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An impact of dynamic loading on the slopes in the Carpathian region of Ukraine

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SUMMARY

In the city of Chernivtsi and its region there are numerous occurrences of landslides in the Neogene argillaceous deposits. Such slopes feature the complex spatial stress-strain state caused by the processes of the Neogene clays deconsolidation and seismic activities. Lateral spreads, earth flows and slides are widespread. The risk that buildings and structures can be destroyed increases not only by the impact of grade 7-9 earthquake shocks and vibrations but also by weaker earthquakes with a magnitude 5-6. Under complex ground conditions of Ukraine, seismic waves can result in destruction of buildings and structures due to the following unfavourable conditions: activation of potential landslides and development of enormous ground cracks with creation of opening up to 1-2m wide, and 7-10 m deep and even more; triggering of fractured rocks falls from benches and steep slopes; enhancement of coast erosion action; intensive formation and streaming of mudflows in mudflow hazardous areas because of activation of thixotropic liquefaction of degraded loess masses under foundations of buildings and structures. As a result, they lose their bearing capacity; activation of suffusion which gradually changes from slow suffusion removal of soil to a catastrophic out-burst of rarefied soil masses. Three main patterns and models of landslide process development (flow, sliding, shear) of change are distinguished, that modelling the litho-dynamic of landslide-dangerous slopes in clays of Neogene Age in the region of Carpathians of Poland and Ukraine. It is set that for the shear landslides the middle width is 11,5 m, maximal width is 40 m, middle width on edge is 23,5 m, middle extent of slope is 380 m, middle width on front is 1000 m and slope angle of slide surface, is not exceed 15 except the area of edge. Consideration is being given to the use of accelerograms of real earthquakes for calculation of strain-stress state of landslide-prone slopes of Chernovtsy city by using PLAXIS software. As a result of numeral modelling of the stress-strain state of shear landslides by direct dynamic method on the basis of software PLAXIS there was found out: the seismic events with intensity up to 6 on a Medvedev scale can considerably to worsen the soil behaviour in the slide zone and to effect on slope firmness and value of shear pressure.

Introduction

In the city of Chernivtsi and its region there are numerous occurrences of landslides in the Neogene argillaceous deposits. Such slopes feature the complex spatial stress-strain state caused by the processes of the Neogene clays deconsolidation and seismic activities. Lateral spreads, earth flows and slides are widespread (Ivanik, 2009, 2011, 2018). Analysis of design works and in-situ implementation of landslide protection measures in the city of Chernivtsi and its region has shown that in the Chernivtsi region the landslide protection facilities have been constructed only for the railway system (Kaliukh, 2019), (Fareniuk, 2018), (Trofymchuk, 2015, 2018). As little as five landslide-prone sites are protected in the city of Chernivtsi although the total number of such sites exceeds 60. As a rule, the landslide protection activities were conducted by non-domestic design and building companies and had a sporadic character. Landslide problem is utterly actual for the Carpathian region of Poland and Ukraine and for the Chernivtsi region particularly where landslides affect more than 9 per cent of the territory (Gerenchuk, 1978). It is the highest indicator throughout Ukraine. So, the problem is acute, what is underlined by the development and approval by the Cabinet of Ministers of Ukraine of the comprehensive program of landslide protection measures on the territory of Chernivtsi region for the period from 2005 to 2014. The risk that buildings and structures can be destroyed increases not only by the impact of grade 7-9 earthquake shocks and vibrations but also by weaker earthquakes with a magnitude 5-6 (Kaliukh, 2018). Under complex ground conditions of Ukraine, seismic waves can result in destruction of buildings and structures due to the following unfavourable conditions: activation of potential landslides and development of enormous ground cracks with creation of opening up to 1-2m wide, and 7-10 m deep and even more; triggering of fractured rocks falls from benches and steep slopes; enhancement of coast erosion action; intensive formation and streaming of mudflows in mudflow hazardous areas because of activation of thixotropic liquefaction of degraded loess masses under foundations of buildings and structures. As a result, they lose their bearing capacity; activation of suffusion which gradually changes from slow suffusion removal of soil to a catastrophic out-burst of rarefied soil masses. Seismic impacts produce complex and strain-stress state in soil masses which serve as foundations or environment for various structures. Depending on intensity of seismic impact, geological structure, and relief of a soil mass, some creep limit areas of various size and shape can be formed in the mass. This situation can eventually lead to permanent displacement or to the loss of local stability. An important factor that influences the character of formation of the strain-stress state in the soil mass is its shape. It is well known that seismic impacts have the greatest effect on slopes or slants because they are concentrators of strain-stress states. Besides, under conditions of natural occurrence, shear stresses, which determine the degree of approximation of the soil mass to the limit state, are pre-dominant in slopes and slants. The overall trend to increase the expected level of seismicity requires adoption of adequate measures aimed at improving seismic safety of existing and planned buildings and structures with due consideration of their physical condition. Seismic safety depends on the following natural conditions of the site: the distance to the seismic center; the parameters of maximum earthquakes which can manifest them-selves in the area and frequency of earthquakes with time; local ground conditions, terrain; presence of fault tectonic structures; spectral composition of vibrations and so on. Ukrainian scientists (Rudko, Salomatin, 1987) have dealt with the problem of landslide development modelling for the Chernivtsi region. They found three main patterns and models of landslide development such as lateral spread, earth flow and slide on the territory of the Chernivtsi region. The known greatest Chernivtsi landslides are lateral spreads with sliding surfaces lying in the Neogene clays. The lateral spreads occur on the slopes with rocks underlying fast horizontally. Yemelianova has studied the engineer and geological features of such landslides in her works. For the landslide slopes that are prone to lateral spreads the following section and form of sliding plane are specific: height exceeds 30m; length in a plan is not less than 70 m; front width exceeds 50 m; and sliding surface inclination □ does not exceed 15□. The specific section of the landslide combined with the regional features of a soil base therefore leads to some peculiar properties of landslide pressure distribution diagram and development of technical solutions on design of supporting landslide-protective buildings. The thicknesses of engineer and geological elements are not given purposely. It should be noted that the thickness of the Neogene clay in the vertical direction may reach more than 200.0 m in the lateral spreads. As Demchyshyn outlines in his works, a characteristic feature of landslides and landslide slopes of the Chernivtsi region is a long preparation period before the stage of a main displacement due to a long period of a gravitation equilibrium disturbance that is more than 80 years in some cases. Naturally, this may be connected with the high values of physical and mechanical properties of the Neogene clays.

Methods of investigation

The Landslip software and computational methods of Maslov-Berer, Shakhuniants, Bishop and Spencer put some restrictions, namely, like the most of computational methods of assessment, they are based on the application of the granular solids limit stress state theory used as mathematical model of cohesive and cohesionless soils, as well as of fissured rock (Vlasyuk, 2015, 2019), (Zhukovskaya, 2015, 2019), (Zhukovskyy, 2019). But when deter-mining the stability coefficients and landslide pressure, the landslides science state-of-the-art allows using the following simplifying provisions not only in the mentioned computational methods:

* the slopes stability is determined by means of two-dimensional problem solution, that is, the narrow strip of the slope is considered and its operation conditions are extended over the neighbouring areas;

* the hypothesis of consolidated body may be accepted, that is the sliding prism is considered either as entirely stiff and undeformed or as composed of a few butt-jointed, but also stiff undeformed blocks. This allows replacing the stresses with the forces, when calculating their ultimate equilibrium;

* The previously defined sliding surface, which a priori should correspond to the ultimate equilibrium conditions and the design sliding coefficient minimum (the landslide pressure maximum), may be accepted;

* the undeclared theories of the limit stress state of the granular media and the additional influences of underground waters and seismic forces on the sliding prism may be taken in-to account;

* in some calculation methods a single equation of statics is accepted, and the forces of interactions between the blocks, which the sliding prism may be divided into, are not considered;

* in many cases the limit stress state theory is applied to the calculations of states of the soil massifs, which are in a prelimit or out-of-limit states (the stability factor is greater or less than 1) not taken into account by this theory.

The further calculations are performed with the application of the Plaxis software. For the description of landslide slopes, the Plaxis software mostly uses the Mohr-Coulomb model. The comprehensive Mohr-Coulomb model is composed of the six functions, which are formulated in the conditions of the main stresses and appear as follows [9]. There-fore, the Mohr-Coulomb model contains five main parameters: Young's modulus; Pois-son's ratio; soil unit cohesion; internal friction angle and dilatancy angle. For modelling a landslide massif by the finite element method taking into account the disturbed soil interlayer in accordance with the sliding line position, the selection of the given interlayer physical-mechanical characteristics can be performed on the basis of computations by LANDSLIP software and laboratory tests by slip-by-slip method.

Results of investigations

Mathematical modelling was performed for the following physical-mechanical characteristics of soils:
1) Loam γunsat=18 кН/м^3; γsat=20 кН/м^3; Eref=6*104 кН/м^2; ν=0.35; c=20кН/м^2; φ=25°;
2) Clay γunsat=21 кН/м^3; γsat=25 кН/м^3; Eref=9*104 кН/м2; ν=0.4; c=22кН/м^2; φ=21°
3) Interlayer γunsat=11 кН/м^3; γsat=11 кН/м^3; Eref=1*104 кН/м2; ν=0.3; c=4 кН/м^2; φ=14°.

The following computations were performed: computations without dynamic loading; computations with dynamic loading of 7-points seismicity. In (Figure 1) there are total displacements, which occur in the same landslide due to its dead weight. In these cases, the coefficient of stability is equal to Kst=1.169.

If the same computations are performed on the given landslide without any interlayer, Kst=2.068. The comparative analysis of stresses was performed in the main locations with the dynamic loading of 7 points and without dynamic loading. For this purpose, five most typical locations were taken in the landslide base. The comparative analysis was performed in three directions in order to determine the direction where the stress variations were the most intense. The analysis showed that with the seismicity increase the loss of structure stability was approximately 11%.

Recommendations and conclusions

The average value of stress drop of all points was 6,75 kN/m2. So, under the effect of dynamic loading the stability coefficient Kst decreased in average by 11% (Kѕт = 1.052), where of a conclusion can be drawn that the slope approaches the state of losing stability. Use of the PLAXIS software made it possible to increase the accuracy of evaluations of landslide slopes and to eliminate errors inherent in conventional methods of Spencer, Bishop, Maslov-Berer, and Shakhunyants. The calculations showed that seismic events of intensity up to 6 points can degrade significantly the characteristics of soil along the sliding surface and influence the slope stability and the value of landslide pressure on supporting buildings. The further increase of the site seismicity (up to 7-8 points) results in the significant decrease of the stability coefficient. Based on the computations results, it is possible to follow step-by-step the process of the stresses redistribution in the landslide slope with its seismicity increase, which eventually causes the slope motion (unloading of accumulated stresses).

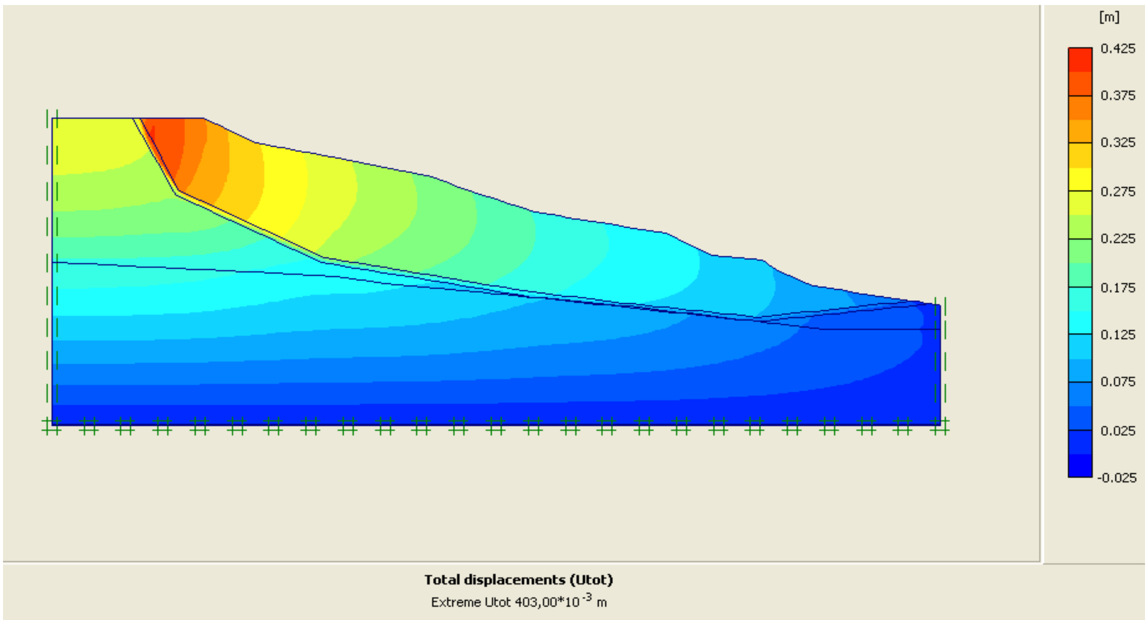

Figure 1. *Total displacements in a landslide because of its dead weight*

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