Study of extensometric measurements in non tidal frequency domain at the Russian and Slovak stations

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A b s t r a c t : The study of the Earth's crust deformations caused by the Sumatra-Andaman earthquake (26$^{\text{th}}$ December, 2004) at large distances from its focal point is the main subject of the paper. The extensometric measurements at stations Protvino (Podmoskovie area) and Baksan (Caucasus) reveal the concordant pattern. A comparative analysis of the measured data for the Protvino and Vyhne (Western Carpathians) was performed for the same time period. The correlation of the observations within three months before the earthquake is quite low. The substantial correlation was observed for the time span of the earthquake and for the following two months. Consequently, the Sumatra-Andaman earthquake manifested itself at the distant points by increasing mobility of the Earth's crust. The mechanisms of this coupling are outlined.

Key words: Earth's crust, Sumatra-Andaman earthquake, deformations, correlation, extensometric stations, synchronous variations

1. Introduction

The Sumatra-Andaman earthquake of December 26$^{\text{th}}$ 2004 with magnitude 9.2 belongs to the strongest earthquakes of the last century. It has released energy by 2 – 3 orders higher than have the regularly repeating earthquakes with magnitude 7 – 8 manifesting themselves often by catastrophic

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damages. The strongest earthquakes are events on the global scale. The corresponding earthquake generated postseismic processes have also a global character. They can be related to the deep mass transfers, as well as to some exogenous effects. The intercontinental transfers of the atmospheric masses may play the role of the triggering mechanism (*Sidorenkov, 2002*). Naturally, it is possible to suppose that these processes manifest themselves on the surface close to the epicenter, as well as at large distances from it. It is assumed, that the Sumatra-Andaman earthquake of 2004 has been generated by the relative movement of the European-Asiatic and Indian-Australian lithospheric plates (*Lay et al., 2005*).

The processes determining the seismicity and/or the processes activated by the strong earthquakes of the sequential failure of the matter in the area of the main rupture and close surroundings are the sources of the post-seismic perturbations of the geodynamic behavior. The manifestation of the geodynamic processes on the Earth's surface is diverse. The registered perturbations of the Earth crust deformations are the subject of our investigations. It is assumed that these perturbations manifest themselves all over, and that they propagate in synchronous way and have a similar form. Based on these assumptions, the authors together with colleagues from Sternberg Astronomical Institute of the Moscow University, made an analysis of the perturbations in the records of the Earth crust deformations for two underground deformation stations: Protvino in the Podmoskovie area and Baksan in Caucasus in the period before and after the earthquake (*Latynina et al., 2007*).

The deformations variations from the interval optimal for tilt and for extensometric measurements were studied. The short period variations (up to 48 hours) were excluded on the ground of the unsteady character of diurnal meteorological processes. Moreover, the records of deformations with periods greater than 20 days were not taken into analysis because they are induced by the movements of local character and by the instrumental drift. The variation of the deformations at the stations Protvino and Baksan for the time span from December 26$^{\mathrm{th}}$ 2004 to the end of March 2005 filtered in the above mentioned manner is presented in Fig. 1. This corresponds to the period between two strong earthquakes in Sumatra region: 26. Nov., 2004 with M = 9.2 and 28. March, 2005 with M = 8.5.

Visual correlation of the graphs for both the stations is quite noticeable.

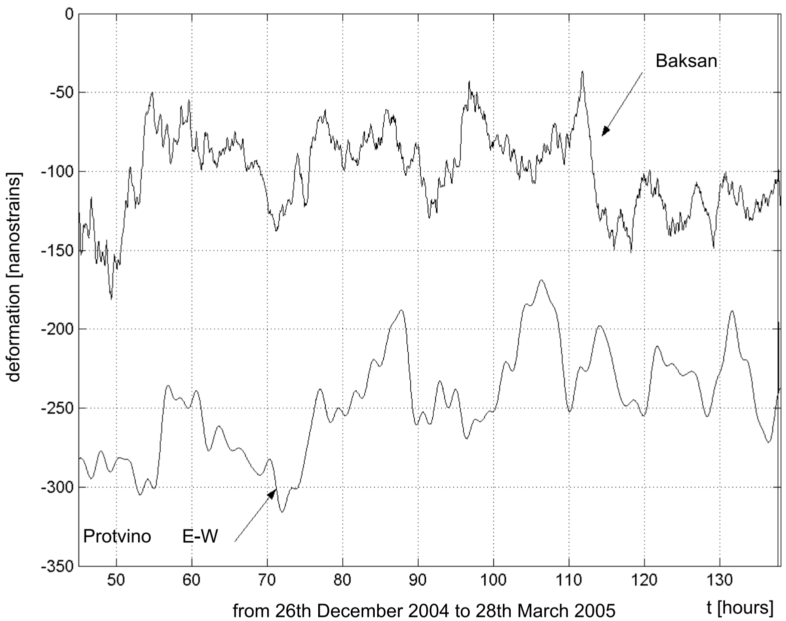

Fig. 1. The course of deformations according to extensometric data at Protvino station in the direction east-west and at the Baksan station in the azimuth 30° to the east in the period from 26.12.2004 till 28.3.2005. Nanostrain – unit of deformation, is equal 10^{-9}.

The correlation coefficient of the curves for the period from the beginning of the earthquake to the middle of March 2005 is equal to 0.5 – 0.6. The substantial correlation of the deformation graphs for two distant stations for the period after the main earthquake event can be interpreted as the evidence for the universal principle in the behaviour of these variations and as the presence of its relation with the processes in the dislocation area. It is possible that some alterations in the deformation character can appear 2 – 4 days before the earthquake. The accuracy of the tectonic signal estimation at every station is determined by the level of the meteorological and local disturbances. These deformation data components are mutually independent at the distant stations. Therefore, the accuracy of the tectonic signal resolution increases with the amount of the stations. The study of deformation variations character before and after the earthquake at many different points is the aim of our investigation. The deformation data from tidal station Vyhne in Slovakia were applied with respect to the Sumatra-Andaman earthquake analysis.

2. Carpathian-Balkan deformation network

Deformation station Vyhne of the Slovak Academy of Sciences was built in the period of the creation of the Carpathian-Balkan station network in the 70s – 90s (*Brimich and Latynina, 1988*). This network was established in mutual cooperation of the Academies of Sciences of Russia, Ukraine, Hungary and Slovakia. Seven deformation stations were intended for the research of the recent geodynamics of the Alpine belt, the most active zone in Europe (see Fig. 2). Three stations operated in Ukraine in the area of the East Carpathians and in Transcarpathian depression (Muzhievo, Beregovo, Korolevo), three in Hungary in the area of the Pannonian basin (Budapest, Sopron, Pecs) and one station Vyhne in Slovakia. The Russian observatory Protvino provides the information about background movements of the East-European platform.

The acquired data were analyzed together with the results of the triangulation measurements in the Pannonian basin obtained for the period of more than 100 years by the Austro-Hungarian Military Institute. GPS measurements data of the European and local systems of the given stations are available. Deformation measurements of the various types have yielded consistent results and allowed to receive the precise picture of the recent movements of the Earth's crust of the region under study. The given task is to investigate the variations of the Earth's crust deformations during the Sumatra-Andaman earthquake on 26$^{\text{th}}$ December 2004. Data from Vyhne in the Carpathians and from the Protvino station are investigated. The variations in the course of the deformations with the duration up to 20 days are analyzed.

3. Earth's crust deformations measured at the Vyhne station

Station Vyhne (longitude $\lambda = 18.8°$, latitude $\varphi = 48.5°$) is situated at foothills of the West Carpathians in the middle Slovakia 10 km northwards from the town Banská Štiavnica. Quartz extensometer with the base

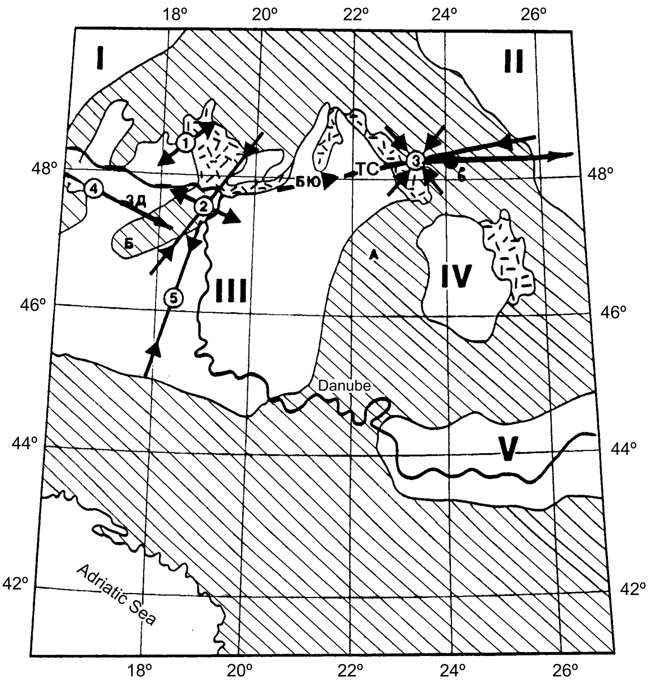

Fig. 2. The scheme of the tectonic structure of the Carpathian-Balkan region. I – Bohemian massif, II – East-European platform, III – Pannonian depression, IV – Transylvanian depression, V – Miziyskaya plate, TC – Transcarpathian depression, ①–⑤ – deformation stations, →↑ – the velocity of the deformations.

of 20.5 m was established in the old mining prospecting tunnel running through granites in the 50 m depth from the surface. The observations of the deformations are conducted since 1984. The optical and optoelectronic transducers were used as the recording instruments in the first years. These devices have been later replaced by the more advanced capacitor transducers made in Hungary and also the digital data registration system was established. The deformation data from the years 2004 and 2005 processed in this contribution were registered with 10 min. interval.

The obtained data have been treated by the low-pass sliding filter using average value of 6 consecutive readings for every hour. The processed data sequence was from August 2004 till the break in the registration in the beginning of April 2005.

Figure 3 presents the time series of observations from August 17th 2004 to April 3rd 2005 at the station Protvino in the east-west direction and at the station Vyhne for the azimuth 55°. Curve 1 illustrates the course of the deformations for the period of about 8 months at Protvino, curve 2 represents the Vyhne station data. The tidal deformations are not excluded; the width of line is specified by the tidal amplitude and is equal to 20 – 30 μm or 5 – 10$\times$10^{-9} in deformation units. Two vertical lines indicate the moments of the earthquakes on 26.12.2004 and 28.3.2005.

The annual and seasonal drift at Protvino station amounts to the units of 10^{-7}/year. According to the long-term observations at Vyhne station, the obtained drift has a character of extension with a rate of 5$\times$10^{-7}/year. The deformation of the seasonal character has been observed in the examined time interval: compression in the autumn-winter months and expansion in the spring time. This measurement component may be compensated in the future investigation taking into account the meteorological data.

4. Earth's crust variations before and after the earthquake of December 26th, 2004

Figure 4 shows the signal of two stations in the range from 48 to 500 hours. The Fourier filter has been applied to the data series. The ends of the 14 days intervals of the filtered series are neglected since they have been distorted by the filtering process. The correlation coefficient of the series after filtering is equal to 0.10 – 0.15. In consequence, the processes at investigated stations are coupled just slightly.

The Fourier analysis is not very efficient for studying the investigated oscillations since they are not harmonic. More probably they represent the aggregations of impulses. The spectral decomposition has been performed using the Wavelet analysis operating with impulse processes. The Haar functions form the orthogonal basis. The Wavelet analysis has been performed for the data sequence before the earthquake of 26. Dec., 2004, in the range of 2500 hours, from 13.9.2004 to 26.12.2004 and for the sequence of the same length from 14.12.2004 to 27.3.2005 involving the earthquake.

Figure 5 shows long-periodic curves obtained after filtering off the data series using Wavelet transformations at both the stations during the period

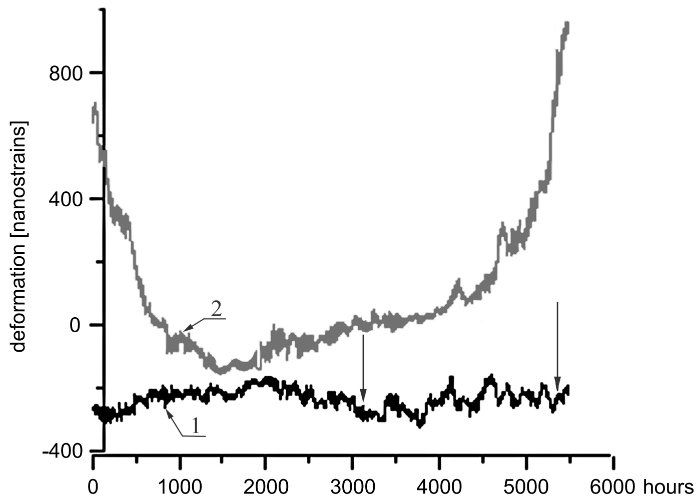

Fig. 3. The course of deformations from 17.8.2004 till 3.4.2005. The curve 1 – Protvino station, the curve 2 – Vyhne station.

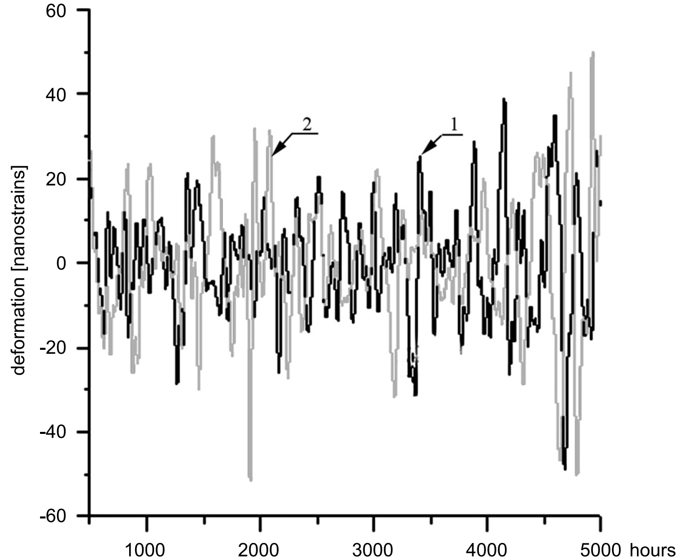

Fig. 4. The course of deformations at Protvino station (1) and Vyhne (2) in the period from 7.9.2004 till 15.3.2005 after the filtration in the range 2 <T< 20 days. The time is in hours. The Fourier transform has been used.

before the earthquake. The mutual phase shift of the curves for Protvino and Vyhne varies in time. The variations correspond in phase to the last 10 – 15 days before the event. The correlation coefficient for the 100 days period before the earthquake is 0.17.

Figure 6 presents the deformation variations at the given stations for the period of 12 days before the earthquake event and 92 days after it. The corresponding curves for both stations coincide in the phase until the middle of February, later the phase difference gradually grows. To a certain extent the graphs show similar behavior. Their correlation coefficient is 0.37. Considering the large size of the data series, the correlation coefficient is formally specified with a high precision. Hence, the oscillating processes at two stations had to some extent similar behavior beginning several days before the earthquake event and continuing for the next two months.

The data from Vyhne station confirm the previous results suggesting the similarity of the oscillating processes at various stations. These stations are situated at distances from 6500 km from the epicenter (Baksan) to 9500 km (Vyhne). The distance between stations is more than 2000 km. The local meteorological processes do not induce the synchronous variations of deformations at all investigated stations. It may happen just in case of massive atmospheric disturbance in the area of Central and South-East Europe at the period of earthquake event and some time after. The meteorological data are necessary to verify this assumption. In our case, the information about massive atmospheric fronts movement in the period from the end of 2004 to April 2005 is required.

5. The nature of the Earth's crust synchronic oscillations

The question about the nature and the mechanism of the periodic processes after the earthquake is not yet resolved. There exist models of the earthquake preparation phase (*Dobrovolskij, 1991*) that can provide necessary effects. There are some geological investigations of the rock medium being in the steady stress-strain state. At a certain time point some nonhomogeneous inclusion is forming within the rock medium. This process is connected with the sequential failure of the medium and manifests itself by

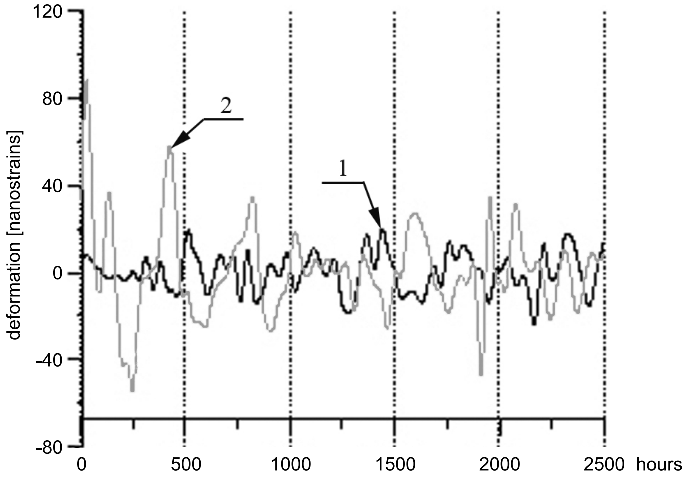

Fig. 5. The variations of the deformations before the earthquake at Protvino station (1) and the station Vyhne (2) from 13.9.2004 till 25.12.2004. The time is in hours.

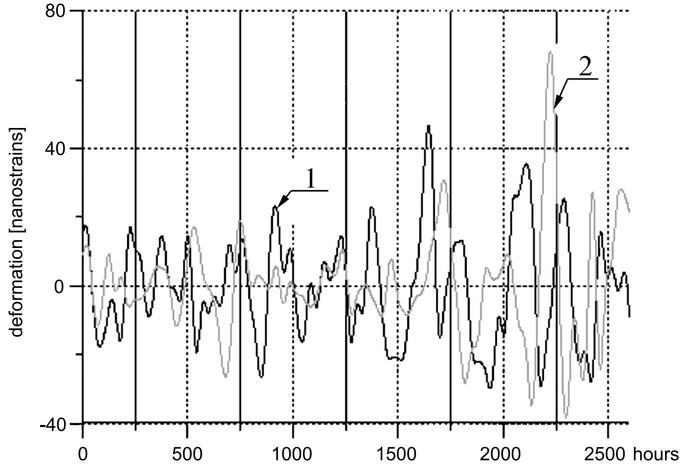

Fig. 6. The variations of the deformations in the period from 14.12.2004 till 27.3.2005 at Protvino station (1) and the station Vyhne (2). The time is in hours.

the changes of the elastic parameters of the inclusion and by the growth of its volume.

The appearance of the inhomogeneity disturbs the stress state of the rock. After the earthquake an analogous process takes place. The main rupture is followed by the process of successive distortion of the rock medium in the focal point and in its surroundings in the form of the aftershocks, terrain deformations and landslides. In consequence, the dimensions of the perturbed zone and the magnitude of its destruction are growing. This process is of multistage character: as the destruction in the earthquake zone grows the dimensions of the inhomogeneity and its contrast to surroundings increases also and the new perturbations of the medium stress state appear at long distance from the earthquake epicenter. The variation of the elasticity modulus of 10% in the volume corresponding to the Sumatra-Andaman earthquake source at the medium stresses $\tau = 10^8$ Pa and the elasticity modulus $\mu = 2 \times 10^{10}$ Pa excites a perturbation in the strain field of the degree $3{\times}10^{-8}$ at distance 6000 km from the epicenter. This quantity is proportional to the observed phenomena.

The anticipating effects of some powerful earthquakes at large distances from the epicentral point were investigated in *Sobolev and Ljubushin, 2006*, *Sobolev and Ljubushin, 2007*. The variation of the microseismic oscillations level with the period of tens of minutes in scope of $5 - 10$ days preceding the powerful earthquake events were found. The regular modifications of the time distribution of the seismic impulses and their polarity were observed. The impulses of a similar character were recorded at the distances from some hundreds to 7000 km from the epicenters. Their generation is connected with the influence of various factors: the atmospheric pressure variations, the cumulative effect of the weak seismicity and other influences. The unstable or metastable medium state in the zone of the forthcoming earthquake source and its extension to a territory of thousands of kilometers is the significant condition of the formation of such impulses.

The given work deals with the periodic movements of the Earth's crust with periods of several days. Apparently, such oscillations can be excited under the influence of longperiodic atmospheric factors or solid Earth tides, and are energetically sustained by themselves. The longperiodic stable oscillations under influence of the mighty source may arise in the sufficiently extended block in the similar way as in the case of the micropulsations in the metastable rock medium. This allows to explain the observed phenomenon in the framework of the recent experimental and theoretical effort in quest for the earthquake precursors related to the metastable condition of the rock medium in the zone of the preparation phase of the earthquake event.

6. Conclusions

The earthquakes of the scale of the Sumatra-Andaman earthquake (26^{th} December, 2004) are induced and accompanied by the tectonic processes of the global character. The present work deals with longperiodic variations of the Earth's crust deformations at large distances from the epicenter according to the data of the tidal observatories. The encouraging results were achieved earlier using the data of Russian stations Protvino and Baksan (*Latynina et al., 2007*), where the variation of deformations had similar character at both places for the period from December 2004 till February 2005. It is not possible to determine precisely if this phenomenon was valid before the earthquake event and how long. The visual comparison of the curves for both stations reveals the coincidence of their phases for 2 – 3 days before the earthquake.

The paper deals with the observations of the tidal station of the Slovak Academy of Sciences Vyhne situated in the Western Carpathians. The same comparative analysis of the deformation data was performed for the stations Vyhne and Protvino. The oscillations in the range from 4 to 20 – 25 days were separated by the Wavelet transformation method. The comparison for this range of periods was performed at two stations for two periods: before earthquake from September till the middle of December and for the period involving the earthquake event from the middle of December till the middle of March. The correlation coefficient for the first period is 0.17 and for the second 0.37. The weaker correlation can be explained by the influence of the local factors as the meteorological effects and/or the effects of the tectonic origin. If their impact on the studied strain field would be considered the resulting discrepancies could be, to same extent, clarified.

Both, in the case of the joint analysis of the data from Protvino and Baksan, and in the case of stations Protvino and Vyhne, the period of the

Sumatra earthquake origination was indicated by the noticeable change of the Earth's crust deformation processes at distant stations. Some models of the gradual destruction of the rock medium in the focal zone, as well as the currently developed concepts of the metastable medium condition at the zone of the preparation phase of the largest earthquakes enable to explain the excitation of the Earth's crust oscillations at large domains.

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