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A comparison of PLAXIS and LANDSLIP software packages for landslide hazard assessment

***V. Shokarev, I. Syvko, E. Shokarev, O. Shokarev, D. Volkov, I. Kaliukh** *(The State Research Institute of Building Constructions)*

SUMMARY

Difficult soil conditions are observed on almost 90% of the territory of Ukraine. Therefore, unpredictable changes in physical and mechanical characteristics of soils due to technogenic and natural geological factors can lead to dangerous deformation processes. A lot of such processes end with soil accidents and catastrophes. Among them, the landslide soil accidents and catastrophes rank first in Ukraine and second in the world (after earthquakes) in terms of the volume of economic damage inflicted. Therefore, construction of buildings and structures on landslide areas is not recommended by Ukrainian building codes. To protect urban areas and existing structures from landslides, it is often necessary to carry out complex and sometimes very expensive engineering protection measures. Preventing landslide disasters helps to avoid casualties and is less costly than eliminating their consequences. Unfortunately, insufficient development of methods for assessing the degree of landslide hazard and reliability of anti-landslide structures leads to the fact that requirements of the building codes are not always met. Therefore, the number of landslide accidents and disasters is growing in Ukraine from year to year. It determines relevance of work to improve the methods for calculating landslide hazard and loads on anti-landslide structures, increasing reliability and efficiency of engineering protection of territories and structures. Currently, due to computerization of calculations, their labor intensity for designers is significantly reduced, which makes it possible to widely use variational methods. In Ukraine, when calculating the stability coefficients, the well-known and widely used calculation methods of Maslov – Berer and Shakhunyants are used. They are recommended for use by the modern building codes of Ukraine. The approximate computational methods of Maslov – Berer and Shakhunyants are based on application of the theory of the marginal stress state of the granular medium, like most other computational methods for assessing landslide hazard. To determine the error of these approximate methods in comparison with the more accurate numerical solution based on the Mohr – Coulomb soil model implemented in PLAXIS software package, the comparative calculations were carried out for the identical landslide sections. Two types of the soil conditions were considered: clay and sand. Therefore, we have calculated the stability coefficient for the same landslide slope using PLAXIS software package based on the Mohr – Coulomb model and using LANDSLIP software package based on the approximate methods of Maslov – Berer and Shakhunyants. The absolute error by the Maslov – Berer method was 0.21 for sand and 0.03 for clay; relative error for sand – 18.75%, for clay – 1.83%. The absolute error according to the Shakhunyants method was 0.11 for sand and 0.2 for clay; the relative error for sand was 9.82%, for clay – 12.2%.

Introduction

In Ukraine, when calculating the stability coefficients of slopes, designers widely use the approximate calculation methods of Maslov – Berer and Shakhunyants. They are based on application of the theory of the marginal stress state of a granular medium like most other approximate calculation methods. This theory is often used as a mathematical model of cohesive and granular soils, as well as fractured rocks (Sokolovsky, 1942). Many simplifying provisions are used to determine the stability coefficient of a landslide and landslide pressure in such a mathematical model (Kaliukh, 2018, 2019), (Fareniuk, 2018). Despite this, use of calculated stability coefficients and values of landslide pressure in design for many decades has confirmed that the methods of Maslov – Berer and Shakhunyants describe a real state of landslide massifs rather satisfactorily. Deviations of calculated results from the experimental ones are caused not so much by imperfection of the approximate calculation methods as by errors in setting of input data: physical and mechanical characteristics of soil layers; sliding surfaces; groundwater position, etc.

Methods of research

The most significant influence on accuracy of the calculated indicators is exerted by accuracy of determining the spatial position of the sliding surface of a landslide. It is being set before calculation of the stability coefficients and landslide pressure. For the cases of existing landslide, methods for determining its position on location are proposed, and theoretical methods – for potential landslide hazard. In isotropic soil masses, the surface of marginal stress state can be determined according to the corresponding calculation formulas for statics of the granular medium (Sokolovsky, 1942) or based on their graphic interpretation. For homogeneous massifs, circular-cylindrical surfaces are considered to be close in shape to the real sliding surface of a landslide. For anisotropic soil massifs, surfaces that pass along the planes of weakening of soil stresses and their different spatial positions are being determined. Methods for determining the planes of weakening of soil stresses in soil massifs are considered in the works of (Fisenko, 1965), (Lomidze, 1954), (Puzyrevsky, 1934), (Trofymchuk., 2013, 2018), (Vlasyuk, 2015) and others.

The most general approach to analysis of landslide massifs, in comparison with those described above, is mathematical and numerical modeling of the spatial stress-strain state of soil massifs based on projection methods. One of successful examples of numerical implementation of this approach is PLAXIS software package. It is based on the finite element method and the Mohr – Coulomb soil model. The PLAXIS software package was specially developed for analysis of deformations and stability of landslide slopes and other geotechnical tasks. It has the user-friendly graphical interface (Figure 1).

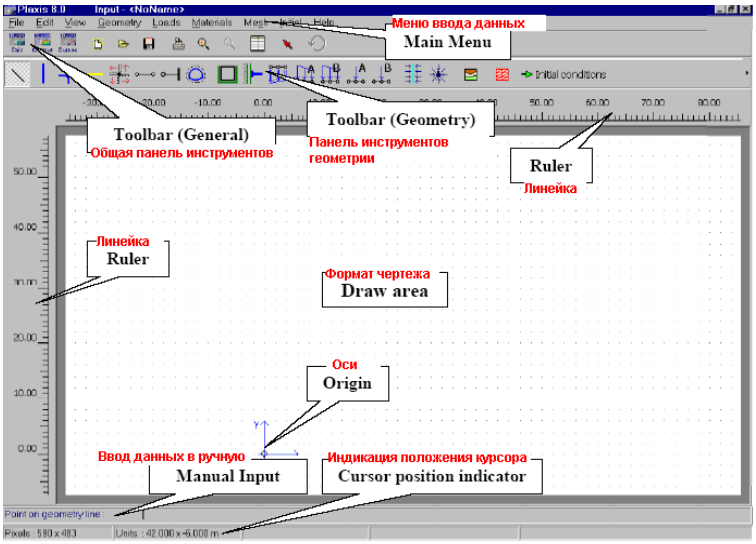

Figure 1 *Software package PLAXIS interface*

It allows a user to quickly create a geometric model and finite element mesh based on a vertical section of a designed structure. It is possible to set various mathematical models of the soil environment in PLAXIS software package. To describe landslide slopes, the Mohr – Coulomb soil model is most often used. The complete Mohr – Coulomb model consists of six functions $f_{ia(b)}$ which are formulated in terms of principal stresses $\sigma_i^{'}$. Two parameters of the model are well known: the angle of internal friction φ and the specific soil adhesion c. These two parameters are also used in approximate models of Maslov – Berer and Shakhunyants. Graphically, the Mohr – Coulomb model is a hexagonal cone in a space of principal stresses. Thus, the Mohr – Coulomb model includes five main parameters: Young's modulus (E); Poisson's ratio (v); the specific soil adhesion (c); the angle of internal friction (φ) and the angle of dilatancy (ψ). The adoption by Ukraine of the Law "On Copyright and Related Rights" of July 11, 2001, led to the need for certified use of expensive licensed copies of software systems in calculations. (Table 1) shows the fragment of one of the latest price lists of the PLAXIS software package (PLAXIS 3D Pricing, 2020).

Table 1 *PLAXIS 3D Pricing*

PLAXIS 3D 12-Month Subscription	$ 9,990 – $ 13,875 USD

Due to the limited possibility of purchasing licensed copies of the PLAXIS software package and its annual support (the need for an annual fee), most engineering design companies in Ukrainian construction market need to continue using traditional methods of Maslov – Berer and Shakhunyants for calculating landslide slopes. These methods are recommended by the current building codes of Ukraine and implemented in the LANDSLIP software package.

Comparative analysis

A numerical experiment was carried out for comparative analysis of calculation results of the same landslide slope using PLAXIS and LANDSLIP software packages. The purpose of the numerical experiment was to determine the error of the approximate methods of Maslov – Berer and Shakhunyants in relation to more accurate numerical solutions in PLAXIS software package. Two types of soil media were considered: clay and sand. Physical and mechanical characteristics of soils in PLAXIS software package were as follows: sand – γunsat = 16 kN/m3; γsat = 20 kN/m3; Eref = 2.8*104 kN/m2; ν = 0.3; c = 2 kN/m2; φ = 32°; clay – γunsat = 17 kN/m3; γsat = 20 kN/m3; Eref = 2.1*104 kN/m2; ν = 0.42; c = 57 kN/m2; φ = 18°. The following physical and mechanical characteristics of soils were used in LANDSLIP software package: sand – γunsat = 16 kN/m3; ν = 0.3; c = 2 kN/m2; φ = 32°; clay – γunsat = 17 kN/м3; ν = 0.42; c = 57 kN/m2; φ = 18°. (Table 2) and (Table 3) show the numerical results of calculating the test example using PLAXIS and LANDSLIP software packages.

Table 2

№	Sand		C_s	Absolute error	Relative error, %
	Software	**Method**			
1	LANDSLIP	Shakhunyants	1.33	0.21	18.75
		Maslov – Berer	1.23	0.11	9.82
2	PLAXIS	Mohr – Coulomb	1.12	0.0	0.0

Table 3

№	Clay		C_s	Absolute error	Relative error, %
	Software	**Method**			
1	LANDSLIP	Shakhunyants	1.61	0.03	1.83
		Maslov – Berer	1.44	0.2	12.2
2	PLAXIS	Mohr – Coulomb	1.64	0.0	0.0

Conclusions

Calculations of the stability coefficient ($\mathbf{C_s}$) of the landslide slope were carried out using PLAXIS software package based on the Mohr – Coulomb model and using LANDSLIP software package based on the approximate methods of Maslov – Berer and Shakhunyants. The absolute error by the Maslov – Berer method was 0.21 for sand and 0.03 for clay; relative error for sand – 18.75%, for clay – 1.83%. The absolute error according to the Shakhunyants method was 0.11 for sand and 0.2 for clay; the relative error for sand was 9.82%, for clay – 12.2%.

Joint calculations showed that the relative error of the approximate numerical methods of Maslov – Berer and Shakhunyants for calculating the stability coefficient of the landslide slope does not exceed 12–19% for sand and clay compared to the results of calculations using PLAXIS software package (within the framework of the example considered). The best matches are characterized by the relative value of 1.83% (for clay according to the Maslov – Berer method). It indicates that the approximate engineering methods of Maslov – Berer and Shakhunyants can be used by design engineers at the initial stages of designing anti-landslide structures and assessing landslide hazard.

Comparative numerical tests of PLAXIS and LANDSLIP software systems should be continued on a wider range of soil conditions and geometry of landslide massifs, taking into account seismic factors, groundwater, etc. to further determine an area of applicability of the approximate methods. It will allow Ukrainian designers to obtain estimated results on more affordable software packages without violating the Law "On Copyright and Related Rights" of July 11, 2001. In this case, the safety margin for the stability coefficient of a landslide massif in some cases will be provided at the level of the input data setting error.

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