PARTICULARITIES OF STOŽE AND LOKAVEC LANDSLIDES - SPECIAL LABORATORY TESTS FOR LANDSLIDES MODELING

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Abstract: - Rainfall, earthquakes and human activities are the most relevant factors, which cause triggering of large landslides in mountain regions. Two severe landslides occurred in November 2000 in Slovenia. They attracted the attention of the entire country and also opened 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 to 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 Slano blato landslide appeared between 18 and 19 November, 2000 near Ajdovščina. Its area was estimated to 20 ha, mostly forest and meadow. Sliding masses were composed from clayey gravel and weathered flysch cover. It was classified as an earth flow. The landslide has not reached the village downstream yet, but it threats it.

The paper describes both landslides and their particularities. Special laboratory equipment, large scale shear-box, has been constructed to test the landslide material. From the test results it was observed the landslides were of different type and behavior. Results from both landslide materials were quite different, especially in the shear properties.

Key-Words: - landslides, debris flow, shear-box, shear strength

1 Introduction

Landslides threaten approximately one-third of Slovenian territory. Two severe landslides that occurred in November 2000 attracted the attention of the entire country and also open up some new technical questions.

Rainfall, earthquakes and human activities are the most relevant factors, which cause triggering of large landslides in mountain regions. When there are inhabited areas in the vicinity of a landslide, it can be very important to estimate the level of hazard and risk.

According to the climate scenarios the global temperature will increase which will larger the risk of erosion and landslides (Y.A. Skold, 2008, Hong-Kal, 2007).

Sudden movements of soils and rocks under the influence of gravity seem mostly to be induced by rainfall or some other cause of ground water level change. Both landslides that are described in the paper, occurred in seismically very active area.

In 1998, the strongest earthquake to have occurred over the last 100 years in the Upper Soča River Valley (ML 5.7) took place (Vidrih, 2001), with its epicentral area near Bovec (Fig.1). The Soča River valley is situated near the Slovenian-Italian border.

Fig.1. Locations of two landslides

The area of NW Slovenia is one of the most seismically active parts in the country. Earthquakes can reach intensities higher than IX on the MCS scale (Ribarič, 1980, 1987), whereas the maximum observed historical event was estimated to have a magnitude of MLH = 6.8 (Lapajne et.al., 1997)

The Stože landslide, which was located about 10 km from the epicentral area, triggered in the year 2000. At a distance of 50 km from the epicentral area, the Slano blato landslide triggered in the same year. The Stože and Strug landslides were associated with debris flow events (Mikoš et al, 2006), and the Slano blato landslide with an earth flow. The whole region has a high risk of landslides (Komac, 2006, Zorn, 2009).

In the year 2000 precipitation was more intense than had been recorded over the previous 10 years. Intense precipitation of long duration always causes changes to the surface of the landslide.

The triggering of landslides due to intense rainfall is well known in the Alpine regions of Italy, (Crosta, 2003), Switzerland, Austria (Moser, 2002) and in mountains in France (Nsom, 2008). Rainfall does not directly trigger failure, but it increases pore pressures by changing the hydraulic, physical and mechanical properties of the soil and the vegetation cover (Matziaris at. all, 2005). Unfavourable combinations of these features can trigger slope failure (Aleotti, 2004).

There were no direct sign of an earthquake in moments of landslides beginnings, but several small ground movements could be the cause of cracks appearance in the base of the landslide. Combined with intensive rainfall, cracks could be a satisfactory condition for ground saturation.

The landslide material, specially in the case of Stože landslide, consist of fines and also gravel which grain sizes make impossible to test it in the simple shear cell. Therefore special laboratory equipment, large-scale shear-box, has been constructed to test the landslide material. A testing method is presented. The results indicate the roles of the water content and rate of displacement on residual shear strength of material.

2 The Stože landslide

2.1 History of landsliding

Continuously rainy weather affected western part of Slovenia in autumn 2000. On November 15th, 2000, a mass of moraine and slope gravel began to move near the Mangartski potok stream. The area is known as Stože (1340 – 1580 m a.s.l.) and is situated under Mount Mangart in the western part of Slovenia. The slipped masses of an estimated 1 million m^3 changed into the dry debris flow and damaged the Mangart local road (Bovec-Predel). It was travelling very fast (concluded from fallen trees and large rocks) and stopped at the bridge near Mlinč on the regional road at 1120 m a.s.l. Only very fine fractions flowed on to the confluence the Predica torrent. The accumulation was about 10 m high, locally even 50 m. Due to the high void ratio of the debris masses, its permeability was rather high. According to reports of the first people who were reaching the area, the water stopped to flow in the Mangart creek for some hours. Water was probably partially infiltrated into the deposited masses.

Just after the midnight on November 17, 2002, the deposited masses of the first debris flow started to flow towards the village of Log pod Mangartom (Fig. 2). More than 1 million m3 of wet material traveled as a wet debris flow through a channel of the Predica torrent for 4 km and reached the village of Log pod Mangartom. (Oštir et al 2001) The velocity of the flow was estimated to be 8 to 15 m/s. Landslide moved downstream to the Koritnica river valley, stopping after 7 km from its origin.

The debris flow in a few minutes killed seven people, destroyed 6 and severely damaged 23 residential or farm buildings.

Fig. 2. Debris flow from Stože landslide when reached the village Log pod Mangartom

The expert group (KMT, 2001) was established to monitor the slide, study the reasons for its occurrence and propose solutions for its stabilization. A special attention was paid to a range of possible causes of the slide, including the earthquakes and rainfall in the period before the landslide occurred.

2.2 Some facts about the landslide

- The area of the second failure, the actual debris flow, was estimated to 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 m3 of material has been moved (Fig.3)
- The ground level during the landslide has been lowered up to 40 m in some places, and has been risen up to 20 m in other
- Two bridges, several residential and industrial buildings were destroyed
- Seven people died
- There stayed about 3,000,000 m3 of unstable material in the landslide area, representing a potential danger of landslide recurrence

2.3 Geology

The geological situation was further investigated using filed geophysical methods such as ground seismometry, ground radar with several structural boreholes in the landslide area.

Geological mapping of the landslide site proved the existence of very good geological reasons for the triggering of the landslide (Fig.4). The mountain ridge west of Mount Mangart is mainly composed of massive Upper Triassic rock consists of three lithostratigraphic units: Cordevol dolomite in the lower part, Julian - Tuvalian calcareous marlstone and in the upper part the main dolomite. The middle lithological layer is very heterogeneous with olive gray limestone, layers of marlstone and claystone. The Stože slope inclined from 20 to 30 in the NS direction.

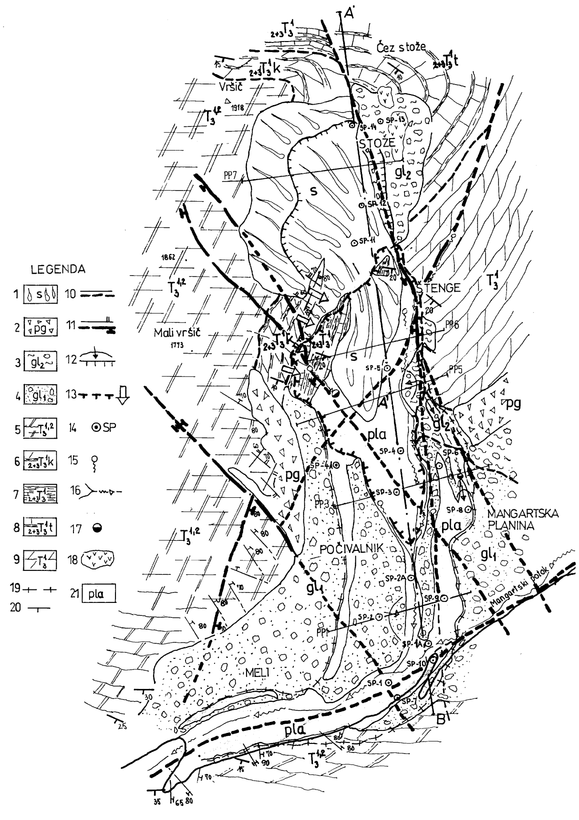
With the site investigation three main strong faults were determined in the region of landslide one of them through the valley of Mangart stream.

Strong faults with the strike NW-SE and NE-SW, tectonized intermidiate material into much fissured rock. Water flows through fissured dolomite to the lower quaternary sediments, with much lover permeability.

Glacial sediments – moraine rich with silt were deposited over stepped bedrock and dolomite gravel in the Pleistocene. The depth of moraine material was approximately 25 m, which triggered on the high of 1400-1600 a.s.l. In the upper part of te landslide, the landslide plane was in the upper trias limestone and in the lower part in very dense moraine material.

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. There has been generally no significant deep land movement observed since the event in November 2000.

Fig. 3. The upper part of the Stože landslide



1. rockfall, 2. slope gravel, 3. moraine with clay, 4. moraine with 5. dolomite, 6. Julian – Tuvalian calcareous marl 7. Julian- Tuvalian dolomite limestone and marlstone 8. Julian – Tuvalian dolomite and limestone 9. cordevol dolomite, 10. geological border, 11. fault, 12. labile zone, 13 border of the landlisde 14. borehole, 15. spring, 16. stream, 17. sink, 18. swamp, 19. debris flow border, 20. dip of the layer, 21. landslide remains

Fig. 4 Geological map of the Stože landslide (Špacapan and Petrica, 2002)

2.3 Material properties

Several laboratory and in situ tests were performed in order to obtain the material properties (Geoinženiring 2001, GEOT 2001). 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 landslide Stože material constitutive parameters

Soil layer	γ [kN/m^3]	γ_{sat} [kN/m^3]	E [MPa]	ν	c [kPa]	φ [°]
Moraine[1]	22	23	50	0.3	20-30	36-38
Gravel[2]	22	23	100	0.3	5	42
Landslide[3]	19	20	110	0.3	0.5	33
Bedrock[4]	25	25	1000	0.3	500	50

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

3 The Slano blato landslide

3.1 History of landsliding

The Slano blato landslide is situated in the west of Slovenia (Fig. 1), above the village of Lokavec (Fig. 5), on the border between the Alps and the Mediterranean region. It has a relatively long history and was first documented in 1887.

Fig. 5 The Slano blato landslide

At that time it destroyed part of a main road, after which reconstruction works took 17 years to complete. A series of retention dams and drainage systems were built on the Grajšček stream, which springs at the upper part of the landslide (Fig 6). Unfortunately, in the area of landslide the old drainage system had not been maintained for a long time.

Fig.6 The upper part of the Slano blato landslide

Over the last decade movement of the landslide was reactivated in November 2000. In first days the estimated velocity of the displaced material was 60-100 m/day. In the worst scenario, at least 30 houses the nearby village of Lokavec were in danger. The Slano blato landslide was reactivated as an earth flow by a combination of several events.

Due to low velocity and strong precipitation the water began to accumulate behind the main body of the landslide. Therefore sliding masses completely saturated and there was a serious danger of earth flow occurrence.

Lower precipitation during the winter, 2000, caused the decrease of sliding velocity and conditions improved. But the risk of an earth flow still re-mains. Constant accumulation of new masses put the pressure on the barrier in the middle part of vast landslide. The behavior of sliding masses shows a close link-up to the degree of saturation and any accumulation of water behind the main body of land-slide 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 grass-land
- 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

The Slano blato landslide is located beneath the hill Mala gora. The crown is at 640 m, and the toe is at 270 m a.s.l. The length of the zone of depletion is 1300 m, and the width is 70 - 250 m. A zone of accumulation extends almost to the village Lokavec.

The main scarp is at an angle of 30°, and the rest of the landslide is at angle of between 13° - 16°. The Grajšček stream flows through the middle of the landslide and springs from the main and several minor scarps. Its flow depends strongly on precipitation.

The Slano Blato landslide is situated at the contact between Triassic limestone and Eocene flysch formations. The Eocene flysch consists of marl and layers of sandstone with a thickness of several centimetres or several metres. The rock is highly tectonically deformed.

The limestone was overthrusted onto the flysch over a very large distance along the Trnovski overthrust. As a consequence the region consists of large synclines and anticlines. The upper part of the limestone, which is fissured into blocks with dimensions of several cubic metres, is at 670 m a.s.l. Throughout the landslide several faults with dips of 55-75° to the N were observed.

Water has been observed in boreholes at several depths, almost always in the fissured layers of sandstone. The dip direction of these layers is NW which is favourable for slope stability.

The zone of depletion finishes with a several metres thick layer of sandstone that forms the Grajšček waterfall. During heavy rainfall, the Grajšček stream flows over the sandstone to form a waterfall.

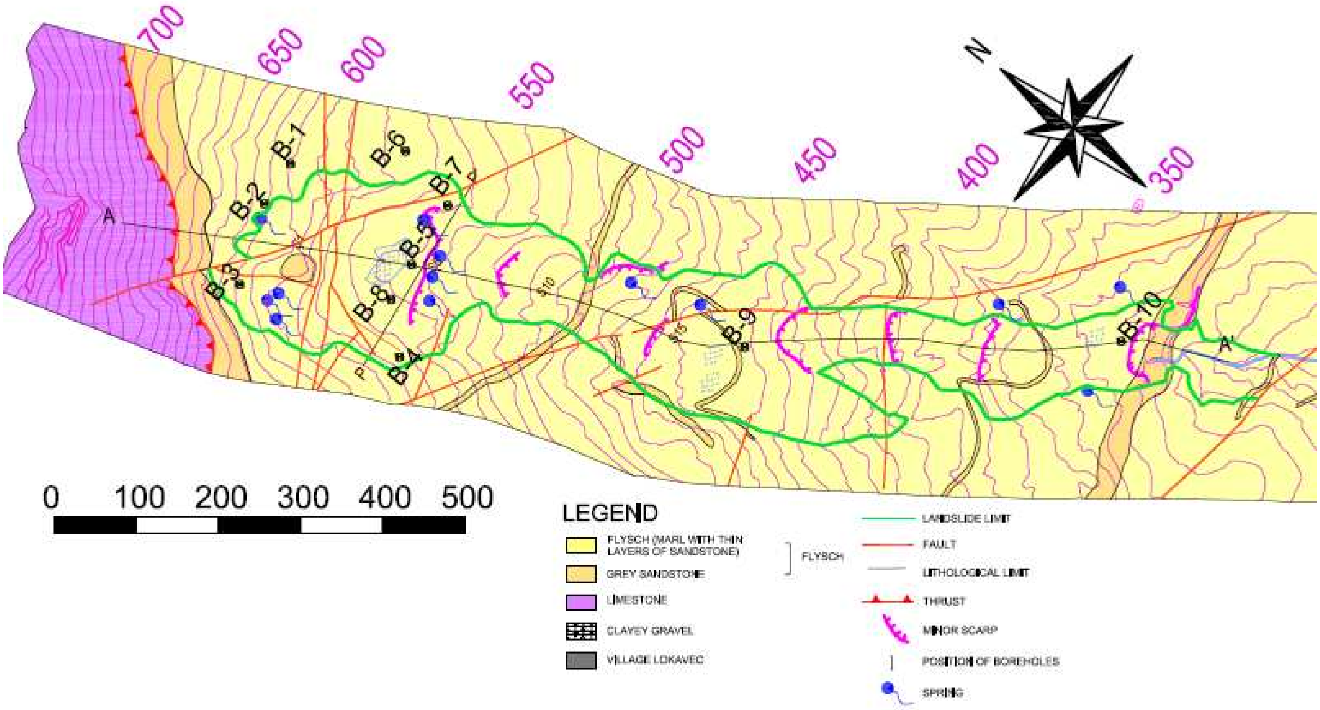


Fig. 7 Geology of the Slano blato landslide

The flysch is covered by clayey gravel, which forms a displaced material. It consists of blocks of limestone, sandstone and clayey silty gravel. The structure of the displaced material does not change a lot down the slope. The thickness of the gravel is 3 to 10 m, as ascertained by borehole logging and geo-physical investigations. The landslide was investigated with one longitudinal profile and several trans-verse geophysical profiles using a seismic refraction method (Stopar, 2003).

Blocks of limestone were found at the village of Lokavec, which is almost 3 km from the landslide. It was estimated that they belong to the displaced material from the first triggering in 1887.

3.4 Material properties

Several laboratory and in situ tests were performed in order to obtain the material properties (Geoinženiring 2001, ZAG, 2004). A preliminary back analysis with different constitutive models was performed, with the aim of confirming the results of the laboratory and on-site defined soil properties, see Table 2.

Table 2: Material characteristics

Sample	γ [kN/m^3]	γ_d [kN/m^3]	I_p	I_c	c [kPa]	φ [°]
Head[1]	19.5	15.4	25.1	0.723	14.4	19.9
Main body	18.5	13.8	25.3	0.616	5.1	30.2

[1] the average of samples

4 The large-scale shear cell testing method

4.1 Material properties

The expert group in the case of Stože landslide assumed (KMT, 2001) 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, has been constructed to test the landslide material including grain sizes up to 45 mm (Fig 8). 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 The apparatus

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

A split box with inner dimension 630 mm x 630 mm is used (Fig. 9). 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.

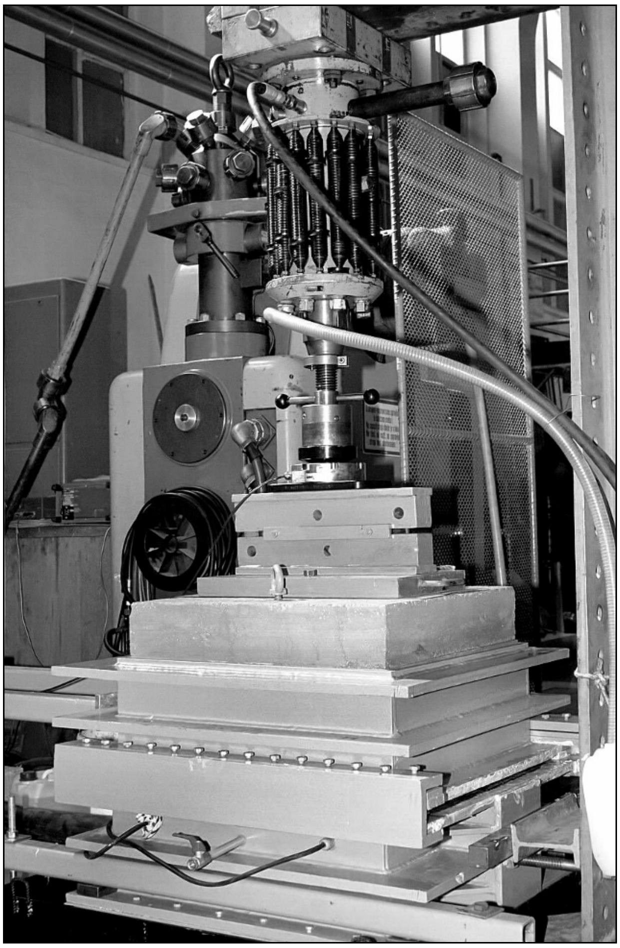
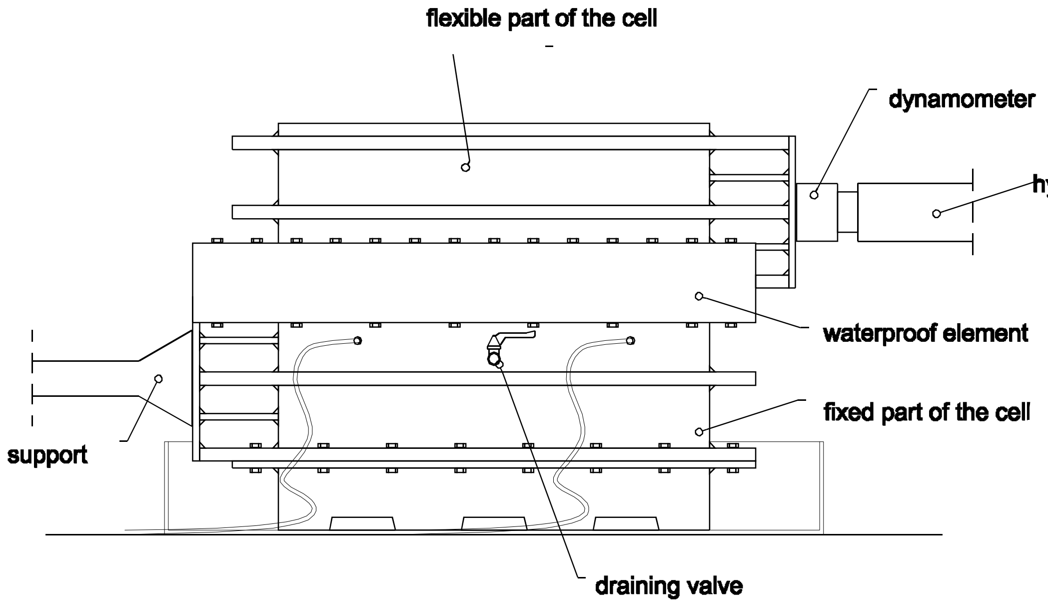


Fig. 8: The large-scale shear cell during the test

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.



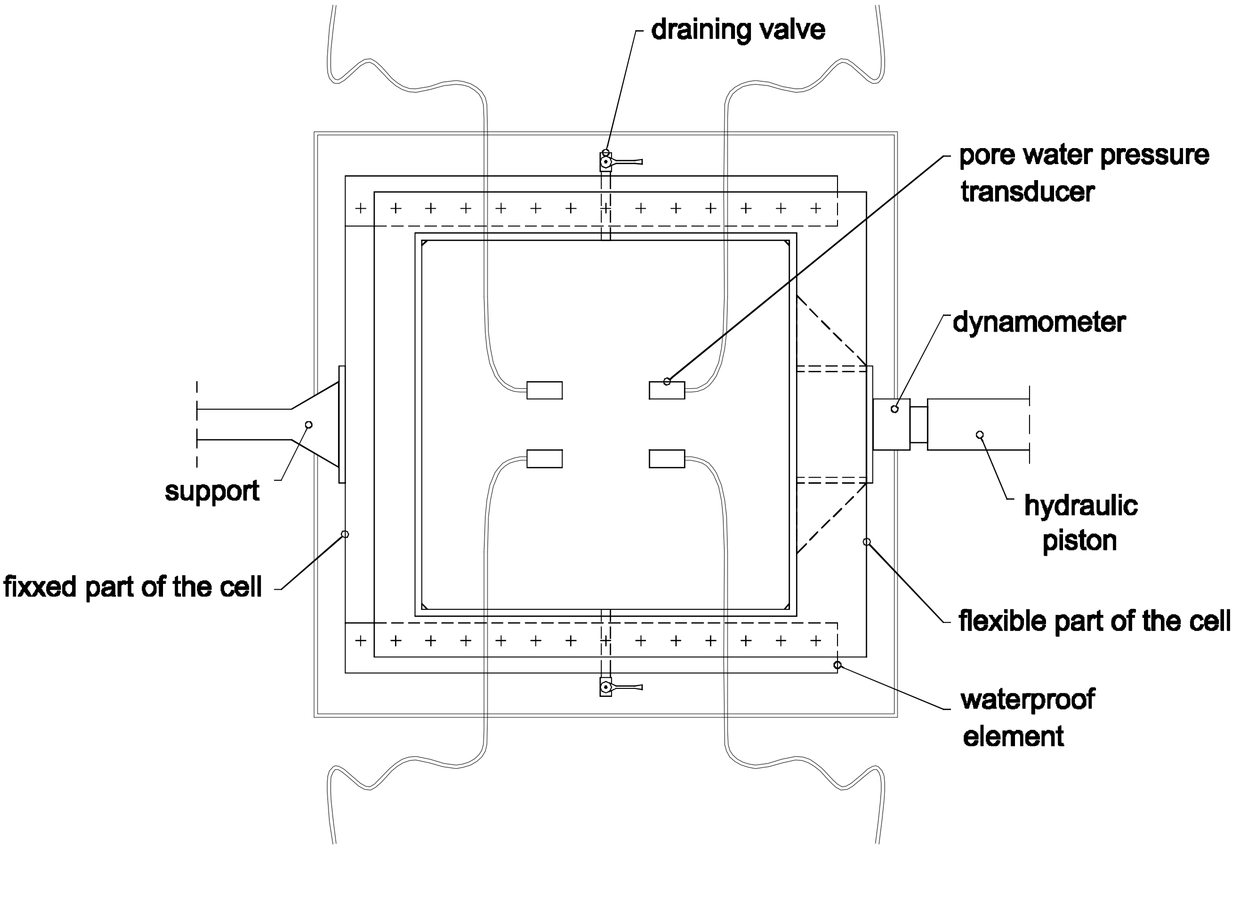


Fig. 9: Arrangement of a large-scale shear cell (plan view)

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 landslide and 28, 40 and 50 % (Slano blato landslide). They were subjected to constant normal stresses 10, 50 and 100 kPa (Stože) and 50, 100 and 150 kPa (Slano blato). 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 Slano blato landslide material is more uniform, and consist out of clayed gravel and weathered flysch.

Following graphs in Fig. 10 – 15 shows the different shear strength dependence upon the rate of displacement and the moisture content.

As expected, in the case of Slano blato, 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 landslide. 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 especially significant in the case of Stože landslide and is smaller in the case of Slano blato landslide. Figures 10-15 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 Slano blato landslide (Fig. 10-11) and increases in the case of Stože (Fig. 12-13).

The variation of shear strength with normal stresses at certain moisture content and rate of displacement is shown on Fig. 14. The apparatus enable to determine the total and effective stresses.

Figure 15 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.

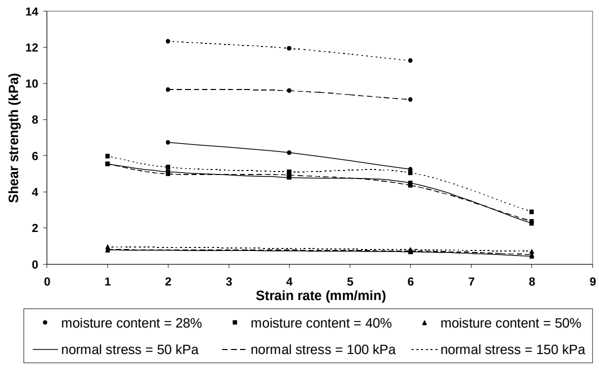


Fig. 10. Variation of residual shear strength of Slano blato landslide material with strain rate at different moisture content and normal stress (undrained shear test)

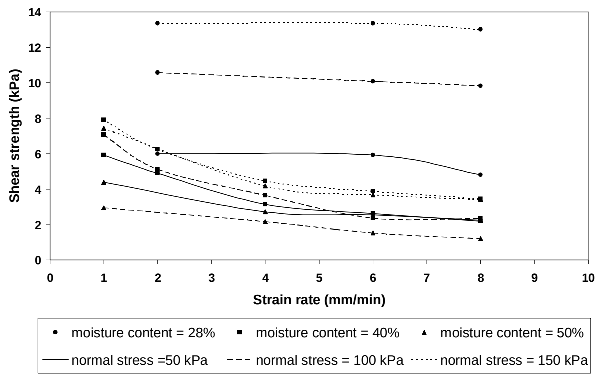


Fig. 11. Variation of residual shear strength of Slano blato landslide material with strain rate at different moisture content and normal stress (drained shear test)

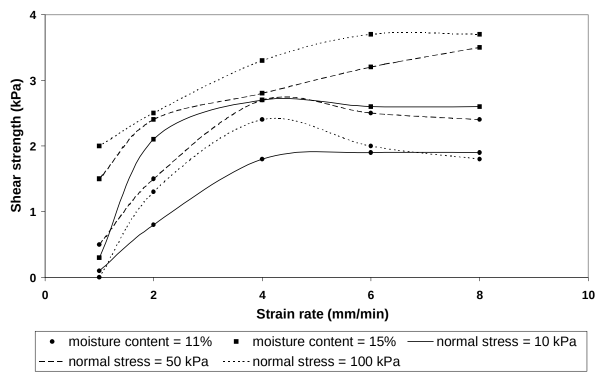


Fig. 12. Variation of residual shear strength of Stože landslide material with strain rate at different moisture content and normal stress (undrained shear test)

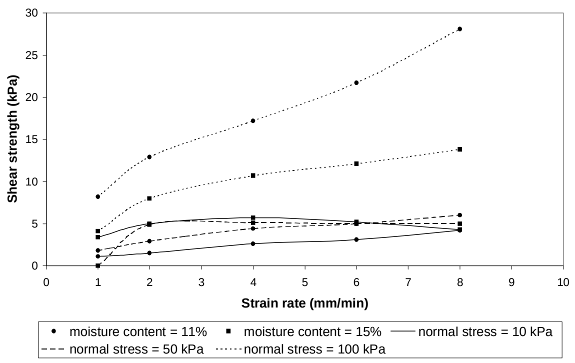


Fig. 13. Variation of residual shear strength of Stože landslide material with strain rate at different moisture content and normal stress (drained shear test)

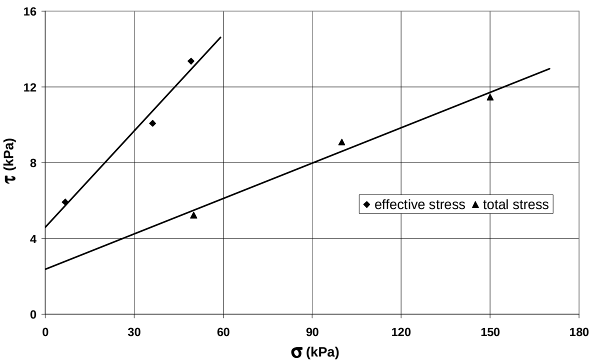


Fig. 14. The influence of normal stress upon residual shear strength, Slano blato landslide, w = 28 %, strain rate 6 mm/min.

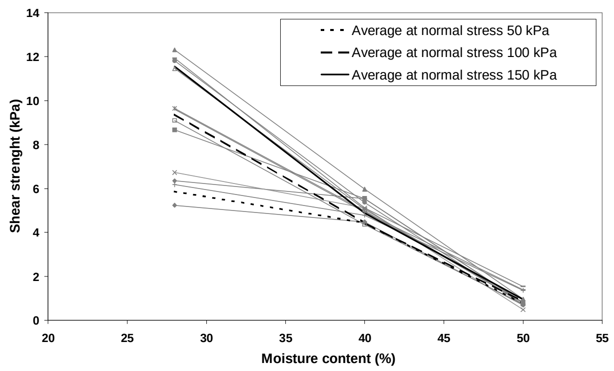


Fig. 15. Variation of residual shear strenght of Slano blato landslide material with strain rate at different moisture content and normal stress (drained shear test)

5 Conclusion

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 increase 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.

It is evident from laboratory tests that analyzed landslides were of two different types: first one was a debris flow and a second one was an earth flow. Results of laboratory tests show different types of behavior of landslide materials and thus prove different landslide types. Similarly, differences were observed on the field test measurements as well.

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