ReSyLAB 2017

3rd Regional Symposium on Landslides in the Adriatic-Balkan Region, Ljubljana

Symposium programme

Book of Abstracts

ICL ABN ADRIATIC-BALKAN NETWORK

GeoZS Geološki zavod Slovenije

Univerza v Ljubljani

11 - 13 October 2017
Ljubljana, Slovenia

Symposium sponzors

Acknowledgments
The Organizing committee is deeply appreciative of the sponsorships generously provided by the following companies:

Dear participants of the 3rd ReSyLAB 2017,

Regional Symposiums on Landslides in the Adriatic-Balkan Region are important meetings of engineers, professionals and researchers in the region. The aim of reducing the risk of landslides is extremely important, and remains a both a decisive directive and challenge in the future. The 3rd ReSyLAB will take place this time in Ljubljana, the capital of Slovenia.

You will be visiting a Central European country where landslides threaten more than one-third of the Slovenian territory, which means some 20 percent of the population is vulnerable. Following the ISDR-ICL Sendai Partnerships 2015–2025 for the Global Promotion of Understanding and Reducing Landslide Disaster Risk and the 2017 Ljubljana Declaration on Landslide Risk Reduction, the symposium will explore possible ways of enhancing cooperation between the landslide science community and the diverse range of stakeholders both in the Adriatic-Balkan Region and around the world.

Over the next few days we hope you will enjoy the numerous opportunities for social and professional interaction with new experts and familiar colleagues and friends. Please take this symposium as an opportunity to visit the photo exhibition of selected images from the WLF4 Landslide Photo Contest and take advantage of our technical program. We will be hosting and presenting four invited lecturers over the course of the symposium. The symposium will be attended by over 60 geoprofessionals, including more than 20 students who are pursuing undergraduate studies in geology and civil engineering. The symposium organisers received 42 abstracts, out of which 38 papers have been accepted for oral presentation. Each paper includes one or more aspects of mapping, investigating, monitoring, analysing or mitigating landslides, as well as case studies on innovative analysis, mitigation techniques and solutions. The symposium will conclude with two interesting field study tours: “Landslides in the Vipava valley” and the “Potoška planina landslide”.

Our wish is that this 3rd ReSyLAB meets and exceeds the high expectations of all participants in the larger effort to achieve two primary objectives: first, it should contribute to improving research and putting knowledge and experience into practice; and secondly, it should serve to enrich a general understanding of this country, together with its rich historical and cultural background, for all those who are coming to Slovenia for the first time.

Our sincere gratitude goes to all of the sponsors who made the organization of this symposium possible. We appreciate all of the help we have received from members of the International Scientific Committee, the Local Organizing Committee, and all of those individuals that expressed their support throughout the organization process.

We wish you a most fruitful and enjoyable 3rd ReSyLAB.

Mateja Jemec Auflič
Timotej Verbovšek
Matjaž Mikoš

Chairs of the Organizing Committee
3rd Regional Symposium on Landslides in the Adriatic-Balkan Region,
Ljubljana, Slovenia

Contents

Organizing Committee

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ICL Adriatic-Balkan Network
Geological Survey of Slovenia
University of Ljubljana, Faculty of Civil and Geodetic Engineering
University of Ljubljana, Faculty of Natural Sciences and Engineering

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General information

Symposium venue, 11 October 2017

University of Ljubljana
Kongresni trg 12
SI-1000 Ljubljana
Slovenia

Registration Desk

The Registration Desk of the first day of the 3rd ReSyLAB will be located in the Hall of Zbornična dvorana in the first floor of University of Ljubljana (entrance from Vegova street).

Symposium venue, 12 October 2017

University of Ljubljana
Faculty of Civil and Geodetic Engineering
Jamova cesta 2
SI-1000 Ljubljana
Slovenia

Registration Desk

The Registration Desk of the second day of the 3rd ReSyLAB will be located in the 2nd floor of Faculty of Civil and Geodetic Engineering.

Official language

The official language of the 3rd Regional symposium on Landslides in the Adriatic-Balkan Region is English.

Photo exhibition

Please take this symposium as an opportunity to visit the photo exhibition of the selected photos from the WLF4 Landslide Photo Contest on the ground floor at the Faculty of Civil and Geodetic Engineering.

Coffee break and lunch

During session breaks, refreshments will be served free of charge to participants wearing symposium identification badges. Lunches are included in the registration fee and will be served during lunch time.

Information for Speakers

Oral Presentations

All accepted abstracts and full papers will be presented orally. Authors should bring their presentations (in PowerPoint or PDF format) on a USB stick or CD/DVD-ROM, and must upload them to the computer in the section room 30 minutes before the actual time of the session. Symposium staff will assist authors with the loading of the presentation and will transfer the presentation files to the computers in the presentation rooms.

Each presentation should be 12 minutes speech followed by 3 minutes of discussion.

Field study tour

Requirements for participants: there will be approximately two hours of walking at the both field study tours. Weather-appropriate clothing and sturdy footwear is required. Travel cost and a lunch box are covered by the organizers and symposium sponsors.

Registration FEE

Symposium fee for all participants is 120 EUR, except for students for whom it is 60 EUR. The registration fee includes: symposium material, admission to all scientific sessions, book of abstracts, Proceedings of the 3rd ReSyLAB, refreshments during coffee breaks and lunches, social event and a field study tours (optional).

Due to delays the Proceedings of the 3rd ReSyLAB will be published soon after the symposium.

Side Event

Round Table Discussion

Title: Enhancing cooperation between the landslide science community and end users

Date: Wednesday, 11 October 2017, 13:30–15:00

Venue: Zbornična dvorana, University of Ljubljana, Kongresni trg 12, 1000 Ljubljana

Organizers

Adriatic-Balkan Network of the International Consortium on Landslides (ICL ABN)

Introductory lecture

International and regional cooperation on reducing landslide risk in Italy
Veronica Tofani, Department of Earth Sciences, University of Firenze, Italy

Moderator

Matjaž Mikoš, Chair of the UNESCO Chair on Water-related Disaster Risk Reduction, Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia

Invited panelists include landslide scientists from academic and research institutions and civil protection administration authorities from Bosnia in Hercegovina, Croatia, Serbia and Slovenia. Following the ISDR-ICL Sendai Partnerships 2015-2025 for Global Promotion of Understanding and Reducing Landslide Disaster Risk and the 2017 Ljubljana Declaration on Landslide Risk Reduction the Round Table Discussion will explore possible ways of enhancing cooperation between the landslide science community and end users from administrative bodies in BIH, Croatia, Serbia and Slovenia.

The round table discussion will cover the following topics:

(1) Disaster risk factors and scenarios, including emerging disaster risks, in the medium and long term;
(2) Enhance research for local, regional, national applications;
(3) Support actions by local communities and authorities; and
(4) Support decision-making with interaction between policy makers and the scientific community.

The aim of the Round Table Discussion is to debate, with a wider audience, the priorities for future practical applications derived from the scientific results gained in the framework of landslide research in those member-countries that belong to the ICL Adriatic-Balkan Network: Albania, Bosnia and Herzegovina, Croatia, Slovenia and Serbia. The discussion among governmental representatives and scientists will be conducted with a view to finding answers to questions related to current and applicable use of geoenvironmental data and information in systems dealing with land-use planning, civil and environmental protection, and to the development of related necessary legislative documentation (e.g., guidelines, laws).

Social event

Date: Wednesday, 11 October 2017, 18:00
Welcome reception in the Ljubljana City Hall (Mestna hiša).
Participants will also have the opportunity to attend a short guided tour in Ljubljana city centre focusing on natural stone in cultural buildings and monuments.

Symposium programme

Wednesday, 11 October 2017

Venue: Zbornična Dvorana, University of Ljubljana, Kongresni trg 12, 1000 Ljubljana

8:30 – 9:30	Registration
9:30 – 12:00	Opening Ceremony, Keynote speakers

Opening Adress
Miloš Bavec – Director of Geological Survey of Slovenia
Maja Makovec Brenčič – Minister of Education, Science and Sport
Igor Papič – Rector of University of Ljubljana
Matjaž Mikoš – Vice president of International Consortium of Landslides
Snježana Mihalić Arbanas – Coordinator of ICL ABN Network

Keynote speakers
Veronica Tofani – Landslide monitoring and rapid mapping
Lisa Borgatti – From slow to fast. Modelling, monitoring and mitigating Deep-seated Gravitational Slope Deformations
Miloš Bavec – Recent developments in landslide research in Slovenia

12:00 – 13:30	Lunch
13:30 – 15:00	Round Table Discussion Enhancing cooperation between the landslide science community and end users
15:00 – 15:30	Coffee break
15:30 – 17:15	Oral Session[1]
18:00	Social event

Thursday, 12 October 2017

Venue: Faculty of Civil and Geodetic Engineering, Jamova 2, 1000 Ljubljana, P-II/6, 2nd floor

9:00 – 17:30	Oral Sessions[1]
17:30 – 18:00	Symposium conclusions

Friday, 13 October 2017

Field study tours (optional)

8:00 – 17:00	1. Landslides in Vipava valley Departure from Faculty of Civil and Geodetic Engineering, Jamova 2, 1000 Ljubljana
8:00 – 15:00	2. Potoška planina landslide Departure from Faculty of Civil and Geodetic Engineering, Jamova 2, 1000 Ljubljana

[1]See Programme Schedule of Oral Sessions for details

Programme schedule of oral sessions

Wednesday, 11 October 2017

Session 1 15:30 - 17:15 Convener(s): Matjaž Mikoš, Snježana Mihalić Arbanas

15:30 – 16:00 **Keynote lecture:** Analysis of Rainfall Preceding Debris Flows on the Smědavská hora Mt., Jizerské hory Mts., Czech Republic
Vít Vilímek, Jana Smolíková, Jan Blahút

16:00 – 16:15 Extreme precipitation events and landslides activation in Croatia and Bosnia and Herzegovina
Sanja Bernat Gazibara, Krešimir Pavlić, Ivana Vlahek, Hamid Begić, Sabid Zekan, Martin Krkač, Marin Sečanj, Snježana Mihalić Arbanas

16:15 – 16:30 Challenges for operational forecasting of rainfall induced landslides in Slovenia
Mateja Jemec Auflič, Jasna Šinigoj, Matija Krivic

16:30 – 16:45 Damage caused by landslides and other natural disasters in Slovenia between 1991 and 2008
Matija Zorn, Mauro Hrvatin, Jure Tičar

16:45 – 17:00 MyDewetra CapRadNet: the evolution of the DewetraNet platform for hydrometeorological risk management and marine ecosystems monitoring
Miranda Deda, Luca Molini, Paolo Campanella, Paola Tepsich, Antonio Libroia, Marco Massabo, Mateja Jemec Auflič

17:00 – 17:15 The role of multisector partnerships in landslide prevention
Špela Kumelj, Tina Peternel, Jernej Jež, Blaž Milanič, Mateja Jemec Auflič

Thursday 12 October

Session 2 9:00 - 10:45 Convener(s): Biljana Abolmasov, Jernej Jež

9:00 – 9:30 **Keynote lecture:** Towards a pan-European landslide database from the Geological Surveys
Gerardo Herrera et al.

9:30 – 9:45 Analysis of rock falls on the road section Renke-Zagorje, Slovenia
Darja Rozina, Mateja Jemec Auflič, Timotej Verbovšek

9:45 – 10:00 Rockfall Risks Management in the Slovenian Road Network
Suzana Svetličič

10:00 – 10:15 Karst structures in heterogeneous lithological units as a potential geo-engineering hazard factor for mining and civil infrastructures
Željko Pogačnik, Kei Ogata, Gian Andrea Pini, Giorgio Tunis

10:15 – 10:30 The use of GPR for determining sheath fold blocks in the heterogeneous horizons of subaquatic gravity flows in W Slovenia – the case of Anhovo
Marjana Zajc, Željko Pogačnik, Andrej Gosar

10:30 – 10:45 GPR facies determination – Pusto Brdo- Srebrnjak Hill's Recent and Hystorical Landslides
Željka Sladović

10:45 – 11:15 Coffee break

Programme schedule of oral sessions

Session 3 11:15 - 12:45 Convener(s): Željko Arbanas, Tina Peternel

11:15 – 11:30 Combined interpretation of optical and SAR data for landslide mapping
Daniel Hölbling, Barbara Friedl, Jirathana Dittrich, Francesca Cigna, Gro Birkefeldt Møller Pedersen

11:30 – 11:45 Identification of potentially unstable rock blocks on the road cut in the Krka National park, Croatia
Marin Sečanj, Sanja Bernat Gazibara, Snježana Mihalić Arbanas, Martin Krkač, Željko Arbanas, Mariana Martinko

11:45 – 12:00 Rockfall monitoring and simulation on a rock slope near Ljig in Serbia
Miloš Marjanović, Biljana Abolmasov, Marko Pejić, Snežana Bogdanović, Mileva Samardžić-Petrović

12:00 – 12:15 The slow-moving landslides of NW coast of Malta: insights from long-term monitoring and modeling
Stefano Devoto, Matteo Mantovani, Alessandro Pasuto, Mauro Soldati

12:15 – 12:30 Preliminary results of Selanac debris flow modelling in RAMMS- a case study
Jelka Krušić, Katarina Andrejev , Biljana Abolmasov, Miloš Marjanović

12:30 – 12:45 Stože landslide triggering simulation using LS-Rapid
Jošt Sodnik, Matej Maček, Matjaž Mikoš

12:45 – 14:00 Lunch

Session 4 14:00 - 15:30 Convener(s): Martin Krkač, Mateja Jemec Auflič

14:00 – 14:15 Automated GNSS monitoring of Umka landslide-review of seven years' experience and results
Biljana Abolmasov, Marko Pejić, Mileva Samardžić Petrović, Uroš Đurić, Svetozar Milenković

14:15 – 14:30 Photogrammetric monitoring of Potoska Planina landslide
Vid Peterman

14:30 – 14:45 Observing the surface movement pattern of Potoška planina landslide using geodetic techniques
Tina Peternel, Marko Komac

14:45 – 15:00 Tools for the real time visualization and analysis of Ground-based data: application to the monitoring of landslides
Giovanni Nico, Uroš Kostić, Andrea di Pasquale

15:00 – 15:15 Visibility analysis for planning terrestrial landslide alert systems with webcams
Florian Albrecht, Damian Taferner, Mateja Jemec Auflič, Daniel Hölbling

15:15 – 15:30 A web service for landslide mapping based on Earth Observation data
Daniel Hölbling, Florian Albrecht, Elisabeth Weinke, Clemens Eisank, Filippo Vecchiotti, Barbara Friedl, Antonia Osberger, Arben Kociu

15:30 – 16:00 Coffee break

Programme schedule of oral sessions

Session 5 16:00 - 17:30 Convener(s): Matej Maček, Timotej Verbovšek

16:00 – 16:15	Estimation of possible economic losses of large water transportation systems due to landslides, Case studies from Republic of Macedonia *Natasha Nedelkovska, Igor Peshevski, Milorad Jovanovski, Sead Abazi, Bojan Susinov*
16:15 – 16:30	Origin of planation surfaces in the hinterland of Šumljak fossil landslides, Rebrnice (Vipava Valley, SW Slovenia) *Tomislav Popit*
16:30 – 16:45	Using tree-ring analysis in studies of slope mass movements *Andrej Novak, Andrej Šmuc, Ryszard J. Kaczka*
16:45 – 17:00	The Spatio-Temporal Dynamics of the Ciprnik complex Landslide, Tamar Valley, Julian Alps, Slovenia *Andrej Šmuc, Karolina Janecka, Michal Lempa, Andrej Novak, Ryszard J. Kaczka*
17:00 – 17:15	The engineering geological - geomechanical properties of soil landslides settlements "Svrake ", Vogosca, Sarajevo and concept of rehabilitation *Hamid Begić*
17:15 – 17:30	Spatial engineering geological and geotechnical modeling of embankment with RNK- method and stability analyses of waste water treatment facility (UPOV) in Vukovar *Želimir Ortolan, Mensur Mulabdić, Krunoslav Minažek, Jelena Kaluđer, Jelena Matijević, Marko Ortolan*
17:30 – 18:00	Symposium conclusions

Keynote lecture

Landslide monitoring and rapid mapping

Nicola Casagli(1), Veronica Tofani(1)

(1) Department of Earth Sciences, University of Florence, Italy *(veronica.tofani@unifi.it)*

The work focuses on the application of innovative monitoring techniques to estimate the deformational evolution of the landslide masses for landslide rapid mapping and early warning. In particular it deals with the optimization and validation of the operational protocols for technical and scientific support in areas at risk, and on the definition of rapid procedures for assessing landslide danger and proper managing of emergency situations. This is achieved by the synergistic use of rapid mobile units for localized survey based on terrestrial, marine and airborne sensors.

Research activities were focused on satellite remote sensing radar data for the identification (detection and mapping), analysis and monitoring of gravitational slope deformations in order to define proper risk scenarios and to support the management of their evolutionary phases. The activities are also aimed at improving the satellite surveillance system based on all the EO data (radar, multi- and hyperspectral) already available from several satellites (ERS, ENVISAT, RADARSAT, COSMO-SkyMed). Such integrated system will be designed for the identification, rapid mapping, monitoring and analysis of risk scenarios. Under the European program, called Copernicus, the recent launch of the SENTINEL-1 satellite (able to provide information in continuity with those from ERS and ENVISAT) offers new opportunities for monitoring the Earth's surface and for the evaluation of ground movements.

Such activities are possible at different scales of investigation and at different geological contexts using advanced processing techniques and interpretation of interferometric data derived from satellite images acquired by old and new systems. In order to optimize this satellite surveillance procedure during forecast, emergency and post-emergency cycles, activities were concentrated on satellite radar interferometric techniques and their integration with ground-based data for:

- monitoring the instability of slopes aimed at the detection of the deformation trends, through the study of temporal series of the interferometric SAR data for early warning purposes.
- Rapid mapping of landslide based on slope displacement patterns.

Keynote lecture

From slow to fast. Modelling, monitoring and mitigating Deep-seated Gravitational Slope Deformations

Lisa Borgatti[(1)]

(1) Department of Civil, Chemical, Environmental and Materials Engineering- DICAM, University of Bologna, Italy *(lisa.borgatti@unibo.it)*

Deep-seated Gravitational Slope Deformations (DGSDs) can involve entire high-relief mountain chain sectors. They have been described as giant, non-catastrophic landslides, or as intermediate class of slope instability processes lying between gravitational movements and gravitational tectonics phenomena. Even if they typically display very slow and discontinuous displacements (0.4–5 mm y−1), they can evolve in catastrophic events and may represent themselves the predisposing factor of eventually smaller but rapid secondary landslides, such as rock falls and rock avalanches. Detailed investigations are still lacking in the field of lateral spreads and related landslides in weak rock masses and more research is required for hazard and risk assessment and mitigation.

Several causal factors control the initiation and the evolution of these phenomena: predisposing factors are related to the structural setting of the slope, the rock mass characteristics and the valley geometry, whereas preparatory factor include glaciation and deglaciation effects, topographic stresses, changes in valley geometry, uplift rate and distribution, regional seismicity. Prolonged rainfalls and earthquakes are recognized as triggering factors. As far as predisposing factors are concerned, these large-scale slope processes occur in moderately strong and anisotropic rock masses and are thus controlled by structural features such as bedding planes, foliation and fractures. In fact, DGSDs are described in different geological contexts: sackungen or rock flows typically occur in schistose metamorphic rocks, whereas lateral spreading normally develops in the presence of rigid blocks overlying a plastic sequence and is more common where antiformal structures are associated with extensional regimes and thrust structures. Where lateral rock spreading phenomena involve brittle rock units overlying a more ductile substratum, associated secondary instabilities such as rock falls, topples and slides may occur at the edges of the plateau, while earth slides and/or flows can impact the underlying terrains. Several examples have been described in Europe (Maltese archipelago, Slovakia), in the Alps (Cinque Torri Group) and particularly in the Apennines of Italy, where historical villages were often built on the top of rocky plateaux (Orvieto, Civita di Bagnoregio, Pitigliano).

On the 27th of February 2014 a large landslide endangered the historical centre of San Leo, a medieval town built on the top of a calcarenitic slab in Val Marecchia (northern Italy). A volume of about 330,000 m^3 of rock detached from the north-eastern side of the plateau, resulting in the evacuation of several houses, a school and a police station. Before the failure, severe undermining of the rock slab was noticed, as a result of the progressive removal of the clay shales. As this erosional process was thought to be associated with surface runoff and shallow landslides occurring in small-scale catchments at the base of the cliff, countermeasures such as earthen dams and retaining walls founded on piles were adopted in the last decades to avoid further slope instability, together with extensive bolting of the rock face.

In this context, numerical modelling, together with field investigations, laboratory tests and monitoring, were used to delineate possible predisposing factors and related failure mechanisms. In particular, the back analysis of the San Leo 2014 landslide complements the understanding of secondary instability phenomena developing at the edges of the plateau and the recognition of the mechanisms leading to catastrophic failure, which are acting on the slope in the medium- to long-term.

The overall results provide the data to plan effective and low impact surveys and monitoring activities in target portions of the unstable slope. In fact, in this outstanding cultural landscape, the conservation of the natural asset has to be ensured together with the safe access to the area by means of adequate landslide risk mitigation measures with low environmental and visual impacts.

Keynote lecture

Recent developments in landslide research in Slovenia

Mateja Jemec Auflič(1), Matjaž Mikoš(2), Timotej Verbovšek(3), Miloš Bavec(1)

(1) Geological Surcey of Slovenia, Slovenia (*milos.bavec@geo-zs.si)*
(2) Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia
(3) Faculty of Natural Sciences and Engineering, University of Ljubljana, Slovenia

The main reason for the relative frequency of landslides in Slovenia lies in the complex geological structure of the territory and the fact that a large part of the country experiences significant tectonic stress, together with frequent heavy rainfall and occasional strong earthquakes. As the population grows, settlements and infrastructure are continuously spreading into areas of increased hazard for landsliding. As a result, more than 10,000 landslides have been recorded by the Administration of the Republic Slovenia for Civil Protection and Disaster Relief (ACPDR) and the Geological Survey of Slovenia (GeoZS) over the past three decades, which translates into an average landslide density of 0.5 landslides per km^2. Also, a number of strategies and measures designed to deal with this increased risk have been developed, ranging from simple risk avoidance to construction projects for mitigation of landslides whose volume exceeds one million m3. In the field of regulation, which will control planning and construction in the landslide risk areas, Slovenian legislation remains insufficient, even given that the government officially adopted the EU Flood Directive in 2007. Legislative acts deal largely with remediation issues instead of prevention measures; and are mainly divided into prevention, emergency protective measures, and permanent measures adopted in the process of remediation. The current protection strategy against landslides is part of The Waters Act (Official Gazette of RS, 2002), which follows the Water Frame Directive of the European Parliament and Council 2000/60/EC, where developments in landslide-prone areas are specified primarily in terms of adverse effects of water – meanwhile, spatial planning in areas that could be the source of or increase the risk of landslide is completely overlooked.

Despite the inadequate legislation, research institutions continue to make determined steps toward reducing the risk of landslides. In general, broader landslide risk studies are performed in the frame of three types of funding schemes. The first are scientific research programs funded by the Slovenian Research Agency that are aimed at gathering new, fundamental knowledge. These studies further support the basis for the second type of studies, which are various applied research projects supported mainly by the relevant ministries and in some cases, by the local communities. The European Commission financing mechanisms also offer opportunities for high-quality research to advance landslide risk reduction through different project calls, either scientific or applicative. Other possibilities for funding of landslide research exist, but here we focus mainly on those that are the most common and have particular impact here in Slovenia.

Many studies have been undertaken in the last two decades related to landslide prevention on the regional and local level. One of the first steps towards an effective prevention strategy for tackling landslides was the initiation of a central landslide database. At the conclusion of the first phase of compiling the National Landslide Database (May 2005) there were more than 6,600 registered landslides. Based on this landslide database a Landslide Susceptibility Map of Slovenia at a scale of 1:250,000 was created. Likewise, a Debris-flow Susceptibility Map for Slovenia at a scale of 1:250,000 was also made available, as well a Rockfall Susceptibility Map (1:250,000), which has not yet been conclusively validated. The results show that one-third of the population lives in landslide-prone areas – which is a clear indication that better spatial and urban planning is definitively required, both at the national as well as local level. Therefore, the next logical step was the development of a methodology model for landslide susceptibility on the municipal level, which was undertaken as a pilot project – "Elaboration of spatial database and web information system on geohazards (slope mass movements, erosion and snow avalanches)", funded by the Ministry of the Environment and Spatial Planning. Within this project, susceptibility maps and web applications were elaborated at a scale of 1:25,000 for 14 Slovenian municipalities (out of a possible 212). Project products (maps, geodatabase, web application) serve as directly applicable warning maps and as a basis for spatial planning at the municipal and regional level.

The fact is that we cannot avoid landslides entirely – but we could minimise their impact on settlements and society as a whole. The ACPDR is fully aware of this matter. ACPDR therefore initiated the development of a system designed to accurately assess and forecast landslide probability (MASPREM) in 2013. A near real-time system for forecasting landslide probability is currently operational and is in the validation phase.

Through the implementation of several research programmes, our capacity to use remote sensing data (InSAR, PSInASR, UAV photogrammetry, and TLS) in the identification, observation and monitoring of unstable slopes has advanced significantly. The application of knowledge and innovative techniques aimed at reducing landslide risk has also been developed through several EU projects. Among others, the Slovenian landslide research community has participated as a partner in Project TERRAFIRMA, ChlimChAlp, AdaptAlp, SEDALP, Start_it_up, Safeland, Pangeo, IngeoClouds, CapRadNet and the ongoing Recall initiatives. The primary objective of these projects is to identify landslide-prone areas and apply new monitoring technologies. Knowledge dissemination is particularly important, which also includes student education – two Slovenian ICL members are active in teaching, presenting the outcomes of the research projects and work of the ICL to students of civil engineering and geology.

All of the Slovenian members of the ICL, comprising the Geological Survey of Slovenia (GeoZS), the Faculty of Civil and Geodetic Engineering (FGG), and the Faculty of Natural Sciences and Engineering (NTF), have been involved in the ICL's activities for several years now: (in FGG since 2008, GeoZS since 2011, and NTF since 2016), and in the Adriatic Balkan Network since 2012. This year, GeoZS and University of Ljubljana, Faculty of Civil and Geodetic Engineering, were both awarded World Centre of Excellence (WCoE) in Landslide Risk Reduction, and joined the group of 20 World Centres of Excellence for the period 2017–2020. All three members have had active or ongoing IPL projects in the frame of ICL activities. The larger overall objective of our research follows the Sendai Framework on Disaster Risk Reduction 2015–2030, which consists primarily in strengthening efforts to reduce losses related to landslide hazards by applying new, advanced technologies for landslide identification/zonation and monitoring.

Towards a pan-European landslide database from the Geological Surveys

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Landslides are one of the most widespread geohazards in Europe, producing significant social and economic impacts. Rapid population growth in urban areas throughout many countries in Europe and potential extreme climate scenarios can considerably increase landslide risk in the near future. In the framework of the Geological Surveys of Europe (EGS), the Earth Observation and Geohazards Expert Group (EOEG) has carried out a survey regarding how geohazards, in particular landslides, are integrated into urban and land-use planning. This survey reveals heterogeneous policies across national borders, 17% of the countries do not include geohazards in their legislation and half of them have no official methodological guides for hazard assessment. Additionally, there is a lack of knowledge about real social impacts of geohazards in many of the countries, although geohazards have a significant effect on their national economies. This overview stresses the need for a common legislative framework and homogenization of the national legislations, including the guidelines, which adopt the principles applicable to the geohazards management and explain the process to be followed in the production of hazard documentation. This is especially relevant in case of landslide and subsidence hazards. Although they are very recurrent in all European countries, there are no common guidelines and practices as defined on the assessment and management of flood risk (Directive 2007/60/EC). With this long-term goal in mind, we analysed the landslide databases from the Geological Surveys of Europe focusing on their interoperability and completeness. From the 849543 landslide records from the Geological Surveys 36% are slides, 10% falls, 20% flows, 11% complex slides and 24% remain either unclassified or correspond to another typology. A landslide density map was produced (LANDEN map) showing, for the first time, 210544 km^2 of landslide prone areas and 23681 administrative areas where the Geological Surveys from Europe have recorded landslides. The comparison of this map with the European Landslide Susceptibility Map (ELSUS 1000 v1) is successful for most of the territory (69.7%) showing certain variability between countries. This comparison also permitted to identify 0.98 Mkm^2 (28.9%) of landslide susceptible areas without records from the Geological Surveys, which have been used to evaluate the landslide database (LDBs) completeness. The estimated completeness of the LDBs from the Geological Surveys is 17%, varying between 1% and 55%. This variability is due to the different landslide strategies adopted by each country. In some of them, landslide mapping is systematic, others only record damaging landslides, whereas in others countries landslides maps are only available for certain regions or local areas. Moreover, in most of the countries LDBs from the Geological Surveys co-exist with others owned by a large variety of public institutions producing LDBs at variable scales and formats. Hence, a greater coordination effort should be made by all the institutions working in landslides mapping to increase data integration and harmonization. Moreover, EOEG compiled for the first time in 2015, the annual report on damaging landslides with data taken from Geological Surveys. The idea behind this initiative is to provide an annual landslide report, based on a pan-European unified database, which can provide information on the spatial distribution, the triggering events, the types of landslides, and their social and economic impact, making this geo-hazard visible to policy makers, decision makers and European citizens in order to reduce the impact of landslide disasters.

Keynote lecture

Analysis of Rainfall Preceding Debris Flows on the Smědavská hora Mt., Jizerské hory Mts., Czech Republic

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In August 2010 extreme rainfall affected the north of the Czech Republic and caused regional floods and landslides. Three torrential debris flows originated in the Jizerské hory Mts., close to Bílý Potok on the north slope of the Smědavská hora Mt. The rainfall situation which triggered the debris flow was analysed and compared with the rainfall situation in 1958 when a debris flow occurred in the same area.

The rainfall data were obtained from rain gauges of the Czech Hydrometeorological Institute. Four rain gauges were chosen close to the Smědavská hora Mt. with data of:

a) daily amounts between 1983 and 2013;

b) hourly amounts and c) 10-minute intensity from the specific period. The data for the 1958 event were available from three different rain gauges (only daily amounts). The data series were not complete so linear regression was applied to interpolate them.

A number of analyses were carried out including daily rainfall, two-day/three-day moving values, antecedent precipitation index (API) of 5/10/30 days, 10-minute intensity and hourly amounts. The trigger factor of the debris flow in the study area was also investigated. It was determined that for the triggering of debris flows both high API values as well as high intensity-short duration rainfall is needed. It was proven that in cases of solely high API indices or high intensity-short duration rainfalls no debris flows were initiated.

1-Mapping and Spatial Analyses

Combined interpretation of optical and SAR data for landslide mapping

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The wide range of Earth Observation (EO) data from different sensors and the increasing temporal and spatial resolution offer new possibilities to derive valuable landslide information. Optical satellite images have been mainly employed for mapping event-triggered landslides in combination with morphological properties derived from digital elevation models (DEMs); traditionally by visual interpretation and manual digitization, more recently by employing semi-automated image analysis methods, either pixel-based or object-based. Since landslides usually appear brighter than their immediate surroundings on optical images due to the exposure of bare ground, mainly the spectral properties of optical images are used for landslide recognition. Multi-temporal Synthetic Aperture Radar (SAR) interferometry and methods such as Persistent Scatterer Interferometry (PSI) and Small Baseline Subset (SB or SBAS) have been primarily used for identifying slow moving landslides and for quantifying movement rates, but only few studies combined semi-automated mapping results based on both data sources to produce added value information. Landslide mapping using object-based image analysis (OBIA) based on SAR data solely is challenging. The combination of post-event optical and SAR data for detecting and delineating event-based landslides using OBIA seems to be more promising, since the properties from both data sources can be exploited. Advantages of SAR sensors over optical sensors are their ability to acquire data during day and night and to penetrate clouds. This can be beneficial for rapid mapping of event landslides that are triggered by intense or prolonged rainfall.

We present three case studies addressing the combination of optical and SAR data for an integrated landslide mapping. For the first test site, located in northern Italy, SPOT-5 data was used together with a DEM to map landslides with OBIA. On the other hand, deformation rates were derived using the PSI technique and ENVISAT and RADARSAT-1 data stacks. The combined interpretation of the landslide boundaries detected through OBIA with radar measures (i.e. surface displacements obtained from PSI) facilitated the updating of the pre-existing landslide maps. The second example comprises the investigation of typhoon-triggered landslides and debris flows in the Khaosiung county, southern Taiwan. Through the integration of multispectral information (SPOT-5), SAR intensity values (TerraSAR-X) and DEM derivatives in an OBIA environment, landslides could be examined in a more efficient way as opposed to relying on single data sources only. The multi-data analysis was especially useful for delineating single, large-scale landslides. Finally, a third case study was performed in the Öræfajökull area in south-east Iceland. We investigated how SAR coherence information and optical imagery could be synergistically used to assist landslide mapping in this glacio-volcanic landscape.

The combined interpretation of different types of EO data offers remarkable possibilities for improved landslide mapping, even if existing (OBIA) approaches still need to be optimized. Such integrated analysis of optical and SAR data can be useful to fully exploit the potential of EO data from different sensors for landslide mapping and monitoring with the aim to provide useful information for supporting disaster management.

Spatial engineering-geological and/or geotechnical modeling of embankment with RNK-method and stability analyses of waste water treatment facility (UPOV) in Vukovar

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The RNK-method, or the Reference Level of Correlation method (RLC-method), represents a procedure for spatial engineering-geological and/or geotechnical modelling, that was tested on many landslides in Croatia. The engineering-geological/geotechnical correlation column can be established in zones of limited extent (sometimes occupying tens of km2) using one or several characteristic layers, one of which is selected as the reference layer. In the established correlation column, a soil liquid limit and plasticity index appear as useful indicators of the peak friction angle, full-softening friction angle and residual friction angle for coherent soils and soft rock formations. As a rule, maximum plasticity index values correspond to the minimum values of such friction angles. It offers the opportunity for correct spatial engineering-geological/geotechnical modelling with differentiation of minimum shear strength zones (the weakest link in the "geotechnical chain of shear strength"), zones of different hydraulic conductivities, and zones of various degrees of natural compaction.

The engineering-geological/geotechnical correlation column of an analyzed area is the „key“ for the interpretation of the overall geotechnical/geological relationships in a required number of selected profiles. Such features ensure the highest level of correctness in the resolution of slope stability problems and provide all relevant information needed to develop a series of representative geotechnical profiles for 2^D and 3^D stability analyses.

Results obtained by the application of the RNK-method will be shown on the potentially unstable area of waste water treatment facility (UPOV) in Vukovar. The correspondig engineering-geological map and geotechnical correlation column will be shown also.

This project and its location is of special interest due to presence of loess soils, vicinity of the river, relatively high seismic activity and warning examples of instability in the broader area of similar conditions.

1-Mapping and Spatial Analyses

Extreme precipitation events and landslide activation in Croatia and Bosnia and Herzegovina

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Landslides are common features in Croatia and in Bosnia and Herzegovina and the most frequent triggering factors are precipitation (rainfall and snow melting) and man-made activities. Landslide activation for a given precipitation event can be analysed based on the database of precipitation events that resulted (or did not result) in landslides in the study area and the neighbouring regions. The main problem with the current practice of landslide risk management in both countries is the lack of a suitable landslide inventories and historical databases of landslide events. This paper focuses on analysing the relationship between extreme precipitation contiditons and rainfall-triggered landslides in the NW Croatia in 2013 and in Bosnia and Herzegovina in 2014. During winter and spring of 2013, extreme weather conditions (re)activated unusually high numbers of shallow landslides in NW Croatia (approximately 10,500 km^2 or 18.5% of the land area). In this period, the Croatian National Protection and Rescue Directorate (DUZS) recorded more than 900 landslide events. The largest number of landslides was recorded in the area of three counties: Krapina-Zagorje County, Varaždin County and the City of Zagreb. To investigate the rainfall conditions that resulted in floods and landslides in Croatia in 2013, precipitation measurements obtained by three meteorological stations were used – Zagreb Grič, Bednja and Zabok. Based on the available historical data for the Zagreb Grič weather station, analysis of the 3-month period from January to March showed that cumulative precipitation for the analysed period in 2013 has the highest value ever measured. Analysis of the historical precipitation record in the City of Zagreb further indicates that the high intensity precipitation in period from January to March 2013 is unique in the last 150 years. In May 2014 the low-pressure cyclone Tamara (Yvette) affected a large area of Southeastern and Central Europe, causing floods and landslides with the greatest damages in Bosnia and Herzegovina. The most affected areas include basins of the Bosna, Vrbas, Drina, Sana and Sava rivers at the territory of 73 municipalities in the Bosnia and Herzegovina (approximately 10,000 km^2 or 20% of the land area). As a result of the flooding, 21 people died, more than 66,000 people were evacuated from their homes, more than 60,000 residential houses and building were damaged or destroyed, more than 7100 landslides were (re)activated and the total damage is estimated at more than a two billion euros. To investigate the rainfall conditions that resulted in floods and landslides in Bosnia and Herzegovina in May 2014, rainfall measurements obtained by three meteorological stations were used – Sarajevo, Tuzla and Zenica. Analysis of cumulative monthly rainfalls at Sarajevo meteorological station for January-May 2014 showed that during April and May cumulative monthly rainfall was 50-55% higher than the average monthly values for the same period from 1949 to 2015. Cumulative monthly rainfall at Sarajevo meteorological station in April 2014 (148.5 mm) is the highest amount ever measured since 1949, while monthly rainfall in May 2014 (186.2 mm) was exceeded only one time in last 66 years with a maximum monthly value of 203.3 mm in May 1978. A comparison between plotted precipitation conditions that caused landslides in NW Croatia in 2013 and Bosnia and Herzegovina in 2014 with published global ID thresholds shows that precipitation conditions exceeded the threshold curves proposed by other authors. Analysis of extreme precipitation conditions showed that both the short- and long-duration rainfalls were responsible for the large number of landslide initiations in the NW Croatia and Bosnia and Herzegovina. Understanding the relationship between landslides, precipitation conditions and climate change is therefore crucially important in planning a proactive approach in hazard and risk management.

Landslide Hazard zonation along the Milot–Kukësi motorway in Albania

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This paper briefly describes the landslide hazard zone along the Milot–Kukësi motorway in Albania. According to landslide zonation information, many critical areas in terms of slope instability are to be found along the motorway. The studied area is located in the northern part of Albania. It represents a mountainous zone, which is comprised of various lithological units such as soil, molasses' rocks of claystone-siltstone-sandstone, limestone, melange formation-blocks in the matrix, basalts and ultrabasic rocks. It should be noted that the motorway crosses an area that is quite complex in terms of morphological and geological structure, characterized by steep slopes, fractured and highly- weathered rocks. As a result, intensive excavations were carried out during the construction of the motorway on the hills and mountain slopes that compromised their stability. Thus both during and after rainfall, several landslides have occurred along the side slopes of the motorway. As a result an engineering geological mapping was performed along this zone in 2015 and 2016 at a scale of 1:10,000 where many of the landslides sites are defined. The mapping indicates that their activity is closely related to geomorphology, lithological formations, tectonic effects, geotechnical properties of the bedrocks and soils, precipitation events and manmade actions and interventions. In addition, a geotechnical zonation map at a scale of 1:10,000 was compiled from the analysis and interpretation of the field and laboratory work, in which several engineering geological zones and sites were identified as being homogeneous in terms of the above-mentioned geo-factors. Also, lot of mass movements that occur along the motorway's side slopes were mapped using the results of the fieldwork. According to Cruden and Varnes (1996), debris flows, rocks slides, toppling-rock falls and earth slides constitute the major natural hazards in the study area.

Furthermore, the studied area was analysed in terms of landslide hazard zonation, which should prove helpful for engineering measurements used to mitigate landslide disasters and in planning development activities. This involves spatial analysis of landslide-prone areas along the Milot–Kukësi motorway using high-resolution satellite data along with field data in a GIS environment. Heuristic approaches have been applied in the assigning of ranks and weights preparation, which is based entirely on field observations and expert a priori knowledge. The analysis includes various terrain parameters like lithology, geological structures, slope, geomorphology and land use/land cover in order to identify landslide hazard zones in the study area. These classes were assigned corresponding rating values as attribute information in the GIS environment. Each class within a thematic layer was assigned an ordinal rating from 1 to 5 according to their assumed or expected importance in inducing slope instability. A summary of these attribute values was then multiplied by the corresponding weights to generate the different degrees of landslide hazard. A landslide hazard zonation map was prepared showing five different zones, ranging from very low-hazard zone to very high-hazard zone, which is essential in carrying out faster and safer mitigation programs, as well as for planning future development. The aim of the present work was to determine hazard zones along the main motorway in Albania, which is central to minimizing associated risks.

Finally, the presented study shows that by performing geotechnical mapping at a scale of 1:10,000 and by analysing geotechnical data using the GIS method, it is possible to determine the hazardous areas made dangerous by the geofactors discussed above. These areas require particular attention in the selection and design of effective mitigation measures, which in turn reflect the need for a clear understanding of the conditions and processes that induced the mass movements and created unstable areas.

Analysis of rock falls on the road section Renke-Zagorje, Slovenia

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The regional road section between the towns of Litija and Zagorje (especially the eastern part between Renke and Zagorje) is one of the most endangered sections in Slovenia considering the amount of traffic and the unfavorable geological conditions. The broader area belongs to the Sava folds, an intensively uplifted area composed of Permo-Carboniferous classic rocks, Triassic and Lower Jurassic carbonates, Upper Cretaceous flysch and Quaternary deposits. On the approximately 15 km long road section, Middle and Upper Triassic limestones prevail, forming very steep slopes. Due to tectonic fracturing, carbonates are intensively fractured and many rock falls are trigged on the road due to these unfavorable geological conditions and steep slopes. Although numerous mitigation measures have been performed (concrete walls, steel wire net barriers, crib walls, berms, gabions, road galleries), the road is still prone to rock falls, indicated by impacts on the asphalt, road fence, car accidents and appearance of rocks on the road. In order to identify the most prone sections a methodology combining field and computer modeling was applied. Rock fall modeling was performed in RocScience RocFall 5.0 software for 14 profiles along the road section to simulate the energy, velocity and bounce height of the falling rocks. Data of the locations of road accidents related to rock falls were collected from the local Police and Road maintenance service and a map of frequency of rock fall events and existing prevention measures on the selected road section was prepared in GIS. Modeling was performed by simulating limestone and dolomite rock falls of 100 rocks of an average size of 35x30x50 cm, although much larger blocks were observed. Results from field observations show that approximately half of the road section has protection measures, but some of the net barriers are damaged and are not cleaned regularly. Road maintenance service has reported 269 rock falls in 2015 and the police 35 accidents for the past three years, but not all accidents were reported. For unprotected sections, rock fall simulations have confirmed the greatest impact kinetic energies (maximum 297 kJ) for most damaged sections. After these analyses the road was classified into four rock fall hazard classes where the first class (no hazard) presents only 1.5% of the road section. Over 90% of the road section is categorized into high hazard classes 3 and 4, which indicates that this road section needs to be treated as one of the most dangerous road section in the country. Recently, several mitigation measures (new steel wire net barriers) have been constructed in 2016 on the most critical section and these measures will continue in the future along the other locations.

Identification of potentially unstable rock blocks on the road cut in the Krka National park, Croatia

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Rock fall is a common phenomenon on the steep slopes along the Croatian part of the Adriatic Coast which can lead to risk of death and injury to people, damage to buildings and infrastructure. The aim of this paper is to present visual and semi-automatic identification of potential rock fall source areas and unstable rock blocks on the road cut in the National park Krka, Croatia. Identification was conducted by traditional surveying and by interpretation of digital surface models derived from the high-resolution point cloud data obtained with the terrestrial laser scanning and unmanned aircraft system (TLS and UAS). The investigated road cut is located on the right bank of the river Krka, on the frequent county road which is the only connection between the villages of Kistanje and Oklaj. Local residents and visitors of National park Krka are endangered by rock falls due to the location of the road, just beside the steep slope of the surrounding hill. The investigated road cut and the slope above it are located in the core of the anticline which is built of Eocene-Oligocene Conglomerates and Breccia (Promina Deposits). Complexity of the geological-structural setting, caused by faulting and folding in the area, led to the formation of numerous discontinuities in rock mass as well as unstable rock blocks with unfavourable orientation and a potential to turn in to rock falls. The investigated road cut and slope above it are around 900 m long, with the maximum height of around 60 m. To identify potential rock fall source areas and unstable rock blocks, detailed mapping of discontinuities and rock blocks was performed based on remote sensing and traditional survey. From the data collected with the terrestrial laser scanning and the unmanned aircraft system, a point cloud with the spacing between points of 1 cm was created and visualized in a CAD software. Spatial data, which was contained in the point cloud, was used to construct a digital surface model in the Split-FX software. To determine geometrical features of rock mass, such as slope and discontinuity orientation, spacing and roughness of joints etc., different semi-automatic and automatic features of Split-FX software were used. Discontinuity sets with unfavourable orientation in respect to the slope and road cut were determined, grouped and visualized. With the spatial kinematic analysis, potential rock fall source areas and the probable instability mechanism were determined, while potentially unstable rock blocks were manually singled out. Identified rock fall source areas, unstable rock blocks and probable instability mechanisms on the investigated road cut and slopes above, present the input data for risk reduction by an efficient design of countermeasures.

The use of GPR for determining sheath fold blocks in the heterogeneous horizons of subaquatic gravity flows in W Slovenia – the case of Anhovo

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Within heterogeneous lithological horizons, the determination of sedimentary anisotropic bodies with the two-dimensional extension of more than 10 times their thickness provides the possibility of a suitable interpretation of the causes of damage as well as a definition of pillars of safety for the construction / reconstruction of an infrastructure. Due to their synsedimentary and structural-diagenetic changes, the spatial position of such bodies conditions the orientation of the local compressive stress and the hydrostatic pressure in the hinterland, which are the greatest contributors to the formation of sliding surfaces and consequently geomechanical deformations of vast dimensions (slips, slides, etc.).

Heterogeneous rock masses, which appear in the W and NW Slovenia in the municipalities of Kanal ob Soči, Tolmin and Kobarid, represent Cretaceous and Paleocene subaquatic gravitational flows, the so-called MTD - mass transport deposits, characterized by strong deformations of the substratum. These sequences are characterized by three geomechanically anisotropic units, which are the lithological horizons U1 and U2 (composed of calcareous breccia with oversized carbonate olistoliths and bedded siliciclastic-carbonate and marly olistoliths); horizons U3 and U4 (graded calcareous breccia, calcirudite and laminated calcarenite); and unit U5 (in the form of massive / laminated marlstone).

The paper presents the use of the Ground Penetrating Radar (GPR) method for the determination of a covered layered block within the U2 unit. The GPR results were integrated with the interpretation of partial outcrops as well as the lithostratigraphic map of the area. Due to its non-invasive nature and efficiency, the application of GPR has been rapidly increasing in various geological studies and has been successfully used in several landslide and geohazard investigations.

As our research area consists of heterogeneous materials with high signal attenuation, a low frequency 50 MHz rough terrain antenna (RTA) was used to ensure the sufficient depth penetration needed for this study. With the use of the low frequency GPR and field mapping we were able to differentiate between different rock layers within a heterogeneous block as well as determine the presence of discontinuities already proven capable of becoming sliding surfaces and producing landslides.

The combination of such investigative methods for the detection of layered bodies has shown to be very successful. Supported by adequate field data, a systematic use of the GPR method can be effective in defining potential / latently unstable rock masses, and can therefore be used for determining the scope of intervention needed for the construction / reconstruction of infrastructure.

Photogrammetric monitoring of Potoška Planina landslide

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The paper describes a practical example of mapping and monitoring of the landslide at Potoska Planina – a landslide above Koroska Bela village in the western Karawanks (mountain range of the Southern Alps) in the northwestern part of Slovenia. With an intention to assess the dynamics of the landslide we established a system of periodical 2-phase observation.

In the first phase we conducted UAV-based periodical measurements twice per year – mid-spring and mid-autumn - in order to assess the magnitude of the movement of the landmass. A geodetic survey network of stationary points was stabilised around the landslide during each of the periodical measurements to determine the positions of photogrammetric ground control points. A hexacopter UAV was used to record overlapping aerial images of the landslide area. A network of tachymetric control points able to slide along with the landslide itself was also stabilised and measured during each of the periodic observations. This offered an independent control of photogrammetric observations of the landslide activity. This paper presents full technical details of periodical observations, image overlap, camera settings, methodology of ground control points signalisation and positioning, as well as a detailed description of image processing workflow needed to produce the required data.

Image processing of each periodical observation was conducted utilizing 3Dsurvey, an in-house developed photogrammetric software. Generating point clouds, digital terrain models and orthophotos with the help of 3Dsurvey is described, as well, as is generated data accuracy assessment and comparison of independent tachymetric control measurements with photogrammetrically generated data. Problems encountered during the periodical observations are also described; from unfavourable weather conditions for UAV flight, to destruction of tachymetric control points due to landslide activity. In order to assess the dynamics of the slope movement, a comparison of subsequent periodical observations was required. Three–dimensional positions of tie points were taken into account, and vectors of sliding of the land mass were calculated. This was the basis for geological determination of the volume of sliding material. The results of periodical observations of the area showed that the average sliding of the landmasses was greater in the periods from mid-autumn to mid-spring than mid-spring to mid-autumn. Displacements observed ranged from 10 cm to more than 2 meters over the six-month period. Results clearly show specific locations in which the sliding material stockpiles, washes away, or is stagnant. Generation of digital orthophotos, digital terrain models and three-dimensional vector grids of sliding of the landmass enable very visual and highly informative representations of landslide dynamics.

In the second phase our goal was to determine if displacements observed during 6 month periods occur all at once, or if they occur little by little. To acquire the necessary information we placed two cameras at the foot of landslide, and programmed them to capture still photos of landslide. From these observations we were able to determine daily displacements of the landslide material ranging from 1 mm to several centimetres. Observations showed that the prevailing magnitude of sliding of the material is around 1 mm, with some larger daily displacements of up to 10 centimetres. In the paper we describe the process of calculation of the landslide dynamics based on periodical capturing of still photos, present the results and draw conclusions on what problems we encountered and how we solved them.

GPR facies determination – Recent and Historical Landslides

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Srebrnjak Hill and Pusto Brdo are situated at the eastern edge of Samoborsko gorje Mountains. The area is covered with woods, lawns and orchards. Former geological surveying implied a pretty simple stratigraphic setting with minor lateral and vertical variation. Sedimentologic/stratigraphic unites refer to upper Miocen shale and silts that could be, according to Vrsaljko, 2004., divided to Andrasevci and Medvednicki Bregi subunits overlain with Quarterly layer at the top of the hill. Tectonic settings vary from author to author, but common to both versions is a regional fault that passes the nearby area.

At the end of 2016 the landslide at the south part of the hill caused the damage on the hangars and shades and stopped in the vicinity of the houses in the Mala Gorica village. The reparation works were performed in 2016. GPR surveying took place in 2017 in order to describe the geological setting of the Srebrnjak and Pusti Breg Hills in details, using GPR (georadar) data set analyses and applying facies determination method. 25 km of GPR profiles were recorded with a shielded 80 MHz antenna. Detailed surveying of the 2016 landslide (1.5 km) was performed as a part of the campaign in order to delineate landslide parts, primarily the surface of the rupture and its relation to rock body layers and fractures. The results were applied to the hill area in order to recognize potential future landslides.

As the results of analyses, historical landslides were recognized on Pusti Breg Hill. Georadar signal analyses workflow included data sorting, profile summation, velocities calculations based on hyperbolas, corrections for elevation and interpretation with GPR facies analyses. Additionally, GPR signal multi-attribute analyses were performed based on Hilberts transformation of recorded data.

The GPR facies were depicted based on method introduced by Neal 2014. and its later adaptations. Three main lithofacies were extracted, and their signal characteristics: a)Shape, interrelationship, continuity and the strength of reflex, b)Unit surface characteristics (concordant, erosional, on lap...), c) Unit scattering characteristics. Wider area analyses enable delineation of three main GPR facies. Lithofacies thicknesses and depths were mapped. Multiatribute analyses, developed for reflection seismic purposes (Sladovic and oth, 2008.) were applied on GPR profiles confirmed by GPR facies determination.

At the 2016 landslide area the GPR signal is fairly good for processing and analyses. There were no significant hyperbolas except the one caused by a construction object built during the reparation. On the section before processing the water niveux on crown profile could be noticed. GPR surveying enables 3D modelling of the 2016[t] landslide. The landsliding features were also noticed on several positions in the area. They differ in their type and volume. The most significant one is at the eastern part of Srebrnjak hill just 300 m away from the 2016 landslide. On Pusti Breg historic landslides were detected within lithofacies 2. Multiattribute analyses improved the visibility of cross sections and enabled detecting timing and extension of landslide.

GPR surveys enable 3D modeling of the landslides in detail, as the base for the discussion about mitigating the risks of the earthslide in the future. 4D modelling and monitoring with GPR 80 MHz antenna with attribute analyses of GPR signal is recommended.

Visibility analysis for planning terrestrial landslide alert systems with webcams

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In mountainous regions like the Alps, landslides frequently cause damage and pose a risk to the population and infrastructure. A clear need can be identified for monitoring known landslides on the one hand and for the rapid documentation of event-triggered landslides and related damages on the other hand, particularly after heavy rainfalls. In the latter case, an automatic system for immediate alert would be most valuable for emergency response and the coordination of infrastructure maintenance activities. As remote sensing methods have shown to be useful for monitoring and documentation of landslides, the question is if these methods can be employed for providing an alert system as well. Therefore, this study suggests a concept for estimating the capability of a landslide alert system based on webcams. The idea is to use multiple webcams in combination to cover the specific regions that have been identified as being susceptible to landslides. This study uses visibility analysis tools for modelling the coverage of webcam constellations for a landslide alert system.

For monitoring and documentation of landslides, sensors for terrestrial and airborne/spaceborne remote sensing have proven to be useful. However, the limitations of these methods make it difficult and less straightforward to create a landslide alert system. Key requirements for an alert system are the response time after a landslide has been triggered and the size of the region that the alert system can cover, i.e. if a region with high landslide susceptibility can be monitored entirely. Optical Earth Observation (EO) satellites can cover large areas for the documentation of weather-induced landslides. But they (1) have limited revisit capabilities, and (2) acquire images only with a certain delay because of the clouds that need to clear up first. Optical EO satellites cannot achieve the response time required by an alert system. For the monitoring of specific landslides, terrestrial cameras with a web connection are often installed and can collect images at a high user-defined frequency. The necessary daylight for image acquisition does restrict the response time at night (or during foggy weather conditions), but this may be an acceptable delay, especially since the preparations for starting maintenance activities also need some time. As single cameras have a field of view that is plainly too small for covering the entire region of operation of a maintenance service, a constellation of multiple webcams is required.

Visibility analysis methods can estimate the optimal distribution and required amount of cameras that enable the identification of landslides in a certain region quickly after they have happened. The ability of a webcam for detecting a landslide depends on its technical limitations, i.e. camera resolution and field of view, the size of the landslides, and the distance and viewing angle to a covered location that shall be monitored. According to these parameters for a webcam location, a map is produced that classifies areas into capability categories for detecting landslides.

Next steps concern the verification of requirements to the input information to the visibility analysis model. This includes both the resolution of the digital elevation model (DEM) that represents the terrain and obstacle landscape and the information about the viewshed parameters, e.g. the resolution and distance at which a webcam is able to detect a landslide. When these issues have been solved, the identification of an appropriate constellation of locations for the placement of multiple cameras can be addressed. The initial tests for the concept for a landslide alert system are promising but still require more research in order to prove the technical feasibility of such a system.

Tools for the real time visualization and analysis of Ground-based data: application to the monitoring of landslides

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The application of the Ground-Based Synthetic Aperture Radar (GBSAR) technique to monitor landslides and natural disasters has been already demonstrated. In many cases, as for continuous monitoring operations, GBSAR can produce a nearly-continual stream of high-dimensional data, and this explosion in the amount of collected information introduces new processing challenges mainly during real-time monitoring applications where high spatial resolution information is needed. In this work we presents the results obtained by using the GBSAR technique to monitor different kind of landslides.

The case studies show landslides having different spatial extension and an average distance from GBSAR installation site ranging from less than 100 m up to 7 km. Details about the visual inspection of landslides needed to choose the most useful location of the installation of the GBSAR, the data acquisition process and processing of GBSAR data up to the generation of displacement maps are provided. In particular, the processing chain of GBSAR data is detailed from the point of view of geologists and geotechnical engineers. The critical points where a real time (or almost real time) visualization and analysis of GBSAR are needed are described in details. In recent years, GPUs have evolved into highly parallel many-core processors with tremendous computing power and high memory bandwidth to offer two to three orders of magnitude speedup over the CPUs. A cost-effective GPU computer has become an affordable alternative to an expensive CPU computer cluster for many researchers performing various scientific and engineering applications. In this work we present the results of a project aiming to demonstrate the usefulness of GPUs in real-time measurement of displacements by GBSAR. In particular, we describe new processing techniques and software tools for the generation of accurate high resolution GBSAR images rendered on a 3D digital surface of the monitored area. The spatial resolution of GBSAR images depends of the frequency bands of the used GBSAR and the distance of the landslide from the radar. Usually, the range resolution is 0.50 m and angular distance between targets which can resolved is 0.5 degrees. The issue of the quality of the time series of GBSAR images is analysed. This is usually assessed by the concept of interferometric coherence. A new algorithm for the adaptive computation of unbiased coherence maps is described and the real-time performances of the corresponding software tools demonstrated. This tool is also useful for the estimation of the local precision of the displacement measurement.

Automated GNSS monitoring of Umka landslide - review of seven years' experience and results

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The Umka landslide is the deepest and biggest active one in Serbia and has been investigated and monitored by different geotechnical techniques for decades. This paper will focus on the automated continuous GNSS monitoring system established in March 2010. This is the first GNSS landslide monitoring system in Serbia and it represents a significant step forward in landslide monitoring.

The Umka monitoring system is an automated permanent monitoring system consisting of GNSS network and supporting software solutions: Leica GNSS Spider and Leica GeoMoS. The GNSS monitoring network, set up to continuously monitor the Umka landslide, consists of four GNSS points. Highly precise, multi-channel, multi-frequency systems (receivers and antennas) are used on all network points. As it is customary in monitoring systems, the network consists of reference and object points. Reference points are placed outside the landslide area and it is presumed that they are stable. Three reference points of the monitoring network (Belgrade, Grocka and Indjija) are points included in the Active Geodetic Reference Network of Serbia (AGROS network). Unfortunately, because of a lack of GPS receivers only one point (Umka) that is placed in the Umka landslide area represents the object point.

The shape of GNSS network was changed due to the replacement of reference stations implemented by the Republic Geodetic Authority (RGA). Two reference points, Belgrade and Lazarevac were established as reference points from March 2010 up to June 2011, but after June 2011 three reference points (Belgrade, Indjija and Grocka) were implemented up to now. Location of the GNSS sensor (object point) placed in Umka landslide area also had to be changed after December 2013 for technical reasons and it was moved to a nearby/neighbourhood location. The GNSS network on the Umka landslide started again in August 2014 with three reference points (Belgrade, Indjija and Grocka) and one object point. Precipitation data from Belgrade MMS and the level of Sava river from Beljin station are continuously collected on a daily basis. The overall obtained results indicate that the Umka landslide is an active, slow moving landslide with significant surface displacement towards the northwest.

The results and experience of automated GNSS monitoring of the Umka landslide during the last seven years will be presented and discussed.

Challenges for operational forecasting of rainfall induced landslides in Slovenia

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The spatial-temporal prediction of landslide hazards is one of the important fields of geoscientific research. The aim of these methods is to identify landslide-prone areas in space and/or time based on the knowledge of past landslide events and terrain parameters, geological attributes and other information. In the last 25 years many countries, regions and cities have been affected by intense precipitation that led to catastrophic landslides. Therefore, public awareness of extreme events has adequately increased across the world in different sectors. Also, the development of information systems has led to progress in the design of landslide forecasting systems that through the inputed rainfall data reflect possible scenarios or situations that have happened in nature. The developed models with a high certainty serve as a useful tool for the prediction of landslide areas where rainfall exceeds the defined threshold and as a warning for the population against the increased probability of landslides occurrences. In Slovenia, the system for landslide prediction was developed in 2013 for the whole country. Designed operational systems are based on real-time rainfall data, rainfall threshold values and a landslide susceptibility map and inform inhabitants of an increased probability of landslide occurrences as a consequence of heavy precipitation that exceed the landslide triggering values. At the moment, MASPREM predicts landslide probability at a national scale (1:250,000) and at a local level (1:25,000) for five selected municipalities where the potential exposure of inhabitants, buildings and different type of infrastructures is displayed, twice daily for both. The system is now in a validation phase which presents an important task of demonstrating that the model reasonably represents actual conditions in nature. The quality and reliability of each model should be properly verified to satisfy analysis objectives. When a rainfall induced landslide is reported the evaluation of the prediction models reliability is taken.

The contribution focuses on the main conceptual and technological challenges faced in the design, the implementation, and the daily operation of MASPREM. Several of the typical elements of an operational landslide forecasting system are considered, including: (i) observing parameters (increase of quality of input parameters), ii) methods for defining rainfall thresholds, iii) the quality of the rainfall information used for operational forecasting, iv) optimal system architecture to calculate complex data, v) validation and vi) communication to end users, selection of proper methods for the criteria used to transform the forecasts into landslide warnings. We will also discuss the main conceptual and operational constrains related to the validation of the forecasts for the possible occurrence of rainfall-induced landslides prepared by MASPREM and proposing possible improvements.

Observing the surface movement pattern of Potoška planina landslide using geodetic techniques

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This paper focuses on the observation of the surface movement pattern at the Potoška planina landslide (NW Slovenia), which has the potential to mobilize the material into a debris flow. The Potoška planina landslide is located in the Karavanke mountain ridge, above the settlement of Koroška Bela, which lies on the outskirts of the town of Jesenice. The geological and tectonic setting of the wider Potoška planina area is fairly complex. The landslide is situated at the contact point between the Upper Carboniferous and Permian clastic rocks – which consists of alternating shale, quartz sandstone and conglomerate – and the Upper Triassic to the Lower Jurassic carbonate rocks. In terms of tectonics, the area is part of the Košuta fault zone and is bisected by numerous NW-SE faults linking two major fault zones (the Sava and Periadriatic fault zones). The given geological and tectonic conditions indicate that the Potoška planina landslide is highly prone to different slope mass movements.

In order to observe the surface movement pattern it was crucial to set up a flexible and reliable monitoring system to monitor visible surface changes through time and space, including displacement rates and extent, changes in elevation and changes in volume. Monitoring of the changes on the surface and observation of surficial displacements can be accomplished using different surveying techniques.

To estimate the surface movement pattern of the Potoška planina landslide periodic monitoring was performed on the basis of results of independent surveying techniques: photogrammetry using unmanned aerial vehicles (UAV), terrestrial laser scanning (TLS) and tachymetric measurements. UAV photogrammetry and TLS enabled us to create detailed surface models (DEMs, orthophotos, etc.), while the classic and highly-accurate tachymetric measurements using a total station were used to determine accurate displacements of object points and to assess the reliability of the photogrammetric data. Periodic monitoring was performed over a period of 3 years and 10 months.

Due to the many challenges and obstacles, the limited coverage of the surveying techniques and various observation periods the amount of surface movement pattern provides only an indication of the actual changes at the Potoška planina landslide in near-real time. However, based on the results, it was concluded that current available modelling data, such as displacement rates, assessments of elevation changes and estimated transported volumes all contribute significantly to a better understanding of the behaviour and dynamics of the Potoška planina landslide.

Previous investigations, engineering-geological mapping and the results of geodetic techniques suggest that the Potoška planina landslide is subject to different slope mass movements. The upper part of the landslide at the main scarp and the part immediately below it are dominated by rockslides and runoff of the scree material. The main body of the landslide is formed by heavily deformed and weathered clastic rocks and is presumed to be a rotational, deep-seated slow-motion slide that has accelerated predominately as the result of percolation of surface and ground water. The toe of the landslide is considered to be the most active part. It is crossed by the Bela torrent and features gully-type morphology. The sliding mass is composed of tectonically deformed and weathered Upper Carboniferous and Permian clastic rocks covered with a large amount of talus material that is prone to slope instability. Additionally, the Bela stream causes significant erosion and increases the possibility of mobilization of the sliding mass downstream. The movement patterns in this part represent a combination of steadily sliding mass towards the torrent gully as well as localised superficial surge slips. Sliding material is moving downslope towards the bottom of the landslide toe, where the material is being fed into the stream.

Designing a regional scale landslide warning system with scarcity of data and progressive ameliorations through time: the Emilia Romagna (Italy) case study

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SIGMA is a regional landslide early warning system based on rainfall thresholds that operates in the Emilia Romagna region (Northern Italy). In this work, we depict its birth and the continuous development process, still ongoing, after over a decade of operational employ.

Traditionally, landslide rainfall thresholds are defined by the empirical correspondence between a rainfall database and a landslide database. However, in the early stages of the research, a complete catalogue of dated landslides was not available. Therefore, the prototypal version of SIGMA was based on rainfall thresholds defined by means of a statistical analysis performed over the rainfall time series: multiples of the standard deviation (σ) of the accumulated rainfall were used as thresholds to discriminate between ordinary and extraordinary rainfall events. SIGMA was purposely designed to take into account both shallow and deep seated landslides.

The advantage of this model is to allow establishing a warning system even in total absence of adequate landslide data: only rainfall data are needed to implement the base version of the warning system. Performances and forecasting effectiveness were initially limited, but were greatly increased with time using the following approach:

- Systematic collection of data about newly triggered landslides.
- Periodical use of the new data to tune the model or just to update the thresholds according to a more robust calibration.
- Quantitative validation of the model performance.
- Error analysis and specific research programs aimed at developing solutions to systematic errors.

This is a general framework that could be easily implemented in any other case of study.

At Emilia Romagna, this approach led to the following results: (1) Enhancement of the forecasting effectiveness: the likelihood ratio of the model almost doubled from 8.38 to 17.01. (2) Specific alert level definition: a specific calibration and tuning of the model allowed to set a correspondence between the alert levels of the warning systems and the number of expected landslides. (3) An additional module was developed to account for snow melt/accumulation effects, allowing to substantially increase the number of correctly predicted landslides in the mountain areas. (4) Coupling with a landslide susceptibility model to improve the spatial accuracy of the warnings: a back analysis showed that the proposed approach would have led to define a more accurate location for 83% of the landslides examined.

Rockfall monitoring and simulation on a rock slope near Ljig in Serbia

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This paper addresses a rock slope on the M-22 road, which is one of the corridors with the highest frequency and heaviest traffic load among all of 1-b category roads in Serbia. Therefore, stability along its slopes is vital. One of its critical points is a medium-sized rock slope located near the town of Ljig. This rock slope is composed of a flysch complex, dominated by brittle and compact sandstone banks (2-3 m thick), interlayered by less-competent, ductile series of marly-shales (several cm thick). Rockfalls on this slope mainly consume larger sandstone blocks severed by three main sets of discontinuity plains, as well as weathered, crumbly crust atop the uppermost sandstone layers. These source areas were precisely identified through 4-year long slope monitoring, based on Terrestrial Laser Scanning technique. However, the runouts and accumulation zone was never precisely determined, because the Public Enterprise Roads of Serbia, which maintains the road infrastructure, reacts quickly after the fall takes place and swipes off all the shatter, so the runout evidence was never recorded in those 4-years.

The research concept included typical back-analysis. Firstly, the source areas were analyzed by comparing point clouds of the first and the latest TLS scanning epoch. Four main source areas were identified and adopted for the model. Secondly, potential rockfall block size and shape were adopted based on the measurements over the first epoch point cloud. Subsequently, some mechanical and physical properties of the rock were determined. These three steps included known and documented facts of the present rock slope. The last step was to simulate the most likely trajectories to obtain runout distances and possible threats to the road asset, based on known source areas and material properties.

The results show that the source area No. 4 is potentially the most critical, because its trajectories' runouts can reach the road infrastructure. This was somewhat expected, given that this source area is positioned on the upper part of the slope, with small horizontal distance to the road. Simultaneously, kinetic energy, componential velocities and forces were also calculated. These showed that rockfalls could be easily controlled as none of the trajectories resulted in energies or forces that would be overwhelming for some standard structural remediation measures (mash, barriers, embankments, etc.). Rock bouncing and fragmentation effects did not show significant influence, because of the relatively short slope, moderate steepness angles of the rock face, and soft weathered material accumulated along the slope's foot that absorbs the impact energy.

4-Landslide Mechanics and Simulation Models

Karst structures in heterogeneous lithological units as a potential geo-engineering hazard factor for mining and civil infrastructures

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Planning of civil engineering infrastructure and exploitation of mineral resources in lithologically and structurally heterogeneous carbonate-dominated rock assemblages, should consider associated complex karst structures as potential geohazards.

A recent study on the Paleocene-Eocene sedimentary succession outstandingly exposed in the Anhovo quarry (Outer NW Dinarides; Slovenia) points out the occurrence of paleokarst structures such as phreatic channels, due to localised dissolution processes. These fluid flow pathways follow the directional anisotropy provided by lithological matrix/clasts contacts in the matrix-richdepositional unit (U2) of ancient, large-scale submarine landslides (mass transport deposits; MTDs), which is in turn originated by specific sedimentary and post-sedimentary processes. Among primary sedimentary processes, down-slope gravitational transport favoured lithological disaggregation and mixing of slide blocks and clasts into a marly-silty matrix, later playing an important role in controlling subsequent diagenetic processes on such exhumed MTDs. Groundwater flow followed different lithological and structural contacts, and blocks/clasts boundaries, allowing the formation of contact karst structures, consequently providing favourable conditions for incipient fracture systems to be formed. The complex "worm-like" network of such phreatic channels, together with paleo-topographic features defined by the shape and orientation of structures and slide blocks/clasts contacts, represents potential zones prone to gravitational collapse.

The presented results suggest that the correct interpretation of syn-sedimentary structures, for instance backed up by georeferencing of contacts and of orientation of slide blocks axis, allow the prediction of potential geomechanically weak areas of the quarry slopes where a landslide would likely be activated, and thereby contribute to implementing efficiency in the decision-making process in terms of safe mining or civil engineering.

Preliminary results of the Selanac debris flow modelling in RAMMS - a case study

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This paper will introduce preliminary results of numerical modeling of the Selanac debris flow as the largest debris flow triggered during extreme rainfall in May 2014 in Serbia. In the study area over 200 mm of rain during a 72h period had fallen, but cumulative rainfall reached more than 480mm per one month.

Generally, geological setting of the wider area, could be described as very complex, and imply ophiolitic melange (J2,3), dolomites, alevrolites and sandstones (T1), bituminous limestones (P3), and dacite-andesite aq. The process has developed along two ravines.

The model was made by using RAMMS Debris Flow software, which actually uses a one-phase approach (similar to avalanches, Voellmy-Fluid). This approach divides the frictional resistance into two parts: a dry-Coulomb type friction (coefficient μ) that scales with the normal stress and viscous-turbulent friction (coefficient ξ) which varies with the square of the flow velocity. Input data included pre-event DEM (30x30 m resolution) and analysis of Pleiades satellite data (from June 2014). RAMMS® software provides an opportunity to simulate results of maximum values of flow height, the velocity and pressure in different parts of the process. After calibration, some of models are chosen as the most representative, and presented discussion between different scenarios. Since the dimensions of debris flow are very large (1.4 km long, and 300 m wide, in the widest part) a lot of research is planned to be performed, but as a first step it will be represented by preliminary numerical models as a result of back analysis according to research up to now.

4-Landslide Mechanics and Simulation Models

The engineering geological and geomechanical properties of soil landslides at settlements Svrake, Sarajevo and the concept of rehabilitation

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The natural disaster of May 2014 affected the entire area of Bosnia and Herzegovina and the wider region. Intensive rainfall facilitated certain geological processes, such as slippage, erosion, landslides, mudflows and similar, with negative effects and widespread consequences everywhere.

One such landslide was the landslide in the village of Vogosca, which caused considerable material damage, and can be classified, according to order of magnitude, as a secondary landslide. The effect of failure mechanism was immediate, and there was very little time to save human lives and material goods. Yet thanks to the knowledge and experience of professionals who were able to help out various administrative bodies of the municipality of Vogosca and the Canton of Sarajevo, there were not a lot of casualties nor extensive material damage as the result of the landslide.

The geomorphological structure of the terrain, both on the micro- and macro-levels is a result of a complex tectonic structure, neotectonic processes, and the specific geotechnical and geological characteristics of the soil in both the blanket and the substrate.

The entire event underlined the need to make certain decisions regarding the continued use of the space that was caught in the landslide, and the need for further engineer geological and geomechanical research, together with the preparation of project documentation on Sanco landslides. Today's subject landslide remediation are carried out with monitoring procedures in order to provide the data necessary for the community to make some serious decisions regarding the utilization of the space concerned in the future. The aim of the paper is to show the characteristics of the micro-region, the concept of rehabilitation of space for future use, and the need to address the needs of permanent observation space, especially those that are subject to sudden geological and geomechanical changes.

Stože landslide triggering simulation using LS-Rapid

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In November 2000, after a long period of rainfall, the Stože landslide was triggered. In the first phase, a relatively dry landslide mass was stopped in the channel of the Mangartski potok. In its second phase, the landslide mass was soaked by inflowing water and turned into a wet debris flow that destroyed part of the village Log pod Mangartom and caused 7 casualties. The Stože landslide was one of the most severe landslides in the recent history of Slovenia, and the second phase of the wet debris flow was investigated by applying debris-flow numerical modelling in order to assess debris-flow hazard in the area under assumption that future debris flows can still be triggered on the Stože slope. Geotechnical laboratory tests were carried out to investigate rheological characteristics of these future potential debris flows. After 2000, several mitigation measures were carried out to protect the Log pod Mangartom village against a possible future debris-flow event of a similar magnitude.

In this study, LS-Rapid model was used to investigate the triggering phase of the 2000 Stože landslide. LS-Rapid was successfully applied to post-event analyses of the triggering phase in different parts of the world.

As topographic data for the Stože debris-flow numerical model we used the new LiDAR-based DTM with the resolution of 1m, and the old pre-event topographic maps to present topography of the Stože landslide area before the 2000 event. To determine geological units and soil parameters for the LS-Rapid model, the Geological map of Slovenia in scale 1:100,000 was used. Soil parameters and the depth of unstable mass for each geological unit on the Stože slope were determined based on geotechnical laboratory tests, experience and professional judgement. Only pore pressure was included as the triggering factor in the numerical model.

The numerical results find good spatial and volumetric agreement with the 2000 event. A comparison of the surveyed contour and the numerical modelling results show good matching with minor derogations which can be caused with a low resolution of geological data used in the numerical model. The estimated volume of the mobilised landslide mass was 1.25 million m^3, the simulated one was 1.29 million m^3. The numerical model of the first phase of the 2000 Stože event clearly showed that the triggered landslide mass from the Stože slope stopped in the channel of the Mangartski potok where then turned into a wet debris flow.

We can conclude on the basis of the study results that the LS-Rapid model can be used as the triggering model for numerical simulation of debris flow events, and as a tool to estimate potential debris-flow magnitudes in the process of debris-flow hazard assessment - nevertheless, debris-flow magnitude estimation in the case of very limited case history in the area under investigation remains one of the main challenges when assessing debris-flow hazard at a local scale.

4-Landslide Mechanics and Simulation Models

Analysis of possible reactivation of the Krbavčići landslide in the north Istria, Croatia

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The Krbavčići landslide occurred near the City of Buzet, Croatia, in January 1979 after long period of heavy rainfall. The landslide damaged local road and retaining wall at the landslide foot and a new stable landslide position was taken after major sliding. The Krbavčići landslide is located in the area of flysch rock mass susceptible to sliding with a lot of different types of mass movements recorded in the past. The field investigation performed in the summer of 1979 consisted of geological mapping and borehole drilling of 15 boreholes. The identified landslide dimensions are length of 370 m, width of 30 in the upper part and 150 m in the lower part. The investigation indicated the sliding surface inside the weathered bedrock zone, at the contact between the weathered and fresh flysch rock mass. Atmospheric activity and unfavourable hydrological conditions caused weathering of the flysch rock mass thus changing geotechnical and shear strength properties forming potentially unstable deposits.

The paper will describe existing information about the Krbavčići landslide occurrence, laboratory testing of flysch deposit samples taken from the landslide body and numerical modelling of a possible landslide reactivation. Basic laboratory tests such as specific gravity, grain size distribution and Atterberg limits determination will be performed. Undrained ring shear testing will be conducted to obtain residual shear strength. Digital elevation model will be derived from airborne laser scanning data performed in March 2016 with 1 cm resolution. Landslide numerical models will be made using LS-Rapid simulation software based on the back analyses and laboratory testing results. Conditions which cause Krbavčići landslide reactivation will be analysed and discussed.

Landslide remediation on north-west slopes in Zagreb area

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Increased construction of houses and urban villas on the slopes of Medvednica mountain on the northern edge of Zagreb accelerated natural processes on slopes, landslides and slope creeping and put it under a loupe of public. On the western part of these slopes in the beginning of 2013 and 2014 around half of all 238 registered landslides occurred. Landslides have been activated after rains and snowmelts. Two nearby locations in the area called Kustošija are described in the following paper. While talking with the residents who owned houses on the landslides, it became obvious that first cracks on slope surfaces were noticed in the previous year due to a long dry summer period. High underground water levels in January and February caused the progression of sliding, and loosened soil on surface absorbed an additional amount of rainwater. On each location we observed, accessing the landslide with heavier machinery was not possible so emergency remedial measures were adopted for a smaller crawling excavator. It was used for excavation of drain trenches, to drive wooden piles, cut from local wood, and to equalize the balance of sliding mass. Emergency measures were targeted at protecting the road, houses, sewage, gas and water supply and to slow down the landslide. While implementing emergency measures vertical inclinometer tubes were installed in the upper part of landslides to monitor landslide progression during remediation. Only after first remedial actions gave results and sliding slowed down, geotechnical investigation works were conducted. On both locations, it took more than six months for the design stage and to start construction works, because of various procedural and other reasons. During that time emergency actions proved to be a good choice and they helped secure people and property till the final remediation. The steep slope on both locations also influenced the technical solution. Landslide remediation measures included a retaining wall founded on small diameter bored piles, shifting soil masses on the slope, construction of drain trenches and planting vegetation. Monitoring these two landslide locations for four years gave good insight in the application of emergency and final remediation measures and their benefit and disadvantages. The aim of this paper is to present remediation process on these two case studies and emphasize positive elements and experiences of landslide remediation.

5-General Case Studies

The slow-moving landslides of the NW coast of Malta: insights from long-term monitoring and modeling

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Coastal landslides are common in the NW part of the island of Malta, which is located in the central sector of Mediterranean Sea. We produced and published a 1:7500 scale geomorphological map of NW coast of Malta including a detailed Landslide Inventory Map (LIM). LIM shows that rock spreads and block slides are more abundant respect other types of slope-failure processes and affect large portions of the NW coasts. Rock spreads affect the external portions of karst plateaus made up of Upper Coralline Limestone and are witnessed by the presence of persistent cracks, which can exceed 200m long. Rock spreads are generated by opposite mechanical properties of resistant Upper Coralline Limestone and underlying Blue Clays. The latter are characterised by a ductile behaviour and residual values of cohesion and friction angle.

Rock spreads often evolve into block sliding processes. Huge limestone blocks and pillars are detached or slowly lowered by the external cliffs of karst plateaus. These extensive block sliding accumulations are peculiar of NW coast of Malta and are made up by thousands of limestone blocks, which cover the gentle clayey slopes located between the sea and the foot of the plateaus' cliffs.

A spectacular example is Il-Qarraba peninsula, where tens of limestone blocks have been scattered by the action of outstanding rock spreads and block slides.

The Department of Chemical and Geological Sciences of University of Modena and Reggio Emilia and the research group of CNR-IRPI of Padua installed in mid2000s two networks of GNNS benchmarks in order to define the rates of surface displacements in two areas affected by extensive rock spreads and block slides.

As reported by scientific literature, GNNS technique is a robust procedure for the definition of surface displacements of landslides characterised by extremely slow or very slow kinematics.

GNNS surveys have been carried out every six months two times per year using a static configurations, related to the expected slow kinematics of the landslides investigated.

The first area monitored is located at the top of a 7000 m^2 wide limestone slab located in the central sector Il-Qarraba peninsula, whereas the second site is situated in the NE part of Anchor Bay, where three limestone blocks moved by a block slide could be hazardous for the buildings and the visitors of the main amusement park of Malta.

We have chosen Anchor Bay site and Il-Qarraba site:

i) for the spectacularity of the landslides;
ii) for the presence of risk elements such as tourist paths and/or buildings;
iii) for the existence of adjacent stable areas, essential for static GNNS procedures.

This paper presents the long-term GNNS outputs and the results achieved by means of 2D modelling of the monitored landslides.

Origin of planation surfaces in the hinterland of Šumljak fossil landslides, Rebrnice (Vipava Valley, SW Slovenia)

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The Rebrnice area represents NE slopes of the Vipava Valley located between the Karst plateau on the southwest and Nanos mountain range in the northeast. Rebrnice slopes are geomorphologically defined by a thrust front of Mesozoic carbonates over Tertiary flysch deposits and characterised by variety of different surface forms, among which recent and fossil polygenetic landslides are most prominent. Among this the Šumljak fossil landslides (0.56 km² large), composed of carbonate breccia, show specific geomorphological features. The most distinctive geomorphological element is the planation surface of the carbonate breccia blocks positioned in the hinterland of the Šumljak fossil landslides. Another one is the presence of local cliffs defining the border between the planation surface in the hinterland and the fossil landslide itself.

Our research suggests that the whole area in the hinterland of Šumljak fossil landslide might be a part of a rotary slip of a carbonate breccia. On the basis of breccia beds dipping in particular parts of the rotational blocks the rotation can reach up to 60°. The rotational blocks represented also the main source area of the slope material of Šumljak fossil landslides. Local cliffs on the external parts of planation surface represent the mains scarps of Šumljak fossil landslides that are the result of the triggering of small to larger mass movement events where the material in the form of debris and/or rock avalanche was transported to the lower slope area. These processes are relatively youngest and in the upper part of the sedimentary bodies cover the older deposits of complex landslides, created by various transport mechanisms and depositions processes.

5-General Case Studies

The Spatio-Temporal Dynamics of the Ciprnik complex Landslide, Tamar Valley, Julian Alps, Slovenia

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Mass movements represent important processes that shape the relief in Alpine areas. In this article, we present the spatio-temporal dynamics of the Ciprnik landslide (Julian Alps, NW Slovenia) and interpret its triggering and evolution. In the study area, mass movement activity is characterised by two phases: normal deposition on the fluvial fans that dominated up to 2000, and a more active phase related to the triggering of the Ciprnik complex landslide and formation of an additional debris- flow fan. The Ciprnik landslide started as a translational movement over the discontinuity plane that was mobilised into a debris-flow. The triggering and slope failure resulted from a combination of tectonics (i.e. dip-slope position of the strata, and strong fracturing), lithology (alternation of thin beds of carbonates and fine-grained clastics), and accumulation of precipitation. The debris-flow fan remains active and interfingers with adjacent active fluvial fans.

Using tree-ring analysis in studies of slope mass movements

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Due to base rock geology, tectonics and climatic conditions, several different types of slope mass movements are a very common phenomenon in Slovenia. They present a natural hazard to infrastructure, pose a potential social and economic disruption, can cause environmental damage and are endangering human lives. To evaluate the risk of potential natural hazards caused by slope mass movements, the key factor is establishing the spatial extent of previous events and determining their occurrence rate. Such information is often undocumented or unknown and consequently needs to be inferred from dating and analysing previous events that are recorded and preserved in the natural archive. Since trees have a specific response to slope mass movements, they can provide vital spatial and temporal information with dating capability of annual or even sub-annual resolution. To gain that kind of information, tree-ring analysis and dendrogeomorphological techniques need to be applied. In this sense we must understand the basic concept of "process – event – response", in which a specific process (i.e. specific type of slope mass movement) represents an event in the life of a tree, to which the latter has a specific growth response. Such responses are marked in tree-ring width and the tree's anatomical features. In cases of mechanical damages of a tree trunk caused by rockfalls, scars are formed to which a tree responds by producing callus tissue, whose purpose is to close the scar. It is produced immediately after the wound is made and provides us temporal information of the rockfall event. Tilting of a tree can be caused by accumulation of debris on one side of a tree or by ongoing ground creeping. Trees respond by producing reaction wood and growing eccentric tree-rings, which can also provide us with the direction of tree tilting. Partial burial of a tree trunk can be caused by debris flows, hyperconcentrated flows, landslides and floods to which trees respond with an abrupt growth reduction. This is expressed in production of very narrow concentric tree-rings. If the vegetation is cleared by a slope mass movement the uninjured neighbouring trees respond with an abrupt growth increase marked by wider tree-rings. Wider tree-rings are produced due to higher amount of accessible nutrition, space, light, water and having less competition. However such a response can be delayed for a few years, therefore dating of events by the growth increase is less accurate. Dendrogeomorphological analysis is widely proven to be very successful in studies of slope mass movements abroad. Although Slovenia is highly forested and slope mass movements pose a threat, tree-ring analysis has not been extensively used in geomorphological studies. Therefore tree-ring studies and dendrogeomorphological techniques present a promising technique in further research of slope mass movements in Slovenia.

5-General Case Studies

Ground movements and effects as the result of mining activity in residential areas of Albania

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This paper describes the results of the geotechnical investigation carried out in the past decade on ground movement-subsidence and the effects of mining activity in residential areas. Albania is a country that is particularly rich in minerals. The exploitation of said minerals constitutes a very important component in the Albanian economy. Traditionally, Albania has produced many minerals and raw materials. The main mineral products of the mining industry that are sold abroad are chrome, copper, iron-nickel, coal, and raw construction materials. Since 1950, some 42 million tons of coal, 37 million tons of chromium and 22 million tons of copper from Albanian mines have been exploited. The chromium and copper were exploited from 23 chromium and 20 copper deposits, which are located in the Tropoja, Kukesi, Mirdita, Dibra, Mati, Pogradeci and Korça districts. They are related to ultrabasic, volcanogenic-sedimentary and volcanogenic-hydrothermal-metasomatic rocks. The present paper presents a picture of mining activity in Albania and its effects on the geo-environment by illustrating several case studies performed in various residential zones. The effects/damage from mining that has recently come to light in the mining area confirm that the geotechnical conditions of the mining areas are both weak and unstable. By exploiting chromium ore from underground, particularly in the Bulqize area, many large cavities have been created, which time and again have collapsed, causing a lot of funnel-shaped subsidence with a diameter of 7-15 m and 12-25 m deep. In addition, we should emphasize that underground works like galleries and tunnels have significant influence on the geo-environment in urban areas. Over the years 1995-2000, a tunnel below the town of Bulqiza and running through the Vajkali valley was built for mining purposes – one that has disrupted the hydrogeological regime of two confined aquifers as well as the fissured-tectonic ultrabasic rocks and the alluvial deposits (rubble, gravels, pebbles, sands, etc.), from which a large amount of underground water is discharged out into the Bejni stream. As a result of the water drainage of the Vajkali aquifer, which consists of alluvial deposits (rubbles, gravels, pebbles, sands etc.) a land subsidence some 0.7-0.9 km wide, 1.2 km long and 2.0-3.5 m and up to 4.1 m deep occurred. As a result several homes and roads were damaged, and some 0.15 km2 of agricultural area was lost to the water and formed a small lake. Furthermore, coal in Albania is generally found in molasses rocks and less so in flysch rocks and is located between layers of claystone and siltstone. There are 14 main coal deposits in the country, located in Mborja-Drenova and Gore-Moker, Tirana, Durres and the Tepelena area. Coal exploitation has created many a subsidence on the land, of which we can mention the subsidence that occurred in the villages of Valiasi and Mezezi (Tirana district), the village of Manza (Durresi district) and the Memaliaj urban area. Generally speaking, they appear in the shape of a funnel, with a diameter of 5.0-10.0 m and are 4.0-8.0 m deep. Similarly, many roads and buildings have been damaged (fissured masonry) and destroyed as a result of these subsidence occurrences. It is important to note that the geotechnical mapping carried out in recent years points to the conclusion that as the result of uncontrolled population movements connected with government institutions after 1995 many new structures (home, roads etc.) were built, which constitutes a high risk for residents.

Finally, from this study we determined the key hazard areas, which was presented in the form of a analytical geohazard map at a scale of 1:10,000. At the end of the present study both conclusions and recommendations are given, and which underlines the locations of the hazardous areas and recommends engineering measures to prevent subsidence-related events.

Construction of Corridor 10 highway - case histories of cut instabilities

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This paper presents the state of practice (SoP) examples in relation to the construction of the Corridor 10 highway project, crossing Republic of Serbia. The eastern branch of Corridor 10, namely E80 highway, crosses several major geological formations, all exhibiting specific rock mass behaviour during and after cut excavation. The dozens of instabilities are a consequence of slaking at the face of excavation, low initial strength parameters and/or time dependant reduction of shear strength properties. Instabilities are grouped according to processes leading to failure. Several examples, each representing one group, are shown in detail.

It is particularly important to mention that over 60% of all problems related to extension of project deadlines and increase in construction costs are a consequence of 'unforeseen geological conditions'.

These experiences show the importance of performing high-quality geotechnical investigations during execution of major civil engineering projects.

6-Remedial Measures and Effects

Recent landslide risk assessment and remediation in the city of Karlovac

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During August, September and October 2014 in the Karlovac area heavy precipitation was recorded. Due to heavy rainfalls and flooding 135 landslides were activated. It was necessary to describe all of the activated landslides and separate them according to the risk assessment degree. Subsequently, emergency remediation measures and actions were adopted. This paper describes the course of the emergency landslide remediation which consisted of field inspection, landslide assessment and actual remediation measures. Field inspections for 30 landslides were conducted and, based on it, landslide assessment is defined. During field inspections standardized forms were fulfilled in order to describe actual engineering geological conditions on each landslide location. The standardized engineering geological forms include a sketch of the landslide and associated photo documentation. Based on results of the field inspection suggestions for further measures are given. These measures were: geotechnical investigation works, temporary retaining structures, remediation designs and actual remediation works. The conducted assessment provides a simple and straightforward way to evaluate landslide condition and risk level for each location. Each landslide is divided into one of three risk levels. Low risk level means there is no jeopardy of the current retaining structures and no damage to buildings and installations. Suggested remediation measures for low level risk are: regular visual inspections carried out by a geotechnician and a selection of standardized technical solutions. Medium risk level means there is a potential for the landslide to speed up or to spread further but without compromising the safety of the nearby inhabitants. Retaining structures may be damaged, but can be repaired and there is no damage on permanent structures. Suggested remediation measures for medium level risk are: regular monitoring, preliminary geotechnical investigation works and a selection of standardized technical solutions. High risk level means there is a strong possibility for a sudden landslide activation in which permanent structures and installations as well as retaining structures can be seriously damaged while safety of the nearby inhabitants would be endangered. Suggested remediation measures for high level risk are: geotechnical investigation works, preparation of the remediation design, the designed remediation work should be conducted and permanent regular monitoring should be established. On each location remediation works should start as soon as possible regardless of the estimated risk level. In the observed Karlovac area low and medium risk level locations were quickly remediated according to typical technical solutions used in geotechnics. High level risk locations were remediated according to the design based on detailed geotechnical investigation works. After the remediation was completed, continuous monitoring was established.

Estimation of the possible economic losses of large water transportation systems due to landslides, Case studies from Republic of Macedonia

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Landslides present a major risk in the Republic of Macedonia. In the past ten years, on the territory of the Republic of Macedonia there had been over 150 landslides with significant economic impact on the infrastructure. Most exposed to the risk of landslides are the roads, waterlines, parts of certain towns or municipalities and some agricultural surfaces. The presented paper deals with two case studies of landslides that had endangered waterline systems. The landslide "K0" in town Bitola, at the intake pipeline that caries water from lake Strezevo to the largest electricity power plant in the country "REK-Bitola" for cooling, and landslide at the siphon "Vrutok" of the system "Sharski vodi" that caries water to the lake "Mavrovo" near town Gostivar. These landslides had significant effect on the functionality of these two very important large water transportation systems. The basic information for the water systems and their importance for Macedonian economy are explained, as well as the geological and geotechnical properties of the landsides K0 and Vrutok. Detail economic analysis is performed for both cases in relation to costs for geotechnical investigations, costs for proposed remediation measurements, and, the possible economic losses if no action is undertaken in near future. The analysis showed that if the landslides are not remediated, the economic losses due to failure will be much larger than the total amount of funds spent on investigation and remediation works.

7-Social, Political and Economic Impact

A web service for landslide mapping based on Earth Observation data

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Landslides pose a recurrent natural hazard in almost all mountainous regions of the Earth, claiming people's lives and destroying man-made infrastructures. Therefore, regional authorities, infrastructure maintainers, and emergency services require information on past and new occurrences of landslides in order to protect infrastructure at risk and to manage the damages. Information on landslides is often collected by time-consuming and expensive ground surveying and manual image interpretation after landslide triggering events. The high workload for data acquisition and the subjectivity associated with visual image interpretation lead to a trade-off between completeness, accuracy and detail. The increased availability and quality of Earth Observation (EO) data in combination with new computational methods foster attempts to automate the preparation of landslide maps while reducing time and costs. However, there is still a lack in science-policy interaction and in providing innovative tools and methods that can easily be used by stakeholders to support their efforts in rapid mapping, documentation and monitoring of landslides.

Taking up this issue, we introduce a web-based service for efficient and user-oriented landslide mapping based on EO data. The three main components of the service are: (1) to gather and define the user needs and requirements, (2) to develop semi-automated object-based image analysis (OBIA) methods and to implement them in the web-service, and (3) the web mapping application with its responsive user interface. User requirements were collected during semi-structured interviews with regional authorities and stakeholders. The potential users were asked about the value they see in using EO data for landslide investigation and about their expectations to a landslide web mapping service regarding reliability and usability. The interviews revealed the capability of the service for landslide documentation and mapping as well as for monitoring of specific sites that are prone to landslides and for updating and complementing existing landslide inventory maps. Furthermore, the users see a substantial potential for landslide rapid mapping. Based on the user requirements analysis a concept for the implementation of the landslide service was defined. Optical satellite imagery from different high resolution (HR) and very high resolution (VHR) sensors, e.g. Landsat 7, Sentinel-2, WorldView-2/3, was acquired for selected study areas in the Austrian and Italian Alps. Semi-automated OBIA methods were developed for mapping landslides. Selected mapping workflows and demonstration examples for landslide mapping and monitoring were integrated in the service by means of a web processing chain, including a step-by-step description. By that, the user is able to gain insights into the service idea, the potential of semi-automated mapping methods and the applicability of various satellite data for landslide mapping. An easy to apply and guided mapping workflow, including image segmentation, statistical classification and manual editing options, enables the user to perform his/her own analyses. Moreover, users can compare the classification results to freely available data such as OpenStreetMap to identify landslide-affected infrastructure (e.g. buildings, roads, mountain trails). They also can upload their own EO data and infrastructure data in predefined formats for specific mapping tasks or assessments.

For validation, the classification results can be downloaded or compared against uploaded reference data using the implemented tools. For the latter, basic accuracy assessment measures are implemented. The service is validated in collaboration with stakeholders, decision makers and experts, which is essential to produce landslide information products that can assist the targeted management of natural hazards. A further step is to evaluate the potential of the pre-operational landslide mapping service towards the development of an operational Copernicus downstream service.

MyDewetra CapRadNet: the evolution of the DewetraNet platform for hydrometeorological risk management and marine ecosystems monitoring

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MyDewetra CapRadNet is the evolution of the Dewetra platform, since 2008 a fully operational platform used by the Italian Civil Protection Department and designed by CIMA Research Foundation to support operational activities at national or international scale. In 2012, the platform has been officially endorsed by the World Meteorological Organization. Originally a single-application web-GIS platform aimed to multi-risk mapping, forecasting and monitoring, the system has evolved into a portal of several applications designed also for marine ecosystem monitoring and to ease the fostering a community of expert users through the capabilities provided by the standards of the web 2.0 like the social networks.

The CapRadNet project has allowed the deployment of the updated system to the national and international (Albania, Bosnia Herzegovina, Croatia and Slovenia).This paper provides a deeper insight on its components and how they can be of use to the stakeholders.

MyDewetra CapRadNet platform is the evolution of the Dewetra and DewetraNet platforms that already have proven themselves to be effective in the full cycle of emergency management: (1) in the preparedness phase, supplying the end user with all the available information needed to assess a complete risk scenario, from the characterization of an incoming hazard to its possible impact to people and infrastructures; (2) in the response phase, with the most updated data provided by the real-time or near real-time monitoring tools; (3) in the recovery phase, displaying data about shelters, infrastructures; (4) in the mitigation phase, updating the risk/hazard maps, making it possible to overlay impacts, human activities, historic data for climate change assessment. Due to its ICT distributed architecture, MyDewetra CapRadNet is able to cope with restraining data policies as the data are not physically transferred from the owners/producers but shared through standard WXSs, thus the providers are in charge of data publishing, sharing, storage and operational efficiency and the end-users eventually have the possibility of visualizing all the needed information. As Dewetra and DewetraNet, MyDewetra CapRadNet is a customization of an open-source application developed following common ISO/WMO standards: interested stakeholders, research and public institutions may request directly to the developer or through a WMO cooperation agreement.

7-Social, Political and Economic Impact

The role of multisector partnerships in the landslide prevention

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Community residents, living in the area exposed to natural hazards, can contribute with practical knowledge in implementing practices in risk management by engaging and working with, local authorities and responsible organisations. Rapid urbanization and growth of unauthorized and densely populated areas in hazardous locations are powerful elements in a risk management cycle. There is an increasing trend of landslide occurrences in recent years, but implementation of landslide mitigation is still lacking.

RECALL project aims to address these issues with the establishment of the local cooperative team and recognizing the particular importance of supporting the multisector partnership in landslide prevention.

RECALL was a two years project, co-founded by the European Civil Protection Financial Instrument, with the main objective oriented to design and implement smart, community-based solutions supporting local authorities in the better planning and implementing of landslide and disaster prevention measures in their territories: (1) detailed analysis of the state of the art of reinforcement measures, state of maintenance, priorities of investments in 4 European pilot areas (Slovenia, Italy, Croatia and Greece); (2) organization and training of special cooperatives teams composed by civil protection personnel and citizens that will cooperate with the local authorities in the monitoring and prevention of landslides risk; (3) development of 2 innovative, specific IT tools, aimed at providing support to the local territorial authorities and cooperative teams in their actions regarding the landslides

On December 2015 the official RECALL cooperative team for the landslide area Potoška planina (Slovenia) was established, involving 20 representatives from Geological Survey of Slovenia, geodetic company, torrent maintenance company, the Municipality of Jesenice, ACPDR Branch Kranj, Agrarian community Potoki and inhabitants of the Koroška Bela.

Specific objectives of such a cooperation can be summarized in five segments: (1) Observation and monitoring landslide changes (through field trips); (2) Recording landslide changes (using e-TOOL-Prevention); (3) Installation of a monitoring system at the lower part of Potoška planina landslide to provide real-time monitoring data of surface movement patterns and the immediate notification of landslide activity and landslide behaviour; (4) Performing small maintenance work at the hinterland of Koroška Bela village, situated at the bottom of Potoška planina area (uninterrupted access to the torrent barrier) and (5) Informing public and responsible national institutions about the importance of prevention.

To provide cooperative team members with the skills and competences that they need for monitoring activities, we have organized more than 20 training sessions with emphasis on scientific knowledge transfer about natural risk mitigation and usage of different e-tools, developed within the project RECALL.

Throughout the RECALL project cooperative team got more professional and accurate information about the state of Potoška planina landslide and its potential risk on Koroška Bela village. The cooperative team was involved in research and measurements/monitoring of the landslide, which contributed to a better understanding of the landslide, and thus the planning of measures to reduce the risk can be improved. The project also included local residents; thereby experts obtain additional information about the landslide characteristics and assistance in monitoring and observing the landslide, while residents obtain information on the landslide activities taking place at the field. All mentioned contributions provide more transparent functioning of the responsible national institutions and the trust of people in their work. The final results of the project will also help the local community in a dialogue with the responsible national authorities to provide additional funding for monitoring landslide and implementation of more effective landslide risk reduction measures.

Damage caused by landslides and other natural disasters in Slovenia between 1991 and 2008

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The paper presents an analysis of data on damages caused by landslides and other natural disasters in Slovenia. The data were systematically collected by the Statistical Office of the Republic of Slovenia from 1991 to 2008 for fourteen categories of disasters: earthquakes, floods, fires, drought, windstorms, hail, frost, glaze, landslides and avalanches, epidemics, epizootics, damage caused by various pests and diseases, ecological disasters, and other natural disasters. Data by statistical regions (NUTS 3) are available from 1992 to 2008, and data by municipalities (LAU 2) and administrative units (LAU 1) are available from 1992 to 2005. The 1991 data are available only at the country level.

Analysis of the data shows that from 1991 to 2008 direct damage caused by natural disasters amounted to an average of 0.48% of annual GDP, or an average of €45 per capita a year.

Unfortunately, the Statistical Office collected data on the damage caused by landslides and avalanches together. Considering that avalanches did not cause substantial damage during this period, it can be concluded that the majority of damage was caused by landslides. According to these data, landslides and avalanches caused 9% of overall damage due to natural disasters. The following years have stood out in this regard: 1991 (11.1% of overall damage due to natural disasters), 1994 (10.2%), 1995 (16%), 1996 (22.4%), 1998 (14.1%), 1999 (32.1%), and 2002 (17.8%).

Damage caused by landslides and avalanches ranked fifth after damage caused by droughts (27.3% of overall damage), hail (17.8%), floods (15.5%) and storms (14.3%).

In total, there was more than 100 million euros in direct damage caused by landslides and avalanches. Considering the available data on costs for the elaboration of landslide hazard maps for Slovenian municipalities, we calculated that the elaboration of these maps for the entire country would require “just” 5% of direct damage that were caused by landslides and avalanches over the study period. These correspond to reports that the ratio between the savings due to prevention and the funds invested in recovery ranges from 1:10 to as much as 1:2,000.

7-Social, Political and Economic Impact

Landslide Risk Reduction and the Slovenian National Platform on Disaster Risk Reduction

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The United Nations Office for Disaster Risk Reduction (UN ISDR; http://www.unisdr.org/) encourages the establishment of multi-stakeholder coordination mechanisms for disaster risk reduction, including National Platforms for Disaster Risk Reduction (NP DRR), to highlight the relevance, added value and cost-benefit of a coordinated and consistent approach to disaster risk reduction at the national level.

Countries and national platforms are therefore key partners to implementing disaster risk reduction strategies at a country level to help build resilient communities – a list of countries with their national platforms and national focal points to support the Sendai Framework for Disaster Risk Reduction (SF DRR) is given here: http://www.unisdr.org/partners/countries.

As of September 2017, there are 68 National Platforms established in the world, looking at the Adriatic-Balkan region, the following countries have their national platforms (given in the alphabetical order): Bosnia and Hercegovina, Bulgaria, Croatia, Greece, Hungary, Italy, Macedonia, Montenegro, Serbia, and Slovenia. Looking at the list, we may conclude that only Albania and Romania (and Kosovo) are still without of a national platform, but they have national focal points for the Sendai Framework. The Slovenian National Platform was established in July 2014 as the Council of the Government of the Republic of Slovenia for Protection against Natural and other Disasters; it is a kind of an advisory body to the national government, acting as the Slovenian National Platform for Disaster Risk Reduction.
The structure of the Slovenian NP is as follows:

a) Governmental bodies:
- Ministries: the Environment and Spatial Planning; Interior; Infrastructure; Health; Foreign Affairs; Education, Science and Sports; Culture; Defence
- Office of the Prime Minister of the Republic of Slovenia
- National Civil Protection Commander

b) Non-governmental organisations:
- Fire Fighting Association of Slovenia
- Slovenian Red Cross
- CIPRA Slovenia – Association for the Protection of the Alps
- Slovenian Electronic Communication Society SIKOM

c) Academic and research institutions: Slovenian Rectors Conference & Research Centre of the Slovenian Academy of Sciences and Arts

d) Local level administration bodies: Associations of Municipalities of Slovenia

e) Private sector entities: Chamber of Commerce and Industry of Slovenia

f) Media: RTV Slovenija (The Radio and Television Corporation of Slovenia)

The main aim of the Slovenian NP is to facilitate dialogue between the Government of the Republic of Slovenia and the civil society as well as non-governmental, scientific and research, and other organizations and associations on disaster risk reduction, building disaster resilience and sustainable development in line with the objectives of the SF DRR 2015-2030.

The paper discusses some strategic UN documents on DRR, stressing the SF and the indicators for its implementation, with regard to NP, and the possible cooperation of NP DRR in the ABN countries with ICL and its on-going and future activities, such as the Sendai Partnerships 2015-2025 as an ICL voluntary commitment to SF DRR 2015-2030.

Rockfall Risks Management in the Slovenian Road Network

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The entire state road network in Slovenia consists of 5936 km, of which over 40% cross rock formations involving slopes with various risks of rockfalls. Due to the increasingly frequent rockfall events and consequent casualties in recent years it has become necessary to establish appropriate procedures for the analysis of rockfall risks for the entire Slovenian road network.

The first part of activities was establishing the Methodology for the Qualitative and Quantitative Analysis of Rockfall Risks. The Methodology is based on historical database of rockfall events of the state road network, on traffic and roads parameters and on morphological and geological parameters. It is also supported by an application for slope risk evaluation. This tool is first level of a decision support system for the road authorities with influence regarding traffic safety and the socio-economic benefits for society.

The next task in the process that is still ongoing, is the production and implementation of "Technical specification for protection against rockfall" that includes effects of actions, design, monitoring and maintenance. We are expecting to conclude this technical specification within a year.

In a preliminary stage is also establishing the system for early forecasting and warning of rockfall events because of increased precipitation in the road infrastructure area with measures to prevent and mitigate the consequences. The activities are going on in cooperation with the Geological Survey of Slovenia that already has significant geological database, experiences and knowledge.

Levels of activities

Under the responsibility of Slovenian Infrastructure Agency- Department for Maintenance and Protection of Roads and Traffic Safety and DRI Investment Management the five levels of activities has been established.

a. Implementation of immediate measures for establishing the transportability of roads just after the rockfall events.

b. Implementation of final measures during the establishing the transportability – the measures has to be completed in a shortest possible period (the design and execution works are taking place practically in the same time).

c. Implementation of measures within the yearly plan of rehabilitation works based on the "Methodology".

d. Monitoring and maintenance of implemented measures.

e. Establishment of the early forecasting and warning system for potential rockfall events.

Case study - Rokfall "Trbovlje"

The case study of the implementation of final measures within the phase of establishing the transportability of the road happened on 20th February 2016 when over 350 cubic meters of rock and debris collapsed onto the state road R1-223/1229 Bevško- Most čez Savo. The road section was closed and the residents were cut off from electricity and water supply, one person had been seriously injured.

In order to establish an immediate connection between the cities, site investigations and software analysis that indicated the design and protective measures had to be completed in the shortest possible time. Due to heavily fractured residual rock mass at the mountaintop, it was not feasible to remove it because of a potential damage of an important nearby railway – that was the reason that the only possible solution was the installation of the 8000kJ rockfall barrier.

The drilling for anchors installation for 8000kJ rockfall barrier started on March 8th 2016. Additionally, two 500kJ barriers systems were selected to protect the lower part of the slope and slope erosion protection has been done as well - everything in extremely short time. On April 4th 2016, 44 days after the rockfall, the technical inspection board issued the confirmation of the acceptance.

Within the yearly plan of rehabilitation works in 2017, the additional measures had been implemented only 60 m away from the previously stabilised area. The stabilisation of 70 cubic meters unstable rock mass with anchoring was performed, additionally 3000kJ and two 500kJ rockfall barriers has been alsoinstalled. After this remedial works the most threaten road section in the area of Trbovlje had been protected against the extremely high risks of rockfalls.

The field of engineering geological investigations, design and implementation of protective measures is complex and need experienced investigators and operators - it should be emphasized that these works are specific and extremely dangerous. We also find that various professionals are dealing with different approaches, which often lead to different conclusions. One part of solution will be the use of Technical specification for protection against rockfalls, as well as the cooperation with scientific groups and institutes dealing with these topics.

Field study tour

1. Landslides Vipava valley

All stops lie in the Vipava valley, SW Slovenia, whose northern flank consists of fold and thrust structure of the External Dinarides composed of a series of nappes of Mesozoic carbonates thrust over Palaeogene flysch. Such a geological setting and steep slope morphology led to a number of various mass movements, which will be visited during the excursion.

STOP 1. First stop will be Stogovce landslide near the town of Ajdovščina. A landslide was triggered during an extreme precipitation event (300–520 mm) between the September 16th and 20th in year 2010. Material is comprised of debris of fractured Upper Triassic limestone and dolomite and weathered flysch, and due to its measured movements, is still capable of being transformed into a debris flow. Present movements (2012–mid 2015 period) are in range of several cm/month, with cumulative movement of 45 cm in this period., and depth to the slip surface was detected from 13 m to 25 m. From this stop, several huge carbonate blocks will also be visible on the slopes of Čaven mountain, which have detached from the high carbonate plateau and rotated during the transport. Transport ranges from 80 m to about 2 km, and block areas range from 7.5–175 ha.

STOP 2. We will continue to the nearby Slano blato landslide above the village Lokavec, one of the biggest mass movements in Slovenia. During the period of heavy rain on 17–19 November 2000, the landslide was reactivated as mudflow with velocities up to 60–100 m/day. The landslide is currently 1.4 km in length and boasts a volume of more than 1 mio m^3. Several mitigation methods were constructed, including a small rockfill dam, deep concrete shafts in the upper part, and two 2 m and 13 m high concrete dams. Present activity is constrained to the main scarp only.

STOP 3. We will stop at the Hubelj spring, among one of the largest water supply karstic springs in the Vipava valley. Spring emerges on the contact of Upper Triassic and Jurassic limestones, overthrusted on Eocene flysch. The spring mean discharge is 3 m^3/s, with minimum and maximum values from 0.2 m^3/s to 59 m^3/s. Apart from being the drinking water source for the town of Ajdovščina and surroundings, spring is important for the evolution of recent landslide morphology. Hubelj spring has eroded a large volume of a huge fossil rock avalanche deposits of nearby Gradiška gmajna, with thickness of carbonate gravel sediments up to 50 m. Estimated volume before the erosion is 19 mio m^3, and present volume about 10 mio m^3. Age of the event is not known.

STOP 4. Final stop will be in the Rebrnice region, a SW-facing slope that borders the Vipava Valley and the NE-lying Nanos Plateau in SW Slovenia. Several fossil and recent complex landslides appear in this region, with total volumes of about 2.8 mio km^3. We will visit the Podboršt landslide, one of the many landslides with open active deep fractures and mitigation measures (pile walls) close to the constructed highway, which transects the landslide body. Sediments mostly comprise the debris, carbonate gravel, and weathered flysch.

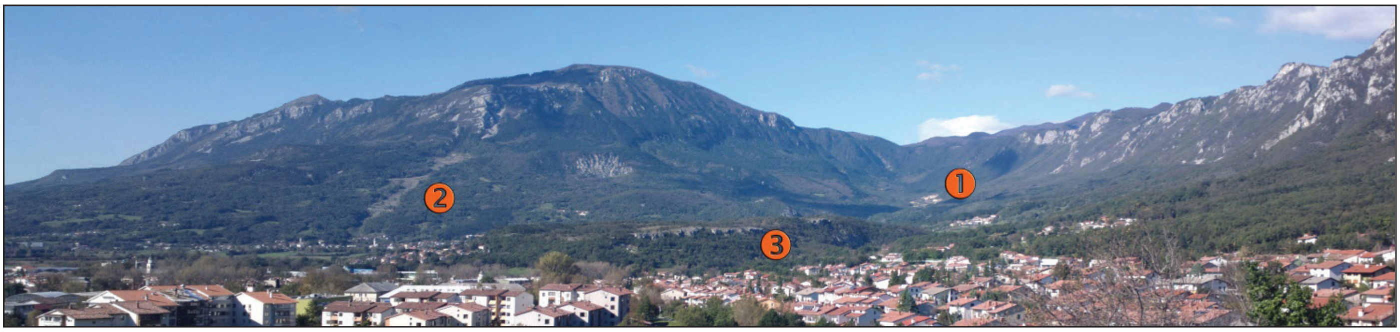

Fig 1. Landslides Stogovce (1), Slano blato (2) and Gradiška gmajna (3).

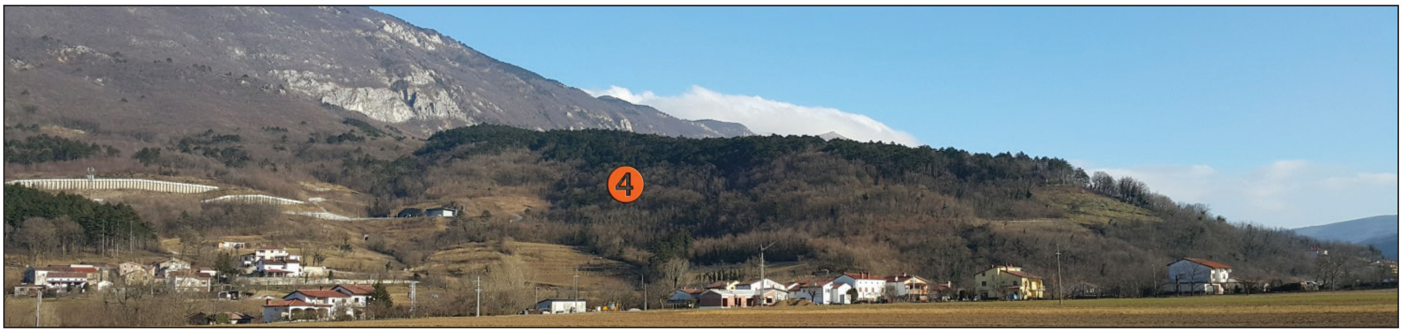

Fig 2. Landslide Podboršt (4).

2. Potoška planina landslide

Potoška planina landslide is situated in the NW Slovenia, in the Karavanke mountain ridge, near the town Jesenice (Fig. 1). During the field trip we will observe surface features, different types of slope mass movements and real-time monitoring techniques.

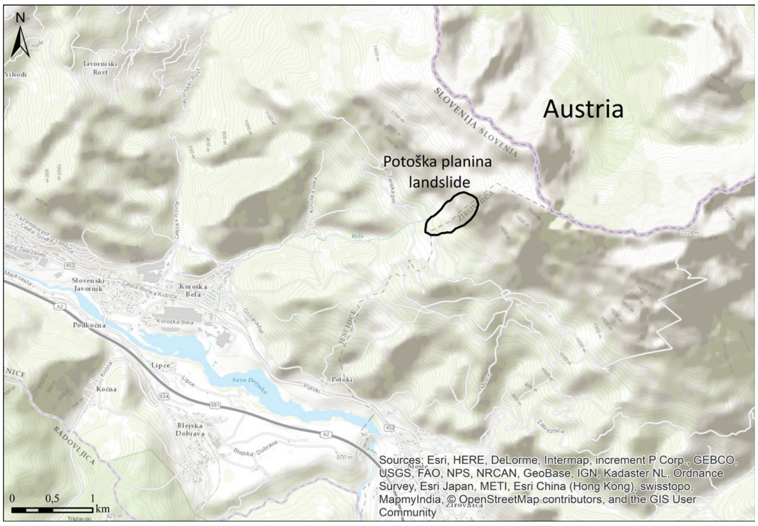

Fig. 1 Location of the Potoška planina landslide.

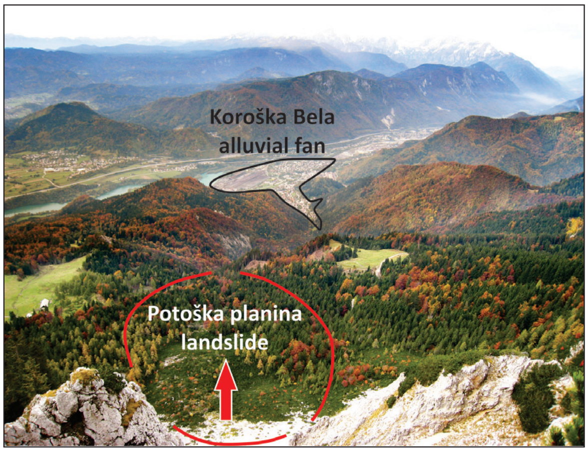

Fig.2 A view from the top of the Potoška planina landslide looking directly down the slide to the underlying village of Koroška Bela.

The broader area of the Potoška planina landslide is known to have experienced severe debris-flow events in the recent geological past. The most recent of these events occurred in the 18th century and caused the partial or total destruction of more than 40 buildings and cultivated areas in a village downslope (Koroška Bela) located in the area of the alluvial fan. Presently, some 2,200 inhabitants live in the area of the alluvial fan of past debris flows.

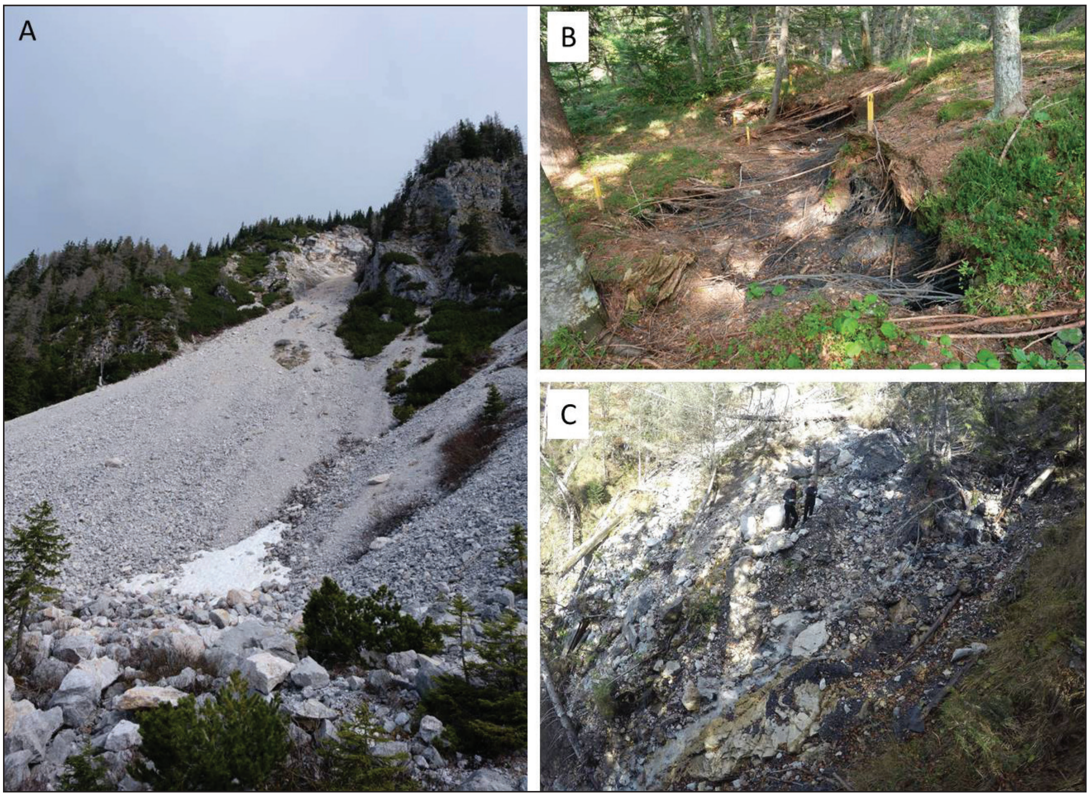

Fig. 3 Potoška planina landslide is subjected to different slope mass movements.

During the field trip we will observe rockslides and runoff of talus material in the upper part (Fig. 3A), to deep-seated slow-motion slide in the middle part (Fig. 3B) and active slope mass movements at the toe of the landslide (Fig. 3C), which is considered to be the most active part of the landslide. The sliding mass in this part is composed of tectonically deformed and weathered clastic rocks covered with a large amount of talus material, which is unstable and prone to landslides.

Along the way we will also see the new established monitoring system which serves for real-time monitoring of the surface patterns at the toe of the landslides (Fig. 4). Monitoring system provides images that are transmitted in real-time through the network for transmission and enable immediate notification of landslide activity and landslide behaviour.

Fig. 4:Real-time monitoring.

Previous studies on the Potoška planina landslide (http://link.springer.com/article/10.1007/s10346-016-0759-6), using UAV photogrammetry and tachymetric measurements, showed a steadily downslope movement of the entire area with localised surges of superficial slips.

The Potoška planina landslide was part of the International Programme on Landslides (IPL) project “Study of the slow moving landslide at Potoška planina (Karavanke Mountains, NW Slovenia)” (IPL-188).

NOTES

Notes

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