

Landslide protection of the ski resort “Mountain Air” on the Sakhalin Island

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Abstract. This article contains the results of engineering and geological surveys and geotechnical calculations made for the development of the sports complex STK "Mountain Air" in the south-eastern part of Sakhalin Island. Design and survey work is performed, as well as reconstruction and setup of the associated infrastructure of the complex, including the construction of ski slopes and cable-ways. The description of the designed supporting and retaining structures is given.

1 Introduction

Ski resorts are among the important recreational and entertainment infrastructures. But their development is directly related to construction in hard-to-reach mountainous areas, often with a difficult geological situation. The geology, typical for mountainous areas, questions the safety and, in general, the efficiency of a sports complex of that kind.

Landslide danger arises when natural processes or people infringe upon the stability of the slope. The danger of a catastrophe is directly related to anthropogenic activity on the slopes prone to landslides. The variety of dangerous consequences, including colossal economic damage, is becoming a serious threat, for the prevention of which comprehensive engineering protection is required. As you know, in cases where it is impossible to unequally ensure safe operation, they consider an acceptable level of safety. As examples, considerable coefficient of slope stability, economic risks, probability of success, etc. Thus, the engineering task is supplemented with an assessment of possible damages and considering the probability of an event.

2 Site survey results

The relief of southern Sakhalin is represented by medium-altitude mountains [1]. According to the survey data, the area under investigation experiences a significant man-made impact, expressed in partial re-subordination of natural channel processes to the results of construction and recreational activities that have caused anthropogenic change in the relief. This object is located on the seismically active territory of Sakhalin Island [2]. Apart from the increased seismicity, linear and planar erosion is developed within the object, as well as underflooding.

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The rate of erosion cuts in loose quaternary sediments can reach 0.5 m per year, with the erosion taking place along the routes of existing ground and skidding roads. As a result, scours, gullies, ravines and valleys are formed. Bottom erosion, in turn, actively develops the bottoms and sides of beams, which significantly contributes to the formation of landslides. Of course, during the period of abundant precipitation, which occurs in the southern part of Sakhalin from July to August, the probability of the bottom erosion significantly increases.

Water of the temporary (seasonal) horizon of the perched groundwater is developed in the cover sediments to depths of 0.5-1.5 m.

According to the performed survey, the level of groundwater was determined. At the time of prospecting (June 2017), groundwaters with depths of up to 23.0 m were opened at depth of 1.0-12.6 m. The chemical composition of groundwater is sulphate-hydrocarbonate calcium-sodium with mineralization of 0.14-0.25 g/l. Therefore, for all types of concretes and reinforcement of reinforced concrete structures, groundwaters are weakly aggressive. But for lead cable sheath they are characterized by high aggressiveness and for aluminum coating – by medium. From this it follows that drainage itself, as well as the drainage measures of engineering protection, are compulsory for the construction of this sports complex. For the subsequent calculation of the stability of the slope, laboratory tests of the soils were carried out, in order to determine their physico-mechanical characteristics. Table 1 presents the consolidated and non-consolidated shift test data.

Table 1. Soil physico-mechanical characteristics.

Soil	Specific gravity γ , kN/m ³	Cohesion c , kPa	Angle of friction φ °
EGE-2 technogenic soil	22.1	19.27 11.32	30.40 24.2
EGE-10b loam	19.7	28.65 21.54	25.04 19.33
EGE-24 gruss soil	19.4	22.61 14.21	29.19 23.12
EGE-26 stony-loam soil	18.3	21.63 12.85	30.06 24.54
EGE-47 metamorphic soil	Soil model: bedrock		
EGE-50 ledge rock	Soil model: bedrock		

3 Factor of safety calculations

Calculations of engineering protection structures include calculating their overall and local stability, calculating the forces arising in the structures, and determining the strength of the structures themselves. One of the zones of the ski resort is located on the slope, which is reinforced with a corner retaining wall. An analysis was made of interaction between the retaining wall and the ground base [3]. For nonrocky soils, we have adopted the following calculated values of the strength characteristics at the contact "structure – soil massif": specific cohesion $c_k = 0$; angle of friction of the soil along the material of the structure, defined by formula (1):

$$\delta = \gamma_{\kappa} \cdot \varphi \quad (1)$$

where γ_{κ} – coefficient of working conditions (in our case 0.67); φ – angle of friction of the soil. Thus, we get that for the construction under consideration the friction coefficient

between the retaining wall and the EGE-24, soil will be $\delta = 23.12 * 0.67 = 15.5^\circ$. In connection with such a low adhesion between the retaining wall and the ground, the stability margin with the basic combination of loads is not enough to ensure reliable operation of the protected object. A similar situation was shown in calculations in the software complexes GEO5 v20 and Plaxis 2D. When seismic action, the collapse of the embankment would occur (Figure 1). Therefore, we decided to design a wall on a pile foundation [4]. The soil mass was modeled using the Mohr-Coulomb model.

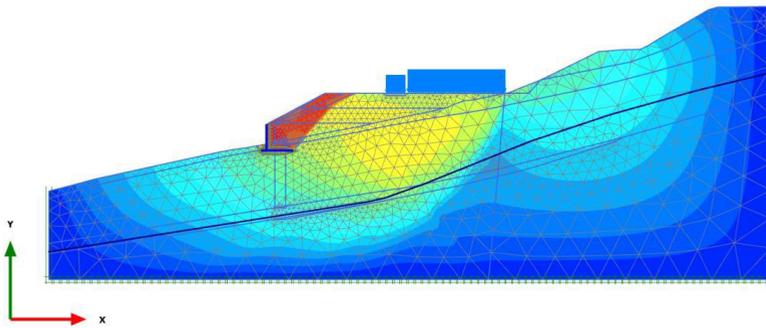


Fig. 1. Slope stability calculation with retaining structure.

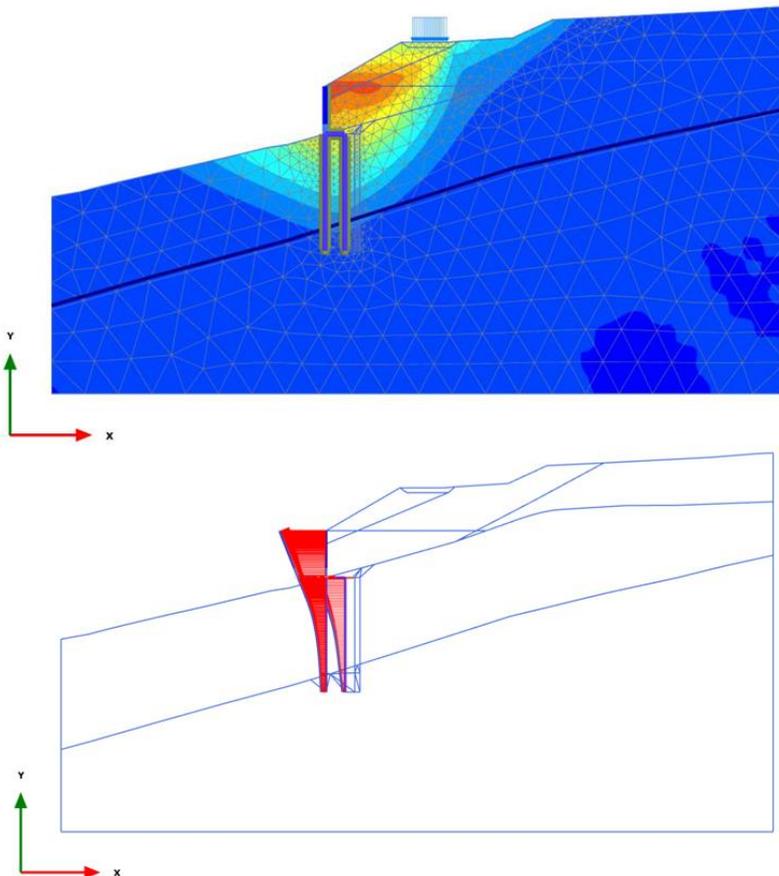


Fig. 2. Section 1 slope stability calculations (FEM).

Calculations of the stability and the resulting forces in the structures, in accordance with SP 116.13330.2012, were carried out by the finite element method with the help of the geotechnical program complex Plaxis 2D and the method of limiting equilibrium using the GeoStudio program. This object was divided into three sections for each engineering-geological section. Calculations were made for keeping structures in the section.

The obtained results of calculations (Figure 2) of the section 1 structures on the slope of the ski resort showed that the necessary reliability is ensured with a very large margin.

Calculations of the section 2 have also shown sufficient factor of safety, equals to 1.392 (Figure 3). Even different loads on the landslide slopes don't significantly affect the stability.

As for previous sections of the slope the calculations of slope stability showed the same adequate factor of safety, equals to 1.435 (Figure 4). And furthermore, this structure is earthquake-resistant, so presumable seismic actions won't lead any tragic consequences.

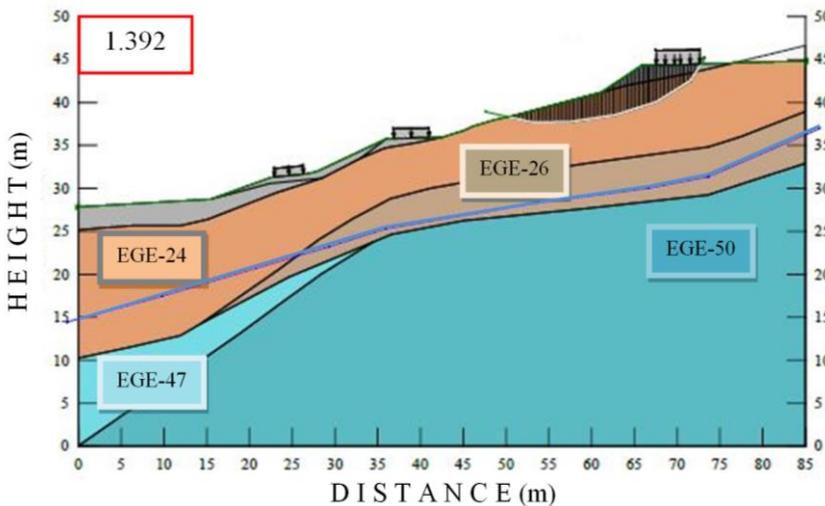


Fig. 3. Section 2 slope stability calculations (LEM).

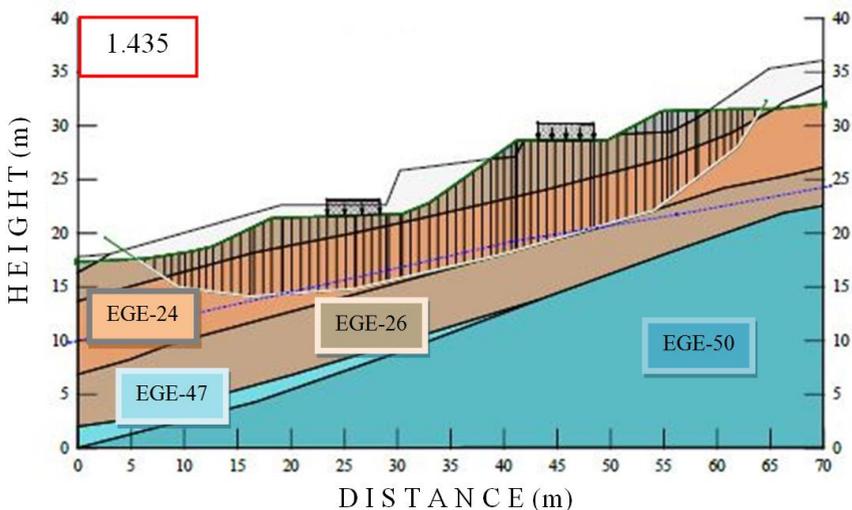


Fig. 4. Section 3 slope stability calculations (LEM).

4 Conclusions

According to the performed calculations, a retaining wall was designed on bored concrete piles, as well as the drainage measures were implemented. Due to the great bearing capacity of the retaining wall, designed at the first unit, the sufficient factor of stability was provided. Competently and timely accepted engineering solutions, relatively difficult geological situation, ensured the safe operation of the mountain ski resort "Mountain Air".

References

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