

Application Form for World Centre of Excellence on Landslide Risk Reduction
2020-2023

1. Name of Organization: Croatian Landslide Group

2. Name of Leader

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Core members of the activities (4 individuals maximum)

Assist. Prof. Vedran Jagodnik, University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia

Assist. Prof. Martin Krkač, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, Croatia

Assist. Prof. Martina Vivoda Prodan, University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia

PhD Sanja Bernat Gazibara, Postdoc., University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, Croatia

3. Date of Submission of Application: 15 August 2019

4. Activity scale and targeted region:

1) **Global**, 2) **Intercontinental**, 3) **Continental**, 4) **Regional**, 5) **National**

5. Short Title characterizing past and planned activities:

Landslide Modeling: From Physical to Phenomenological Models

6. Objectives for the initial 3 years:

(i) Physical modelling of landslide initiation and landslide remediation constructions behavior under static and seismic actions; (ii) Further development of landslide displacement phenomenological models as a tool for landslide early warning; (iii) Physical and numerical modeling of landslide initiation caused

by rainfall infiltration; (iv) Spatial modeling of landslide activation under different rainfall thresholds as a base for landslide hazard and risk maps as well as early warning system; (v) Promotion of landslide science to regional and national authorities as well as to global science community.

7. Background Justification:

The members of Croatian Landslide Group (CLG) are the landslide scientists in the fields of engineering geology and civil engineering employed at the University of Rijeka and University of Zagreb. The CLG members are involved in the wide spectrum of activities related to landslide risk reduction from high education and scientific research to cooperation with industry, as well as with local and national authorities. The results of the scientific joint research of CLG scientists (2017-2019) are published in 3 PhD dissertations, 6 papers in international journals (3 paper in the Landslides journal) and 21 papers at the international conferences (16 papers at the WLF4), as well as 7 chapters in Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools. The regional scientific and high-education projects and cooperation are the following: one national scientific projects funded by Croatian Scientific Foundation; mobility of lecturer, researcher and students between Croatia and Italy, Slovenia, Bosnia and Herzegovina, and Austria; co-coordination of regional ICL Adriatic-Balkan network; organization of regional symposia (3rd ReSyLAB, Ljubljana, Slovenia, 2017 and 4th ReSyLAB, Sarajevo, Bosnia and Herzegovina) and WLF 4 (Ljubljana, 2017). CLG has continuous cooperation with Croatian local, regional and national governments and agencies; consultative support to authorities related to landslides investigation and urgent situations; design of landslides remedial measures, presentation of application of scientific results in praxis (e.g., landslide inventories, landslide hazard and risk zonation, landslide monitoring, prediction and early warning); and involvement in joint activities related to ICL (e.g., Sendai Partnership, editing of ISDR-ICL Landslide Interactive Teaching Tools and the Landslides Journal).

8. Resources available for WCoE activities (Personnel, Facilities, Budgets, and Affiliation and Contribution to ICL/IPL-GPC):

CLG encompasses two university departments from the University of Rijeka and the University of Zagreb (Department for Geology and Geological Engineering) with 2 Full Professors, 4 Assistant Professors, 3 Postdoctoral Researcher and, 2 Doctoral Researchers working in the field of landslide science and 4 PhD students. The key infrastructures for scientific research are: Geotechnical laboratory at the Faculty of Civil Engineering University of Rijeka equipped with modern equipment for soil and rock testing (triaxial and dynamic triaxial apparatus, undrained ring shear apparatus, resonant column, triaxial apparatus for rock testing, direct shear), Observatory of the Kostanjek landslide at the University of Zagreb and Observatory of the Grohovo landslide at the University of Rijeka equipped with integrated automated monitoring

systems. High-educational activities are fully supported from the faculties. Funds for scientific research is ensured through national scientific projects, international multilateral and bilateral projects as well as from the cooperation with industry.

CLG has been involved in the following ICL/IPL activities: coordination of 2 ICL Networks (regional Adriatic-Balkan Network and thematic Monitoring Network); leading of two IPL projects (IPL 219 Project and IPL 220 Project); editing and reviewing in the Landslide journal; editing and contributing to the ICL Landslide Teaching Tool (7 chapters); contributing to WLF4 in Ljubljana; convening 2 session at WLF4 in Ljubljana with editing of the session's papers; and organizing regional ICL symposia.

9. Description of past activities related to risk reduction of landslides and other related earth system disasters:

Scientific activities related to risk reduction of landslides through development and/or applications of landslide science were as follows:

- Development of methodologies for automated and visual interpretation of high- and very high-resolution DEMs in identification and mapping of shallow landslides and variety of landslide types associated with erosion processes in complex geological environments built in flysch and carbonate rocks in the wider zone of Adriatic Coast. Identification of landslide triggers on the basis of compilation of a catalog of precipitation events that have caused landslides in the NW part of Pannonian Basin covering the period between June 2006 and October 2014.
- Landslide characterization aimed at interpretation of landslide model for the purpose of design of remedial measures in Croatia using: (a) surface and subsurface investigation of landslides (deep-seated Valići landslide and more than 25 shallow landslides endangering roads and residential houses); (b) surface investigation of rock falls/topples using airborne (ALS) and terrestrial laser scanning (TLS) as well as structure from motion (SfM) digital photogrammetry taken from unmanned aerial vehicle (UAV) that endanger sites of cultural heritages (Momjan Castle, City of Omiš), natural heritage (National Park Krka), as well as roads (e.g. the Radljevac Rockfall near Knin) and railways (e.g. the Raspadalica Rockfall near the City of Buzet).
- Laboratory testing of soft rocks-hard soils (flysch) materials with determination of parameters that allow the prediction of a material's strength, deformation, or permeability in response to changes over time due to weathering process, stress or other environmental conditions (climate change). Application of the described research results are demonstrated by use in numerical simulations of behavior landslides in flysch rock mass (e.g., the Valići landslide). Laboratory research of water infiltration in soil and impact of unsaturated zone of slope cross-section on overall slope stability and triggering of deep seated landslides in flysch deposits. Application of the described research results are used in numerical simulations of initiation of deep seated landslides in flysch rock mass.

- Landslide monitoring by integrated automated monitoring systems, the deep-seated large Kostanjek landslide and the Grohovo landslide. Analysis of temporal data series of movement and groundwater level data captured by the Kostanjek landslide monitoring system and development of a methodology for prediction of deep-seated slow moving landslide displacements using phenomenological modeling.
- Numerical simulation of landslides using LS-Rapid software for deterministic 3D landslide stability analyses (Grohovo landslide and Kostanjek landslide under different precipitation and dynamic conditions), determination of scenarios of the natural and anthropogenic risk (simulation of the Valiči landslide reactivation under influence of different reservoir water levels in the landslide foot) and deterministic landslide susceptibility analyses in the flysch area of North Istria. Analysis of propagation of a possible mudflow from the Grohovo landslide and Montaguto earthflow (Italy) downstream using the smoothed-particle hydrodynamics (SPH) model and LS-Rapid Model.
- Testing of the behavior of horizontally loaded piles on testing site constructed in natural sandy gravels that would enable better control of forces in a piles used as a remedial measure of a landslides.
- Analysis of time-dependent deformation of reinforced cuts in carbonate and flysch rock mass based on long term monitoring results with the focus on time-dependent deformation in slopes composed of weak rock mass and consecutive redistribution of the forces in rock mass reinforcement elements during the time that can lead to the progressive failure of a slope.
- Assessment of landslide hazard and risk in Croatia and contribution in creating of strategic plan of risk management in Croatia: Assessment of Disaster Risks in Republic of Croatia. Contribution to Croatian National Platform for Disaster Risk Reduction.
- Enhancement of landslide science in the Adriatic-Balkan Region through the leading of ICL Adriatic Balkan Network activities, organization of regional ICL symposia and bilateral scientific cooperation.
- Promotion of landslide research and science for regional, national and local applications and support in the system civil protection system, land use and adoption to climate changes through development of landslide inventories, landslide hazard and risk maps, as well as strategic documents and policies which are necessary for landslide risk management.

10. Planned future activities /Expected Results:

Planned scientific activities related to landslides risk reduction in the period 2020-2023 are as follows:

- Development of physical models of landslide to study remediation constructions behavior under static and seismic actions. The research will encompass testing of behavior of different construction applied for landslide remediation in physical models of scaled landslides in static and dynamic conditions where static conditions imply conditions for rainfall triggered landslides and dynamic conditions imply conditions for earthquake induced landslides. Observations of landslide movements in a physical model will be carried out by sensor network for measuring displacements, pressures, forces and pore pressures

and innovative photogrammetric equipment including terrestrial laser scanner and infrared camera. The measured parameters from physical model will be included in 3D numerical simulation. The results of both physical and numerical modelling will enable better understanding of landslide remedial construction behavior.

- Further development of landslide displacement phenomenological models as a tool for landslide early warning systems. The model will be developed based on series of measured monitored data on established landslide monitoring system (the Kostanjek Landslide) and will be verified on other deep seated slow moving landslides with existing monitoring data.
- Further development of methodologies for automated and visual interpretation of high- and very high-resolution DEMs for identification and mapping of shallow landslides and variety of landslide types associated with erosion processes in complex geological environments.
- Physical and numerical modeling of landslide initiation caused by rainfall infiltration will include measurement of surface water infiltration in physical landslide model as well as belonging pore pressure and matric suction values. Physical modeling data will ensure adequate numerical modelling and assessment of unsaturated zone impact on stability and initiation of deep seated landslides.
- Spatial analyses of massive landslides during historical rainfall events in Croatia will enable modeling of landslide activation under different rainfall thresholds that will use as a base for landslide hazard and risk maps in Croatia as well as for establishing of early warning systems in areas endangered by shallow landslides.
- Landslide hazard and risk assessment in Croatia for the purpose of national, regional and local physical planning and strategic documents.
- Promotion of landslide research and science for regional, national and local applications and support in the system civil protection system, land use and adoption to climate changes through development of landslide inventories, landslide hazard and risk maps, as well as strategic documents and policies which are necessary for landslide risk management.

11. Beneficiaries of WCoE:

Society, through implementations of new advances in landslide science. National, regional and local authorities, through development of landslide hazard and risk maps and strategic documents which are necessary for landslide risk management in the civil protection system, land use and adoption to climate changes. Governmental agencies and industry, through implementation of new technologies and knowledges. Academic society, scientists, and professionals, through new scientific knowledge transfer.

12. References:

Arbanas Ž, Pajalić S, Jagodnik V, Peranić J, Vivoda Prodan M, Đomlija P, Dugonjić Jovančević S, Čeh N (2019) Development of physical model of landslide remedial constructions' behavior. In: Proceedings of the 4th Regional Symposium on Landslides in the Adriatic-Balkan Region. Sarajevo, Bosnia and Herzegovina (in press).

Bernat Gazibara S, Krkač M, Sečanj M, Begić H, Mihalić Arbanas S (2017) Extreme rainfall events and landslide activation in Croatia and Bosnia and Herzegovina. In: Proceedings of the 3rd Regional Symposium on Landslides in the Adriatic-Balkan Region. Ljubljana, Slovenia.

Krkač M, Špoljarić D, Bernat S, Mihalić Arbanas S (2016) Method for prediction of landslide movements based on random forests. *Landslides* 14(3):947–960.

Mihalić Arbanas S, Sečanj M, Bernat Gazibara S, Krkač M, Begić H, Džindo A, Zekan S, Arbanas Ž (2017) Landslides in the Dinarides and Pannonian Basin – from the largest historical and recent landslides in Croatia to catastrophic landslides caused by Cyclone Tamara (2014) in Bosnia and Herzegovina. *Landslides*. 14(6): 1861–1876.

Mihalić Arbanas S, Bernat Gazibara, S, Sečanj M, Damjanović V, Oršanić D, Penović S, Krkač M, Đomlija P, Jagodnik V, Arbanas Ž (2019) Landslide risk management in Croatia: Current state and perspectives. In: Proceedings of the 4th Regional Symposium on Landslides in the Adriatic-Balkan Region. Sarajevo, Bosnia and Herzegovina (in press).

Peranić J. Arbanas Ž, Cuomo S, Maček M (2018) Soil-water characteristic curve of residual soil from a flysch rock mass. *Geofluids*, Article ID 6297819, 2018:15 pages.

Vivoda Prodan M, Mileusnić M, Mihalić Arbanas S, Arbanas Ž (2017) Influence of weathering processes on the shear strength of siltstones from a flysch rock mass along the northern Adriatic coast of Croatia, *Bulletin of Engineering Geology and the Environment*, 76(2): 695-711.

13. If your organization is an ongoing WCoE 2014-2017, please attach the articles reporting activities of WCoE, IPL project and ICL network published/contributed to either in *Landslides: Journal of International Consortium on Landslides* or/and the *Fourth World Landslide Forum 2017*:

Mihalić Arbanas S, Arbanas Ž, Krkač M, Bernat Gazibara S, Vivoda M, Đomlija P, Jagodnik V, Dugonjić Jovančević S, Sečanj M, Peranić J (2017) Landslide Risk Reduction in Croatia: Scientific research in the framework of the WCOE 2014-2017, IPL 173, IPL 184, ICL ABN. Sassa, K, Mikoš, M, Yin, Y, (eds.): *Advancing Culture of Living with Landslides*, Volume 1. Springer, Berlin, pp. 301-313.

14. List of published or planned reports of WCOE 2017-2020 in journal “Landslides” or “WLF5 books” for ongoing WCOE organization:

Mihalić Arbanas S, Arbanas Ž, et al. (2020) Landslide Risk Reduction in Croatia: Scientific research in the framework of the WCoE 2017-2020, IPL 219, IPL 220, ICL ABN. In Landslides Thematic Issue. (in prep.)

Note: Please fill and submit this form **by 15 August 2019** to ICL secretariat <secretariat@iclhq.org>