Acta Geodyn. Geomater., Vol.3, No.2 (142), 39-49, 2006

DEFORMATION TRENDS IN THE JEZEŘÍ CASTLE MASSIF, KRUŠNÉ HORY MTS.

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(*Received* April 2006*, accepted* May 2006)

ABSTRACT

Brown coal open pit mining in the basin under Krušné Hory Mts. came to contact with slopes of the mountains, and a problem of the stability in high and steep slopes in the crystalline rock became an important question. The question concerns Jezeří Castle built on the top of one of the hills in a most endangered section where even a supporting pillar in the sediments under the slope toe was left to support the slope. As a result, an extensive monitoring program regarding deformations was initiated in the region. The program involved several methods and some important results are discussed. The results that are displayed concern mainly measurements done in geophysical tiltmeter stations in two underground galleries driven into the two steep slope sections showing most dangerous situation, as well as extensometers located in the same locations.

Long-term monitoring revealed a tectonic deformation process of a natural origin that is registered as slow and systematic tilts. Besides, it revealed several periods of anomalies that are of basic importance. During a long period of observation from 1982 till 2005 three important deformation anomalies were registered: the event of 1994, the event of 2002, and the event of 2003/2004. The first and the third event have been classified as of a large regional character that affected a wide mountainous area and could be interpreted as a tectonic impulse originating within the mountainous structure of the so called „Dome of Hora Svaté Kateřiny“. The second event has been considered different, strictly connected with extreme precipitation of August 2002. The anomaly was evidenced even deep in the crystalline, so that it could not be seen as of a superficial character only. The movement which was registered at that time was oriented right into the pillar supporting the slope. It is concluded that it was a short manifestation of instability in the critical profile "Jezeří – pillar", which stresses the important stabilisation function of the supporting pillar without which the profile will be probably destabilised.

KEYWORDS: rock slope stability**,** deformation monitoring, coal mining, Krušné Hory Mts.

INTRODUCTION

The conflict between open pit mining of brown coal seam with the mountains started in the 70th of the last century when the stability problem of the slope of the Krušné Hory Mts. became questioned due to results of engineering-geological mapping in the area. Mining was to contact the mountains. Crucial historical aspects of the problem were recalled recently by Marek (2005/6), who provided also a list of papers pertinent to the research of the early stages of investigations. Soon, two tracks in the investigations could be followed: one strictly concerned with the stability problems connected with mining advance, second concerned with the stability of crystalline, which involved the Jezeří Castle built on a giant block of crystalline. No doubt, the second problem was considered dominant and it resulted in a decision to leave supporting pillars in two critical cross sections of the slope: under Jezerka and Jezeří Castle hills. Meanwhile, mining continued till today. Both the supporting pillars with a considerable amount of coal are left respectfully in place and mine front curved around. Mining operations deal with daily problems in the cuts where deformations reach meters but are still technologically acceptable. Hill slopes deform in the transient zone of the debris under a control of monitoring. The volume of such a moving rock is considerably high. Crystalline rocks of the massif are apparently stable. Are they really ?

It is an important question with many aspects regarding the mines, the castle, and also the ecology of the mountains. Stability cannot be seen to be a question of our days only. It should be considered even in a long-term horizon. Detectable low order movements in the crystalline must be interpreted carefully since the rock is hard and brittle and even low order movements may be of importance and develop in size.

Jezeří Castle massif represents a block located right between the mine and the mountains (Fig. 1a). A historical value of the castle calls for safeguarding of the stability. It is only long-term monitoring that can provide reasonable data to see possible effects of the mining or even of the natural conditions.

MONITORING DATA

A lot of investigations as well as of monitoring was done in the region. It is out of the scope of this

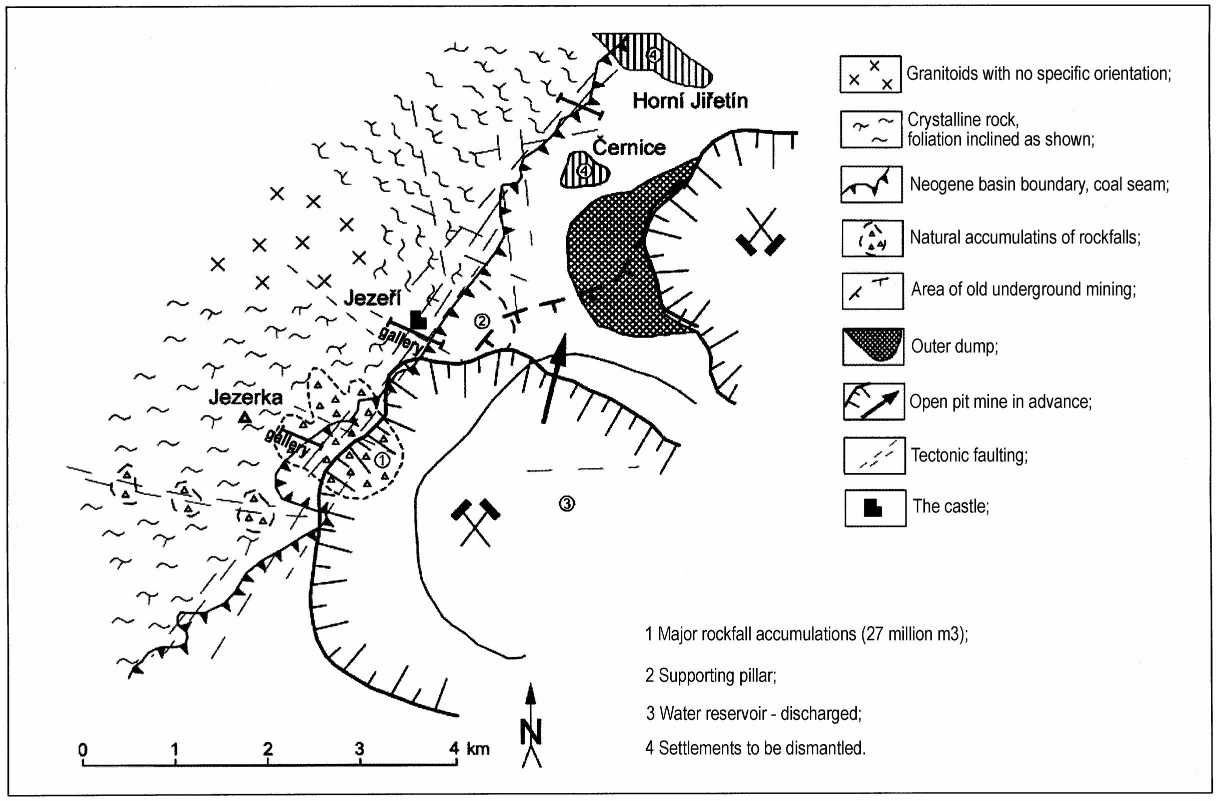

Fig. 1a A schematic situation of the mines in contact with Krušné Hory Mts. in the area of Jezeří Castle. (After J. Marek 2005/6).

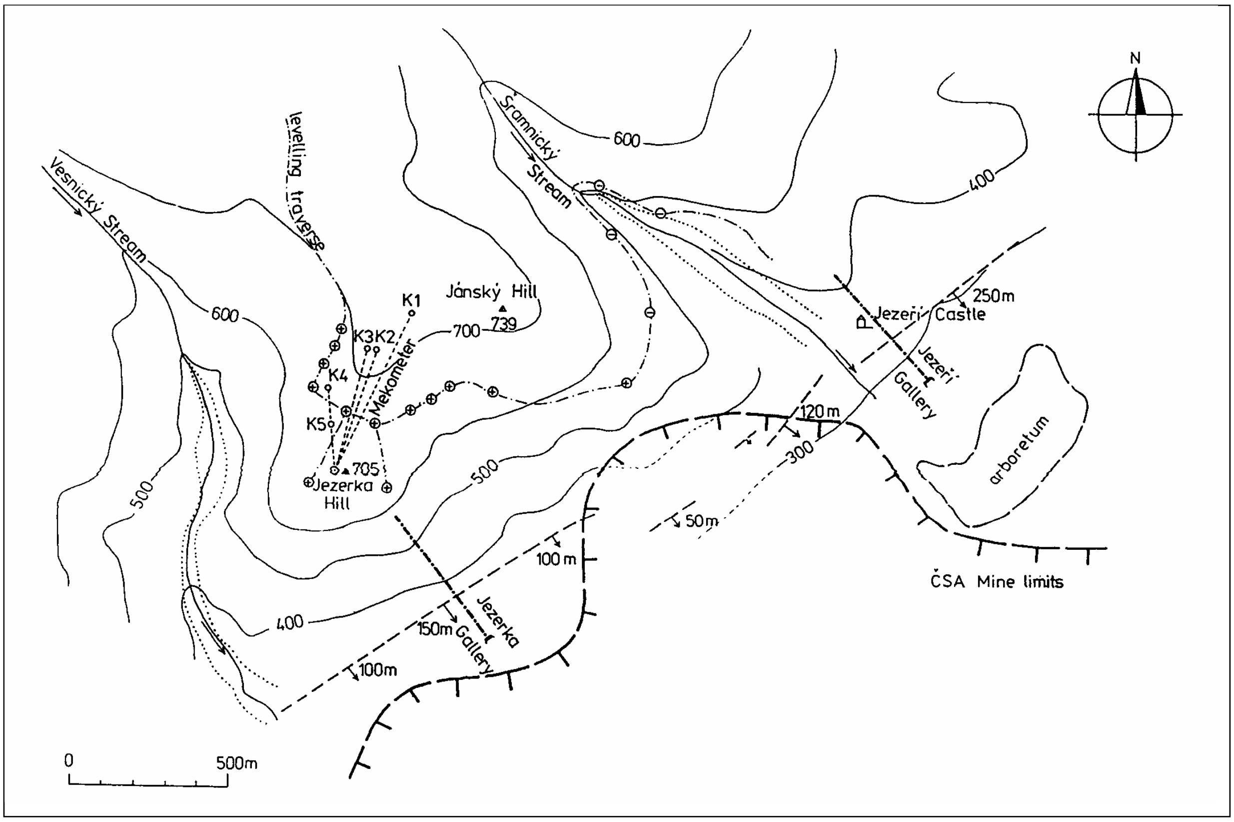

Fig. 1b Situation of the Krušné Hory Mts. slope area between Jezeří Castle and Jezerka Hill where most of the monitoring data concerning the deformation trends in the massif were obtained.

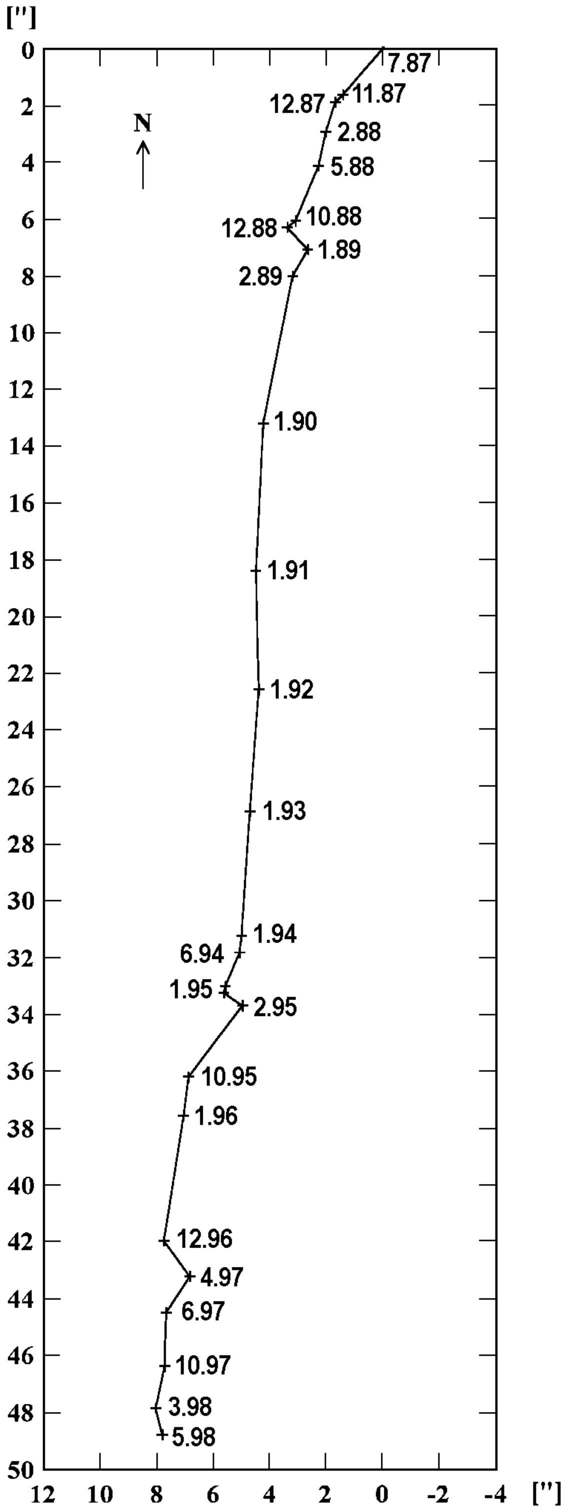

Fig. 2 Long-term tilts registered at Jezerka 2 station deep in the massif of crystalline between 1987 and 1998.

work to show all the details that are scattered in a series of reports. Most recent evaluation of monitoring results, investigations and conditions were made by Rybář and Košťák (1998), and by Košťák et al. (2003). A situation of the area where monitoring took place and results to be described were obtained, is in Fig. 1b.

Two galleries driven into the massif under Jezerka and Jezeří Hills provided most important insight into the massif and its long-term deformation was registered systematically using high accuracy geophysical tiltmeters (Skalský, 1988, 1990, 1995). This measurement together with tape extensometry and precision levelling detected characteristic slow movements in the massif. First of all it concerned the debris and an adjacent weathered superficial zone of the slope in crystalline. In both the galleries shearing of the gallery frontal zone was registered indicating downslope slow movement along a slipping plane exposed clearly in the galleries as a step. The thickness of the superficial loosened zone in both the galleries was indicated of up to 150 m and the volume showing displacements could have been estimated to several million cubic meters. The slide under Jezerka Hill entangled Quaternary debris to a depth of about 60 m with a total volume of about 7 million m^3.

Deep in the galleries rock indicated creep movements, as well as episodic movements of tectonic origin (Košťák, 1998, 2000). Indicated creep strain rate $\varepsilon = \Delta d/d$ (a non-dimensional number where d represented axial gallery length) in the crystalline rock was calculated reaching in average a value of $\varepsilon = -1.8\ 10^{-5}$ per year. The negative value means compression and can be interpreted as being due to a tectonic horizontal pressure in the massif.

Tiltmeters were operated by Geophysical Institute of the Czech Ac. Sci. Tiltmeter Jezerka 2 was located deep in the solid crystalline, and indicated persistent trend in tilts (cleared from Earth tides) reaching 4.7´´ per year and oriented to S (azimuth 190 ^{o} - see Fig. 2). Although the tilts being generally downslope, they did not follow exactly the dip orientation of the slope, which is rather to SE. Tilts registered deep in the solid rock of the Jezeří gallery were lower and not so persistent. Their trend between 1982 and 2001 was only 0.75´´per year in average and the tilts oriented to WSW (azimuth 225^o / 270^o - see Fig. 3), i.e. mostly parallel with the slope face of the mountains.

Other two tiltmeters were installed in gallery frontal zones, just behind the superficial loosened zone found in the two said galleries. They indicated more complex results and more variable orientation in tilts. Most important observation comes from the year 2002 when *tilts between August 11 and 15 accelerated at the station Jezeří 2 up to six times* reaching the value of 0.154´´ in one single day of August 13, 2002 and reoriented from SW to SE. Later, they normalized and returned back to SW again (Fig. 4). The station Jezeří 1 down in the solid crystalline rock registered a temporary sudden turn to SE, i.e. parallel with Jezeří 2, at the same time (Fig. 5) This happened during the period of extreme torrential rains that resulted in floods all over Bohemia (Chán et al., 2003) and can well explain the unusual event.

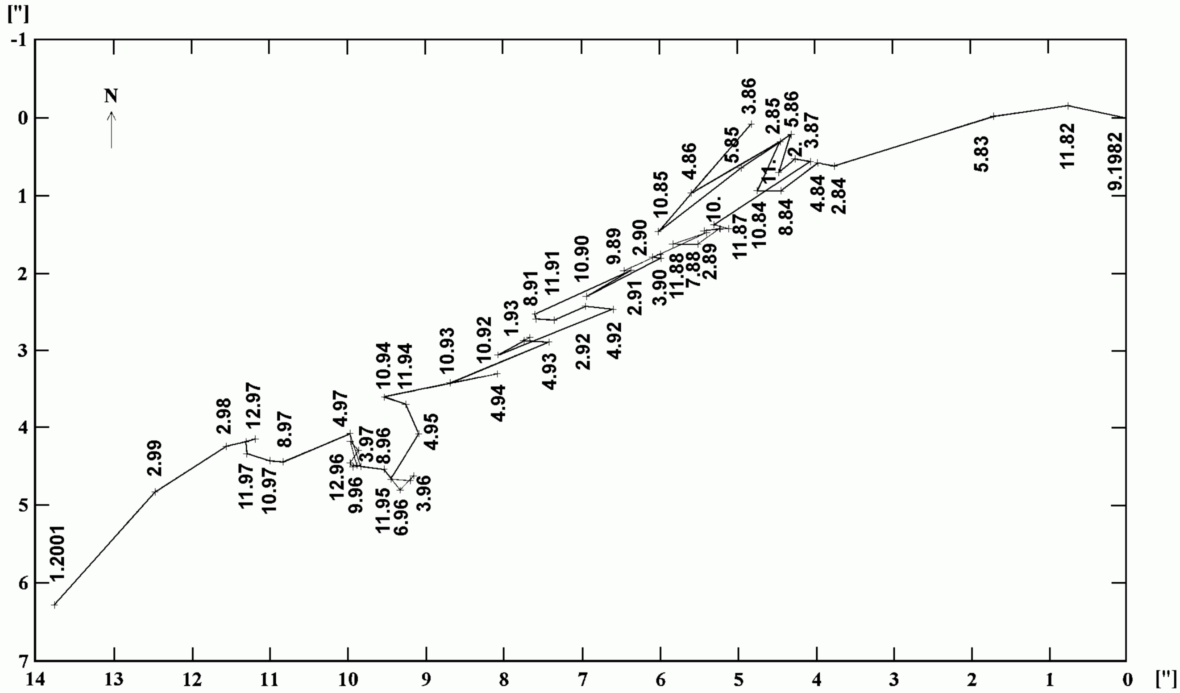

Fig. 3 Long-term tilts registered at Jezeří 1 station deep in the massif of crystalline between 1982 and 2001.

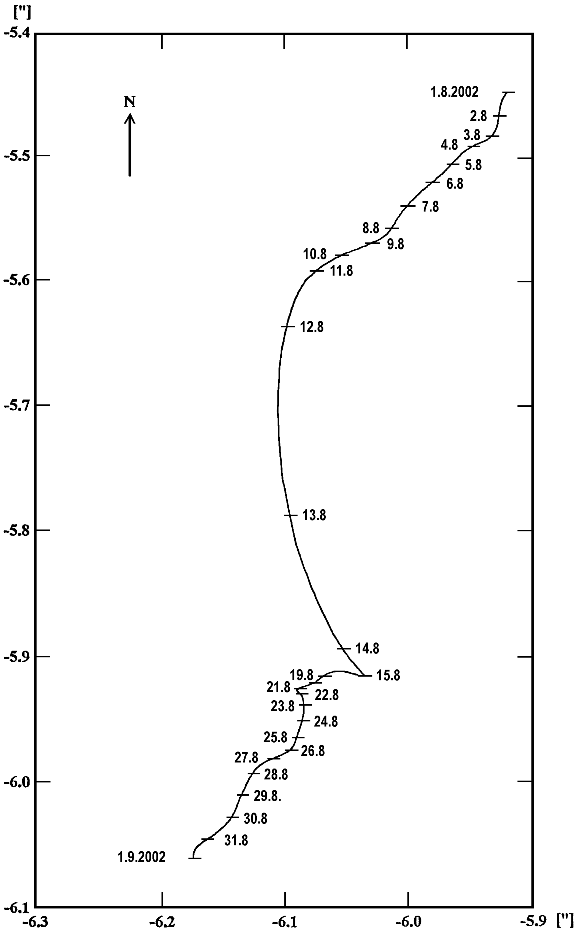

Fig. 4 The effect of extreme precipitation of August 2002 registered in the tiltmeter station close to the superficial zone of the crystalline of Jezeří gallery. For a short period of about three days of maximum precipitation the tilt accelelared and reoriented from SW to SE.

Precise levelling on an altitude traverse established between the top zone of the mountains and the slope edge (Fig. 1b) was performed for years in this crucial section of Krušné Hory Mts. and has shown movements in the very early stages of the monitoring. It was a very demanding measurement in which a series of institutions participated: Geodetical Research Institute, Zdiby; Geodetical Institute, Prague; Building Faculty of the Czech Technical University, Prague; and Charles University, Faculty of Natural Sciences, Prague. Results were described in a series of reports and publications (e.g. Kalvoda et al., 1994); most recent data interpreted by Vilímek (1996).

Levelling results proved different trends in the two different blocks of Jezerka and Jezeří. The two blocks were found geologically separated. Uplifts were indicated in Jezerka top zone reaching 1 to 4 mm in 6 years from 1984 až 1989 (including one point of deep stabilisation), while zero trends near Šramnický Creek or even subsidence on points ENE from Jezeří top point was found. This, however, might have been due to superficial rock slope subsidence of individual points: between 4.5 and 11 mm in 1984/1989. Later levelling work proved to continue such trends. Such trends were interrupted with an unusual event, however. This general event was observed in the period Fall 1988/ Spring 1990 when trends turned first to subsidence of about 2 to 3 mm being compensated later by uplifts.

Rangefinder measurements were performed by the technical survey group of Vodní Díla Comp., with a high precision electro-optical rangefinder instrumentation in the top zone of Jezerka Hill which represents rock crystalline. Distance between five

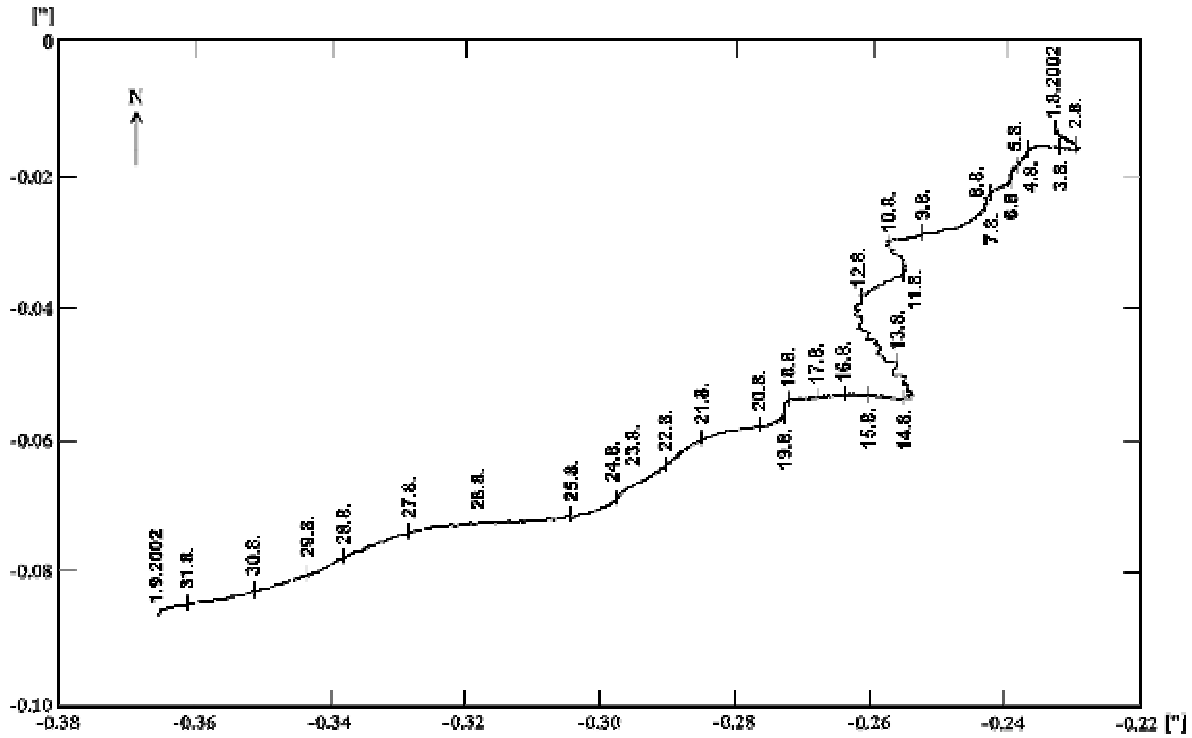

Fig. 5 The effect of extreme precipitation of August 2002 registered in the tiltmeter station deep in the crystalline of Jezeří gallery. For a short period of about four days of maximum precipitation the tilt accelerated and reoriented from WSW to SE.

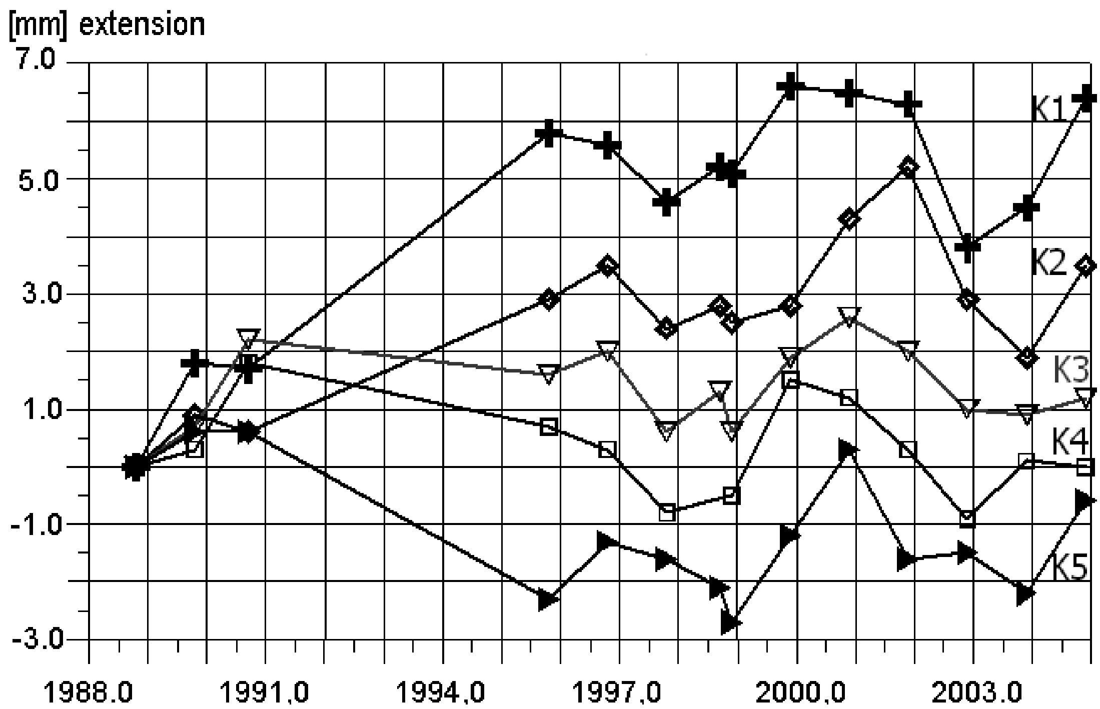

Fig. 6 Mountainous top zone - rangefiner (Mekometer) measurements showing increments of distance between a rock spur above Jezerka fault slope and five points in a profile up to the mountains. The points are numbered consecutively starting from the point in the mountains (K1) to the slope edge (K5).
(Years are given systematically at the end of year intervals in all our graphs, i.e. in a decimal time scale!)

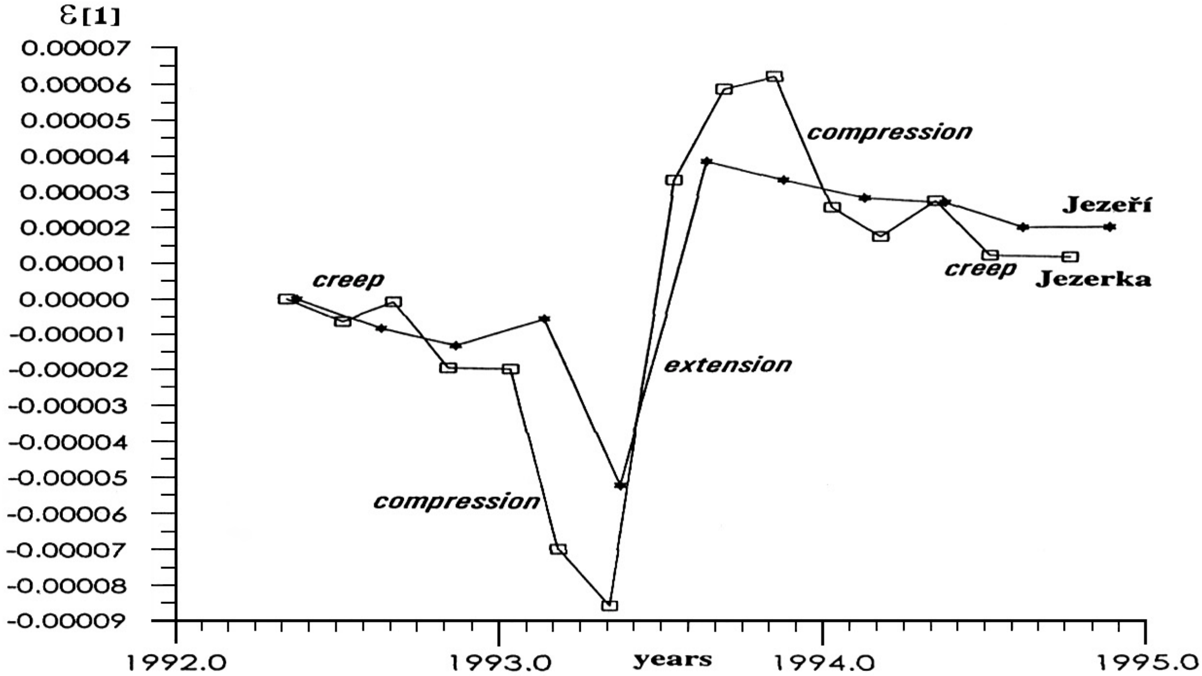

Fig. 7 Tectonic pressure impulse of the year 1994 registered by tape extensometers in Jezerka gallery. Strains were calculated in profiles along gallery axes, at a length of 200 m of the zones deep in the crystalline of the massif.

rock spurs and one reference point on a rock spur located right on top of the steep slope plane, were checked systematically. Points K1, K2, K3, K4, K5 were selected approximately in a profile of the top zone crossing a saddle behind the Jezerka peak (Fig. 1b). Regarding the profile, points K1 to K4 were situated in mountains beyond the Jezerka saddle, K1 being the most distant one of them, 550 m from the reference point, and K5 in the edge zone before the saddle. Measurements took place repeatedly in the late fall seasons to minimize climatic effects. Results from the period 1989/2005 are given in Fig. 6.

One can observe different development in the crystalline before 1996 and after 1996. The period of 1991/1996 developed extension, while 1996/2005 proved general stability with two seasons of pressure events. The first anomaly could have been observed in 1999, the second in 2003/2004. One year frequency in such measurements does not allow for more precise dating of the anomaly events.

OBSERVATION OF ANOMALIES

The anomaly connected with extreme precipitation of summer 2002 has been mentioned above.

There were other two outstanding anomalies in the registered data that appeared during the long period of observation from 1982 till 2005. The first appeared by *high compressive strain acceleration registered in the galleries by precise tape extensometers* operated by Monitoring AZ Conzult, Most. Longitudinal compressive displacement of the internal section of the two galleries Jezerka and Jezeří, was registered simultaneously in February/April 1994. It was then followed by a pressure release culminating between July and November 1994 (Fig. 7). This anomaly was evident also in the tilts. Jezerka 2 geophysical tiltmeter deep in the crystalline, indicated the only major reversal tilt of about 0.9′′ back to N at that time. It was registered between April and June 1994. However, the tilt was of minor value as compared with regular tilts to S. More impressive tilts (up to 6.5′′ back to N) were registered at the same time at Jezerka 2 tiltmeter station located not so deep in the massif. The event was reported by Košťák, 1998 and interpreted as a horizontal tectonic pressure impulse coming from the local superstructure of the mountains called „Dome of Hora Svaté Kateřiny".

Another impressive anomaly appeared by the end of 2003. An unexpected loop was registered at Jezeří 1 tiltmeter deep in the massif between 19.10.2003 and 1.3.2004 (Fig. 8). The tilt turned first to W, then back to E and returned to SW, which was a long-time general trend. *Groundwater level measurements in borehole JZ41 at the toe of Jezeří Hill registered an enormous lift of water level* just that time (Chán 2005 - Fig. 9). Then, tilts at the shallower station Jezeří 2 registered the event also but with a delay, at the end of the above period: between 1.2. and 1.4. 2004 (Fig. 10).

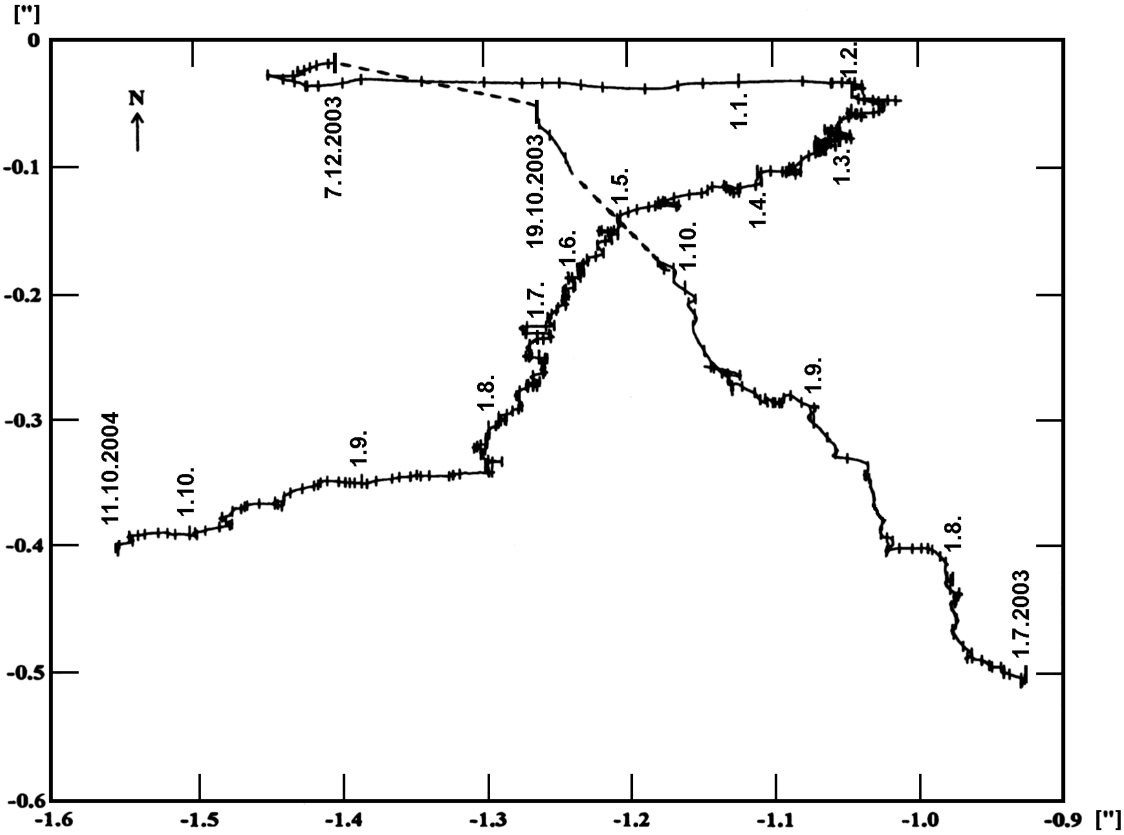

Fig. 8 An impressive tilt anomaly registered at geophysical tiltmeter station deep in the crystalline of Jezeří gallery at the end of 2003. From December 2003 to February 2004 the tilt has formed a loop turning its orientation from NW to E and back to SW. The anomaly coincide with a sharp groundwater level lift in the borehole JZ41.

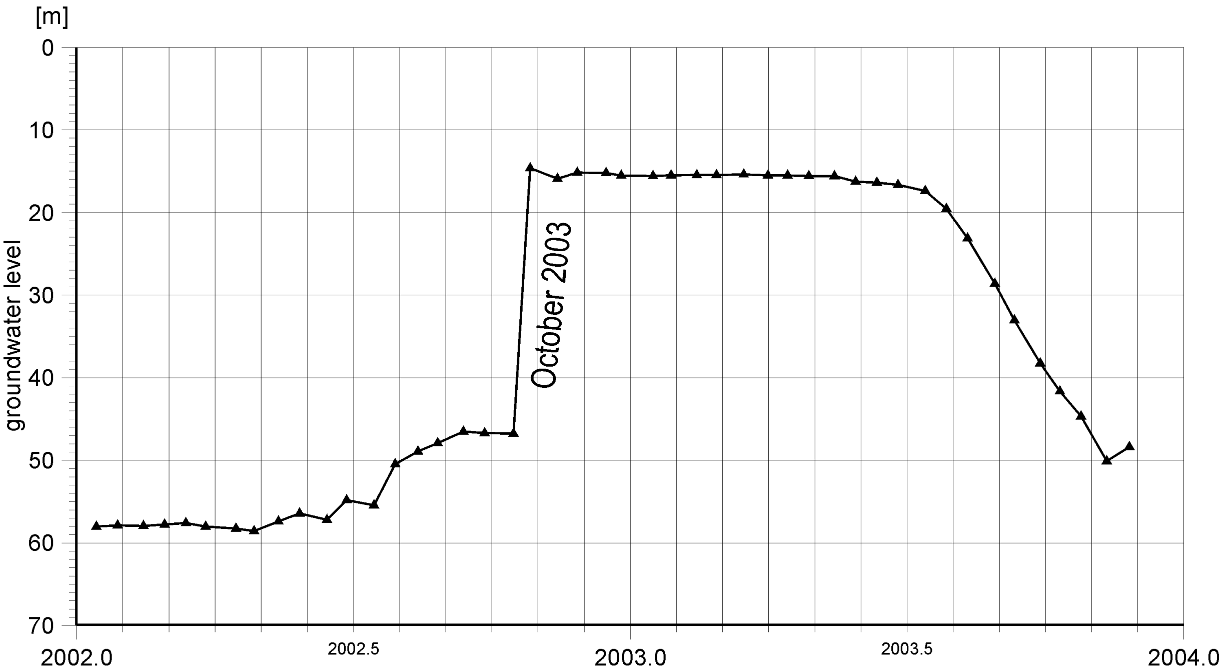

Fig. 9 Groundwater level lift in the borehole JZ41 at the end of 2003. The borehole is located at the slope toe of Jezeří Hill reaching crystalline in the depth. The lift can be correlated with anomalies registered at Jezeří tiltmeter stations and Jezeří and Jezerka TM71 micro-displacement observation points. The effect was observed in a fall period when no precipitation extremes were reported.

(Years are given systematically at the end of year intervals in all our graphs, i.e. in a decimal time scale!)

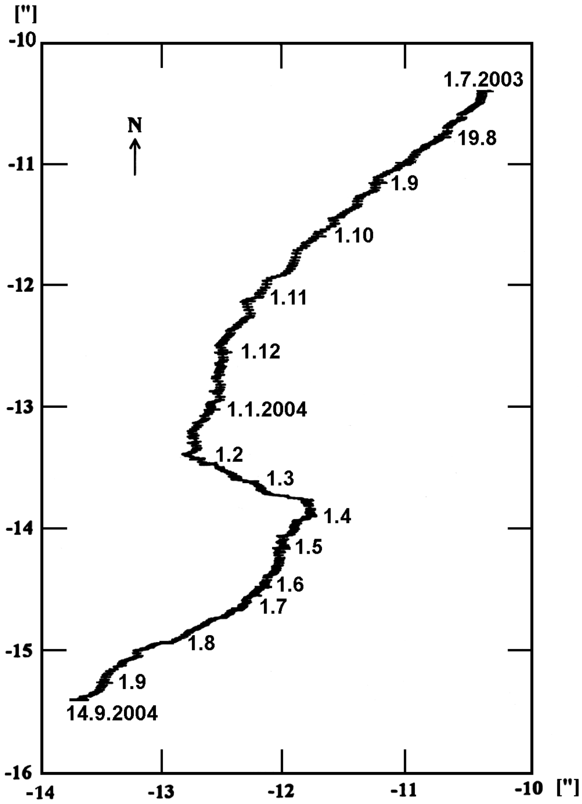

Fig. 10 A tilt anomaly registered at geophysical tiltmeter station close to the superficial zone of the crystalline of Jezeří gallery. From February 2004 to April 2004 the tilt reoriented from SW to SE. This effect of tilt toward the pillar is similar to that of August 2002. In this case it could be connected with the effect of groundwater level lift in the borehole JZ41 and it was delayed as compared with the reaction of the other tiltmeter deeper in the crystalline (see Fig.8).

Crack gauges TM71 operated by Institute of Rock Structure and Mechanics, Czech Ac, Sci., provided supplementary data about the anomalies. A crack gauge TM71 installed on an internal structure of gneiss deep in the Jezeří gallery registered a unique sharp relative reversal micro-displacement just at the time of the groundwater level lift in JZ41. The displacement was horizontal, left-lateral, with a NW lift/ SE subsidence (Fig. 11). The event was registered at the Jezerka Hill as well. TM71 installed at a fissure high on the slope registered a significant angular deviation in vertical plane at that time (Fig. 12) and another point in a fissure lover on the slope indicated subsidence of about 1 mm from 2003 to 2004 (Fig. 13).

Both *the events were registered not only locally but on both monitored hills of the massif.* Besides, to compare it with the reaction due to the extreme rains of 2002, no special reaction was recorded due to the rains at any of the six TM71 points installed on Jezerka Hill, neither on the slope nor in the gallery. It is therefore evident that the events of 1994, as well as of 2003/2004 were triggered by a tectonic impulse of regional scale.

Seismic reactions were generally of minor effect. The anomalies were not registered seismically. Most important effect came probably from the Sumatra earthquake of 26.12.2004 and subsequent tsunami well observed on the tiltmeters. (Petrovský and Pěgřimek, 2005).

SLOPE STABILITY

Geological investigations found the frontal zone of the mountains cut by a series of tectonic lines separating the massif into individual blocks (Rybář, 1987). The block of the *Jezeří Castle massif* was found shifted out of the front leaving it as *an outstanding morphological dominant of the terrain.* The internal structure of the block was documented by the Jezeří gallery driven right under the castle showing a series of discontinuities between zones of uneven quality, which cuts down stability of the block (Rybář and Košťák, 1998).

Observations concerning the effects of torrential rains of the year 2002 upon the course of the tilts revealed an important fact. The block of Jezeří Castle tilted to SE at that time, i.e. in the direction of the supporting pillar. The tilt was limited and stopped when the extreme conditions ceased (Chán et al., 2003).

Two deductions can be made. The tilt declined from the direction of long-term permanent tilts recorded by the tiltmeter in the depth of the massif showing *one short step of slope movement* into the mine. On the other hand, permanent tilts restored soon their general orientation to SW. This means that *long-term tilts cannot be simply interpreted as slope movement.* On the other hand *some episodic tilts are of this nature*. Thus, two deformation processes were superposed in the event. It was the slope movement during a short period of several days due to the exogenous factor of water saturation and the permanent process of tilts which was evidently of an endogenous origin. This process represents creep in the massif induced by internal stresses of natural origin – an endogenous factor.

We can see that the stability of the Jezeří block is limited. Under extreme conditions, its internal structure will not defend the block safely against slope movements as experienced during the floods. The movement was oriented to the supporting pillar. This shows that *Jezeří Castle block stability is eminently connected with the stability of the supporting pillar* left at its toe. The pillar is an essential element of Jezeří block stability.

This is in full compliance with earlier calculations based on stochastic considerations. There was a result that probability of failure is unacceptably high here without the pillar. In case of full decoaling,

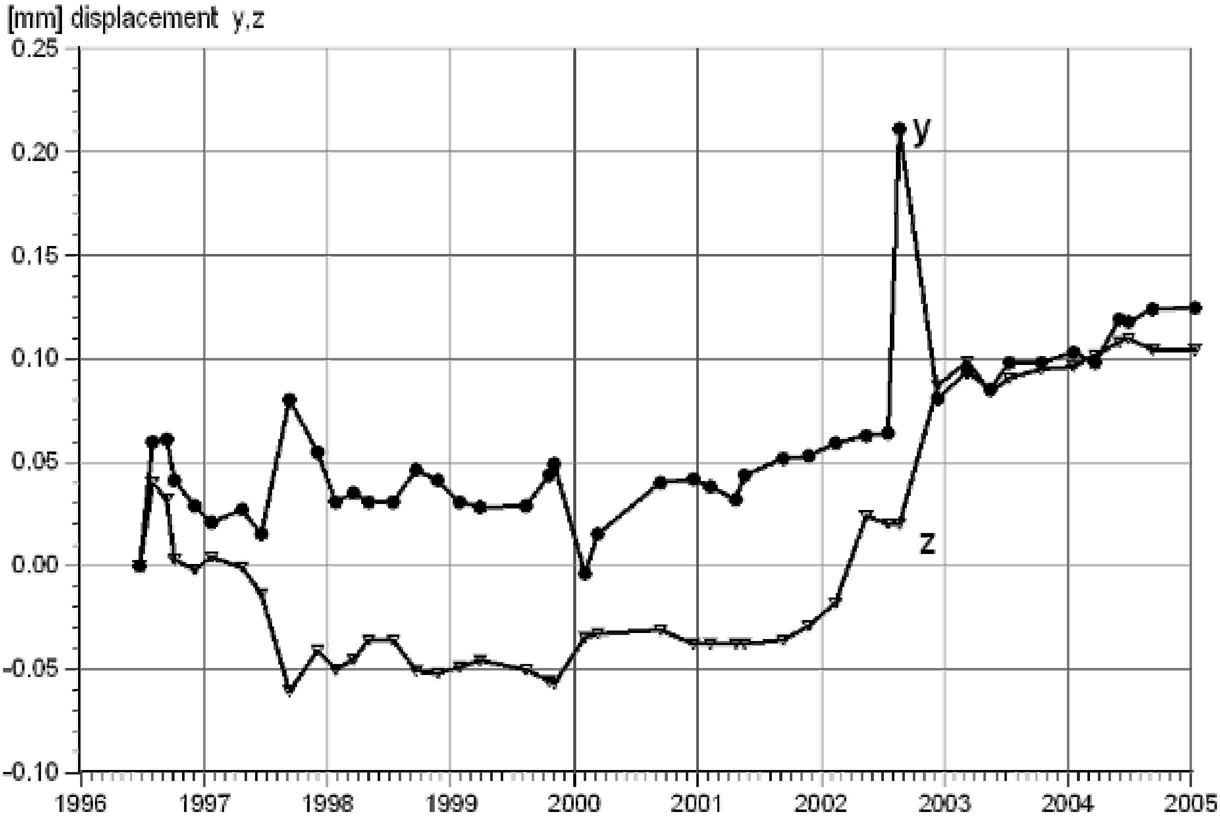

Fig. 11 Relative movement registered late in 2003 (tectonic impulse period) by crack gauge TM71 in micro-displacements on a rock structure deep in the crystalline of Jezeří gallery.

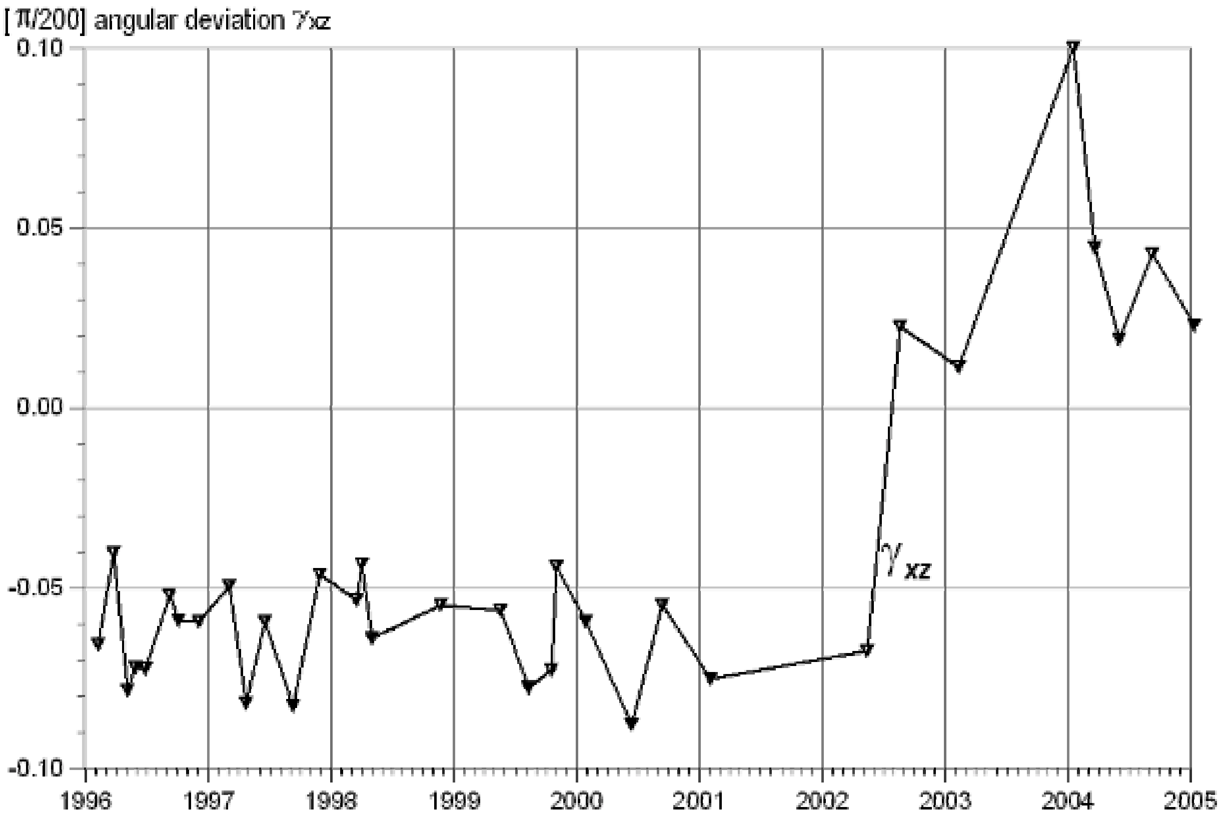

Fig. 12 An unusual angular deviation in vertical plane registered during 2003 tectonic impulse period by TM71 crack gauge in a fissure high on the slope of Jezerka Hill.
(Years are given systematically at the end of year intervals in all our graphs, i.e. in a decimal time scale!)

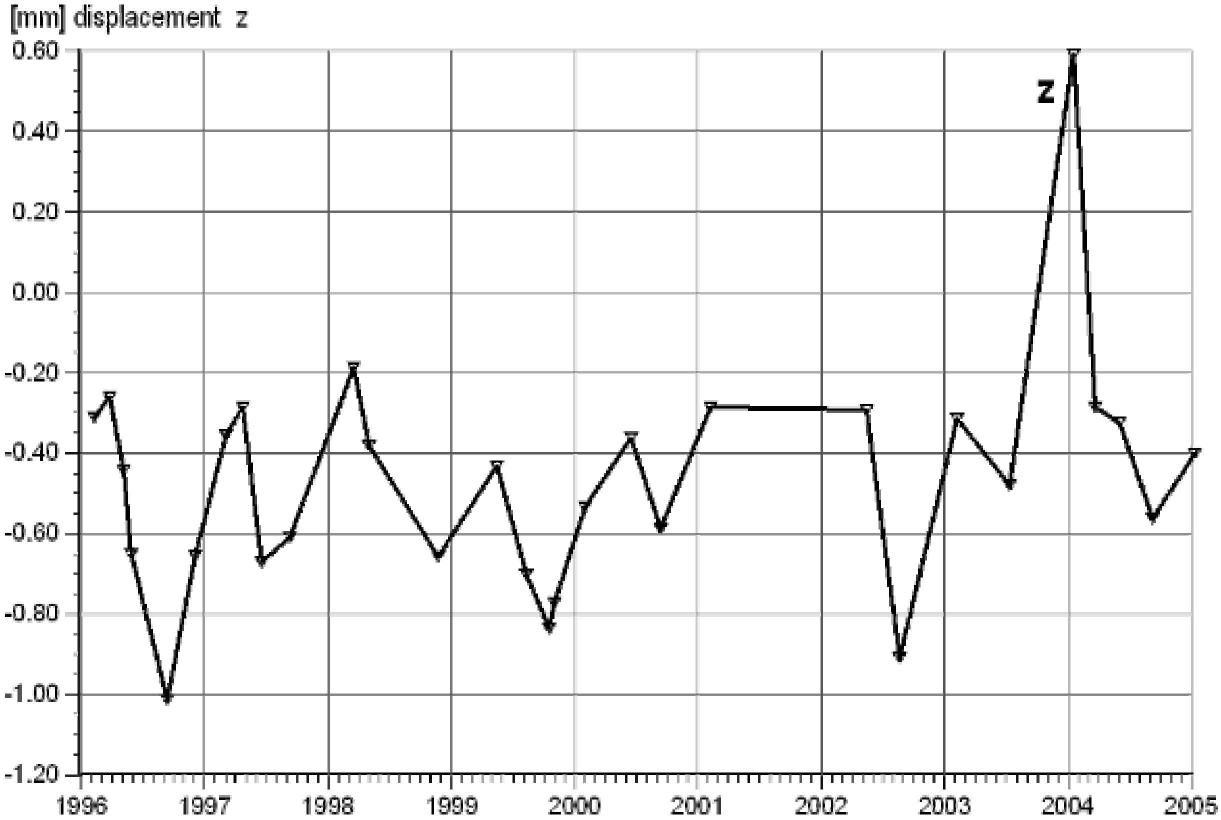

Fig. 13 Relative subsidence in a slope fissure of Jezerka Hill registered during 2003/2004 tectonic impulse period by TM71 crack gauge.

i.e. without the pillar, the risk could be expressed with an unacceptably high failure probabilty of 28 to 39 per cent (Košťák and Kudrna, 1987; Košťák, 2005). This is in contrast to the block of Jezerka Hill where calculations came to relatively good stability. The contrast was approved by monitoring: no movement accelerations were indicated in Jezerka Hill during the critical period of rains.

The above considerations spoke about the present situation which need not be seen critical as far as the pillar keeps on its supporting function. However, in *long-term perspective* the situation of the Jezeří Castle massif may deteriorate. It depends on the pillar condition. Susceptibility of the pillar to failure is relatively high unless supported by fill in time.

CONCLUSIONS

Jezeří Castle massif monitoring has shown that the massif is subjected to exogenous as well as endogenous deformation processes and its stability is limited to the presence of the supporting pillar at its toe. Stability of the pillar is the main condition of the stability of the rock massif behind.

Monitoring methods registered several periods of increased tectonic pressure. Such periods appeared in 1994 and in 2003/2004. The character of the pressure is not likely to be induced by mining, its orientation being inclined to S and SW, i.e. not directly to the pit. Also, any tensile zone that would indicate formation of a crack behind the upper edge of the slope has not been indicated. However, presence of the horizontal stress in the massif had not been known in time and the original stability calculations did not therefore include it into the input conditions of the introductory calculations.

The massif reacted even to such impulses like the increased precipitation of the flood period of 2002 when a short period of slope movement into the pit developed but ceased to continue. Also, the catastrophic earthquake of Sumatra and consequent events at the end of 2004 were registered by a number of instruments, notably by geophysical tiltmeters (Petrovský and Pěgřimek, 2005). There is no doubt that the tiltmeter monitoring as well as other instrumentation if properly used and operated continually are able to provide warning data regarding the stability of the massif.

ACKNOWLEDGEMENT

Monitoring and evaluation of the results of the Jezeří massif in their present stage was supported by Grants of focused research and development of the Grant Agency of the Czech Academy of Sciences, Prague, No. S3012008 and S3012353, as well as by the project of the Grant Agency of the Czech Republic No 205/03/0335, which is fully acknowledged.

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