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SITE-FRIENDLY DILATOMETRIC SLOPE MONITORING AT CELTIC MOUNTAIN CITADEL OF OBŘÍ HRAD, S. BOHEMIA

Abstract: In this article, we summarize and evaluate the data gathered during more than 3 years of uninterrupted dilatometric measurement, taking into account the clues detected during several years of intensive field, laboratory and cameral research. The contribution deals with the monitoring of the block slope movements on the archaeological site of Obří Hrad. Geomorphological, engineering geological as well as geophysical evidence, gathered during detailed investigation on the site, pointed towards recent and even current activity of geodynamical processes, particularly slope movements, enhanced by suitable structural and relief characteristics. Therefore, in order to understand present-day behaviour of the rock outcrops, we established a system of dilatometric monitoring As there was possibility of further endangering of the remnants of an ancient Celtic site, the main aim of the monitoring is to assess the real hazard by on-site monitoring of the current activity of slope movements.

Keywords: Šumava Mts., dilatometric monitoring, slope movements, cultural heritage

INTRODUCTION

Although Šumava Mts. is generally considered to be geomorphologically rather stable region with a low activity of relief shaping processes, there are localities bearing proofs of surprisingly high recent and even present day intensity of geomorphological processes (Záruba, Mencl 1987). Generally, the largest of these high-activity areas are located on the crossings where the deeply incised rivers penetrate through the main outer slopes of Šumava Mountains, as was found during the detailed research of the Šumava Mts. morphology (Hartvich 2006).

One of these "hot spots" is situated in the vicinity of the site Obří Hrad. Obří Hrad site (in English "Giants´ Castle") is a well-known for the Celtic fortifications at a mountain top. During the archaeological research, it was found that the remnants of the ramparts are incomplete - almost half of the inner fortification ring is missing. As one of the working hypotheses, a big rockslide was considered to cause that damage (Zvelebil, Slabina 2002, Fig. 1).

Rather fresh-looking rockslide forms were documented by morphological mapping (Zvelebil 1999, Hartvich 2005b). Geophysical profiling enabled us to trace slide zones deep inside slope rock mass; moreover, it provided also clues of present-day activity along some of them. Age of that rockslide is not known, but if it had damaged the Celtic site, it would have to be within last 2500 years, nevertheless our findings suggest its placing closer to the present day.

In order to assess degree of current activity of the slope movements, which might continue in endangering of the cultural heritage protected site, we installed a network of accurate dilatometric measurements on the rock outcrop near the remnants of the supposed rockslide scarps

SITE DESCRIPTION

The site of Obří Hrad is situated in the Šumava Mts. in Southern Bohemia. Its position near the rim of the uplifted planation surfaces of the Šumavské Pláně, where the steep outer slopes fall into the lower relief of Šumava foothills (Chábera et al. 1985). The site itself is located on a northwards outstretched spur of the ridge of Valy in the altitude about 950 m a. s. l., with steep slopes falling into the narrow, almost 200 m deep incised valley of the Losenice R.

The celtic site of Obří Hrad has been subject to the archaelogic research since 1920ies. The site consists of the forecastle approximately 370 m x 80 m in size, and of the inner citadel (Fig. 1). Due to the lack of material evidence other than the remnants of the fortifications and a few coins, the function and exact time of building is still unclear (Slabina, Waldhauser, Konečný 1990). There are two possible uses of the site: a refugium (a refuge in the case of danger) or a religious / ritual centre. Best time estimate pinpoints the building of the citadel to the Halstatt period, i.e. 8th - 5th century BC (Slabina 2005). The ramparts have mostly lost their original shape, there are, however, segments in better condition. Some places of these segments bear traces of repairs, which might indicate possible instability already in celtic times.

Geologically, the bedrock is formed by metamorphic paragneisses (Babůrek 2001, Müller 1999) with strongly expressed foliation planes, which predispose tilted (on the site 20° - 35°) discontinuity planes. The foliation planes are sloping roughly towards northeast. Vertical or near-vertical segmentation of the rock is due to several joint systems, of which the most prominent have strike direction about 110°, 85° and 25° (Hartvich 2005a) A reconstruction of the general structure of the slope under the celtic site, based on the results of geophysical profiling and geomorphological and engineering geological mapping is shown on fig. 2.

The rock outcrop "Brána" ("The Gate"), which is incorporated into the remnants of the celtic fortifications, was found to be the most suitable place for installation of the dilatometric measurements. It was believed to be a real gate into the citadel. The outcrop is aproximately 30 m long, of asymmetrical shape (on the western side only about 1 m high, on the eastern side reaches the height 6 m)

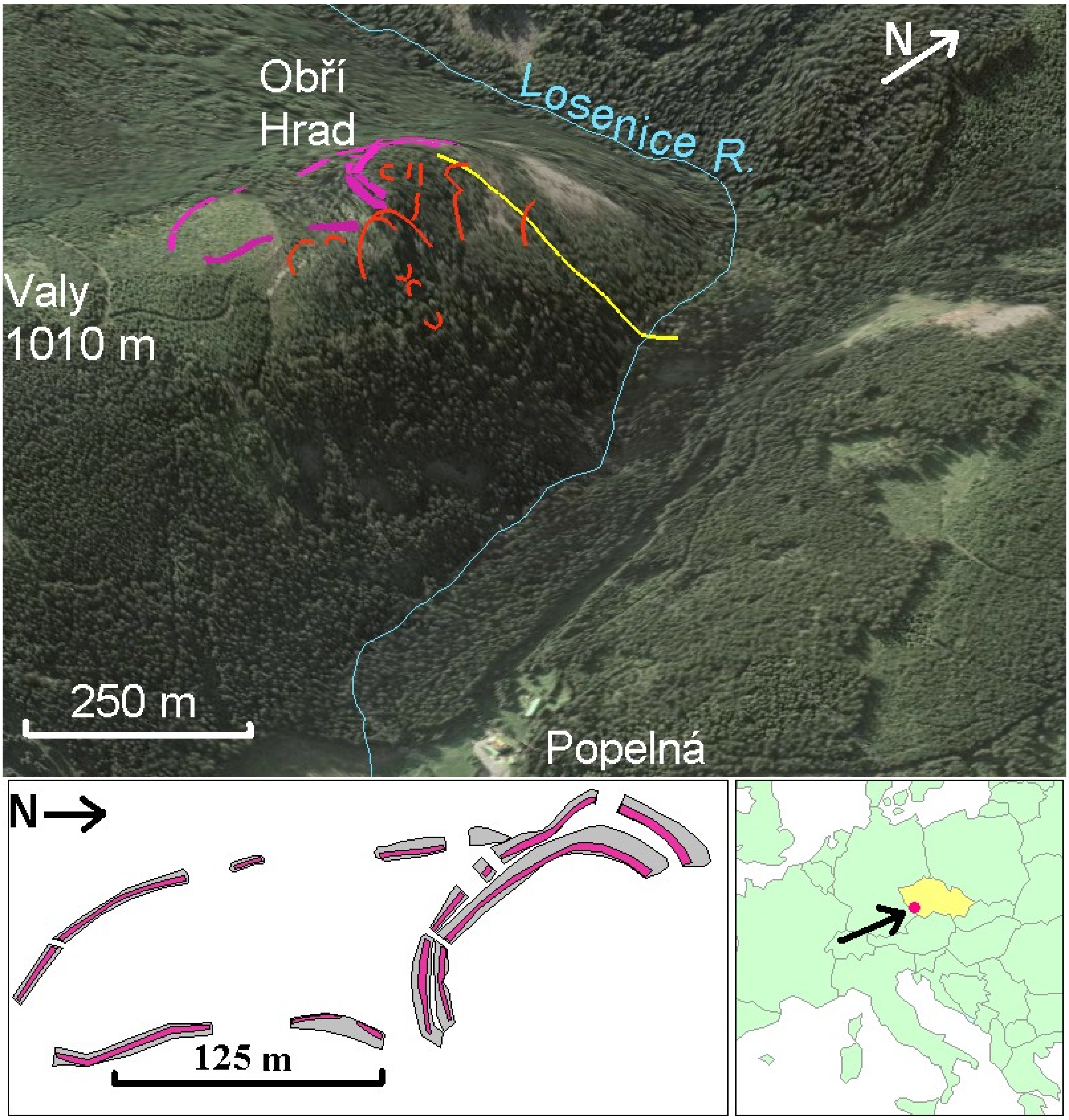


Fig. 1: Situation and position of the area of interest. Main image – 3D aerial photo. Red lines indicate scarps of rocksliding, yellow line shows geophysical profile. Down left: situation of Celtic fortifications.

, and divided by open cracks into several separated blocks (Fig. 3). The higher eastern side of the outcrop forms an overhang of approximately 15°. For the uses of the monitoring we took into account 10 main blocks, among which the monitoring network was installed.

METHODS

The scope of the research methods and techniques, employed in the complex geodynamic research of the Obří Hrad vicinity, was much wider, including geomorphological mapping, geophysical and engineering geological research (Beneš 2002) and many supporting methods such as investigation of the geomechanical rock properties, floodplain sediment analysis, powder X-ray analysis, and recently also automatic estensometric network (Hartvich 2005b). We also cooperate with archaeologists in order to this article, however, focuses on the results of the dilatometric monitoring and its significance.

Network description

The dilatometric monitoring on the outcrop "The Gate" was installed in August 2003. We decided to use portable rod dilatometer of Hölle type. This dilatometer type measures with the precision if 0,0001 m +/- 0,00005 m, which we consider satisfactory for the measured block movements of mm scale.

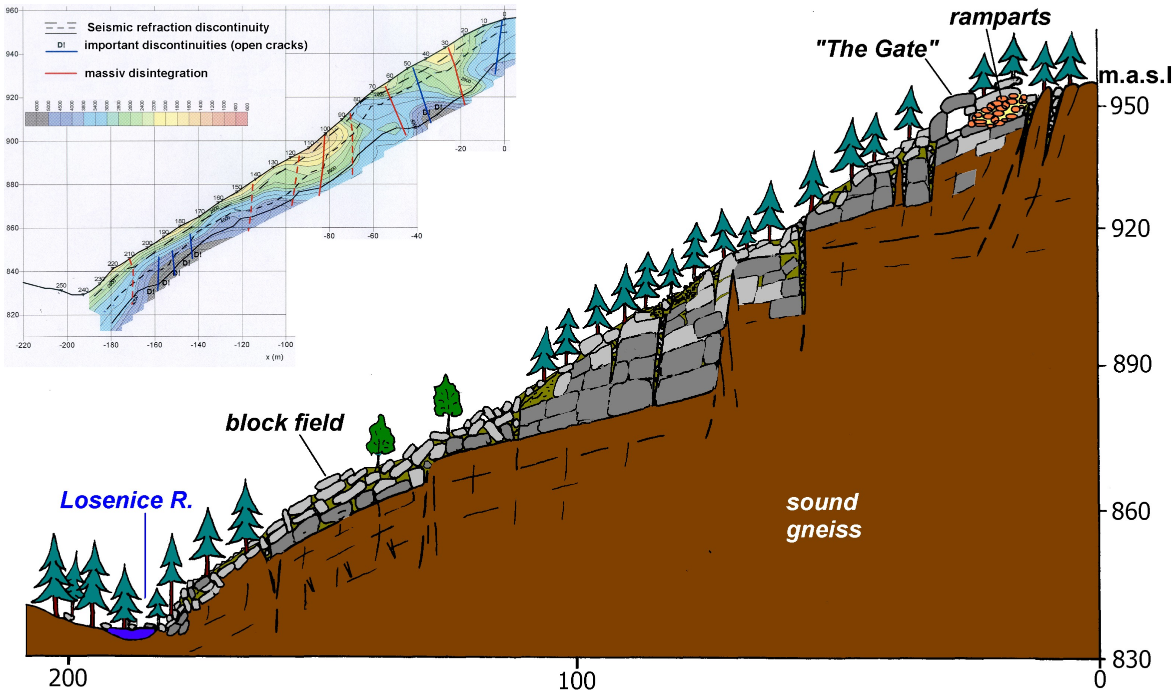


Fig. 2: Reconstructed profile under the Obří Hrad site. Upper left: seismic refraction profile, one of sources for reconstruction

This device has several advantages for the intended use:

- the measurement is simple and installation fast
- site friendly technique - site is located in 1st, most strictly protected zone of the Šumava National Park. We have good experience with this measuring system for instance from Machu Picchu in Peru, where also one of the conditions was to use system as site friendly as possible
- except for tiny brass knobs there is nothing left permanently on the site - the rod dilatometer is portable
- as there is practically no equipment left, the monitoring is not endangered by climatic or human interference

We have created a network of 10 measurements in 6 groups, designed so that we are able to calculate the movements of all the blocks. The configuration of the measurements is depicted on Fig. 3.

First group (measurements 1A, 1B and 1C) controls the minor blocks (2-9 m^3) on the southern end of the outcrop, where the measurements should show the speed of rock outcrop disintegration than general trends. We expected these small blocks to either fall, or follow closely the temperature trends. The 2A measurement oversees the relation between two largest blocks, No. 3 (ca. 90 m^3) and No. 7 (ca. 80 m^3).

Measurements 3A and 3B span over a narrow (ca. 0,5 m) gap between blocks 7 and 9. This opening looks very fresh and also the archealogists claim they did not notice it when their research started here on 1980ies (Slabina 2003). The main opening between blocks 9 and 10 (called "The Gate") is controlled on each end by measurements 4A and 5B (Fig. 4). Measurements 5A and 6A are controlling the lintel of both openings, block 8 with volume approximately 20 m^3.

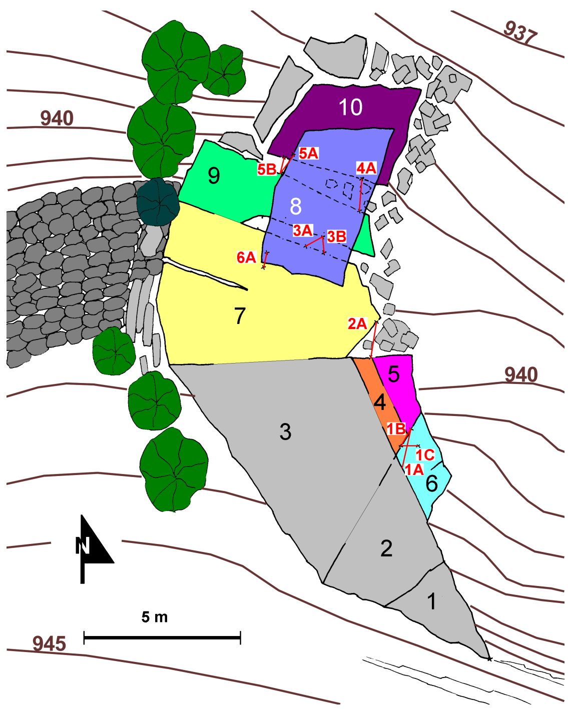


Fig. 3: Plan of the Gate outcrop, showing the position of the measurements and block indication.

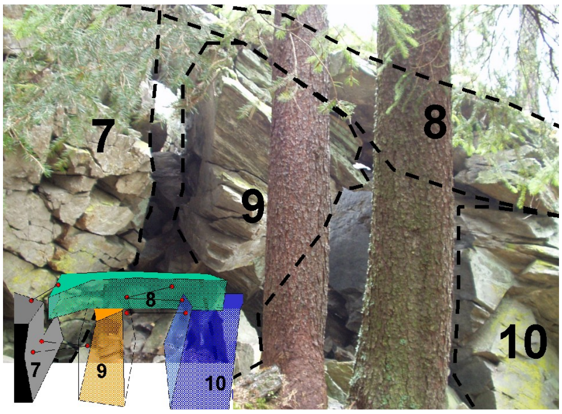


Fig. 4: Two main openings between blocks 7/9 and 9/10

Data processing

Taking the measurements was but a first stage of the research. The initial part of data processing was to prepare the data for further analyses. Each measurement was taken 4 times: twice with measuring head on one side, twice on the other to avoid errors from incorrect device applying as well as from wrong recording. An arithmetic average of the four values is calculated. The values are converted into relative movement (first measurement in August 2003 = 0).

As the iron rod of the dilatometer reacts on the temperature, it is necessary to normalize the values by the measured temperature. As the thermal dilatation of iron is approximately 1,02 x 10^{-2} m/°C we can obtain normalized the value from a formula:

$$Vn = Va + (700 * T * 1{,}02 * 10^{-5})$$

where Vn is temperature-normalized values, Va is the average of measured values and T is measured air temperature

Thus we obtained a record of distances relative to the first measurement for each time horizon. Further step in the use of the processed data was naturally their plotting on xy chart, where the x-axis shows time, y-axis relative values of displacement.

RESULTS

Phenomenological analysis of individual monitoring time series together with 2D vertical plane comparative analysis of all the results of the former reveal that there are three main zones of irreversible displacements on the sub-vertical fissures between blocks of the Gate outcrop.

Proceeding along the outcrop from South to North, an irreversible movement of 0.2 mm/3 years has been recorded on the site No 1B – i.e. between blocks 4 and 5. The similar displacement magnitude of 0.15 mm/3 years takes place at measurement No. 2 (Fig. 5.1)– i.e. on the crack between blocks 3 and 7.

The main displacements take place on the fissures enclosing the block 9. On the southern boundary fissure – i.e. on the measuring site No. 3A (fig. 5.2), the displacement magnitude reaches 3.20 mm/3 years. On the southern boundary crack – i.e. on the site No. 4 (Fig. 5.3), relative displacement magnitude reaches 0.2 mm/3years. The displacements are well (No 3) and fair enough (No 4) pronounced against the screening noise by seasonal quasi-cycle of voluminal changes of rock blocks in sides of both cracks. Those cycles are driven by the seasonal cycle of air temperature changes.

Regarding the relative nature of dilatometric measurements, one should assume vectorial compounding of measuring results from all the sites listed above. Considering the results, one can present following picture. Whilst relative displacements in the upper part of the outcrop, i.e. between the blocks 3 and 4 (demarcated by measurements site 1B) and between blocks 3 and 7 (meas. 2A) are rather slow, the main displacements are realised in the lower part, by blocks 9 and 10 – i.e. demarcated partially by fissures with sites 3A and 4A.

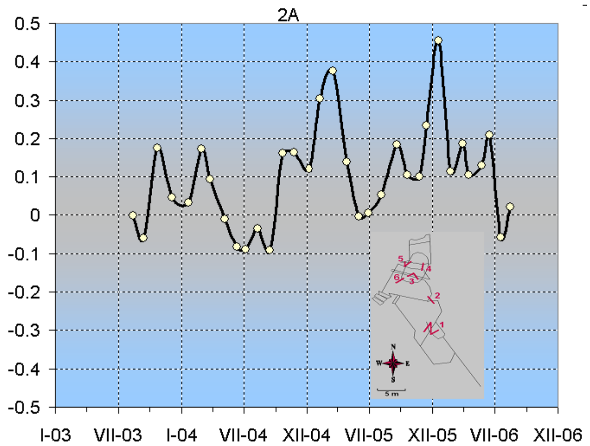
Taking into account the nature of deformation process and its main driving forces, correlogram plots were constructed for displacements vs. temperature, as well as for displacements measured in the same time at different places.

An example of quite good correlation of displacements measured on the site No 5 (Fig. 5.4), which represents only reversible movements – i.e. relatively calm, and temperature changes is given on Fig. 5.5. On the other hand, there is nearly no movement/temperature correlation presents in fig. 5.6, and nearly no correlation in the plot of fig. 5.7. These plots represent two types of correlation patterns characterising all plots of for irreversible displacement displaying sites. Events of temperature changes without corresponding movement events are manifested by sub-vertical lines, whilst movement events with no relevant temperature changes are marked by sub-horizontal lines in the plots in question. It means that the irreversible deformation mechanism is not temperature driven, and one should look for another influencing factor, as e.g. precipitations.

Patterns of slight to medium time correlations of occurrence of movement episodes between different sites of irreversible displacement are presented on figs. 5.8 to 5.11. Particularly important are the correlation patterns between displacements taking place on the both marginal joints of the outcrop studied plotted on Fig. 5.11. In general, all the correlograms for irreversible displacement sites could be interpreted in two ways. There is another, universally operating environmental factor which takes effect on movement dynamics, or there is an inner, to the rock mass failure inherited dynamics which demonstrates itself without any outer perturbation throughout all irreversible displacements disregard of to the site of their measurement.

Plan model

To enrich our knowledge of deformation kinematics, the data from dilatometric monitoring were used in reconstruction of relative block movements in 2D plan model. There were some more data processing steps necessary before the plan model could be drawn.



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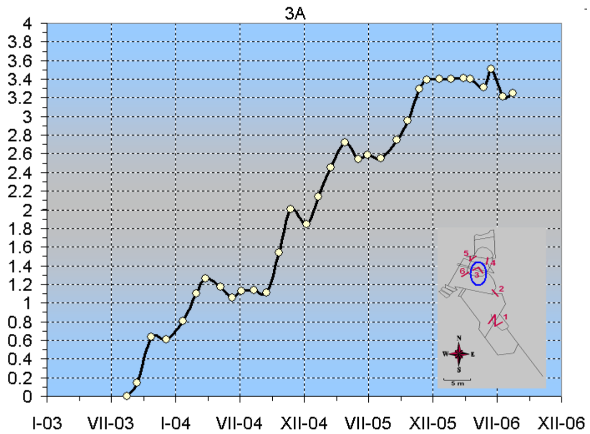

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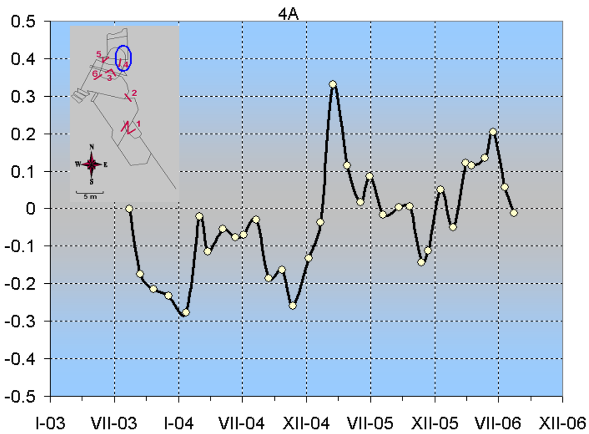

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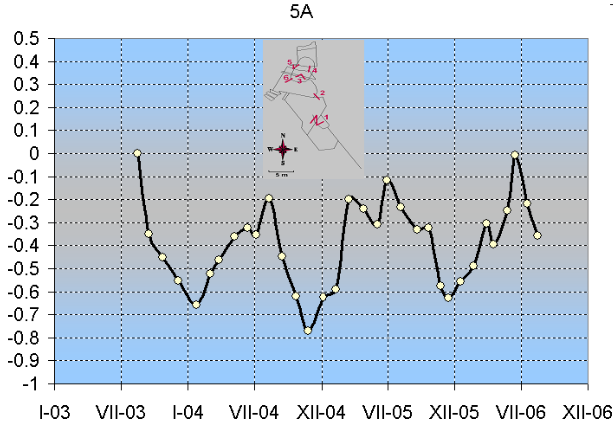

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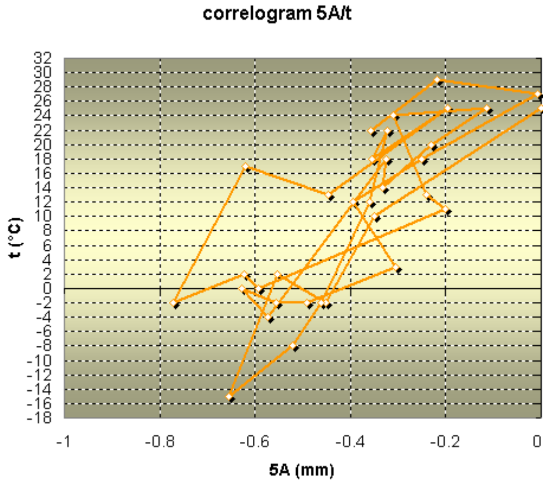

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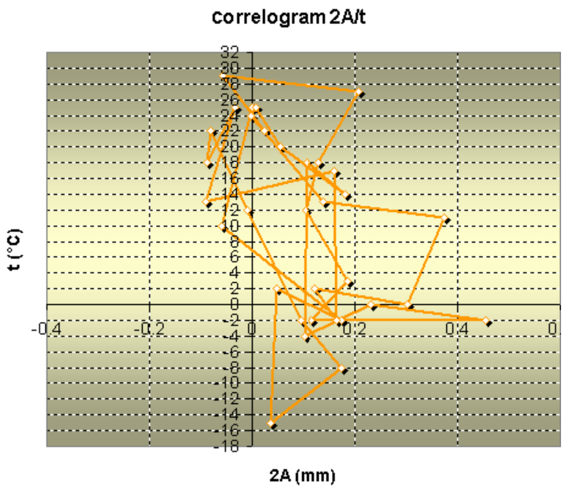

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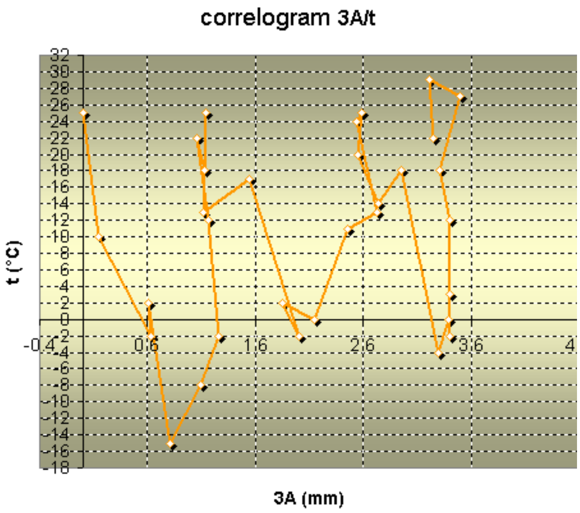

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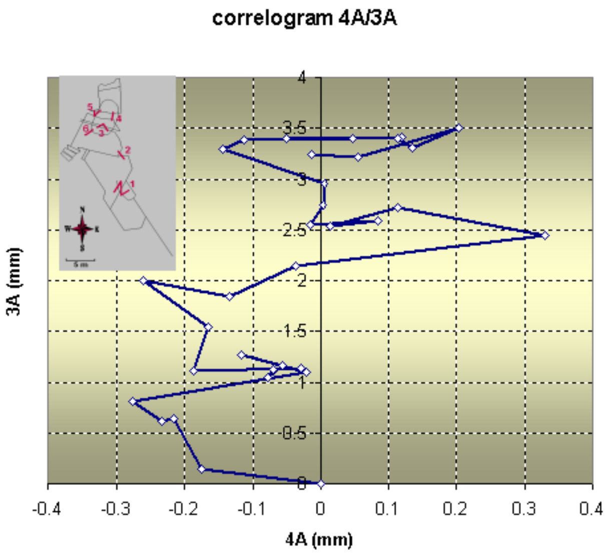

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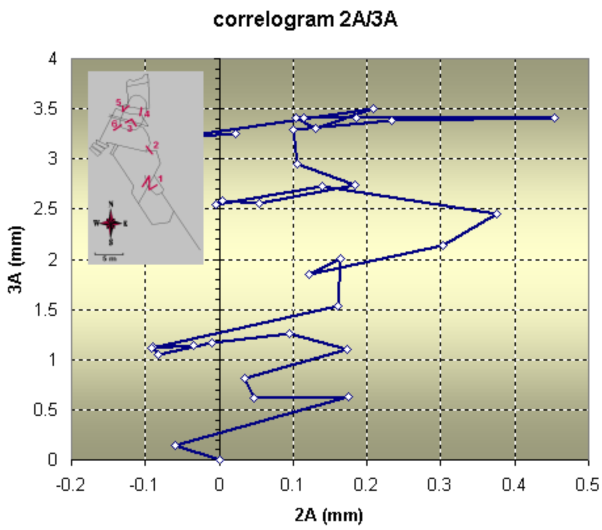

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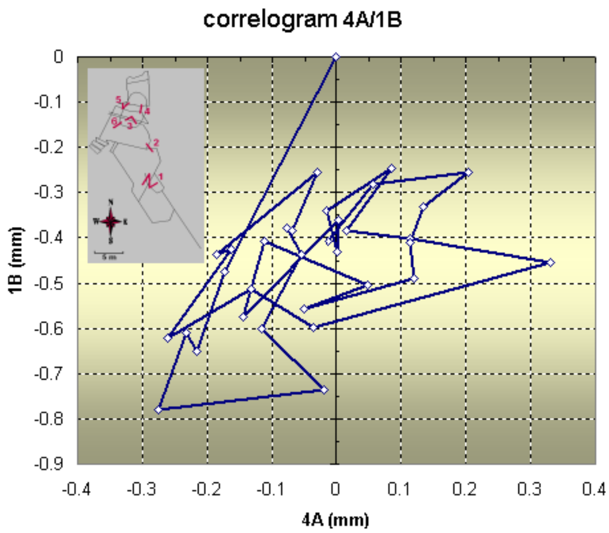

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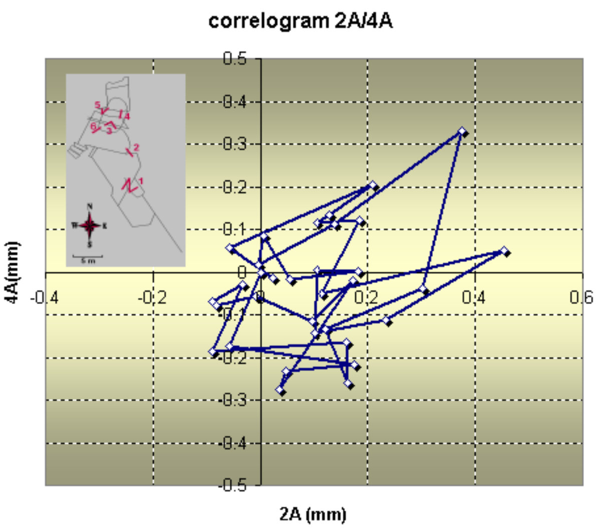

5.9

Fig. 5:
5.1 – 5.4 plots of individual movements on the measurements 2A, 3A, 4A and 5A

5.5 – 5.11 correlograms showing the relations between indicated values (see text)

Firstly, as the measurements were performed in 3D space, it was necessary to calculate the horizontal component of the measurement. In second step, we calculated the two horizontal vector Cartesian components x and y. Finally, the measurement points as well as the main vertices of the blocks sketch obtained a pair of X, Y coordinates in S-JTSK coordinate system in the GIS environment. For each point it was also recorded to which block it belongs.

Now it was possible, employing the vector algebra and goniometric operations, to calculate the exact position of each point at any time horizon. As the measurements are relative between two blocks, in calculation of new JTSK coordinates it was necessary to include each "previous" block (i.e. the one between stable part of the outcrop and the block in account). The movement of the last block No. 10 was calculated as a sum of movements between blocks 3 / 7, 7 / 9 and 9 / 10.

The resulting movements were, naturally, too small for plotting into a map, reaching in maximum into the range of few milimetres. To show the trends in block movement and rotation, we decided, however, to draw a plan with 100x exaggerated movements (Fig. 6)

DISCUSSION

We have already presented the advantages of the Hölle dilatometric monitoring network, there are, however, some drawbacks. Among them is the necessity to visit personally the measurement site once a month, including winter months, when the site becomes often almost inaccessible or the access is extremely difficult, as the snow cover reaches more than 1 m.

Another problem of this technique presents the low amount of data - during 3 years we collected values in 33 time horizons, which is far from sufficient for detailed analyses of influences on the movements. Regarding the low sampling frequency it is difficult for instance to decide between the hypotheses of environment driven, or inner dynamics of the rock slope failure driven movements.

The possible development of the monitoring in the future should be aimed at removing or minimalising the above mentioned disadvantages. In order to obtain denser and more accurate data, we started to equip the site with automatic extensometric monitoring network, which is now running in trial mode. All 5 induction extensometers are installed across the two most active openings (between blocks 7/9 and 9/10). The sampling interval is 3 hours, so we will have almost 3000 time horizons per year, i.e. more than 260 x denser than dilatometers. The system also measures temperature and we are considering installing of pluviometers as well. All the data are immediately transmitted wirelessly to the server databank, thus we have immediate control of the measurements without necessity to visit the site. Another advantages of the automatic extensometers is the possibility to compare the results with the current dilatometric monitoring and also a possibility of raising the alarm in case of significant or accelerating movement practically without delay. It is also possible to create a plan model, similar to the one created for the dilatometers, which shall operate automatically on the basis of the data incoming on the server.

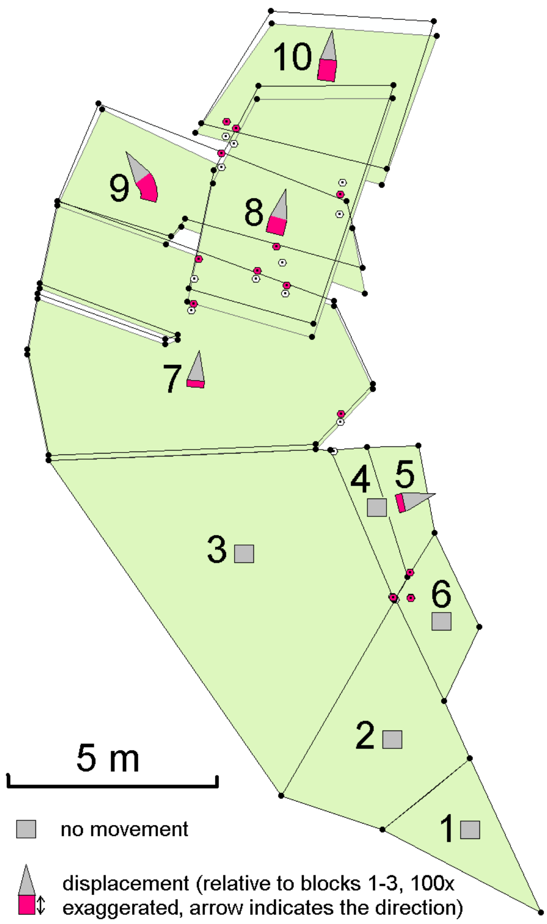

Fig. 6: Plan of the Gate outcrop showing in exaggeration the movements and directions of rotation of individual blocks

CONCLUSION

The three years of dilatometric monitoring on an outcrop incorporated into the remnants of Celtic fortifications on Obří Hrad, a part of complex research of this highly interesting site, has yielded several significant facts.

Firstly, it is clear that the slope movements on the site are still active. We assume that generally the chief drive of this movement is the continuing incision of the Losenice River in this area (Hartvich 2005a, Hartvich 2005c) combined with specific structural conditions. It is significant that on some openings an irreversible movement was found, confirming the hypothesis of downhill rock disintegration on the chief joint systems.

It was originally believed that so-called "Gate" in the rock outcrop was a Celtic entrance into the citadel. This can be ruled out as extremely unlikely for several reasons, including the fact, obtained by the dilatometric measurement, that the velocity of the block movement is such that the opening in question ("gate") is much younger than the Celtic times. If we consider linear extrapolation of present day movement velocity, the total movement since the citadel building would be in the range of meters (2,5 m if the movement were only 1 mm/year).

The plan model, which was created, reveals also the rotation of the blocks, particularly the most active block No. 9. This is an extremely curious fact, if we take into account that the lower block 10 is rotated similarly and that the blocks move downwards in the range of meters per 1000 years. Therefore, we can imagine that the presently fastest opening fissure between blocks 7 / 9 nowadays occupies the same position as some time ago the most opened "Gate" - whence we could derive the hypothesis that the movement may not be limited to the surfacial block movements, but it might reach much deeper, particularly in the light of the fact that approximately somewhere in this area the missing part of the fortification should be situated.

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