Features of landslide structures’ designing in emergency situations

A K Ryabukhin*, D V Leyer, N N Lyubarsky
Kuban State Agrarian University named after I.T. Trubilin, 13, Kalinina str., Krasnodar, 350044, Russia

E-mail: r-a-k-1987@mail.ru

Abstract. During the operation of the M-27 highway, a landslide became active on the km 56 + 680 section of the Tuapse district (Russia). As a result of the landslide masses’ displacement, the roadbed was destroyed and, as a result, traffic was restricted. In emergency situations, with the rocks’ continued displacements, it was necessary to develop the constructive solutions for the landslide structures in a short time. Engineering protection of roads on landslide slopes requires a detailed analysis of the source data, as well as a set of calculations to determine the designed structures’ strength and the slope’s stability. However, in emergency situations, it is often necessary to install the structures even with insufficient initial data based on a visual inspection of the site, as well as archival data. The article presents the results of a landslide site survey, as well as the results of modeling a slope with various combinations of loads. In addition, the constructive solutions of both priority measures and the main landslide control structures are presented.

1. Introduction

With the activation of a landslide-stall on a slope in the Tuapse region (Russia), asphalt concrete pavement was destroyed on the Dzhubga-Sochi highway, km 56 + 680 (Figure 1). A number of private residential buildings were demolished by landslide rocks (Figure 2). Significant deformations of the roadbed led to difficulties in the vehicles’ movement on the only federal road in the area. In addition, after the displacement of the ground masses, the landslide tongue blocked the existing stream, which led to the flooding of the lower part of the slope [1]. A reconnaissance survey revealed the following [2]:

- The highway covering was destroyed in the upper part by 7–9 meters, in the lower part (in the site of the preserved barrier) about 40 meters. The stall depth in the region of the existing upper wall is 3–4.5 m, the stall depth in the lower barrier is up to 10 m. The estimated volume of displaced landslide masses is up to 20-25 thousand m³.

- At the exit from the side-ledges of the subgrade, onto the terrace and to the floodplain of the beam, landslide masses destroyed several houses. A landslide lobe blocked the stream, which led to the flooding of the neighboring plot (territory with outbuildings).

- The side parts of the landslide dump blocked the inter-house passage, partially destroying it, partially falling asleep to a height of 3–9 m. The right side of the dump came close to the newly built cottage, destroying small courtyard buildings of several households on its way.
• The distance between the landslide masses (including the lobe and other geotechnical manifestations - spill fragments, secondary collapses, capture and removal of weak soils and flooded interlayers) until they stop - about 50 m. Width along the slopes is 40-45 m.
• There was no continuous protrusion of the beam bottom, however, on the right side there is a rise in the beam bottom by 0.3-0.4 m (behind the right end of the dilapidated house).
• In the lowering, the slope of the trees is “drunken forest”, clumsy trees are more characteristic. And so, on the entire height of the slope at 100-120 m.

Based on the site reconnaissance survey data, the territory survey, geotechnical surveys (pilot holes) results, the recommendations of leading specialists - geologists and geo-technicians, as well as relevant regulatory [3-6] and scientific literature [9-14], the following reasons for activation landslide can be highlighted:

• Long-term soaking of clay soils composing the slope.
• Intensive seasonal rainfall.
• Human activities (loading the slope with bulk soil).
• Violation of the groundwater regime, leakage from water-bearing communications, and as a result, saturation of bulk soils and slope deposits.
• Active erosion activity of the stream located in the lower part of the slope.
• Dynamic impact on the slope of the heavy-laden vehicles.

The analysis of the landslide activation causes showed the following: on the slope, composed of clay mudstones, the soil was randomly dumped during the road construction, which led to uneven sediments of the canvas. With a significant steepness of the lower slope, bulk soils gradually shifted downward, capturing the underlying rocks. Then long rains and heavy rains flooded these mixed unstable ground formations. All this greatly influenced the physical and mechanical properties of soils and the stress state of the massif, which led to the formation of a landslide [0].

![Figure 1. View of the landslide from the Tuapse side (Russia)](image1)

![Figure 2. Landslides contours and displacement vector](image2)

2. Modeling a landslide slope using the geotechnical programs
The calculations and design of engineering protection structures are performed in accordance with [3-6]. The calculations of engineering protection structures include the calculation of their general and local
stability, calculation of efforts, arising in structures, as well as determining the strength of the structures themselves. The slope’s investigated section stability assessment was carried out taking into account the prevailing engineering and geological conditions, as well as the design changes in the relief for the road restoration and the construction of engineering protection structures. Moreover, the influence of adverse conditions such as washing out the slope during the flood period and seismic impact of up to 9 points was also considered.

According to the survey, engineering geological elements (EGE) were identified in the soil massif, the physical and mechanical properties of which are shown in Table 1. When calculating the slope stability for the landslide soils of EGE-2 and EGE-3, the characteristics obtained by accelerated shear using prepared wetted soil surface were used. The engineering protection structures’ strength calculation is based on the conditions [3]:

\[ \psi \cdot F \leq \frac{\gamma_d \cdot R}{\gamma_n} \]

where: 
- \( F \) – is the calculated value of the generalized force impact on the structure or its structural elements (force, moment, voltage);
- \( R \) – is the estimated value of the generalized bearing capacity or strength established by the relevant design standards depending on the type of structure and materials used, taking into account the safety factors for the material and (or) the soil.
- \( \psi \) – is the load combination coefficient accepted: for the main load combination \( \psi = 1,0 \); for a special combination of loads \( \psi = 0,9 \); for the construction period and repair \( \psi = 0,95 \);
- \( \gamma_n \) – is the reliability coefficient for the responsibility of the structure adopted for the structures of a normal level of responsibility \( \gamma_n = 1,15 \);
- \( \gamma_d \) – is the coefficient of working conditions accepted as \( \gamma_d = 0,95 \).

The stability calculations in accordance with [0] can be performed on the basis of the condition:

\[ k_{st} \geq [k_{st}] \]

where: 
- \( k_{st} \) – is the calculated value of the stability coefficient, defined as the ratio of holding forces (moments) \( R \), acting along the slip line, to shear forces (moments) \( F \);
- \([k_{st}]\) – is the normalized value of the slope stability coefficient (slope) taken: for the main combination of loads \([k_{st}] = 1,25 \); for a special combination of loads \([k_{st}] = 1,15 \); for the period of work \([k_{st}] = 1,15 \) [3].

In accordance with the preliminary stability calculations’ results, in order to ensure even limited traffic on a reverse circuit, as well as to carry out the main complex of landslide measures, it is necessary to install the temporary holding structures. During the design process, a number of structural calculations and slope stability were performed both for the main (transport load of the NK type) and the special (seismic of 9 points) load combinations. The study of the stress-strain state of the slope was performed in the software package Plaxis [7], based on the finite element method. Slope stability, including taking into account the landslide measures’ device, is determined using the software package GeoStudio Morgenstern-Price method [8]. When developing the design solutions for the road engineering protection, the calculations were performed both on the identified sliding surface of the active landslide and on the predicted one. Table 2 presents the calculation results for one of the sections.

**Table 1.** Soil characteristics taken during slope modeling
### Name of the engineering-geological element

| Soil model          | Coulomb Mora | Coulomb Mora | Coulomb Mora | Linear elastic model |
|---------------------|--------------|--------------|--------------|----------------------|
| Material type       | drain        | drain        | drain        | non-porous           |
| Specific gravity, g (kN/m³) | 18.6         | 17.2         | 19.2         | 20.9                 |
| Specific grip, c (kPa)     | 21.1         | 10           | 15           | -                    |
| Angle of internal friction, j (hail) | 11.2         | 10           | 8.8          | -                    |
| Deformation modulus, E (MPa) | 8.5          | 9.6          | 10.7         | 100                  |
| Poisson’s ratio, m      | 0.42         | 0.35         | 0.35         | 0.27                 |

Table 2. The results of slope stability calculations for one of the sections

| Settlement situation                                                                 | Estimated load combination |
|-------------------------------------------------------------------------------------|-----------------------------|
| Slope in the natural state before the landslide displacement, taking into account    | basic combination of loads  |
| the transport load                                                                  | special combination of loads|
| The slope after the landslide displacement, taking into account the reverse traffic  | 0.825                       |
| pattern when temporary restraining facilities                                        | -                           |
| Slope after the displacement of the landslide, taking into account the full (normative) | 1.159                       |
| transport load and the device of the main holding facilities                          | -                           |
|                                                                                     | 1.356                       |
|                                                                                     | 1.192                       |

3. Development of preliminary measures to stabilize the landslide

To make the constructive decisions, the following initial input data were used. [1]:
- results of visual inspection of the site;
- Google shooting;
- archival data on the topographic slope structure;
- field information on engineering and geological conditions for three exploratory wells made in the upper part of the highway.

Based on the results of the current emergency study, as well as the examples analysis of the traffic restoration after emergencies [9, 11-13], a set of measures was determined (Figure 3):
- Priority:
  - Counter-banquet device at the base of the slope.
  - The device of a gravitational retaining wall made of reinforced concrete blocks for the temporary passage organization according to the reverse traffic pattern.
  - Drain storm water from the landslide source in order to prevent abundant landslide soaking.
  - Pipe laying at the slope bottom to settle the stream channel.
- Monitoring organization at the site.

- Basic:
  - Construction of the landslide anti-landslide structure.
  - Restoration of the landslide destroyed part of the upper retaining wall.
  - The roadway restoration.
  - Performing instrumental observation (monitoring) of the site.
  - Organization of surface water drainage (layout, trays).
  - Regulation of the channel of an anonymous stream in order to prevent slope washing.

1 – soil cutting;
2 – counterberm device;
3 – temporary construction of concrete blocks for the organization of reverse traffic;
4 – main construction on a pile foundation, reinforced with anchors;
5 – landslide contour;
6 – landslide displacement vector;
7 – priority drainage activities;
8 – additional drainage measures;
9 – predictive development of a landslide.

**Figure 3.** The measures scheme on the 56 + 680 km section of the Dzhubga-Sochi highway (Russia)

**Summary**

A section of the federal highway was disabled by a landslide near the Tuapse city (Russia). In an emergency, a number of studies were carried out (visual inspection of the site and adjacent objects, reconnaissance surveys, geological surveys, computer modeling of the slope in modern geotechnical software complexes), the results of which developed a set of anti-landslide measures and stabilized the slope’s condition. Thanks to the comprehensive and timely work of designers and builders, safe traffic on the highway was ensured and the private households adjacent to the site were protected.

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