Monitoring of rockfall prone areas in eastern Slovenia

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Abstract In recent years, about ten large rockfalls with a volume of more than 10,000 m³ have been observed in the eastern part of Slovenia, causing damage to infrastructure, and resulting in two fatalities. Because rockfalls occur suddenly and usually without visible warning signs, they are extremely difficult (or impossible) to predict and thus pose a major potential risk to people and infrastructure. Within the framework of the project Development of Research Infrastructure for International Competitiveness of Slovenian Responsible Research and Innovation Space a set of pilot areas were equipped with meteorological and geotechnical sensors (rain gauges, air temperature and humidity sensors, tilt gauges, kit for measuring rock stress and deformability, laser distance metres, crackmeters and rock temperature sensors) providing real time monitoring data. In this paper, we present seven months of monitoring data from a pilot area considered to be the Oligocene Smrekovec volcanic complex outcrops. The first correlation between temperatures and the movement of rock blocks is presented.

Keywords rockfalls, monitoring, sensors, temperature, eastern Slovenia

Introduction

Rockfalls are the result of a long geological process (tectonics, weathering, etc.), but the fall is sudden. The questions most often asked are what causes rockfall to fall (what factors) and how (what mechanisms)? In the case of a meteorological factor, several physical mechanisms may be involved, which may manifest as rockfalls initiated by a slide or a fall (Krautblatter and Dikau 2007; D'Amato et al. 2016; Macciota et al. 2015; Matsuoka 2019). Rock mass is a type of heterogeneous material that contains many nonpersistent joints. When the daytime temperature is high, the water in the joints undergoes periodic freeze-thaw cycles. The periodic freeze-thaw cycles induce the joint cracks to expand continuously, which will lead to the failure of the rock mass. Temperature fluctuations of high magnitude have been shown to cause irreversible displacements leading to cracks in discontinuities. Thermal shock occurs due to rapid temperature change which leads to significant variation of stresses and displacements in brittle rocks. In transient heat flow, rapid cooling leads to large tensile stresses at the surface, while rapid heating causes large compressive stresses (Kim and Kemeny 2009; Collins and Stock 2016; Notti et al. 2020). The redistribution of stress can lead to the appearance of microcracks, and the development of the microcracks can lead to the failure of the rock face.

Rockfalls are widespread phenomena in mountain ranges, coastal cliffs, volcanos, river banks, and slope cuts (Corominas et al. 2017). Recent studies have shown that losses due to rockfalls are mainly concentrated in populated areas where there is a research deficit and lack of appropriate risk strategies (Petley 2012).

The morphology of slopes, unfavourable geological and tectonic conditions, and climatic diversity contribute significantly to the large rockfall potential in Slovenia (Čarman et al. 2011; Jemec Auflič et al. 2017). According to the information from the rockfall database of DRI Investment Management Ltd (which manages a rockfall database for national roads for the Slovenian Infrastructure Agency), more than 600 km of road links are affected by rockfall events. In Slovenia, major rockfall phenomena, such as large-scale rockfalls with a volume of more than 100.000 m³, are not very common. They occur in the seismically active upper Soča valley and even there they are limited to smaller areas (Ribičič and Vidrih 1998; Mikoš et al. 2006). More often we have to deal with rockfalls and blockfalls that endanger residential and commercial buildings, roads and railroads lines. Despite protective nets, falling rock often penetrates the protective net, or the falling rock hits the track after passing the protective net. In some particularly exposed locations, rockfalls severely affect the safety and normal operation of the railroads and cause great economic and material losses. The most problematic are very narrow valleys with very steep slopes above and below the railroads in the eastern part of the country. In the years between 2010 and 2020, about ten large rockfalls with a volume of more than 10,000 m³ have been observed in the eastern part of Slovenia, causing damage to infrastructure, and claiming two fatalities (URSZR, annual report 2021). Deciding for the installation of an early warning system is an important step towards the protection of railroad users and residents in areas with high risk for a catastrophic event. Because rockfalls occurs suddenly, usually without visible warning signs, they are extremely difficult (or impossible) to predict and pose a great potential threat to people and infrastructure.

In this paper we will present the monitoring of rockfall-prone area in eastern Slovenia only for a pilot marked with number 2 in Fig. 1. Based on the results, we will show the preliminary correlation between the monitored temperatures and the displacement rates determined by the nearby crackmeters.

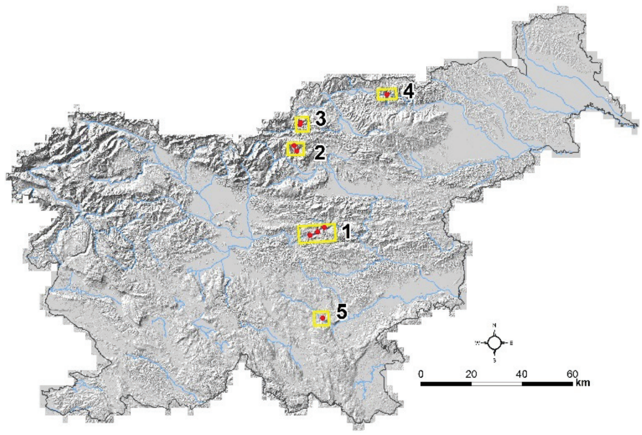

Figure 1 Map with the location of the pilot areas, numbered 1-Zasavje, 2-Smrekovec, 3-Mežica, 4-Brezno, and 5-Žužemberk.

Methods and material

In the frame of Project »Development of research infrastructure for the international competitiveness of the Slovenian RRI space–RI-SI-EPOS, co-financed by the Republic of Slovenia, Ministry of Education, Science and Sport and the European Union from the European Regional Development Fund, the following measuring equipment have been installed at the selected monitoring areas early in 2021: rain gauges, sensors for air temperature and humidity, tiltmeters, kit for measuring rock stress and deformability, laser distance gauges, crackmeters and near surface rock temperature sensors. The sensors of temperature at the depth of 25, 50 and 75 cm were drilled in homogenous, intact rock with at least 30 cm distance to joints following the design of Gruber et al. (2004). This sampling strategy does not reflect the importance of nonconductive heat transfer through joints, but we avoided complex micro-topography from surrounding bedrock to minimize shadowing or concentration of surface runoff (after snowmelt). Some of the installed sensors can be seen in Fig. 2. Table 1 shows the basic specification of sensors and the number of sensors for each pilot area. The monitoring areas in eastern Slovenia (Fig. 1) were selected according to the following criteria: Frequency of rockfalls, risk to the population and infrastructure, and diversity of rock composition (carbonate and igneous). Each individual rock type has different engineering properties and predisposing factors that can affect exfoliation, discontinuity formation, and fractures. However, the type of rock, its mineralogical nature, anisotropy or isotropy very often determine the susceptibility to the formation of fractures and their opening.

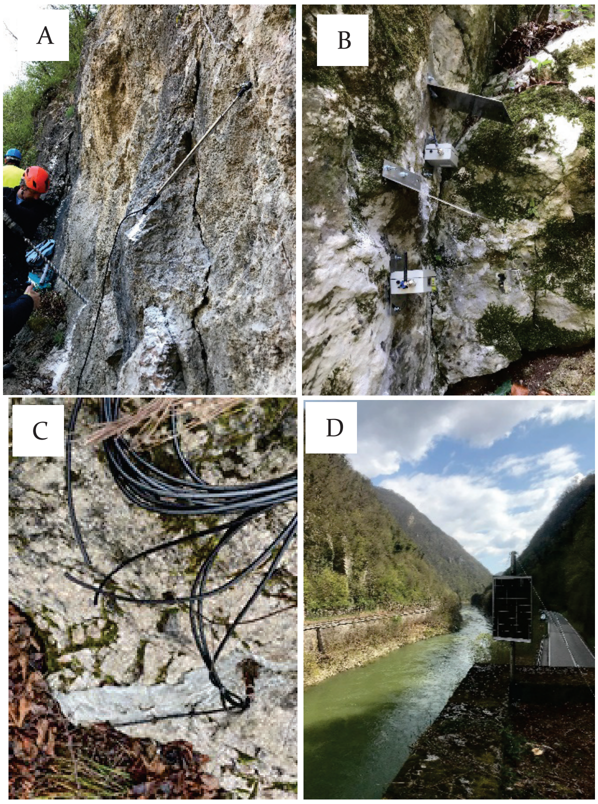

Figure 2 Instalation of the sensors: A-crackmeter, B-tiltmeter and laser distance meter, C-rock temperature sensor, and D-base station with solar panel.

The geotechnical sensors are wired using LoRa communication protocol and LoRa gateway and powered by a base station, which also serves as an in-situ data logger. The Nodes connected to board so that every data coming from the sensor can forward right away using the LoRa network (Long Range Wide Area Network). Thus, the collected data are not transferred right away but going through data processing firsthand. The data also stored in the local storage to minimize the data loss because of a network error. Wide Area Network (WAN) is used in this research based on the LoRa module and makes it possible to send data in an approximately 2 km radius. Due to emerging technologies, battery powered devices using LoRaWAN to communicate can run for many years even without replacement.

Table 1 The basic specification of the sensors and the number of sensors in the pilot areas. The pilot areas are shown in Fig.1 and are marked with numbers from 1 to 5. Abbreviation F.S. characterized Factor Safety.

	Range	Precision	Sampling frequency	Sensor numbers per pilot area (Fig. 1)				
				1	2	3	4	5
Rain gauges	400 cm^2	0.2 mm/pulse	30 min	1	1	1	1	1
Sensor for air T	-40 to +60 °C	± 0.1 °C	30 min	1	1	1	1	1
Sensor for air humidity	0-100 % Rh	± 1 %	30 min	1	1	1	1	1
Tiltmeter	± 15° biaxial	± 0.01°C	30 min	5	4	2	3	2
Kit for measuring rock stress and deformability	±8.5 MPa	± 0.25 % F.S.	30 min	4	3	3	4	1
Laser distance gauges	0.05 -150 m	0.1 mm	30 min	1	3	1	4	2
Crackmeter	100 mm	± 0.1 % F.S.	30 min	8	8	3	7	3
Rock T sensors	-50 to +150 °C	± 0.2 °C	30 min	4	4	2	4	1

Smrekovec monitoring area

The Oligocene Smrekovec Volcanic Complex outcrops along south-easternmost surface extending of the Periadriatic Faut System and forms a part of south-western system of the Pannonian basins (Kralj 2021). It is a remnant of a submarine andesitic stratovolcano composed of complex successions of lavas, autoclastic, pyroclastic, syn-eruptive resedimented volcaniclastic and mixed siliciclastic-volcaniclastic deposits. The stratovolcano hosted hydrothermal system with a deep igneous source and convective-advective flow of hydrothermal fluids that resulted in extensive alteration of volcanic rocks, in particular, the formation of zeolites and clay minerals. Extensive tectonic activity along the Periadriatic Fault System dissected the volcano and displaced the northern sections on a several ten-kilometre-scale toward the south-east, and as a result, only a quarter of the original edifice has been preserved. The present-day rugged morphology of the Smrekovec Volcanic Complex is also a result of extensive glacial erosion that occurred during the last Ice Age (Komac and Zorn 2007).

Results and discussion

In this paper, we presented monitoring data from June 2021 to mid-December 2021. To show the temperature differences in the rock face, in the air, and near the ground, we used the box and whisker plots (Fig. 3). Fig. 3 shows the distribution of temperature data in quartiles, with the mean and outliers highlighted. The boxes have vertical lines indicating variability outside the upper and lower quartiles, and any point outside these lines or whiskers is considered an outlier. Fig. 3 shows temperature readings from the temperature sensor measuring temperature at 25, 50, and 75 cm depth (T37157), air temperature, and temperature sensors T12002, T12008, and T12023 attached to the crackmeters and measure temperature 5 cm above the ground. The position of the sensors on the rock face is indicated by red circles in Fig. 4.

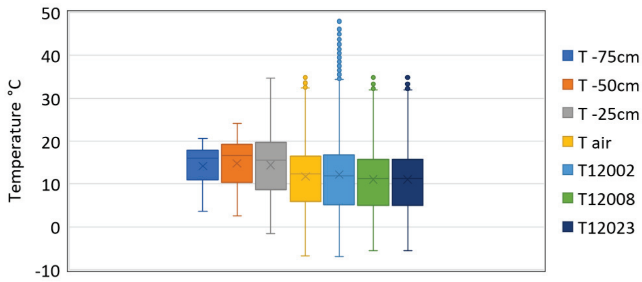

Figure 3 Distribution of temperature data in quartiles, with the mean and outliers highlighted. T air is temperature from the meteorological station (3 km away from the monitoring area). Temperature sensors T37157 which measure the rock temperature at three depths: 25 cm, 50 cm, 75 cm. Sensors T12002, T12008 and T12023 are integrated at the crackmeters and measure temperature 5 cm above the ground.

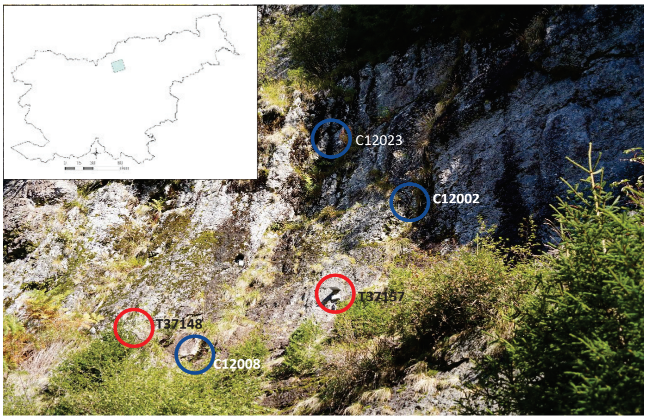

Figure 4 Smrekovec monitoring area. Crackmeters sernsors incuding temperature sensors 5 cm above the ground: CT12002, CT12008, CT12023 (blue circles). Temperature sensors at depths of 25, 50, 75 cm: T37157 and T37148 (red circles).

To show the first observed trends, we plotted the time series of temperatures and measured displacements on the one cracmeter separately for the summer months (June, July, August, September) and for the fall and winter months (October, November, December) (Fig. 5). The time series of the temperature sensors clearly showed that the higher temperatures are measured in the summer months (Fig. 5a), while the air and rock temperatures decrease in the fall and winter (Fig. 5b). The air temperature measured at a height of 5 cm above the ground, and the temperature at a depth of 25 cm in the rock face are very similar during the summer months (Fig. 5a), while the air temperatures fluctuate and remain quite high during the day. Temperatures at 25 cm depth and 5 cm above the ground are rather constant in winter and do not fluctuate significantly (Fig. 5b). Temperatures at depths of 50 and 75 cm are constant and lower in winter (Fig. 5b). From the observed period of seven months, some trends in the movement of the rock block can be seen. Positive crackmeter readings (the values are on the y-axis to the right of the graph) are considered to be expansion of the rock block and negative ones are considered to be contraction of the rock block. Based on the first finding, we correlate this trend of rock expansion with the drop in temperature at the end of the fall and during the winter months. Although the measured expansion rate is very low, about 0.5 mm, this could be due to a measurement error. The plotted trend line (red colour) tentatively indicates some changes in the motion that could be related to meteorological factors. When T air and T12008 fall below 5°C, the trend line indicates an expansion of the block. However, more observation periods are needed before this assumption can be confirmed.

To find a significant correlation between the temperatures and the displacements, we made a diagram (Fig. 6) showing two T readings (T air and T12008-temperature sensor at 5 cm above the ground). Over the seven-month period, movements of -1 mm to 0.2 mm can be seen. As temperatures decrease, the rates of movement go from negative to positive values (up to 0.2 mm), which could indicate expansion of the rock block during cooling of the air and rock.

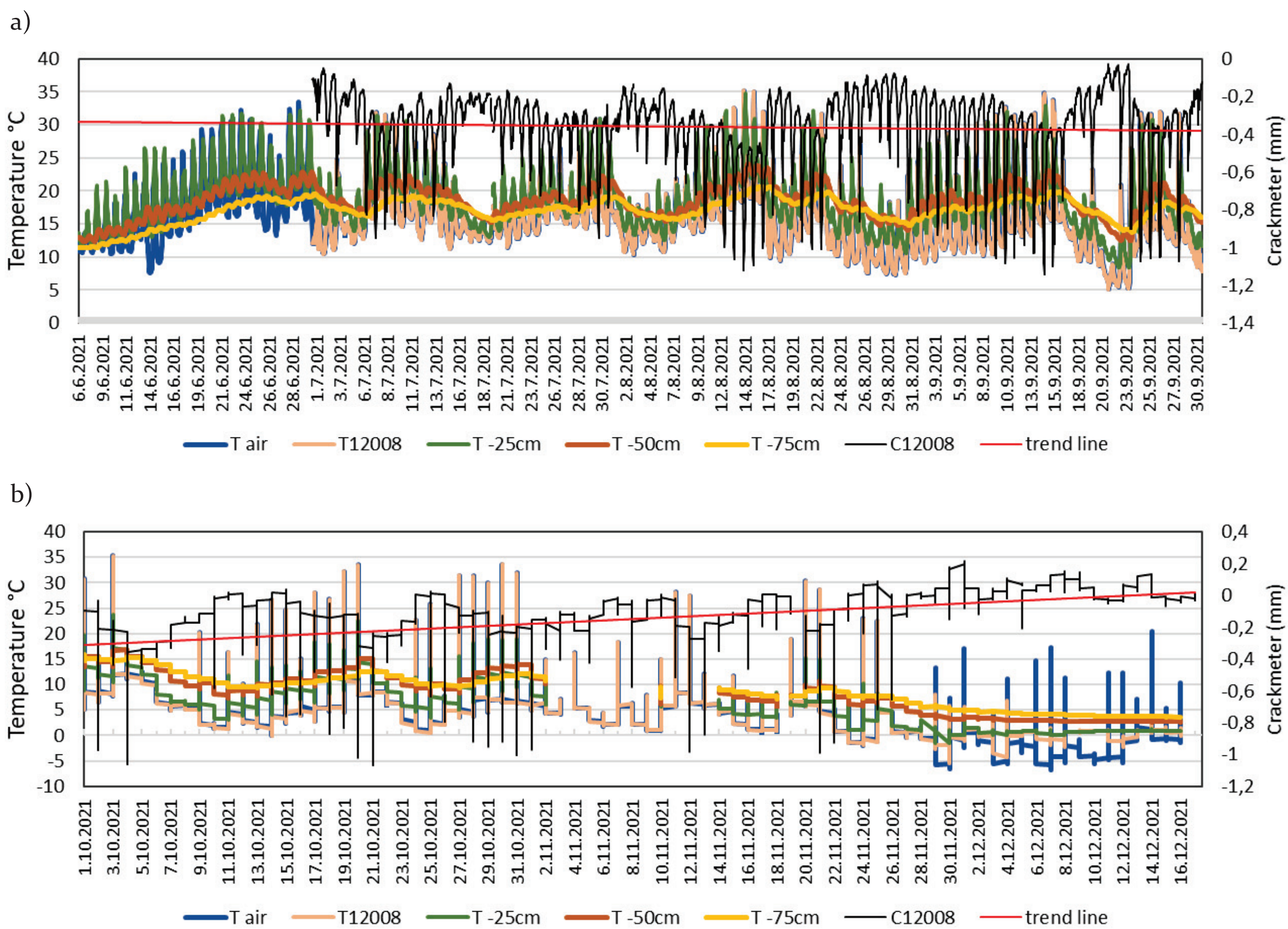

Figure 5 Observed time series of temperature sensor T37157 measuring rock temperature at three depths: 25 cm, 50 cm, 75 cm. T air is the temperature of the meteorological station (3 km from the monitoring area). Crackmeters values are on the y-axis to the right of the graph. Time series of displacements (mm) measured with the C12008 crackmeter (black line), trend line of displacements (red line) and T12008 temperature sensor at 5 cm above the ground. A) The monitoring period is from June to September 2021. B) The monitoring period is from October to mid-December 2021.

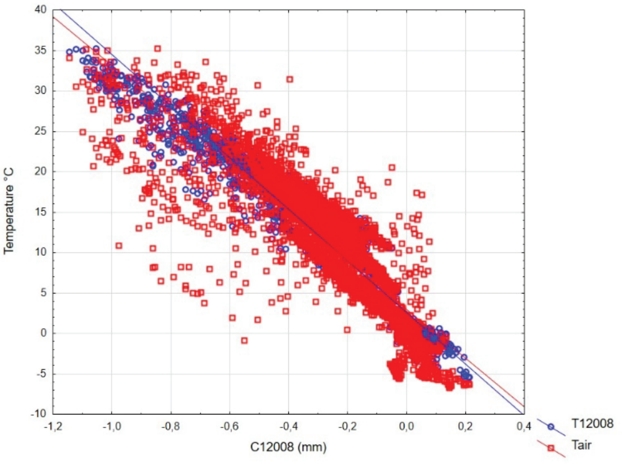

Figure 6 Graph of displacements (C12008) and temperatures (Tair - red colour; T12008 - temperature sensor at 5 cm above the ground - blue colour). The monitoring period is from June to mid-December 2021.

Conclusions

The overall goal of monitoring is to decipher the sensitivity of rock faces to climatic changes and freeze-thaw cycles using a multi-method approach. In this paper, we focused on the outcrops of the Oligocene Smrekovec volcanic complex, which appear in many places in the eastern part of the country and represent rockfall-prone areas. However, the presented observation period is too short to draw relevant conclusions on the correlation of temperatures and displacements. Preliminary results from seven months of observations suggest a correlation between temperature fluctuations and rock block movement, especially in the late autumn and winter months. For next steps, we are aware of the lack of rock surface temperatures, so installation of new sensors is planned (Ibuttons). Rock surface temperature will help us identify freeze-thaw episodes.

Acknowledgments

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