Deformation Measurement of Railway Bridge Abutment Pier

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SUMMARY

The paper presents experience and results from the five years monitoring of a railway bridge abutment pier with non-stable basement structure. GPS as well as some of the classical terrestrial geodetic measuring techniques were employed here with aim to assess the nature, directions and velocities of deformations of the monitored bridge abutment pier and the adjoining railway track structures. Discussed are the possibilities of GPS technique applications in deformation surveys. Accuracy evaluation is carried out in comparison with precise levelling and parallactic distance measurement results. Analysed data were acquired during five years monitoring of railway bridge and track deformations on the railway line Brno - Hrušovany nad Jevišovkou, in vicinity of western abutment pier of the Ivančice viaduct where deformation effects are inducing frequent maintenance works.

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1. INTRODUCTION

Department of Geodesy of the Brno University of Technology has been carrying out geodetic deformation measurements of many engineering structures as well as natural objects in recent time, with employment of various kinds of measuring techniques. The activities included e.g. settlement measurements of bridges, tunnels, factory chimneys, buildings, and other civil engineering structures, deformation measurements of dams, industrial machinery etc. Several kinds of measuring technologies were employed –, classical distance and angle measuring methods, EDM, precise levelling, and in last twelve years also the satellite methods. Since 1992 the Department is utilizing the GPS technology for various surveying purposes, i.e. also for 2D or 3D deformation surveys. Examples are the long term monitoring of surface geometric changes in Czech part of the Králický Sněžník massif, the monitoring of displacements of boulders in western parts of the Krkonoše Mts (Švábenský and Weigel, 2004) and others.

Surveying interests of the Department of Geodesy were from the very beginning of its existence involving the bridge surveying. It was demonstrated in cooperation by many bridge loading tests (e.g. highway suspension bridge at Poděbrady, suspension bridge at Tábor and others). One of the most interesting bridges in Czech Republic is the Ivančice viaduct over the valley of Jihlava river in central Moravia, near Brno. We have been carrying out the check surveys of the bridge steel construction parts, and the setup measurements during construction of the new bridge in years 1975 – 1977. Later we took part in various activities concerning the structure monitoring. Department of Railway Structures and Constructions of the Brno UT had also took part in solving of problems which are connected with this structure for many past years, e.g. by cooperation on design of improvement measures which had to increase stability of the adjoining earth filling on western side of the bridge where frequent changes of railway track geometric parameters occured.

Long term problems in maintenance of the construction and geometric rail relations in the vicinity of the western abutment pier brought i.e. decision to start the geodetic monitoring of the pier and the adjoining railway structures. On grounds of lasting movements the Brno University of Technology started the geodetic monitoring in 1999, which partially followed on some previous measuring activities. Epoch deformation measurements are going on for five years up today.

2. IVANČICE RAILWAY BRIDGE STRUCURE

The Ivančice viaduct is located at km 130,187 of the railway line Hrušovany on.J. – Brno, about 20 km southwest from Brno, overcoming the deep valley of Jihlava river. Original viaduct was builded in years 1868 - 1870 as steel continuous carrier construction with 6 spans of total length 373,5 m. But already in 1876 the displacement measurements of western abutment pier had begun. In years 1972 – 1976 the new viaduct was constructed paralelly to the old bridge in 15 m distance to the south. The new one-track bridge parameters are: height 44.5 m above river level, foundations of reinforced concrete up to 20 m deep on piles, 5 steel pillars, and 6 spans with total length 387 m. The structure is formed by steel chamber continuous carrier of trapezoidal cross-section, with directly embedded railway track.

Fig. 1: Distortions of Rail Geometry

In 1978 the bridge was put to full operation. Nevertheless, the problems in stability of western end of the new bridge appeared soon after. Main problems are caused by different foundation conditions of abutments. While the eastern abutment pier is founded in solid bedrock without any functional defects, the western abutment pier shows problems from the very beginning of the viaduct operation up to the present. Adjoining earth filling is up to 23 m high here. The deffects are manifested by railway track settlement and distortions of rail geometry, with frequent needs for maintenance works (Fig. 1).

From the geological point of view there are many factors which are probably taking part in the unstability of the pier and the adjoining earth fill. Hydrogeologic situation is very complicated here. Layers of washed loess loam and drift loess which abound here are lacking the absorptivity. On the other hand sediments composed of sands, gravel sands and rockfall are showing high degree of absorptivity, and with direct connection to the river bed they are functioning as regulators of surface water flowing. Another possible causes are the shocks and vibrations coming from railway traffic. In loess and less consolidated sands the intergranular bonds may be broken with consequent decrease of consistency, and in the sands and sensitive sand clays the shocks may cause sudden increase of fluidity. Probable causes of the area non-stability could also be: the erosive activity of river Jihlava, tectonic lability of the area, infiltration of fine-grained sands into the broken bedrock, volume changes in thick loess layer, or irregular settlement of the earth fill body.

In previous time various geotechnical measures were adopted to increase the stability and to stop the deformations. At foot of the fill the double row pile wall 75 m long with pile bores 14 m deep, with pile heads joined through reinforced conrete plate was constructed. Another measures were the improvement works covering the reconstruction of existing drainage on left side of the track in total length 150 m, and the installation of new construction layers in the upper railway track body in 90 m length using hydroinsulating materials like geomembranes and geotextile. Neither of these measures did remedy actively the deformation causes which are manifesting in continued shifts of the abutment pier and in settlement of the adjoining earth fill body.carrying the railway track structure(Zvěřina 2001).

Previous inklinometric and geodetic measurements in vicinity of the abutment pier showed that the pier undertakes shifting during which it is rotating horizontally and at the same time tilting to the west and backwards. Detected and proved was seasonal rocking motion of whole abutment structure.

3. DEFORMATION MEASUREMENT OF THE BRIDGE ABUTMENT PIER AND ADJOINING STRUCTURES

Long term problems in maintenance of the construction and geometric railway track relations in vicinity of the western abutment pier brought i.e. decision to renew and to enlarge the geodetic monitoring of the pier and the adjoining railway structures. Brno University of Technology started the geodetic monitoring in 1999, which partially followed on previous measurements.

Spatial positional changes of the bridge abutment pier, the earth fill body, and the railway track were measured by combination of geodetic and GPS satellite methods. Vertical component had been determined by precise levelling (PL), and horizontal components were measured by GPS complemented with classical terrestrial methods, e.g. angle and distance measurements. Displacements of the fixed points representing both the old and new abutments were performed by static observation procedure. Deformations of the railway track construction were measured by modification of Stop&Go method. All the measurements had been carried out without interruption of the railway line operation.(P)

Vertical displacements were monitored by precise levelling with use of Zeiss Koni 007 levelling instrument and invar levelling staffs adapted for use on rails. The levelling is referenced to benchmark NZ located on building Réna, and to another two benchmarks F1, F2 located at stable surroundings. In each epoch there were measured individual single height differences betwen the benchmarks and marker points so that the loops could be formed and checked by the loop closures. An average loop closure was 0,35 mm, an accuracy of a single height difference was about 0,1 - 0,2 mm. Final heights were computed by least squares adjustment. Horizontal displacements were determined by trigonometric method, with measured angles and distances. Directions were measured with precise optical instruments Zeiss Theo 010A and total stations Leica TC1700, Topcon GTS-6A. Some of the distances were measured by parallactic method with 2 m subtense bar. An accuracy level of horizontal positions of markers was about 2 - 3 mm.

GPS measurements were tied to station V located on the stable eastern abutment of the old bridge in 400 m distance over the valley, and to permanent EUREF station TUBO located at Brno University of Technology in 20 km distance which operates Trimble 4700 receiver equipped with Trimble choke ring antenna (TRM29659.00). Local reference was at station SO located on western abutment of the old bridge where Leica SR399 receiver/antenna was used until end of 2003. Since 2004 the station was measured with Leica SR502 receiver equipped with AT504 choke ring antenna which is much more resistant to multipath and similar disturbing effects. Another two markers NS, NJ are located on abutment pier of the new bridge, and additional markers R1, R2 are situated at the southern side of the earth fill crest. Fig. 2 shows the view of the Ivančice viaduct from west, and Fig. 3 shows the surroundings of the local reference station SO with AT504 antenna on special short tripod for reduction of centring errors Behind is the monitored abutment pier of the new bridge.

Sixteen epochs of deformation surveys since 1999 are completed by now. Three Leica 299/399 dual frequency receivers were used in early epochs. Since 2001 two Leica SR520 receivers with AT502 antennae were also used. Static intervals were of several hours duration. All measured data were reprocessed recently with commercial software Leica SKI-Pro v. 3.0, and parallelly also with scientific Bernese GPS software v. 4.2. Alternative processing of GPS data had been performed (L1, L1+L2, L3 with ambiguities fixed). Combination of GPS and classical terrestrial surveying methods permitted to carry out some comparisons and evaluations of real GPS accuracy. GPS horizontal positions and height differences in each epoch were compared with results of classical horizontal surveys, and with precise levelling.

Fig. 2: View of the viaduct

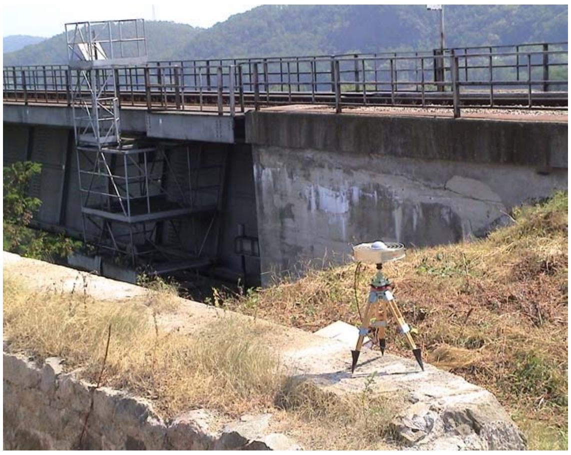

Fig. 3: Local GPS reference station SO

For horizontal components the accuracy was estimated with help of the EDM and the parallactic distance measurement results. Parallactic distances between markers R1, R2, SO were measured with accuracy better than 0,5 mm. Standard deviation of the differences between GPS and paralactically measured distances was cca 3 mm. EDM distances were measured with accuracy 2-3 mm + 2 ppm. Standard deviation of the differences between GPS and EDM distances was cca 4,5 mm.

Comparison of vertical displacements computed from PL heights and GPS height differences yielded following standard deviations which can be considered as indications of real vertical GPS accuracy: average std.dev. 2,8 mm and max. dev. 6,0 mm (L1), average std. dev. 2,6 and max. dev. 5,8 mm (L1+L2), average std. dev. 8,1 mm and max. dev. 12,2 mm (L3).

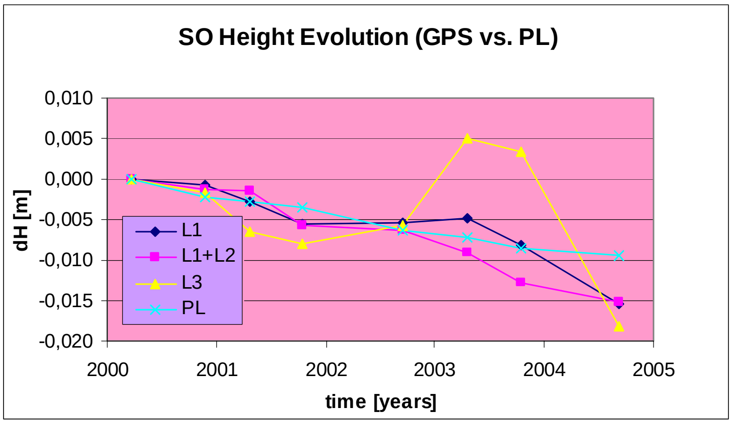

Fig. 4: Vertical displacements of station SO (GPS vs. PL)

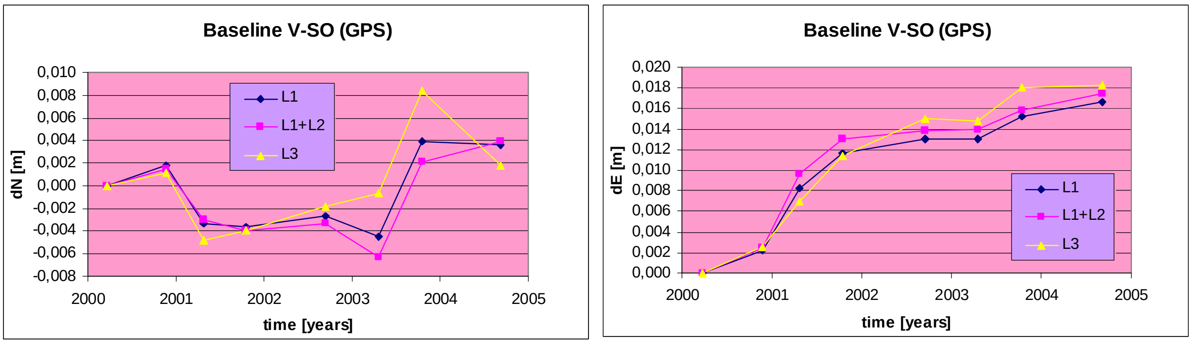

Fig. 5: Evolution of baseline V-SO components dN, dE

Fig. 4 shows the time evolution in height of the reference marker SO which is situated on western abutment pier of the old bridge. Results of precise levelling and GPS (L1, L1+L2, L3) solutions are compared. GPS heights were determined in respect to reference marker V in 400 m distance situated on the other end of the bridge. Differences between commercial and scientific software results were negligible in this case. Best results gave L1+L2 processing, L1 results were almost on the same accuracy level. L3 results were of significantly lower accuracy here what wass caused by practical elimination of the ionosphere effect for neighbouring stations, and by higher noise level on L3 frequency combination.

In Fig. 5 the time evolution of baseline V-SO horizontal components components dN, dE from three alternative GPS solutions (L1, L1+L2, and L3 with previously fixed ambiguities) are shown. L3 combination gave somewhat better results here in comparison with L1 or L1+L2 processing. Nevertheless, again best was the use of L1 or L1+L2.

Railway track deformations were measured by GPS Stop&Go method. Object of measurements was the section of railway line 120 m long in vicinity of the bridge western abutment. 10 epochs were measured in period 1999-2003, with purpose to determine the actual changes of railway track spatial position induced by traffic or by maintenance works. In each epoch the survey was repeated more times with time separation. Reference station was established at marker SO. Measuring points were marked on rail heads (identical points were measured by precise levelling). Survey of the rail track was enabled by use of a special light antenna carrier (Švábenský 2001). Real accuracy of Stop&Go method was estimated from differences in repeated observations, and from differences PL-GPS. Horizontal accuracies (standard deviations) were under 5 mm (L1), resp. 6 mm (L1+L2) in dN component, and under 4 mm (L1), resp. 3 mm (L1+L2) in dE component. Difference between dN and dE accuracy can be probably accounted for by additional centring errors of the antenna carrier. It seems that L1+L2 processing gives slightly better results than L1 only. Average height accuracy (standard deviation) was better than 8 mm in both cases.

4. CONCLUSIONS

GPS technique is in many cases an interesting alternative to the classical terrestrial surveying methods, with discernible advantages of better operativeness, as well as of lesser time and personnel demands. Even the commercial software products offer still more sophisticated evaluation of GPS measurements. Employing of advanced observation and processing procedures brings the GPS results on qualitatively higher level which is more and more nearing the accuracies needed in deformation surveys of structures (Švábenský and Weigel 2002).

GPS measurements are influenced by many factors among which important role play the uncertainties in phase center positions/variations of the GPS antennae, but also others like multipath and diffraction of satellite signals. Most efficientent practical way to the reduction of inconsistencies in antennae phase center offsets/variations is the special individual field testing procedure which can effectively determine the actual relative correction values for groups of antennae, or for particular combination of two antenna types. Mutual testing of Leica PCO values for SR 299/399 and AT 502 antennae found difference of 12 mm in L2 relative height offset, while the horizontal offsets differ only by few milimeters. After authors experince it is advisable to perform individual tests for every pair of GPS antennae used in the deformation surveys. Strongly recommended is the use of choke ring antennae which are much more resistant to multipath and diffraction effects in varying structural environment. Detection and elimination or mitigation of multipath effects is important especially for shorter observation times, which applies also for diffraction diluted signals. These factors have direct impact on the accuracy and reliability of resulting displacements (Švábenský and Weigel, 2004).

Five years of epoch measurements of positional displacements at Ivančice railway viaduct established fundamental knowledge about the structure behavior in time. On grounds of the monitoring results it can be stated that the southern side of the earth fill shows settlements and shift in transversal direction to the south and east. The settlement is greatest in vicinity of the abutment pier (up to 30 mm/5 years) and with growing distance it is diminishing. The actual pier is slowly sinking (cca –0,8 mm/year) with hints of irregularities, and horizontally it shows rotation and rocking motions of periodic character (Zvěřina Jr. 2001). The nearby abutment pier of the old bridge on the northern side is sinking regularly (-2,4 mm/year).

In last epochs the deformation surveys were extended by monitoring of the earth fill body in vicinity of the bridge which should bring additional informations needed for better understanding the deformation causes.

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BIOGRAPHICAL NOTES

Otakar Švábenský. graduated in 1971 at Czech Technical University in Prague, under the Faculty of Civil Engineering. He worked for a short period as a surveyor. Since 1975 he has been lecturing at Brno University of Technology, Department of Geodesy. First scientific degree (CSc.) in 1987 . Associate Professor since 1993. Czech national delegate for FIG Commission 6. His interests are: satellite geodesy and engineering surveys.

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