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Criterion assessment of soil transport structure stability

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Abstract. This paper considers features in forming stress -strain state (SSS) and stability of soil transport structures (cut and embankment) on the basis of calculation with the certified finite element method (FEM) GenIDE32. Numerical calculations make it possible to see the whole process of modeling organization of a soil structure: places where "plasticity" zones appear and develop, gradual formation of a landslide body. The analysis of SSS uses graphs of changes of SSS trajectories in the space of invariants of stress tensor σ_{ij} and relative deformations ε_{ij} in important nods and finite elements located at the sliding lines. At each step of modeling stability of depression or embankment is evaluated. Many signs indicate the termination of the landslide body formation. Noted in figures and graphs evolution of a landslide prism allows one to understand where the system is from the condition at which the landslide body formed: k_{stmin}=1,00±0,02≈[k_{st}]=1,00.

1 Introduction

Periodically, for example, [1-3] problems related to the evaluation of stability of natural and man-made soil structures are discussed.

Stability of soil structures can be assessed according to results:

1) one-time solution of an applied problem (instant construction of a structure);

2) successive modeling of construction of a structure.

In the first case, stability often is evaluated with engineering methods; in the second with numerical techniques that allow one to carry out successive modeling.

The result of criterion assessment of stability in both cases can be assessment, for example, k_{stmin}=1.33> [k_{st}]=1.30. In what way can a designer understand with these figures how far from the limiting state of stability a soil structure is? It is impossible for the first case. In the second one, the successive modeling makes it possible to see at the computer monitor the origination and development of "plasticity" zones or the limiting state, and also vertical cracks. Stability is evaluated at all stages of modeling structure and the first figure in the inequality allows one to see "plasticity" zone development in a future landslide massive. So, at the condition k_{stmin}=1.00±0.02≈[k_{st}]=1,00 the limiting values of depth d_u or height h_u of man-made structures are found.

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For recording the termination of a landslide body formation various graphs can be used, for example, graphs of changes of SSS trajectories in the space of invariants of stress tensor σ_{ij} and relative deformations ε_{ij} in important nods and finite elements (FEs) located in the structure foots where the sliding lines appear at the surface of soil massive.

Φ -c technique makes it possible to evaluate stability of a structure with set geometrical size at successive change of its strength parameters by the same magnitude; in doing so, the location of the sliding surface [3] is determined automatically. As is known [4], the values of the strength parameters φ and c change in time in a different way: the first by several degrees, the second can vary several-fold. The evaluation of to what degree they vary equally, in calculation of stability, requires additional study.

The present paper considers criterion assessments on the basis of stability prediction at designing soil structures with the use of the certified software GenIDE32 [5, 6].

2 Investigation results

The general scheme of the problem solution of the element's SSS for the "structure–geomedium" system is the following:

1) the determination of the initial SSS of the natural massive of soil;

2) successive modeling of the construction of a structure;

3) application of surface loads if needed.

Further given are the investigation results for SSS of a depression and the evaluation of its stability on the example of layer- by-layer numerical modeling of its design. The cut has a depth of around 15.000 m when the condition achieved at which contours of the landslide body are seen kst min≈1.00±0.02. The horizontal equivalent of the cut slope was 1:1. The thickness of excavation layers is equal to 1.10 m. The parameters of soil of a uniform calculated area are given equal to (variant №1): γ=0.0207 MN/m3, E=45MPa, ν=0.39, φ=02 grad, c=0.015 MPa. In other variants, the values of parameters φ and c change.

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

The program interface makes it possible to show on the computer monitor the fields of the bias vector 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. At that, "rotation circles" become visible, which were revealed by Prof. Soloviev Ju.I [3]. If shown is the field of the bias vector "among stages of excavation", these are whirls1, if "from the initial SSS" these are whirls2.

At the evaluation of stability, the mode I crack, the depth of which is denoted as h90 or hcr has always been the problem. In the words of Prof. Maslov N.N. (1977): "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". According to the idea given in [7], on the potentially dangerous landslide slope mode I crack appears at some moment of time t1 (landslide phenomenon I). Then, at t2 mode II cracks appear, which bound the future landslide body (landslide phenomenon II). Further, at the moment t3 the bias surface occurs that severs the future landslide body from the massive. And at the moment t4, shift of rocks occurs with the formation of the breakdown wall and landslide proper (landslide phenomenon IV).

Analysis of SSS for the "cut – geomedium" system is based on the methodology given in [8] in comparative studies of SSS for cut and embankment.

The calculation results as fields of bias vectors, "plasticity" zones, sliding lines with kst min are shown in Fig.1.

Zones of "plasticity" or of the limiting state (uniaxial compression with shear and vice versa – cross-hatched finite elements) appeared at the slope of the depression 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 (d=13,20 m), between tracks of centers of whirls1 and whirls2 (Fig. 1, c) appeared were and then developed upward and to the left towards the horizontal surface of the slope of "plasticity" zones with dilatation (hatched vertically or horizontally and also vertically and horizontally finite elements) (Fig. 1, d).

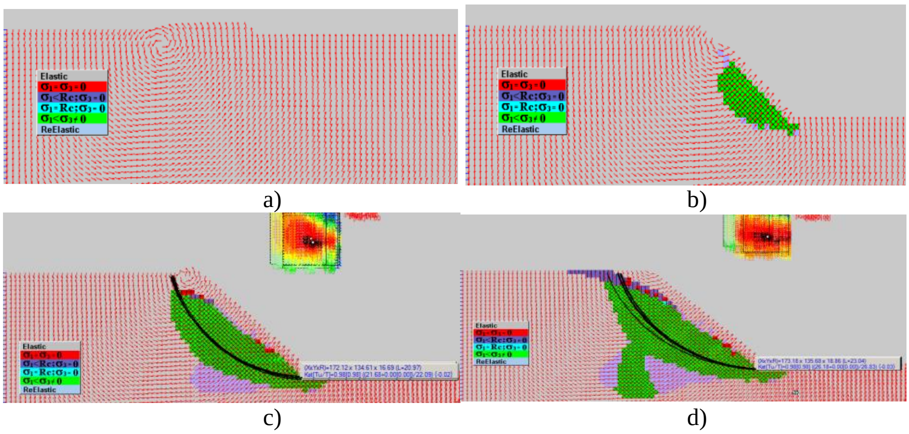


Fig. 1. Field of the bias vectors for the "depression – geomedium" system: a) the appearance of the 1st whirl1 and whirl2 (at the 1st excavation stage); b) "plasticity" zone (uniaxial compression with shear and vice versa), the appearance of the whirl1 at the slope surface (between 7th and 8rd stages of excavation, $k_{st\ min}$≈1,33); c) whirl2 near the slope surface, the origination of "plasticity" zones (extension) at the 12th stage, $k_{st\ min}$≈0,98; d) the appearance of the whirl2 at the top of the slope (at the 13th stage, $k_{st\ min}$≈0,98).

At the same 12th stage, the soil of the depression slope turned into a limiting state in stability (Fig.1, c). All sliding lines with kst min (the variant of "limiting tangential stresses": kst = τu/τ) are virtually in a limiting state zone. At the top, the lines cross the finite element (red), in which all major stresses equal zero: σ1=σ3=0.

It can be said that the "plasticity" zones (extension) always appear at some distance from a horizontal surface inside the massive of soil of the slope immediately above the "plasticity" zones (compression) when its stress state is close to the limiting in stability. In our opinion, in this place the origination of horizontal cracks (peeling) and then vertical ones, which, for some time, do not appear at the slope surface. This phenomenon is noted in all the results of calculations done (variation of magnitudes of strength parameters).

The appeared "plasticity" zones with extension are due to the opposite motions of bottom (load) and top (unloading) parts of formed in the depression slope landslide body.

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 depression 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.2.) It should be noted 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 formula: hcr=h90=(2c/γ)·tg(45° + φ/2)=2,15 m.

Figure 2 shows the path of motion from the left to the right of rotation centers of 8 whirls1 as flags in nodes and analogous 12 centers of whirls2 given as marks on Y axis. For all calculation variants (variation of φ и c) the paths of centers motion are similar, and the magnitudes of depth of their location depend as in formula hcr on parameters involved.

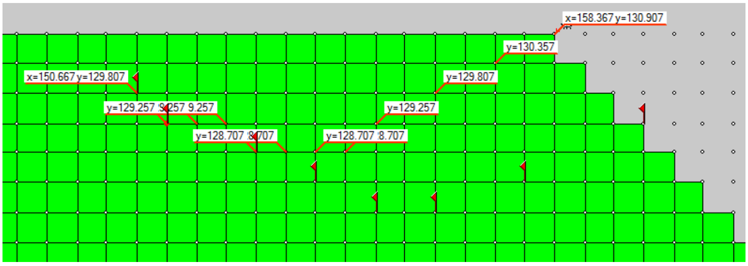


Fig. 2. Nodes with the rotation centers of whirls1 (flags) and of whirls2 (Y-coordinates).

We think 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 massive of ground (Fig.1, c). At 14th stage of ground excavation (du=15,40 m), the formation of the landslide body and mode I cracks terminate the FE with a vertical hatch).
Fig. 3, according to the calculations with the magnitudes of a mean relative deformations, clearly shows a formed landslide body. Cylindrical sliding lines with k_{stmin}=0,98 pass near the boundary of the landslide body that separates zones with ε≤0. и ε>0.

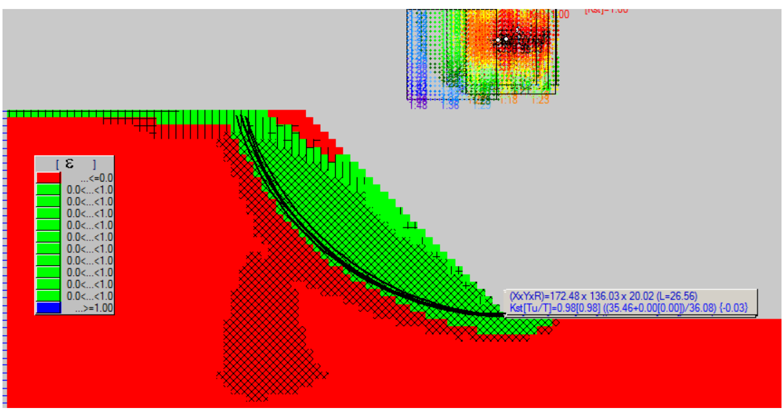
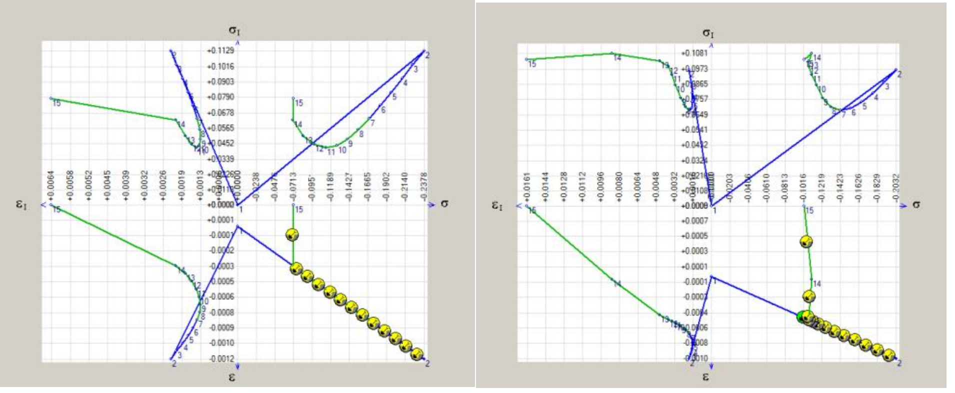


Fig. 3. Calculation results after 14th stage of excavation – “plasticity” zones and levels of magnitudes of spherical invariant of relative deformation tensor ε: ε≤0. – red or dark red; ε>0. –green or light green color.

In Fig.4, a, for the last 14th stage of excavation when contours of the landslide body are clearly seen (Fig.3) shown are graphs of loading trajectories in space of invariants of stress tensor σij and relative deformations εij for the FE located at the slope foot where sliding lines exit from it. For this graph the trajectories in space σi – σ changed in the following way (Fig.4, a): at 7th stage trajectory of “crush” is replaced by trajectory of “extension” (loading on deviator σi and unloading on the ball invariant σ). Further it is replaced by trajectory of “simple shear” with the appearance of a long site of “shear” in space of deviators σi – εi (shape change deformations), where up to 11th stage of excavation unloading on σi occurred, and after it loading with the exit to the site of shear.

In space σ – ε (volume deformations) to 14th stage elastic unloading occurs on σ and ε, at the last part at σ = const. In calculation, at 7th stage whirls1 were not observed any more, and at 12th one where centers of whirls2 were located “plasticity” (extension) zones appeared and at 13th stage whirls2 appeared at the top of the depression slope. View of the final parts of graphs of all loading trajectories indicates the termination of the formation of the landslide body. Figure 4, b shows analogous graphs characteristic of the FE located at the sliding line under “plasticity” zones (extension) and upper then the slope foot. Everywhere in space σi – σ at the sliding line there is the final site with unloading on σi and σ.

The appearance of this site at graphs at the last stage of modeling cut is also indicative of soil of the slope turning into the limiting stability state. There are also other signs of that.



a) b)

Fig. 4. Calculation results (depression – geomedium) – graphs of loading trajectories in space of invariants of stress tensor σ_{ij} (MPa) and relative deformations ε_{ij}: a) for the FE at the slope foot; b) for the FE located at the sliding line upper then the foot.

For the calculation variant given, computed magnitudes of kst min for depression modeling are: №7 – 1,33, №8 – 1,22, №9 – 1,13, №10 – 1,06, №11 – 1,02, №12 – 0,98, №13 – 0,98, №14 – 0,98. So, the stage №7 (d=7,70 m) is characterized by the start of change of the "crash" trajectory (unloading) in space σi – σ by "extension" trajectory (Fig. 2, a) and the appearance of whirl1 at the slope surface and the size of "plasticity" zones (Fig.1, b). It should be noted that deformations of volume and form are virtually of a linear shape.

3 Conclusions

So, state-of-the-art software used in geoengineering make it possible to see what will take place in a structure when it undergoes successive modeling. Figures in criterial assessment of stability allow one, using the potential of computer interface, to understand how far from the limiting stability state the structure is.

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