Modeling of Engineered Slopes for the Effective Design of Protection Structures: Example in the City of Sochi (Russia)

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Abstract

Active works are being held currently to develop mountain-climatic resort infrastructure of Sochi. Plan of works includes making the transit, sports, engineering and touristic infrastructure of Sochi to meet the world standards, finishing the Airport reconstruction and others. Due to increased technogene influence on geological environment, exogenous processes have reactivated on many sections of the construction area.

Keywords

Landslide • Pre-portal construction • Soil models • Slope stability

370.1 Introduction

Difficult situation has occurred at the Adler—the Airport railroad line section (Figs. 370.1 and 370.2). In the spring of 2011 the development of landslide soil deformation has taken place during installation and construction works on pre-portal construction at western portal of railway tunnel. Retaining wall, still under construction, had a displacement down the slope and it's sections have displacements from each other (Fig. 370.3). Occurred situation was a direct threat to the safety of continuing installation (Sochitisizproekt 2011) and construction works and also to the operating conditions of exploitation of lower down constructions. To reveal geological situation at the construction site data from geological investigation were analyzed, geotechnical and equipment network was installed and also additional geological and geophysical investigation were held. Emergency situation has demanded to make an immediate constructive design decisions.

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370.2 Geotechnical Situation Analyses

On the site was installed 3 inclinometers at the top, in the middle (above the retaining wall), and the bottom of the slope. Comparing the results of monitoring with geological investigation data allowed to reveal significant differences in established depth of landslide's surface of failure, in ground water line placement, in displacement vector (Table 370.1). It was recognized that construction site bedding was formed by highly weathered, highly fractured argillites of very low resistance. Bedding had tectonic joints as well as softening in soil massive block structure. Sections of water stagnation and zones water encroached soil were noted. Complexity of construction site conditions demanded to carry out immediate technical and other actions, such as performance of stability and stability calculations of protective structures, modeling of slope behavior under various engineering-geological conditions, development of long-term monitoring program.

Calculations of slope stability and stability of protective structures are executed by a method of finite elements. The estimation of stability is made under the following conditions:

- in calculations change of slope landscape during the stage-by-stage course of protective structures construction was taken in account in design marks;
- level of ground waters is accepted as expected maximum (Sochitisizproekt 2009, 2011).

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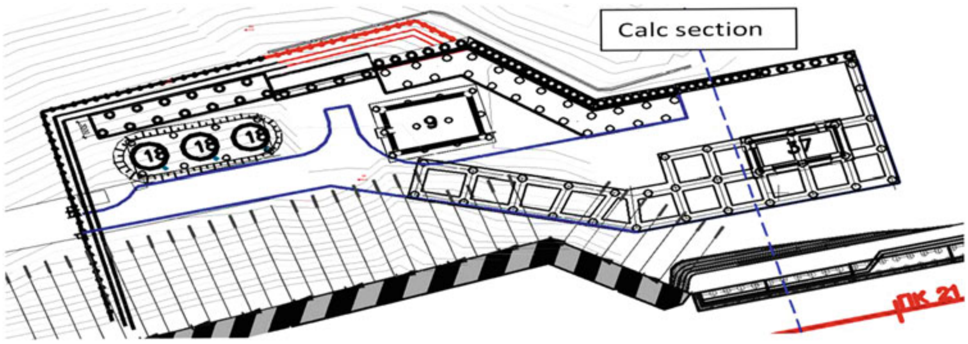

Fig. 370.1 The scheme of the constructed railway tunnel and pre-portal construction

Fig. 370.2 General view on the constructed railway tunnel and pre-portal construction

Fig. 370.3 Displacement of retaining wall sections up to 24 cm

Performing series of slope stability and stability calculations of protective structures with use of physicomechanical properties of soil according to geological investigation has revealed that results, in most cases, don't correspond to the actual situation. So, the obtained slope stability (*Kst*), on the active landslide centers had values, exceeding one, and calculated displacements of protective structures did not correspond to data of in situ supervision. The main reason for discrepancy between calculations results and developed engineering-geological conditions is connected with

Table 370.1 Comparing the results of geological investigation with monitoring data

Characteristics	Geological investigation	Monitoring data
Driiled/inclinometric hole depth, m	15	40
Slide surface depth, m	13	20–26
Ground waters	Sporadic spread	Level is static—26 m
Direction of landslide movement	Not determined	Vector of landslide is determined

calculated values of strength characteristics of the soil. These characteristics have been taken according to (Publishing house of standards 1997) and they can differ from real values of sliding surface soil characteristics (Bezuglova 2005). It demands carrying out of the back-calculations of stability (Construction management and design of highways federal road agency 2011; Federal agency for construction and housing and communal services 2003), in which strength characteristics of soil have to be selected from the range between peak and strength values (Construction management and design of highways federal road agency 2011).

The back-calculations allowed to specify values of soil strength characteristics of protective structures and to execute further modeling of a slope condition.

370.3 Modeling of the Landslide Situation

Modeling of a landslide slope condition was executed by means of the *Plaxis* program complex with application of various soil models: Linear Elastic and Mohr-Coulomb. Other models weren't considered, due to the lack of necessary investigations data. Three hypotheses were considered. They correspond to three calculated situations, which are given below in the Sects. 370.1–370.3.

370.3.1 Calculated Situation No. 1

Displacement of a pre-portal construction top reaching up to 24 cm was modelled with landslide pressure increase. Landslide and potential landslide accumulation (eluvial-landslide soil and deluvial soil) were described by the Mohr-Coulomb model with use of the physicomechanical soil characteristics obtained by the back-calculations; soil of the foundation is described by the Linear Elastic model (very strong rocky soil).

Results of calculations: with construction's displacement up to 24 cm and more, bending moments arising in a pre-portal construction are exceed admissible limits. In this case there would be a reinforced concrete pile destruction. During research period the cracks on a body of a pre-portal construction are not revealed, so it is possible to assume the existence of uniform displacement, from a pile heel to the top. In this calculated situation slope stability is provided (*Kst* = 1,180), that doesn't correspond to the landslide load of the actual developing displacements. Therefore, correction of the calculation scheme is necessary.

370.3.2 Calculated Situation No. 2

For modeling the displacement of the construction's top in this calculated situation strength characteristics of the foundation soil were updated. Unlike a calculated situation No. 1, in this scheme foundation soil is taken into the account corresponding to the Mohr-Coulomb model, thus strength characteristics were obtained by the back-calculations.

Result of calculations: with construction's displacement exceeding 24 cm, bending moments in piles don't reach limiting values. It means that the pile construction moves in parallel-sided direction, thus the calculated sliding surface passes below the ends of piles. However, during the visual inspection of the slope the soil heave at the basis of a pre-portal construction of a tunnel isn't revealed. It means that the estimated sliding surface bears against the lower part of the already constructed object. Such situation doesn't confirm a hypothesis of sliding surface's placement below the ends of piles. This calculated scheme doesn't reflect a real situation on a construction site.

370.3.3 Calculated Situation No. 3

The slope condition is modelled with use of interface function (it is required for modeling of the set sliding surface), and placement of an expected sliding surface at a depth of about 20 m (Fig. 370.4). Landslide and potential landslide accumulation, and also soil in a zone of a surface of sliding are described by the Mohr-Coulomb model with use of the physicomechanical characteristics obtained by the back-calculations; soil of the foundation is described by the Linear Elastic model (very strong rocky soil).

Results of the calculations: the expected sliding surface passes in weathered fractured argillites at a depth of about 20 m, rated value of slope stability isn't provided (*Kst* = 1,047). The obtained calculated displacements of a pre-portal construction are confirmed by actual data. The results analysis of three calculated situations (hypotheses) showed the expediency of further use of the third calculated situation in strengthening structures design of a pre-portal construction. The choice of the correct model allowed to obtain rational parameters of protective structures design (use of anchors and reinforced concrete rafts) and to provide safe operation of the Adler—the Airport railroad line.

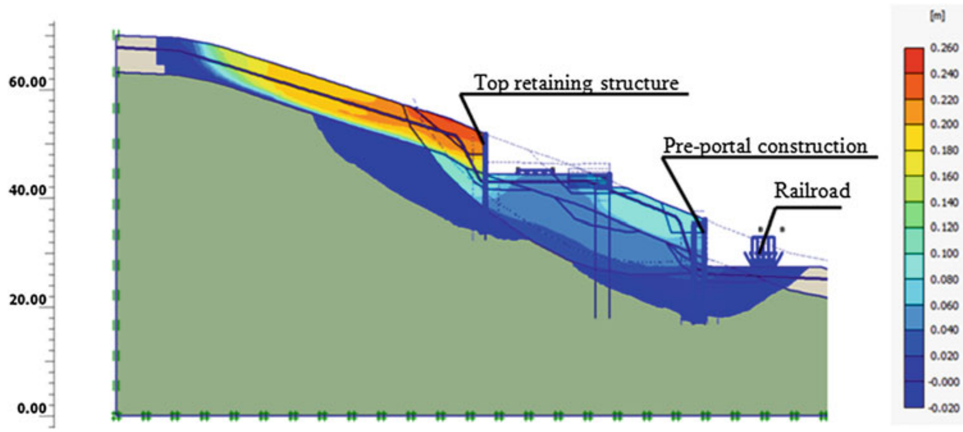

Fig. 370.4 Modeling of a calculated situation No. 3: slope section with a pre-portal construction and an expected sliding surface

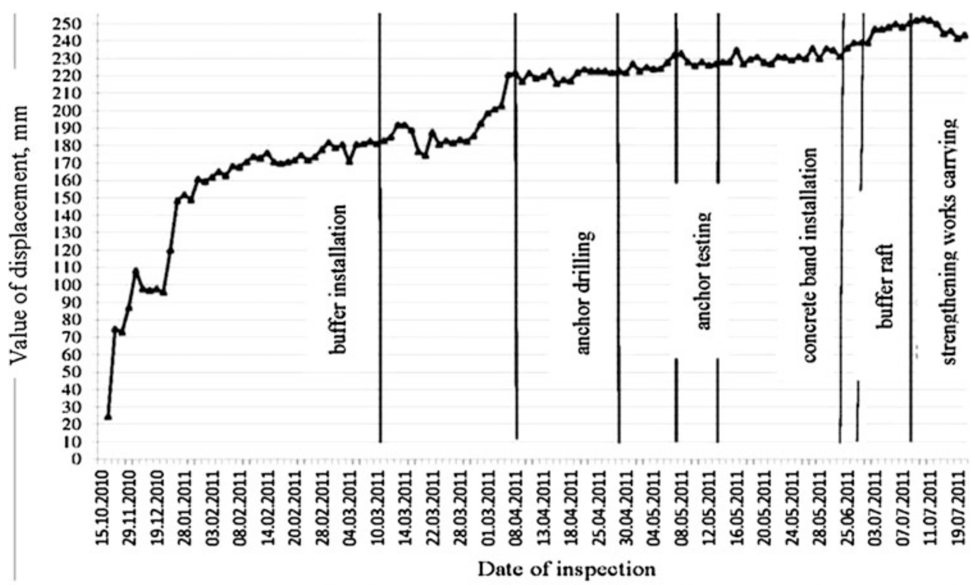

Fig. 370.5 Schedule of deformations development of a pre-portal construction depending on a type of performed works

370.4 Performance of Consolidation Work

It should be noted that from the moment of revealing of landslide process on the construction site, and also during construction period of the designed structures of engineering protection, geotechnical monitoring was carried out. As an example, Fig. 370.5 shows the actual schedule of deformations development of the pre-portal construction after performance of the strengthening actions, obtained by results of the data analysis from one of the established reference point. It is obvious that slope stability is provided after use of strengthening actions.

370.5 Conclusions

Modeling of a landslide situation on a researched construction site on the basis of various hypotheses allowed developing the effective designs of engineering protection structures, providing safe operation of a landslide site of the Adler—the Airport railroad line. The analysis of calculated situations results showed that standard models of the rock soil (Linear Elastic), used for standard calculations, are not always applicable. Monitoring performance allowed to reveal in due time a tendency of development of deformations of designs and to execute strengthening actions

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