ORIGINAL PAPER

LOADS OF SEWER MANHOLES WITHIN MINING AREA

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ABSTRACT

Purpose	The purpose of this paper is to present the method of taking into account additional external horizontal loads acting on sewer manholes within mining areas, caused by the impact of horizontal strains on the subsurface soil layer.
Methods	The determination of the dependencies of the changes in the cross-sections of flexible manholes' riser pipes (with different circumferential stiffness) on the values of horizontal soil strains, based on laboratory tests.
Results	The results include formulas for determining the values of external horizontal loads acting on sewer manholes within mining areas, in particular flexible manholes made of thermoplastics.
Practical implications	The results will be used for the assessment of conditions in which sewer manholes can be used within mining areas – and will be beneficial when considering the following: design, protection and assessment of resistance to horizontal strains.
Originality/ value	The presented method is an original concept. It enables the determination of additional external horizontal loads acting on sewer manholes within mining areas, in particular the flexible manholes made of thermoplastics. It also enables the determination of dependencies of changes in the cross-sections of risers of flexible sewer manholes (with different circumferential stiffness) on the horizontal soil strains.

Keywords
sewer manholes, loads, mining area

1. INTRODUCTION

The impact of mining deformations in subsurface soil layer on the structure of sewer manholes is manifested mainly by the interaction of horizontal strains. This interaction may result in the bearing capacity of the components of manholes being exceeded, causing them to fail as well as leading to changes in the shape of cross-sections from the flexible (deformable) objects. In the case of modular manholes made of plastics, prefabricated concrete or reinforced-concrete elements, the interaction can also cause angular deviations of such elements and even a loss of tightness.

The evaluation of the conditions in which the sewer manholes can be used within mining areas consists of determining the foundation depth for the expected values of horizontal strains in subsurface soil layer as well as the type and condition of the soil. In order to determine this depth, it is necessary to know the values of the external horizontal loads. These values constitute the basis for the calculation of bending moments and axial forces acting on the walls of such objects and, afterwards, they are compared with their bearing capacity. These loads are also used for determining the values of the relative deformation of the flexible man-

hole cross-section, which is compared to the permissible deformation (Kalisz, 2010).

This paper focuses on the impact of horizontal strains in subsurface soil layer caused by underground mining on the walls of, both flexible and rigid, sewer manholes. It was assumed that the level of groundwater is does not reach the bottom of the manhole. The exemplary results of preliminary laboratory tests concerning the impact of horizontal soil strains on models of flexible risers of sewer manholes made of plastics with different circumferential stiffness have been presented. As in the case of pipelines (Mokrosz, 1998), the cross-section deformability of the riser of a sewer manhole means its susceptibility to change of shape under the impact of unevenly distributed external horizontal forces. This change affects the values and distribution of external loads which are induced by soil. An important parameter, which characterizes the flexibility of sewer manholes made of plastics, is the circumferential stiffness of the manhole riser pipes, determined based on test results (Rydarowski & Walczak, 2000). These riser pipes are characterized by the following stiffness classes: 2, 4, 8 as well as 12 and 16 kN/m^2.

2. IMPACT OF HORIZONTAL SOIL STRAINS ON THE WALLS OF SEWER MANHOLES

2.1. The initial state of loads of flexible and rigid manholes

It is assumed that the distribution of external horizontal loads on sewer manholes with a circular cross-section is even before mining deformations in subsurface soil layer occur and their value increases along with the foundation depth of the manhole (Fig. 1a and Fig. 1b). In the case of sewer manholes made of plastics, a slight unevenness of loads on their circumferences can occur. This is caused by the uneven compacting of the non-cohesive soil layers of backfill. The stresses in the soil layer at a depth of z amount to (Wiłun, 2013)

$$\sigma_{11} = \gamma z + q_n + q \tag{1}$$

and

$$\sigma_{22} = \sigma_{33} = \xi_0 \, \sigma_{11} = \xi_0 \, (\gamma z + q_n + q) \tag{2}$$

where:

σ_{11} – vertical stress of soil,
σ_{22} – horizontal stress of soil at the main direction x (Fig. 2),
σ_{33} – horizontal stress of soil at the main direction y (Fig. 2),
ξ_0 – at rest soil pressure coefficient,
γ – unit weight of soil,
z – foundation depth of the analysed cross-section of the manhole,
q_n – surface weight,
q – useful load of surcharge over the analysed cross-section of the manhole.
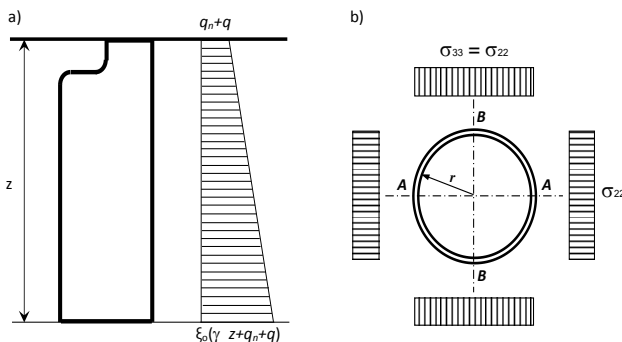

Fig. 1. Distribution of loads along with the foundation depth of the manhole – a, distribution of loads on the circumference of the manhole – b

External horizontal loads on sewer manholes lead to the creation of circumferential compressive forces in their walls. Thermoplastics are materials with viscoplastic properties and thus, they creep under loads. The walls of manholes deform and thus, the diameter of manhole riser pipes reduces slightly. The soil, around the manholes, loosens which leads to an active limit state. The lateral soil pressure coefficient reduces to the limit value ξ_r (Petroff, 1994) which is assumed in static calculations instead of the at rest soil pressure coefficient ξ_0. In such cases, 21% of load unevenness at the circumference of such objects is assumed.

2.2. Loads of flexible and rigid manholes

Depending on the position of the exploitation edge, the impact of horizontal soil strains around the walls of a sewer manhole can be separated into three stages: horizontal soil loosening, compacting and loosening again.

2.2.1. Rigid manholes – loosening of the subsurface soil layer

Loosening of the subsurface soil layer results in the reduction of external horizontal loads on objects buried within it, both in a parallel and perpendicular direction to the exploitation edge. At the same time, the horizontal loads on the walls of objects are unevenly distributed and it contributes to changes in axial forces and bending moments. In contrast to flexible objects, deformation of the cross-section of rigid manholes is so small that it has no impact on the values and distribution of the uneven loads acting on them (Mokrosz, 1998). During the horizontal loosening of the subsurface layer of non-cohesive soil for the horizontal strains of 2–3 mm/m, an active limit state occurs.

The horizontal stresses acting in a perpendicular direction to the exploitation edge (x-axis, Fig. 2) are determined according to the following formula

$$\sigma_{22}^r = \xi_r \, \sigma_{11} \tag{3}$$

Changes in horizontal stresses are as follows:

$$\Delta\sigma_{22}^r = \xi_0 \, \sigma_{11} - \sigma_{22}^r = (\xi_0 - \xi_r) \, \sigma_{11} \tag{4}$$

and

$$\Delta\sigma_{33}^r = \nu\Delta\sigma_{22}^r = \nu \, (\xi_0 - \xi_r)\sigma_{11} \tag{5}$$

Then

$$\sigma_{33}^r = \xi_0\sigma_{11} - \Delta\sigma_{33}^r = \xi_0\sigma_{11} - \nu\Delta\sigma_{22}^r = \left[\xi_0 - \nu(\xi_0 - \xi_r)\right]\sigma_{11} \tag{6}$$

thus, the difference of horizontal stresses $\Delta\sigma$, acting on the walls of rigid manholes at the soil loosening stage, assuming that $\sigma_{33}^r > \sigma_{22}^r$ as well as $\sigma_{min} = \sigma_{22}^r$ and $\sigma_{max} = \sigma_{33}^r$, amounts to

$$\Delta\sigma = \sigma_{max} - \sigma_{min} = \sigma_{33}^r - \sigma_{22}^r = \left[(\xi_0 - \xi_r) \, (1 - \nu)\right]\sigma_{11} \tag{7}$$

where:

ξ_r – active soil pressure coefficient,
ν – Poisson's ratio.

2.2.2. Rigid manholes – compacting of the subsurface soil layer

Compacting of the subsurface soil layer results in an increase in the values of the external horizontal loads on rigid manholes buried in it. In extreme cases, the pressure value can reach the value of passive pressure – in non-cohesive soils with deformations of 30–35 mm/m. In the immediate vicinity of the walls of the rigid manholes, there is a significant concentration of horizontal soil strains which results in a spatial deformation state and spatial stress state within that area, however slight changes in the values of vertical stresses are ignored. Changes in horizontal stresses $\Delta\sigma_{22}^z$ and $\Delta\sigma_{33}^z$ during soil compacting, taking into account the concentration of horizontal strains $\bar{\varepsilon}$ defined with the coefficient k_0 (Kwiatek, 1998), can be determined based on the following dependences

$$\Delta\sigma_{22}^z = -\frac{2G\bar{\varepsilon}}{1-\nu} = -\frac{2Gk_0\varepsilon}{1-\nu} \tag{8}$$

and

$$\Delta\sigma_{33}^z = \nu\Delta\sigma_{22}^z = \nu(\sigma_{22} - \xi_0\sigma_{11}) = -\frac{2G\nu\varepsilon}{1-\nu} \tag{9}$$

where:
ε – horizontal soil strains,
G – the modulus of transverse elasticity of soil.

Then

$$\sigma_{33}^z = \xi_0\sigma_{11} + \Delta\sigma_{33}^z = \xi_0\sigma_{11} - \frac{2G\nu\varepsilon}{1-\nu} \tag{10}$$

and taking into account that $\sigma_{min} = \sigma_{33}^z$ and $\sigma_{max} = \sigma_{22}^z$, the difference of horizontal stresses $\Delta\sigma$ acting on the walls of the rigid manholes at the soil compacting stage amounts to

$$\Delta\sigma = \sigma_{max} - \sigma_{min} = \sigma_{22}^z - \sigma_{33}^z = \frac{2G\varepsilon(\nu-k_0)}{1-\nu} \tag{11}$$

2.2.3. Flexible manholes – loosening of the subsurface soil layer

In cases where an active limit state has not occurred yet as a result of creeping plastics, loosening of the subsurface soil layer results in the reduction of external horizontal loads on flexible manholes. Simultaneously, there is an uneven distribution of horizontal loads at the circumference of such objects and it results in the deformation of their cross-section (the axis in a perpendicular direction to the exploitation edge increases). Due to the flexibility of cross-sections of the manholes, there is a less unevenness of their horizontal loads in relation to rigid objects. Moreover, the changes in soil strains are smaller in the immediate vicinity of flexible manholes than in the vicinity of rigid objects where disorder occurs. An active limit state in the area of the soil adjacent to the flexible object occurs later than in the area of the soil which is distant from this object.

The complete deformation of the cross-section of a flexible manhole $2s_1$ depends on the circumferential stiffness of the riser pipe and the values of horizontal soil strains and at the soil layer loosening stage this can be determined using the following formula

$$2s_1 = \Delta\alpha^r d = \alpha_1^r \Delta\varepsilon\, d \tag{12}$$

where:
$\Delta\alpha^r$ – the increment of the relative deformation of the riser cross-section of the flexible manhole, caused by soil loosening,
α_1^r – the coefficient of the relative deformation of the riser cross-section of the flexible manhole for soil loosening,
d – the average diameter of the manhole cross-section.

The coefficient of relative deformation of the object's cross-section α_1 has been implemented based on the scientific work (Kalisz, 2001) which is a derivative of the function $\alpha(\varepsilon)$ describing the dependence between the increment of deformation of the object's cross-section and the horizontal strains of the subsurface soil layer ε caused by mining exploitations, after such strains

$$\alpha_1 = \frac{d\alpha(\varepsilon)}{d\varepsilon} \tag{13}$$

In the case of the linear function, the coefficient α_1 is a constant determined by the ratio of the increment of relative deformation of the objects' cross-section to the increment of strains which induce it

$$\alpha_1 = \frac{\Delta\alpha}{\Delta\varepsilon} \tag{14}$$

The value of the coefficient α_1 depends on the circumferential stiffness of the object, as well as the properties and compacting of the non-cohesive soil which constitutes its backfill and can also depend on the foundation depth of the object. The values of the coefficient α_1 can be determined based on the dependencies (obtained during experimental tests) of the deformation of cross-sections of manhole riser pipes with different circumferential stiffness on the values of horizontal soil strains.

Assuming that the horizontal stresses σ_{22}^r and σ_{33}^r are respectively $\sigma_{22}^r = \sigma_{min}$ and $\sigma_{33}^r = \sigma_{max}$, their values can be determined by the formula (Kwiatek, 1998):

$$\sigma_{22}^r = \xi_0\sigma_{11} - \Delta\sigma_{22}^r \tag{15}$$

and

$$\sigma_{33}^r = \xi_0\sigma_{11} - \nu\Delta\sigma_{22}^r \tag{16}$$

then in such a case, the difference in the horizontal stresses is

$$\Delta\sigma = \sigma_{33}^r - \sigma_{22}^r = \Delta\sigma_{22}^r - \nu\Delta\sigma_{22}^r = \alpha_1^r\, \varepsilon\, E_m\left(\frac{s_s}{r}\right)^3 \tag{17}$$

where:
E_m – the elasticity modulus of the material of which the manhole is made,
s_s – thickness of the manhole wall,
r – average radius of the manhole cross-section.

The values of the horizontal stresses σ_{22}^r, which are reduced during the loosening of the soil layer, cannot be lower than the value of the pressure occurring during the active limit state $\sigma_{22}^r = \xi_r\,\sigma_{11}$. Thus, the difference in the horizontal stresses $\Delta\sigma$, acting on the walls of flexible manholes at the soil loosening stage, is

$$\Delta\sigma = \sigma_{11}(\xi_0 - \xi_r) - \nu\Delta\sigma_{22}^r \tag{18}$$

2.2.4. Flexible manholes – compacting of the subsurface soil layer

Soil compacting leads to significant unevenness in the distribution of external horizontal loads on the manhole. In the case of a flexible manhole, its cross-section deforms and thus, this unevenness is reduced in comparison with a rigid manhole. The wall of the flexible object moves back in a perpendicular direction to the exploitation edge under the pressure of soil. In such cases, the value of the horizontal strain of soil in the area adjacent to the manhole is lower in comparison with a rigid object. It can also be lower than the values of horizontal strains, caused by mining exploitation in the soil layer outside of the impact from the object placed in it. The value of pressure is also lower. In the parallel direction to the exploitation edge, deformation of the object's cross-section causes an additional deformation and passive soil pressure in the vicinity of the manhole walls.

Compacting of the subsurface soil layer causes much greater changes in loads and their greater unevenness at the circumference of flexible manholes than occurs during loosening. Therefore, the impact of horizontal soil compacting on the structures of flexible sewer manholes has the most adverse effect. Figure 2 shows the distribution and values of loads at the circumference of a flexible sewer manhole for

horizontal soil compacting, using a modified *Molin* model (Janson, 2003; Kalisz 2010). It is assumed that the axis of the circular cross-section of a flexible object is reduced by the value $2s_1$ both in a parallel direction (*y*-axis) and a perpendicular direction (*x*-axis) to the exploitation edge (Kalisz, 2010)

$$2s_1 = \Delta\alpha^z d = \alpha_1^z \Delta\varepsilon\, d \tag{19}$$

where $\Delta\alpha^z$ is an increment of relative deformation of the object's cross-section caused by horizontal compacting of the soil layer, $\Delta\alpha^z = \alpha_1^z \Delta\varepsilon$.
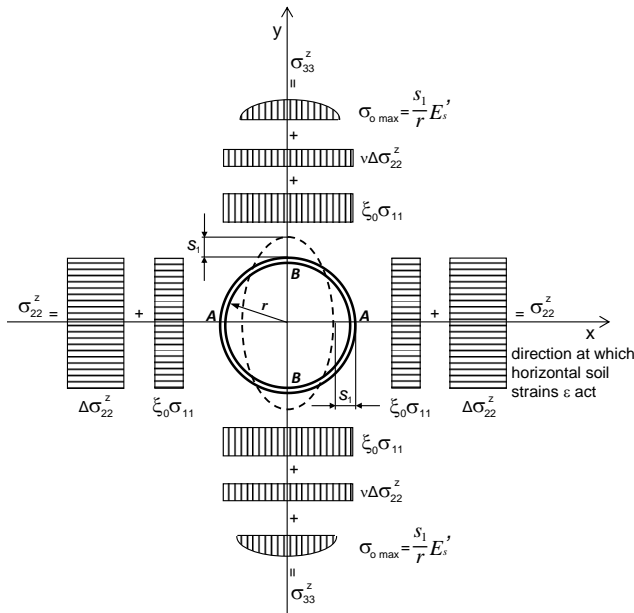

Fig. 2. Distribution of loads at the circumference of a flexible manhole at the stage of soil compacting

The value of horizontal stresses acting in a direction perpendicular to the exploitation edge can be represented by the general formula

$$\sigma_{22}^r = \xi_0\sigma_{11} + \Delta\sigma_{22}^r \tag{20}$$

In a direction parallel to the exploitation edge, the value of horizontal stresses also increases. Additionally, as a result of the deformation of the flexible manhole cross-section, passive soil pressure occurs. The extreme horizontal stresses acting on the walls of the riser pipe of a flexible manhole in this direction can be presented by the general formula

$$\sigma_{33}^r = \xi_0\sigma_{11} + \nu\Delta\sigma_{22}^r + \sigma_{o\max} \tag{21}$$

where $\sigma_{o\max}$ is the extreme passive soil pressure in the *y*-axis.

The value of passive soil pressure is proportional to the value of displacement of the flexible object's wall and depends on the type and condition of soil, characterized by the secant modulus of horizontal soil reaction E_s'. Analogously, as for the flexible pipes, it is assumed that the passive soil pressure has parabolic distribution (Janson, 2003) with the maximum value in the direction parallel to the exploitation edge equal to

$$\sigma_{o\max} = \frac{s_1}{r} E_s' = \Delta\alpha^z\, E_s' = \alpha_1^z\, \Delta\varepsilon\, E_s' \tag{22}$$

In the assumed distribution of horizontal loads, soil pressure value σ_{33}^z is the sum of the at rest soil pressure charac-

terized by the lateral earth pressure coefficient ξ_0, the stresses resulting from the compaction of the soil layer in a perpendicular direction to the exploitation edge and the passive soil pressure caused by displacement of the object's walls with a parabolic distribution

$$\sigma_{33}^z = \xi_0\sigma_{11} + \nu\Delta\sigma_{22}^z + a\,\alpha_1^z\,\Delta\varepsilon\,E_s' = \xi_0\sigma_{11} + \frac{\nu E\Delta\varepsilon}{1-\nu^2} + a\,\alpha_1^z\,\Delta\varepsilon\,E_s' \tag{23}$$

where:
a – the coefficient resulting from the distribution of passive soil pressure, $a = 0{,}51$,
E – modulus of soil elasticity.

The difference of horizontal stresses $\Delta\sigma$ acting on the walls of flexible manholes at the soil compacting stage, assuming that $\sigma_{\min} = \sigma_{33}^z$ and $\sigma_{\max} = \sigma_{22}^z$, is

$$\Delta\sigma = \sigma_{22}^z - \sigma_{33}^z = \Delta\sigma_{22}^z - \Delta\varepsilon\left(\frac{\nu}{1-\nu^2}E + a\,\alpha_1^z\,E_s'\right) \tag{24}$$

then

$$\Delta\sigma_{22}^z = \left\{\alpha_1^z\left[a\,E_s' + E_m\left(\frac{s_s}{r}\right)^3\right] + \frac{\nu}{1-\nu^2}E\right\}\Delta\varepsilon \tag{25}$$

and

$$\sigma_{22}^z = \xi_0\sigma_{11} + \left\{\alpha_1^z\left[a\,E_s' + E_m\left(\frac{s_s}{r}\right)^3\right] + \frac{\nu}{1-\nu^2}E\right\}\Delta\varepsilon \tag{26}$$

3. LABORATORY TESTS CONCERNING THE IMPACT OF MINING EXPLOITATION ON MANHOLES PLACED IN THE SUBSURFACE SOIL LAYER

Only preliminary laboratory tests consisting of determining the dependence of changes in the deflection of circular cross-sections of flexible manhole models on the horizontal strains of the surrounding non-cohesive soil layer and circumferential stiffness of such models have been carried out so far (Kalisz, 2010; Zięba & Kalisz, 2012). Equipment which enables the simulation of the impact of horizontal soil strains on the lateral loads of underground pipelines (Kalisz, 2001) and sewer manholes was used in order to carry out preliminary laboratory tests. The changes in the diameter of the cross-section of the flexible manhole model in the direction where the strains are induced were measured. The purpose of these measurements was to determine the impact of the horizontal compacted soil (as the most adverse stage of the impact of mining exploitations on these objects) on the changes in the shape of the cross-section of flexible object models tested. Examples of results from two experiments (Zięba & Kalisz, 2012), which were carried out on flexible object models made of plastics and with various circumferential stiffness, are presented below.

The relative deformation $\Delta\alpha$ of the model's cross-section was determined from the dependence (13), and in the case of linear dependence of deformation of the flexible object cross-section on the horizontal strains of soil layer, the coefficient α_1 was determined from the dependence (14).

The graph (Fig. 3) presents the obtained test dependencies of the relative deformation of the cross-section of flexible

manhole models on the horizontal strains induced in compacted non-cohesive soil. The pictures (Photo 1 and Photo 2) present the condition of the cross-sections of flexible manhole models before and after the laboratory tests.
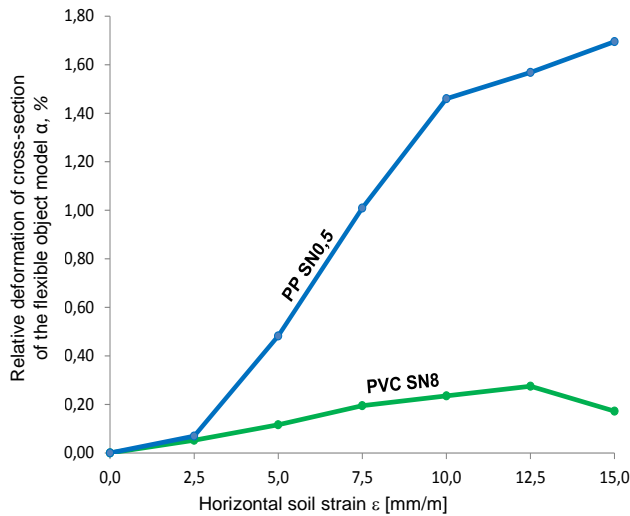

Fig. 3. Dependence of relative deformation of cross-sections of manhole models made of polypropylene and polyvinyl chloride on the horizontal soil strains
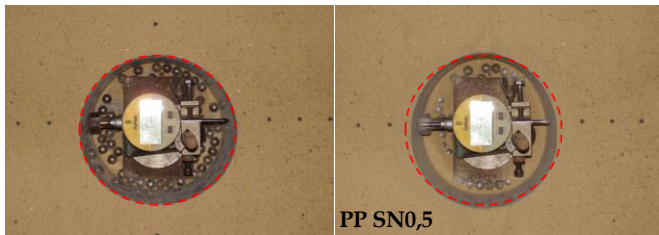

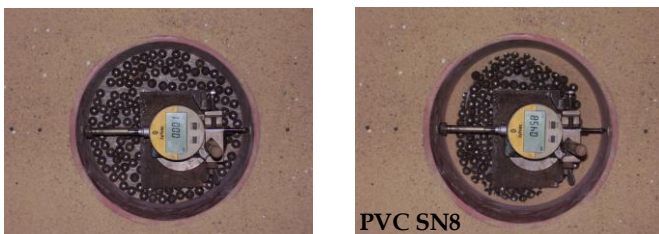**Photo 1.** Model of manhole made of polypropylene before (left) and after (right) laboratory tests

Photo 2. Model of manhole made of polyvinyl chloride before (left) and after (right) laboratory tests

Experiment no. 1 was performed on the sample of a pipe made of polypropylene (PP) with the following parameters: average external diameter $d = 157.5$ mm, wall thickness $s_s = 2.5$ mm and circumferential stiffness SN 0.5 kN/m^2. The value of coefficient of relative deformation of the tested sample cross-section obtained in these strains ranges from 2.5 to 10 mm/m was $\alpha_1 = 1.85$.

Experiment no. 2 was performed on a sample of a pipe made of polyvinyl chloride (PVC) with the following parameters: average external diameter $d = 200$ mm, wall thickness $s_s = 6.1$ mm and circumferential stiffness SN 8 kN/m^2. The value of the coefficient of relative deformation of the tested sample cross-section obtained in the strains ranges from 0 to 12.5 mm/m was $\alpha_1 = 0.22$.

4. SUMMARY AND CONCLUSIONS

The impact of underground mining exploitation on sewer manholes placed in the subsurface soil layer is manifested mainly by the interaction of horizontal soil strains on manhole walls. These strains cause changes in the values and distribution of external horizontal loads. In comparison with rigid manholes, the unevenness of the distribution of such loads is lower for flexible objects, however this is, in turn, the cause of the deformation which takes place in their cross-sections. Horizontal soil strains can lead to failures in the structure of manholes as well as a loss of tightness in the joints of elements.

The evaluation of possibilities and conditions in which sewer manholes can be used within mining areas consists of the determination of the foundation depth for the expected values of horizontal strains of the subsurface soil layer, as well as the type and condition of soil. In order to determine this foundation depth, it is necessary to know the values of external horizontal loads. In order to describe the distribution and values of horizontal loads of flexible objects, it is necessary to know the dependencies of the cross-section deformation of such objects on the values of horizontal soil strains with different circumferential stiffness and foundation conditions. The foundation depth of standard produced sewer manholes, generally, should be limited, especially for category III and IV mining areas or additional reinforcement to their bottom parts should be applied.

Based on the results obtained from laboratory tests concerning the determination of experimental dependencies of deflection of circular cross-sections of flexible manhole models made of polypropylene (PE) and polyvinyl chloride (PVC) on the values of the horizontal strains of the surrounding soil and different circumferential stiffness of such objects in the condition of compacted non-cohesive soil, it was stated that:

- deformation of the flexible manhole cross-section depends, not only on the value of horizontal soil strains caused by mining exploitation, but also on the circumferential stiffness of the riser pipe of this object – the lower the value of circumferential stiffness, the higher the value of the coefficient of relative deformation of cross-section α_1 is,

- the initial compaction of non-cohesive soil (which constitutes its backfill) plays an essential role in placing a sewer manhole. In addition, it determines an even load and proper cooperation of such objects with the surrounding soil, including the resistance of these objects to the settlement caused by dynamic loads deriving from traffic. Along with an increase in the value of the soil concentration coefficient, greater deformation of the flexible object cross-section takes place. Moreover, the foundation depth of the flexible object in the subsurface soil layer is also important, as well as the value of vertical stresses σ_{11}. Consequently the value of pressure from the backfill on the object's walls depends on this foundation depth.

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