Health Monitoring of Structures Using Natural Effects as Excitation Signal

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Key words: building, deformation, earthquake, Earth tides, tower.

SUMMARY

Monitoring of movements of hazardous industrial objects, high buildings, bridges, etc. meets a rising interest because the damage of such structures can cause environmental accidents. The movements and deformations of objects may be influenced by different geodynamical processes like earthquakes or in some special cases (e.g. high buildings, long bridges) Earth tides. These phenomena are natural excitation signals for investigations to assess the health and safety of objects and eventually to forecast damages.

This paper shows how natural effects can be used as excitation signals for the investigation of the soil-structure interaction regarding the safety of hazardous industrial establishments and, therefore, for health monitoring and earthquake risk assessment of structures. For health monitoring using natural excitation the TV tower in Sopron was chosen. High towers move not only due to strong winds and sunshine, but also due to geodynamical effects, e. g. earthquakes, tectonic movements and Earth tides. So, the movements of the tower and the coupling between the ground and the building can be investigated in a broad range of frequency, from “high” frequencies (0.01 ... 10 Hz) down to periods of years. The paper shows the measuring method using tiltmeters and deals with the analysis and interpretation of continuously measured data series with a length of about two years. In this paper the behaviour of the tower due to Earth tides is investigated.

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1. INTRODUCTION

Monitoring of movements of hazardous industrial objects, high buildings, bridges, etc. meets a rising interest because the damage of such structures can cause environmental accidents. The movements and deformations of objects may be influenced by different geodynamical processes like earthquakes or in some special cases (e.g. high buildings, long bridges) Earth tides. These phenomena are natural excitation signals for investigations to assess the health and safety of objects and eventually to forecast damages.

- For the investigation the TV tower in Sopron was chosen because high towers have large movements due to earthquakes and in special cases due to Earth tides. Using these effects as input signals the movements and deformations of the object can be investigated from "high" frequencies (0.01 ... 10 Hz) to periods of years.
- The Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences has experience in global and local geodynamical measurements as Earth tides (Mentes 2001) tectonic movements (Mentes 2002, 2003) and landslides (Mentes 2004).
- The measurements were carried out in the frame of a scientific and technical co-operation between the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences and the Section of Applied Geophysics at the Geological Institute of the University of Bonn. The preliminary results of the investigations between ground and building motions were published by Mentes and Fabian (2001).

2. MEASUREMENT OF THE TOWER AND GROUND MOTION

Figure 1 shows the map of the vicinity of the TV tower on the top of Mt. Dalos (394 m) in Sopron, Hungary. The TV tower is a 176 m high concrete building with a deep cemented foundation in gneiss. A borehole of 3.6 m depth was drilled in south-west direction about 90 m apart the tower for installation of a borehole tiltmeter to monitor ground tilts. The tower's tilt is being observed by a borehole tiltmeter installed in an iron pipe placed on the concrete foundation of the tower. By this experimental solution both the tower and the ground motions are measured by comparable instrumental set-ups. The tilt measurements have been carried out by means of dual-axis borehole tiltmeters Model 722A made by Applied Geomechanics Inc. (AGI), Santa Cruz, California. The installation of the instruments is written more detailed by Mentes and Fabian (2001).

3. RESULTS OF THE MEASUREMENTS

Figure 2 shows raw data recorded from 04.11.1999 to 05.07.2001. X_T, Y_T and T_T sign the values of the X and Y tilt components and the temperature of the tiltmeter at the TV tower, X_B, Y_B and T_B the corresponding values of the instrument in the borehole. The data were collected with a sampling rate of 1 data/hour. Both tiltmeters were installed so that their Y directions were parallel and corresponded the North direction.

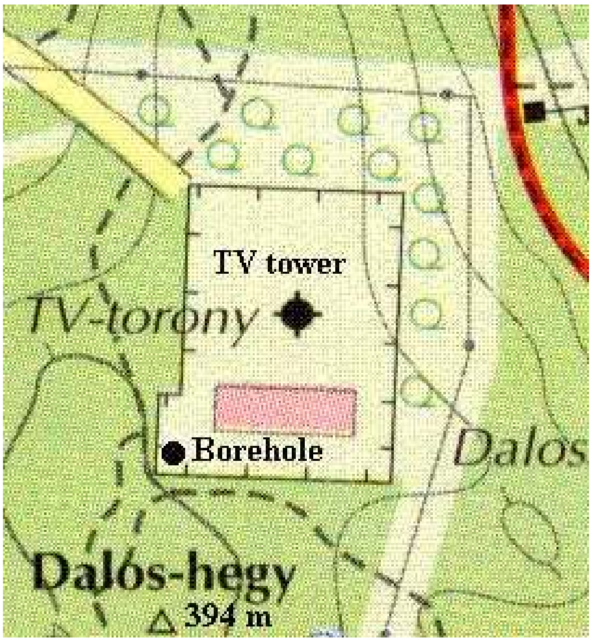

Fig. 1: Site of measurements

The tilt signals have a seasonal variation with yearly period. In Figure 2 long-term correlations between the temperatures and tilts seem to be obvious.

From the raw data a linear trend was also calculated to get an idea about the direction of the continuous tilting of the tower and the one of the ground. All time series show an individual linear long-term trend during the observation interval: X_T = -39 μrad/year, Y_T = -36 μrad/year, T_T = 1.18 °C/year, X_B = -1.5 μrad/year, Y_B = -5 μrad/year T_B = 0.19 °C/year. The long-term trend of the tilts have the same directions. According to the topography of the Mt. Dalos in surroundings of the TV tower, one part of the ground tilts may be of tectonic origin. The tilts may be in connection with the rising of the Alps because the Mt. Dalos belongs to the mountain chain of Alps. The other part of the tilt trend may be in connection with the trend of the temperature. For a more reliable interpretation of the trend longer data series are necessary.

To study the short periodic movements a polynomial of 9 order was fitted to the raw data and this polynomial was subtracted from the original data. Figure 3 shows the residual curves which represent the short periodic variations. To get the dominant frequencies of the variations the residual signals were Fourier-transformed. The amplitude spectra are shown in Fig. 4. Diurnal and semidiurnal periods appear both in the tower and ground tilt signals. The presence of the diurnal signals is obvious because the temperature variation has a daily period. The appearance of the semidiurnal signals is slightly surprising. Because the tiltmeters are sensitive enough to sense Earth tides in a borehole drilled in gneiss, the characteristic frequencies of the spectra were compared with the tidal frequencies. Our institute has a geodynamical observatory in Sopronbánfalva some kilometers far from the TV tower. In this observatory extensometric measurements are carried out for observation of the Earth tides and tectonic movements. So we could use theoretical and practical data for the comparison. The diurnal signal K_1 has a much higher amplitude than the usual K_1 tidal component because the thermal effect gains this signal. The obtained frequency of this component 0.04175 1/hour = 1.002 1/day coincides with the theoretical one: 1.002737909 1/day (Melchior 1978, Mentes 2001). The frequencies of the M_2 and S_2 are 1.93224 1/day and 1.99944 1/day and the theoretical ones are 1.932273616 1/day and 2.0000 1/day respectively. This coincidence prove that the obtained dominant frequencies are of tidal origin. It is interesting to note that the tidal wave M_2 has a very low amplitude at the tower tilts. The reason of this is not jet known.

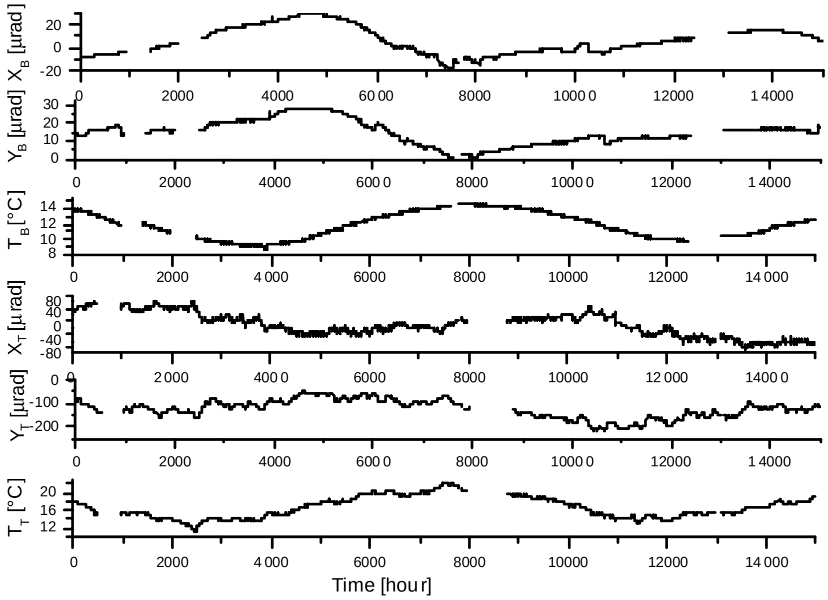

Fig. 2: Raw data recorded from 11.04.1999 to 05.07.2001

- The ratio of the tower and ground tilt amplitudes in X direction is about 28 at both frequencies. The same ratio in Y direction is about 16 in the case of the diurnal signals and about 1 in the case of the semidiurnal signals. Maybe the structure of the ground causes these differences.
- The diurnal and semidiurnal variations of the recorded temperatures are very small which proves also that the semidiurnal frequencies are of tidal origin.

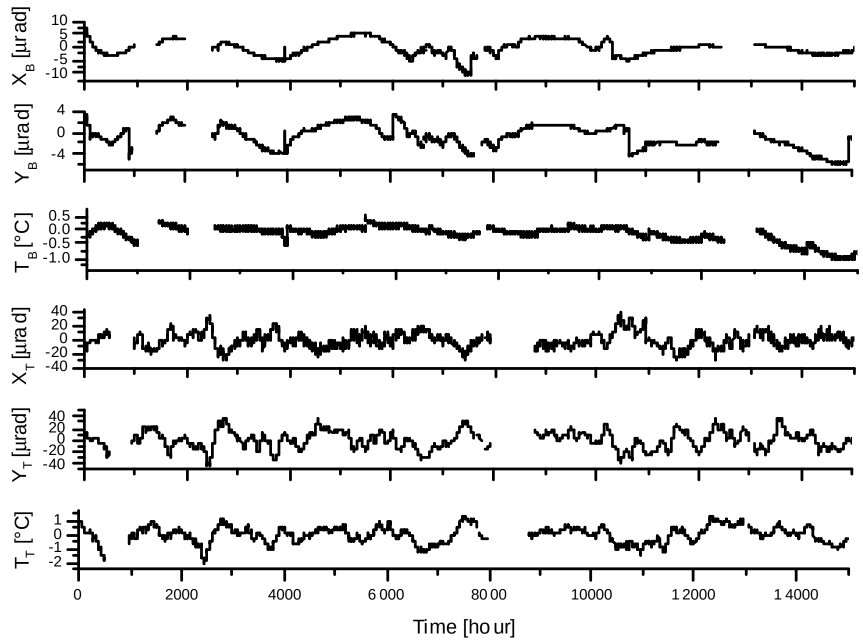

Fig. 3: Short periodic tilt variations from 04.11.1999 to 05.07.2001

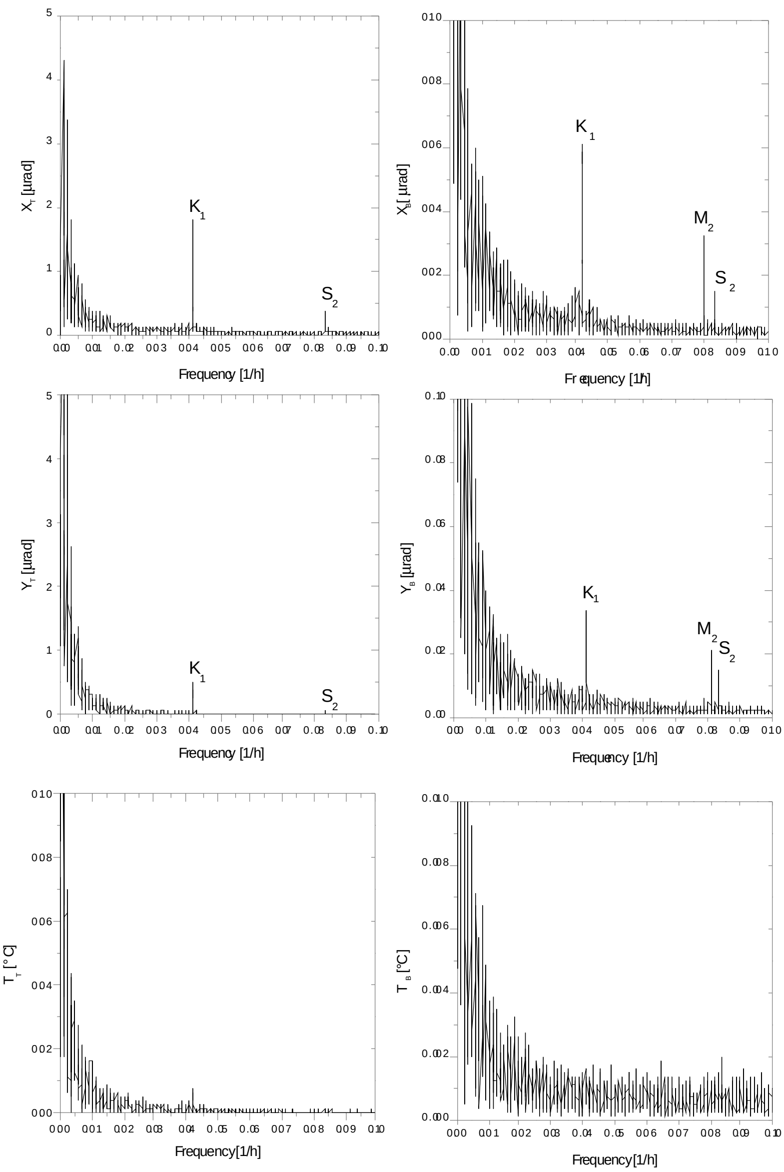

Fig. 4: Amplitude spectra of the residual signals

4. CONCLUSIONS

Data were recorded and analysed from very long periods (e.g. tectonic movements) to “high” frequencies of earthquakes. Based on these measurements the ground - building transfer function can be determined which can be used at the earthquake risk assessment of the construction (Mentes and Fabian, 2001). Using a multi sensor system (tiltmeters, extensometers, accelerometers, etc.) the deformations and movements of the structure can be determined in the frequency range of the different geodynamical phenomena. The exciting (input) signal of the building can be determined by sensors installed in the ground and the response of the building by the sensors placed on the structure. Simultaneous monitoring of ground and building movements and deformations gives a very good possibility for health assessment and control of structures.

The long-term data show a continuous trend in the motions of the TV tower and the borehole in a similar manner. This could be caused by a slow deformation or motion of the whole site. The trend is superposed by an one year-cycle in all components, which is also present in the temperature data of both instruments.

The appearance of tidal frequencies in the high resolution tilt data give a possibility to control the health of large objects (e.g. very high buildings, long bridges, etc.) in special cases because they are well defined input signals. The constituents of the tidal wave can be very exactly calculated from celestial data. The change of the response of the object can be used to assess the health of the object.

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BIOGRAPHICAL NOTES

Name: Gyula Mentes
Born: 1950
1971: Graduated: from the Kandó Kálmán College of Technology and Electricity
1977: Graduate from Budapest University of Technology
Profession: Electrical engineer
Since 1971: Employed at the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences (GGRI)
1971 -1977: Electrical engineering
1977 – 1987: Scientific co-worker, Head of Electrical Laboratory
1986: Candidate of Sciences (PhD)
1987 - 1999: Senior member, Head of the Department of Instrument Development
1989: Academic Prize in Earth tides research
1991 – 2002: half time assistant professor at the University of West-Hungary in Sopron
1992 -1994: Lecturer at the University of Technology in Vienna
1999: Prize "Széchenyi Professor Scholarship"
2000: Doctor of the Hungarian Academy
Since 2000: Scientific advisor at the GGRI, Head of the Geodetic Main Department
Since 2003: Half time professor at the University of West-Hungary in Sopron

Field of research:

Global and local geodynamics: Earth tide research, tectonic movements, landslides, atmospheric tide.
Investigation of local effects: connection between ground water level and ground tilt, connection between ground and building motions
Development of instruments for Earth tide monitoring: horizontal pendulum, quartz tube extensometers, hydrostatic tiltmeters, calibration of instruments, automation of data recording
Development of data processing methods, data interpretation
Engineering Geodesy: Investigation of deformations and movements of structures and objects
More than 120 publications and 100 papers on international conferences.

Memberships of societies:

Member of the Hungarian Geophysical Association
Member of the Hungarian Association of Surveying, Cartography and Remote Sensing
Member of the International Association of Geodesy
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