Date of Submission	7th August 7, 2017

IPL Project Proposal Form 2017

(MAXIMUM: 3 PAGES IN LENGTH)

1. Project Title: *KOSTANJEK LANDSLIDE MONITORING PROJECT (Zagreb, Croatia)*

2. Main Project Fields

Select the suitable topics. If no suitable one, you may add new field.

(1) Technology Development

A. Monitoring and Early Warning,

B. Hazard Mapping, Vulnerability and Risk Assessment

(2) Targeted Landslides: Mechanisms and Impacts

A. Catastrophic Landslides,

B. Landslides Threatening Heritage Sites

(3) Capacity Building

A. Enhancing Human and Institutional Capacities

B. Collating and Disseminating Information/ Knowledge

(4) Mitigation, Preparedness and Recovery

A. Preparedness, B. Mitigation, C. Recovery

3. Name of Project leader:

Martin KRKAČ

Affiliation:

Assistant Professor

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Core members of the Project

Names/Affiliations: (4 individuals maximum)

- **Snježana Mihalić Arbanas, Full Professor,** University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
- **Sanja Bernat Gazibara, Research Assistant,** University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
- **Marin Sečanj, Assistant,** University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering
- **Željko Arbanas, Full Professor,** University of Rijeka, Faculty of Civil Engineering

4. Objectives: (5 lines maximum; what you expect to accomplish?)

   The project aim is to develop a procedure for prediction of the Kostanjek landslide movement in order to mitigate the landslide risks. Establishment of the procedure for prediction of the landslide movement consists of two objectives. First objective is development of the phenomenological (statistical) model for prediction of landslide movement and the second objective is automatization of the landslide prediction process through the development of customized software.

5. Background Justification: (10 lines maximum)

   In cases of deep-seated and large landslides, costs of remediation are often unsustainable and the stabilization of slopes often cannot be achieved. In areas where deep seated and large landslides occur in urban area, prediction of landslide movements is sometimes the only risk prevention measure that has a practical benefit in the avoidance, or at least minimization, of adverse impacts on humans, property and the environment. The Kostanjek landslide is urban, deep seated landslide, which endanger approximately 290 buildings placed inside landslide borders. Kostanjek landslide is located in the City of Zagreb, covering an area of approximate 1 km^2. Prediction of the Kostanjek landslide movement is an important step that enables prescriptions of adequate emergency management measures, necessary for public safety. Additional benefit of the project is opportunity for the research community to test instrumentation and monitoring technologies, to develop landslide movement prediction models, early warning systems and to better understand the mechanics of slow-moving masses.

6. Study Area: Kostanjek landslide, located in the urbanized area of the City of Zagreb, Croatia.

7. Project Duration: (1 line maximum): 2 years

8. Resources necessary for the Project and their mobilization, Personnel, Facilities, and Budgets

   Resources necessary for the Project are available at the University of Zagreb (Faculty of Mining, Geology and Petroleum Engineering) and City of Zagreb (City Office of emergency management).

9. Project Description: (30 lines maximum)

   The IPL project is an extension of bilateral scientific Japanese-Croatian SATREPS FY2008 project 'Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia' that lasted from 2009 to 2014. During this project a monitoring system on the Kostanjek landslide has been established for the purpose of an early warning system (EWS). Landslide monitoring activities began in 2011 with continuous monitoring of landslide movement, groundwater level and precipitation.

   Next phase in Kostanjek landslide research (the aim of the IPL project) is development of a procedure for an EWS, necessary for emergency management. EWS procedure consists of development of various prediction models and customized software for automatic prediction of landslide movement. Prediction models within the framework of the project are statistical models

based on methods such as random forests or multiple linear regression. In order to obtain prediction model it is necessary to establish the complex relationships between precipitations, groundwater level and landslide movement from the continuous monitoring data for the period between 2012 and 2018. Complex relationships between landslide movement and triggers will be established with different training models using various parameters obtained from time series of monitoring landslide movement, groundwater level and precipitation data. After definition of appropriate parameters, statistical models should be tested for different periods. The most accurate models will be selected for the landslide movement prediction and EWS.

After definition of appropriate models, automatic procedure for prediction should be established. Automatic procedure consist of customized software which allows daily automatic input of monitoring data, filtering of data, calculation of parameters necessary for landslide movement prediction and prediction of landslide movement for different periods. Software should allow automatic update of models with new measured data allowing more accurate predictions. Predictions of landslide movement should provide useful information in periods of landslide reactivation and can serve as a decision making tool for emergency management offices in City of Zagreb.

10. Work Plan/Expected Results: (20 lines maximum; work phases and milestones)

The project encompasses several stages. First phase include preliminary analyses of the data collected in the period from 2012 to 2018. The GNSS, groundwater level and precipitation data time series should be examined and filtered in order to remove false data from further analyses. In second phase various prediction parameters, such as antecedent precipitation or groundwater level change rate, should be calculated. Third phase include development of several landslide trigger-movement models with statistical methods such as random forests and multiple linear regression. In model development the most important prediction parameters will be examined. Fourth phase include testing of developed models by comparison of prediction results with measured data, for different periods. The model with best prediction result will be selected as a model for prediction of the Kostanjek landslide movement. The last phase of the project is development of customized software which includes visualization of monitoring data in real time, calculation of prediction parameters and prediction of landside movement with selected statistical model. The prediction model should be updated on a daily basis, as new data are receiving from the monitoring site, enabling greater accuracy predictions.

Results of landslide movement prediction should provide information to City of Zagreb authorities related to emergency management. To make prediction information useful, it is necessary to establish different threshold values, for different levels of preparedness. According to selected threshold values, emergency management offices in cooperation with scientists should prepare and define efficient emergency measures in case of risky landslide movements.

11. Deliverables/Time Frame: (10 lines maximum; what and when will you produce?)

The project starts in January 2018 and will end in January 2020. Phase of preliminary analyses will end up until June 2018. Phases of parameter selection, development and testing of statistical models

for prediction of landslide movement will end up until the end of 2018. During the 2019 customized software for prediction of landslide movement will be developed. After development, the software will be tested at least two months before the end of project and probably 10 months after the project. During the software testing phase members of Zagreb city emergency offices will be acquainted with the software and in the same time they will, together with scientist, prepare and define efficient emergency measures in case of landslide movements.

12. Project Beneficiaries: (5 lines maximum; who directly benefits from the work?)
    The main beneficiary will be emergency management offices and the civil protection of the City of Zagreb, as well as residents endangered by the Kostanjek landslide. The research will promote innovation in the field of landslide monitoring and prediction. The beneficiaries of the research will also be the professionals and scientists involved in geological and geotechnical engineering who are in charge of landslide research and high education.

13. References (Optional): (6 lines maximum; i.e. relevant publications)

KRKAČ M, MIHALIĆ ARBANAS S, ARBANAS Ž, BERNAT S, ŠPEHAR K (2014) The Kostanjek Landslide in the City of Zagreb: Forecasting and Protective Monitoring. In: Lollino G et al. (eds) Proceedings of the XII IAEG Congress 'Engineering Geology for Society and Territory', Vol. 5 'Urban Geology, Sustainable Planning and Landscape Exploitation'. Heidelberg: Springer, pp. 715-719

KRKAČ M, MIHALIĆ ARBANAS S, ARBANAS Ž, BERNAT S, ŠPEHAR K, WATANABE N, OSAMU N, SASSA K, MARUI H, FURUYA G, WANG C, RUBINIĆ J, MATSUNAMI K (2014) Review of Monitoring Parameters of the Kostanjek Landslide (Zagreb, Croatia). In: Sassa K et al. (eds) Proceedings of the 3rd World Landslide Forum, Landslide Science for a Safer Geoenvironment: Volume 2: Methods of Landslide Studies. Cham: Springer, pp. 637-645

KRKAČ M, MIHALIĆ ARBANAS S, OSAMU N, ARBANAS Ž, ŠPEHAR K (2014) The Kostanjek landslide - Monitoring system development and sensor network. In: Mihalić Arbanas S and Arbanas Ž (eds) Landslide and Flood Hazard Assessment, Proceedings of the 1st Regional Symposium on Landslides in the Adriatic-Balkan Region. Croatian Landslide Grup, Zagreb, pp. 27-32

KRKAČ M, ŠPOLJARIĆ D, BERNAT S, MIHALIĆ ARBANAS S (2016) Method for prediction of landslide movements based on random forests. Landslides 1-14, doi 10.1007/s10346-016-0761-z

MIHALIĆ ARBANAS S, KRKAČ M, BERNAT S (2016) Application of advanced technologies in landslide research in the area of the City of Zagreb (Croatia, Europe). Geologia Croatica 69(2): 231-243, doi: 10.4154/gc.2016.18

Note: Please fill and submit this form by 1 September 2017 to ICL secretariat <secretariat@iclhq.org> and ICL network <ICL-network@iclhq.org>