Extensometric measurements in Hungary

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Abstract: From the beginning of the eighties till 2000 four extensometric stations were established in Hungary for observing Earth tide deformations and recent tectonic movements. This paper presents these observatories and deals in detail with the results of measurements concerning the determination of tidal parameters and gives the rates of the tectonic movements in the Pannonian Basin on the basis of the latest measurements.

Key words: Earth tide, extensometer, in-situ calibration, tectonic movements

1. Development of extensometers in Hungary

The first extensometer in Hungary was installed in the spring of 1980 by the Loránd Eötvös Geophysical Institute (ELGI) in Budapest in the frame of a scientific co-operation with the Geophysical Institute in Moscow *(Latynina et al., 1984)*. The displacement sensor of this instrument was a photo-recorder and in 1981 a capacitive transducer developed in the Geodetic and Geophysical Research Institute (GGRI) was mounted. The second extensometer was built at the end of the eighties. This later instrument was equipped with a capacitive sensor by *Mentes (1981; 1991)*. In the middle of the nineties the extensometric measurements in the observatory were finished due to technical and financial problems. In 2004 these instruments were renewed and equipped with new capacitive sensors which were produced in the GGRI and a new digital data acquisition system was installed by ELGI in the observatory.

In the frame of a scientific co-operation between the GGRI and the Geophysical Institute in Moscow an extensometer was installed in the Geodynamical Observatory in Sopronbánfalva (Sopron) in May 1990. The quartz

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tube body, the magnetostrictive calibration unit and a photorecorder were designed by L. A. Latynina. The capacitive transducer and the automatic controller of the calibration unit were developed by *Mentes (1991)* in the GGRI in Sopron.

For the investigation of tectonic movements and deformations in the vicinity of a planned repository for radioactive waste of high-level radiation an extensometer was established by the Mecsekérc Corporation in the frame of a co-operation with the GGRI in 1990 *(Mentes and Berta, 1997)*. This was the first extensometer completely (mechanical and electrical construction) developed and made by GGRI. This extensometric station was placed in the uranium mine at a depth of 1040 m from the surface far away from the working area of the mine.

Since the uranium mine was closed in 1999, a new observatory was established in Bakonya (also near Pécs) in 2000. This is the first observatory in Hungary, where three-dimensional measurements can be carried out by four extensometers.

The extensometers in Sopronbánfalva, Budapest, Pécs, Bakonya, Vyhne (Slovakia) and Beregovo (Ukraine) – beside of Earth tide investigations – were taken into the monitoring of recent tectonic movements in the Carpatho-Balkan region. Fig. 1 shows the extensometric network and in Table 1. the parameters of the extensometers are given.

The precise calibration of the extensometers is very important, especially for the investigation of recent tectonic movements. For the sake of unified calibration of the network instruments a new calibration device with a resolution of 1 nm was developed by *Mentes (1993; 1995a; 1995b)* in the GGRI. The characteristics of the calibration device can be determined by means of a laser interferometer in large (5 – 10 μm) steps and in the knowledge of the characteristic, displacements with a resolution of 1 nm can be measured. This device is applicable for laboratory test of magnetostrictive coils before building-in into the extensometers during the installation. The scale factor of the magnetostrictive coils can be changed during the long-term operation of the extensometers. Therefore the regular, in-situ calibration of the extensometers is necessary because the laboratory calibration of the magnetotstrictive coils is not possible after they are built-in into the instruments. The in-situ calibration of the extensometers was solved for the first time at the GGRI. All extensometers in Hungary and the instrument in Vyhne

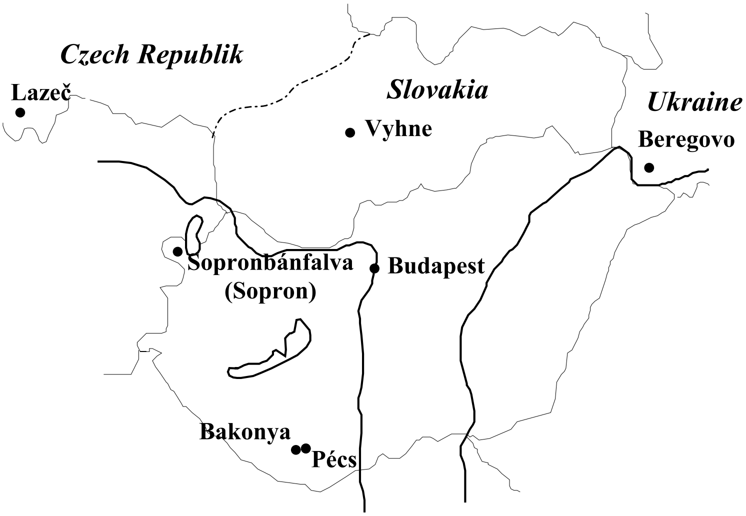

Fig. 1. Extensometric network in the Carpatho-Balkan Region.

were calibrated by this device *(Mentes, 1997; Mentes and Brimich, 1996)*.

Beside the development of instruments and stations, a very close co-operation with the Geophysical Institute in Moscow, Bratislava and the Geodynamical Observatory in Moxa were formed in the field of tidal theory. A distinguished collaboration exists between the GGRI and the Geophysical Institute of the Slovak Academy of Sciences. Common instrument developments, data processing and interpretation of data characterize this cooperation *(Bednárik et al., 2003; Bednárik and Brimich, 2005; Brimich and Mentes, 2003; Dudášová, 1998)* which plays a very important role for both countries in studying the recent tectonic movements of the Carpatho-Balkan Region.

2. Extensometers and geodynamical observatories in Hungary

2.1. The Budapest Mátyás-hegy Geodynamical Observatory

The Mátyás-hegy Geodynamical Observatory is situated in the NW part of Budapest in a natural cave formed by thermal water in limestone. The

Table 1. The parameters of the extensometers in the Carpatho-Balkan Region

Extensometer	Coordinates of the station		Azimuth	Length of the instrument [m]	Registration
	Latitude	Longitude			
Bakonya Ext1.	46.1°	18.1°	0°	20	Capacitive
Bakonya Ext2.	46.1°	18.1°	0°	1.7	Capacitive
Bakonya Ext3.	46.1°	18.1°	90°	1.7	Capacitive
Bakonya Ext4.	46.1°	18.1°	Vertical	1.7	Capacitive
Beregovo I. Ukraine	48.2°	22.7°	73°	27.5	Photo
Beregovo II. Ukraine	48.2°	22.7°	37°	11.4	Photo
Budapest I.	47.6°	19.0°	114°	21.3	Capacitive
Budapest II.	47.6°	19.0°	38°	13.8	Capacitive
Lazeč I. Czech Republic				20	Capacitive
Lazeč II. Czech Republic				20	Capacitive
Pécs	46.1	18.1	19°	20.5	Capacitive
Sopron	47.7°	16.5°	116°	22	Capacitive
Vyhne	48.5°	18.5°	55°	20.5	Capacitive

level of the karstic water is about a hundred meter deeper than the level of the station. The river Danube flows about 2 km far from the observatory. According to *Latynina et al. (1984)* the data series do not show any connection with the water level changes of the Danube but they can have a connection with the level variation of the karstic water. The instruments are installed in a distance of about 80-90 m from the entrance and 30-35 m from the surface, so the thermal variation near the instruments is very small, less than 0.1°C which ensures stable thermal conditions for the extensometers *(Varga and Varga, 1994; Mentes et al., 2006).* Fig. 2 shows the ground plan of the observatory and the places of the instruments (Ext. 1 and Ext. 2).

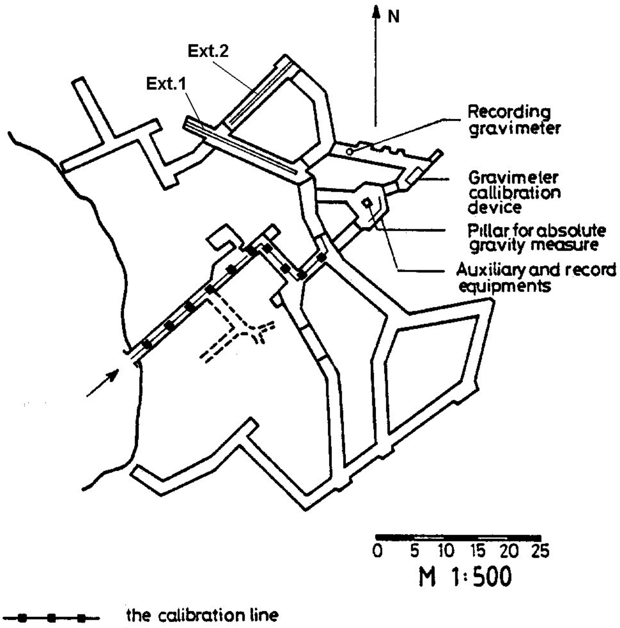

Fig. 2. The ground plan of the Mátyás-hegy Geodynamical Observatory.

2.2. Geodynamical Observatory in Sopronbánfalva

The observatory was completed in 1968. A horizontal mine gallery was driven in the lowest part of a gneiss quarry. The inner cover of the walls is concrete and moisture-free. The overlay of the gallery is 60 m thick. The ground plan of the observatory is shown in Fig. 3. The primary aim of the observatory was to record Earth tides by horizontal pendulums. The inner room was formed for the pendulums, the main gallery was made for testing geodetic instruments which require vibration-free conditions and a second room was built for seismometers. Later, at the beginning of the eighties a third small room was separated at the outer end of the gallery for a gravimeter. As the new building of the GGRI was completed in 1973 and in the basement of the building a vibrations-free laboratory was established for instrument testing, the long pillar in the main gallery became available to install a long quartz-tube extensometer in 1990. Due to this reason the extensometer is not in the tunnel axis. The place of the extensometer is separated from the gallery by a thermal insulation. The observatory has a very good thermal stability, the annual temperature variation at the instruments is less then 0.5°C and the daily one is about 0.05°C.

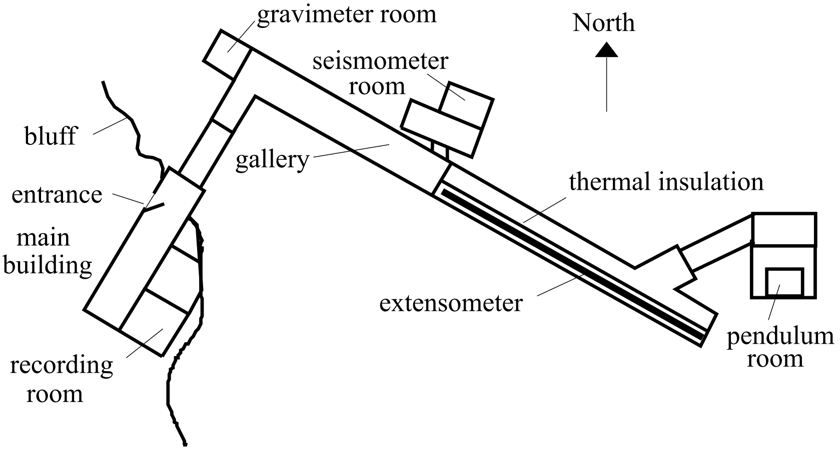

Fig. 3. Ground plan of the Geodynamical Observatory in Sopronbánfalva.

2.3. Extensometric Observatory in Pécs

The extensometer was placed in a depth of 1040 m from the surface far away from the working region of the uranium mine. A short blind working was excavated from an unused main transporting tunnel of the mine for the instrument. The blind working was separated and thermally insulated from the major opening where the air ventilation system was working by sluice-gates and plastic foam bulkheads (Fig. 4). The insulation ensured an annual temperature stability of 0.5°C and the monthly variation of the temperature was less than 0.1°C in the extensometer gallery. The variation of the temperature at the instrument did not depend on the working of the ventilation system because of the triple thermal insulation and the low heat-flow through the rock. The temperature near the instrument was 41°C.

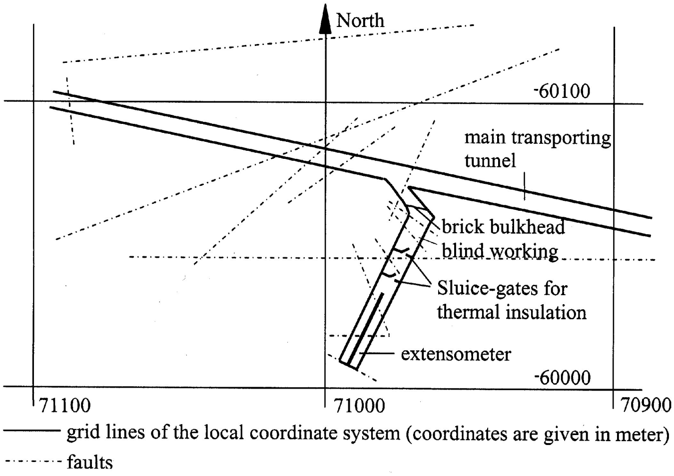

Fig. 4. Ground plan of the Extensometric Observatory in Pécs.

2.4. Three-dimensional extensometric observatory in Bakonya

A 3D extensometric station was established near the uranium mine in the western part of the Mecsek Mts. The new station was placed in an abandoned underground explosive repository of the uranium mine in Bakonya. It is a near surface observatory overlaid by the bedrock with a thickness of about 60 m. The extensometers are placed in the most inner gallery about 130 m from the entrance. The lay-out of the extensometers (E1, E2, E3, E4) in the station is shown in Fig. 5. There is a 20 m long extensometer (E1 = Ext. 1) operating parallel with a short instrument (E2 = Ext. 2) with a length of 1.5 m. There are two other instruments: a short extensometer (E3 = Ext. 3) is perpendicular to the long one and a vertical extensometer (E4 = Ext. 4). Both are 1.5 m long. This observatory is in the phase of stabilisation now, so we have not yet long continuous data series from all of the instruments working there.

3. Results of extensometric measurements

The earlier results of the extensometric measurements at the stations Budapest Mátyás-hegy were published by *Varga et al. (1993), Varga and*

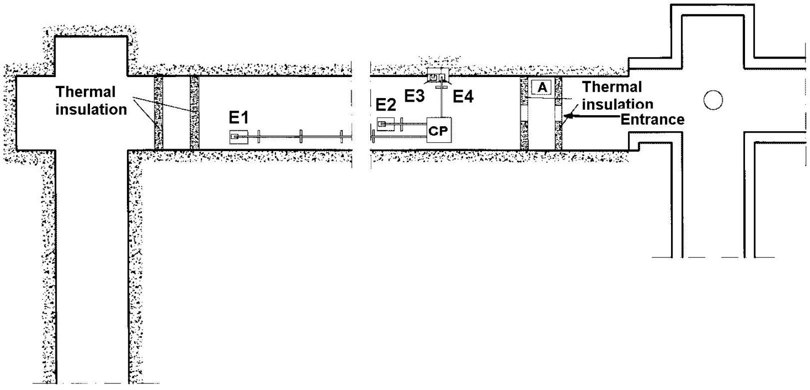

Fig. 5. Lay-out of the extensometers in the station of Bakonya.

Varga (1994) and the results at the stations Sopronbánfalva and Pécs by *Mentes (2001)*.

To compare the different stations and instruments, results from tidal analyses of the data series can be applied. For the calculation of the tidal parameters *(Eperné, 2005)* the Earth tide data processing program ETERNA 3.30 *(Wenzel, 1996)* was used. The theoretical and the calculated tidal parameters for the stations Budapest, Sopronbánfalva and Pécs are given in Table 2–4. The differences between the theoretical and calculated tidal amplitudes are due to local effects and the special geological circumstances in the vicinity of the observatories. These local specialities cannot be taken into consideration when the ETERNA is taken since it makes the calculations with the utilization of global parameters. In Table 2 the tidal parameters obtained only from Ext. 2 are listed because – according to our investigations – there is something erroneous in the other instrument (Ext. 1) at the Budapest station.

The observatory in Bakonya is the first three-dimensional extensometric station in Hungary therefore the results obtained here are shown in more detail. In spite of the fact that the station was established in 2000, we have continuous data series since only the beginning of 2003 due to some technical problems. In this year the recorded displacements were very high and the signals went out of the measuring range very often. The situation was

Table 2. Tidal parameters obtained from Ext. 2 at the Budapest Observatory *(Mentes et al., 2006)*

Wave group	Measured amplitude [nstr]	Amplitude factor	Standard deviation	Phase lag [degree]	Standard deviation [degree]
Q_1	0.5424	0.5055	±0.199	-0.564	±22.657
O_1	4.2227	0.7535	±0.044	7.150	±3.365
M_1	0.1339	0.3039	±0.490	-12.791	±92.410
K_1	4.8763	0.6189	±0.038	14.231	±3.476
J_1	0.7639	1.7334	±0.553	50.006	±18.286
N_2	1.5320	0.9059	±0.092	16.384	±5.795
M_2	7.1469	0.8091	±0.018	18.219	±1.304
L_2	0.0894	0.3580	±0.506	-8.9869	±80.999
S_2	3.0990	0.7542	±0.032	20.490	±2.435

Table 3. Tidal parameters obtained at the Geodynamical Observatory Sopronbánfalva

Wave group	Theoretical amplitude [nstr]	Calculated amplitude [nstr]	Phase lag [degree]
Q1	1.262	0.646±0.060	-3.752±6.824
O1	6.594	4.205±0.013	-4.261±1.152
M1	0.518	0.388±0.151	-8.801±11.575
P1	3.067	0.746±0.027	17.004±6.369
K1	9.269	4.517±0.009	-0.058±1.093
J1	0.519	0.339±0.160	0.920±14.056
OO1	0.284	0.146±0.279	-11.643±30.962
2N2	0.155	0.129±0.125	-12.387±8.609
N2	0.968	1.023±0.026	-10.930±1.425
M2	5.057	5.313±0.005	-13.233±0.277
L2	0.143	0.136±0.171	-26.034±10.341
S2	2.353	3.942±0.011	-4.112±0.372
K2	0.639	0.659±0.043	-15.615±2.387

Table 4. Tidal parameters obtained in the uranium mine in Pécs

Wave group	Theoretical amplitude [nstr]	Calculated amplitude [nstr]	Phase lag [degree]
Q1	0.909	0.232±0.165	-41.754±37.092
O1	4.749	2.235±0.036	-21.029±4.331
M1	0.373	0.059±0.344	-108.542±123.984
P1	2.209	1.077±0.065	-41.343±7.6573
K1	6.676	2.662±0.024	-19.322±3.485
J1	0.373	0.410±0.428	-10.949±22.330
OO1	0.204	0.204±0.998	-37.368±54.235
2N2	0.333	0.181±0.237	-54.951±25.128
N2	2.087	1.024±0.052	-39.696±6.021
M2	10.902	5.041±0.010	-46.265±1.271
L2	0.308	0.296±0.405	-74.083±24.168
S2	5.072	2.382±0.022	-45.408±2.734
K2	1.378	0.711±0.106	-48.696±11,810

the same in year 2005, so the data series obtained in 2004 were chosen for the analyses.

The step corrected extensometric raw data are given in Fig. 6. The curves obtained from the parallel instruments Ext. 1 and Ext. 2 exhibit very similar characteristic, but their relative strain rates are different i.e. the ratio of the lengths of instruments differs from the ratio of the measured displacements. The absolute displacement measured by extensometer Ext. 1 is about 75000 nm and the one obtained by Ext. 2 is about 22500 nm. The difference is probably caused by the inhomogeneity of the rock. Displacements measured by the transversal (Ext. 3) and the vertical (Ext. 4) extensometers are much more disturbed than those measured by the longitudinal instruments. The reason is probably the fact that the gallery of the instruments is strongly deformed by the water content of the soil above the station. There are four galleries not far from each other, therefore the transversal and vertical deformations of the observatory are much higher than the longitudinal one (cavity effect). Unfortunately, the precipitation was not measured during the investigated period, so it was not possible to investigate its influence on the registration.

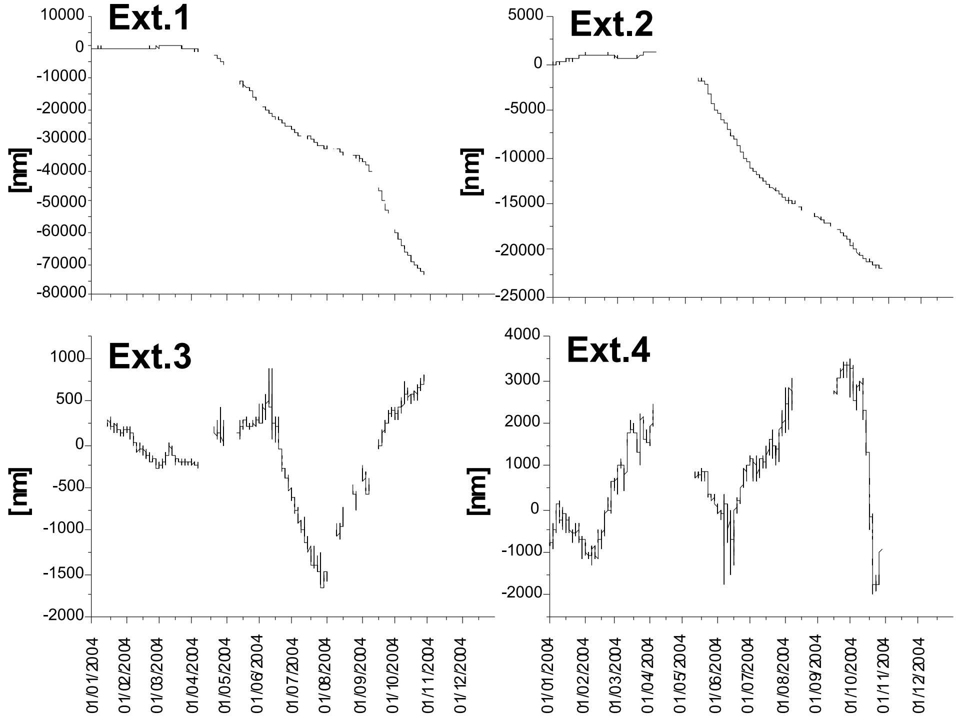

Fig. 6. The displacements recorded by extensometers at the Bakonya station in 2004.

To retrieve the tidal waves from the data a polynomial of 9th order was fitted to the raw data and this polynomial was subtracted from the original series to obtain short periodic variations. These residual data were Fourier-transformed to get the amplitude spectrum. The amplitude spectra of the data series are given in Fig. 7. All the spectra show clearly the main diurnal and semidiurnal tidal waves except the vertical extensometer (Ext. 4). One of the short horizontal extensometers (Ext. 2) does not produce clearly emerging tidal lines in the diurnal band, these peaks are hidden by the spectral noise, while the other short extensometer (in the transversal direction) gives the proper spectral peaks in both tidal bands. Nevertheless at S2 frequency the amplitude ratios calculated in the case of the parallel short and long extensometers are approximately the same as the ratio of their lengths.

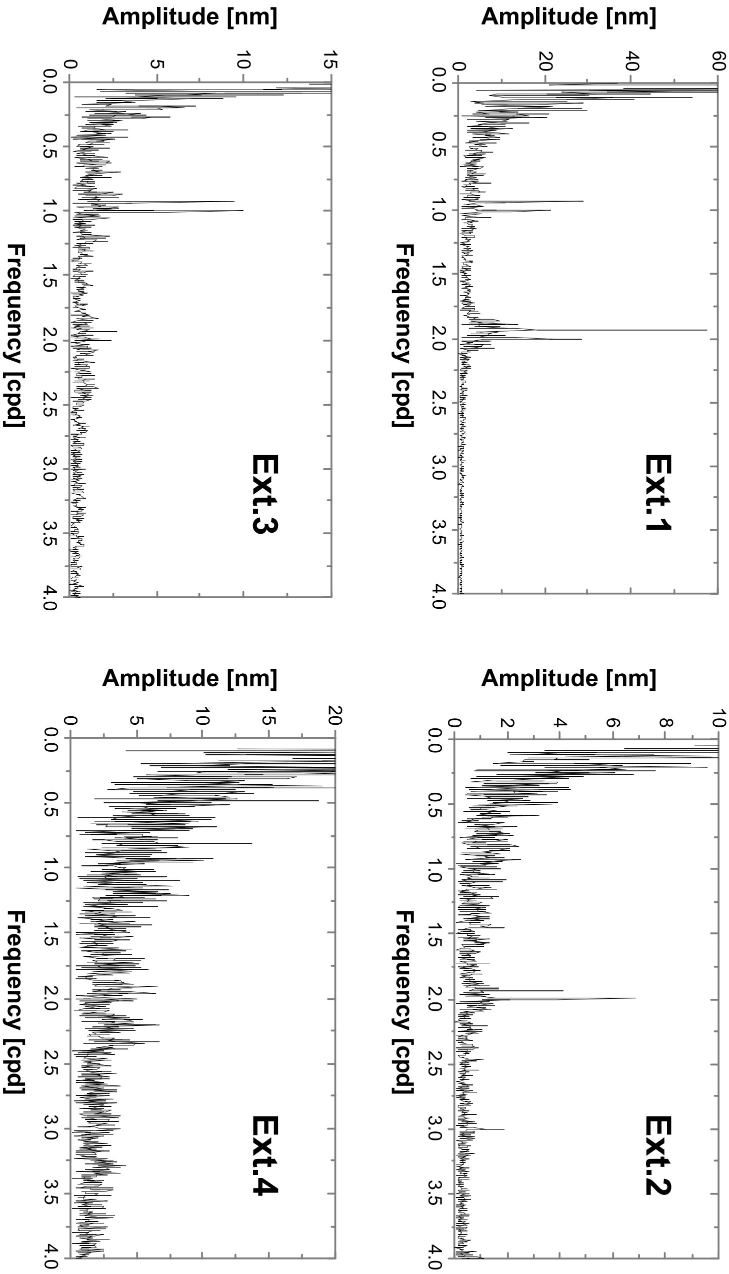

Fig. 7. Amplitude spectra of the extensometric data.

Tidal parameters were also calculated. In the case of the vertical extensometer the tidal parameters could not be determined because of the strongly disturbed signal. In Fig. 8 the obtained tidal amplitudes measured by the horizontal extensometers are compared with the theoretical values. We can see that the measured amplitudes are smaller in the case of the longitudinal extensometers than the theoretical amplitudes. At the transversal extensometer (Ext. 3) it is inverse, the amplitude factors are higher than 1.0. Although different characteristics of the tidal responses in the case of the perpendicular extensometers can be observed, this discrepancy presumably may be attributed to the same factors (local geological inhomogeneities, geometry, surface topography) which develop their effects differently into the perpendicular directions.

The tidal evaluation of the data proves that all of the instruments measure realistic deformation of the rock in the vicinity of the instruments. According to our investigations we assume that the magnitude of the instrumental and local effects is at least by two orders less than those of the tectonic deformations *(Mentes, 2000; Mentes et al., 2006; Mentes and Eperné, 2006)*. The investigations show clearly that the velocity of tectonic movements is not constant. This can be proved by long-term GPS measurements in the future.

The rates of tectonic movements are summarised according to the recent measurements in the extensometric network in Fig. 9. If we compare these values published earlier on the basis of shorter measurements *(Mentes, 1997; 2001; Varga et al., 1993)* we see that to detect tectonic movements long-term measurements are required for precise determination of the rate of tectonic movements and deformations. The rate of the tectonic movement measured in Vyhne is given according to *Brimich (1988; 2005)* and *Dudášová (2005)*. The investigations made by *Brimich and Latynina (1989)* and *Brimich (1992)* show that in this geodynamical station the deformation measurements are also realistic for tectonic considerations.

4. Conclusions

The developed instruments remarkably contributed to a better understanding of the Earth tidal deformations and the recent tectonic movements

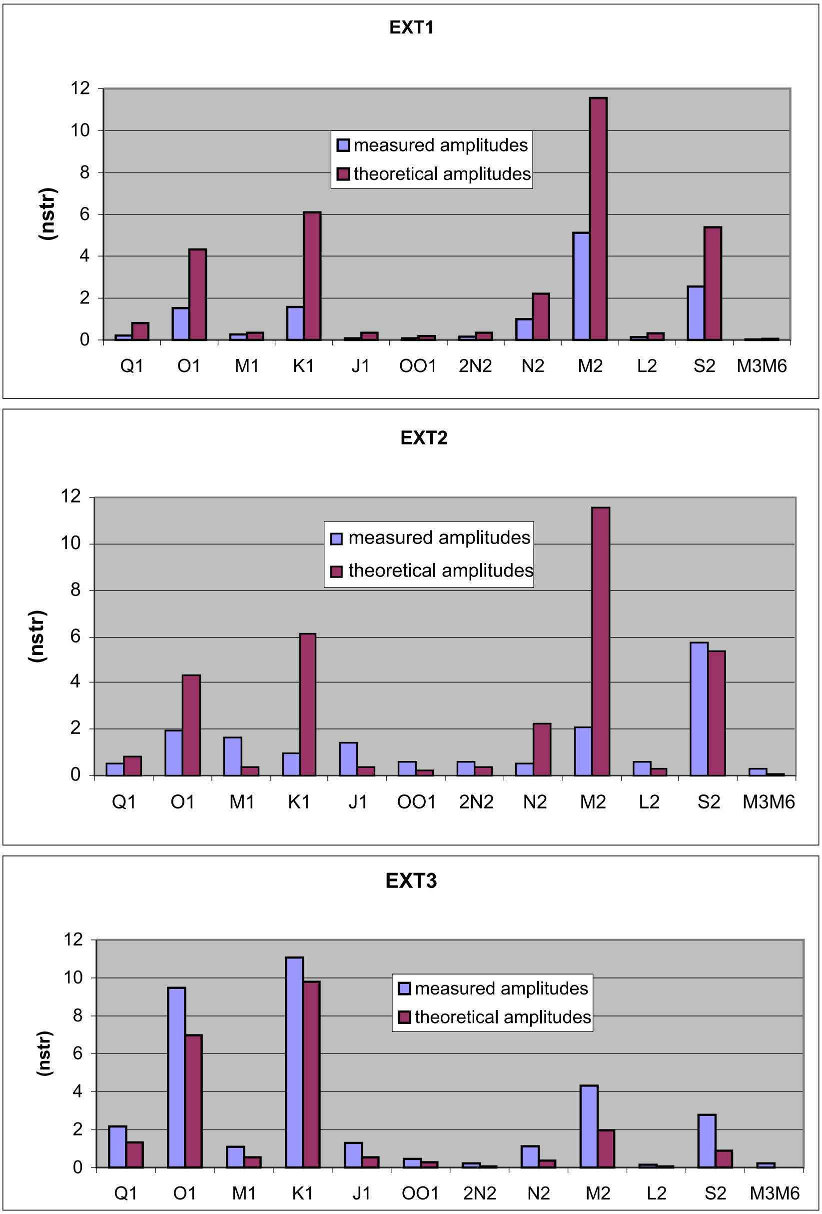

Fig. 8. Tidal amplitudes measured by the horizontal extensometers and the calculated theoretical amplitudes.

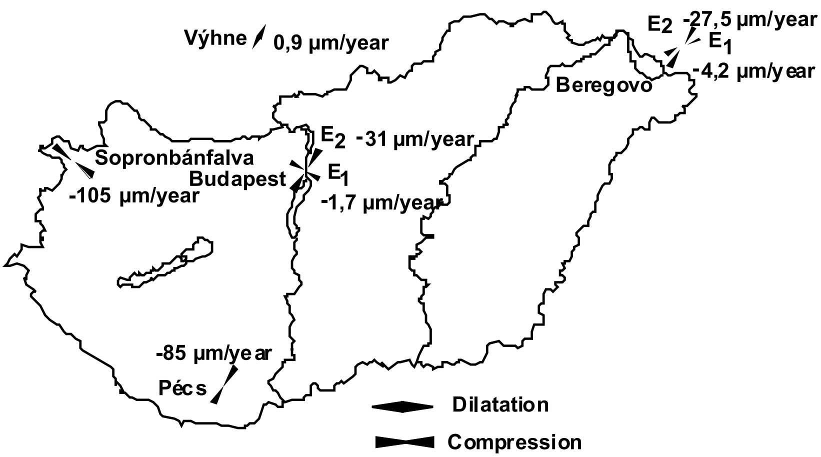

Fig. 9. Rates of displacements in the Pannonian Basin measured by extensometers.

in the Pannonian Basin. In the future a lot of effort will be made to elaborate more sophisticated methods for correction of local and disturbing effects to achieve better interpretation of the Earth's deformations.

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