Special Laboratory Test for Landslides Modelling - The Case of Stože and Lokavec Landslides

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Abstract: - Two severe landslides occurred in November 2000 in Slovenia. They attracted the attention of the entire country and also opened up some new technical questions. Both landslides were initiated by a period of heavy rainfall. The Stože landslide occurred between 15 and 17 November, 2000 close to Mt Mangart in the Julian Alps of western Slovenia. It destroyed about 25 ha of forest as well as a considerable section of the road leading over the Predel Pass. The landslide turned into a debris flow, and reached the village of Log pod Mangartom more than 4 km downstream, where it took seven lives. Approximately 1 million m$^3$ of material was displaced. The Lokavec landslide occurred between 18 and 19 November, 2000, near Ajdovščina. Its area was estimated to have been 20 ha, mostly forest and meadows. The sliding masses were composed of clayey scree and weathered flysch cover. There was only sliding, and the danger of a debris flow. The landslide has not reached the village downstream yet, but threatens it. The paper describes both landslides and their particularities. Special laboratory equipment, a large-scale shear box, has been constructed to test the landslide material. An original testing method is presented.

Key-Words: - landslides, debris flow, shear-box, residual shear strength, water content, rate of displacement

1 Introduction

Landslides threaten approximately one-third of Slovenian territory. The two severe landslides that occurred in November 2000 attracted the attention of the entire country, and also opened up some new technical questions. Both landslides were initiated by a period of heavy rainfall. The Stože landslide occurred between 15 and 17 November, 2000 close to Mt Mangart in the Julian Alps of western Slovenia. It destroyed about 25 ha of forest as well as a considerable section of the road leading over the Predel Pass. The landslide turned into a debris flow, and reached the village of Log pod Mangartom more than 4 km downstream, where it took seven lives. Approximately 1 million m$^3$ of material was displaced. The Lokavec landslide occurred between 18 and 19 November, 2000, near Ajdovščina. Its area was estimated to have been 20 ha, mostly forest and meadows. The sliding masses were composed of clayey scree and weathered flysch cover. There was only sliding, and the danger of a debris flow. The landslide has not reached the village downstream yet, but threatens it. The paper describes both landslides and their particularities. Special laboratory equipment, a large-scale shear box, has been constructed to test the landslide material. An original testing method is presented.

Fig. 1: The village Log pod Mangartom was destroyed by a landslide

2 The Stože landslide

2.1 History of the landslide

Continuous rainy weather affected the western part of Slovenia in autumn 2000. On November 15th, 2000, a mass of moranic material and slope gravel began to move near the Mangartski potok gorge. The area is known as Stože (1340 – 1580 m a.s.l.) and is situated beneath Mount Mangart in the western part of Slovenia. The mass damaged the Mangart local road (Bovec-Predel) and moved down to the Predelica ravine. It dammed up there the
stream known as Mangartski potok at an altitude of 1250 m. The accumulated mass was about 10 m high, and was deposited over a length of 1450 m of the Mangartski potok stream.

As a consequence of the extreme rainfall a second - major slide occurred on the slopes of Mount Mangart in the early morning of November 17th, 2000. The mass reached the water collected behind the first landslide and saturated itself there.

In a few hours it was transformed into a debris flow - a mixture of water and soil. The flow moved along the bed of the Predelica and reached the village of Log pod Mangartom (Fig. 1). The velocity of the flow was estimated to be 8 to 15 m/s [1].

An expert group was established to monitor the slide, study the reasons for its occurrence and propose solutions for its stabilization. Special attention was paid to a range of possible causes of the slide, including the earthquakes and rainfall in the period before the landslide occurrence.

2.2 Some facts about the landslide
- The area of the second failure, the actual debris flow, was estimated to cover about 25 hectares of forest.
- Its width was about 300 m, and it was 1.5 km long and up to 50 m thick.
- Approximately 1,500,000 m$^3$ of material was moved.
- The ground level during the landslide was lowered by up to 40 m in some places, and has been risen up to 20 m in others.
- Two bridges, and several residential and industrial buildings, were destroyed.
- Seven people died.
- About 3,000,000 m$^3$ of unstable material remained in the landslide area, representing a potential danger of landslide reoccurrence.

2.3 Geology
Geological mapping of the landslide site proved the existence of very good geological reasons for the triggering of the landslide (Fig. 2). The mountain ridge west of Mount Mangart is mainly composed of massive Upper Triassic carbonate, which is partly interrupted by clastic rocks and some poorly permeable Carnian Calc stoneware [1]. The base of the landslide forms a block of poorly permeable carbonate-clastic strata situated between blocks of massive and bedded dolomite. Glacial sediments rich with silt were deposited over stepped bedrock and dolomite gravel in the Pleistocene.

The event occurred at an altitude of 1525 m, in glacial sediments - moraine and slope debris, which covered tectonically highly-fractured dolomite overlying impermeable layers of marly limestone [2]. Dolomite is an excellent aquifer, and during heavy precipitation the water level in the rock rises substantially, saturating the overlying soils, rich in clay, with water. The exact water level at the moment of the beginning of the slide is not known. An estimate was made using a back analysis.

2.4 Material properties
Several laboratory and in situ tests were performed in order to obtain the material properties [3, 4]. A preliminary back analysis of the slope failure was performed, with the aim of confirming the results of the laboratory and on-site defined soil properties, see Table 1.

Table 1: The constitutive parameters of the landslide Stože material

<table>
<thead>
<tr>
<th>Soil layer</th>
<th>$\gamma$ [kN/m$^3$]</th>
<th>$\gamma_{sat}$ [kN/m$^3$]</th>
<th>$E$ [MPa]</th>
<th>$\nu$</th>
<th>$c$ [kPa]</th>
<th>$\varphi$ ['']</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moraine$^1$</td>
<td>22</td>
<td>23</td>
<td>50</td>
<td>0.3</td>
<td>20-30</td>
<td>36-38</td>
</tr>
<tr>
<td>Gravel$^2$</td>
<td>22</td>
<td>23</td>
<td>100</td>
<td>0.3</td>
<td>5</td>
<td>42</td>
</tr>
<tr>
<td>Landslide$^3$</td>
<td>19</td>
<td>20</td>
<td>110</td>
<td>0.3</td>
<td>0.5</td>
<td>33</td>
</tr>
<tr>
<td>Bedrock$^4$</td>
<td>25</td>
<td>25</td>
<td>1000</td>
<td>0.3</td>
<td>500</td>
<td>50</td>
</tr>
</tbody>
</table>

1. silty-clay glacial moraine with limestone gravel
2. dolomite gravel with rock inclusions
3. landslide material with fine grained gravel
4. dolomite bedrock

Fig. 2: The Stože landslide

3 The Lokavec landslide

3.1 History of the landslide
The landslide named Slano blato (Salty mud) is situated beneath Mala Gora (1032 m) in western Slovenia. Following continuous rainy weather, the historically recorded landslide Slano blato was triggered on the night of 18 to 19 November, 2000. The same landslide was noticed already 200 years ago, and it was rehabilitated in 1903 by regulation of the nearby torrents and Grajšek stream.
The landslide occupied ravines of two Grajšek affluxes at an altitude of 360 to 660 m (Fig. 3). The mud flow that was created started to move in the direction of the less than 2 km away settlement Lokavec near Ajdovščina. The toe of the landslide moved with a velocity of 50-60 m/day in the first few months. Due to the low velocity and strong precipitation, water began to accumulate behind the main body of the landslide. The sliding masses were therefore completely saturated, and there was a serious danger of a debris flow occurrence [5].

Lower precipitation during the winter, 2000, caused the decrease of sliding velocity and conditions improved. But the risk of a debris flow still remains. Constant accumulation of new masses put the pressure on the barrier in the middle part of vast landslide. The behaviour of sliding masses shows a close link-up to the degree of saturation and any accumulation of water behind the main body of landslide could threaten the safety of settlement under the landslide again.

3.2 Some facts about the landslide
- The landslide area covers around 20 ha of forest and grassland
- Its width is about 60 to 200 m, and it is 1.1 km long
- The ground level has been lowered for 20 to 30 m
- Accumulation of water behind the main body of landslide threatens the debris flow occurrence
- The landslide has not reached the village

3.3 Geology and precipitation characteristics
The basis of the slope where the landslide appeared is flysch rock, covered on the upper brow of the hill with a stratum of limestone and dolomite [5]. Slope debris limestone layer downhill is more than 30 m thick. The crown of the landslide is situated on marshy land. Due to the water accumulated there and heavy rainfall, the material saturated. The increasing of water content caused the decreasing of the shear strength characteristics of the flysch rock. Masses composed from clayed scree and weathered flysch cover started to slide therefore.

3.4 Material properties
Results of some laboratory tests are shown in Table 2. Samples of material from the head of the landslide and the other from the main body of the landslide were tested [5].

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\gamma$ [kN/m$^3$]</th>
<th>$\gamma_i$ [kN/m$^3$]</th>
<th>$I_p$ [%]</th>
<th>$I_c$ [%]</th>
<th>c [kPa]</th>
<th>$\phi$ [$^\circ$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>19.5</td>
<td>15.4</td>
<td>25.1</td>
<td>0.723</td>
<td>14.4</td>
<td>19.9</td>
</tr>
<tr>
<td>Main body</td>
<td>18.5</td>
<td>13.8</td>
<td>25.3</td>
<td>0.616</td>
<td>5.1</td>
<td>30.2</td>
</tr>
</tbody>
</table>

4 The large-scale shear cell testing method

4.1 Reasons for its use
The expert group in the case of Stože landslide assumed [3, 6] that the moraine, silt and clay fines, with grain sizes smaller than 4 mm, in the sliding material could lead to the general behaviour of the landslide. It was necessary to prove that. On the other side, it was a need to control the effective shear strength of the material and its dependence upon the velocity of sliding that was not possible to ensure with a simple (small) shear box test. Therefore a large-scale shear box apparatus, has been constructed to test the landslide material including grain sizes up to 45 mm. This size shear box also gives the possibility to measure the pore water pressure. It incorporates a special hydraulic loading system, which controls the rate of displacement.

4.2 Apparatus
The large-scale shear box apparatus consists essentially of components similar to those of the standard (small) shear box except that they are on a larger scale. It comprises a drive unit with a loading piston, shear box assembly and as a difference to the standard shear box, the pore pressure transducer.
facility is included.

A split box with inner dimension 630 mm × 630 mm is used. A lower fixed part of the box is 230 mm high. It is filled during the test to 140 mm high with a saturated porous material through which the draining is enabled. A specimen with a height of 180 to 205 mm is positioned above this layer. The specimen is impermeable covered at the top to prevent the draining in the vertical direction and is supposed to be subjected to shear under a certain vertical load applied by a hydraulic piston. Two valves in the bottom part of a shear box are used to determine whether the drainage, i.e. the change of water content, is permitted during the test.

The shear load is applied by a hydraulic piston capacity of 160 kN and capable of applying displacements amplitude ± 125 mm. Another hydraulic piston, which can provide up to 200 kN presents the normal loading system.

The upper and bottom parts of a box are fixed together in longitudinal direction with special waterproof elements covered with Teflon on sliding plate. Sliding plates are waterproofed in transversal direction by rubber washer combined with impermeable fat.

Four pore pressure transducers build into the specimen measure the pore water pressure in the specimen during the test. Two of them are built above the surface of sliding and two of them are built under it.

The friction between both two parts of a box is measured before the test at different strain rates. The results of the shear test are corrected by its value.

4.3 Testing procedure

Materials from the Stože and Lokavec landslide sites were used in the tests. Reconstituted samples were used, all prepared by means of wet temping with the objective of achieving the certain moisture and densities.

Samples were prepared at moisture content: 11-12% and 15-16% (Stože) and 28, 40 and 50% (Lokavec). They were subjected to constant normal stresses 10, 50 and 100 kPa (Stože) and 50, 100 and 150 kPa (Lokavec). Tests were performed at different strain rates 1, 2, 4, 6 and 8 mm/min, respectively.
4.4 Results

Results indicate the big differences in two tested materials. Stože landslide present glacial moraine, silt and clay fines mixed with gravel, and on the other side Lokavec landslide material is more uniform, and consist out of clayed scree and weathered flysch.

Following graphs in Fig. 8 – Fig. 12 shows the different shear strength dependence upon the rate of displacement and the moisture content.

As expected, in the case of Lokavec, the shear strength of tested material decreases as the moisture content increases. Probably due to the different moisture content, this effect is not so clear in the case of Stože. It is evident that the shear strength increases with an increase in normal stress. Drained conditions during the test cause the increase of shear strength. This increase is special significant in the case of Stože and is smaller in the case of Lokavec. Figures 7-10 compare drained and undrained conditions. Different behaviour of tested materials can be noticed from comparing the influence of rate of displacement upon shear strength. The shear strength decreases with an increase in rate of displacement in the case of Lokavec (Fig. 7 and Fig. 8) and increases in the case of Stože (Fig. 9 and Fig. 10).

The variation of shear strength with normal stresses at certain moisture content and rate of displacement is shown on Fig. 11. The apparatus enables to determine the total and effective stresses.

Fig. 12 presents the shear strength as a function of normal stress and moisture content. The shear strength still varies according to the normal stress, but at certain value of the moisture content the normal stress seems not to be important anymore.
Fig. 11: Effective and total shear strength characteristics, Lokavec landslide, w = 28 %, strain rate 6 mm/min.

Fig. 12: Variation of shear strength of Lokavec landslide material with moisture content at different normal stresses (undrained shear test)

5 Conclusions

Special laboratory equipment, large-scale shear box apparatus, has been constructed to test the material from Stože and Lokavec landslide. It enables to test material including grain sizes up to 40 mm. This size shear box also gives the possibility to measure the pore water pressure. It incorporates a special hydraulic loading system, which controls the displacement rate.

Two very different materials were tested and results point to some not expected properties of them. The shear strength of the material seems to decrease as the moisture content increases and is not affected by normal stress when the moisture content achieves a certain level. Also the influence of a rate of displacement has been noticed, but it differentiates in case of both materials.

The large-scale shear box enables more detailed testing of soils. Its main advantages are testing of soil with bigger grain sizes, displacement control and measuring of pore water pressure during the test.

References: