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THE TILT OF THE ELEVATOR SHAFT OF BUNKER SKUTINA

NÁKLON VÝTAHOVÉ ŠACHTY BUNKRU SKUTINA

**Abstract**

The measurement of deformations of the elevator shaft in the Skutina fortress between the 2nd floor and the depth of 33 m below the surface took place in 2009. These measurements showed that, in addition to the tides, the diurnal thermoelastic wave deforms the body of the bunker, particularly in the NS direction. The amplitude of this deformation depends mainly on the cloudiness (opposite to the irradiance). Morning and evening deformation curves depend mainly on the time of sunrise and the geometry of the body of the bunker (irradiance of the bunker walls) and less of the outside temperature.

**Abstrakt**

V roce 2009 probíhalo v bunkru Skutina měření deformace výtahové šachty od druhého nadzemního podlaží bunkru do hloubky cca 33 m pod povrch. Tato měření ukázala, že kromě slapů se na deformaci tělesa bunkru podílí celodenní termoelastická vlna, zejména ve směru S-J. Amplituda této deformace závisí zejména na oblačnosti (protiklad osvitu). Ranní a večerní obraty deformační křivky jsou závislé zejména na době východu Slunce a na geometrii tělesa bunkru (osvitu stěn bunkru) a méně na venkovní teplotě.

**Keywords**

Tilt, solar irradiance, thermoelastic waves, deformations.

## 1 INTRODUCTION

The deformation of the walls in a block of flats has been measured since Aug 1, 1998, when the first vertical static pendulum was installed there [1] [2]. As revealed in the subsequent analysis of the results of measurements of the air temperature and irradiation on the roof and walls of the block of flats, the deformations of the building were related to the variations in temperature and particularly to the changes of the irradiation of the walls. At the time when it was cloudy or rainy, the deformations of the building were smaller. The same was observed at the time when the sun for a moment went behind the clouds (Fig. 1). Tilts of the walls depended not only on the temperature and the light exposure of the building, but the deformation curve also changed its azimuth in the course of the year.

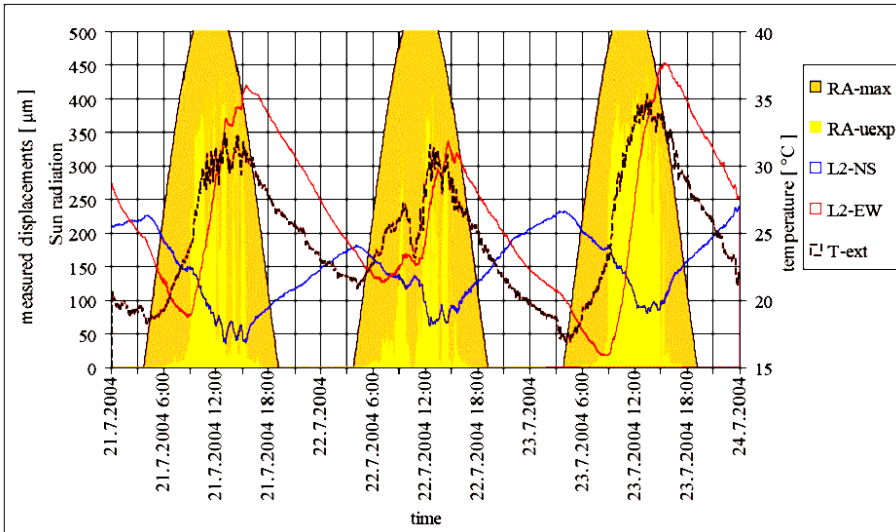
As the block of flats is influenced by a number of factors, mainly anthropogenic, we tried to measure the deformation of a shallow object, which is considerably larger and better anchored in the ground than the block of flats - military fortress - built in the 30s of the last century. We assumed that if the sightseeing tours do not take place in the fortress, the anthropogenic influences will be

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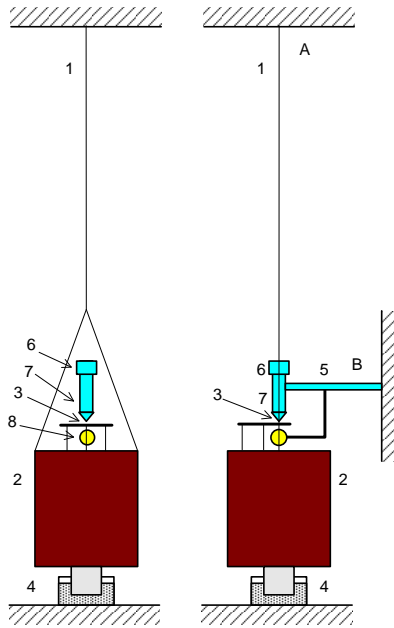
completely eliminated. Also the wall thickness and strength of the anchor of the object directly on the rock will be a precondition for the exact measurement of the deformation of the object.



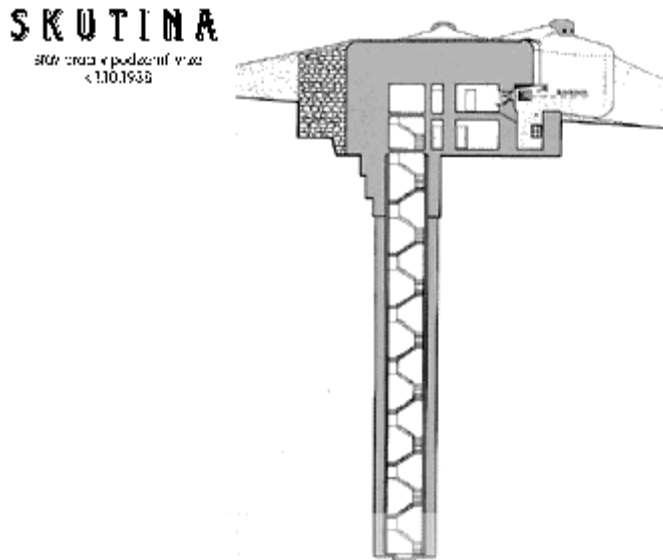
**Fig. 1** The time development of deformation of building, air temperature and irradiation of the building

## 2 THE APPARATUS AND THE SYSTEM OF THE MEASUREMENT

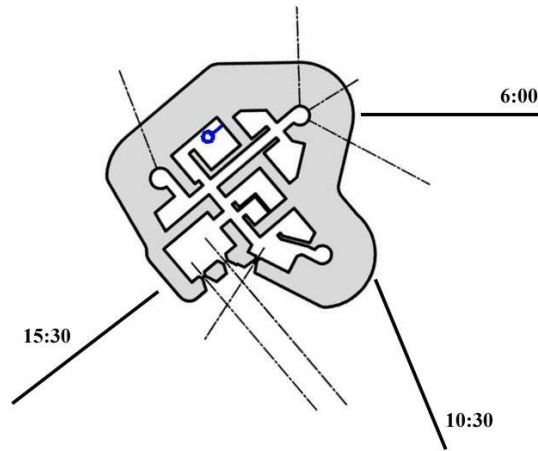
The pendulum (see Figure 2) was anchored in the ceiling at point A. On the pendulum mass (2) there was a microraster (3). The camera (6) took pictures of the reference pattern through the microscope (7) with the sampling period of 10s. The camera was mounted (5) on the wall at point B. The measurement of small displacements of the microraster against the camera (deformation of the wall between points A and B against the vertical) was converted to the angle (tilt of the massif). The non-contact optical measurement allowed to eliminate the effects of friction. The accuracy of the evaluation of the shifted pictures of the patterns with regard to the reference pattern was 1 pixel, which in the case of the bunker Skutina corresponded to 660 nm at the magnification of 20x of the optical lens. Then 1 pixel of the precision of the measurement corresponded to the vertical angle of 18 nRad for the pendulum length of 36.55 m.



**Fig. 2** Scheme of the apparatus for the measurement of small movements and tilts



**Fig. 3** The cross-section of the Skutina fortress – the pendulum is installed in the lift shaft between the roof of 2nd floor and the bottom of the shaft in the depth of 36.55 m.



**Fig. 4** Plan view of the 2nd floor of Skutina fortress. Blue circle denotes the pendulum.

The vertical static pendulum was installed on March 28, 2009 in the bunker Skutina in the elevator shaft between the ceiling of the shaft at the level of the second floor and the bottom of the shaft at the depth of 36.55 m, approx. 1 m above the floor (see Figures 3 and 4). The pendulum itself was placed in the protection box, closed from all sides.

The tilt measurement was therefore between the concrete ceiling, which was 3 m thick and the poured concrete walls of the shaft at the depth of 36 m, which were firmly connected with the massif. The southern part of the roof of the bunker was about 4 m above the ground and from the northern part was about 6 m above the ground.

The measurement was carried out with the period of 10s and the resulting values were determined as the average of 180 values measured in the 30-minute window. We evaluated four parameters: two components of average values in both directions (N-S and E-W) and two components of “noise”, which were evaluated as the variations of the positions of the pendulum around the average positions.

### 3 RESULTS OF THE MEASUREMENT

Already the first measurements showed that the largest tilts of the bunker were in the N-S direction and they had prevailing diurnal periods. Much smaller tilts were observed in the E-W direction and those usually had half-day periods, and they corresponded to tides [3].



**Fig. 5** The development of the tilt of Skutina fortress in April 2009



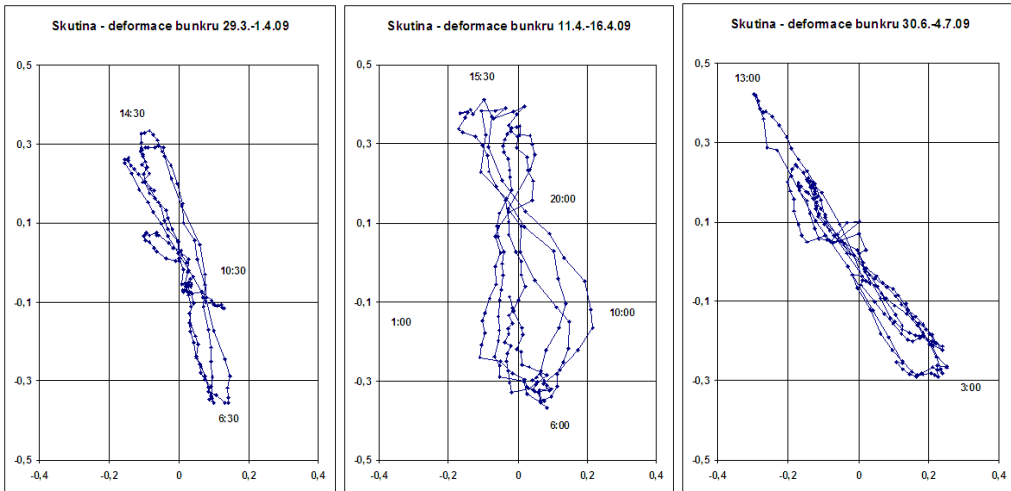
**Fig. 6** The development of the tilt of Skutina fortress in July 2009

The amplitudes of the tilt in both directions (N-S, E-W) became comparable during the days with the increased cloud cover (see June 30 – July 2 in Figure 6). During the sunny weather, the amplitudes of the tilt in the N-S direction were greater than in the E-W direction.

The local minima and maxima (points of trend reversal of the tilt) on both curves (N-S and E-W) occurred almost at the same time in the morning and in the afternoon. In March and April, the turnover in the morning was between 6:00 and 7:00 (UT), at the time of sunrise. The morning turnover was in July between 4:00 and 6:00 on the N-S component of the tilt and on the E-W component even earlier. The afternoon turnover occurred in March and April between 2 p.m. and 3:30 p.m. in July and it was at about the same time (Fig. 5, 6).

If we draw curves of the elevator shaft deformation (tilt) (see Figures 7 a, b, c) we can see that they change their character over time, the curve may resemble a sponge cake (Fig. 7a) or may be in the shape of figure eight (Figure 7b), or can be almost linear (Fig. 7c). All curves have their common features - relatively rapid deformations started in the morning, when the bunker was tilted to the

south and finished in the afternoon, when the bunker was tilted to the north. The second part of the deformation was much gradual and the bunker relaxed during the whole afternoon and night until the sunrise. The main axis of the deformation changed its azimuth during the year.



**Fig. 7a,b,c** The development of the tilt of Skutina fortress in July 2009

#### 4 DISCUSSION

The greatest deformations of the bunker Skutina were not caused by tidal influences, but the diurnal periods of the tilt showed the influence of either temperature or solar irradiation. A similar conclusion was also found analysing the seismicity data in California [4].

If we analyse which of the two effects - temperature or light exposure - has a greater influence on the deformation of the bunker Skutina, then we can see that the early morning deformation of the bunker coincides in time with the increasing temperature at sunrise, especially during the summer months. Fastest movements, however, coincided with the exposure of the southern and southeastern side of the bunker at around eight o'clock in the morning (see, eg, Figure 6 - 3 July 2009). The result that the deformation of the bunker is conditioned by solar irradiation rather than temperature, corresponds with the fact that the reversal time of the tilt in the afternoon corresponds with the time of exposure of the walls of the bunker, while the air temperature continues to rise. On the contrary, the reversal time of the tilt of the bunker to the south begins when the sun begins to fall on the northwest wall of the bunker (see Figure 4). This moment is almost independent of the season and depends only on the cloudy weather.

The reversal time of the tilt of the bunker is relatively fast and the primary data clearly shows that the response of the tilt of the bunker to the exposure is almost immediate in the course of minutes. Such quick changes can't be explained by the penetration of the thermal wave into the depth of the concrete, which is very slow (the thermal wave can penetrate to the depth of 0.15 m during half a day [5], but it must be explained by a different mechanism. This mechanism was probably described by Hvožd'ara et al. [6] using data from the strainmeter at Vyhne (Slovakia) as the excitation of the thermoelastic wave. In this case the only near-surface portion of the material is heated and expanded and only this thin layer of material deforms elastically its surroundings. The thermoelastic wave then penetrates the deeper material immediately after the thermal expansion of the surface. In our case, it can be documented that this thermoelastic wave is able to deform the entire elevator shaft of the bunker in a very short time even though its walls are three meters thick. The first walls, which expand, are in the southeast, then in the south and finally southwest, which leads to the inclination of

the whole bunker, mainly to the north and slightly to the northwest. The night cooling of the surface of the walls of the bunker and the decreasing of temperatures and subsurface parts of the walls of the bunker leads to the return of the bunker to its original condition (in the south).

The question still remains, to which extent the deformation of the shaft is influenced by the deformation of the hill on which the bunker stands. However, because the whole mountain is covered with a forest and the changes of the trend of deformation correspond with the geometry of the bunker and not the geometry of the hill, we assume that the deformations of the hill will also contribute to the tilt of the bunker, but their impact will be less significant than the deformations of the bunker itself.

### 3 CONCLUSIONS

Measurement of deformations on the bunker Skutina showed that the main mechanism of short-changing the tilt of the bunker is caused by the thermoelastic waves, which are generated by the solar exposure of the surface of the bunker, which is then warmed and expanded. The thermoelastic waves have a diurnal period and its influence on the deformation of the bunker is connected with the geometry of the walls of the bunker with regard to the solar irradiation. The tilt of the bunker to the north is associated with the irradiation of the southern wall of the bunker, and this motion is much faster than the relaxation (deformation of the bunker to the south). The beginning of the movement of the bunker to the south is related to the exposure of the western wall of the bunker to the first rays in the afternoon.

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