# Automated Monitoring of the Danube Bridge Apollo in Bratislava

**Alojz KOPÁČIK, Peter KYRINOVIČ, Imrich LIPTÁK and Ján ERDÉLY, Slovakia**

**Key words**: bridge monitoring, measuring system, tilt measurement, robot station, GeoMoS, accelerometer, GNSS receiver, time synchronisation

## SUMMARY

The Apollo Bridge is one of the five road bridges across the Danube in Bratislava, which connected the center of the city with the district Petržalka. The bridge consist from eight parts, from the main part is build as the arch steel structure with span length of 231.0 m and arch high of 36 m. The bridge was build form February 2003 to September 2005. The traffic load and temperature changes result deformation of the bridge structure. The developed automated measurement system (AMS) for long term monitoring of deformation enables the determination of actually information about the state of the main structure in real time and also suggest the dangerous situation eventually. The AMS consists of the robot station Leica TS30 with Automated Target Recognition (ATR) and two multi-frequency GNSS receivers, inclination sensor Leica Nivel 210. The automated measurement, data registration will made by the software GeoMoS from Leica. The system is completed by electronic sensors for acceleration and tilt measurement with 10 Hz and 1 Hz frequency. The first phases of the system development will the data in more notebooks registered. The time synchronization is given by the same time on all notebooks using Local Time Server (LTS) and GNSS time signal with accuracy of 5 msec.

## SUMMARY (German)

Die Apollo Brücke ist eine von 5 Donaubrücken in Bratislava, die die Verbindung zwischen Bratislava und Petrzalka bilden. Die Brücke ist von acht Teilen aufgebaut, von dem den Hauptteil mit Stahlkonstruktion von Lenge 231.0 m und Bogen von 36.0 m Höhe ist gebildet. Die Brücke wurde von Februar 2003 bis 2005 aufgebaut. Die Transportintensität und die Temperaturenderungen rufen Deformationen der Brückenkonstruktion vor. Die entwickelte automatisierte Messsystem (AMS) für Langzeitmessung der Deformationen ermöglicht die Bestimmung von aktuelle Information über die Brückenverhaltung im real-time und gleichzeitig die Aufdeckung der gefährliche Situationen. Die AMS ist von Leica TS30 mit ATR Funktion, zwei multi-frequenz GNSS, Neigung- und Beschleunigungssensoren zusammengestellt. Die Datenreihenregistrierung läuft mit Leica GeoMos Programpacket. Die erste Version des Systems ist mit mehreren Computer ausgerüstet, welcher Synchronisation wurde mit Local Time Server (LTS) und GNSS Zeitsignal von Genauigkeit 5 msec sichert.

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## 1. INTRODUCTION

One of the main tasks connected with the safety of civil engineering structures is the deformation measurement of these structures. The modern and often non typical form and structure of these objects increase requirements on deformation measurement and their accuracy. The Department of Surveying of the SUT Bratislava deals with this topic many years. The presented paper describes the way of automated measurement system development for long term monitoring of large bridges. The developed system consists from two parts, based on the geodetic and non-geodetic methodology. In the paper are described the system parts and the design of first control measurement with the system on the Apollo Bridge in Bratislava (Slovakia).

## 2. BRIDGE STRUCTURES DESCRIPTION

The Apollo Bridge is one of the most important transportation corridors in the capitol of Slovakia, Bratislava. The traffic load, water level changes in Danube and many other factors influence the basic function and safety of the bridge. The Apollo Bridge is one of the 5 bridges crossing the Danube in Bratislava. The position on the river is defined by km 1867.300. The hall longitude of the bridge is 854.0 m, was build from February 2003 to September 2005 (Fig. 1).

Figure 1 Apollo Bridge in Bratislava

The bridge structure consists from eight parts – the steel bridge with length of 517.5 m, concrete approach viaduct Petržalka with length of 236.0 m, concrete approach viaduct Bratislava with length of 195.0 m and five additional parts – three staircases and two cycling bridges. The main part of bridge is the arch steel structure with span length of 231.0 m and arch high of 36.0 m.

The main part is build by two steel timbers with orthotropic bridge floor (deck). The timbers are suspended on two central inclined steal arches. This part consists from 6 dilatation fields with spans of 52.5 m, 2 x 61.0 m, 63.0 m, 231.0 m and 49.0 m. The arch top is in 36.0 m high over the bridge deck. The pillar bases were builds by deck improved by injection or micro pilots. One of the pillars is positioned in the river. The main bridge field was mounted on the river bank and after this moved to the right position over the pillars and crossing the river.

## 3. AUTOMATED MEASUREMENT SYSTEM

The measurement system was designed according the bridge structure geometry and consist from geodetic and non-geodetic part. The geodetic part is build by Leica TS30 total station and GNSS receivers Leica Viva GS15 and GPS1200+. The total station enables automatic targeting ATR (Automatic Target Recognition) and measurement prism identification using CMOS, which determines the prism searching direction (Fig. 2). The angel measurement accuracy is given by 0.05 mgon, distance 0.6 mm + 1 ppm (Leica Geosystems, 2010).

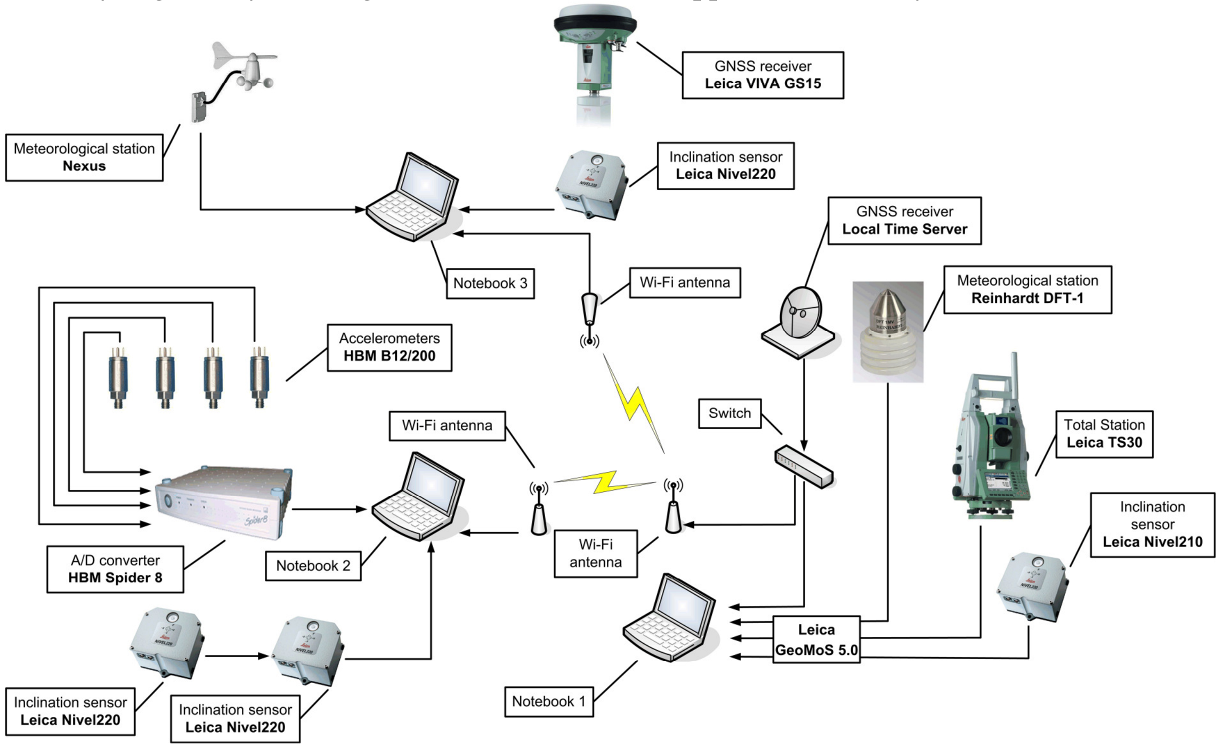


Figure 2 Components of automated measuring system

Other components of the geodetic part system are inclinometer sensor Leica Nivel 210, metrological station Reinhardt DFT-1, 13 standard prisms (GPR1) from Leica. Inclination sensor controls the stability of the total station position on the pillar. The sensor enable the inclination measurement up to ±3 mrad/m, with accuracy of ±0.0047 mrad/m, which representing the angel value of $9^{cc}$/m (3´´/m) (Leica Geosystems, 2006). Metrological sensor measures the air temperature (accuracy 0.3 °C), air pressure (accuracy 0.8 hPa) and air humidity (accuracy 2%) for distance corrections (Reinhardt, 2009). All three devices ware connected to the personal computer and the date from stations and sensor ware direct received to this computer. The measuring and data processing was operating by software GeoMoS from Leica Geosystems. The Leica Viva and GPS1200+ are multi frequency GNSS receivers, which enables the usage of GPS (NAVSTAR) and GLONASS satellite signal.

The non-geodetic part of the system is build by two inclination sensors Leica Nivel 220 and four 1D accelerometers HBM B12/200 from HBM (Hottinger Baldwin Measurements). There are inductive sensors, with operating frequency of 0 Hz do 100 Hz and measuring area of 200 m.s$^{-2}$. The accuracy of the sensors is defined by relative error up to ± 2 %.

The measured data was registered in three notebooks with 1 Hz and 10 Hz frequency. The homogeneity of data and synchronisation of the notebook time was given by usage of special time server LTS, which is using GPS time signal from NAVSTAR satellites. The accuracy of this time signal is ± 5 ms. The time signal from LTS was transferred by WiFi antennas with 5 GHz operation frequency. LTS time server was positioned near the total station and the signal was switched to the notebook and the „AP" antenna (Access Point). The other two antennas was operating in „client" mode and was mounted on the different part of the bridge to give the synchronised signal for data registration in other notebooks.

## 4. CONTROL AND OBSERED NETWORK POINTS

The total station was installed on the control network point (observation pillar VB16) situated on the river bank (Fig. 3).

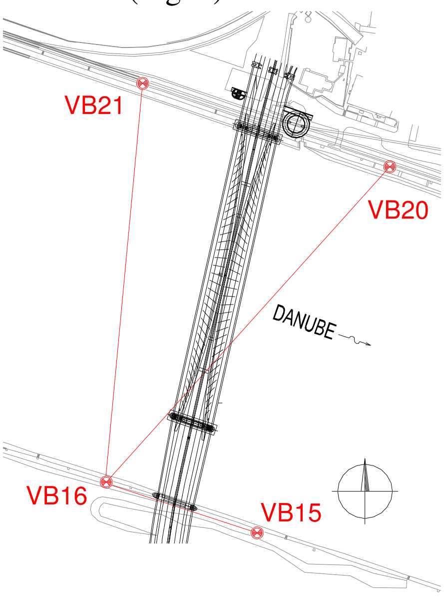


Figure 3 Configuration of control network points (left) and control point VB16 (right)

The control network points are builds as steel borehole tubes which were to fill with concrete and on top equipped whit special centring equipment. On other control points were installed prisms, which enabled the total station control orientation by distance and angle measurement. The inclination of the pillar was controlled by two axis inclinometer Leica Nivel 210.
Eleven observed points, signalised with prisms – points PBH01 to PBH11, ware situated on

the bridge (Fig. 4). At the booth side of the bridge floor, ware used 10 standard prisms Leica GPR1. One prism GPR1 was on the top of arch (point PBH06). The GNSS receiver Leica Viva was positioned on the top of the bridge arch – point PBG01.  GNSS reference receiver Leica GPS1200+ was situated on the building of Slovak University of Technology in the centre of the city.

The inclination sensors Leica Nivel 220 were situated at the two side of the bridge floor in the middle – points PBN01 and PBN02 and on the top of bridge arch – point PBN03. The sensor was oriented along the longitudinal and the cross bridge axis. Three accelerometers HBM B12/200 was situated at the left side of the bridge floor in the ¼, ½ a ¾ of the main bridge field (points PBZ01 to PBZ03) and the fourth accelerometers was situated on the right side in the ½ of the main bridge field (point PBZ04). The measurement axis of these was vertical.

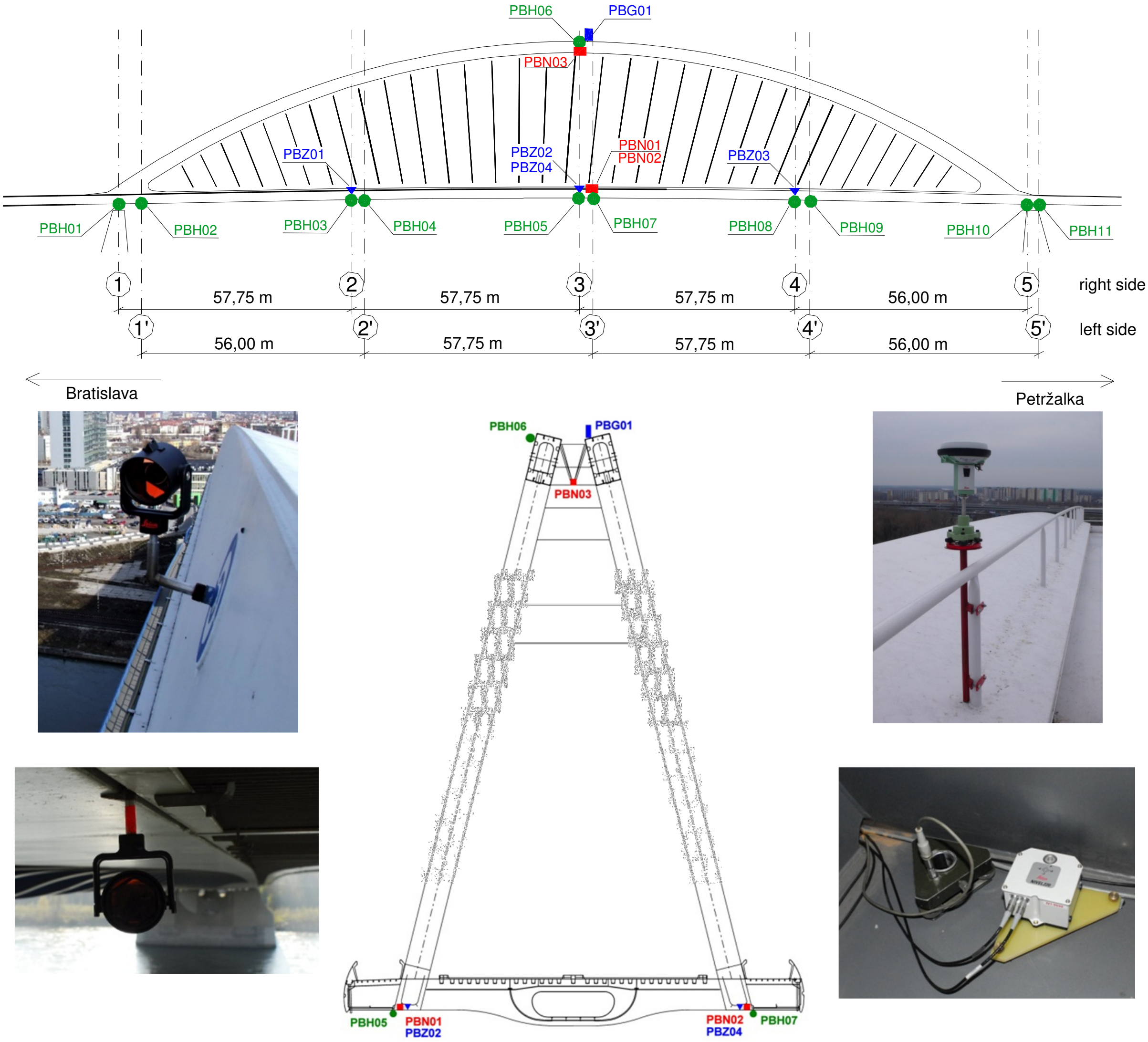


Figure 4 Longitudinal and cross section with localisation of the observed points

## 5. AUTOMATED MONITORING OF BRIDGE STRUCTURE

The automated monitoring of bridge structure was made during 24 hours from October, 27 to October 28, 2010.

The aim of the bridge steel structure measurement (monitoring) was the determination of:

- spatial (3D) displacements of observed points, situated at the bridge floor and at the top of bridge arch,
- horizontal displacements of observed point situated at the top of bridge arch,
- longitudinal and cross inclination of the bridge,
- dynamic deformation of the bridge construction in vertical direction.

The 3D position of the measurement points ware determined by the total station automatic way with the period of 10 minutes during 24 hours. The measurement pillar stability is controlled by measurement of horizontal directions to the neighbourhood control points situated on the river bank. The measurement results are corrected by the inclination of the measurement pillar also. All measurements made during the experiment and the data processing is managed by GeoMoS software. The accuracy of the 3D position of measuring points is up to 1.0 mm.

The horizontal displacement of the top arch was determined by GNSS Leica Viva receiver in static mode measurement. The data was received with 1 second period. All data was registered into internal receiver's memory (SD memory card). Longitudinal and cross inclination of the bridge monitored by Leica Nivel 220 inclinometers was registered with 1 Hz frequency and dynamic deformations, monitored by vertical accelerometers HB B12/200, with 10 Hz frequency. The measured date (inclination and acceleration) was registered into computer.

## 6. DATA PROCESSING

Resulting the 24 hour measurement are time synchronized data sets from total stations, GNSS, inclination and acceleration measurement and meteorological data. According the big volume of data sets will presented the result of data processing and analyze of the:

- stability the point VB16 (total station position),
- 3D deformation of the measured points (determined by Leica TS30).

The coordinates of the control network points are determined in the local system S-APOLLO, which „X“ axis is parallel with the longitudinal bridge axis. The stability of the measurement pillar was controlled by Leica Nivel 210 in each measurement epoch. According the measured pillar inclination was determined the correction for calculation of X and Y coordinates in each epoch:

$$Y_i = Y_Z + h\left(tg\,\varphi_{Y_i} - tg\,\varphi_{Y_Z}\right), \quad (1)$$

$$X_i = X_Z + h\left(tg\,\varphi_{X_i} - tg\,\varphi_{X_Z}\right), \quad (2)$$

where $Y_Z$, $X_Z$ are pillar VB16 coordinates determined in the zero epoch,

$h$ is the pillar high,

$\varphi_{Y_i}, \varphi_{X_i}$ is the measured inclination in X and Y direction.

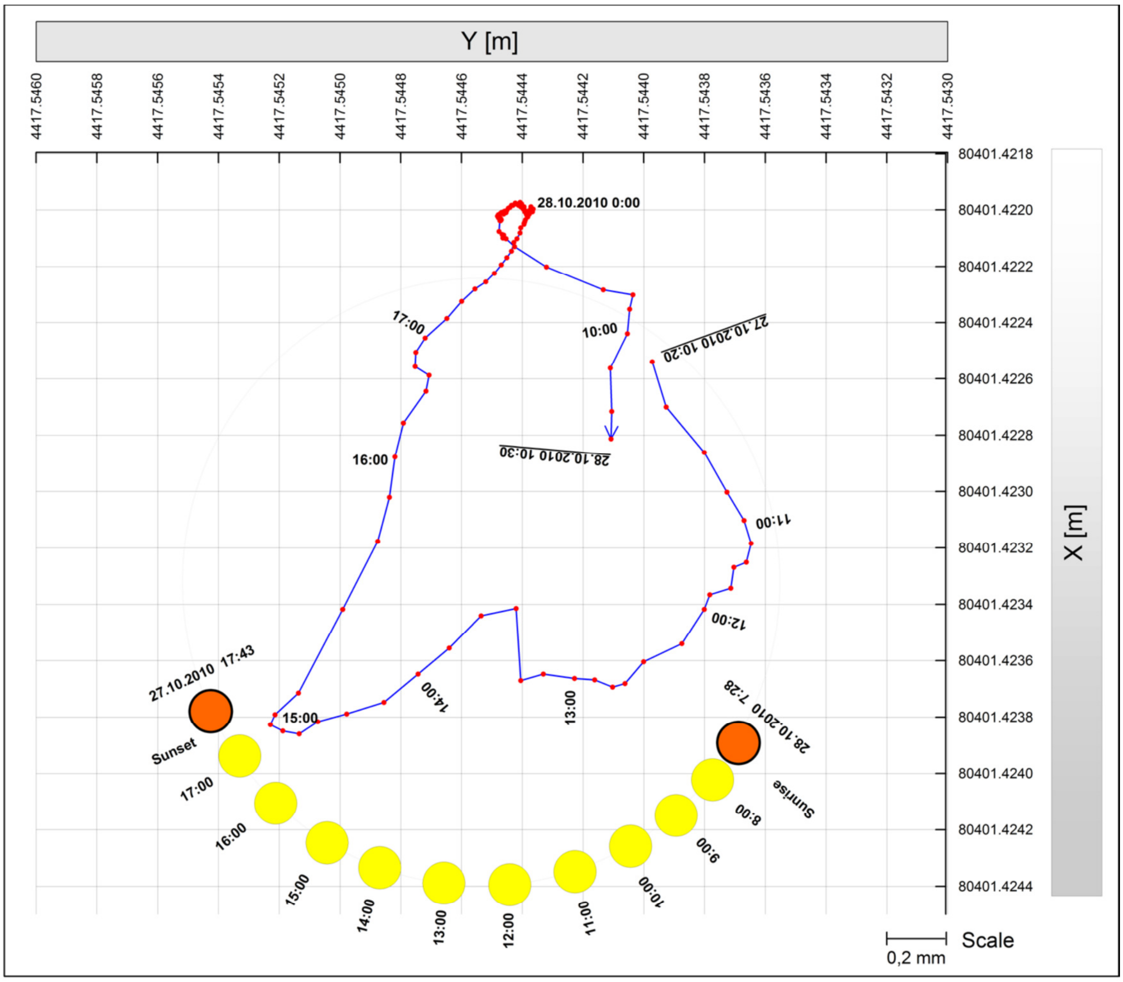


Figure 5 Horizontal displacements of the control point VB16

The accuracy of the inclination of the pillar VB16 measured at the pillar head is 0.14 mm. The range of the inclination is 1.8 mm (dy) a 1.9 mm (dx). The inclination is caused by the sun shine, one side pillar heating and temperature changes in the pillar surrounding. The maximum displacement vector is 1.2 mm.

3D coordinates of measured bridge points are determined by polar method using Leica TS30. The angle and distance measurement was made in each epoch two times (two faces) whit automated data acquisition using GeoMos the ATR function of the Leica TS30. The measurement was made every 10 minutes. The total number of epochs is 146 (Fig. 6).

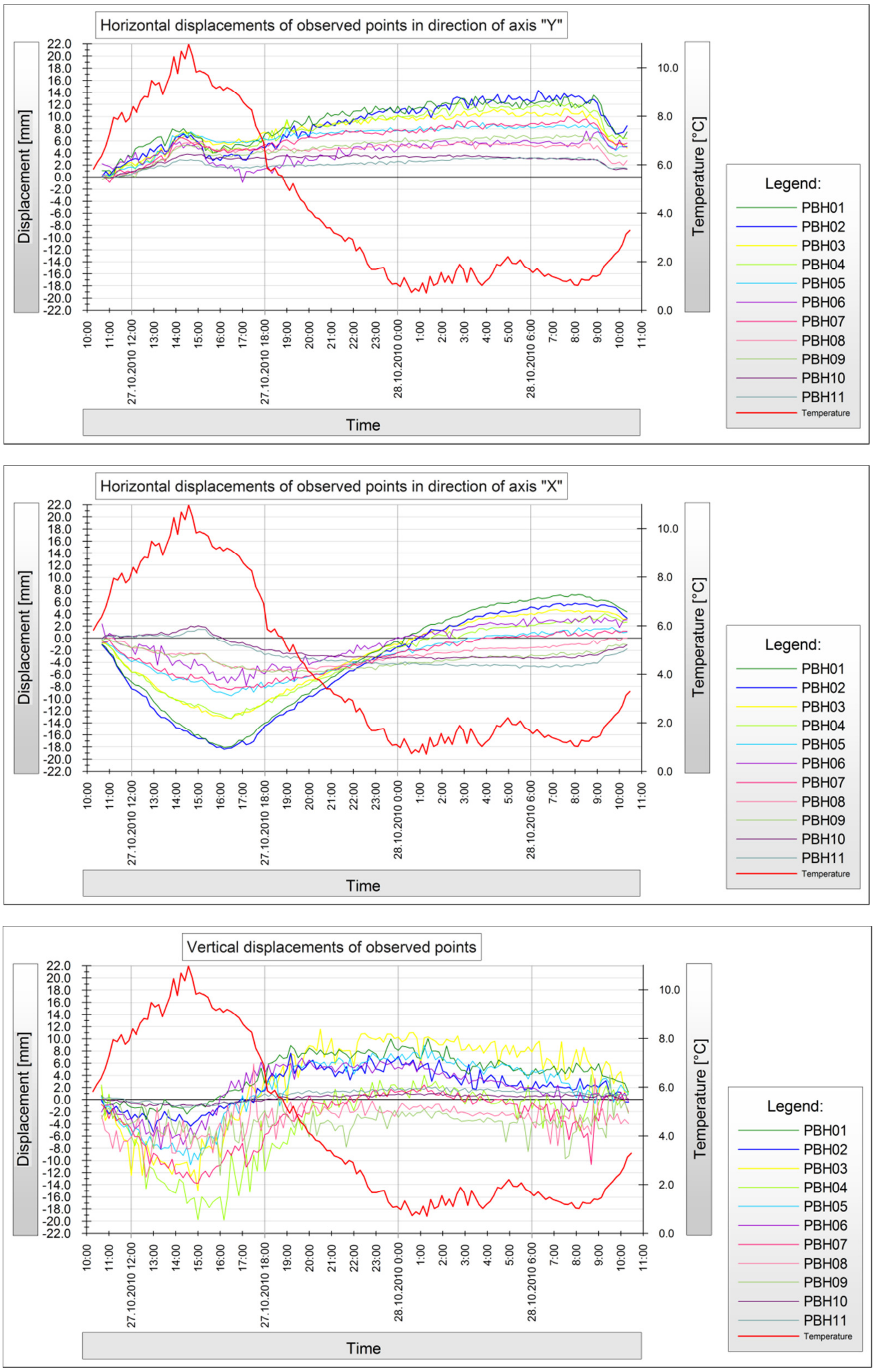


Figure 6 Spatial displacements of the observed points

The time series of the 3D bridge deformation has the similar trend (Fig. 6). While the steel structure of the bridge, the most important for the data analysis will be the air temperature influence. This will effects the volume and the dynamic of the bridge structure.

The horizontal deformation in „Y“ direction is relative stabile, the most intensive changes were registered at 28.10.2010, 09:00 a.m. This is caused by both the sun shine and the traffic. The biggest deformation was registered at the point PBH02 with absolute value 14.2 mm. The deformation in “X” direction suggestive the trend, change the form in the direction of the longitudinal bridge axis according the temperature changes. The bridge structure is fixed at the pillar No.10, which avoid the movement of the structure in longitudinal direction. The pillar No.11 at the left side (Bratislava) river bank is equipped by bearing, which enables the bridge structure movement in the longitudinal direction.

With the increasing distance from the pillar No.10 has increasing trend the longitudinal deformation, also. This is caused mainly by temperature changes. The maximum value 18.4 mm is registered at point PBH02 at 27.10.2010, 16:10. At points PBH10 and PBH11, where the minimum deformation was predicted, was registered the maximum value 5.0 mm at 28.10.2010, 5:30 a.m.

The vertical deformation is effected by the high variation measured time series. The maximum deformation 19.0 mm was measured at PBH04 at 27.10.2010 afternoon. The bridge structure deformation are effected by both the air conditions and the traffic, also.

## 7. CONCLUSION

The paper presents results of the ATS testing for long term monitoring of bridges. The aim of the experiment realised on the Danube bridge Apollo is to verify the functionality and responsibility of the developed measurement system including data processing and analysis. The developed system would be completed by other sensors, which will contribute to the fully automated system usage. Results of the system development process and the experiment will be used for development of central measuring system for permanent monitoring of all Danube bridges in Bratislava.

## REFERENCES

Leica Geosystems AG: Leica TS30, 2010.
http://www.leica-geosystems.com/en/Leica-TS30_77093.htm
Leica Geosystems AG: Leica Nivel 220. Heerbrugg, Switzerland. 2006.
Lipták, I.: Deformation measurement of the Danube Bridge Apollo in Bratislava. Bratislava 2010, Diploma thesis, 62 p. (in Slovak)
Reinhardt System und Messelectronic GmbH: Wetter und Klimasensoren, 2009, (in German).
http://www.reinhardt-testsystem.de

## BIOGRAPHICAL NOTES

**Alojz Kopáčik** is Professor at the Slovak University of Technology.
Study Geodesy and Cartography SUT Bratislava 1977-82. Doctor studies at the Department of Surveying the SUT Bratislava in 1982-85. Senior lecturer 1985-1998, 1998-2004 Assoc. Professor, since 2004 Professor at the Department of Surveying. Lecture from Geodesy for CE, the Underground and Mine Surveying and Engineering Surveying, Measurement systems in engineering surveying and Surveying for Civil Engineering (in English).
Past Chair of FIG C6, delegate national for the FIG C2 (Education). Member of the Slovak Chamber of Surveyors and Cartographers, Member of the board of Geodetski list (Croatia) and the WG's of FIG and IAG, which activity is oriented to implementation of laser technology in geodesy. Research in the filed of TLS applications, automated measuring systems, calibration. Chairman of the TC 89 - Geodesy and cartography (Slovakia).

**Peter Kyrinovič** is Lecturer at the Slovak University of Technology Bratislava, Department of Surveying. Lectures from Engineering Geodesy, Underground Measurement and Field Courses on Engineering Surveying. Study Geodesy and Cartography SUT Bratislava 1993-1998. Publications in various journals and conference proceedings.

**Imrich Lipták** is PhD. student at the Slovak University of Technology Bratislava, Department of Surveying. Study Geodesy and Cartography SUT Bratislava 2005-2010.

**Ján Erdélyi** is PhD. student at the Slovak University of Technology Bratislava, Department of Surveying. Study Geodesy and Cartography SUT Bratislava 2004-2009.

## CONTACTS

**Univ.-Prof. hab. Alojz Kopáčik, PhD.**
Department of Surveying SUT Bratislava
Radlinského 11
813 68 Bratislava
SLOVAKIA
Tel. +421 2 5927 4559
Fax + 421 2 5296 7027
Email: alojz.kopacik@stuba sk
Web site: www.stuba.sk

**Dipl.-Ing. Peter Kyrinovič, PhD., Dipl.-Ing. Imrich Lipták, Dipl.-Ing. Ján Erdélyi**
Department of Surveying, SUT Bratislava
Radlinského 11
Bratislava
SLOVAKIA
Tel. +421 2 5927 4390
Fax + 421 2 5296 7027
Email: peter.kyrinovic@stuba.sk
Email: imrich.liptak@stuba.sk
Email: jan.erdelyi@stuba.sk
Web site: www.stuba.sk