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Deformation monitoring of Danube bridges in Bratislava by integrated measurement system

Alojz KOPÁČIK

Bridges over the Danube

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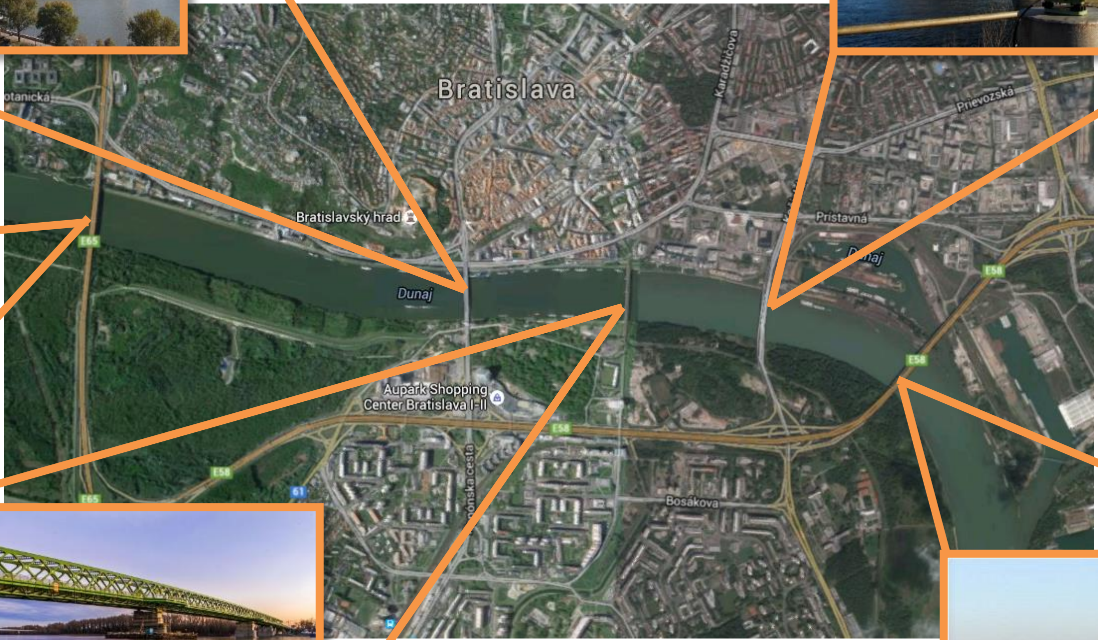
Bridge of Slovak National Uprising

Apollo Bridge



Lafranconi Bridge

Old Bridge

Port Bridge

Research at Department of Surveying

Automated Measurement System Development, 2013-2015,

- Multi-Sensor Measuring System Development
- Synchronisation
- Data Processing

Bridge Monitoring by Repeated Measurements, 2015-2017

- Bridge Health Care
- Methodology
- Data Processing
- Bridge Classification

Research at Department of Surveying

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Bridge of Slovak National Uprising connects the city centre with the city district Petržalka over the Danube, construction began in 1969 and to full operation was given in 1972

The bridge consists from the asymmetric cable-stayed steel structure with one pylon

The overall length of the bridge is 688.4 m and width 21.0 m the pylon is 95.0 m higth

Basic Concept and Requirements

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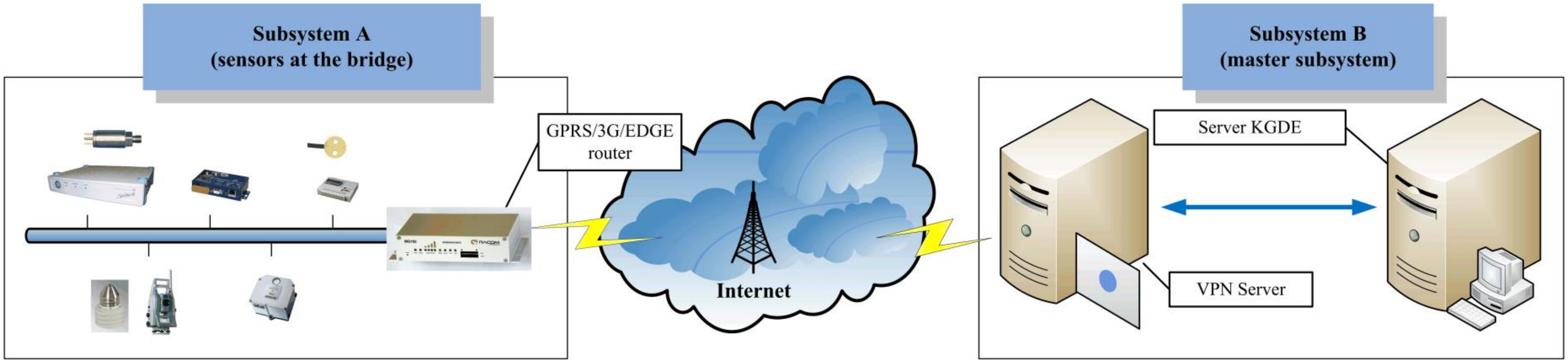

- continuous and time unlimited monitoring of the bridge girder and pylon
- determination of dynamic short-term deformation of the bridge girder, cables and the pylon
- providing an information about the deformation in real time
- remote access and management of the system

Communication solution

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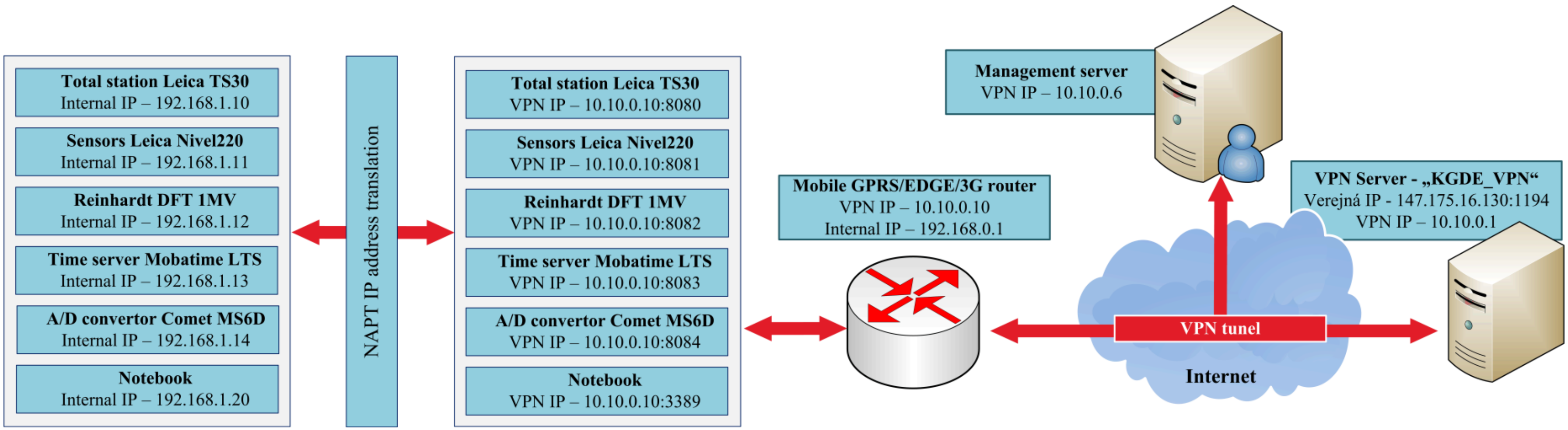

Communication between the systemcomponents

- connection between the subsystems realized by **mobile internet connection**,
- communication by **virtual private network VPN**,
- **each sensor** is identified by own **IP address** in VPN network**,**
- time synchronization by **local time server** with receiving time signal from NAVSTAR GPS satellites**.**

Synchronisation

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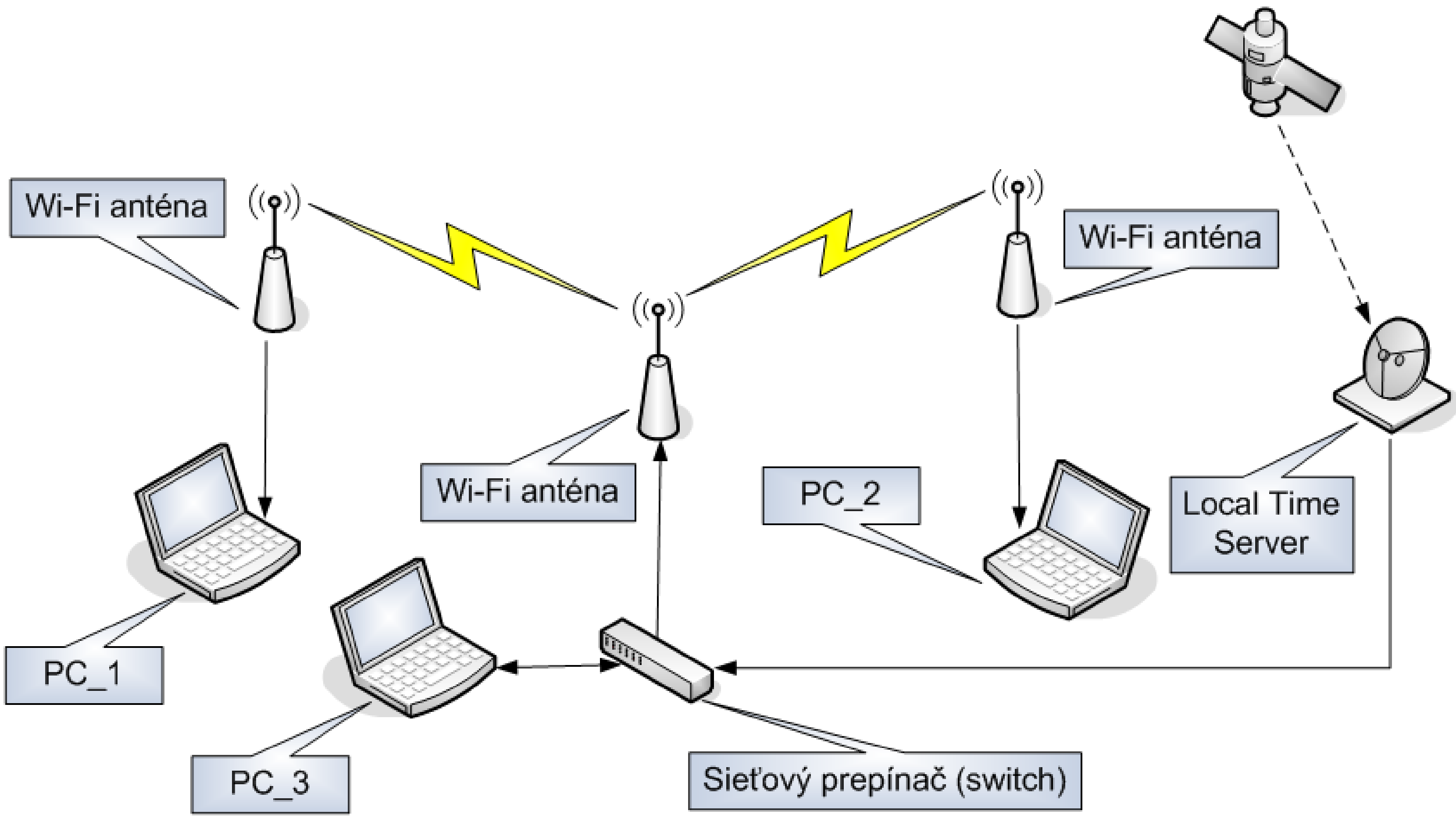

Sensors

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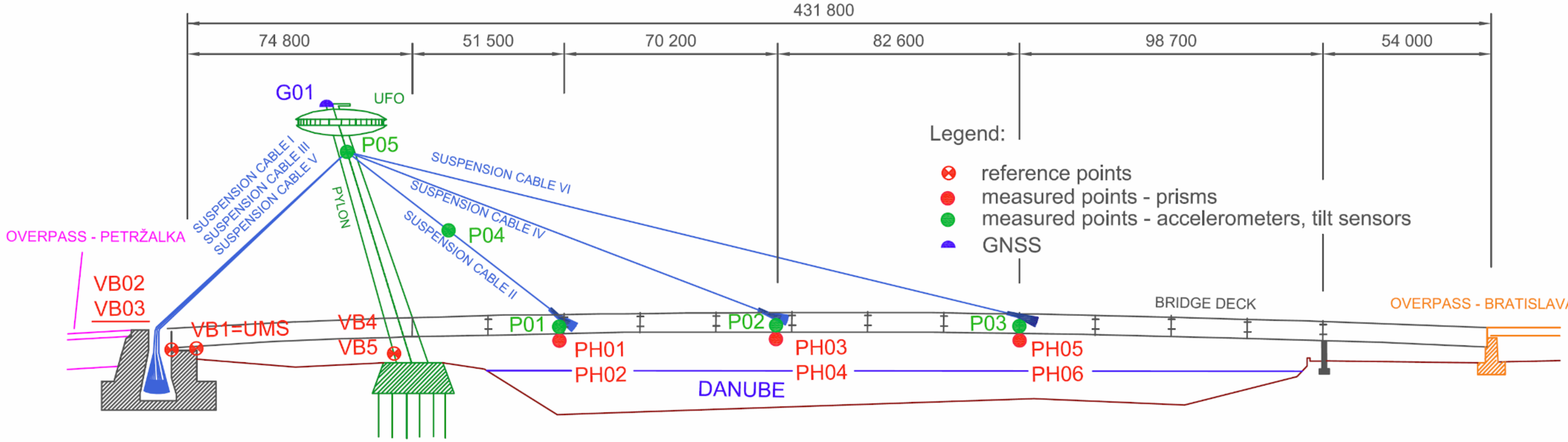

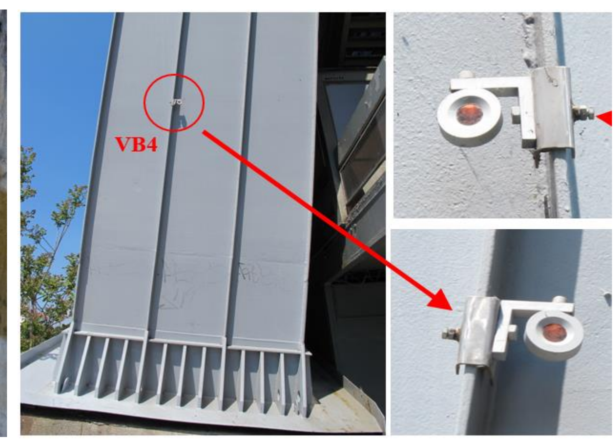

VB1 – total station ***Reference point VB2*** ***Reference point VB4***

Sensors

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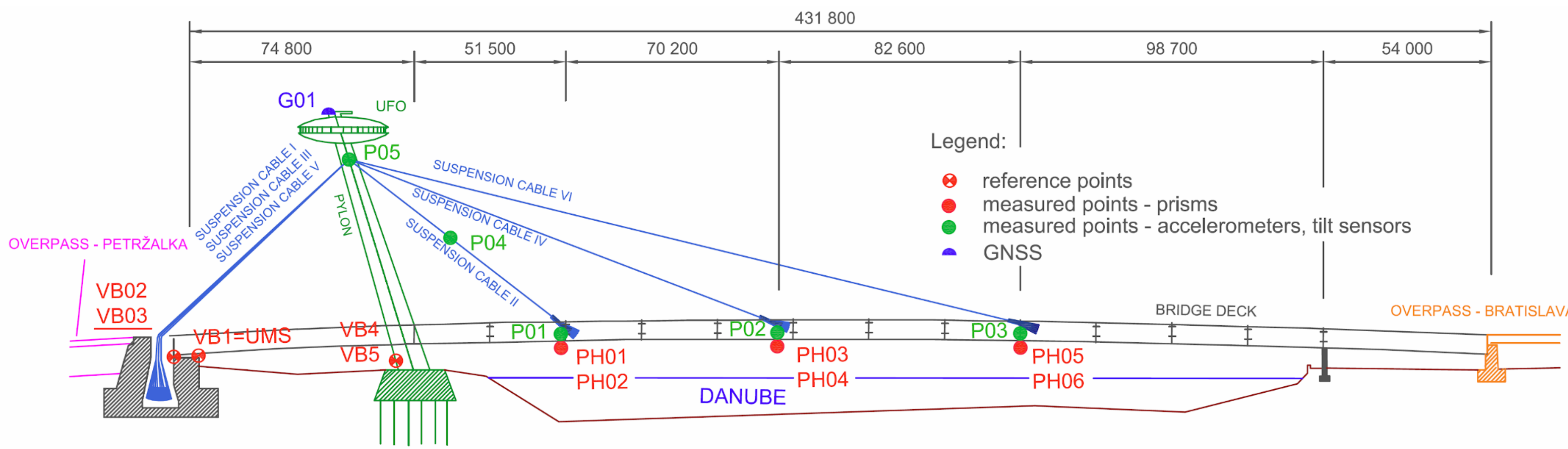
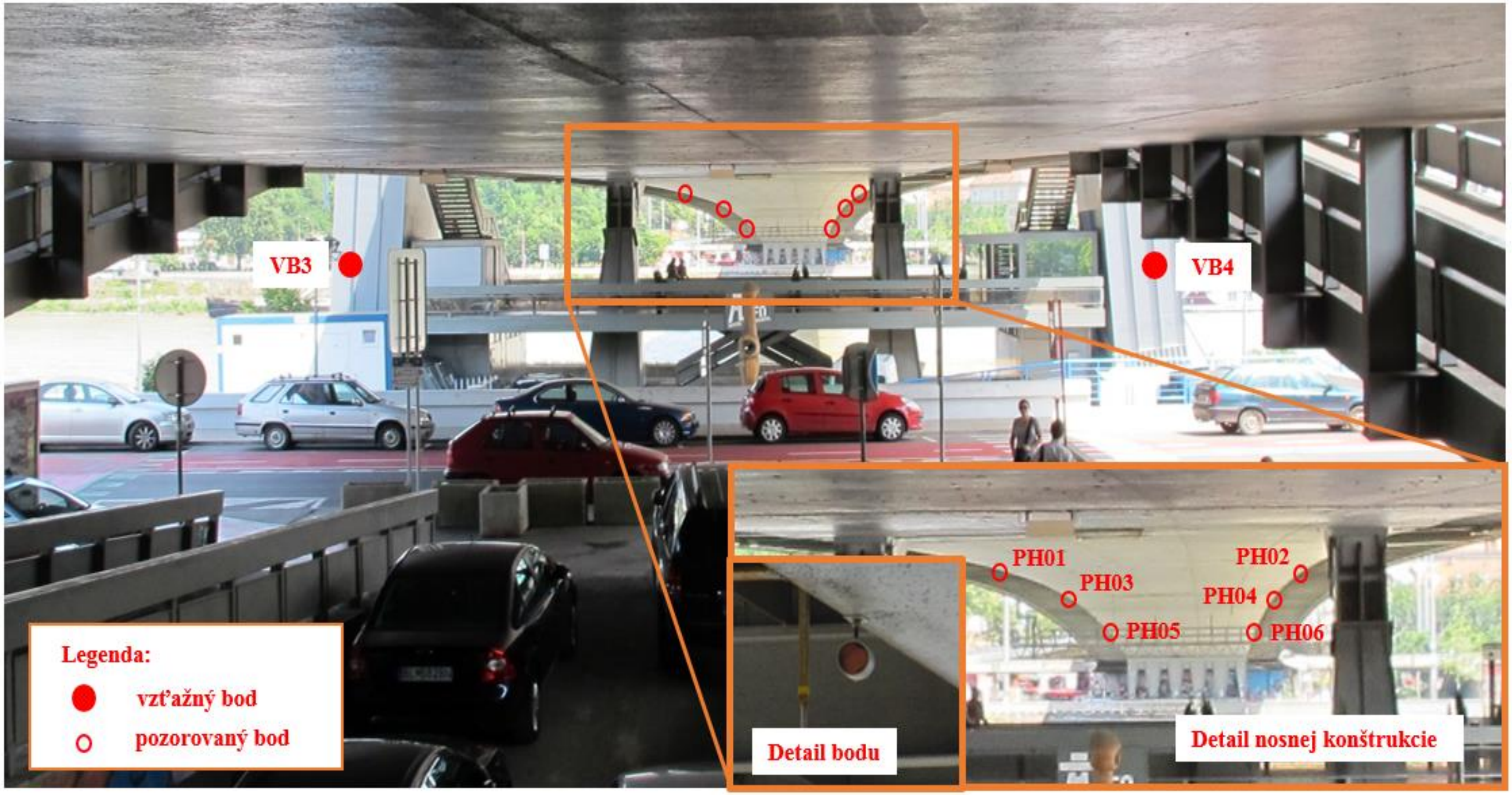


Prisms and sensors

- 6 measuring points (prisms) for measuring of spatial deformation,
- 3 tilt sensors, accelerometers and temperature sensors.

Sensors

- view at measuring points



Sensors

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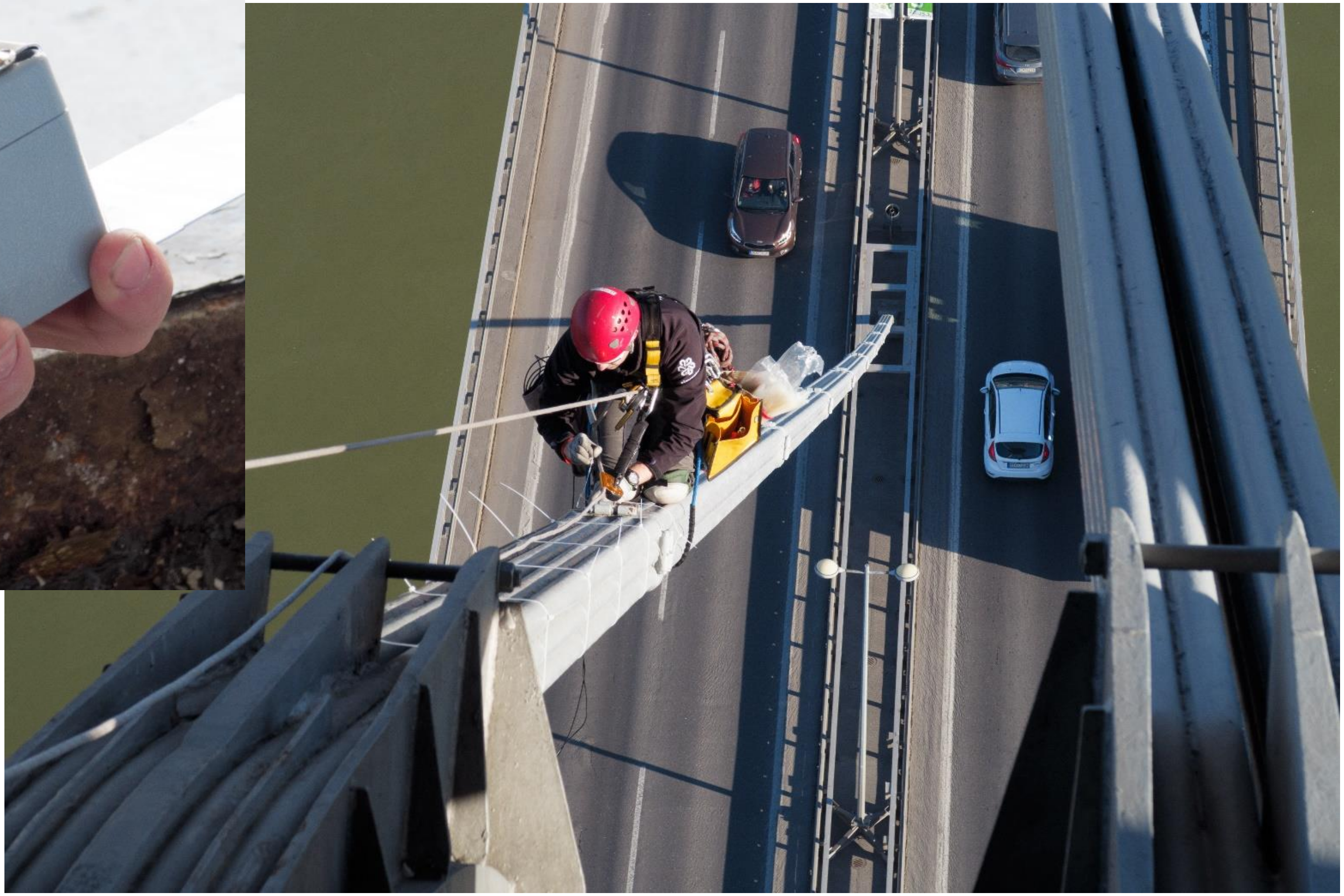
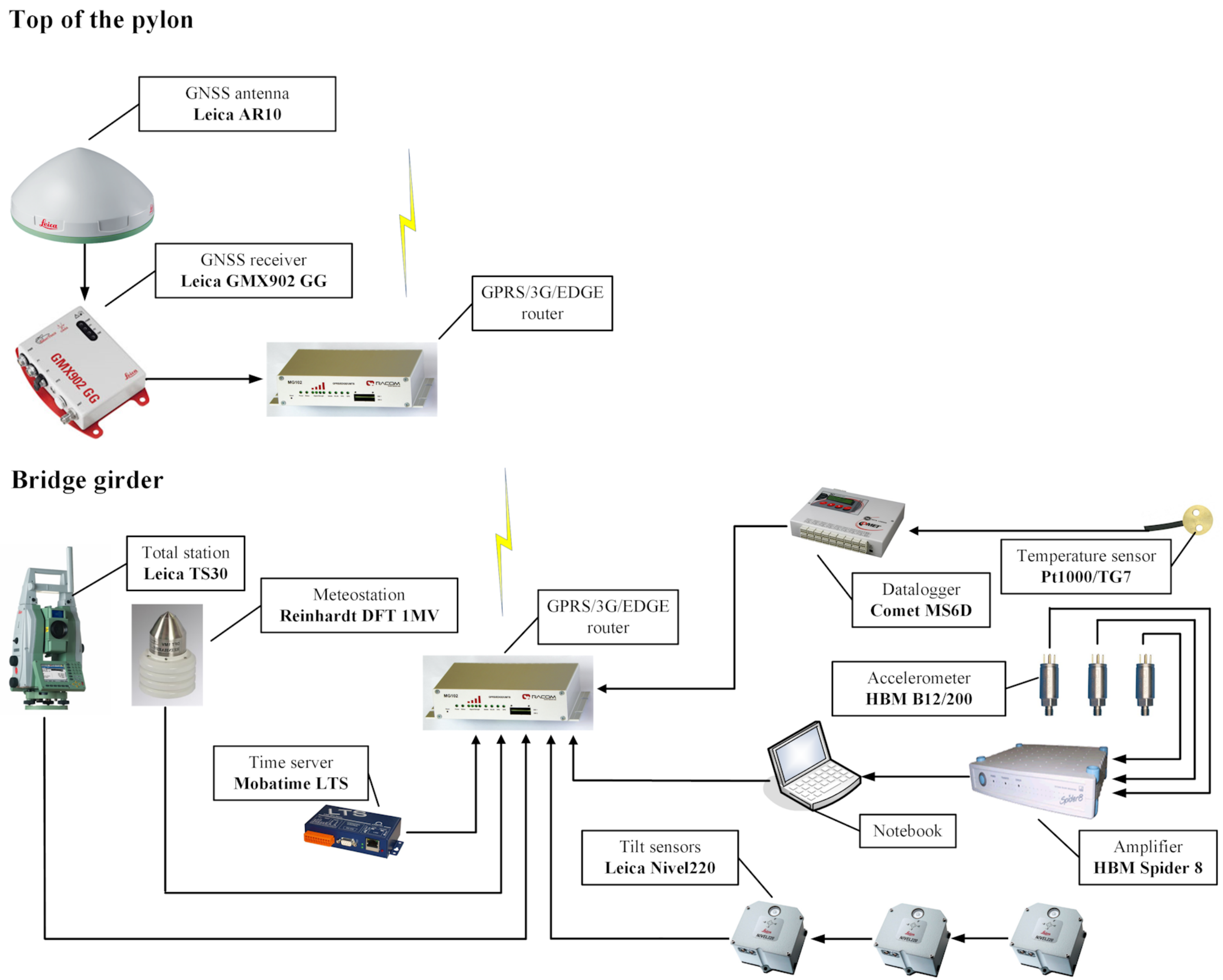
- continuous and time unlimited monitoring of the bridge pylon by GNSS

Sensors



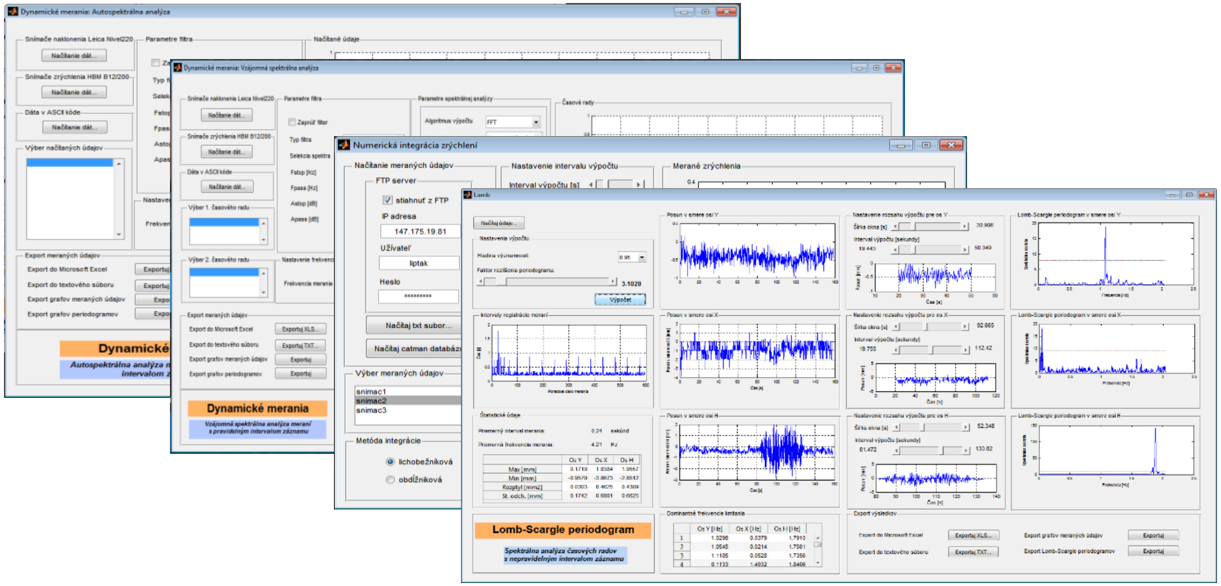
Sensors


Top of the pylon
GNSS antenna
Leica AR10
GNSS receiver
Leica GMX902 GG
GPRS/3G/EDGE
router
Bridge girder
Total station
Leica TS30
Meteostation
Reinhardt DFT 1MV
GPRS/3G/EDGE
router
Datalogger
Comet MS6D
Temperature sensor
Pt1000/TG7
Accelerometer
HBM B12/200
Time server
Mobatime LTS
Notebook
Amplifier
HBM Spider 8
Tilt sensors
Leica Nivel220

Software solutions

Software for remote control and data processing and analysis:

- **TrackingTS30** for dynamic measurements control and management,
- **Lomb** for data processing of dynamic measurements by total stations,
- **DynMer** for auto-spectral and cross-spectral analysis of the measurements,
- **AccInt** numerical analysis of the accelerometer data.



- software with **GUI interface,**
- modules for real-time **data download** from **FTP server** of AMS.

Monitoring

- **Long-term monitoring** .... time domain
  (GNSS, TS, tilt sensors)

- **Short term monitoring** .... frequency domain
  (accelerometers, TS, GNSS)

Long-term monitoring in time domain

- continuous and time unlimited monitoring of the bridge girder deformation by TS
- auto-spectral and cross-spectral analysis of the bridge long-term deformation induced by temperature changes
- processing of tilt measurement data the longitudinal and the torsional oscillation of the structures was determined and compared with the TS data
- using double integration of accelerations (leads to displacements) the bridge girder deformation was determined and compared with TS data

Long-term monitoring in time domain

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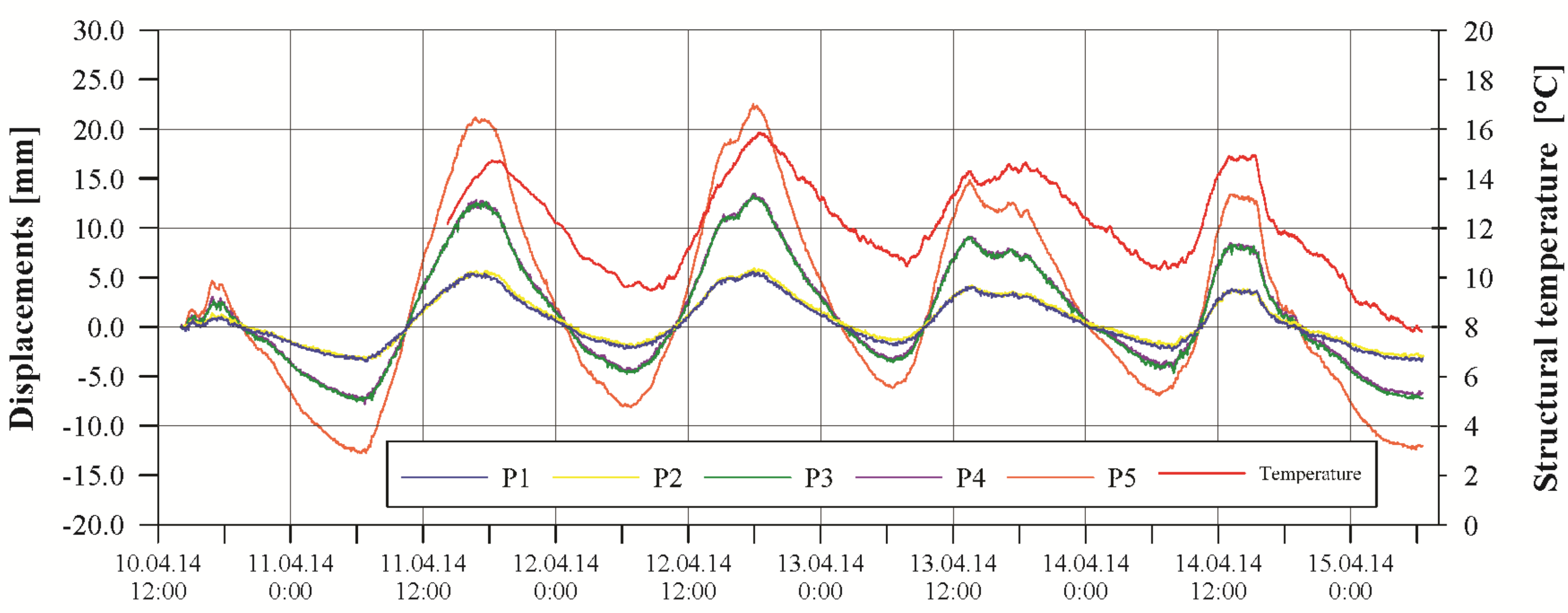
Longitudinal displacements of the structure



- high coherence (at level 0.95) between the structure's temperature
- phase delay of time series describes structural response on temperature changes approximately in 1 to 1.5 hour
- highest amplitudes varies from 10.0 to 18.0 mm
- accuracy of the displacements determined in each direction was 1.2 mm

Frequency domain

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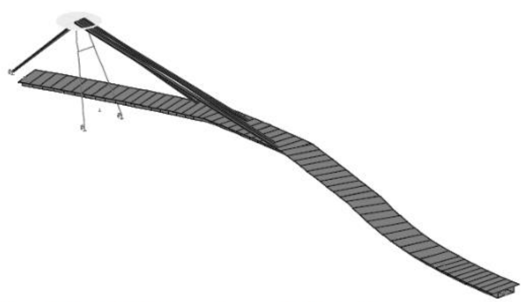
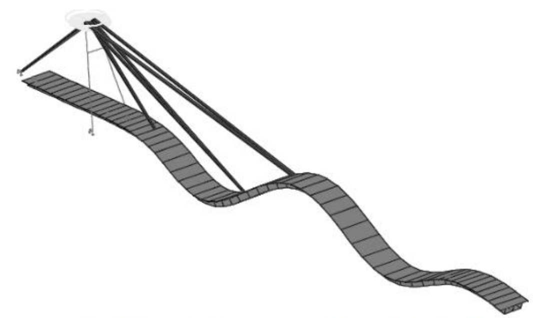
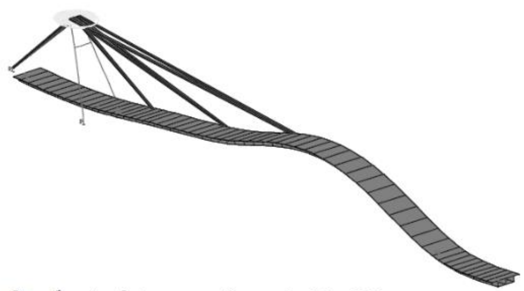
Model frequencies of the bridge structure –
calculated using FEM



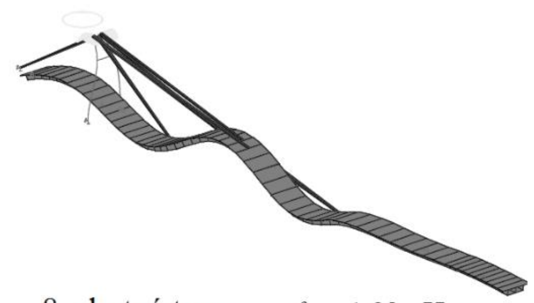
1. vlastný tvar $f_{(1)} = 0.15$ Hz



7. vlastný tvar $f_{(7)} = 1.36$ Hz



2. vlastný tvar $f_{(2)} = 0.41$ Hz

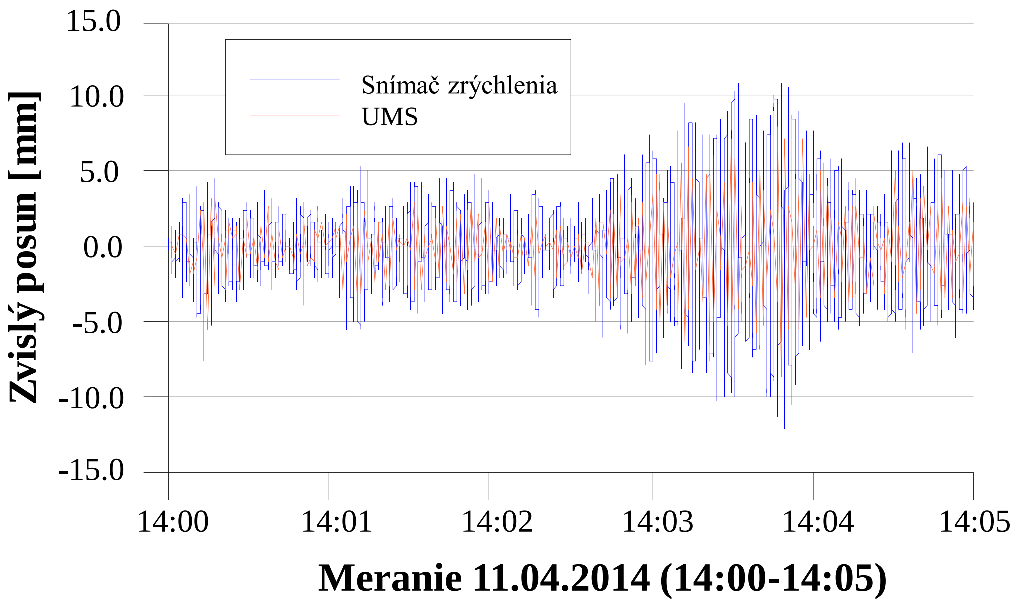


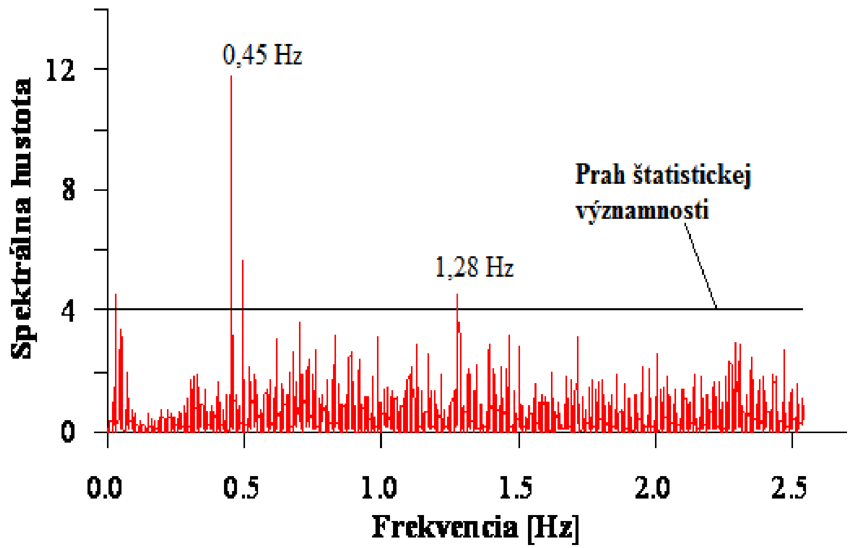
8. vlastný tvar $f_{(8)} = 1.82$ Hz

Frequency domain

- data processing is based on spectral analysis and signal processing, which enable to describe not only the static, but the dynamic behavior of the monitored structure, also
- for data processing of time series is general FFT used
- sensors generate data sets in evenly (time series) and unevenly spaced time intervals (generate by TS)
- for spectral analysis of unevenly spaced data Lomb-Scargle Periodogram (LSP) was used, which produces better results as FFT
- results in the frequency domain contain from two parts – the power spectrum (periodogram) and the phase spectrum of the signal
- cross-spectral analysis of two time series (signals) is used for determination of the cross-correlation (common frequency amplitudes) and the time delay between them

Frequency analysis – TS data





Vibration mode	Frequency calculated [Hz]	Frequency measured [Hz]	Difference [%]
2.	0.41	0.45	8.9
7.	1.36	1.28	5.9

Frequency analysis of accelerometer data

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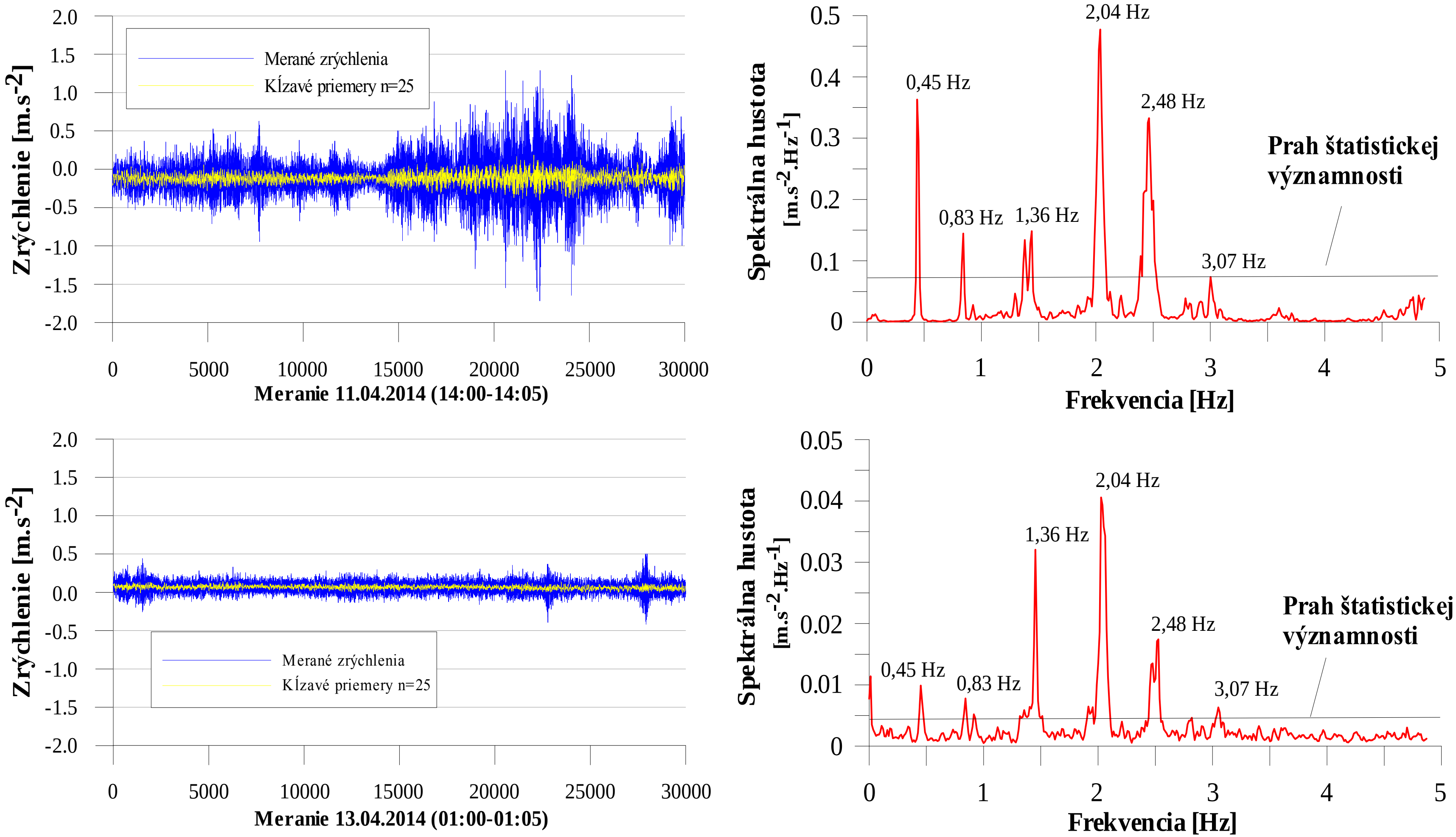

Daily variations of the vibration frequencies

Daily variations of vibration frequencies

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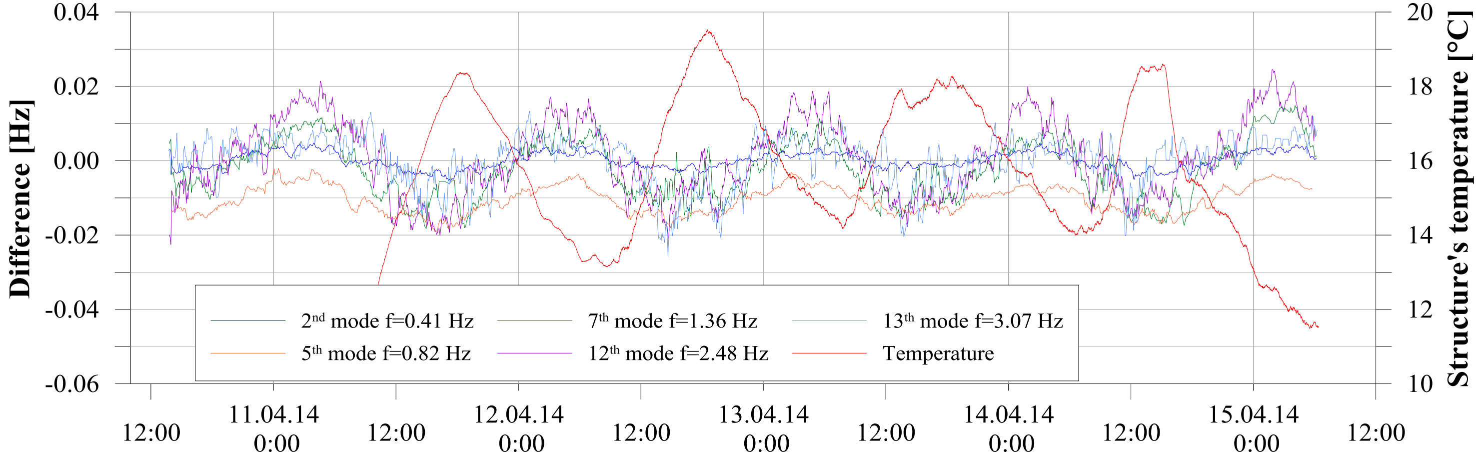

Vibration mode	Frequency Calculated [Hz]	Average Daily Frequency Measured [Hz]	Difference [%]
2.	0.41	0.45	9.7
5.	0.82	0.83	1.2
7.	1.36	1.28	2.9
12.	2.48	2.48	0.0
13.	3.07	3.00	2.3

Conclusion

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- multi-sensor AMS developed, tested by series of 24 hour measurements
- synchronisation (level 0.05 sec), data capturing in real-time, data transfer in side VPN and to the server via IP solved, tested
- data aces, management and processing possible using smart phone
- spectral analysis of unevenly spaced data (generate by TS) Lomb-Scargle Periodogram (LSP) solved, tested, max difference up to 9%
- spectral analysis of time series (acceleration, inclination, GNSS) using FFT solved, tested, max difference up to 3%
- cross-spectral analysis of two signals could be made to determine the common frequency amplitudes and the time delay between signals

Conclusion

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- developed AMS builds part of common AMS developed for 3 Danube bridges with the server and data processing at Department of Surveying FCE
- research suported by 2 research projects (grants)
- during these were one PhD thesis and 2 master thesises finalised at the Department
- in co-operation with the municipality of Bratislava
- next development of the AMS using FOS, only at the 3rd Danube bridge, which was fully rebuild this year

Thank you for your attention!

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Erdélyi Ján, Ing., PhD.,
Peter Kyrinovič, Ing., PhD.

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Programme

Plenary sessions | Social events | The day before | The day after

Programme at a glance

	17 October Tuesday	18 October Wednesday	19 October Thursday	20 October Friday	21 October Saturday
Morning		Opening Session **Plenary session** Technical session	Technical session **Plenary session** Technical session	Technical session **Plenary session** Technical session	The day after **Surf day** or **Green and gold tour**
Afternoon	The day before **Visit to LNEC**	Technical session **Plenary session** Technical session	Technical session **Plenary session**	Technical session **Plenary session** Technical session	
		Conference dinner	*Walking tour in downtown Lisbon*	Closing Session	

Plenary sessions

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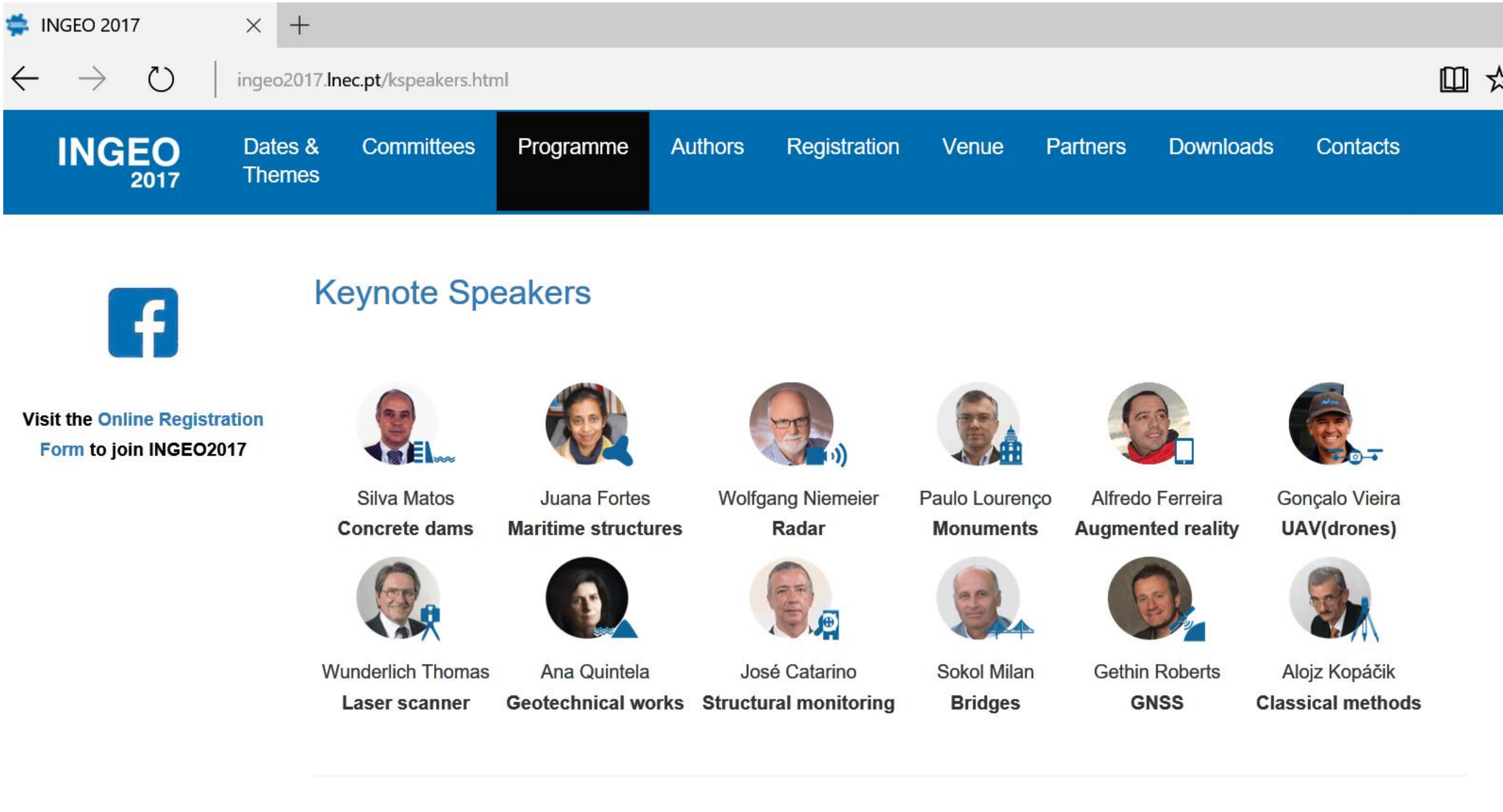

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Important dates

	Peer reviewed papers	Non peer reviewed papers
Abstract submission deadline	15th February	30th June
Notification on paper acceptance	25th February	25th July
Paper submission deadline	30th April	1st September
Deadline for reviewers	30th June	
Final paper submission	1st September	

Papers not send by September the 1st will not be included to the conference proceedings

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