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Deformation of new pipes in soils containing Neogene clay – Case-study

Déformation de nouveaux tuyaux dans des sols contenant de l'argile néogène – Étude de cas

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ABSTRACT: The pipelaying in Chernivtsi city, Ukraine, was carried out with a trenchless method at a depth of approximately 5 m in Neogene clay. After completion of the works (in a day) a teleinspection of the pipeline was carried out and it was determined: in the first section the geometry of the pipe was not broken; on the second section - broken: gradual deformation in the vertical plane; on the third section the geometry of the tube is broken: gradual deformation in the horizontal plane; on the fourth section the geometry of the tube is broken: gradual deformation in the horizontal plane. After some time, the second teleinspection was carried out: two branches of the new sewer pipes were deformed practically throughout the whole length of the plots. The approximate value of the residual pressure was at least 0.33 MPa at a depth of 5 m, which was the cause of the deformation of the tubes. High values of pressures, especially horizontal ones, which were registered in many exploring and mine openings in Chernivtsi region of Ukraine, were sometimes ten times higher than those of the vertical pressures. High values of subsidence as a result of shrinkage may be of significant hazard to buildings and structures because the value of average subsidence for brick buildings with reinforced belts should not exceed 15 cm. The report also analysed the landslide formations in Chernivtsi city in soils containing clay of the Neogene age.

RÉSUMÉ: La pose de la canalisation dans la ville de Tchernivtsi, en Ukraine, a été réalisée avec une méthode sans tranchée à une profondeur d'environ 5 m en argile néogène. Après l'achèvement des travaux (en une journée), une télésurveillance de la conduite a été effectuée et elle a été déterminée: dans la première section, la géométrie de la conduite n'a pas été rompue; sur la deuxième section - cassé: déformation progressive dans le plan vertical; sur la troisième section, la géométrie du tube est rompue: déformation progressive dans le plan horizontal; sur la quatrième section, la géométrie du tube est rompue: déformation progressive dans le plan horizontal. Après un certain temps, la deuxième télésurveillance a été effectuée: deux branches des nouveaux tuyaux d'égout ont été déformées pratiquement sur toute la longueur des parcelles. La valeur approximative de la pression résiduelle était d'au moins 0,33 MPa à une profondeur de 5 m, ce qui était la cause de la déformation des tubes. Des valeurs de stress élevées, en particulier horizontales, enregistrées dans de nombreuses zones d'exploration et de mines dans la région de Tchernivtsi, en Ukraine, étaient parfois dix fois plus élevées que celles des contraintes verticales. Des valeurs élevées d'affaissement résultant du retrait peuvent constituer un danger important pour les bâtiments et les structures, car la valeur de l'affaissement moyen des bâtiments en briques avec des ceintures renforcées ne devrait pas dépasser 15 cm. Le rapport a également analysé les formations de glissements de terrain dans la ville de Tchernivtsi dans des sols contenant de l'argile du Néogène.

Keywords: Neogene clay, pipe, deformation, landslide, formation of slip surface

1 INTRODUCTION

Over 90% of the territory of Ukraine has complex soil conditions. Chernivtsi region is the smallest among 25 regions of Ukraine (its area is 1,3% of the whole territory of the country). Nevertheless, the landslides are significant there. There are approximately 1600 landslide sites. That is more than 9% of the territory (the highest factor in Ukraine). Landslides occupy more than 1500 ha of Chernivtsi city that is 10% of the city area. Local seismological station registers nearly 110-130 seismic events per year. 70-80% of the above events occurs within 100 km radius and are of 2-4 earthquake intensity. Chernivtsi region belongs to the area of intensive heavy rains. Some rains last up to 7 hours and amount of precipitations can reach a month and a half norm. These anomaly parameters were connected with the complex influence of natural and technogenic factors: crossing the slopes of dense slopes of dense river network; seismological activity connected with 6 local earthquakes zones; active deforestation of slopes during last decades of XX century (from 60% to 25% and less); increasing of the global climate changes factors influence (heating, increasing of precipitations, flooding etc.). New and additional factor of landslide activation within Zakarpatsky region is increasing of seismic movements after anomaly rainfalls and flooding. Connection between anomaly rainfalls, flooding and earthquakes has been identified during the last decades (Table 1, 2). The intense of earthquakes is 5-6 balls but their frequency is growing and time intervals between cycles of intensification being shorten.

Table 1 Time distribution of the earthquakes (I≥5balls) and anomal floodings within Zakarpatsky region (1882-1941 y.y.).

Anomal floodings (1882-1941 y.y.)	**1882**	**1887**	**1902**	**1912**	**1925**	**1941**
Time interval between floodings tfl ,years	0	5	15	10	13	16
Earthquakes,years (I≥5 balls)	1738	1802	1829	1838	1908	1912
Time interval between earthquakes tqu,ears	0	64	27	9	70	4

Table 2 Time distribution of the earthquakes (I≥5balls) and anomal floodings within Zakarpatsky region (1947-2004 y.y.).

Anomal floodings (1947-2004 y.y.)	**1947**	**1970**	**1978**	**1980**	**1998**	**2001**
Time interval between floodings tfl ,years	6	23	8	2	18	3
Earthquakes,years (I≥5 balls)	1934	1940	1977	1986	1990	
Time interval between earthquakes tqu,ears	22	6	37	9	4	

The issues of assessment of slopes stability and landslides originating in complex soil conditions have been described in numerous works of foreign researchers: Terzaghi (1951), Sigtryggsdottir at all (2018), Jonsson (1996), Lollino (2014), Lacasse (2013), Bobrowsky (2008), Cassagli at all (2010), Barla at all (2014), Wu at all (2011) and many others. Among national researchers the following scientists should be mentioned: Trofymchuk at all (2017), Ginzburg (1979), Kaliukh at all (2014,

2015) and others. Two case studies from practice in Chernivtsi will be described below: forming of slip surface in Neogene clay landslides and deformation of new sewage system pipes laid partially through the Neogene clay slope.

2 DEVELOPMENT AND EVOLUTION OF LANDSLIDES FORMED IN NEOGENE CLAY

Three main schemes and corresponding models of sliding process development mechanisms ("slip", "flow", "cut") can be distinguished within the territory of the Chernivtsi region Polevetskyy (2009).

1. The *slip slides* are formed in inclined stratified multi-layered rock mass of Pre-Carpathian foredeep. Soil displacement occurs on the layers surfaces or on the cracks that cut the slope solid mass. The landslide process mechanism can be defined as the slip of large blocks or disperse rocks masses of various composition due to "instantaneous" loss in strength (fragile destruction) or the development of creep process causing landslide. The volume of rocks displaced is from 3-10 million m3 to 0.1-0.2 million m3. The movement speed varies widely and ranges from several meters to dozens of meters per day.

2. The *cut slides* are formed on slopes close to the horizontal occurrence of rocks. They are characterized by long (up to 60-70 years) primary periods with rather slow drift velocities and a very fast active stage with high drift velocities m / day. The displacement rocks volumes reach ten million cubic metres. The “Earth slides” refer to deep-mass masses displacing more than 20 m in thickness. Due to the mechanism, landslide manifestations develop as a result of the creep process (visco-plastic flow or fragile fracture, which is traditional for over consolidated soils) in the clay bed, mainly from Neogene age clay. Deformations of the clay layer lead to the gradual subsidence of the overlapping layer, with the formation of cracks in it, on which separation begins from the root slope of a massive block of rocks.

*3.*The *flow slides* – are the most common in deluvial sedimentary cover. According to mechanism, this type of displacement is manifested in the form of viscous plastic deformation. Let us consider the engineering-geological section of the slope composed of clay of the Neogene age typical for Chernivtsi region (Fig. 1-2). The capacities of the engineering geological are not indicated intentionally. Fig. 1 shows three engineering and geological elements: 1 – fill-up ground, 2 - diluvium, 3 - clay of the Neogene age. The slip curve № 1 is typical for the "flow" and "slip" displacements, curve № 2 - for cut slices. Let us retrace the development of the cycle (70-80 years) of Chernivtsi slope landslide manifestations:

- ♦ At first the flow slides are developed that could be directly connected with stormy rainfall regime and roughness of relief;
- ♦ Then slip slides are developed in deluvial overmoistened sedimentary cover. According to Polevetskyy (2009) “flow” and “slip” manifestations are developed simultaneously.
- ♦ Tensions influencing formation of slide surface in Neogene clay through existing surfaces of weakness are gradually accumulated;
- ♦ Cut slide are catastrophically as a rule;
- ♦ After catastrophic activation of a cut slide on the slope it transforms into balanced state and again starts the cycle of landslide manifestations development.

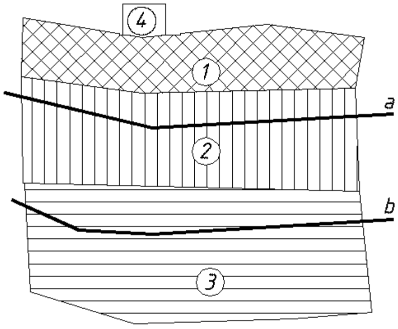

Figure 1 Engineering and geological slope section: a- slip curve № 1; b – slip curve № 2; 1 - surface soil; 2 – deluvium; 3 – Neogene clay; 4 – building construction.

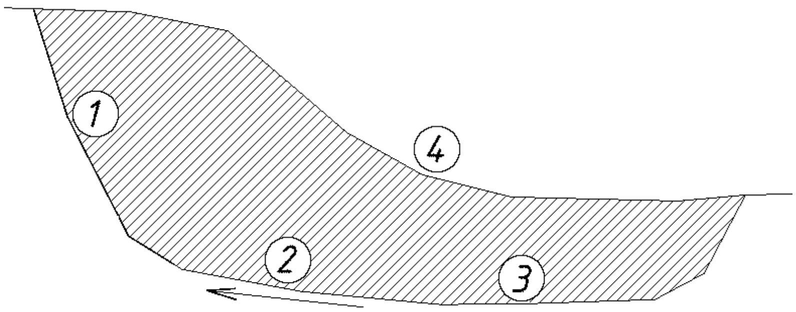

Figure 2 Mechanism of cut slide slip surface development: 1 - site without developed slip surface; 2 - direction of slip surface formation; 3 - site with slip surface; 4-relief.

Accordingly, the physical-mechanical characteristics of the slopes soil are decreased and the value of the landslide pressure is increased in the course of the cycle development. Slope engineering protection is carried out at one of the stages of this sequence, which accordingly increases the period of the cycle of landslides development. It should be noted that the existing methods of engineering geological surveys can not at this time clearly determine whether the slide surface was completely formed for cut slides, or to fix their manifestations. Since the slopes of the area, as a rule, are already complicated by flow or slip slides.

3 CASE STUDY 1

Let us calculate the stability of the slope in the city of Chernivtsi, composed predominantly of Neogene age clay (Fig. 3).

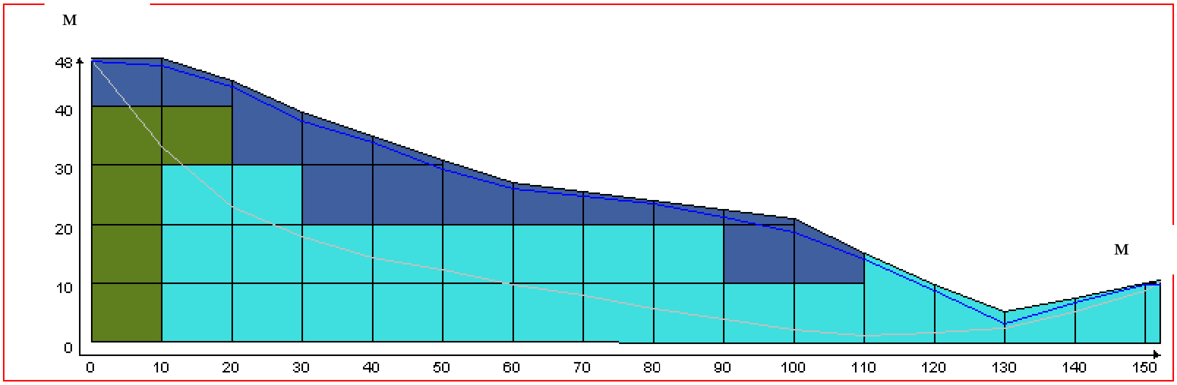

Figure 3 Landslide slope cross section:

loam: specific weight 19,0 кН/м3; angle of internal friction φ=7°; specific cohesion c=14кПа;

(Neogene clay: specific weight 19,9 кН/м3; angle of internal friction φ=7° (5°); specific cohesion c=40 (25)кПа (the values for the deformed soil are given in brackets).

Since there are landslide manifestations on the given slope, it is landslide hazardous. As it has been shown by the results of numerous laboratory researches, the adhesion bond is 6-9 kPa for Neogene age clay. According to the condition that on the slope (fig. 2) there is a fully formed slide surface, let us calculate stability taking into account adhesion bond only (φ=5°, c=6kPa). We get $\mathbf{K}_{st}$ (stability index) =0,5731. That is, in fact, this natural slope with such a coefficient of stability should be shifted, but it is not ("cut" slides have not been fixed since 1963).

Let us perform mathematical modelling of the upward slope “cut” slide surface formation mechanism with the maximum level of groundwater and seismic manifestations (tables 1-2).

The above calculations are performed using the Bishop and Spencer methods. On the sites with no slide surface formed we will assume the value of stress-related characteristics of the undisturbed ground, and on the sites with formed slide surface – as for the disturbed ground on slide surface.

As it can be seen from Tables 3 and 4, the slope stability is lost when slide surface formed from 10 to 150 m (for the slope compression curve see Fig. 4). Therefore, it is very important for Chernivtsi city to identify areas of the slope plane, where the cut slide surface is already formed.

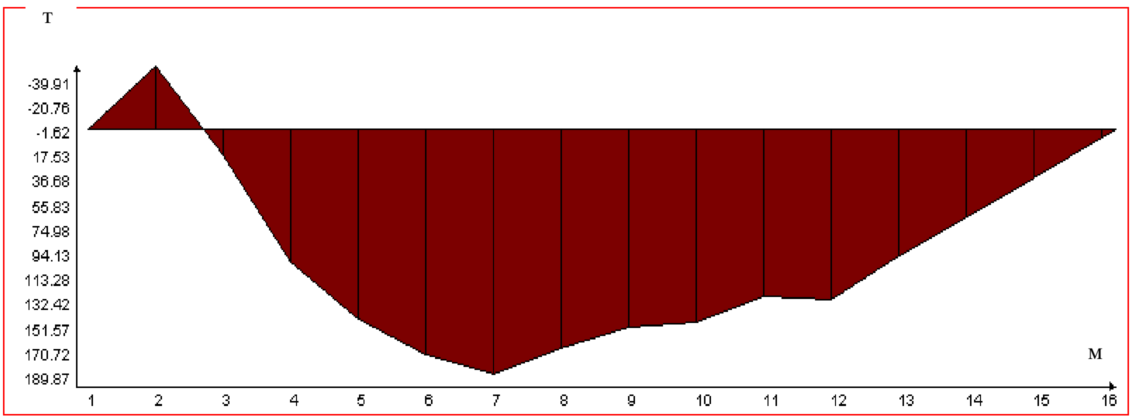

Fig. 4 Slope compression curve.

Table 3. Modelling of Neogene age clay slope slide surface development

Stability index	No surface	120-150 m of slide surface	100-150 m of slide surface
$\mathbf{K}_{st}$	1,3169	1,2549	1,2103

Table 4. Modelling of Neogene age clay slope slide surface development

Stability index	60-150 m slide surface	40-150 m slide surface	10-150 m slide surface
$\mathbf{K}_{st}$	1,0940	1,0116	0,9157

4 CASE STUDY 2

Private company has performed construction of outside water supply and sewage system in Chernivtsi city. The sewage route should go under Storozhynetska Street that is on the slope consisting mainly of Neogene age clay soil. The works planned to be cut-and-cover. Neogene clay bulk density exploring has been implemented - 23-24 kn/m^3. During detailed study of the project it was revealed that sewage trench should be more that 5 m in some places. Since Storozhynetska Street is an important road in Chernivtsi city, there is no possibility to arrange an alternative way. Therefore, the decision to find another way using modern technologies of horizontal drilling for sewage pipelaying has been made. The works were performed in the following sequence (fig.4): 1) preliminary drilling of the well about 80 mm in diameter using water; 2) reaming up to 350 mm in diameter using water; 3) lying of the pipe about 200 mm in diameter using 250 mm expansion head. Installation of the pipe about 80 mm in diameter with maximum possible inner pressure of P=0,6 Mpa. After works completion (in 24 hours) the teleinspection of sewage pipeline has been carried out and the following has been identified (fig.1):

1. The shape of the pipe has not been affected on the site 1-2;
2. On the site 2-3 the shape of the pipe has been deformed: delayed deformation in vertical plane towards outside drainage pit 3 (pipelaying was carried out from pit 2 to pit 3);
3. On the site 3-4 the shape of the pipe has been deformed: delayed deformation in vertical plane towards outside drainage pit 4 (pipelaying was carried out from pit 3 to pit 4);
4. On the site 5-4 the shape of the pipe has been disrupted: delayed deformation in vertical plane towards outside drainage pit 5 (pipelaying was carried out from pit 5 to pit 4);

After that the works were performed on the opposite side of Storozhynetska Street. The second pipe was deflected in the same way.

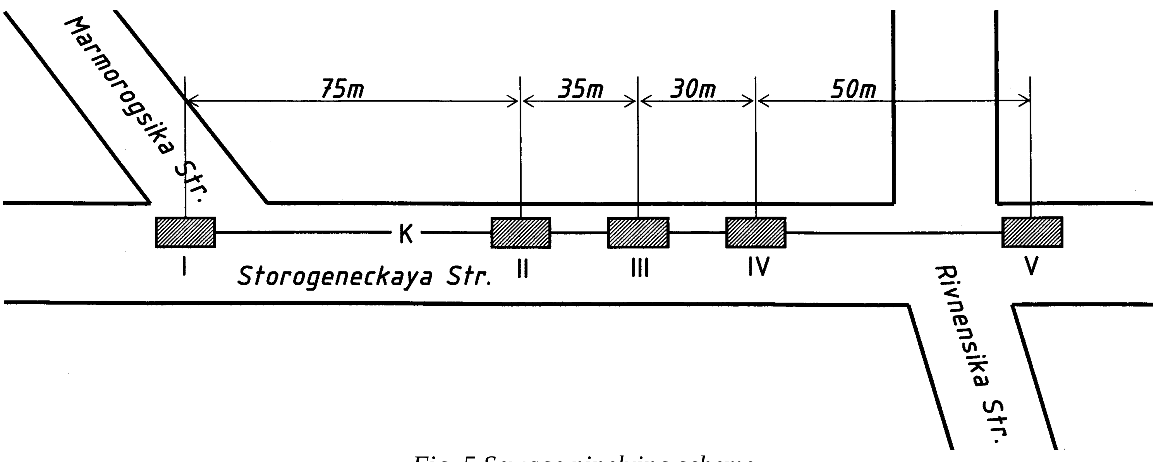

Fig. 5 Sewage pipelying scheme.

After the case analysis it was revealed that the works site is on the **slope**, pipe deformation took place in **Neogene clay** only. On the site 1-2 where the pipe route went through loamy soil, pipe deformation did not take place (fig.1).

Let us analyse using back calculation what pressure could cause such pipe deformation. Taking into account horizontal well diameter 350mm to the drilling depth 5-6 m ratio, we can consider it as a tunnel. Maximum pressure on the tunnel walls (pipe) could be $3p_z$, where p_z is soil pressure Zaruba, Mencl (1971). As for our case, the natural pressure is approximately 0,1 MPa. Maximum possible pipe inner pressure is 0,6 MPa. It should hold pipe external pressure nearly 1,2 MPa. Let us accept possible maximum horizontal pressure that caused deformation as 1,3 MPa.

As a result of back calculation, we can state that pressure caused pipe deformation is 0,33 MPa. The question that has to be answered is: How 0,33 MPa pressure can be at the depth of 5 m if the natural pressure is 0,1 MPa?

Anticipation № 1 – Residual ancient pressure. Ph.D. Polevetskyy (2009) explains the above case aas follows: according to the researches carried out by Czech scientists Zaruba, Mencl (1971), increased horizontal pressure in the soil are often observed as residual one from ancient pressure when covering them layer thickness reached some hundreds meters. Such cases can be observed in Neogene age clay Zaruba, Mencl (1971), where residual horizontal pressure was registered. High horizontal pressure is often observed in bow areas. Such pressure could be of modern origin related to neotectonic processes Polevetskyy (2009). Residual horizontal pressure action results in cracks formation within the slope. Neogene age clay is marine deposits. Pressure under which they have been formed was significantly higher that they are now, being raised by tectonic and bared by erosive processes. Residual pressures in clay also have been fixed during development of Toktogulske water reservoir on Narina River.

Anticipation № 2 – Softening of Neogene age clay as a result of watering during underground trenches digging. As it is known, natural geological processes (erosion, denudation, raising tectonic movements) as well as engineering human activity cause change in the rock stress state that is accompanied by their softening. The character and intensity of softening are defined by the degree of stress state change (differential pressure) as well as rock strength in the conditions of their occurrence. The main factor of rock softening is natural pressure release, as a rule acts slowly during natural geological processes and relatively fast during construction and mining works (deep excavations design, tunnel boring and shaft sinking, etc.). One of the characteristics of Neogene age clay is its peculiarity to expand during watering. Expansion index is defined by mineral and grading of clay soil, its consistency – moisture, and percent composition of clay fractions less than 0.005 mm. Soil raising as a result of softening of nominal unit volume could be more than 14 cm. Ziangirov P. (1979) made a conclusion that for surface thickness of clay soil of 6-10 m there is no balance between operating natural pressure and porosity-moisture, and properties of surface thickness are mainly defined by soil over consolidation as a result of shrinkage, diagenesis, grouting and mineral formation processes.

5 CONCLUSIONS

1. The main schemes and models of landslide processes in Chernivtsi region of Ukraine in the soils composed mainly of Neogene age clay have been identified. Mathematical modelling of the Neogene clay slope „cut“ slide slip surface formation mechanism has been performed. Stability index is changing from 1.31 to 0.92 depending on the length of formed slip surface.
2. In order to prevent „cut“ slopes manifestations it is very important to identify sites on the slope surface where there is formed slip surface and to take appropriate actions for their stabilization.
3. Case study of deformation of new underground sewage trenches and pipes in Chernivtsi city in the slopes composed of Neogene age clays. To our opinion, the main reason is **Anticipation № 2** – technology of horizontal holes drilling and reaming using great amount of water. As a result of watering the Neogene age clay swelling took place that caused deformation of underground trenches and sewer pipes. As a result of tele-inspection of trenching the site on Storozhynetska Street in Chernivtsi city, the pipes and both trenches were deformed practically throughout the whole length of the new sewage lines in the slope composed mostly of Neogene age clay.

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7 REFERENCES

Barla M., Antolini F., Dao S. 2014. Il monitoraggio delle frane in tempo reale, *Strade e Autostrade* **107**, 154–157.

Borja R.I., White J.A., Liu X.Y., Wu W. 2011. Factor of safety in a partially saturated slope inferred from hydro-mechanical continuum modelling, *International Journal for Numerical and Analytical Methods in Geomechanics* 63(**2**), 140-154.

Cassagli N., Catani F., Del Ventisette C., Luzi G. 2010. Monitoring, prediction, and early warning using ground-based radar interferometry, *Landslides* 7**(3)**, 291–300.

Engineering Geology for Society and Territory. 2014. *IAEG XII Congress Volumes* (Ed: Lollino G.), 8643 p. 8 volume-set. IAEG, Springer-Verlag, Berlin.

Ginzburg L. 1979. *Landslide protection retaining constructions*, Stoiizdat, Moscow.

Highland L., Peter B. 2008. *The Landslide Handbook—A Guide to Understanding Landslides*, Geological Survey Circular, Reston.

Jonsson B. 1996. Geotechnical Field Classification of Basalts in Iceland. *Proceedings of the XII Nordic Geotechnical Conference* (Eds.: Erlingsson E., Sigursteinsson H.), 469-473. Reykjavik.

Kaliukh I, Senatorov V., Marienkov N., Trofymchuk O., Silchenko K., Kalyukh T. 2015. Arrangement of deep foundation pit in restricted conditions of city build-up in landslide territory with considering of seismic loads of 8 points. *Proceedings XVI ECSMGE*, 535-540. ECSMGE, Edinburgh.

Lacasse S. 2013. 8th Terzaghi Oration Protecting society from landslides – the role of the geotechnical engineer. *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering*, 15-34. ECSMGE, Paris.

Polevetskyy V. 2009. The Regional features of landslide protect structures and landslides of the Chernivetska area. *The thesis for a candidate degree of technical sciences on the specialty 05.23.02 "Bases and Foundations"*, SE RIBK, Kyev.

Sigtryggsdottir F. G., Snæbjörnsson J. T., Grande L.O. 2018. Statistical model for dam-settlement prediction and structural-health assessment, *Journal of Geotechnical and Geoenvironmental Engineering.* 144 (**9**).

Terzaghi K. 1951. *Mechanism of landslides*, Harvard University, Harvard.

Trofymchuk O., Kaliukh I., Silchenko K., Polevetskiy V., Berchun V., Kalyukh T. 2015. Use accelerogram of real earthquakes in the evaluation of the stress-strain state of landslide slopes in seismically active regions of Ukraine. In: (Ed: Lollino G.) *Engineering Geology for Society and Territory* **2**, 1343-1346. IAEG, Springer-Verlag, Berlin.

Trofymchuk O., Kaliukh I., Klymenkov O. 2017. TXT-tool 2.380-1.1: Monitoring and early warning system of the building constructions of the Livadia palace, Ukraine (Book Chapter) *Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools*: **1**: *Fundamentals, Mapping and Monitoring*: 491-508. Springer-Verlag, Berlin.

Ziangirov P. 1979. *The volumetric deformability of clay soils*, Science, Moscow.

Zaruba K., Mencl V. 1971. *Inzhenernaya geologiya*. Hardcover .