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Formation of Landslide Bodies at Numerical Calculations of Making Soil Constructions (Cut and Embankment)

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Abstract The paper considers the problems in forming the landslide bodies taking into considerations the features of forming Stress Strain State (SSS) and stability of soil structures (cut and embankment). The investigation was carried out on the basis of calculation with the certified finite element method (FEM) GenIDE32. The analysis of phenomena of curls of the displacement vector has been done for the excavation from the uniform soil. It is shown how they influence the places of vertical cracks formation and their size and the stability of the top. Curls are not observed in the uniform embankment with the same geometrical (hu=du=const, 1:m=1:1) and other parameters as cut has. The calculation results make it possible to see the appearance and evolution of "plasticity" zones or the limiting state as "compression" and "expansion" zones. Consistent modeling of cut or embankment allows one to see how the landslide body forms including body with vertical cracks. The analysis uses graphs of trajectories of SSS variation in the space of invariants of stress tensor σij and relative deformations εij in important nods and finite elements located at the foots of constructions, where the sliding lines with kst min. appear. These make it possible to see, on graphs of form and volume deformations, where the system is located with the condition, for example, kstmin=1,33> [kst]=1,30 from the condition at which the landslide body formed: kstmin=1,00±0,02≈[kst]=1,00.

1. Introduction

How do technogenic landslides originate? According to the idea given in [1], on the potentially dangerous landslide slope mode I crack appears at some moment of time t_1 (landslide phenomenon I). Then, at t_2 mode II cracks appear, which bound the future landslide body (landslide phenomenon II). Further, at the moment t_3 the bias surface occurs that severs the future landslide body from the massive (landslide phenomenon III). And at the moment t_4, shift of rocks occurs with the formation of the breakdown wall and landslide proper (landslide phenomenon IV).

Prof. Maslov N.N. [2] explained the landslide phenomenon I in the following way: "The initial stage of the stability violation is characterized by the fact that on the plateau, behind the top of slope, the extension cracks appear".

In this century, the investigation works are under way on numerical methods of attacking problems concerning the features of landslide bodies formation in rock masses through study of SSS and the stability of systems of “cut – geomedium”, “embankment – geomedium” related to this state.

2. Urgency of the problem

Engineering methods of stability evaluation, central to which is the theory of the limiting state, do not “understand” the difference in SSS of such constructions as cut and embankment. If calculate such constructions with the same geometrical parameters (d_u=h_u=const, 1:m=1:1) and values of physico-mechanical characteristics and evaluate their stability, the result will also be the same [3, 4]: k_{stmin}=1,00. Meanwhile, due to the difference in the technology of constructing cut and embankment, the formation of landslide bodies in rock masses of their slopes occurs with their own features.

These peculiarities must be studied. In the first case, rock mass at first is unloaded and then loaded. In the second, it always loaded. The knowledge of peculiarities of SSS variation of those systems will show ways of studying more complex natural and technogenic landslide processes, which occur in the river valleys, foothills and mountains due to various factors including economic activity of man.

3. Ends and means for problem solving

The goal of the present study was the investigation of peculiarities in SSS variation of soil masses of slopes at the construction of cut (embankment) and landslide phenomena occurring in them.

Numerical modelling of construction of “cut (embankment) – geomedium” system was done with the certified code GenIDE32 [4], in which the final element method (FEM) was used. In SSS calculation, a nonlinear model of soil was employed on the basis of associated law of the plastic flow with the Mohr-Coulomb failure criterion for shear strength.

The general scheme of the problem solution of the element’s SSS for the system is the following:

1) the determination of the initial SSS of the natural soil mass;
2) successive modeling layer-by-layer of the construction of a structure;
3) application of surface loads if needed.

The program interface makes it possible to show on the computer monitor the fields of the bias vector u_i in the form of three results of each calculation: “absolute”; from the initial SSS; “among stages of changes” of the calculation scheme both on excavation and applied loads. This makes it possible to see “rotation circles” [5] or whirls: whirl1 when fields of the bias vector u_i «between the stages of variation; whirl2 from the initial SSS. This phenomenon requires special investigation.

4. Results

Further given are the investigation results of SSS for the cut as an example of layer-by-layer numerical modelling of its construction. The depth of the cut was on the order of 15,00 m and when the outlines of the landslide body were seen: $k_{st\ min}$≈1,00±0,02. The horizontal equivalent of the cut slope was 1:1. The thickness of excavation layers was equal to 1,10 m. The parameters of soil of a uniform calculated area were given equal to (variant №1): γ=0,0207 MN/m^3, E=45MPa, ν=0,39, φ=02 grad, c=0,015 MPa.

The size of the calculated area was chosen from the condition that boundary conditions on bias vector could not influence numerical results of the solution.

As is known [6], the assessment of the slope stability is made according to the condition

$$k_{st} \geq [k_{st}], \qquad (1)$$

where k_{st} and $[k_{st}]$ are calculated and required values of safety factor, respectively.

The glide line for which the safety factor is calculated as the track of the glide surface on the vertical plane may be arbitrary or cylindrical.

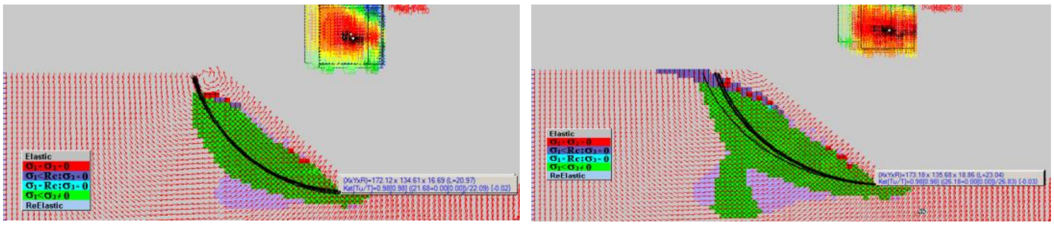
There are three variants of k_{st} calculation:

1) On the basis of SSS calculation for a soil construction with a set geometrical size [7];
2) The same at modelling of one-time its construction;
3) The same at modelling of its successive construction according to the standard technology [3].

For example, for cut (d=15,4 м, 1:m=1:1) with designated values of strength parameters and rock deformation (the Mohr-Coulomb model) the calculation results for $k_{st\ min}$ according to [4] are: 1) $k_{st\ min}$=1,00, 2) $k_{st\ min}$=1,00, 3) $k_{st\ min}$=0,98. The assessments were made with the use of cylindrical glide lines. The safety factor was computed according to the technique of "the limit tangential stress»: $k_{st\ min}=\tau_u/\tau$.

The calculation results make it possible to see the appearance and evolution of zones of "plasticity" or of the limiting state in the form of "compression" and "dilatation". "Plasticity" zones or the limiting state (uniaxial compression with shear and vice versa – cross-hatched finite elements) appeared at the slope of the cut during forth stage of excavation. Further, as the cut became deeper, these widened upward and to the left inside the cut slope and slightly downward from its current position. After 12th stage of excavation between tracks of centers of whirls1 and whirls2 (Fig. 1, a) appeared were and then developed upward and to the left towards the horizontal surface of the slope "plasticity" zones with dilatation (hatched vertically or horizontally and also vertically and horizontally finite elements) (Fig.1, b).

At the same 12th stage, the soil of the cut slope turned into a limiting state in stability (Fig.1, a). All glide lines with $k_{st\ min}$ are virtually in the limiting state zone. At the top, the lines cross the finite element (red), in which all major stresses equal zero: $\sigma_1=\sigma_3=0$.



a) b)

Figure 1. Field of the bias vectors for the "cut – geomedium" system: a) whirl2 near the slope surface, the origination of "plasticity" zones (dilatation) at the 12th stage, $k_{st\ min}$≈0,98; b) the appearance of the whirl2 at the top of the slope (at the 13th stage, $k_{st\ min}$≈0,98).

Signs of the fact that the landslide body formed at modelling cut with a depth of d_u=15,40 m (14th stage of excavation) are the following:

1)Violation of stability condition: $k_{st\ min}$≈1,00±0,02 (occurred at 12th excavation stage. Possibly, when horizontal cracks formed above "plasticity of compression" zone. (Fig.1, a)).

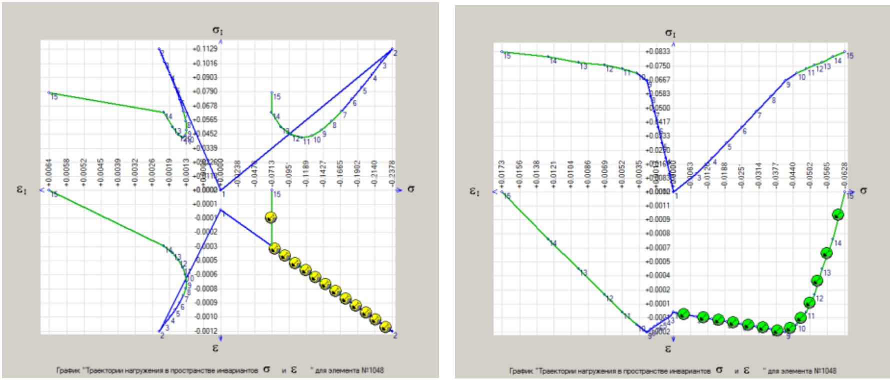
2)The appearance of "plasticity of dilatation" zones above "plasticity of compression" zones (occurred at 12th excavation stage, (Fig.1, a)).

3)The appearance of "plasticity of dilatation" zones and whirls2 at the surface of mass (occurred at 13th excavation stage. (Fig.1, b)).

4)The origination of long sites at various graphs: in quadrant $\sigma_i - \varepsilon_i$ (Fig.2, a) and at graphs $u_x - u_y$ (Fig.3, a);

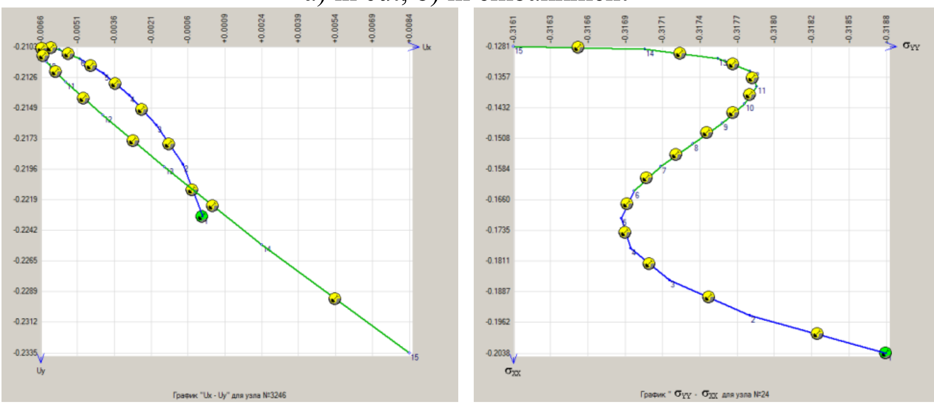
5)The landslide prism does not influence SSS of the soil mass (values in nods tend to be constant, for example, σ_{xx} ≈const. (Fig. 3, b));

6)The origination of landslide body outlines at the output on the computer monitor of mean relative deformations ε (Fig. 3, a).



a) b)

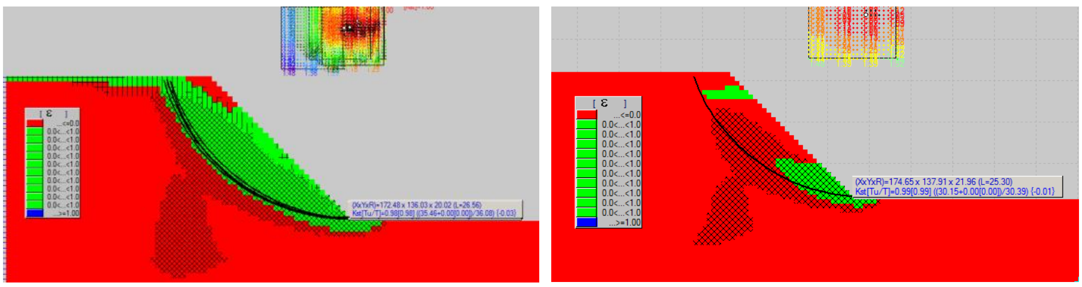
Figure 2. Calculation results (cut – geomedium) – graphs of loading trajectories in space of invariants of stress tensor σ_{ij} (MPa) and relative deformations ε_{ij} for the final element at the slope foot: a) in cut; b) in embankment



a) b)

Figure 3. Dependencies $u_x - u_y$ (m-m) and $\sigma_{xx} - \sigma_{yy}$ (MPa-MPa) for nodes in cut: a) at the slope; b) at the left vertical boundary with the slope foot

During modeling of soil excavation from the cut, the rotation centers of whirls1 and whirls2 moved from the left to the right to the surface of the cut slope. In doing so, they always were at some limit or above in depth. For this variant for whirls1 that depth was 3,30 m, for whirls2 – 2,20 m (Fig.4, a.) We note that the magnitudes of the limiting depth of the rotation centers for whirls2 are comparable with the magnitude of the critical depth for the mode I crack calculated according to the familiar formula: $h_{cr}=h_{90}=(2c/\gamma)\cdot tg(45^o + \varphi/2)$=2,15 m.



a) b)

Figure 4. Calculation results – "plasticity" zones and levels of magnitudes of spherical invariant for the relative deformation tensor ε ($\varepsilon \leq 0.$ – red or dark red; $\varepsilon > 0.$ –green or light green color): a) cut; b) embankment

For all calculation variants, paths of centers motion are similar, and the magnitudes of depth of their location depend as in formula h_{cr} on parameters involved.

With respect to “plasticity” zones, it can be said that they always appear at some distance from a horizontal surface inside the soil mass of the slope immediately above the “plasticity” zones (compression) when its stress state is close to the limiting one in stability. We think that in this place horizontal cracks and then vertical ones originate, which, for some time, do not appear at the slope surface. This phenomenon was observed in all the results of calculations done.

The appeared “plasticity” zones with dilatations were due to motions, in opposite directions, of bottom (load) and top (unload) parts of the landslide body. Possibly, dependencies u_x – u_y for nodes are also indicative of that fact. The nodes are located in zones of the whirl centers, where they have a shape of hysteresis loops (Fig.3, a). The distance from the top of the loops to the point where the lines cross was around 4 mm.

It is possible that the bottom part of an appearing landslide body comes off its top part which turns into a temporary semiarch console associated with the main soil mass (Fig.1, a). At further soil excavation (14th stage: d_u=15,40 m), the landslide body and mode I cracks appear (the final element with a vertical hatch h_{90FEM}=2,20 m). This is readily seen at the graph (Fig.4) with levels of mean relative deformations ε. Glide lines with $k_{st\ min}$=0,98 pass near the boundary that divides zones with $\varepsilon \leq 0$. и $\varepsilon > 0$.

For comparison, calculations of SSS for the similar “embankment – geomedium” system were made. At the embankment height h=15,40 m, the soil of its slopes turned into the limiting state with respect to stability: $k_{st\ min}$=0,99 <[k_{st}]=1,00. In contrast to the cut, in the embankment mass there were not deep whirls, “plasticity of dilatation” zones and the landslide prism was not completely formed. It formed later, at a height of 19,80m.

5. Conclusions

Numerical calculations of the “soil construction – geomedium” system made it possible to see the origination of the landslide body with vertical cracks. As a first approximation, for the “cut – geomedium” system conclusion can be made that the rotation centers of whirls2 related to the appearance and evolution of “plasticity” zones (dilatation) and ultimately with the formation of the mode I cracks. The magnitude of depth for these cracks were determined by the limiting values of depth where centers of whirls2 were located.

6. References

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