Deformation monitoring of Danube bridges in Slovakia by integrated measurement system

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Key words: Bridge Monitoring, Measuring System, Tilt Measurement, Robot Station, GeoMoS, Accelerometer, GNSS Receiver, Time Synchronisation

SUMMARY

One of the main tasks associated with the safety of civil engineering structures are monitoring of their deformation. The modern and often non-typical shape of these objects generates special requirements on structural deformation monitoring. Current approach in automation of the geodetic measurements allows the application of automated systems for structural monitoring. The paper presents the design of developed automated measurement system for permanent geodetic monitoring of bridge structures over the river Danube in capital city of Slovak Republic - Bratislava. Describes the topology and preliminary experimental testing of the automated system at the real bridge structure. The base of the system are geodetic total station, tilt sensors, accelerometers and complementary sensors such as meteorological station and temperature sensors. Measurement process control is realized by remote management and data server by mobile internet connection. The system is able to monitor long-term deformation and the dynamic behaviour of the bridge in real-time.

SUMMARY (optional summary in one other language in addition to English, e.g. your own language)

Zusammenhang der Sicherheit der Baustrukturen ist die Hauptaufgabe der Messung von dieser Deformationen. Die modern und nicht-typische Struktur dieser Bauten bringt oft extra Bedingungen für Messung der Deformationen. Der aktuelle Stand in Automatisation geodätischer Verfahren ermöglicht ihre Verwendung auch bei Deformationsmessung von Bauten nicht typische Struktur. Der Beitrag bringt Informationen über die Entwicklung ein automatisches Messsystem für die Donaubrücken in Hauptstadt Slowakei – Bratislava. Weiter ist die Systemtopologie und die Ergebnisse der Testmessungen auf reale Brücke beschreiben. Neben der Hauptanteil des Systems, der Totalstation, sind in System weitere Sensoren implementiert – Beschleunigungsgebern, Temperatursensoren, meteorologische Sensoren, usw. Systemmanagement ist über Smartphone via Internet möglich. Das System ermöglicht die Messung von Langzeitdeformationen und auch Beschreibung der dynamischer Verhalten der Brücke.

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1. INTRODUCTION

The issue of an investigation, realization and implementation of new technologies in monitoring of civil engineering structures is generally discussed as Structural Health Monitoring (SHM). Important part of these activities is geodetic monitoring of bridges. Several operation restrictions in monitoring of large bridge structures leads to increasing number of installations of automated measurement systems (AMS) at these structures. AMS are implemented at large bridge structures around the world, mainly in Japan, China and USA (Hill *et al*. 2002, Hsieh *et al*. 2006, Yong *et al*. 2008, Wenzel 2009, Ko 2005). Information about their operation, significantly determine the approach in this research area, especially in the area of monitoring of the dynamic behavior of bridge structures. In these countries, the monitoring is focused to the seismic resistance of structures, due to many structures is situated in areas affected by increased seismic activity.

USA has implemented program of long term monitoring of significant bridges supported by legislative frame as LTBP program (Long-Term Bridge Performance). This frame helped to implement several permanent long-term automated monitoring systems of bridges.

AMS at bridge structures are implemented especially at significant traffic corridors with high operation load. In Europe are implemented several systems at highway bridges focused on dynamic monitoring of the structures (Wenzel 2005, 2009, Enckell 2007, Geier 2009). The most famous project in this area is the bridge crossing Oresund strait, which connects Sweeden and Denmark (Peeters 2009).

Requirements on geodetic bridge monitoring in Slovak republic is anchored by legislative frames and national technical standards. Realization of bridge monitoring is performed mostly by classic geodetic approach. This approach includes several disadvantages, such as requisition for some operation breaks, which cause traffic problems. These can be avoided by installation of AMS at bridge structures.

The Department of Surveying at the Faculty of Civil Engineering of the Slovak University of Technology in Bratislava (FCE STU) has been monitoring dynamic effects on civil engineering structures of different types and dimensions for a long time. Our recent research is focused on automation of the monitoring process, the preparation of innovative geodetic technologies for multi sensor fusion, with the aim of integrated automated structural health monitoring of large bridges in Slovakia. The paper is focused on recent research in the area of development of an integrated monitoring system of two Danube bridges in Bratislava – the Apollo Bridge and the Bridge of Slovak National Uprising. Mathematical models of data processing and new software modules for spectral analysis are presented. The paper brings first result of the AMS application at the Bridge of National Uprising, also.

2. HIGHWAY AND RAILWAY BRIDGES OVER RIVER DANUBE IN BRATISLAVA

Bratislava – the capital city of Slovak republic is significant road and railway traffic hub in Slovakia. The Danube which flows throw Bratislava is crossed by several highway and railway bridges. These bridges are extremely loaded by traffic. General traffic load is averagely at the level from 50 000 to 120 000 vehicles per day. The most significant bridges crossing the Danube are following:

- Old Bridge – a city road bridge (in reconstruction),
- Bridge of Slovak National Uprising – a city road bridge,
- Port Bridge – a combined rail-road bridge,
- Lafranconi Bridge – a highway bridge,
- Apollo Bridge – a city road bridge.

Fig. 1 Danube bridges in Bratislava – Old Bridge (above left), Bridge of Slovak National Uprising (above center), Lafranconi Bridge (above right), Port Bridge (bottom left) and Apollo Bridge (bottom right)

Old bridge is the oldest bridge spans over Danube in Bratislava (Fig. 1). The bridge was finished in 1890 and had truss construction with overall length 454.7 m (Paulík 2014). During the 2nd World War was completely destroyed in April 1945. The renovation of the bridge was realized in 1946 to its previous shape. Recently the whole structure is in general renovation which will be finished in 2016. Structural health monitoring of the structure in service will be realized by an automated measurement system, based on geodetic and fiber optics technologies.

Bridge of Slovak National Uprising is a city road traffic structure (Fig. 1). Connects the center of the city with city district Petržalka over the Danube. The construction began in 1969 and to full operation was given in 1972. Structure is asymmetric cable-stayed steel structure by one pylon with overall length at the level of 688.4 m and width 21.0 m. Height of the pylon is 95.0 m (Tesár 1978). Bridge is monitored by automated measurement system which is presented in this paper.

Port Bridge spans the Danube in Bratislava as the rail-road bridge in the area of the Bratislava port (Fig. 1). Construction works began in 1977 and completely operation started in 1985 (partially in 1983). The whole structure with flyovers at the river banks has total length 2582.0 m and is the longest bridge in Slovakia (Fábry *et al.* 2014). Bridge monitoring is realized by classic geodetic monitoring using precise leveling. Actually is developed the technology for long-term monitoring of bridge dynamics using the automated measurement system based on accelerometers and a ground-based radar in combination with long-term deformation monitoring by total station.

Apollo Bridge is the youngest bridge over Danube in Bratislava with a length of 517.5 m (Fig. 1). The main part of the bridge is an arched steel structure with a span length of 231.0 m and an arch height of 36.0 m. The structure of the Apollo Bridge was used for the experimental testing measurements made by the developed automated measurement system described in this paper (Lipták 2014).

Lafranconi Bridge is a highway bridge at the international highway connection between Austria, Hungary, Czech Republic and Slovak Republic (Fig. 1). It is first concrete bridge over the Danube in Slovak Republic. The bridge has overall length of 761.0 m. The bridge structure is monitored using precise leveling in annual periods (Paulík 2014).

3. AUTOMATED MEASUREMENT SYSTEM FOR BRIDGE MONITORING

Current geodetic monitoring of bridge structures is generally based on periodic measurements of selected parts of the bridge structure, which are realized when the structure is without traffic. According these limitations, especially in the case of large bridges with significant operation load by traffic, arises the requirement on design and realization of an AMS. AMS is able to monitor a bridge structure in arbitrary moment in time and frequency according the requirements of the bridge management. These eliminate requisites on realization of regular operation breaks, or minimize the time of the operation breaks and brings significant logistic and economic advantages to bridge management.

Design of an AMS for long-term monitoring is focused on monitoring of behavior of the bridge girders. These parts of the structures are extremely loaded under the influence of weather conditions and operation. AMS is designed for:

- a continuous and time unlimited monitoring of the bridge girder,
- determining the dynamic and long-term deformation of the bridge girder,
- providing an information about the deformation in real time,
- a remote access and management of the system.

The designed AMS is divided into two separated and interconnected subsystems (Fig. 2). Both subsystems are time synchronized. Subsystem of the sensors is designed for installation on the bridge structure. This subsystem communicates with master subsystem by internet connection, which is situated on the Department of Surveying of the FCE STU. Remote access to sensors is possible in real-time through the master subsystem.

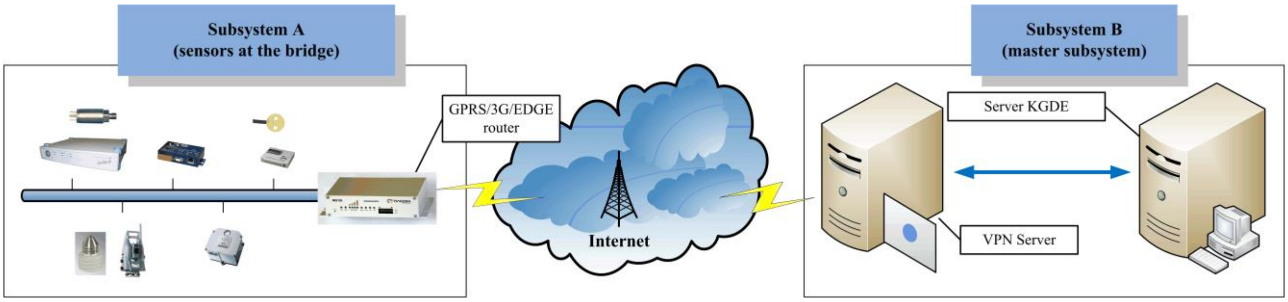

Fig. 2 Subsystems of the AMS

The subsystem on the bridge is build by several types of sensors and communication devices (Fig. 3):

- total station Leica TS30,
- tilt sensors Leica Nivel220,
- meteorological station Reinhardt DFT 1MV,
- accelerometers HBM B12/200 and universal amplifier HBM Spider 8,
- temperature sensors Pt1000/TG7 and data logger Comet MS6D,
- local time server Mobatime LTS,
- GPRS/EDGE/3G router Racom MG102.

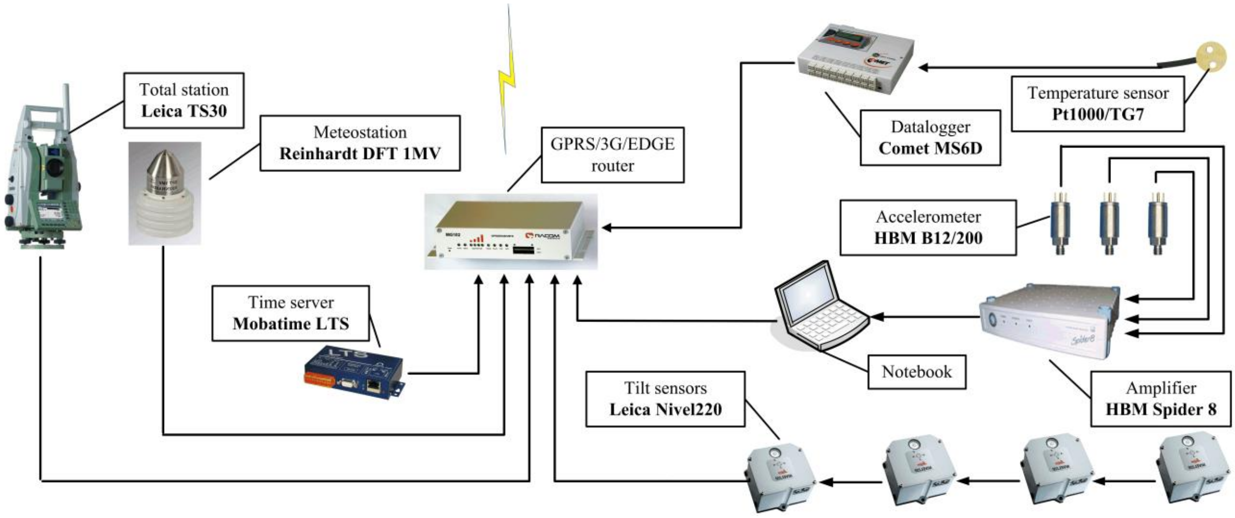

Fig. 3 Subsystem of sensors

The base of the subsystem of sensors is the total station Leica TS30, which is used for measurement of the spatial long-term and dynamic deformations of the bridge girder. Tilt sensors measure longitudinal and transversal tilts of the bridge girder. This measurement are useful for monitoring of both the vertical bending and the torsional deformation of the girder. Accelerometers are used for measurement of vertical vibrations of the bridge deck. These sensor configuration is suitable for long-term continuous monitoring of changes and the vibrations of the monitored structures, also. AMS is able to monitoring changes in both the structural and air temperature by contact resistive temperature sensors Pt1000.

The master subsystem is built by server located at the Department of Surveying. The server is running permanently and with the subsystem of sensors communicates by virtual private network (VPN). The advantage of this solution is the stabile and safety access to components of the system in real time and the possibility of the system configuration. Time synchronization of the system is realized by the local time server Mobatime LTS, which provides the time signal of the satellite navigation system NAVSTAR GPS. The accuracy of this synchronization is given by 0.05 second with evenly spaced actualization of the system time with frequency of 1 Hz.

The measurement and the registration process by most of components is provided by proprietary software. To made dynamic measurements using total station, was development own software "Tracking TS30" using Leica GeoCoM protocol. This software is a unique solution for dynamic monitoring in real time and build an important part of the developed AMS (Lipták 2014).

4. MATHEMATICAL MODELS OF DATA PROCESSING AND ANALYSIS

Sensors and measurement devices generate data sets in evenly and unevenly spaced time intervals. The data are generally collected in the form of time series. Using suitable mathematical models of data processing and analysis is possible to determinate not only static and dynamic deformation of the monitored structure but the stochastic properties of the sensors, also.

Mathematical models used for data analysis by the developed AMS are based on spectral analysis and signal processing. According the data and the sensor type are used different combination of mathematical models. In the case of total station are applied two models:

- auto-spectral and cross-spectral analysis of the bridge long-term deformation induced by temperature changes,
- auto-spectral analysis of unevenly spaced data of the bridge dynamic measurement.

Processing of tilt measurement data is realized by:

- auto-spectral and cross-spectral analysis for determination of the spectral behavior of the longitudinal and the torsional oscillation of the structures.

Data processing and analysis of the accelerometer data is realized in following steps:

- auto-spectral and cross-spectral analysis of the measured accelerations,
- double integration of accelerations which leads to displacements.

The mentioned approaches of data processing and data analysis enable us to determine also:

- the average frequencies and amplitudes of the structural deformation,
- the frequency variations of the structural deformation.

The basic purpose of the spectral analysis is the determination of periodic components in measured time series. From the point of view of the determination of dynamic behavior or long-term deformation, respectively, the principle of both methods of the spectral analysis is identical. The time interval of measurements is the dominant parameter in this case (Kuo *et al.* 2001).

The most often used method of spectral analysis in frequency domain is the Fourier transformation (FT). The Fourier transformation describes a signal according to its harmonic functions and can also be used for transforming a signal from a time domain to a frequency domain. The Fourier transformation is generally defined as

$$F(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt. \tag{1}$$

A practical application of the Fourier transformation procedure requires that data sets with a finite amount of data. In practical applications a signal is defined in discrete form, in regular time interval. From this reason is significant the discrete form of FT – Discrete Fourier transformation (DFT). The most famous and most often used algorithm for calculation the time series parameters using DFT is the Fast Fourier transformation (FFT) (Cooley *et al.* 1965). The spectral density of a time series could be determined by a Fast Fourier Transformation (FFT), which is defined as

$$D_k = \sum_{j=0}^{N-1} y_j w(j) e^{\frac{2\pi ijk}{N}}, \tag{2}$$

where k = 0,1,... N-1; the *w* is a spectral window function (Kuo *et al.*, 2001). In this case the Hamming spectral window is generally used. For determining the significant frequencies from the discrete frequency spectrum, the Fisher’s asymmetric statistical test of periodicity was used (Cipra, 1986).

The final results in the frequency domain contain from two parts – the amplitude or the power spectrum (periodogram) and the phase spectrum. A cross-spectral analysis of two time series (signals) is used for determination of the cross-correlation and the time delay between them. The amplitude spectrum in the case of cross-spectral analysis describes the common amplitudes at the selected frequencies of both time series. The phase spectrum describes the time delay of both time series. Correlation of two time-synchronized signals for the specific period can be defined by their coherence (Trauth 2010).

Spectral analysis of more time series is based on determination of the common spectral density of the time synchronized measurements. Distribution of the spectral density in separate time series is often strongly differentiated. Resulting the average normalized spectral density is calculated, which can be determined as the arithmetical average of all normalized periodograms. The average normalized power spectral density describes the distribution of spectral density of every time series included in the analysis. This fact enables us to get complex view on static and dynamic properties of the monitored structure.

Unevenly spaced data generally occur in cases when measurements are performed by total stations or some data is missing in the data set. The spectral analysis of such data, which describes structural deformations, could be realized by different approach. The FFT algorithm is applicable in the case, when the average time of the data registration is calculated. But this may cause distortion of the calculated values, lower accuracy of the estimated characteristics (power spectrum, etc.), and finally lead to an estimation of false frequency values. In this case the Lomb-Scargle periodogram (LSP) gives more reliable results than the FFT algorithm (Kopáčik *et al.* 2013). LSP is defined as

$$P(T)=\frac{1}{2\sigma^2}\left\{\frac{\left[\sum_{i=1}^{N}\left(x_j-\bar{x}\right)cos\left(\frac{2\pi\left(t_i-\tau\right)}{T}\right)\right]^2}{\sum_{i=1}^{N}cos^2\left(\frac{2\pi\left(t_i-\tau\right)}{T}\right)}+\frac{\left[\sum_{i=1}^{N}\left(x_j-\bar{x}\right)sin\left(\frac{2\pi\left(t_i-\tau\right)}{T}\right)\right]^2}{\sum_{i=1}^{N}sin^2\left(\frac{2\pi\left(t_i-\tau\right)}{T}\right)}\right\}, \tag{3}$$

where the parameter τ is defined as

$$tan\left(\frac{4\pi\tau}{T}\right)=\frac{\sum_{i=1}^{N}sin\left(\frac{4\pi t_i}{T}\right)}{\sum_{i=1}^{N}cos\left(\frac{4\pi t_i}{T}\right)}, \tag{4}$$

where N is the number of measurements in a data set, t_i is the time of registration, $\bar{x}$ is the mean value calculated for the data set, and σ^2 is the variance of the data set (Lomb, 1976).

Accelerometers generate an output signal in the form of a time series of the accelerations. Determining relative displacements can be accomplished by several methodologies. The most common method is the double integration of the acceleration defined as

$$s(t)=s_0+v_0\times t+\int_0^t\left(\int_0^t a(t)dt\right)dt, \tag{5}$$

where s_0 is initial position, v_0 is initial velocity, $a(t)$ is acceleration. Numerical solution of double integration can be realized by a rectangular or trapezoidal rule. The selection of the appropriate sample rate has a significant effect on the accuracy of the calculations. In this case it is recommended to provide the measurement with a sample rate at least twice that of the highest significant frequency of the vibration of the structure. Another important factor influencing the accuracy of the integration of the measurements is the implementation of a high-pass filter. By using a suitable filter, the long-term components of the measured signal (e.g., drift) can be eliminated. It is necessary to design such a filter with a minimum frequency and magnitude response. This effect of the filter on the raw measurements can be analyzed by a transfer function (Lipták 2014).

Based the described mathematical models are developed three new modules for data processing and analysis, the module for:

- spectral analysis of evenly spaced data,
- spectral analysis of unevenly spaced data,
- displacement determination from acceleration data.

Software has integrated FTP interface for automatic or manual downloading data for analysis of measurements. Modules are stand-alone applications with graphic user interface, what able the effective and user friendly data processing and analysis (Lipták 2014).

5. APPLICATION OF THE AMS AT THE BRIDGE OF SLOVAK NATIONAL UPRISING

During the development of the AMS several versions and installations were realized at the cable-stayed steel bridge of Slovak National Uprising in Bratislava. The developed AMS could be applicate at arbitrary bridge structure and enable the permanent control of the bridge structure. The proposed AMS consists of total station, tilt sensors, accelerometers and temperature sensors. For monitoring of physical conditions in the bridge surrounding was used the meteorological station.

To have permanent information about the stability of the total station during the measurement, the network of reference points was established, which contains of permanently stabilized points, both the inside and outside the bridge abutment (anchorage block). There are increased pedestrians and car traffic in the bridge surrounding, which brings some limitations for the correct location and stabilization of the reference network points. Resulting these limitations were the reference points VB4 and VB5 stabilized at the bridge pillar abutment, which leads to higher number of control measurement. Finally are there stabilized 5 reference points for total station measurements (Fig. 4 right).

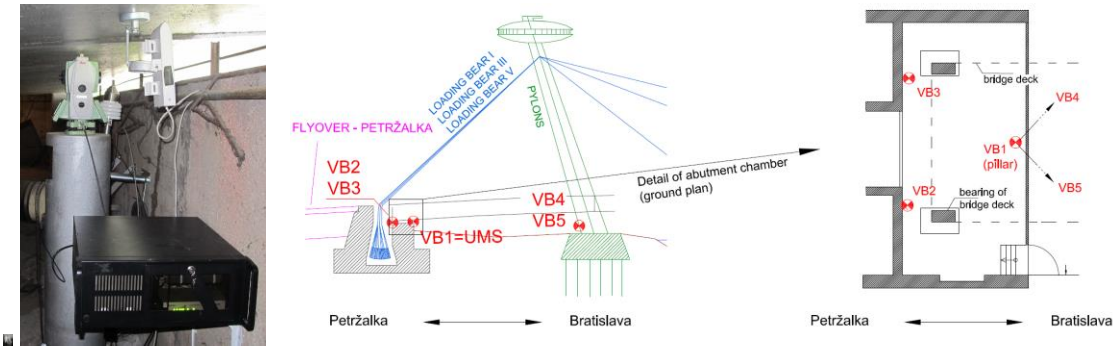

Fig. 4 Stabilization of the reference points. Total station positioned at reference point VB1 (left). Longitudinal section of the bridge pillar and abutment (center). Position of the reference points inside the bridge abutment – situation (right)

The reference point VB1, with the total station (Fig. 4), is built in the bridge abutment chamber at the right bank of Danube (Petržalka). The position of this point provides good protection of the total station and good visibility to each reference and measuring points at the bridge deck, also. The point VB1 is stabilized by cylindrical shaped and 1.20 m high steel pillar of the diameter of 300 mm with concrete filling. Tilt sensor Leica Nivel220 monitors the stability of the pillar in horizontal direction. The meteorological station Reinhardt DFT 1MV situated near the pillar to monitor the weather conditions in the surrounding of the total station.

The position of the measuring (control) points of the bridge deck is given by typical (characteristic) points of the structure, points where the deformation have the highest influence on the stability of the structure. Points are designed in three cross sections, which are defined by the locations of the catenaries hanging (Fig. 5). In each cross section, at the outboard bottom flange, are stabilized two prisms Leica GPR1 (Fig. 6 left). In chambers of catenaries hanging are situated tilt sensors Leica Nivel220, accelerometers HBM B12/200 and temperature sensors Pt1000/TG7 (Fig. 6 right).

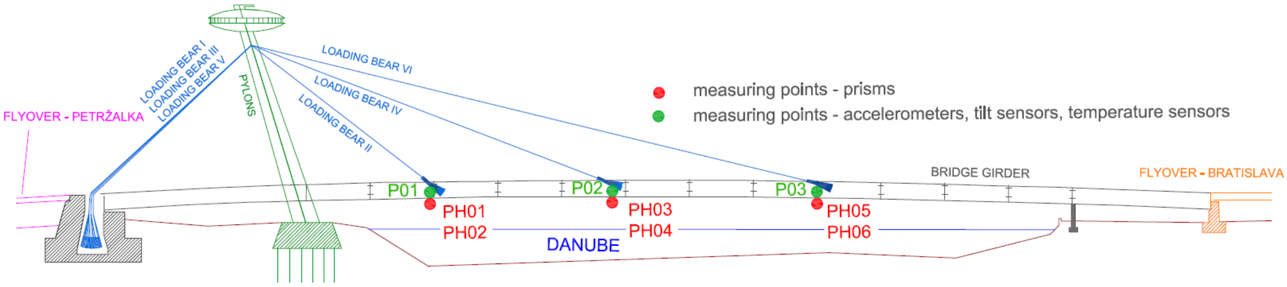

Fig. 5 Situation of measuring (control) points

Fig. 6 Stabilization of the measuring points

The online connection between the sensors and data loggers is realized by UTP and FTP cables. UTP cables are used for interconnection of tilt sensors, for connection of accelerometers and temperature sensors are used FTP cables. These are resistant to the influence of external conditions and to changes in the electric voltage, which reduces the risk of signal distortion. Measuring bus for power supply and the communication unit for interconnection of the sensor subsystem with the master, is installed in the thrust block of the bridge support near to the reference point VB1. Registration laptop and universal amplifier HBM Spider8 are located in the chamber of the catenaries hanging No. 4. Communication of this part of the system with the measuring bus is realized by Wi-Fi working at 5 GHz frequency.

6. LONG-TERM MONITORING OF THE BRIDGE

Application of the AMS enable us to monitor structural deformation in common time resolution and time range. The possibility of the continuous monitoring of the bridge dynamics is significant advantage of the developed AMS too. These measurements can be used for analysis of the bridge dynamics, but can perform useful data about the long-term deformation (static deformation), also. According the limited space are described in this chapter selected parts of the bridge monitoring using the developed AMS, only.

6.1 Long-term monitoring of the bridge deck by total station

The long-term monitoring using total station enable us to monitor 3D displacements of the chosen parts (characteristic points) of the bridge structure, for example the bridge deck. The measurement was made by total station Leica TS30, the measurement process was managed by Leica GeoMoS software. Results of the realized experimental measurements show on strong oscillation of the structure with dominant cyclical component at the level of 24 hours. Figure 7 brings the longitudinal bridge deck deformation during the experimental measurements realized since 10th April 2014 to 15th April 2014.

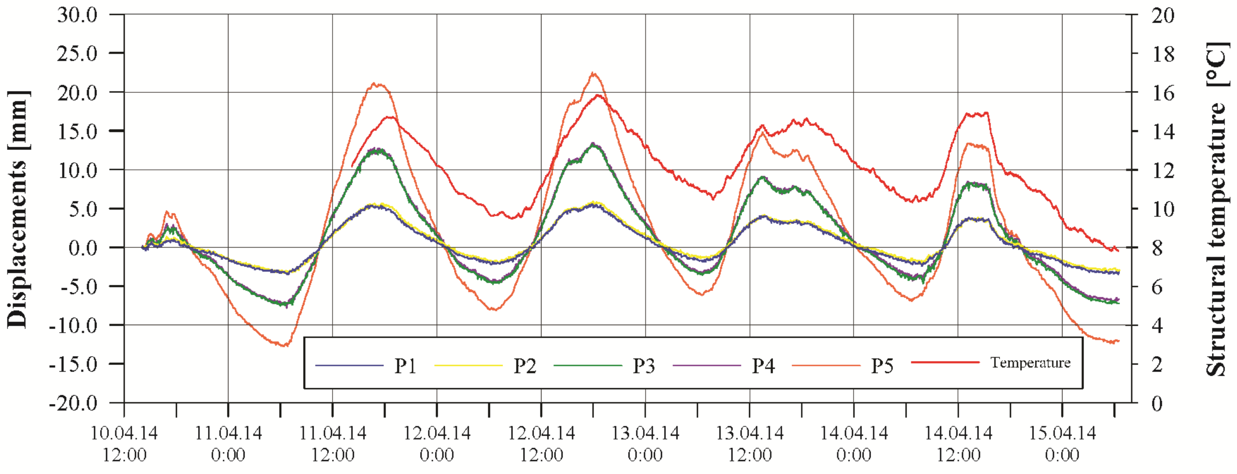

Fig. 7 Longitudinal displacements of the bridge structure

Results of the cross-spectral analysis of longitudinal displacements and the structure's temperature underlines the strong influence of the temperature variation at the bridge deck deformation. This fact was confirmed by high coherence (at level 0.95) between the structure's temperature and the displacements at each measuring point. Analysis of the phase delay of time series describes structural response on temperature changes approximately in 1 to 1.5 hour. Average amplitudes of daily variations of displacements at the points PBH01 and PBH02 are at level of 5.0 mm and at the points PBH03 and PBH04 are at level of 10.0 mm. The highest amplitudes varies from 10.0 to 18.0 millimetres, at control point PBH05.

The accuracy of the displacements determined in each direction was 1.2 millimetres. Monitoring the bridge deck deformation in real time and short time intervals provides high quality information about the structure health, for example the temperature influence on the structure. The realized permanent measurements using the AMS has significant advantages against the classic long-term monitoring made in annual or longer intervals (period).

6.2 Long-term monitoring of the bridge by accelerometers

Accelerometers are stabilized at the typical (characteristic) points of the bridge deck, where the dynamic response of the structure is most significant. The aim of the dynamic deformation analysis is the determination of natural frequencies of vertical oscillation of the structure and the analysis of their variations. Important part of the dynamic bridge behaviour monitoring is the determination of relative vertical displacements of the bridge deck, also. Deformations of the bridge deck of Bridge of Slovak National Uprising are described by Finite Element Method (Benčat *et al.* 2012), and characterized by vertical bending modes at significant frequencies at the level form 0.1 Hz to 5.0 Hz.

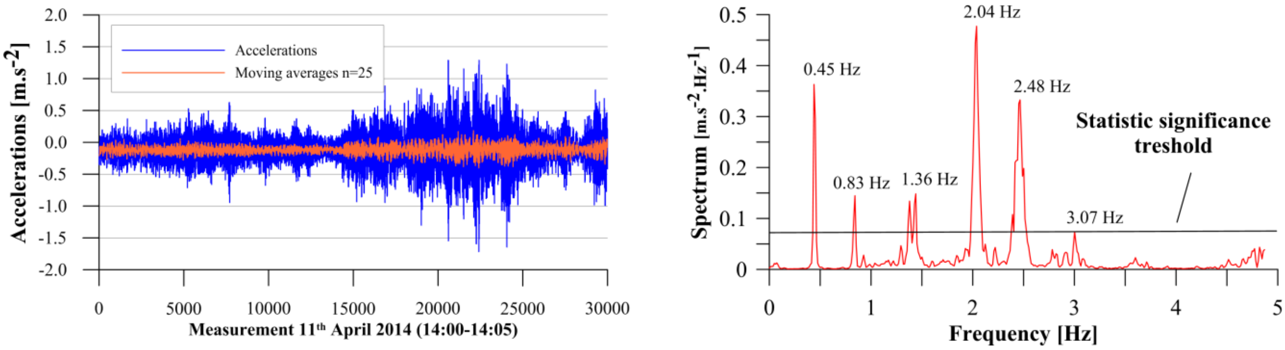

Fig. 8 Spectral analysis of the accelerometer measurements

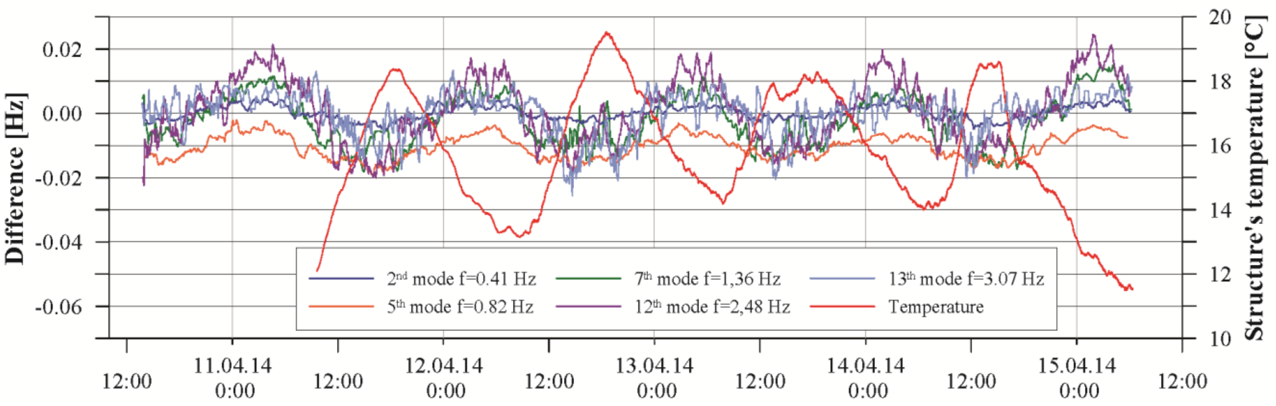

Fig. 9 Daily variations of the vibration frequencies

Determination of average daily vibration frequencies is realized in several steps. In the first step are realized continual measurements extracted into discrete 5 minutes long blocks. In each block is in the first step removed the trend component of the time series and then are estimated frequencies of the structural deformation using spectral analysis. The calculated average daily frequencies of the structural deformation are in minimum different from the modelled frequencies, at level lower than 10 %. This fact shows on very good compliance of the results from permanent measurements and the numeric model of the structure. The average vibration frequencies of the structural deformation determined by the accelerometers shows minimal fluctuations at the level of each vibration modes. Figure 9 shows the changes of vibration frequencies during experimental measurements since 10th April 2010 to 15th April 2014.

Differences reached the minimum values at the level 0.02 Hz. The highest fluctuations are at the 12th vibration mode at the frequency 2.48 Hz. The minimum changes are registered at the vibration mode with lower frequencies, where the daily variations are maximally 0.01 Hz. Frequency variations have at each significant vibration modes cyclical pattern with 24-hour long period. Results of cross-spectral analysis of oscillation frequencies and structural temperature shows on their significant coherence at level higher than 0.75. Phase delay of the changes in vibration frequencies and the temperature of the structure at the level around -150° of shows on fact that parallel with the increasing structure’s temperature is decreasing the vibration frequency with time delay from 1.4 to 2.4 hours. Results of the realized measurements shows on good use not only for dynamic measurements but for long-term monitoring of the structure’s vibration, too.

7. CONCLUSION

The paper brings information about the development of integrated measurement system, which is able to monitoring short time variations of spatial deformation of the bridge structures in fully automated mode. Data processing and analysis is based on mathematical models used general for time series analysis. The designed system was installed and tested at the Bridge of the Slovak National Uprising in Bratislava, by several experimental measurements. Results of the cross-spectral analysis of longitudinal displacements determined by total station and the structure's temperature underlines the strong influence of the temperature variation at the bridge deck deformation. This fact was confirmed by high coherence (at level 0.95) between the structure's temperature and the displacements at each measuring point.

Important part of the dynamic bridge behaviour monitoring is the determination of relative vertical displacements of the bridge deck, also. These were determined from vertical movements of the bridge deck measured by accelerometers. Natural frequencies of the structure (their vertical oscillations) and the analysis of their variations in time describes the dynamic behaviour of the structure. Daily variations of the vibration frequencies are determined. The calculated average daily frequencies of the structure show good compliance with modal (calculated) frequencies, at level lower than 90 %. This fact shows on very good compliance of the results from permanent measurements and the numeric model of the structure.

The results shows wide possibilities of the system usage mainly in the field of monitoring of large civil engineering structures. Provide parallel significant base for research in engineering surveying and in modal analysis in the field of structural engineering. The realized measurements show the good use of the applied technologies and measurements also the developed methodology of data processing in this sphere. The development of the presented AMS prototype is not finished today. For the future, the extension of the system by another sensors is planned, parallel with the installation at all Danube bridges in Bratislava which are described in this paper. This approach will ensure the integrated measurement system for structural health monitoring of the busiest bridges in Slovak Republic, in the future.

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