The retaining wall collapse prevention during the multifunctional complex construction on the slope of Staronavodnytska ravine in Kyiv

 # 305

Fareniyk G, Ischenko Y, Melashenko Y, Kaliukh Iurii

(kalyukh2002@gmail.com)

Research Institute of Building Constructions

Mediterranean Symposium on Landslides

Geological structure. Physical and mechanical characteristics

Multistorey garage at 2-20 Staronavodnytska Street in Kyiv is the buildings and structures complex for cars storage, repair and movement, the administrative and auxiliary purposes buildings, as well as the engineering structures in the form of retaining walls. In terms of geomorphology, the site for the designed multistorey garage is located on the right slope of the ancient Staronavodnytska Ravine (Fig. 1).

Fig.1. General view of the multifunctional complex on the Staronavodnytska Ravine slope

Geological structure. Physical and mechanical characteristics

The slope is located in a landslide hazard area, but during the research phase prior to the construction the area was stabilized by:

a) the artificial terracing with three terraces strengthened by 1.5-m high retaining walls (slope angles did not exceed 200 ... 300);

b) the drainage system arrangement for surface and ground waters drainage.

The absolute marks on the ravine slope vary within 140.50 ... 178.60 m. The height difference reaches 38.1 m. The garage complex construction site is located on two lower terraces.

According to engineering and geological surveys, the geological structure up to the explored depth of 30.0 m is composed of a complex of Quaternary and Neogene deposits represented by sands, sandy loams, loams and clays, covered from the surface with a filled soils layer.

Garage complex design features

The complex of landslide protection and retaining structures includes the Ø 620 mm piles with a 700-mm spacing in axes and variable lengths from 13.3 m to 14.85 depending on the terrain, made to the absolute elevation of 150.9 m and combined with each other in a single ground beam.

The Ø 620 mm piles with a spacing of 800 mm in axes and variable lengths from 13.3 m to 14.85 m depending on the terrain, made to the absolute elevation of 150. 9 m and combined with each other into a single ground beam etc.

In some axes the piles are arranged in a checker-board order and combined with each other into ground beams along axes.

Soil accident

The intensive soil development lasted from 18.11.2003 to 01.12.2003 and after soil excavation to the absolute elevation of 155.95 m the landslide protection structures could not withstand shearing pressure and began to move in the pit direction, which has led to a soil disaster and an emergency situation in the civil structures of landslide protection structures.

When the landslide protection structures deformations increased almost twice and the horizontal movement of their walls reached 835 mm, the soil excavation from the pit was stopped.

But the landslide protection structures horizontal deformations continued to increase and on 12.12.2003 the displacement amount reached 1093 mm.

Soil accident

That meant that a shear body had formed on that portion of the slope. It was clearly indicated by the crack of stabbing, which appeared higher on the slope and increased in time, plan, and depth. Detailed photographs of the stabbing crack above the land-slide protection structures on the slope beyond the У" axis as of 28.11.2003, 14.12.2003 and 21.12.2003 are shown below.

Fig. 2. – Stabbing cracks above the LPS on the slope as of: 1) 28.11.2003; 2) 14.12.2003; 3) 21.12.2003

Soil accident

The left and right wings of the upper tier retaining wall received significant horizontal displacements (1000-1200 mm and more), which caused the reinforced concrete ground beam destruction by vertical cracks with the widths of up to 50 mm due to retaining walls continuous horizontal movements and the emergency situation occurrence.

Soil accident

The deformations ("bending" under the shearing pressure action) of the garage complex fence piles ground beam along the У axis in the 31 ... 39 axes are shown below.

A). State as of 28.11.2003 г. B). State as of 17.02.2004 г. C). State as of 13.10.2004 г.

Fig. 3. Soil accident: deformations ("bending" under the shearing pressure action) of the garage complex fence piles ground beam

Soil accident

The results obtained while engineering and geodetic observations of these structures movements along the У axis in the period from 23.02.2003 to 20.09.2004, indicate the following:

1.By mid-December 2003, the ground beam maximum movement along the У axis at the intersection with the 7-axis exceeded 1070 mm, and its development rate reached 3 ... 5 cm per day.

2. In Fig. 4 the horizontal movements of the ground beam top along the У axis in the period from 23.02.2003 to 20.09.2004 are shown according to engineering and geodetic observations in the 31 ... 37 axes. The similar results are received in the 1 ... 30 axes.

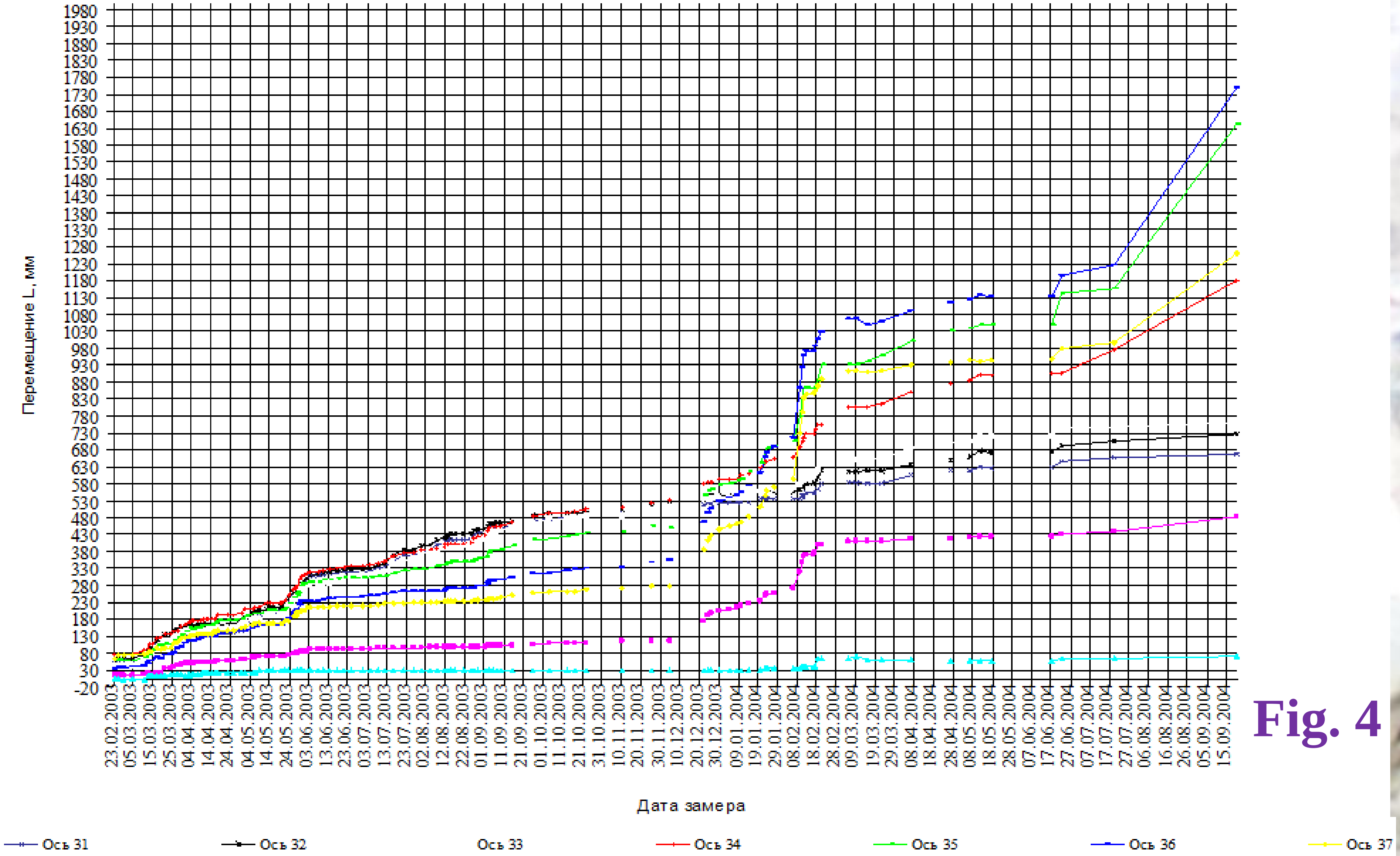
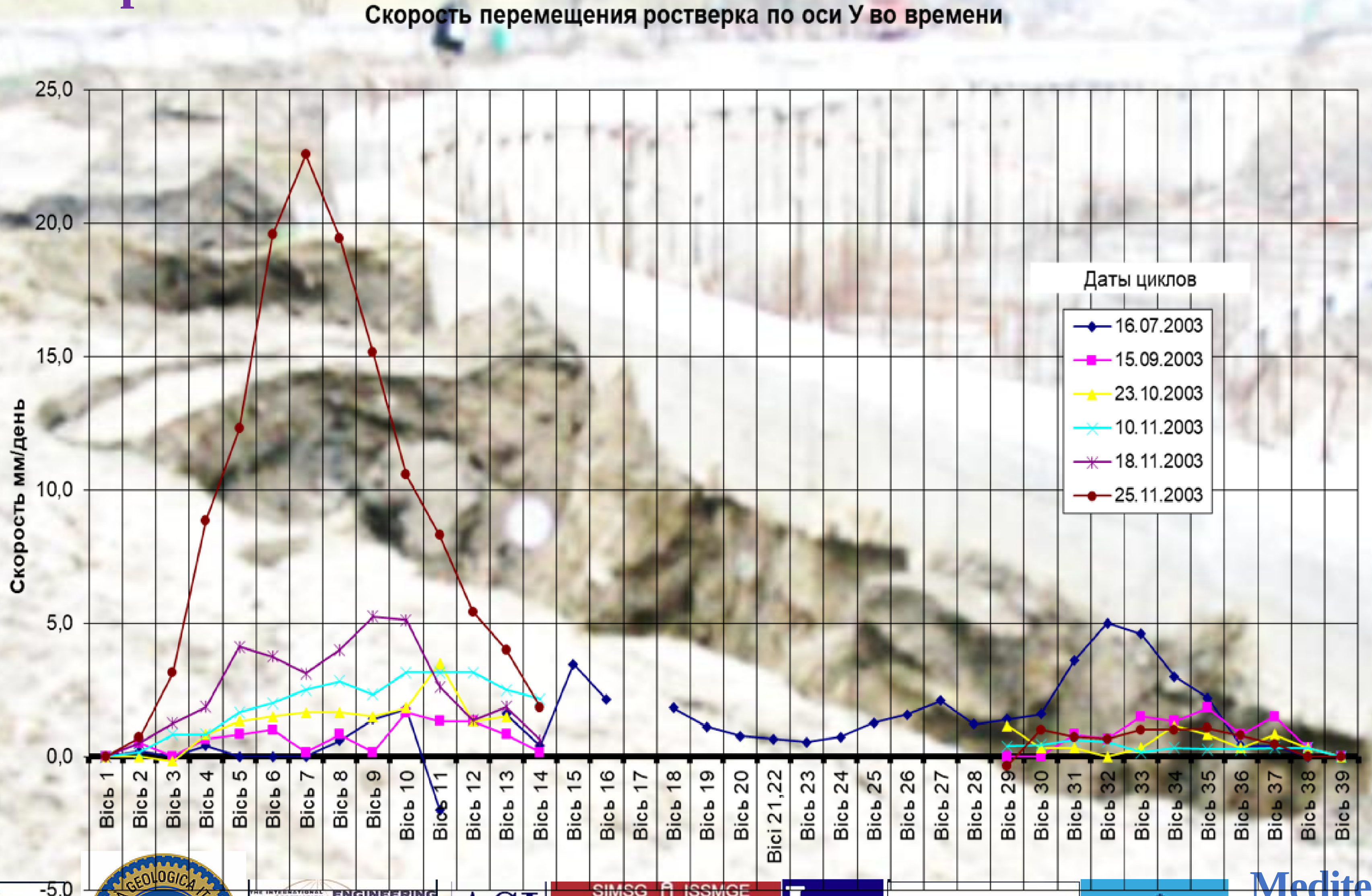
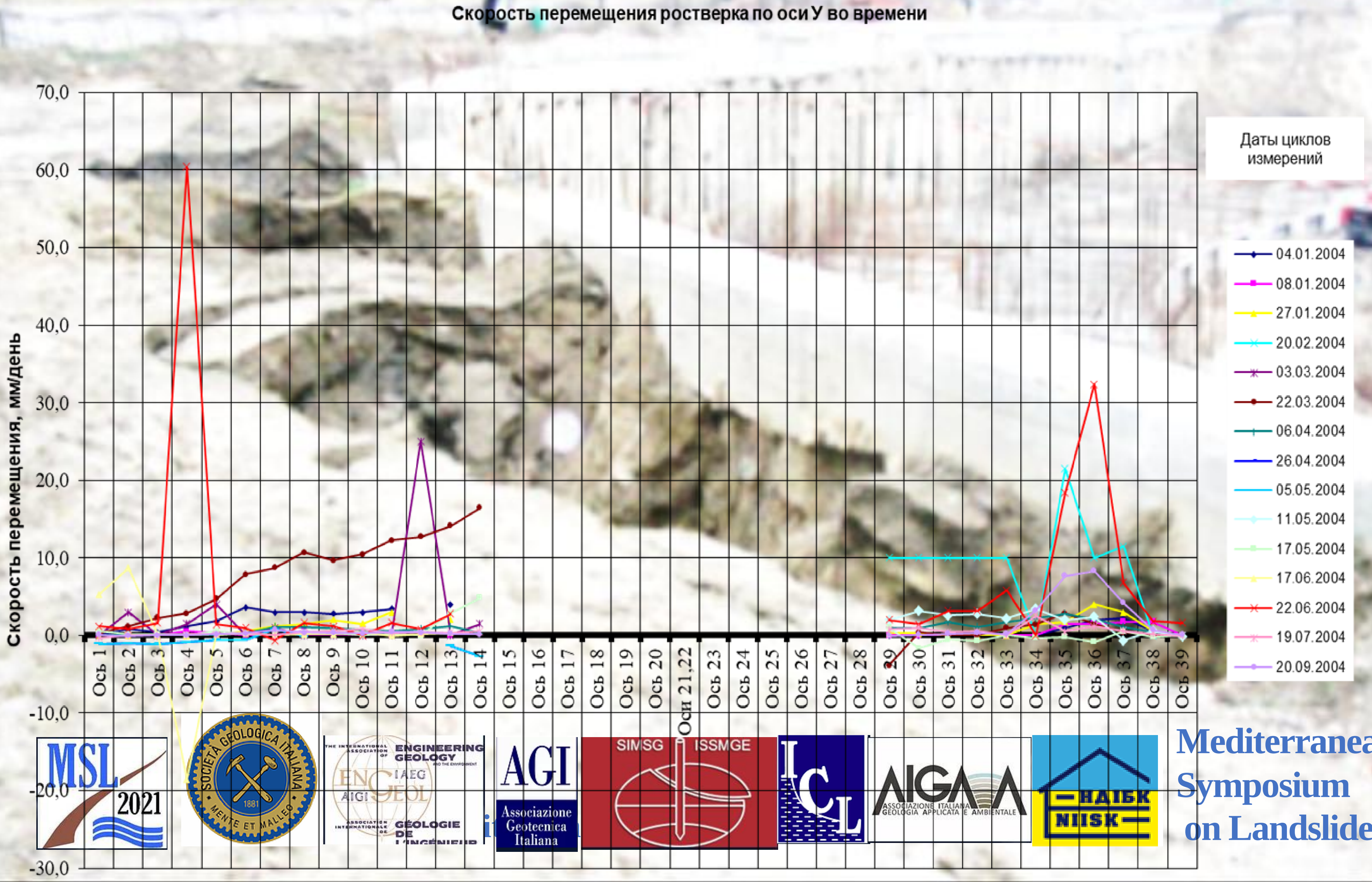

Перемещение L, мм
Дата замера
Ось 31
Ось 32
Ось 33
Ось 34
Ось 35
Ось 36
Ось 37

Fig. 4

3. In Fig. 5 the diagram of the retaining structure ground beam movement velocity along the У axis in the period from 16.07.03 to 25.11.03 is shown.



4. In Fig.6 the diagram of the retaining structure ground beam movement velocity along the У axis during the period from 04.01.04 to 20.09.04 is shown.



Soil accident

The ground beam horizontal deformations the during the reporting period constantly increased and had the maximum value of 1350 mm along the 7 axis, 1409 mm along the 8 axis, 1359 mm along the 9 axis, 1310 mm along the 10 axis, 1180 mm along the 34 axis, 1642 mm along the 35 axis, 1750 mm along the 36 axis and 1260 mm along the 37 axis.

The further soil deformations could lead to a larger soil accident and deformations of building structures located above the buildings of a multi-storey urban development.

The values of the ground beam top horizontal displacements indicated that the structures retaining the pit in the У axes did not operate as the landslide protection structures.

As a result, a shear body was formed in the 5… 12 axes, which was clearly indicated by the stabbing cracks appeared higher on the slope beyond the У axis (Fig. 2). Moreover, the through cracks with opening widths up to 60 mm emerged in the ground beam along the У/35…37 axis (Fig. 7).

Fig.7. The through cracks with opening widths up to 60 mm in a fence pile ground beam along the У axis in the 35 … 37 axes as of 13.10.2004.

Audit and priority structural measures

To save and correct the situation created, as well as to perform the design documentation comprehensive analysis and audit, the existing structures visual inspection and mathematical modeling of the stress-strain state of slopes and garage complex civil structures, the concept and principles of the landslide protection structures construction in restrained urban conditions were applied.

To determine the slope stability taking into account its undercut for the construction, the mathematical modeling of the soil mass together with the pit fence structures was performed; the slopes stability was assessed using the Morgenstern and Price, Bishop, Yanbu and finite element methods with the assumption that sliding surfaces had a circular cylindrical shape or were assigned in the form of broken lines.

The calculation was carried out in three phases.

The first phase envisaged the determination of the soil mass stress-strain state prior to the landslide protection structures arrangement and the pit opening to the design marks.

Audit and priority structural measures

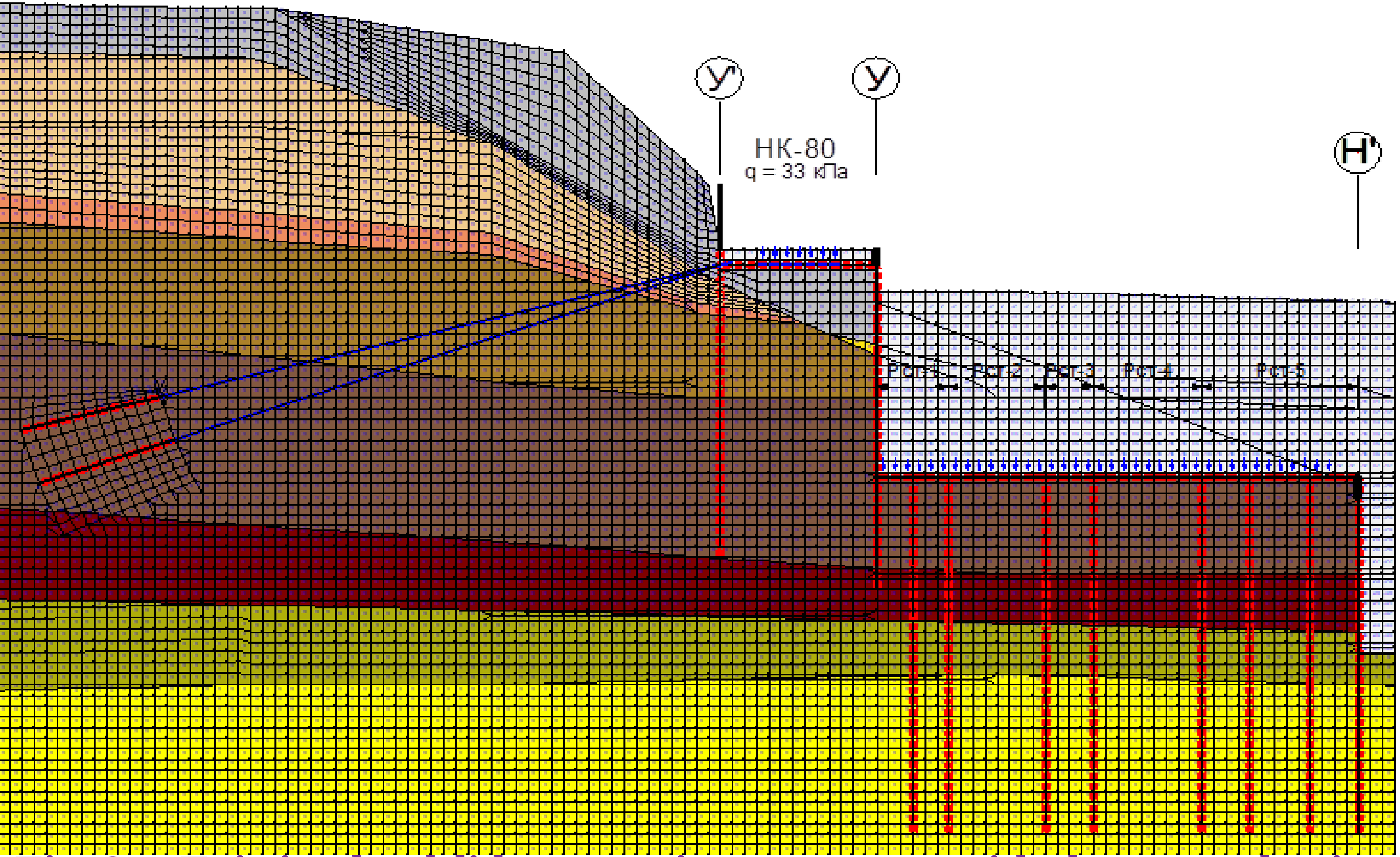
The **second phase** was carried out after the landslide protection structures arrangement and the pit opening to the design marks. This phase was divided into calculation steps, which allowed to analyze the soil mass stress-strain state in time.

The **third phase** was the stability assessment of this slope portion with the formed stress-strain state, which was obtained as the calculation result of the second phase.

The limit conditions for the geotechnical model were as follows:

horizontal movements were prohibited along the scheme right border;

horizontal and vertical movements were prohibited along the left and lower borders.



The calculation schemes for phases 1, 2 and 3 are shown in Fig. 8.

Fig. 8. – Existing landslide protection structures with the strengthening means (with an allowance for the fill weight) in the calculation scheme of the slope portion in the 5 ... 12 axes

Urgent stabilization measures

1. The retaining wall strengthening along the У axis by arranging the inclined soil anchors via a multi-span metal beam.

2. The inclusion of the retaining walls pile rows into the joint operation along the У' and У axes by connecting them by reinforced concrete beams and creating a frame structure that would ensure their joint operation.

3. The walls rigidity increasing in the У'... У axes by means of tie spreaders in the form of reinforced concrete beams and thus creating a spatial retaining structure, the stability of which would increase in the subsequent construction phases.

4. Soil backfilling into the pit near the fence wall in the У... H1 ... 10 axes.

5. The slope cutting along the У axis beyond the 5 ... 12 axes.

Urgent stabilization measures

6. The new retaining wall designing and construction along the У1 axis in the 31 ... 40 axes.

The wall consisted of the following civil structures: one 20.0 m long foundation row of CFA piles with Ø 820 mm and 1100 mm axes spacings along the У1/31 ... 39 axis.

Two pile rows of CFA piles with Ø 820 mm and 1100 mm axes spacings with 2500 mm distances between the axes in plan along the axis У1/39 ... 40.

The piles were connected by a ground beam of a single reinforced concrete slab with a cross section of 3650 mm 1000 mm. A reinforced concrete wall with 4500 mm high and 600 mm thick buttresses was made of the slab ground beam.

Measures 1 and 4 were carried out as temporary ones to be used only in the process of piles and pile ground beams arrangement in the У axes.

Calculation of retaining structures with soil anchors

Verification of the structural stabilization measure with soil anchors is performed using the "Lira-Windows" software-based computer modeling of the pile row portion У axes on the basis of a finite element approximation of the landslide protection retaining structures.

Loads and effects on the calculation model elements are as follows:

1. Loads due to the effective shearing pressure are determined in accordance with the slope stability calculation and vary along the piles lengths.

2. The unilateral rigidity value in the horizontal direction, which simulates the piles surfaces and retaining wall contact with the soil, is determined depending on the calculation areas deepening.

3. The loads preset during the anchors tensioning were specified under the appropriate angles in the spreading beam nodes at the anchors installation points. In the calculation model the tension value of 60 tons was taken.

The results of the retaining structures calculation when installing anchors

The maximum value of horizontal deformations at the pile nodes (Fig. 9) is 1.9 cm.

In Fig.10 the calculation model deformed scheme projection on the XOZ plane is shown.

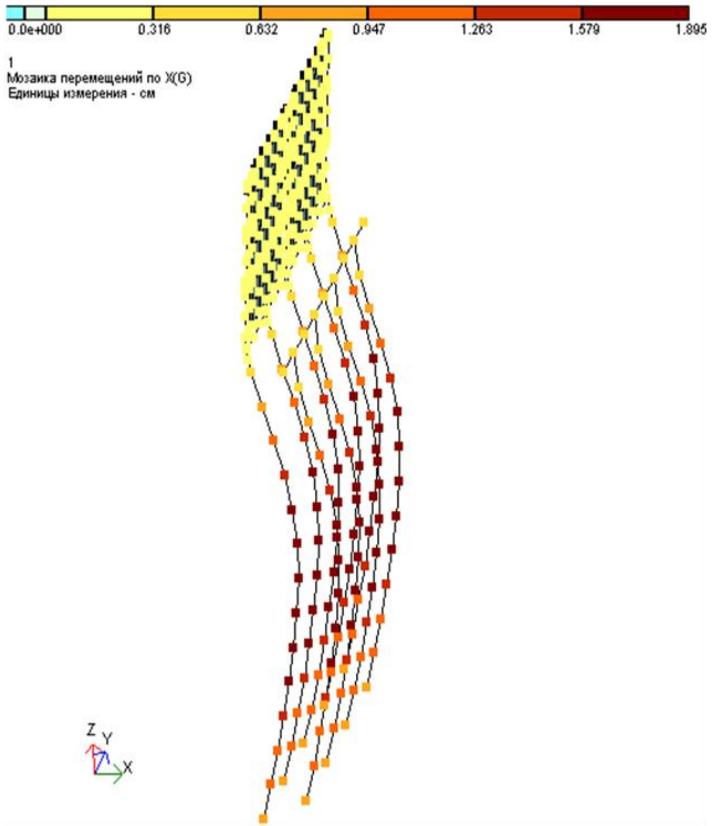


Fig. 9. – The deformed scheme of the calculation model nodes along the OX axis

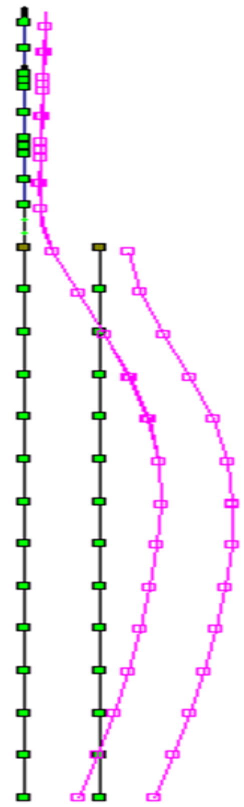


Fig. 10. – The deformed scheme projection on the XOZ plane

The results of the slope stability calculation when installing anchors

The most probable sliding surfaces and the stability coefficient values for this slope portion are shown in figures 11 and 12.

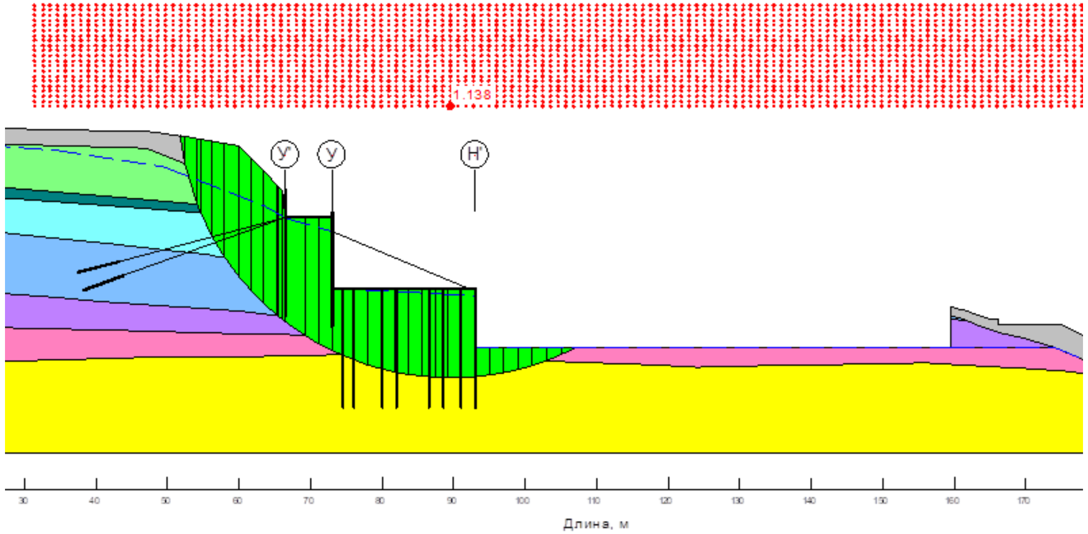


Fig. 11

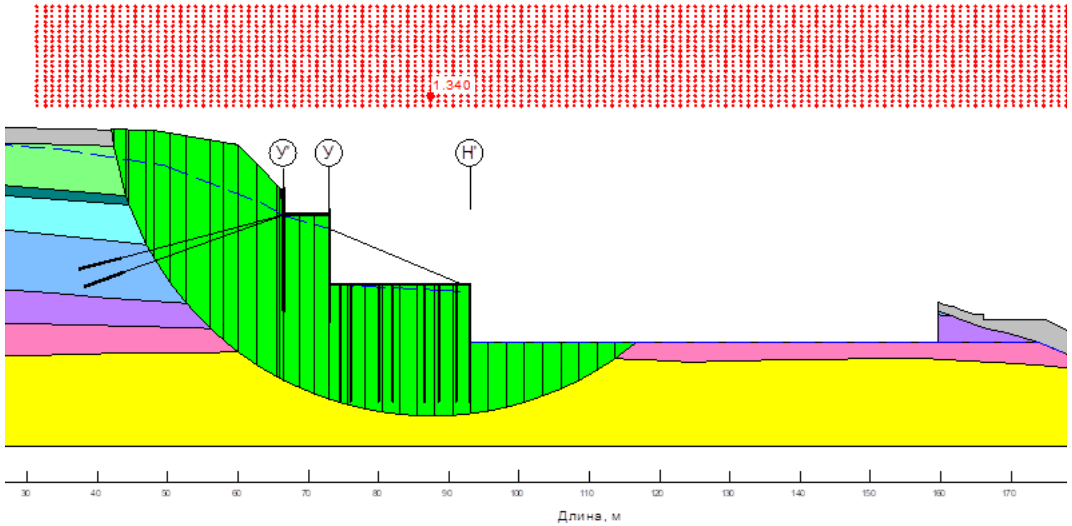


Fig. 12

The results of the slope stability calculation when installing anchors

The engineering-geological structure (types of engineering-geological layers, their capacity and physical-mechanical and strength properties) under each of the conditional areas of the calculation scheme is taken according to the engineering-geological surveys data. The pressure intensity along the conditional foundations bottoms is accepted as uniform. As a result of the calculation, the value of the base soils deformations along the conditional foundations vertical axis is determined, and by means of the layer-by-layer summation the full and elastic settlements of foundations are obtained with and without taking into account the mutual influence.

The base rigidity coefficients obtained for the foundations system were introduced into the input data to perform the three-dimensional calculation of the garage complex structures in the iterative calculation process.

Conclusions

1. A complex three-dimensional computer model of the building is developed. It consists of two substructures operating in a unified automatic mode and combined at the level of contact with the base.
2. Carried out numerical studies show that the additional structure along the У axis at the top of pile row of soil anchors with a 60-t working tension can stop the ever-increasing slope soil deformations with its stability coefficient of [1.351; 1.354].
3. To stabilize the structures retaining the slope along the У axes in the 1 ... 12 axes, the following works were performed:

- the retaining wall strengthening along the У" axis by installing the inclined soil anchors via a multispan metal spreading beam;
- the retaining walls pile rows inclusion into the joint operation along the axes У due to their integration by connecting elements at the ground beam level;
- the walls rigidity increasing in the axes У by installing the tie-spreaders in the form of reinforced concrete beams and thus creating a three-dimensional retaining structure, the stability of which will increase at the subsequent construction phases;
- the soil backfilling in the У … H1/7… 10 axes;
- the slope cutting beyond the У axis in the 5… 12 axes.

Recommendations for the revision of the multistorey garage structural scheme general concept

The decision was made to revise the general concept of the multistorey garage structural scheme. According to it, the load-bearing structures of the multistorey garage retaining walls had to:

a) be located in a cascade on the slope;

b) be interconnected by underground elements;

c) be held by the load-bearing elements of the buildings frames to form a united rigid three-dimensional system.

THANK YOU FOR YOUR ATTENTION