Mechanisms of Landslides and Creep in Over-Consolidated Clays and Flysch (WCoE 2014–2017)

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Abstract

The Faculty of Civil and Geodetic Engineering of the University of Ljubljana (UL FGG), Slovenia, Europe, was voted in 2014 at the 3rd World Landslide Forum in Beijing, China to be one of the 15 new World Centres of Excellence (WCoE) in Landslide Disaster Reduction for the period 2014–2017. This successful nomination followed the period 2011–2014, in which UL FGG successfully fulfilled the role as one of the WCoEs for the second time. The title of the activities of the WCoE in this third term was slightly modified to be “Mechanisms of Landslides and Creep in Over-Consolidated Clays and Flysch”. We can divide the activities of the WCoE at UL FGG into international and national research activities. The international ones consisted of the ICL related activities with the main task of being the main organizer of this 4th World Landslide Forum 2017, international cooperation, European research activities, and bilateral cooperation. The national ones consisted of the national projects and the national research program “Water Science and Technology, and Geotechnics”. In the paper, these activities of the WCoE at UL FGG are elaborated in more detail, with a comprehensive list of publications to show the dissemination and capacity building efforts.

Keywords

Creep • Debris flows • Flysch • Laboratory tests • Landslides • Slovenia • Suction • WCoE

Introduction

The Faculty of Civil and Geodetic Engineering of the University of Ljubljana (UL FGG), Slovenia, Europe, was elected at the 3rd World Landslide Forum in Beijing, China to be one of the 15 new World Centres of Excellence (WCoE) in Landslide Disaster Reduction for the period 2014

to 2017. The title of the activities of the WCoE at UL FGG was slightly changed from the WCoE 2011–2014 to a new title “Mechanisms of landslides and creep in over-consolidated clays and flysch”.

In this paper we present the WCoE research activities in the domain of international and national activities, respectively.

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International Research Activities

ICL-Related Activities

Among the ICL/IPL related activities of the WCoE at UL FGG we can name:

- Cooperation in the ICL regional “Adriatic-Balkan Network”, where we actively supported the 2nd Regional Symposium on Landslides in the Adriatic-Balkan Region (2nd ReSyLAB; <http://resylab2015.rgf.rs/>) in May 2015 in Belgrade, Serbia, and
- Cooperation in the ICL thematic network “Landslide Monitoring and Warning Thematic Network—LaMa-WaTheN”, in which we were one of the initiators of this network (Maček et al. 2014).
- We intend to co-host, together with the Geological Survey of Slovenia, the 3rd Regional Symposium on Landslides in the Adriatic-Balkan Region (3rd ReSy-LAB) in September/October 2017 in Ljubljana, Slovenia. The initial idea to hold this symposium as a WLF4 side event was abandoned in favor of a separate event with post-conference proceedings.
- We support the ICL activities also by serving in ICL/IPL working bodies, i.e. as the elected ICL Vice President (Mikoš 2015–2017), and chairing the IPL Evaluation Committee: (<http://icl.iplhq.org/category/icl/structure-and-officers/>).
- Our different experiences in the field of landslide disaster risk reduction have been submitted as text teaching tools (TXT-Tools 2017a, b, c) to a new Springer reference work entitled “Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools”.
- The main ICL-related activities were dedicated to the preparation of the 4th World Landslide Forum in 2017 in Ljubljana (www.wlf4.org), for which the University of Ljubljana (jointly Faculty of Civil and Geodetic Engineering and Faculty of Natural Sciences and Technology) is the major organizer in Slovenia (Forum Chair), together with the Geological Survey of Slovenia. At UL FGG we have prepared a 3-day WLF4 Post-Forum Technical (Study) Tour to Slovenia entitled “Living with slope mass movements in Slovenia and its surroundings”. We have been personally involved in the preparation of the WLF4 Landslide Photo Contest entitled “Landslides and Mankind”, collecting photographs in three categories, and in the WLF4 Student Award Contest. Together with the Ministry of the Environment and Spatial Planning, we are working on organizing an one-day national workshop as a side event to WLF4 on Wednesday, May 31, 2017.
- We have represented ICL at the General Assembly of IUGG in Prague in June 2015.

International Research Cooperation

We have been actively involved into the 3rd WCDRR in Sendai in March 2015, and have disseminated its results to stakeholders (Mikoš 2015a, c, 2016).

In 2016, we succeeded in establishing a UNESCO Chair on Water-Related Disaster Risk Reduction at the University of Ljubljana (www.unesco-floods.eu). Among the supporting partners were the International Consortium on Landslides (ICL) and one of its members, Niigata University, Japan. The next step is already envisaged, i.e., the establishment of a UNESCO Category 2 Center at the University of Ljubljana.

Rainfall-induced landslides and debris flows in mountainous and hilly areas are seen as parts of sediment-related disasters, i.e., closely associated if not covered by the water-related disasters.

European Research Activities

In 2014, we collaborated in the framework of the European Alpine Space project START_it_up “State-of-the-Art in Risk Management Technology: Implementation and Trial for Usability in Engineering Practice and Policy” (ended in December 2014; project leader S. Rusjan).

As a part of the project deliverables, we have prepared an overview of legislation in Slovenia in the field of landslide hazard and risk assessment (Mikoš et al. 2014).

Using as a theoretical base of how monitoring is connected to perception of natural hazards and to hazard warnings (Fig. 1), and practical experiences gained in installing debris-flow monitoring sites in the Alps (see Fig. 2 for an example), an overview of available debris-flow monitoring techniques has been prepared (Hübl and Mikoš 2014).

Bilateral Research Cooperation

In years 2014 and 2015, we collaborated with the University of Rijeka, Croatia (member of the Croatian Landslide Group, also an ICL member), on a bilateral research project SoLi-FlyD “Study of landslides in flysch deposits: sliding mechanisms and geotechnical properties for landslide modeling and landslide mitigation” (Project leader M. Mikoš). Using staff exchange (early stage researchers) and via short visits (see Fig. 3), we compared geotechnical (Maček et al. 2015) and geological aspects (Peternel et al. 2015) of landslides in flysch in Slovenia and the Croatian Istrian Peninsula.

The project goals were to collect, unify and exchange data and knowledge in the field of landslide investigation in

Fig. 1 From perception via monitoring to warning against natural hazards (from Hübl and Mikoš 2014)

Fig. 2 A conceptual scheme of the debris-flow monitoring site at Lattenbach, Austria, showing sensors, communication, and energy supply (from Hübl and Mikoš 2014)

flysch deposits in Slovenia and Croatia. The study area in Slovenia ($\sim 1050 \text{ km}^2$ i.e. $\sim 5\%$ of Slovenia) covers a territory of clastic rocks that includes flysch deposits (Fig. 4).

Fig. 3 A group of Slovenian and Croatian researchers visiting landslides in flysch in the Istrian Peninsula in Croatia (Photo: Tina Peternel, September 25, 2014)

Fig. 4 The study area in Slovenia with the locations of landslides (according to Slovenian National landslide database—Status on August 2014) shown on the Geological map of Slovenia: 1 Alluvium; 2 Eocene Flysch deposits (adopted from basic geological map of SFRJ sheets: Gorica, Postojna, Trst, Ilirska Bistrica)

The study area in Croatia (approximately 550 km^2) lies in the Grey Istria (Fig. 5).

From a geological point of view, the common characteristic of large landslides in flysch deposits in Slovenia and Croatia is that they are mainly formed on the contact of carbonate rocks and flysch deposits. Typical landslides include the Slano Blato, Stogovce and Grohovo landslides.

In each case the Mesozoic carbonate rocks (mainly limestone) are over-thrust on the Eocene flysch deposits. The consequence of active tectonics is that the flysch deposits are folded and ruptured and consequently very prone to fast weathering to depth (Logar et al. 2005; Petkovšek et al. 2011; Benac et al. 2014). Furthermore, the carbonate rocks are also prone to weathering, and as a result the flysch slopes are covered with a large amount of talus material and slope sediments that are very prone to slope instability (Petkovšek et al. 2011; Benac et al. 2014).

The second common characteristic of landslides in flysch deposits in Slovenia and Croatia is the complexity of the sliding phenomena, which is connected with the softening of clay-bearing rock layers and that is mostly activated or reactivated by extreme weather events (Petkovšek et al. 2011). In the last decades a large number of landslides have

Fig. 5 The study area in the Grey Istria with the locations of landslides shown on the simplified Geological map of Istria: 1 Paleogene flysch, 2 Alluvium, 3 Cretaceous Limestone, 4 Jurassic Limestone (after Velić et al. 1995)

occurred in Slovenia and Croatia in flysch deposits, mostly triggered by prolonged rainfall or short intensive rainfall events.

In Slovenia several landslides in flysch deposits are also related to earthquakes, which are quite a common phenomenon (Logar et al. 2005; Petkovšek et al. 2011).

For rainfall-induced landslides, there is a difference between shallow landslides, which are generally triggered by short duration and intense rainfall, and deep-seated (and often also large scale) landslides, mainly triggered during or after prolonged rainfall. This was confirmed by a study of rainfall-triggered landslides in Slovenia in the last 25 years (Bezák et al. 2015a, b), which included both landslides in flysch and in other geological strata.

The results shown in Fig. 6 indicate that when using empirical rainfall-threshold curves as part of an Early Warning System in Slovenia, different empirical curves

(Caine 1980; Clarizia et al. 1996; Aleotti 2004; Guzzetti et al. 2008) should be applied using a rainfall measuring network with an appropriate high density. This step was recently partially carried out by dividing Slovenia into four regional units, and by using rainfall data from 41 pluviometers (Rosi et al. 2016). Both studies confirmed that No Rain Gap (Rosi et al. 2016), respectively Inter-Event Time (Bezák et al. 2015a), as a parameter indicating the number of consecutive hours without rain, has a large impact on rainfall intensity and rainfall duration values.

This bilateral research project was evaluated as successful, since a new bilateral research project between Slovenia and Croatia was confirmed for the period 2016–2017, entitled “Laboratory investigations and numerical modelling of landslides in flysch deposits in Croatia and Slovenia” (Project leader M. Maček). With the Croatian side we will exchange knowledge and will cooperate in the field of

Fig. 6 Evaluation of a few empirical rainfall-threshold curves for selected landslides (shallow and deep-seated landslides and debris flows), which occurred in Slovenia in the last 25 years (from Bezak et al. 2015a)

laboratory research on rheology parameters of potential debris flows as a part of a debris flow hazard assessment on torrential fans.

National Research Projects

In 2014, we finished a national research project on the protection efficiency of beech-dominated forests against

debris-flow hazards in a narrow Alpine valley in NW Slovenia of the Sava Bohinjka River gorge called Soteska, with the main state road and railway (Project leader M. Mikoš). The study area was a part of the Soteska gorge, where we assessed the starting points of potential debris flows based on a small-scale field geological survey that produced a geological map of the study area in the scale 1:5000 (produced by the Geological Survey of Slovenia—GSS). General lithological and structural geological data

Fig. 7 The debris-flow susceptibility map of the study area in the Sava Bohinjka River gorge called Soteska

were taken into account in the creation of the geological map, with special emphasis on the identification of unconsolidated sediments such as scree deposits that can be involved in mass movement processes.

The debris flow susceptibility map (Fig. 7) was created using methods that the GSS developed for different spatial resolutions and different types of mass movements (e.g., landslides, mass-flows, rock falls). The methodology consists of four consecutive phases: a synthesis of archived data, geostatistical modeling with the GSS algorithm (Komac 2005), elaboration of a geohazard map, and field verification of the most susceptible areas. In addition to data on lithology, crushed tectonic zones, and distance from structural elements, the impact analysis and creation of the

susceptibility model included elevation data, slope and curvature, distance to surface waters, energy potential of streams, and 48-hour rainfall intensity.

Furthermore, we modelled debris flows with the Top Run Debris Flow (TopRunDF) model, version 1.1. (Scheidt 2009). The model is a tool for the two-dimensional run-out simulation of the debris flow deposit phase on debris cones. TopRun DF produces two estimates: (1) an inundated simulation area, combined with overflow probability of each related cell (this was used as a debris flow warning map—Fig. 8); and (2) a deposited area and the deposition height of each cell. The goal was to identify debris-flow hazard areas on the debris cones in the valley hitting the railroad. The details of the study can be found in Fidej et al. (2015).

Fig. 8 The debris-flow warning map at a scale of 1:15,000, prepared with the TopRunDF model. The color chart shows the debris-flow overflow probability for the stretch of the regional railroad Jesenice-Nova Gorica

In the field of landslide terminology, we published a paper in the national journal dedicated to natural and other hazards (Mikoš 2014), and at the XIIth IAEG Congress in Turin we reported on the investigation on torrent check dams as debris-flow sources (Sodnik et al. 2015b). We published a research paper in the journal *Landslides* on the executed mitigation measures on two large deep-seated landslides in Slovenia (Pulko et al. 2014).

On the Slano blato landslide, 11 dowels or shafts (Fig. 9) were constructed for both drainage of the upper part of landslide and as retaining works. The arch of 11 dowels is seen in Fig. 10. The 3D finite element method has been applied for the calculation of landslide stability and for the internal forces in the shafts.

At the Slano blato landslide a drop of suction was one possible reason for landslide instabilities (Petkovšek et al. 2009). In 2007 suction monitoring started at three different locations (MS on Fig. 10). One of the results of monitoring

was dry and wet envelopes of pore pressures during monitoring periods and changes in the factor of safety due to water level variation (Fig. 11). A scientific report on these six years of suction monitoring was published in an Italian geotechnical journal (Maček et al. 2016).

National Research Program

In 2015, we studied empirical rainfall thresholds for rainfall-induced landslides in Slovenia (Bezák et al. 2015a; 2016), tailings dam failure related risk management (Petkovšek and Pulko 2015), and the effects of over-consolidation ratios and shear rate on the shear strength of soils in a direct shear apparatus (Šelekar 2015). The in situ investigations on the Slano blato landslide were compared to laboratory tests. The results show that at the Slano blato landslide soil suction measurements cannot be used as an

Fig. 9 Vertical and horizontal cross section of the modified dowel design at Slano blato landslide (from Pulko et al. 2014)

indicator of new earth flow occurrences, however they may serve as an indicator of the periods with the lowest safety, when the new instabilities may appear (Maček et al. 2016).

We have compared the investments into water infrastructure (including landslide risk mitigation) in Slovenia and Austria (Sodnik et al. 2015a). We helped with the bibliometric analysis of the achievements of the ICL journal *Landslides* (Sassa et al. 2015). We currently support the activities of the Slovenian National Platform on Disaster Risk Reduction, established in 2014.

At UL FGG, four chairs established a new research institute called Research Institute for Geo and Hydro Threats (RIGHT; www.right.si) that will help to coordinate research work in the field of natural disaster risk reduction at the faculty level between hydrology, hydraulic engineering, geological engineering, remote sensing, and geodetic engineering.

Fig. 10 Monitoring of the Slano blato landslide: *C1* TV camera, *P1* Piezometer, and *MS1* suction measurement station (Maček et al. 2016)

Fig. 11 Pore water pressure envelopes for measurement profile MS1 and factor of safety against depth for the dry and wet envelopes, and for the case of ground water at a depth of 0.5 m

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