# Tidal deformations observed at the Vyhne tidal station

L. Brimich
Geophysical Institute of the Slovak Academy of Sciences[1]

A b s t r a c t : In the paper the results of the extensometric measurements obtained by two different methods are presented. From the comparison of the different time series of extensometric data, we can conclude that the observed amplitudes and phase differences of the main tidal waves are at the Vyhne tidal station extraordinary stable.

**Key words:** earth's tides, tidal deformations, extensometer, tidal analysis

## 1. Introduction

Investigation of the Earth crust deformation is of great interest for studying recent global and geodynamical processes. For this reason a quartz tube extensometer was installed at the tidal station of the Geophysical Institute of Slovak Academy of Sciences in Vyhne. High precision $10^{-9}$ – $10^{-11}$ extensometric (strain) data have been used recently to study the local tectonic condition. In this paper the results of the analysis of the measurements of the tidal deformations at the tidal station in Vyhne obtained by two different methods are compared. The results of the observations at the stations equipped with such instruments are strongly influenced by local effects, e.g. topography effect, cavity effect (see *Kohút and Kostecký, 1995*). The interpretation of the data from the network of such stations is difficult because each single site equipped with extensometer is differently disturbed by local effects. Nevertheless successful experiments were made to use extensometric data for tectonic purposes in connection with seismicity in active areas (*Latynina and Karmaleva, 1978*). In *Varga et al. (1993)* and *Varga and Varga (1994)* the investigation of the regional activity with quartz tube extensometers was realized.

[1] Dúbravská cesta 9, 845 28 Bratislava, Slovak Republic; e-mail: geofbrim@savba.sk

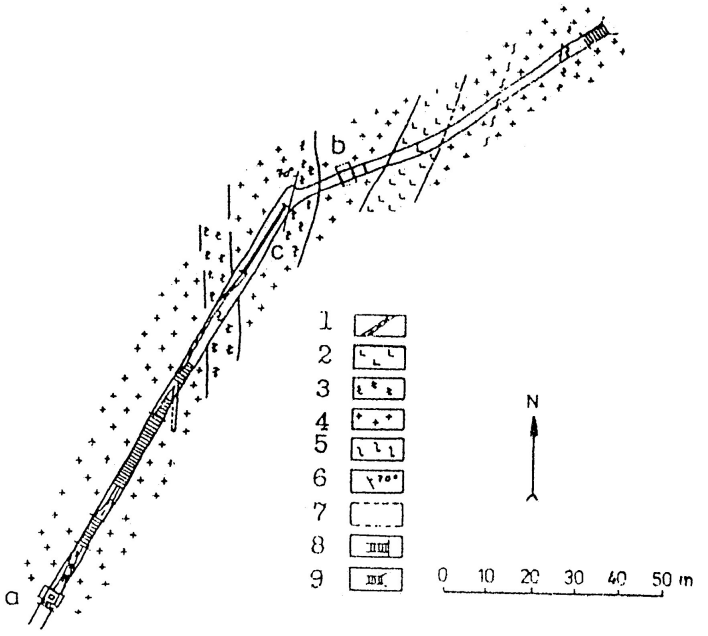


Fig. 1. Tidal station in Vyhne. Geologic and tectonic situation in the Anton Paduánsky gallery (*Brimich, 1988*): 1 – granite zone with mylonites and quartz; 2 – dacite (Neogene); 3 – ancient zone in granite; 4 – granite (Vyhne ancient granite – Palaeozoic); 5 – fault; 6 – fault with its slope; 7 – location of instruments (a – tiltmeter chamber, b – recording instrument chamber, c – extensometer); 8 – walled-up areas; 9 – entrance to gallery.

## 2. Description of the station

The Vyhne tidal station is located in Central Slovakia in the cadastre of the village of Vyhne (about 10 km from Banská Štiavnica) in the St. Anthony of Padua gallery (*Brimich, 1988; Brimich and Latynina, 1989; Dudášová, 1998*). Its geographic coordinates are: $\varphi = 48°29'52''$ (latitude); $\lambda = 18°49'48''$ (longitude) and h = 420 m (height). The relative humidity in the gallery is 80% and air temperature 6.8°C. The seasonal changes of the air temperature between summer and winter at the location, where the extensometer is installed, protected by a polystyrene cover, are $\pm 0.04$°C. The relative depth of the extensometer location is 50 m. In Fig. 1 the scheme of the tidal station in Vyhne is presented.

The deformations of the Earth's crust at the Vyhne tidal station are

recorded by a rod extensometer manufactured in the Institute of Physics of the Earth in Moscow. The overall length of the instrument is 20.5, the rod of the extensometer is assembled of three-metre quartz pipes with an external diameter of 40 mm and wall thickness of 3 mm. The separate pipes were joined by epoxy cement. The joints were strengthened by invar sleeves. The rod is supported by suspensions spaced at 2.5 m. The whole instrument is covered by polystyrene. The extensometer is cutting across the line of one of local faults. The azimuth of the quartz rod is $55°27'57''$. The relative motion of the free end of the rod is recorded directly optically, photoelectrically and by capacitive transducer. The capacitive transducer was installed in June 1998 in collaboration with Geodetic and Geophysical Research Institute of Hungarian Academy of Sciences. The capacitive transducer is a differential condenser, which is connected in a capacitive bridge, the output signal of which is amplified by a carrier-frequency amplifier *(Mentes, 1998)*. The output signal of this amplifier could be both analogous and digitally recorded. The more precise description of the capacitive transducer used at the Vyhne tidal station is in *Mentes (1986; 1995)*. Datalogger CR10X produced by Cambell Scientific, inc. in Great Britain is used for the digital recording of the extensometric signal. The CR10X makes voltage measurements by integrating the input signal for a fixed time and then holding the integrated value for the analogy to digital conversion. The normal environmental variables of concern are temperature and moisture. The standard CR10X is designed to operate reliably from $-25°$C to $+50°$C.

## 3. The results of the analysis of the extensometric measurements

In this chapter the results of the tidal analysis using two different methods are presented.

The first one is the Venedikov's method M74. The results of the analysis of the extensometric measurements at the Vyhne tidal station obtained by this method are given in Tab. 1.

In the first column of Tab. 1, wave groups and their Darwin's symbols are given. In the second column, the number of the waves in each group of tidal waves is considered. In the third and fourth columns, there are

Tab. 1. Results of the analysis of the extensometric measurements obtained by Venedikov's method M74

| Wave Group | Number of waves | Old sensitivity Amplitude | Old sensitivity Phase | New sensitivity Amplitude | New sensitivity Phase | Theoretical values Amplitude | Theoretical values Phase |
|---|---|---|---|---|---|---|---|
| $Q_1$ | 65 | 1.293 | 23.6° | 1.423 | 23.6° | 1.22 | |
| | | ±0.031 | ±6.4° | ±0.031 | ±6.4° | | |
| $O_1$ | 26 | 7.326 | 18.0° | 8.058 | 18.0° | 6.38 | 14.8° |
| | | ±0.018 | ±1.2° | ±0.018 | ±1.2° | | |
| $K_1$ | 33 | 9.173 | 22.1° | 9.989 | 22.1° | 7.14 | 19.2° |
| | | ±0.017 | ±1.0° | ±0.016 | ±1.0° | | |
| $_1N_2$ | 24 | 1.762 | -38.6° | 1.938 | -38.6° | 1.20 | -46.0° |
| | | ±0.014 | ±2.6° | ±0.015 | ±2.6° | | |
| $M_2$ | 26 | 7.630 | -44.1° | 8.393 | -44.1° | 6.22 | -46.0° |
| | | ±0.008 | ±0.5° | ±0.008 | ±0.5° | | |
| $S_2$ | 47 | 4.053 | -38.2° | 4.458 | -38.2° | 2.89 | -46.0° |
| | | ±0.011 | ±1.0° | ±0.011 | ±1.0° | | |
| $M_3$ | 17 | 0.055 | -52.2° | 0.060 | -52.2° | | |
| | | ±0.048 | ±42.8° | ±0.048 | ±42.8° | | |

the amplitudes and phases of corresponding tidal waves. The analysis was performed using the old values of the sensitivity of the extensometer. In the fifth and sixth columns, the tidal characteristics obtained from the analysis using the new values of the sensitivity of the instrument are given. The differences in the amplitudes of the tidal waves (the third and fifth columns) are greater than estimated mean square errors except for the small wave M3. The differences between the observed tidal parameters and their theoretical values could be caused by the influences of the indirect effects of the ocean tides, regional inhomogeneities, local structure, topographic or cavity effects. Increasing of the tidal deformations could be caused also by the deflection of the instrument's axis from the axis of the gallery. The angle of this deflection is difficult to determine because the gallery has a curved axis.

The second one is the analysis of the tidal deformations. It is performed using the program ETERNA. The measurements registered by capacitive transducer in the period between July 4, 2001 and February 11, 2002 were analysed. The results are given in Tabs 2-5. The amplitudes of the tidal waves computed from the data of various periods, using different methods of the analysis and obtained from different recording systems differ by 10%. This differences are caused by the systematic errors in the determination of the scale coefficient of the optical and photoelectric recording systems.

Tab. 2. Results of the analysis of the extensometric measurements obtained by the programme ETERNA (Chojnicki's method)

```
 Program ANALYZE, version 3.40 970921              File:   40010931
#########################################################################
# STATION 0931 VYHNE                HORIZONTAL STRAIN                   #
#  48 29 52 N   18 49 48 E     H  420 M   P   50M   D 1000KM            #
# GEOPHYSICAL INSTITUTE, SLOVAK ACADEMY OF SCIENCES                     #
# QUARTZ TUBE STRAINMETER                                               #
# DIGITAL RECORDING, 10min. SAMPLE RATE                                 #
# CALIBRATION                                                           #
# INSTALLATION    L.LATYNINA,L.BRIMICH                                  #
# MAINTENANCE     L.BRIMICH, M.BEDNARIK                                 #
#                                                                       #
#                                                                       #
#########################################################################
 Latitude: 48.4980 deg, longitude: 18.8300 deg, azimuth: 55.4630 deg.
 20010704...20010813     2 blocks. Recorded days in total:     39.042
 Tamura (1987)          TGP, threshold: 0.100E-06      1200 waves.
 UNITY window used for least squares adjustment.
 Sampling interval:     3600. s
 Numerical filter is  PERTZEV59   with   51 coefficients.

 Average noise level at frequency bands in  nstr
 0.1 cpd***********      1.0 cpd   0.170157        2.0 cpd   0.093910
 3.0 cpd   0.115797      4.0 cpd   0.076135    white noise   0.054188

 adjusted tidal parameters :

                         theor.
 from      to      wave    ampl. ampl.fac.    stdv. ph. lead    stdv.
 [cpd]     [cpd]     [ nstr   ]                          [deg]    [deg]

 0.501370 0.911390 Q1     1.2103   0.82083  0.11503 -12.1428   8.0207
 0.911391 0.947991 O1     6.3214   0.72401  0.02488   2.2125   1.9590
 0.947992 0.981854 NO1    0.4971   0.71006  0.29317  12.5789  23.8811
 0.981855 1.023622 PSK1   8.8903   0.65201  0.01439  -0.6760   1.2945
 1.023623 1.054746 J1     0.4971   0.36770  0.27524 107.2034  43.6377
 1.054747 1.470243 OO1    0.2720   0.32285  0.70773 -30.8774 126.5771
 1.470244 1.914128 N2     1.1970   0.78772  0.05995   4.0159   4.3567
 1.914129 1.950419 M2     6.2521   0.72022  0.01320  -1.1355   1.0458
 1.950420 1.984282 L2     0.1767   1.13368  0.37429  -3.3840  18.8838
 1.984283 2.451943 S2K2   2.9088   0.94864  0.03308   3.6553   2.0063
 2.451944 3.381378 M3     0.0302   3.98069  3.04369   7.8850  43.7164

 Standard deviation:                    0.884   nstr
 Degree of freedom:                       815
 Maximum residual:                      3.805   nstr
 Maximum correlation:                   0.343 Y-wave-MTM with Y-wave-MF
 Condition number of normal equ.        4.896

 Routine GEOEXT. Execution time=     2.580 sec
```

Tab. 3. Results of the analysis of the extensometric measurements obtained by the programme ETERNA (Chojnicki's method)

```
 Program ANALYZE, version 3.40 970921              File:   40010931
#########################################################################
# STATION 0931 VYHNE               HORIZONTAL STRAIN                    #
#  48 29 52 N   18 49 48 E     H  420 M   P   50M    D 1000KM           #
# GEOPHYSICAL INSTITUTE, SLOVAK ACADEMY OF SCIENCES                     #
# QUARTZ TUBE STRAINMETER                                               #
# DIGITAL RECORDING, 10min. SAMPLE RATE                                 #
# CALIBRATION                                                           #
# INSTALLATION     L.LATYNINA,L.BRIMICH                                 #
# MAINTENANCE      L.BRIMICH, M.BEDNARIK                                #
#                                                                       #
#                                                                       #
#########################################################################
 Latitude: 48.4980 deg, longitude: 18.8300 deg, azimuth: 55.4630 deg.
 20010704...20020211     4 blocks. Recorded days in total:    208.583
 Tamura (1987)          TGP, threshold: 0.100E-06      1200 waves.
 UNITY window used for least squares adjustment.
 Sampling interval:     3600. s
 Numerical filter is  PERTZEV59   with   51 coefficients.

 Average noise level at frequency bands in  nstr
 0.1 cpd***********      1.0 cpd   0.267236        2.0 cpd   0.120835
 3.0 cpd   0.081236      4.0 cpd   0.051240    white noise   0.062193

 adjusted tidal parameters :

                         theor.
 from      to      wave    ampl. ampl.fac.    stdv. ph. lead    stdv.
 [cpd]     [cpd]     [ nstr   ]                        [deg]    [deg]

 0.501370 0.911390 Q1     1.2103   0.81977  0.17164  -0.4706  11.9913
 0.911391 0.947991 O1     6.3214   0.72480  0.03349   6.0069   2.6502
 0.947992 0.981854 NO1    0.4971   0.94383  0.36863 -54.9950  22.4148
 0.981855 1.023622 PSK1   8.8903   0.67705  0.02146   2.6519   1.8175
 1.023623 1.054746 J1     0.4971   0.53181  0.41063 -45.9986  44.2528
 1.054747 1.470243 OO1    0.2720   0.70524  0.72867 -37.8120  59.2130
 1.470244 1.914128 N2     1.1970   0.78806  0.07611  -0.3733   5.5353
 1.914129 1.950419 M2     6.2521   0.72790  0.01543  -2.3902   1.2136
 1.950420 1.984282 L2     0.1767   1.27312  0.54056  37.0493  24.3213
 1.984283 2.451943 S2K2   2.9088   0.66253  0.03330   9.2044   2.8821
 2.451944 3.381378 M3     0.0302   2.74192  2.02747  52.7990  42.3850

 Standard deviation:                    2.433   nstr
 Degree of freedom:                      4784
 Maximum residual:                     17.141   nstr
 Maximum correlation:                   0.083 X-wave-O1  with Y-wave-Q1
 Condition number of normal equ.        1.290

 Routine GEOEXT. Execution time=    11.800 sec
```

Tab. 4. Results of the analysis of the extensometric measurements obtained by the programme ETERNA (Chojnicki's method)

```
 Program ANALYZE, version 3.40 970921               File:   40010931
#########################################################################
# STATION 0931 VYHNE     HORIZONTAL STRAIN           SLOVAKIA       #
#  48 29 52 N   18 49 48 E     H  420 M   P   50M    D  600KM       #
# GEOPHYSICAL INSTITUTE, SLOVAK ACADEMY OF SCIENCES                 #
# QUARTZ TUBE STRAINMETER                                           #
# DIGITAL RECORDING, 10min. SAMPLE RATE                             #
# CALIBRATION                                                       #
# INSTALLATION     L.LATYNINA,L.BRIMICH                             #
# MAINTENANCE      L.BRIMICH, M.BEDNARIK                            #
#                                                                   #
#                                                                   #
#########################################################################
 Latitude: 48.4980 deg, longitude: 18.8300 deg, azimuth: 55.4630 deg.
 20010704...20020211     4 blocks. Recorded days in total:    208.583
 Tamura (1987)          TGP, threshold: 0.100E-06      1200 waves.
 UNITY window used for least squares adjustment.
 Sampling interval:     3600. s
 Numerical filter is  PERTZEV59   with   51 coefficients.

 Average noise level at frequency bands in  nstr
 0.1 cpd***********      1.0 cpd   0.265307        2.0 cpd   0.119256
 3.0 cpd   0.081217      4.0 cpd   0.051332    white noise   0.061683

 adjusted tidal parameters :

                         theor.
 from      to      wave    ampl. ampl.fac.    stdv. ph. lead    stdv.
 [cpd]     [cpd]     [ nstr   ]                        [deg]    [deg]

 0.501370 0.911390 Q1     1.2103   0.82604  0.17044  -0.6763  11.8169
 0.911391 0.947991 O1     6.3214   0.72491  0.03325   6.0347   2.6307
 0.947992 0.981854 NO1    0.4971   0.96338  0.36843 -49.9369  21.9485
 0.981855 0.998631 P1     2.9413   0.73640  0.07328  -7.8612   5.7071
 0.998632 1.023622 S1K1   8.8903   0.67740  0.02420   4.6190   2.0476
 1.023623 1.054746 J1     0.4971   0.50242  0.40818 -49.5735  46.5706
 1.054747 1.470243 OO1    0.2720   0.70123  0.72343 -37.1066  59.1233
 1.470244 1.880264 2N2    0.1912   1.27083  0.37601   4.4929  16.9399
 1.880265 1.914128 N2     1.1970   0.76992  0.07662   0.1012   5.7052
 1.914129 1.950419 M2     6.2521   0.72763  0.01523  -2.4075   1.1986
 1.950420 1.984282 L2     0.1767   1.28186  0.53528  39.9031  23.9209
 1.984283 2.002738 S2     2.9088   0.65713  0.03324   9.1513   2.9002
 2.002739 2.451943 K2     0.7908   0.74417  0.12233  17.6455   9.4149
 2.451944 3.381378 M3     0.0302   2.78941  2.02705  52.9967  41.6546
 3.381379 4.347615 M4     0.0003  70.61221150.82180  98.5068 122.4758

 Standard deviation:                   2.413   nstr
 Degree of freedom:                     4776
 Maximum residual:                     17.325   nstr
 Maximum correlation:                   0.189 Y-wave-2N2 with Y-wave-OO1
 Condition number of normal equ.        1.724

 Routine GEOEXT. Execution time=    11.760 sec
```

Tab. 5. Results of the analysis of the extensometric measurements obtained by the programme ETERNA (Chojnicki's method)

```
 Program ANALYZE, version 3.40 970921               File:   40010931
#######################################################################
# STATION 0931 VYHNE                HORIZONTAL STRAIN                 #
#  48 29 52 N   18 49 48 E     H  420 M   P   50M    D 1000KM         #
# GEOPHYSICAL INSTITUTE, SLOVAK ACADEMY OF SCIENCES                   #
# QUARTZ TUBE STRAINMETER                                             #
# DIGITAL RECORDING, 10min. SAMPLE RATE                               #
# CALIBRATION                                                         #
# INSTALLATION     L.LATYNINA,L.BRIMICH                               #
# MAINTENANCE      L.BRIMICH, M.BEDNARIK                              #
#                                                                     #
#                                                                     #
#######################################################################
 Latitude: 48.4980 deg, longitude: 18.8300 deg, azimuth: 55.4630 deg.
 20011016...20020211     1 blocks. Recorded days in total:    117.792
 Tamura (1987)          TGP, threshold: 0.100E-06      1200 waves.
 UNITY window used for least squares adjustment.
 Sampling interval:     3600. s
 Numerical filter is  PERTZEV59   with   51 coefficients.

 Average noise level at frequency bands in  nstr
 0.1 cpd***********      1.0 cpd   0.402927        2.0 cpd   0.172065
 3.0 cpd   0.115286      4.0 cpd   0.073208    white noise   0.090728

 adjusted tidal parameters :

                         theor.
 from      to      wave    ampl. ampl.fac.    stdv. ph. lead    stdv.
 [cpd]     [cpd]     [ nstr   ]                        [deg]    [deg]

 0.501370 0.911390 Q1     1.2103   0.87520  0.28148  10.0611  18.4613
 0.911391 0.947991 O1     6.3214   0.74590  0.04983   6.1853   3.8292
 0.947992 0.981854 NO1    0.4971   1.84514  0.58283 -66.7814  18.1259
 0.981855 1.023622 PSK1   8.8903   0.68328  0.03003   1.5650   2.5182
 1.023623 1.054746 J1     0.4971   0.28637  0.67955 -20.1885 135.7777
 1.054747 1.470243 OO1    0.2720   1.38261  1.10345 -64.8019  45.7450
 1.470244 1.914128 N2     1.1970   0.68179  0.11967   4.6393  10.0539
 1.914129 1.950419 M2     6.2521   0.72511  0.02201  -3.1799   1.7394
 1.950420 1.984282 L2     0.1767   2.70937  0.91755  27.3857  19.3912
 1.984283 2.451943 S2K2   2.9088   0.56503  0.04899  15.3905   4.9695
 2.451944 3.381378 M3     0.0302   2.26483  2.87659  81.8265  72.7823

 Standard deviation:                    2.697   nstr
 Degree of freedom:                      2755
 Maximum residual:                      16.743   nstr
 Maximum correlation:                   -0.110 X-wave-OO1 with Y-wave-J1
 Condition number of normal equ.         1.359

 Routine GEOEXT. Execution time=     1.490 sec
```

The differences between the observed tidal parameters and their theoretical values could by caused by the influence of the indirect effects of the ocean tides, regional inhomogeneities, local structure, topographic or cavity effects. In the first line of Tab. 2 the theoretical amplitudes and the phase differences of the waves $M_2$ and $O_1$ for the elastic spheric symmetrical Earth are given. B. P. Percev and M. V. Ivanova computed the tensor of the surface deformations at the tidal station Vyhne caused by the ocean tides. In the second line of Tab. 2 corrected values of the tidal parameters are given considering the indirect effects of the ocean tides. In the third line of Tab. 2 the amplitudes and the phases of the tidal waves $M_2$ and $O_1$ are given corrected for topographic effect. Preliminary estimation of the influence of the topographic effect was made by Harrison's model for a V-shaped valley with tides sloping at 24° (*Harrison, 1976*).

## 4. Conclusions

The tidal deformations are characterized by small positive anomalies, which can be explained by a high mobility of the region surrounding the Vyhne tidal station. From the comparison of the different time series of extensometric data, we can conclude that the observed amplitudes and phase differences of the main tidal waves are extraordinary stable. The influences of the local effects (cavity effect, topography effect and geologic effect) can contribute to the changes of the amplitudes and phase of tidal waves *(Kostecký and Kohút, 1998)*, too.

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