NEW TRENDS OF AUTOMATED BRIDGE MONITORING

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INTRODUCTION

Instruments with ATR were used in Slovak Republic for first time in year 1990 during the loading test of the Bridge Lafranconi in Bratislava within cooperation with the Institute of engineering surveying of TU Vienna. Results from at that time testing measurements were positive and support the experience of usage this type of instruments for deformation measurement during the bridge loading in the future.

At the Department of Surveying of Slovak University of Technology in Bratislava was designed the automated measuring system (AMS) for bridge monitoring. The AMS was successfully used for loading tests of the New Bridge and the long term monitoring of the Apollo Bridge in Bratislava (Fig.1).

Fig. 1. New Bridge (left) and Apollo Bridge (right) across the Danube in Bratislava.

1. LOADING TEST OF THE NEW BRIDGE

The New Bridge over the Danube in Bratislava is the one pylon, steel, cable-stayed bridge. It is the only one bridge in Bratislava, which has no pillar in flow of the Danube River. The bridge was built in years 1968 – 1972. The first loading test was made in august 1972. Characteristic sign of the bridge is the sloping steel "A" shaped pylon, leaning to right waterside of the Danube. Through the segment, located in transverse girder of the pylon in height app. 75 m, is led the system of cables from the anchorage block to three points of the bridge framework. The bridge framework has total length 431,8 m, and it is all-welded two floor construction. The top level is restricted for cars, and beneath the roadway there are lanes for bicycles and pedestrians on both sides. A special attraction of the bridge is the flying saucer-shaped structure housing of the restaurant, called "UFO" on the bridge pylon in 84,6 meter high. One can reach the

restaurant using an elevator situated in the left pillar. The restaurant offers a nice view of the city Bratislava. In the right pillar there is an emergency staircase with 430 stairs.

For the loading test of the New Bridge was used three automated total station (TS) Leica TCA1201, which were situated on the pillar on both watersides of the Danube. The measuring points were situated on the steel bearing structure and signalized with reflected prisms Leica 360° (6 points) and standard Leica prisms (8 points). All measuring points were measured at the same time in each loading phases with all three TS. The results of measurements done on the New Bridge underlines, that for deformation measurement during the bridge loading tests is the usage of modern surveying instruments advantageous. These instruments allow automation of the measuring process and they acquit very good not only with the achieved accuracy, but also with the velocity of the measurement, the time which is needed for the measurement.

The requirement of the main bridge structural engineer was to determinate the vertical deformation of measuring points in the anchoring point of bearing cables (KÁBEL 2, 4, 6) in each loading phases. Considering to number and position of the control points and the loading test time schedule was the trigonometric method and UMS Leica TCA 1201 chosen for determination of vertical deformations.

Instrument stations A, B and C are chosen in closeness of the bridge, on both watersides of the Danube (Fig. 2). There were stabilized by concrete columns with centring plate during the bridge construction. The stability of the instrument on the column is in addition assured by triplet of fixing jacks.

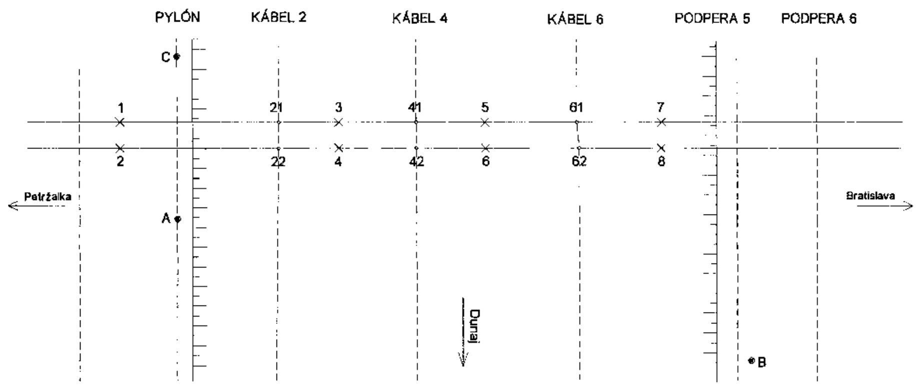

Fig. 2. Instrument stations (A, B, C) and the measuring points on the bridge.

As it was mentioned before, for loading test was in regard to short time interval of particular measuring phases chosen the trigonometric method. From this purpose it was needed to assure new stabilization of measuring points on the carling in the form of reflected prisms. The measuring points 21, 22, 41, 42, 61, 62 were stabilized by 360º reflected prism Leica in bottom side of bearing structure on its right and left side so that vertical deformations (deflections) of this bearing structure parts can be designated at the same time from three positions of instrument (Fig. 2). The measuring points 1, 3, 5 and 7 were stabilized on the top table of the contra-flow bearing structure part and points 2, 4, 6 and 8 on the top table of the flow bearing structure part. In both cases were points signalised with standard reflected prisms Leica. The vertical deformations

on contra-flow site points were determined from position C and on flow site from positions A and B.

According the test measurement results, which were done before the loading test, was achieved the accuracy of vertical deformation in range 0.3 mm to 1.0 mm for distance 100 m to 300 m (max. distance).

The timetable of geodetic measurement came out from timetable of the loading phases defined by the structural engineer. In the first measuring phase all three UMS at the same time target step by step the reflected prisms at the bottom part of the bearing structure. After that two or one UMS target the measuring points stabilized on the table of the bearing structure. With this consecution is ensured the control of the measurement and also the higher accuracy of vertical deformations. The preparatory measurement was done in the afternoon hours during the day lighting.

The loading test of the New Bridge over the Danube in Bratislava was realized on 12-th of April 2008 in night hours from 0:00 to 3:00. Atmospheric conditions was very good, temperature was stabilized + 14 ºC during the measurement.

For loading was used 10 trucks, each with weight 16 ton. Maximal loading in particular phases reached 160 ton. The trucks were step by step placed symmetric to the longitudinal bridge axis, five trucks on each side, in closeness of the anchoring singular cables (fig. 3). In first position of the loading were trucks centred near the longest cable – No. VI, in the second position near the middle cable – No. IV and in the third position near the shortest cable – No. II.

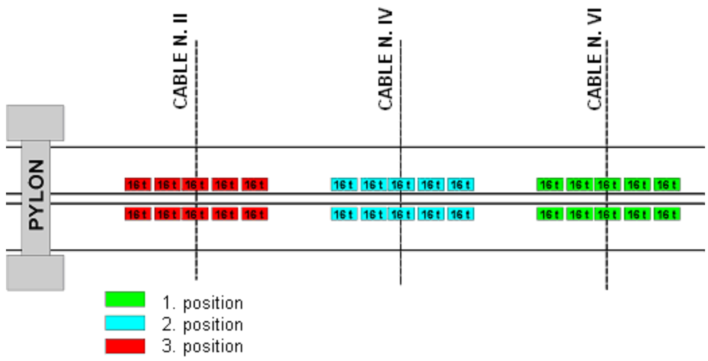

Fig. 3. Scheme of the truck position during the loading test.

The loading test consists of three loading positions distributed to several phases. In all loading position were done two initial “zero” readings (bridge without loading), two readings at maximal loading near the cable and one zero reading at entire unloading bridge.

During the loading test made in night hours at first was staked out in the first position of the telescope the spatial position of each prism and then exactly pointed to the middle of the prism by ATR function. For each measuring point were done three measurements. All measured data were registered to the instrument’s memory card,

whereas value of calculated elevation difference to measuring point was parallel noted to data record sheet. From the differences of vertical differences in individual positions and phases of the loading were calculated the vertical displacements, with the estimated accuracy from 0.3 mm to 1.0 mm.

Maximal deformation was registered on points 61 and 62 namely in the case of loading the bearing structure in the place of the cable No. VI anchoring. The brace in near the pylon evocated, in effect of loading of the structure near the cable No. VI, IV and II the measuring points 1 and 3 allocate positive deformation values (Fig.4).

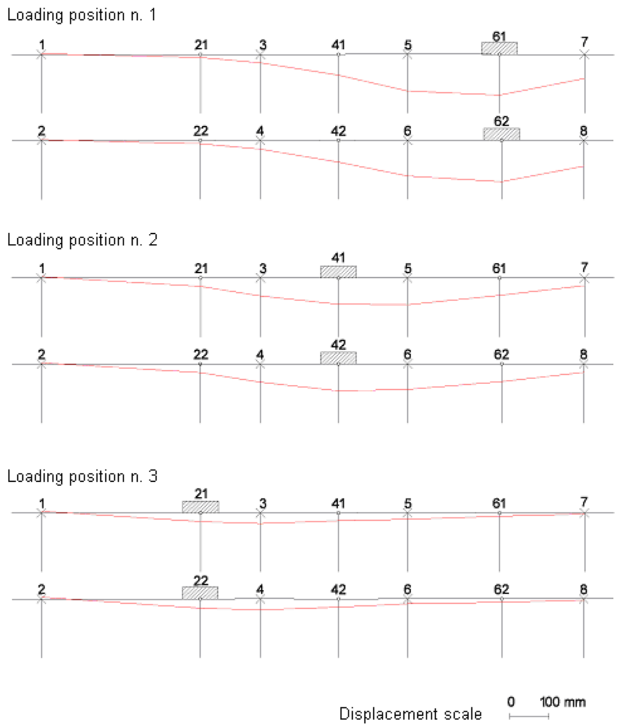

Fig. 4. Graphical presentation of vertical deformations.

2. MEASUREMENT OF THE APOLLO BRIDGE

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

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.

2.1 Automated measurement system development

The measurement system was designed according the bridge structure. The geodetic part of the system 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. 5). The angel measurement accuracy is given by 0.05 mgon, distance 0.6 mm + 1 ppm (Leica Geosystems, 2010).

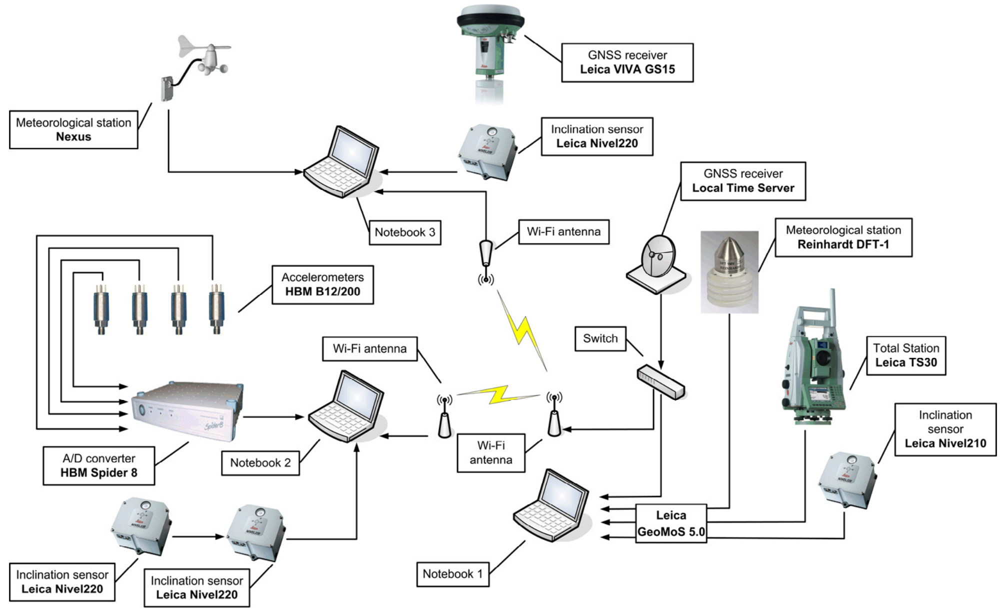

Fig. 5. Components of the automated measuring system.

Other components of the geodetic system part are inclinometer sensor Leica Nivel 210, meteorological 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). The meteorological 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 were connected to the personal computer and the date from stations and sensor were 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 up to 100 Hz and measuring range up to 200 m/s^2. The relative accuracy of the sensors is defined by ±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 msec. 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.

The total station was installed on the control network point (observation pillar VB16) situated on the river bank. 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. 6). 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. The GNSS reference receiver Leica GPS1200+ was situated on the roof of the Slovak University of Technology building 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.

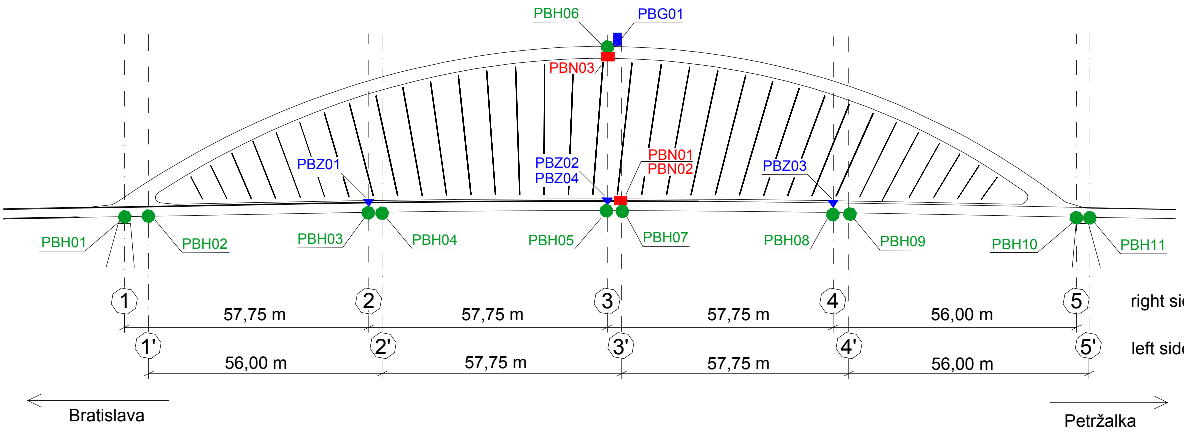

Fig. 6. Cross section with localisation of the observed points.

2.2 Data acquisition and processing

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 horizontal displacement of the top of the bridge 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. Resulting the 24 hour measurement are time synchronized data sets from total stations, GNSS, inclination and acceleration measurement and meteorological data.

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.

The most important for the data analysis is the air temperature influence (Fig. 7). This effects both the volume and the dynamic of the bridge structure in longitudinal direction. The horizontal deformation in „Y" direction is relative small, 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 maximal deformation was measured 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 is effected by both the air conditions and the traffic, also.

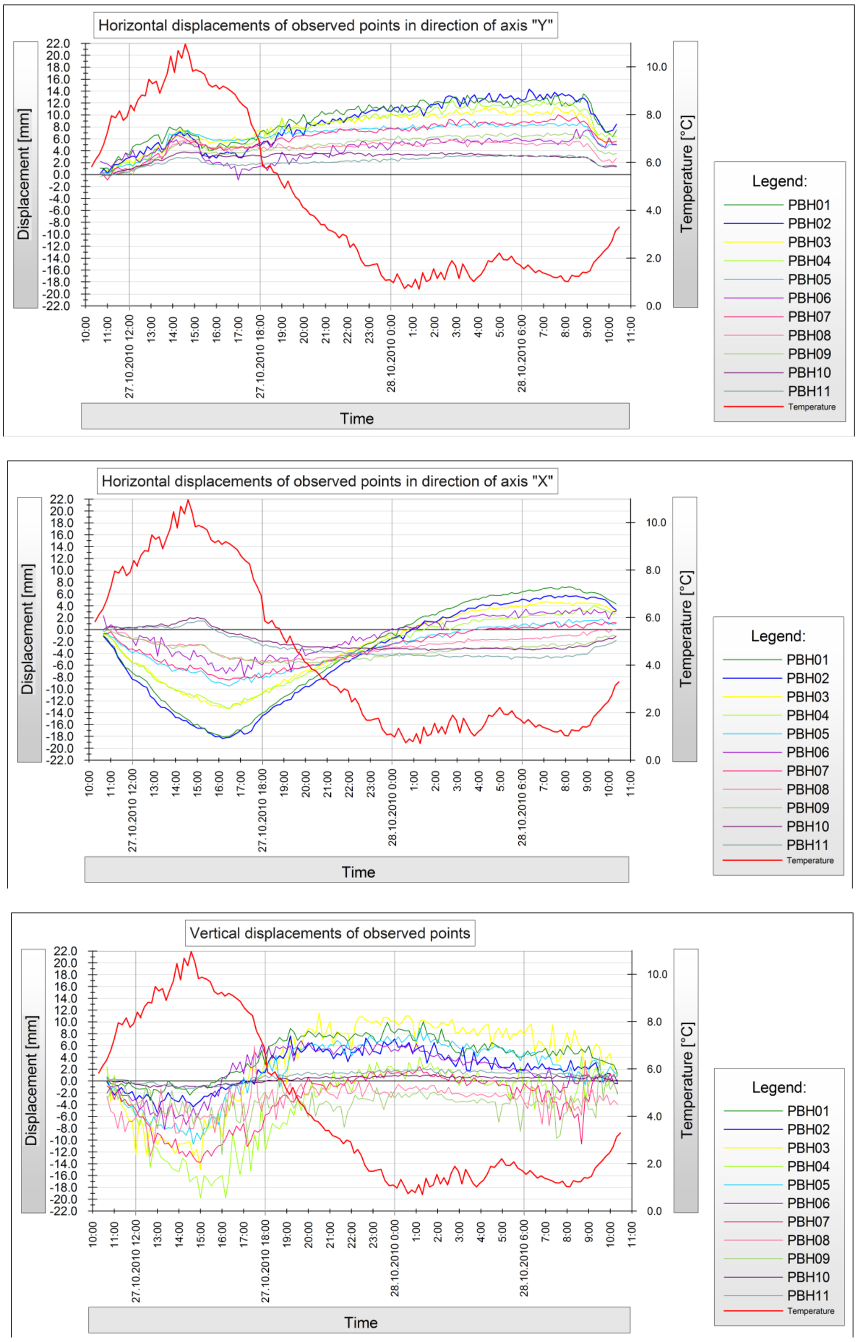

Fig. 7. Bridge deformation in measured points.

3. CONCLUSIONS

The paper presents results of the ATS testing for long term monitoring of bridges. The aim of the experiment realised on the Apollo Bridge 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.

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