

Date of Submission	
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IPL Project (IPL - 219) Annual Report Form 2023

1 January 2024 to 31 December 2024

1. **IPL – 219 (2017) Rockfall hazard identification and rockfall protection in the coastal zone of Croatia**

2. **Main Project Fields**

(1) Technology Development

B. Hazard Mapping, Vulnerability and Risk Assessment

(2) Targeted Landslides: Mechanisms and Impacts

B. Landslides Threatening Heritage Sites

(4) Mitigation, Preparedness and Recovery

A. Preparedness, B. Mitigation

3. **Name of Project leader:** Professor Željko Arbanas

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Core members of the Project:

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4. **Objectives:** Study of triggering conditions and rockfall mechanisms and run out paths and processes in carbonate rocks and at along the contacts of carbonate rocks and flysch formations in Croatia; Modeling of typical historical and recent rockfalls in Croatia: back analyses; Identification of conditions that influence and cause rockfalls in carbonate rocks and at along the contact of carbonate rocks and flysch formations in Croatia; Recommendations for rockfall hazard identification and rockfall protection in the coastal zone of Croatia.

5. **Study Area:** Coastal zone of Croatia, City of Omiš, Vinodol Valley, Rječina Valley, North Istria

6. **Project Duration:** 4 years (+2 years)

7. Report

Progress in the Project:

During the second year of the Project, the activities from the following phases of the Project were conducted:

1st phase: Data collection, FIELD INVESTIGATION AND SURVEY.

Field data base establishment is completed during the previous year of the Project.

2nd phase: NUMERICAL MODELING.

Based on UAV photogrammetry and TLS surveys 3D digital terrain models were established for pilot sites City of Omiš (rock slopes above the city centre), rockfall Plavno at the County road 6034 near Knin in Šibensko Kninska County, rockfall Raspadalica Cliff above the railway route in Istria, rockfall Banska Vrata above the state road D403 in Rijeka, the rock slope above the Cemetery in The City of Buzet in Istria and rock cut Špičunak above the state road D8 near mountain part of Primorsko-Goranska County. Numerical modelling of rockfall propagation was conducted including determination of rockfall sources, rockfall propagation modeling and simulation, determination of rockfall run-offs, as well as rockfall hazard assessment. The milestone: Methodology for establishing typical rockfall models in different types of limestone cliffs and cuts is realized.

3rd phase: SPATIAL ANALYSES.

Spatial analyses of rockfalls are conducted through the study “Landslide risk assessment in the Republic of Croatia” that was prepared in joint cooperation with Ministry of Civil Engineering and Spatial Planning of the Republic of Croatia (MGIPU) and Croatian Platform for Risk Reduction where the landslide (including rockfalls) risk assessment analysis was carried out for the whole territory of the Republic of Croatia. The research for the purpose of rockfall susceptibility and hazard map guides preparation is ongoing. The milestones: Rockfall susceptibility and hazard maps for the pilot areas of historical and recent rockfalls in Croatia. Recommendations for rockfall susceptibility and hazard map guides preparation are almost completely realized.

4th phase: ROCKFALL PROTECTION MEASURES APPLICATION.

Analysis of the assessment of most effective protection measure to reduce rockfall hazard and risk was conducted at tree pilot sites: City of Omiš (rock slopes above the city centre), rockfall Plavno at the County Road 6034 near Knin in Šibensko Kninska County, rockfall Raspadalica Cliff above the railway route in Istria, rockfall Banska Vrata above the state road D403 in Rijeka, rock slope above the Cemetery in The City of Buzet in Istria, and rock slope above Arsenalska Street in th City of Pula, Istria. The first two location were analyzed in detail that resulted with two designs of rockfall protection. The third and fourth locations, rockfall Raspadalica Cliff and the Banska Vrata rockfall were analyzed considering the efficiency of applied protection measures (rockfall barriers). For the rock slopes above the Cemetery in The City of Buzet, and above Arsenalska Street in Pula, in Istria the rockfall protection designs were completed. The rock cut Špičunak above the state road D8 was modeled, and design for rock protection was completed and protection measures are applied. The milestone: Assessment of the most effective rockfall protection measures and construction application and recommendations for rockfall protection measures application guides preparation are almost completely realized.

5th phase: RESULTS PRESENTATION.

The results of the project were to scientific community:

- Arbanas, Željko; Udovič, Dalibor; Mihalić Arbanas, Snježana: Rockfall analyses and rockfall protection at the Raspadalica Rockfall, Croatia. 20th International Conference on Soil Mechanics and Geotechnical. Sydney, Australia.
- Lukačić Hrvoje, Krkač Martin, Bernat Gazibara Sanja; Arbanas Željko; Mihalić Arbanas Snježana: Detection of geometric properties of discontinuities on the Špičunak rock slope (Croatia) using high-resolution 3D Point Cloud generated from Terrestrial Laser Scanning. Helsinki, Finland,

8) Planned future activities or Statement of completion of the Project

The future activities will develop according to the Project Work Plan. In the next Project year, the following activities will be continued:

4th phase: ROCKFALL PROTECTION MEASURES APPLICATION. Assessment of the most effective rockfall protection measures and construction application. Recommendations for rockfall protection measures application guides preparation.

5th phase: RESULTS PRESENTATION. Presentation of current results to the local authorities and stakeholders in the study area, as well as other types of Project results dissemination.

9) Beneficiaries of Project for Science, Education and/or Society

Society, through implementations of Project's results in physical planning and urban areas protection (Ministry of Physical Planning, Construction and State Assets of the Republic of Croatia (MPGI), Croatian Platform for Risk Reduction, City of Omiš). Local authorities, through better understanding of conditions of land use planning (City of Omiš). Companies those maintain facilities (highways, roads, railways, cemetery, etc.) and constructions in urban areas through identifying of rockfall hazard on existing and new facilities (City of Omiš, County Road Administration in Šibensko Kninska County, City of Buzet; City of Pula, City of Rijeka, Croatian Roads). Scientists, through new scientific knowledge of rockfall behavior (University of Rijeka, University of Zagreb).

10) Results:

- Dalibor Udovič: Rockfall Risk Identification in Carbonate Masses along the Transport Routes in the Republic of Croatia. PhD Thesis. University of Rijeka, Faculty of Civil Engineering, Rijeka, 2021. Supervisor: Professors Leo Matešić and Željko Arbanas
- Udovič, Dalibor; Kordić, Branko; Arbanas, Željko: Geotechnical Study of Raspadalica Cliff Rockfall, Croatia. Applied Sciences, 12 (2022), 13; 6532, 26 doi:10.3390/app12136532
- Arbanas, Željko; Udovič, Dalibor; Mihalić Arbanas, Snježana: Rockfall analyses and rockfall protection at the Raspadalica Rockfall, Croatia. Proc of the 20th International Conference on Soil Mechanics and Geotechnical Engineering. Rahman, Md Mizanur; Jaks, Mark (Eds.). Sydney, Australia: Australian Geomechanics Society, 2022.

- Sušac, Maroje; Vugrinski Mirjana; Udovič, Dalibor; Marušić, Davor; Arbanas, Željko: Design of the rockfall protection at the Špičunak location, Gorski Kotar, Croatia. *Landslide Modelling & Applications: Proceedings of the 5th Regional Symposium on Landslides in the Adriatic-Balkan Region*. Peranić Josip; Vivoda Prodan Martina; Bernat Gazibara Sanja; Krkač Martin; Mihalić Arbanas Snježana; Arbanas Željko (Eds.). Rijeka: Faculty of Civil Engineering, University of Rijeka and Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, 2022. pp. 225-230
- Lukačić Hrvoje, Krkač Martin, Bernat Gazibara Sanja; Arbanas Željko; Mihalić Arbanas Snježana: Detection of geometric properties of discontinuities on the Špičunak rock slope (Croatia) using high-resolution 3D Point Cloud generated from Terrestrial Laser Scanning. *IOP Conference Series: Earth and Environmental Science*, Helsinki, Finland, 2022. pp. 1-9.
- Arbanas, Željko, Peranić, Josip; Mihalić Arbanas, Snježana: Analysis of an old rock avalanche using different remote sensing methods. In: *New Challenges in Rock Mechanics and Rock Engineering, EUROCK 2024* Eds: Roberto Tomás, Miguel Cano, Adrián Riquelme, José Luis Pastor, David Benavente, Salvador Ordóñez, Alicante, Spain, CRC Press, London 2024 (Accepted)
- Josipa Barić: Kinematic Analysis of Rock Slopes. BSc Thesis, University of Rijeka, Faculty of Civil Engineering, Rijeka Croatia, 2022. Supervisor: Professor Željko Arbanas