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Landslide Hazard Assessment at "Sakhalin-2" Main Pipeline Project

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Abstract

In the given article, 2 various approaches to a landslide hazard assessment are considered. Landslide hazard means probability of a slope failure. The calculations have been carried out using a landslide hazardous section of Sakhalin-2 main pipeline route as an example.

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Abstract

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Introduction

A problem of landslide hazard and risk assessment in geotechnical construction is of great importance. It is connected with a natural disaster phenomenon as well as with a reclamation of new lands, which are located, as a rule, in the areas being unsuitable for construction. The sections of the slopes and slants being prone to landslide processes belong to such areas.

At present, a probabilistic approach based on Monte Carlo method is one of the most prospective approaches of slope stability assessment. It gives an opportunity to take into account a stochastic instability of soil characteristics, to upgrade quality and reliability of estimates, to improve assessment of a degree of landslide hazard and, consequently, of landslide process development risk. But the results being obtained depend greatly on geotechnical survey detail.

Geotechnical Conditions of “Sakhalin-2” Main Pipeline Route

Subsurface oil and gas pipelining is envisaged within the framework of Sakhalin-2 project. In the vicinity of the town of Makarov, pipeline route runs across rough country where 60 landslide sections have been registered. Out of them, 6 sections belong to the highest category of engineering risk.

One of the sections (No. 106) is a block landslide with thickness of 9 m, which is in a limiting equilibrium stage. The landslide length in plan is 180 m, its width is 40 m. Slope process activation is provoked by slope watering and landslide tongue underscouring. The pipeline route runs across watershed in the landslide head (Figure 1).

A geologic lithologic section of the surveyed area is characterized by deluvial deposits, deluvial-proluvial ones and eluvial formations.

Figure 1. Landslide hazardous section No. 106 with an indication of the pipeline route axis and the landslide limits.

According to the data of the performed field and laboratory surveys of the monoliths and disturbed structure samples in the given section in accordance with GOST 25100-95, seven engineering geological elements (EGE), which reflect the engineering lithologic section of the slope, have been determined. The landslide hazardous section No. 106 is composed by the following engineering geological elements:

EGE-12a: clays;
EGE-15a: soft plastic loams;
EGE-16a; EGE-16b: semi-solid loams;
EGE-29: gravel soil;
EGE-31: pebble soil;
EGE-32: argillites.

Soil displacement takes place along a contact of the layers of loams and gravel soils.

Irregular temporary water on the pipeline route has a limited distribution and takes place in clay soils in rain period on high benches, on the slopes and on flat watersheds with hampered surface flow.

Slope landslide hazard assessment according to historical data

Safety and efficiency of the antilandslide measures depend on reliability of forecast of local stability of the slopes and landslide hazard. Land reclamation, water balance, nature changeability as well as other factors exert great influence on landslide hazardous slope behaviour.

A known approach is in the fact that first of all a relative average probability of slope failure is determined within the limits of the whole area of the surveyed section. Then breakdown probability of the target slope is calculated with the help of a system of adjusting factors.

Probability of failure of the target slope is determined according to the formula:

$$P_e = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5 \cdot F_e \quad (1)$$

The limits of possible values of independent correction factors for the landslide slope surveyed section No. 106 are given in Table 1.

Table 1. Value range of the correction factors

Index	Assumed value range		Independent indices	Characteristic	Relative significance
F_1	1.25	0.25	Age	Age	High
F_2	4	0.9	Geology	Unfavourable soil conditions. Weathering processes	Very high High
F_3	2	0.1	Slope geometry	Slope height	High
F_4	4	0.1	Geomorphology	Slant incline	Very high
F_5	4	0.5	Ground water	Ground water level. Drain conditions. Vegetation availability on the slope surface. Technogenic factor	Very high Average High Very high
F_6	6	0.5	Cases of slope stability failure	Availability of rupture cracks	Very high

The calculations being carried out (Table 2) have shown that probability of failure of the target slope is within the range of 1.6% to 36.1%.

The values of the correction factors were obtained by Fell and Finlay by means of analysis of a large number of the landslide hazardous slopes. The factors allow to take into account the characteristic geotechnical and hydrogeoligic conditions of the landslide being surveyed. The approach takes into account other data concerning historic activation of the slope, technogenic factor and other indices, which exert an influence on a degree of landslide hazard.

Probability computations of the target slope with the help of Monte-Carlo method

On the grounds of variant design, the diagrams of pipeline engineering protection against the landslide influences have been worked out in order to provide safe operation of the pipelines.

Table 2. Probability of failure estimation of the technogenic slope No. 106 within the framework of Sakhalin-2 project

Factors	Feature	Characteristic of area	Value
Correction factor	Slope age Geology Geometry Geomorphology Ground water Rupture cracks	- Rupture cracks. Slope height < 5 m, angle of slant < 50° Incline 15÷30°. ⅓ part of slope -	0.25÷1.25 0.9÷4 0.7 1.1 2.7 (+0.25) 3
Final correction factor	$(F = F_1 \times F_2 \times F_3 \times F_4 \times F_5 \times F_e)$		1.53÷34.07
Average probability	P_e*		0.0106
Probability of failure of the target slope	$P_e \times F$		0.016÷0.361

* P_e – is average probability of failure within the limits of the whole area

Probability computations of the slope were carried out with the help of SLOPE/W computation set on the grounds of Monte-Carlo method. The values of standard deviations of physical and mechanical characteristics of soils (Table 3) were determined with the help of transient coefficients.

The probability computation results are given in Table 4.

Table 3. Data for probability computation for the landslide hazardous section 106

Soil	Unit weight γ, kN/m^3	Cohesion c, kPa	Angle of internal friction φ, degrees
12a – clays	19.1 (*SD*=0.1)	20.0 (*SD*=3.68)	10.0 (*SD*=1.41)
15a – soft plastic loams	18.4 (*SD*=0.07)	17.3 (*SD*=3.18)	7.0 (*SD*=0.99)
16a – stiff loams	18.7 (*SD*=0.05)	14.5 (*SD*=2.67)	11.0 (*SD*=1.55)
16в – stiff loams	19.7 (*SD*=0.11)	16.2 (*SD*=2.98)	14.0 (*SD*=1.97)
29 – gravel soil	19.1 (*SD*=0.06)	7.4 (*SD*=1.36)	28.0 (*SD*=3.95)

The following design diagrams have been considered:

1. slope cutting 1:2 without an accomplishment of additional measures;
2. slope cutting 1:2 with an accomplishment of the set of antierosion measures;
3. slope cutting 1:2 with an accomplishment of the set of antierosion measures as
4. well as berm arrangement at the height of 2.5 m from the slope base.

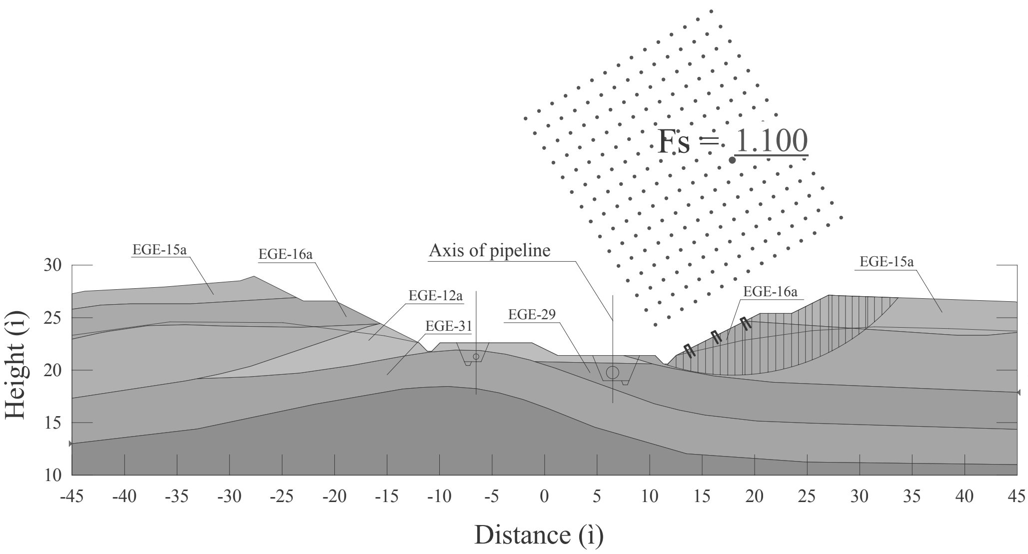

Figure 2. Results of probability computation of stability of the landslide hazardous slope No. 106 according to design values mechanical and physical characteristic of soils.

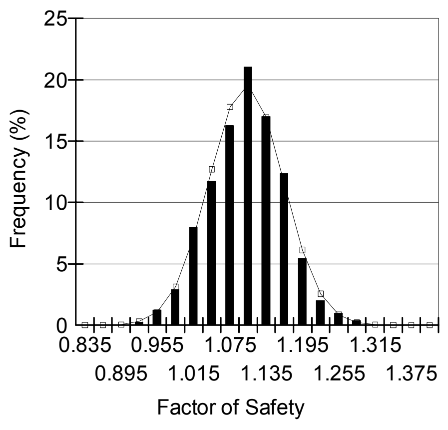

Figure 3. Normal distribution density.

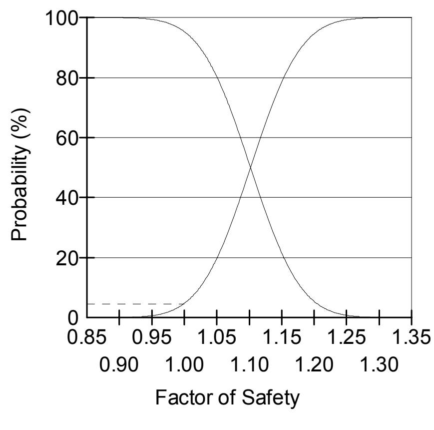

Figure 4. Probability distribution function.

Table 4. Summary table of probability computation of slope stability at Sakhalin-2 main pipeline project

Nos	Engineering measures	Stability factor	Probability of failure, %	Factor of safety
1	Slope cutting 1:2, without additional measures	0.554	100	-6.881
2	Slope cutting 1:2, with antierosion protection arrangement	0.985	54.85	-0.137
3	Slope cutting 1:2, with arrangement of berms and antierosion protection	1.100	20.35	0.818

The main results of probability computation are given in Table 4.
On the grounds of the performed probability computation of slope stability (Figs 2-4), a set of engineering measures, which included an arrangement of the slopes with the berms, was designed in combination with antierosion measures. The drains were arranged in order to reduce a ground water level in the pipeline trenches.

Conclusion

Probabilities of slope failure have been surveyed on the grounds of two different techniques. A significant spread in quantitative characteristics of landslide hazard has been obtained on the grounds of the computations employing the technique, which is based on the historical data and a correction factor system.

The technique based on Monte-Carlo method has allowed to choose an optimal variant of engineering protection with minimal probability of failure. This approach allows to take into consideration stochastic changeability of strength properties of landslide hazardous slope soils.

The surveys have proved actuality and indisputable significance of the problem of quantitative estimation of landslide hazard. An accurate assessment of landslide hazard exerts a decisive influence on risk value and, consequently, on life and health of people as well as on economic efficiency of construction.

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