

In-Situ Monitoring Of Cracks Affecting The Madara Horseman Historical Rock Monument, Northeastern Bulgaria

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Abstract

The rock bas-relief Madara Horseman is carved into limy sandstone on the main rockwall of the Madara Plateau in the 8th Century AC. The monument is included in the World Heritage List of UNESCO. The monument was subjected to the destructive effects of various natural processes throughout its 12 centuries of history, namely weathering, erosion, cracking, creep, and rocktoppling. This requires urgent action for the selection of measures for strengthening and preservation of the monument. Due to the delicate balance of the rocky slope, bearing the bas-relief, the choice of such measures should be clarified very carefully after a thorough analysis of the processes developing in the rock massif. For this reason the precise in-situ monitoring system has been installed to monitor movements of rock blocks around the monument and at the edge of the plateau. Up to present, the results show slow movements in the cracks around the monument with a rate about 0.05 mm/year. However, the movements detected at the plateau edge show large motion of the rock slices separated from the rock massif – more than 0.8 mm/year strike slipping and subsidence. It is also established that movements at the edge of the plateau are strongly influenced by regional and local earthquakes.

1. Introduction

The Madara Horseman is a historical bas-relief carved on the NW rock scarp of Madara Plateau. It is situated about 10 km E from the town of Shumen, NE Bulgaria. The bas-relief was created in 8th Century AC during the rule of the First Bulgarian State. It is sculpted in a place where different cultures are combined from different periods - the Thracian, Roman and Byzantine. The rock composition represents a scene of a horseman, who is said to be Bulgarian Khan Tervel (701-717) on his horse, piercing a lion with a spear and followed by a dog (Fig. 1). The monument is cut to a rock scarp at height of 23 m above the terrain and including cut inscriptions is 7.2 m wide, and 6.5 m high. There are Greek inscriptions from various Khans, ruled Bulgaria during this period. This is the only rock bas-relief of the early Middle Ages in Europe. The monument is included in the World Heritage List of UNESCO.

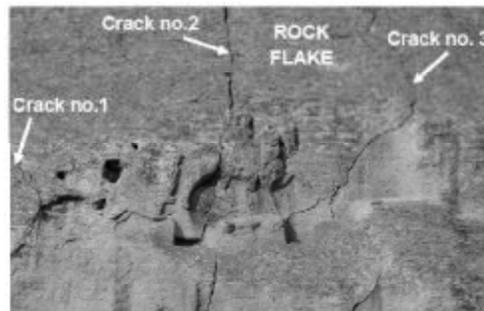


Fig. 1. The Madara Horseman bas-relief with the location of the main cracks and the dangerous rock "flake"

In its present form, the bas-relief has survived for 12 centuries, but with significant deterioration. Nowadays, there is a disappeared pigmentation, missing parts of the inscriptions, damaged surface (such as certain parts of the horseman are unclear), and three vertical cracks cut through the rock composition. Two of these cracks (no. 2 and 3) divide a thin rock "flake" that creates the main danger for the bas-relief. Due to the delicate balance of the rocky slope, bearing the bas-relief, the choice of protective measures should be clarified very carefully after a thorough analysis of the processes developing into the rock massif. To preserve this monument, various studies were conducted in recent years to identify these processes and to take appropriate decisions for countermeasures.

2. Geological setting

The Northwestern part of the Madara plateau is characterized by 80-120 m vertical scarp, and with a 1 km strip of slope deposits dipping from 10 to 20° (Fig. 2). Morphology of the slope is determined by a two layer model of its structure (Fig. 3). The rock massif consists of two complexes [1, 2]: the upper one comprises limy-sandy sediments of Upper Cretaceous – Cenomanian age; the lower one is marly of the Lower Cretaceous – Hauterivian age. There are no sharp lithologic boundaries between the individual units. Yet, it can be recognised that individual layers are characteristic of either high or low carbonate contents, which will result in variation of physico-mechanical rock properties. This variation is highly reflected in all strength properties of this rock [2]. The bas-relief has been carved out of yellowish limy sandstones found between 17 and 100 m. The second lower complex is marly, and consists of grey-bluish layered marlstones, creeping if heavily loaded. Between the Hauterivian and Cenomanian complexes a layer of yellow plastic montmorillonite clay has been discovered. Due to gravitational unloading of the plateau massif, rock slices (lamellae) are divided from the plateau. The height of the slices is about 100 m, but its width is barely 3 m. The fissures reach the plastic clay layer, in which they sink. Unstable substrate involves a wide range of fluctuations, especially in their upper parts, where the amplitudes are larger. As a result, they are increasingly moving away from the massif, with increased inclination towards the slope, with subsequent overturning.

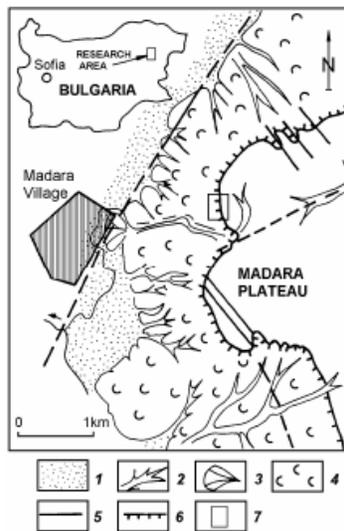


Fig. 2. Geomorphological map of the research area [3]: 1 – alluvial deposits; 2 – gully; 3 – alluvial fan; 4 – creeping deposits; 5 – fault; 6 – plateau edge; 7 – Madara Horseman locality

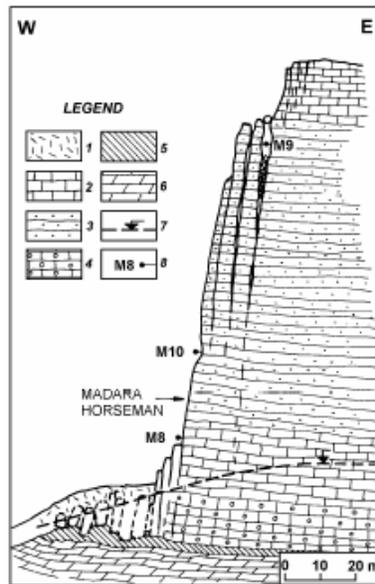


Fig. 3. Engineering-geological profile of Madara Plateau [2]: 1 – slope deposits; 2 –sandy limestone; 3 – limy sandstone; 4 – con-glomerated limestone; 5 – clay; 6 – marl; 7 – groundwater table; 8 – 3D monitoring site

3. Monitoring

Main purpose of the instrumental monitoring is to obtain real values of the movements occurring in the plateau and the slope below it. This will help to understand the dynamics of the processes, factors that influence these processes and to take right decisions for the preservation of bas-relief. Due to this reason, engineering geological surveys were made in 1990 in the area around the monument [2, 4]. During these studies, an in-situ monitoring system was created. The observation is located at two sites: 1) around the bas-relief, and 2) at the edge of the plateau just above the monument.

The monitoring system includes the use of 3D extensometers and minor shifts. The 3D instrumentation includes the TM71 crack gauge, which is designed especially to monitor the micro-displacements along cracks (Fig. 4) [5]. The gauge works of mechano-optical principle of interference, which records displacement as a fringe pattern on superposed optical grids mechanically connected with the opposite walls or crack faces. Practically, it means that values recorded during periods of decades can be well compared. Results will then be provided as displacements on structural planes in mm, and time trends derived as rates in mm per year. Sensitivity of the system is 0.05 to 0.0125 mm in all the three space coordinates of displacement. The meaning of three spatial axes is as follows: X means extension or compression of the monitored crack; Y means horizontal slipping long the crack; Z means a vertical movement. Generally, the crack gauges are to be mounted on steel holders made of thick wall tubes and cemented to drill holes. The holders bridge the fracture with the gauge attached to the holders permanently.



Fig. 4. A view of 3D extensometer site M8 below the bas-relief

3.1. Monitoring on cracks around bas-relief

Two 3D extensometer points (M8 and M10 arranged at crack no. 2) and five shift points observe the movements. Here the measurements show large variations at the X axes due to the seasonal temperature fluctuations (Fig. 5). However, the long-term observations identified a clear trend in the processes in the front part of the rock scarp. The trend of movement of rock flake outside the massif ("flaking") is revealed clearly [6]. The obtained rate is 0.05 mm per year. The subsidence of the rock flake is calculated as 0.03 mm per year.

3.2. Monitoring at the edge of the plateau

Five monitoring points control it. One extensometer point (called M9) is installed in a wide fissure between two rock slices just below the plateau main edge. Later (in 2008), the minor shifts were installed in other cracks in that area. The objective of use of these minor shifts is to control the separation process of the new slice behind the main edge of the plateau just above the bas-relief composition.

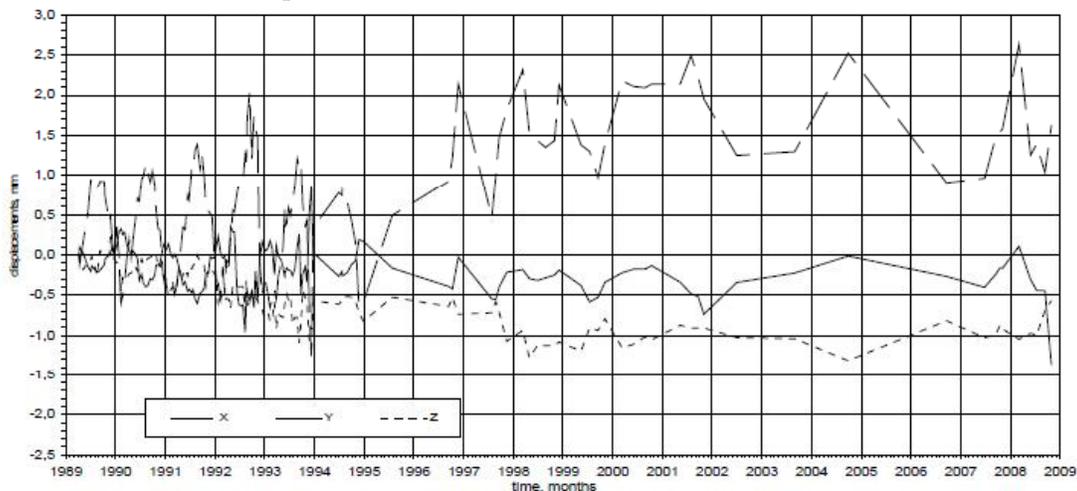


Fig. 5. Diagram of displacements established at monitoring point M8 for the period 1990-2009: +X – compression of the crack; +Y – the rock flake moving inside the massif; +Z – the rock flake uprising

The results of the measurements at the edge of the plateau show continuous slip movement of the rock slice at a speed of 0.85 mm per year towards SSE (Fig. 6). The vertical movements of the slice are characterized with subsiding with 0.8 mm per year during the period 1990-1999, and a relatively stable state from 1999 up to present. Movements along the X-axis show both periods of opening and closing the fissure. For the past 10 years, a clear trend of compression of the crack has been recorded. This is confirmed by the shifts behind the plateau edge. This process of compression could be explained as a formation of a new rock slice. The acceleration of the process started in 1999 as an influence of the August 17, 1999 Izmit Earthquake, Turkey (M=7.4). Meanwhile, the obtained results by the shifts confirmed mutual horizontal slipping along the crack to SSE, as the 3D monitoring site M9 already found it.

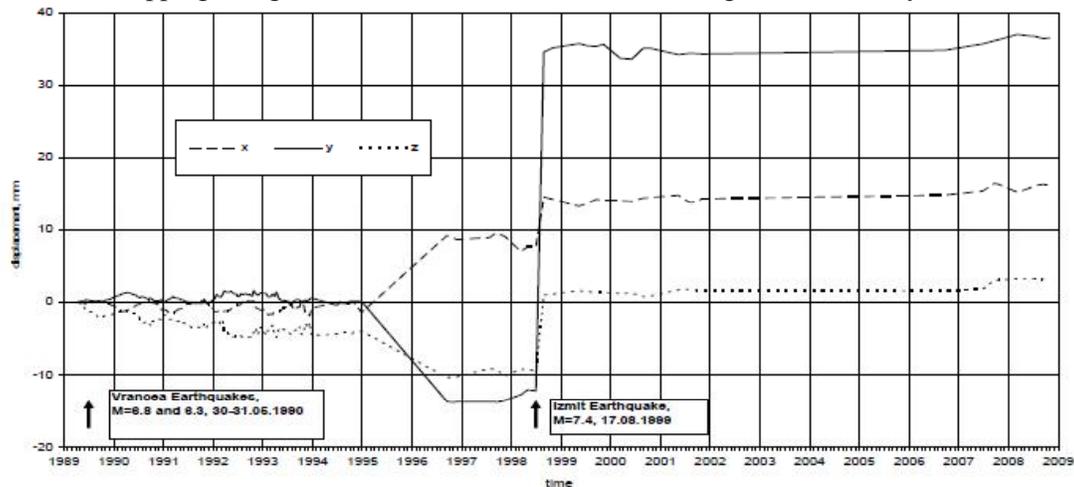


Fig. 6. Diagram of displacements established at monitoring point M9 for the period 1990-2009: +X – compression of the crack; +Y – the rock slice to SSE; +Z – uprising of the rock slice

4. Influence of seismicity

Until the present, effects of earthquakes on micro-displacements along the cracks at the bas-relief have not been established. However, such effects were detected at the upper parts of the plateau. There are large variations, mainly related to the compression and extension of the cracks, but also with slight acceleration movements on the other axes (subsidence and slip to the south). Local earthquakes occur mainly at two source zones, namely Provardia (20 km E) and Shabla-Kaliakra (100 km ENE). Only part of these events influences the movements, mainly from Provardia source zone [4]. The largest effects were established after the earthquakes in Vrancea, Romania, from May 30-31, 1990 (M=6.8 and 6.3), and the second one – with a higher-value after the Izmit Earthquake, Turkey. The monitoring point M9 recorded sharp displacements as the following: $\Delta X = +6.91$ mm compression of the fissure; $\Delta Y = +46.78$ mm horizontal slip to SSE; $\Delta Z = +10.43$ mm vertical movement (uprising) of the rock slice (i.e. sharp subsiding of a new-formed slice behind the plateau edge).

5. Conclusions

The long-term monitoring succeeded to establish the main trends of movements of rock units at the bas-relief and the plateau edge above it. Despite the successful results, other questions still remain unclear: 1) the impact of soil creep on the stability of rock slope, and 2) the

impact of earthquakes on the blocks around the monument despite it was not established during the present monitoring. The answers to these questions will help to take decisions on the protective works on the monument. The most of the opinions envisage a fixation of the unstable rock "flake" to the massif with use of anchors so that it does not fall. In this case, the monitoring of micro-displacements will demonstrate where to focus the countermeasures:

- The strengthening structures to be calculated not only for the tensile stresses but also for shear strain;
- To estimate the possible change of stress state in strengthened bas-relief during a sharp destabilization of the massif (e.g. seismic impact, landslide, rocktoppling, etc.).

Answers to all these additional questions should be taken after a careful analysis before reaching a final decision on strengthening the rock bas-relief.

References

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