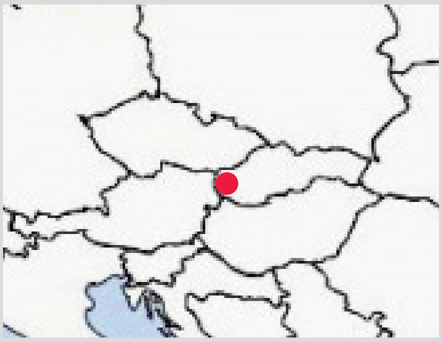
Leica Geosystems TruStory

Automated Deformation Monitoring
Apollo Bridge, Bratislava, Slovakia

- **Company**
  Department of Surveying of the STU Bratislava
- **Challenge**
  Deformation due traffic load and external conditions (e.g. temperature)
- **Date**
  October 2010
- **Location**
  Bratislava, Slovakia



- **Project**
  Instruments
  Leica TS30
  Leica Nivel200 Series
  Leica Viva GNSS
  Meteo sensor
  Software
  Leica GeoMoS
  Data logging software
- **Objectives**
  - 3D determination of bridge deformation
  - Measurement of bridge deck vibrations using accelerometers
  - Synchronisation of system components
  - Feasibility study for the long-term monitoring of all bridges across the Danube in Bratislava

The Apollo Bridge is one of five road bridges across the Danube in Bratislava, connecting the centre of the city with the district Petržalka. The traffic load and temperature changes cause deformation of the bridge structure. In addition, the use of the developed automated measurement system (AMS) for long term monitoring allows the Department of Surveying of the STU Bratislava to determine actual information about the deformation of the main structure in real time. The AMS consists of the Leica TS30 high-precision total station with Automated Target Recognition (ATR), a Leica Viva GS15 and GPS1200+ GNSS receiver, and a Leica Nivel 220 inclination sensors as well as accelerometers.

One of the main safety tasks of civil engineering structures is the measurement of deformation. The modern and often very complex structure of these objects underlines the importance of high accurate measurements of their movements.

Bridge Structure
The Apollo Bridge is one of the most important transportation corridors in Bratislava, the capital of Slovakia. The traffic load, the changes Danube water level and many other factors influence the basic function and safety of the bridge. The steel bridge has a total length of 517.5 m and consists of eight sections; the main section is an arch steel structure with a span length of 231.0 m and an arch height of 36 m.

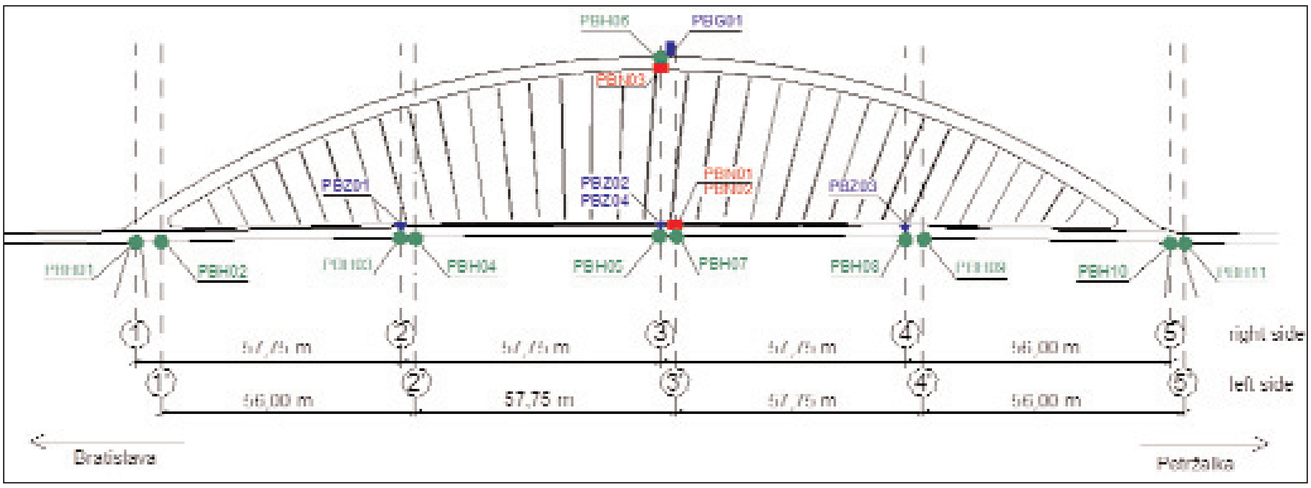
The main structure of the bridge consists of two steel arches and the deck. The bridge deck consists of 6 sections with spans of 52.5 m, 2 x 61.0 m, 63.0 m, 231.0 m and 49.0 m, separated by dilatations and supported by 5 bridge piers. Only one of the piers supporting

Benefits

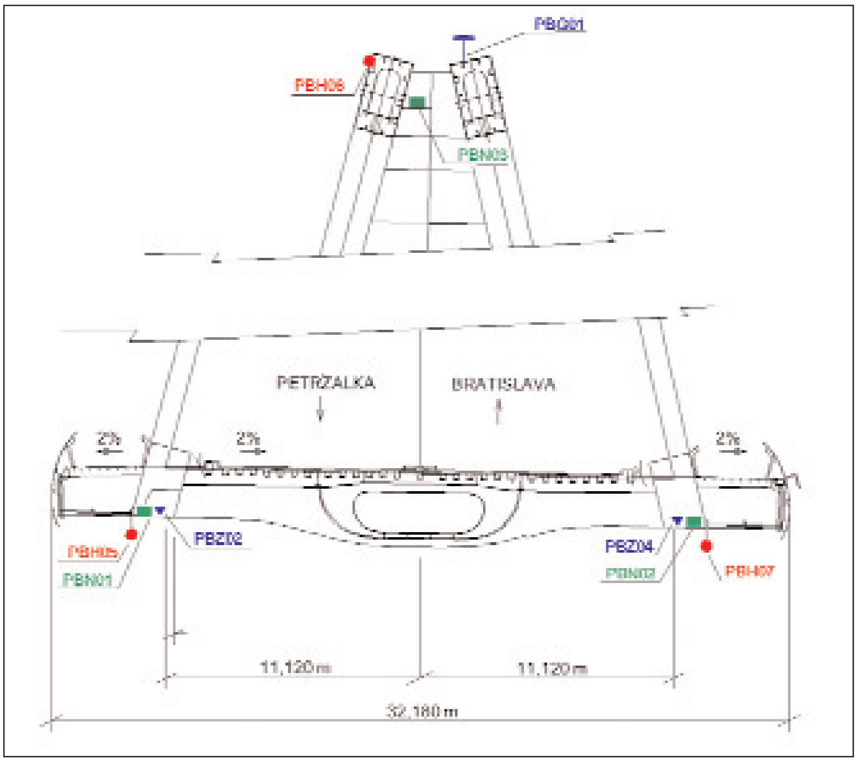
- Real Time 3D Monitoring
- Easy Monitoring Configuration
- Effectiveness of measuring real time deformation
- Robust sensors suitable for permanent monitoring

the bridge floor is positioned in the river. The top of bridge arches is 36.0 m above the bridge deck. The main bridge deck with arches was constructed on the river bank and then moved (rotated) to the final position over the piers and crossing the river. This operation of 36 hour duration was fully navigated and monitored by geodetic technology.

Monitoring System Setup
The measurement system was positioned according to the geometry of bridge structure and consists of geodetic and geotechnical sensors connected to the Leica GeoMoS software. The geodetic sensors are a motorised Leica TS30 high-precision total station, and GNSS receivers; Leica Viva GS15 and GPS1200+. The measurement system was completed by Leica Nivel210 inclinometer sensor, a Reinhardt DFT-1 metrological station, and 13 standard prisms (GPR1) from Leica Geosystems. The angle and distance measurements were made by Leica TS30 using Leica GeoMoS and the ATR function every 10 minutes in two faces with automated data acquisition. The inclination sensor controls the stability of the total station position on the pillar. All three devices are connected to the personal computer and the measurement data is sent directly to the computer with the Leica GeoMoS Monitoring software installed, which is also used for controlling the measurement cycles and data processing in each 146 epochs. The Leica Viva GS15 and GPS1200+ use GPS (NAVSTAR) and GLONASS satellite signals. The second part of the system comprises of two Leica Nivel 220 inclination sensors and four 1D HBM B12/200 accelerometers. The measured data is registered with 1 Hz and 10 Hz frequency. The homogeneity of data and synchronisation of the notebook time are achieved by using special time server LTS, which use the GPS time signal from GPS satellites. The accuracy of this time signal is ± 5 msec and the time signal from LTS is transferred via WiFi antennas with 5 GHz operation frequency.



Longitudinal section with observed points.



Cross section with observed points.

Automated Monitoring of the Bridge Structure
For 24 hours, between the 27th and 28th October 2010, automated monitoring was used to measure the bridge. The aim of the bridge monitoring was to determine:

- 3D displacements of observed points, positioned at the bridge floor and at the top of bridge arch measured by total station,
- horizontal displacements of the observed point on top of the bridge arch measured by GNSS sensors,
- longitudinal and cross inclination of the bridge measured by inclinometers,
- vertical vibration of the bridge deck measured by the accelerometers.

The stability of the pillar, with the Leica TS30 mounted on it, was controlled by measuring to the neighbourhood control points situated on the riverbank. The measurement results were corrected taking the inclination of the pillar into account and all measured values were sent to be processed by the Leica GeoMoS software. The accuracy of the 3D position for the observed points was less than 1.0 mm.
The GNSS Leica Viva GS15 was to static mode measurement and receiving data at an update rate of 1 Hz was used to determine the horizontal displacement of the top arch. All the data was stored in the internal receiver's memory (SD memory card). The Leica Nivel220 inclinometers, registered with 1 Hz frequency were used to determine the longitudinal and cross inclination of the bridge. The vibration of the bridge deck was monitored by one-axial accelerometers HBM B12/200 (in vertical direction) with a sample rate of 10 Hz.

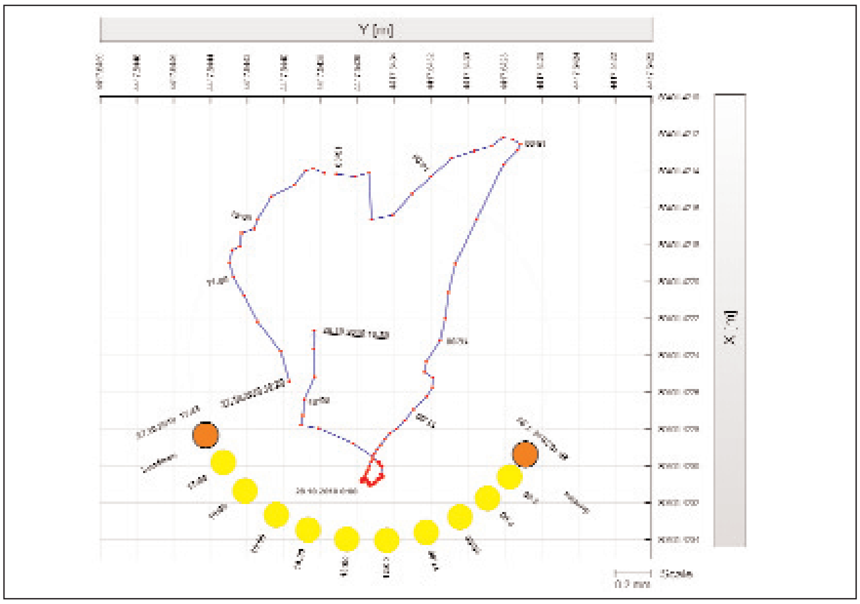
Data Processing and Results
The results of the 24 hour measurements were time synchronized data sets from total stations, GNSS, inclination sensors, accelerometers, and meteorological data. The horizontal deformation in the perpendicular direction to the bridge's roadway (Y) was relatively small; the most intensive changes were registered on the 28th October 2010 at 09:00, this was caused by both the sun shine and the traffic load. The biggest deformation was registered at the point PBH02 with an absolute value of 14.2 mm. The deformation in the parallel direction to that bridge's roadway (X) indicates a trend of the movement of the structure according to the temperature changes. The bridge structure (deck) is fixed at pillar No.10, which avoids the movement of the structure in the longitudinal direction. Pillar No.11, at the left side (Bratislava) of the river bank, is equipped with a joint that allows movement of the bridge structure in the longitudinal direction.
With an increasing distance from pillar No.10 the bridge structure trends to longitudinal deformation, which is mainly caused by temperature changes. The maximum value of 18.4 mm is registered at point PBH02 on the 27th October 2010 at 16:00. The minimum deformation was predicted at points PBH10 and PBH11, which corresponded with


Leica Viva GS15 GNSS receiver on top of the bridge arch.

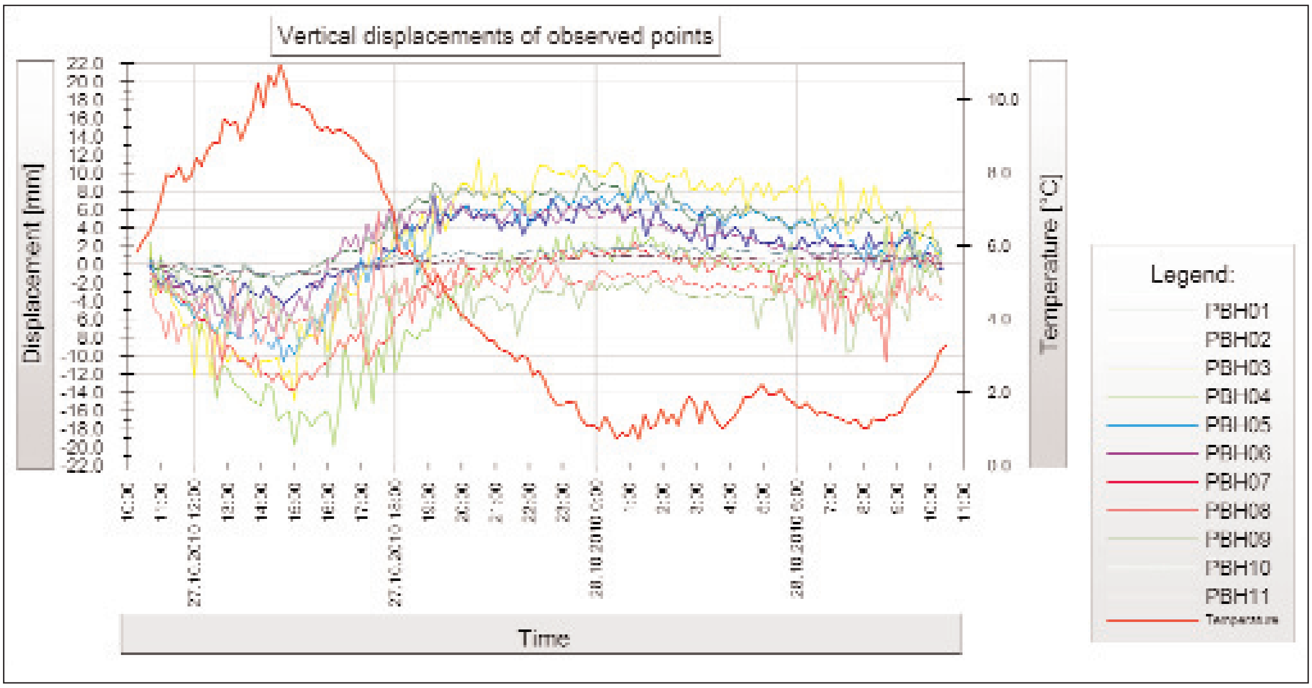
the largest value 5.0 mm registered at these points on the 28th October 2010 at 05:30. The vibration of the bridge deck is described by the measured vertical accelerations. The registered data sets build time series with high variations. The vertical movement of the bridge deck was derived from these data sets in the form of trend curves. Amplitudes, frequency characteristics of the structure were determined using frequency analysis. The maximum amplitude (deformation) of 19.0 mm was measured at PBH04 on the afternoon of the 27th October 2010. Significant frequencies at level of 0.98, 2.18, 2.88 Hz were calculated, which fit together with the theoretical frequency spectrum of the structure calculated by the designer. Different behaviour (response) of the bridge was derived (described) from these data sets according different effects the air conditions and the traffic.

The Apollo Bridge project was used to show the personal (department) responsible for the bridge maintenance the effectiveness of measuring real time deformation from traffic and temperature. The project has proven the use and the feasibility of automatic deformation monitoring systems and we hope that will therefore lead to permanent monitoring of all the bridges on the Danube in Bratislava in the future.

For more information please visit: http://www.svf.stuba.sk/generate_page.php?page_id=3486



Horizontal displacement of obervation point VB16 located on a pillar head.



The graphic shows the vertical displacement of observed points.

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