the external surface of host pipes, as well as against pipe bell joints, flanges and
elements of pipeline fittings. In connection with the above the liner will be subjected to the impact
of longitudinal tangent forces, acting on the surface of its contact with pipes of the renovated
pipeline. These forces will generate longitudinal internal tensile or compressive forces causing
longitudinal deformations of linings. The scheme of impact of deformation of the ground layer
adjacent to the surface on liners in the longitudinal direction was presented in Figures 2 and 3.

In the case of pressure pipelines, such as water and gas pipelines, the impact of mining ex-
ploitation is considered with respect to sections equal at least to the double length of the radius of
main impact reach $2r$; tension occurs at a length of at least r. However, for sewers the impact of
mining exploitation is considered in sections between chambers (wells). In the case of pipelines
built of short pipes more disadvantageous for the liner is the impact of tensile forces, caused by
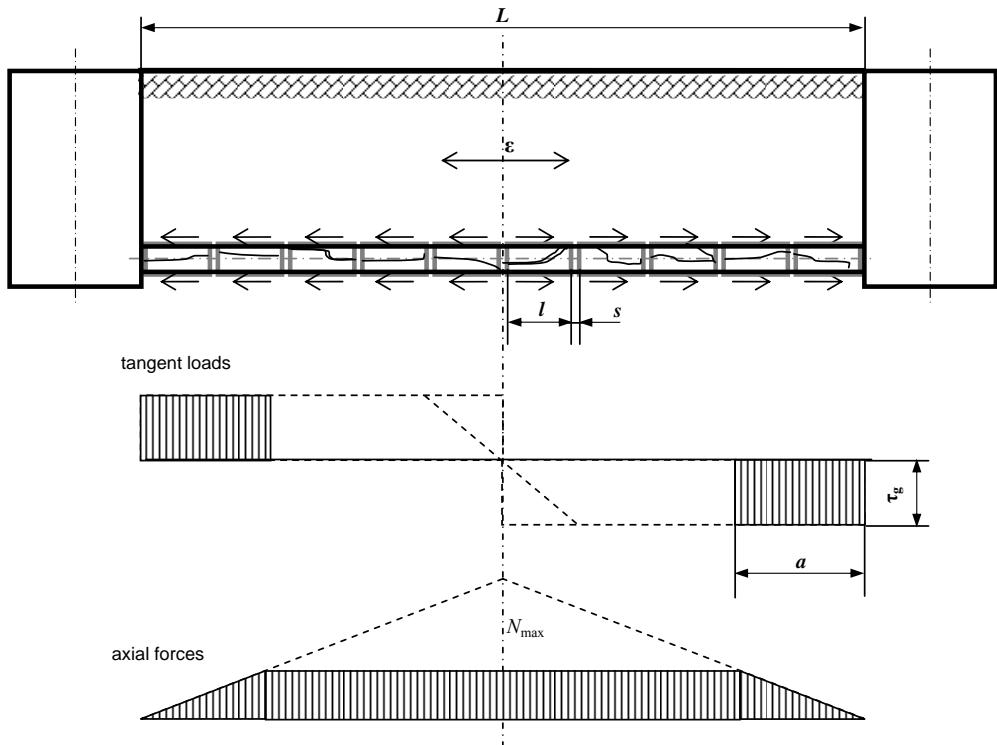soil loosening (lengthening). In the central part of pipeline section comprised by the deformation

Fig. 3. Impact of mining exploitation in the liner's longitudinal direction,
distribution of longitudinal tensile forces

impact occur the most considerable longitudinal forces, which cause the biggest lining strains. In the case of flexible liners, soil deformations at the outermost, outside ends with lengths a (Fig. 3) of the considered section of renovated pipeline will create "seizure" of the lining causing that the elongation of its central part will be equal to $\varepsilon(L - 2a)$ (Kalisz & Mokrosz, 2007).

The lengths a of these ends can be determined using the formulas

$$a = \frac{EA\varepsilon}{\pi D_z \tau_g} \tag{1}$$

or

$$a = \frac{EA\varepsilon}{\pi u D_w \tau_p} \tag{2}$$

where:

- E — longitudinal elasticity modulus of liner, [kPa]
- A — cross-section area of liner, [m^2]
- ε — horizontal strains of soil taking into account random dispersion and exploitation breaks (Gustkiewicz, 2003; Popiołek, 2003),

D_z — host pipe external diameter, [m]
D_w — liner external diameter, [m]
u — part of liner perimeter adherent to the old pipe (host pipe),
τ_g — boundary value of tangent forces per unit of external surface of outside pipe, lower value of unit friction forces $\tau_g = \sigma_n \mu$ or unit shearing forces in the soil around the pipeline $\tau_g = \sigma_n \mathrm{tg}\,\varphi + c$, [kPa]
τ_p — boundary value of tangent forces per external surface of liner on the contact surface with host pipe, [kPa]
σ_n — average normal load on pipeline perimeter, [kPa]
μ — coefficient of soil friction against the external pipeline surface,
φ — angle of soil internal friction around pipeline, [°]
c — soil cohesion, [kPa].

When analysing the impact of horizontal deformations of the ground layer adjacent to the surface the possibility of occurrence of non-uniform strains of their lengths should be taken into consideration. The concentration of strains will depend on the value of tangent forces between the internal surface of the pipeline and external surface of the liner, and it will appear in dilatations between the pipe ends and possibly in existing transverse and diagonal cracks of the pipe walls. The elongation of the central part of the section $L - 2a$ (when $a < L/2$) will be equal to

$$\varepsilon(L - 2a) = \sum \Delta s + \sum \Delta l = \varepsilon_s zs + \varepsilon_l (L - 2a - zs) \qquad (3)$$

where:
ε_s — liner strains in dilatations,
ε_l — liner strains in places of contact with renovated host pipes,
z — number of dilatations in the section $L - 2a$,
s — average distance of pipe ends width (Fig. 3), [m]
l — pipe length (Fig. 3), [m].

The largest strains ε_s will occur in dilatations between pipe ends (and in cracks)

$$\varepsilon_s = (\varepsilon - \varepsilon_l)\left(\frac{L - 2a}{zs}\right) + \varepsilon_l \qquad (4)$$

The concentration of strains does not occur when the tangent forces between the pipe and the liner are not big and allow free deformation of its wall, then $\varepsilon_s = \varepsilon_l = \varepsilon$. The maximum concentration occurs when the liner is joined (for example glued) with the pipes of the repaired pipeline. Then the strains occur only in dilatations, because the lining strains in places of connection with external pipes are generally very small, then $\varepsilon_s = \varepsilon(L - 2a)/zs$. From this reason these kind of technologies shouldn't be use in mining areas.

For $a \geq L/2$ the value of extreme deformations ε_s of the liner results from extreme values of longitudinal forces caused by tangent forces

$$\varepsilon_s = \frac{\pi u D_w L \tau_p}{2EA} \qquad (5)$$

Additional lining deformations will be caused also through surface curvatures. Assuming that the liner curvature will be the same as the curvature K of the surface, the deformations ε_K in outermost fibres of the liner will be equal to

$$\varepsilon_K = \frac{D_w}{2} K = \frac{D_w}{2R} \qquad (6)$$

where R is a radius of surface curvature, [m].

The value of extreme longitudinal strains ε_p of outermost liner fibres is equal to the sum $\varepsilon_p = \varepsilon_s + \varepsilon_K$. The value of extreme longitudinal strains and stresses cannot be higher than the permissible values for the lining. When assessing the possibilities of use of the given trenchless method of pipelines renovation in mining areas, essential is the knowledge of the value of tangent forces on the contact surfaces of the lining with the repaired pipes, because on this basis we can assess the value of extreme strains and longitudinal stresses that can occur in the lining. The concentration of strains and stresses restricts the usefulness of trenchless methods of pipelines renovation in mining areas. Unfavourable is the use of linings, which are joined with old pipes or very closely adhere to their internal surfaces and are characterised by low longitudinal deformability.

The renovation of pipelines, especially in sewerage systems, in mining and post-mining areas must be every time preceded by an analysis of their current drops. This analysis should be carried out on the basis of geodesic measurements and take into consideration the hydraulic properties of liners. The existing or predicted unfavourable changes of pipeline drops restrict the usefulness of trenchless methods of sewerage network renovation in mining and post-mining areas. For pipeline sections characterised by inversed drops renovation is possible only through new pipelines performing.

The possibility of taking over of mining deformations of the foundation acting on the longitudinal direction is conditioned by the longitudinal deformability of linings and internal pipes as well as values of tangent forces, occurring on the surface of the contact between the repaired pipes and external surface of lining. This is especially essential in the case of linings that exactly adhere to the internal surface of repaired pipes. In order to determine these forces it is necessary to carry out tests consisting in causing longitudinal displacements of the lining towards the repaired pipe and measurement of the value of occurring at that time tangent forces between the lining and the pipe. These tests can be realised in a double manner – on short pipe segments with carried out internal lining or on segments composed of two pipes with a joint. The manner of test execution has been shown in Figures 4 and 5.

The scheme presented in Figure 4 shows the method of testing of adherence of the lining or internal pipe to repaired pipes using the vertical testing machine. During the displacement of the internal lining towards the short segment of the external pipe the tangent force is registered. Figure 5 shows the scheme of a stand for testing of pipe joint with lining or internal pipe using the horizontal testing machine. During the tests separation and pushing away of pipes is carried out, recording the value of the longitudinal force resulting from tangent forces on the surface of the contact of lining with the pipes according to their mutual displacement.

Still important is the execution of tests of mechanical properties of the lining material with special regard to extension on the longitudinal direction, on the basis of which the value of permissible deformation for this material on the distinguished direction should be determined.
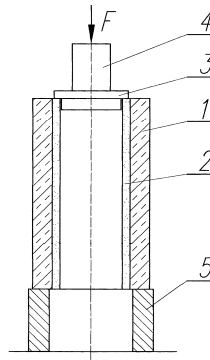
Fig. 4. Scheme of a stand for testing of adherence of the coating to the reinforced stoneware or concrete pipe; 1 – concrete or stoneware pipe; 2 – coating; 3 – loading element; 4 – force sensor; 5 – bearing element
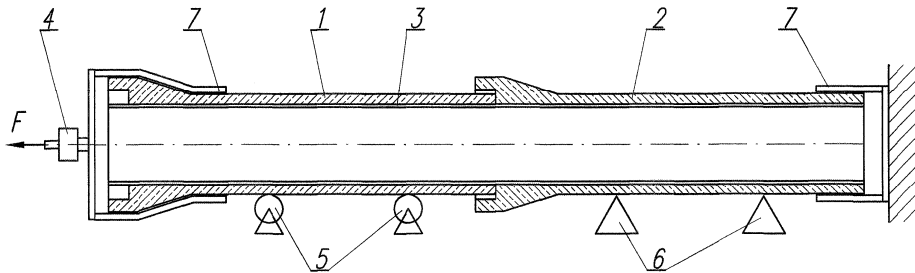

Fig. 5. Scheme of a stand for tension and compression tests of pipe joint with internal coating, 1, 2 – stoneware or concrete pipe, 3 – coating, 4 – force sensor, 5 – bearing roller, 6 – constant bearings

3.2. Impact of mining exploitation in the transverse direction towards the pipeline axis

The impact of deformations of the ground layer adjacent to the surface occurring in the transverse direction changes the conditions of pipelines foundation and liners loading. Liners in pressure pipelines are designed with regard to the internal pressure and in the case of loose-fitting they must independently transfer all internal and external loads. However, in the case of close-fitted liners also the load-bearing capacity of renovated pipes can be taken into consideration. The selection of wall thickness of liners as well as liner structure in the case of composite use depends on their short-term and long-term strength properties. Both the circumferential and longitudinal stresses, resulting from the internal pressure, are considered.

In the case of non-pressure pipelines the dimensioning of liners serving their renovation and reconstruction depends on the technical condition of the repaired pipeline. In the literature (Falter, 2001; Falter et al., 2002; Thépot, 2004) three static states of pipelines are distinguished (Fig. 6):

- state I – the pipeline has not lost the ability to transfer loads, and the liner's task is only its tightening,

- state II – the system pipe-soil is still able to transfer loads, only small damage occur, mainly in the form of longitudinal cracks as well as small deflections of the cross-section of pipes (less than 5%), side passive soil pressure (bedding reactions) occurs, the liner's task is first of all to tighten the pipeline,
- state III – the system pipe-soil has lost the ability to transfer loads or the loss of this ability is expected in the near future, cross-section deflection is higher than 5%, the liner must transfer the loads caused by soil pressure, traffic and ground water pressure.
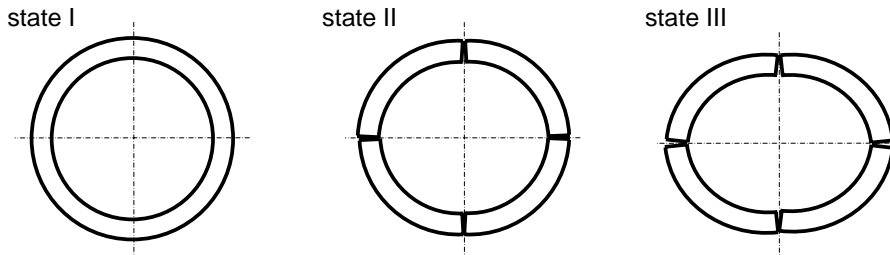
state I   state II   state III

Fig. 6. Static states of renovated sewerage pipelines

In mining areas in the case of state I the load-bearing capacity of the repaired pipeline with regard to additional transverse loads, resulting from the impact of mining exploitation, should be checked. The states II and III in mining areas should be treated similarly, because the considered side passive soil pressure in the state II in the zone of soil loosening is subject to decrease, what can result of additional, considerable deflection of the repaired channel and considerable additional loads of the liner. Thus in mining areas two cases of liner's load should be considered:

- the liner does not transfer the soil pressure – its resistance to the hydrostatic pressure of ground water with regard to the possibility of its level rise should be checked; moreover, the load-bearing capacity of external pipes with regard to additional loads resulting from the impact of horizontal deformations of the ground should be verified,
- the liner independently transfers the soil pressure - its resistance to the hydrostatic pressure of ground water and the resistance to soil loads should be checked, including additional loads resulting from the impact of horizontal strains of the ground layer adjacent to the surface.

The value of soil pressure during horizontal foundation strains can change from the value of active pressure at loosening to the value of passive pressure at thickening. This causes considerable changes of horizontal loads of liners (Fig. 2) and thus unfavourable changes of bending moments. In the case of renovation of pipes with considerable cross-section deflection, most unfavourable will be the impact of ground loosening in the transverse direction of pipelines, which will cause the decrease of the horizontal pressure and side passive soil pressure (bedding reactions) triggered off by pipe deflection (Fig. 2 pos. 1, 2 and Fig. 7). Thus soil loosening will cause the decrease of horizontal loads and will contribute to the increase in the liner's cross-section deflection.
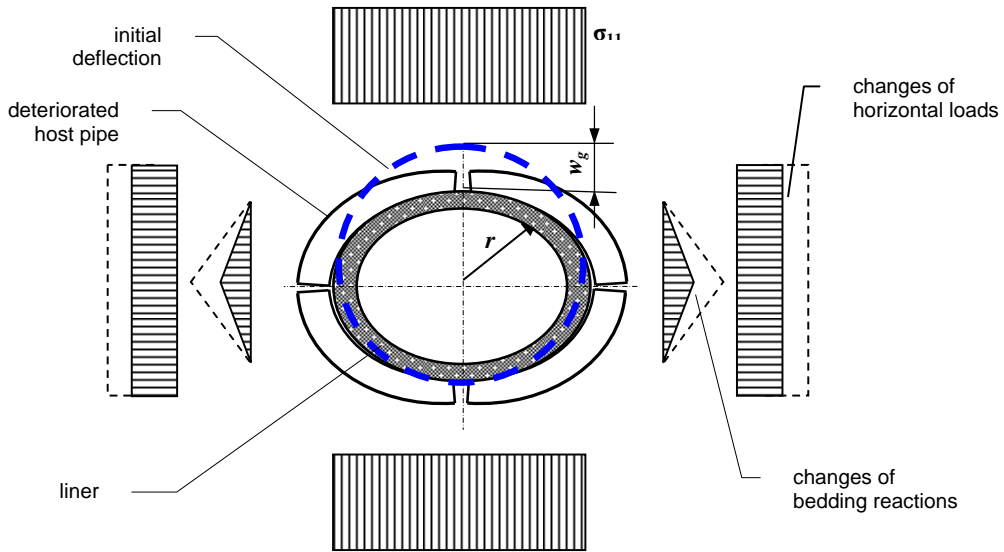
Fig. 7. Additional deflection of the deformable liner in the zone of ground loosening

Additional deflection of the deformable pipe can be described by the general relationship

$$\frac{w_g}{2r_L} = \alpha_1 \varepsilon \tag{7}$$

where:

w_g — liner deflection, [m]

r_L — average radius of deformable pipe, [m]

α_1 — experimental coefficient of pipe cross-section deflection of deformable pipe,

ε — value of horizontal deformations of ground layer.

On the basis of investigations carried out at the Główny Instytut Górnictwa (Central Mining Institute) (Kalisz, 2001) for flexible pipes buried in initially compacted sands the following relationship was obtained

$$\alpha_1 = \left[\left(-\frac{1,17}{1 - 0,12 I_D} + 0,93 \right) \ln S_R + \frac{6,08}{1 - 0,12 I_D} - 4,98 \right] (0,04 \sigma_{11} + 0,09) \tag{8}$$

where:

S_R — pipe circumferential rigidity, [kN/m^2]

I_D — relative density of soil,

σ_{11} — vertical pipe load, [kPa].

Ground thickening in the case of considerably deflected cross-sections, especially relating to pipes in the static state III, will cause the decrease of unfavourable load difference and will

contribute to the decrease of the bending moments acting on the liner. However, at low initial deflection of repaired pipes, in the case of considerable strains of the ground layer, thickening can also be unfavourable. The final value of cross-section deflection (ovalisation) should not exceed 10% (Falter, 2001). The impact of mining exploitation creates the necessity to increase the circumferential rigidity of liners.

3.3. Impact of mining exploitation on coatings overlaid by means of spraying methods

The action of longitudinal forces cause additional longitudinal deformations of walls of old pipelines, which are transferred to the protecting coat. Therefore on account of the impact of mining exploitation on pipelines with continuous construction essential is its deformability. The friction forces act at considerable lengths of pipelines and can lead to the interruption of their continuity. For this reason steel pipelines in mining areas are protected by compensators placed every several dozen of meters. The compensators should be protected by special coats, enabling their work after pipeline renovation performing (Kowalczyk, 2002). The coat carried out in the sectorial pipeline, for instance built of socked cast-iron pipes, will be subject to fractures in joints.

Considerable cross-section deflection, particularly of steel pipelines with big diameters, can cause the damage of the internal coat with low deformability. An example of a damaged coat carried out from cement mortar is the pipeline built of steel pipes with diameter 1.2 m and thickness 6.4 mm with an internal coat of cement mortar (concrete liner) (Talesnick, 1998) with thickness of about 20 mm and external surface covered with a concrete layer about 25 mm. The existing internal coat was damaged in consequence of considerable pipe cross-section deflection before the pipeline exploitation start. The pipe deflection about 0.4% caused the cracks in the coating amounting to 0.15 mm in width, and the deflection about 1.0% caused the origin of cracks 0.45 mm. The deflection about 5.0% caused damage of the internal coat.

The materials used for pipeline renovation by means of spraying methods should be characterised by higher deformability than the renovated pipes. In mining areas desirable is the use of polymer coatings, and in the case of cement mortars, mortars with plasticizing additives, serving the renovation of heating installations.

4. Conclusion

Mining exploitation causes in the liner additional longitudinal and circumferential strains and stresses as a result of impact of horizontal strains of the ground layer adjacent to the surface and surface curvatures. The longitudinal forces are caused by tangent forces, occurring on the surface of the contact of liner with renovated pipeline. In connection with the above the deformability of liners used for the renovation of pipelines with continuous construction should be higher than the deformability of repaired pipes, especially coatings joined with their walls.

The deformability of liners used for the renovation of pipelines with sectorial construction, built of short pipes, should enable to take over in a safe way the deformation of soil with the appropriate level of reliability (Kwiatek, 2010). In the case of occurrence of small tangent forces on the contact surface of the liner with old pipes we can assume that the deformations in the central part of the considered section, covered by the influences of mining exploitation, will

be the same as soil deformations. In the case of liners closely adherent to the internal surface of repaired pipelines, especially when they are joined (glued), concentration of longitudinal strains of liner in dilatations between the pipes will follow. The impact of soil deformations can cause exceeding of permissible longitudinal strains and stresses of liners, what restricts their use in mining areas even in the case of liners with big deformability.

The impact of underground mining exploitation in the transverse direction causes essential, unfavourable changes of horizontal pipeline loads. These changes must be taken into account when assessing the load-bearing capacity of renovated pipes, and in the case of their considerable degradation when assessing of the liner's load-bearing capacity. For degraded pipelines with high cross-section deflection most unfavourable is ground loosening, what can cause deflection growth of the liner up to the permissible values. This should be also taken into account in the case of renovation design in mining areas.

No-dig methods of sewerage renovation in mining and post-mining areas can be used in sections characterised by correct drops. Renovation must be preceded by an analysis of pipeline drops with regard to the hydraulic properties of liners.

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