Base Deformation Measurement of New Highway Bridge Structures in Slovakia

Štefan LUKÁČ and Milan ŽÁK, Slovakia

Key words: Bridge surveying; Deformation measurement, Highway bridge, Vertical deformations

SUMMARY

This article documents knowledge and experiences from the base deformation measurement of highway bridge structures at highway sector from Horná Streda to Hričovské Podhradie (between Bratislava and Žilina), which were step by step devolved to operation in 1997-2006. Objective measurements create necessary foundation to the inspection of each bridge structure and they are component of complex quality control, eventually bridge diagnostics. At the same time they create a base of created information system of bridge structures in Slovakia.

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1. INTRODUCTION TO THE PROBLEM

Wide sociable value of bridges reflects in responsible transportation and therefore bridge engineering refers to the prominent place in area of building industry. Responsible function of transits and international corridors meaningly depends on quality of bridge structures, which became in recent few years a limited element in road and railway transportation. Special place create highways and therefore also highway bridges. Highway has an international character and is overtimed because of its knot to international corridors and it will serve to transportation several tenth years. It is also a part of transport infrastructure and has to have connections to the railway, combined, aerial and water transport system. Alone construction of highways and highway bridges is one of the definitive activities, which helps to the economic development of the country, by valuation of its territory and in a range of infrastructure is approaching to the level corresponding to the standards of countries of European Union.

2. CONTRIBUTION OF SURVEYOR AT QUALITY CONTROL OF BRIDGE STRUCTURES

Bridge is relatively complicated construction and as by every building work also by bridges are its phases of building up process connected to the concrete place of its permanent function. For qualitative presentation of resultant quality of bridge it is necessary to determine and define quality of individual phases of building up process and to determine ways and physical parameters for its control. Therefore we can divide partial parameters of quality control in each phases of building up process of object into the following gropus, in which also a surveyor meaningly takes part in quality assurance:

- Preparation and designing – quality of bridge suggestion *(contribution of surveyor – preparation of map foundations and purpose mapping of particular territory),*
- Building up process – quality of manufacturing realization *(contribution of surveyor – staking out of bridge structure, inspection of geometric parameters),*
- Operation process – quality of application and maintenance *(contribution of surveyor – deformation measurements of bridge during loading test and long-time periodical deformation measurements during operation).*

By bridge designing analogous to designing of other structures are used general characteristics of bulding material. Therefore for suggestion and building up of bridges have a huge theoretical and practical importance **various special control deformation**

measurements as well as exams realized with various measuring instruments on models or direct at the concrete bridge.

Each new bulding causes soil deformation at its background, which results from deformation of basic soil or its creeping. Suggestive control measurements at models and especially at concrete objects we obtain data about correctness and serviceability of suggested way of building establishment. Results from these control measurements enable beforehand to do design arrangements for deformation decreasing of bridge construction and bridge foundation and to do more precise methods of calculation of construction and foundations.

With control measurements at bridges we verify:
- quality of used building materials,
- function of construction and examination of correctness and assurance of bridge,
- theoretical knowledge about properties of constructional materials and background.

Systematically, professional and in a wide range realized deformation measurements give valued foundations for solution of many controversial questions by foundation and designing of construction and pillars of bridge and essentially increase efficiency of construction.

3. RANGE OF DEFORMATION MEASUREMENTS

Range and content of deformation measurements depends on largeness of bridge, foundations, material of construction and used building technology. By designing and building up it is necessary to realize systematic deformation measurements in the following stages:
- by laboratory tests of models,
- by foundation and building up of bridge foundations (underwork),
- by installation of bearing construction of bridge,
- by passing of bridge into operation:
    - deformation measurements during loading test,
    - base deformation measurement before inspection,
- by operation and control of reliability and assurance of bridge construction:
    - stage deformation measurements, normally after one year, eventually after several years in dependency on bridge parameters, its ground bearing, carrying capacity.

By laboratory tests of bridge models is namely verified correctness and reliability of suggested construction. By foundations and building up of bridge foundations we detect sinking of bridge bearings and its time running, whereby we verify if deformations don‘t cross predicted values and if they have a character of stabilization. Installation of bridge bearing construction normally introduces correct and certain step of bearing parts of construction. Measurements in this stage of building up are particularly necessary and imperative by building up of steel-concrete prestressed bridges, by cable and arc bridges. Objective deformation measurements are necessary also by decentring of concrete bridges with big range. By loading test we verify a quality of used constructive materials, we realize a control of reliability and assurance of construction and its function. By operation of bridges we monitor long-time deformation of construction, caused by internal and external powers during operation and we also verify assurance of construction.

Values of deformations of bearing construction and bridge foundations are calculated for a certain phases of building-up. Beginning, completion and time interval of control deformation measurements result always from static assumptions, eventually from technology of building-up of bridge structure.

4. FACTORS WHICH INFLUENCE STABILITY OF CONSTRUCTION

Stability of bridge construction is influenced by various factors, which cause permanent or temporary deformation of bearing construction and bridge foundations. Influences, which activate these changes we can divide into three groups:

- influences of geological and hydrogeological conditions of bridge location,
- influences of the main loading (construction weight, static and dynamic influences),
- influences (changes) of external character, eventually additional loading (wind, temperature, snow, ice, level of ground water and others).

By influences of static loading whole construction or only its part deform. By the main loading it is namely about flexure of bearing construction and sinking of bridge pillars. By dynamic inlfuence, which has variable, vibration or blowing character, originate permanent or temporal shape changes in bearing construction of bridge till meantime before kinetic energy of bridge material doesn't spend. Additional, eventually external influences cause various temporal or permanent changes in construction and also in bridge foundations. By bearers and bearings of bridge originate permanent or temporal changes in horizontal and also in vertical direction (especially).

Change of shape and position of bridge construction occurs by activity of internal and external powers. Shape changes of bridge are caused by geotechnical conditions (change of level of ground water), by influence of the main repeated loading (weight of construction, static and dynamic influences) and by influence of additional loadings (temperature changes, wind, braking power, etc.). Bridge foundations transfer all loadings from the above construction into the ground soil. Deformations of background transfer from ground joint back on the foundations of construction and activate vertical eventually horizontal deformations of construction. From the bridge assurance point of view the bigger importance has unequal sinking of individual elements of construction in comparison with equal sinking, which isn‘t indeed also insignificant.

In general we can say that purpose of control deformation measurements is to find out spatial change of flexure line of construction and sinking of bridge pillars, eventually their tilt. Flexure line has namely very difficult shape by influence of various effects. In practice this task we simplify so that mostly we measure only vertical changes, eventually distance changes, which occur by influence of static, dynamic and external effects. By non-typical, eventually more difficult bridge constructions or by bridges with big range we measure more elements (position changes, vertical changes, tilt), on a base which then can consider correctness and reliability of construction of particular bridge. By all deformation measurements it is necessary to detect, eventually to measure also other factors, it means temperature (of pillars, of bearing construction, of air) or atmospheric moisture, elevation of level of ground water, power and direction of wind etc. Influence of these factors is definitive by analyse of results of particular measurement, by calculation of deformations and consecutive interpretation of results, on which usually take part specialists from various branches (specialist in geology, in statics, in mechanics of soil, in foundation of building, in hydrology, for steel construction, for concrete construction, surveyor).

5. NECESSITY OF LONG-TIME DEFORMATION MEASUREMENTS OF BRIDGE STRUCTURES

Necessity of long-time deformation measurements of bridge structures as well as control of state, function and assurance of whole object and its individual parts comes out especially from Slovak Technical Norm STN [1], [2], as well as from requirements of investor or inspector, who usually wants to realize base deformation measurements before inspection. Results from these base measurements and consecutive stage measurements are foundation for interpretation, which enables early elimination of results or eventually potential extreme deformations of some constructional parts of bridge.

5.1 Requirements for Accuracy of Deformation Measurements of Bridge Structure

Requirements for accuracy of deformation measurements of bridge structure can be defined as follows:

a.) Value (intensity) of vertical theoretical flexure of construction by steel road bridges is 1/500 of distance of bridge panel. Measurement accuracy has to be approx. 0.5 to 1.0 % from the value of maximal flexure. It means that by range bridge (bypass of distance) of l = 50,00 will be expected maximal bridge flexure max = -60 to -100 mm, accuracy of measurement 0,3 to 1,0 mm.

b.) Flexure of steel-concrete bridges is in range of 1/500 to max. 1/1000 of distance of field. Flexure of overstrain concrete bridges 1/600 of distance of field. Accuracy of vertical deformation measurements should be at 0,3 mm. By continuous bearing constructions are mentioned values valid for flexure of whole bridge field. By inserted fields flexure shouldn't be higher than fragment of particular distance of bridge bearers (pillars).

c.) Excess, swing and other changes is sufficient to measure mainly with accuracy of 1 to 2 mm, eventually 1 % of expected magnitude of deformations. In special cases there is necessary to achieve accuracy more than 1 mm.

d.) Magnitude of pillar sinking is various and depends especially on geological composition, foundations shape and loading of bridge construction. Lots of time it has values of several milimetres, centimetres and sometimes also tenth of centimetres. Measurement accuracy of sinking depends on magnitude of expected sinking and should be in a range of 0,3 to 1 mm, eventually 1 % from expected sinking of bearers (pillars).

e.) About shape change of bridge construction we can say when measured deformation is at least two times higher than accuracy of measurement expressed by mean error of measurement.

Value of expected flexure we can calculate according to the following formula:

$$y_{\max} = \frac{5}{384} \cdot \frac{Q.l^4}{E.J} \quad ,$$

where Q = q + P (weight of bridge construction + useful weight),
l – length of beam (ranges of bridge fields),
E – module of elasticity of used material,
J – moment of persistence.

Flexure of bridge construction calculated by static calculation shouldn't be in comparison with the real measured flexure higher than 25 %.

Accuracy of deformation measurements is given by the following reguations „STN 73 0405 – Deformation measurements of building structures" in article 9-13. It is characterized by base mean error in determination of distance of the final vector of movement.
Base mean error m_1 in mm, as it is not given by another way is characterized by value:

$$m_1 = 1 / 15\, s \,,$$

where *s* - is expected global movement in mm, calculated according to the norms STN 73 1001.

By new designed buildings, according to the character of base soil, value of base mean error of measurement of vertical deformations hasn't be higher than the following values:

a) m_2 = 0,5 mm, for craggy and half craggy rocks,
b) m_3 = 1,0 mm, for sandy, argillaceous and other compressible soils and rammed mounds,
c) m_4 = 2,5 mm, for non-rammed mounds and strong compressible soils.

Accuracy of deformation measurements is inspected by achieved value of empiric mean error of measurement, which is compared with value of base mean error.
Observance of defined accuracy of measurements is tested by interval

$$P\,(t_1 \,.\, m \leq s \leq t_2 \,.\, m) = 1 - \alpha \,,$$

where *P* - is probability of achievementof defined accuracy for significance level α,
t_1, t_2 – limits of interval of confidence in tab.1 form for various degree of freedom *k*, for P = 0,95, it means α = 0,05,
m - base mean error of deformation measurements in mm,
s - empiric mean error of movement in mm.

6. OVERVIEW OF BASE PARAMETERS OF BRIDGE STRUCTURES ACCORDING TO THE HIGHWAY SECTORS

D61 Bratislava – Trenčín highway is a part of international corridor E75 and of Transeuropean artery North – South. By its finishing was reached a connection to D1 and so to intrusion to the international highway network also in direction of West-East. Highway is situated in direction of the highest transport charging in Slovakia, it means that near by the important economic and cultural centre of West Slovakia-towns as Trnava, Piešťany, Nové Mesto nad Váhom, Trenčín, Nemšová, Považská Bystrica, Žilina.
Siting of individual highway sectors presents this summary map.

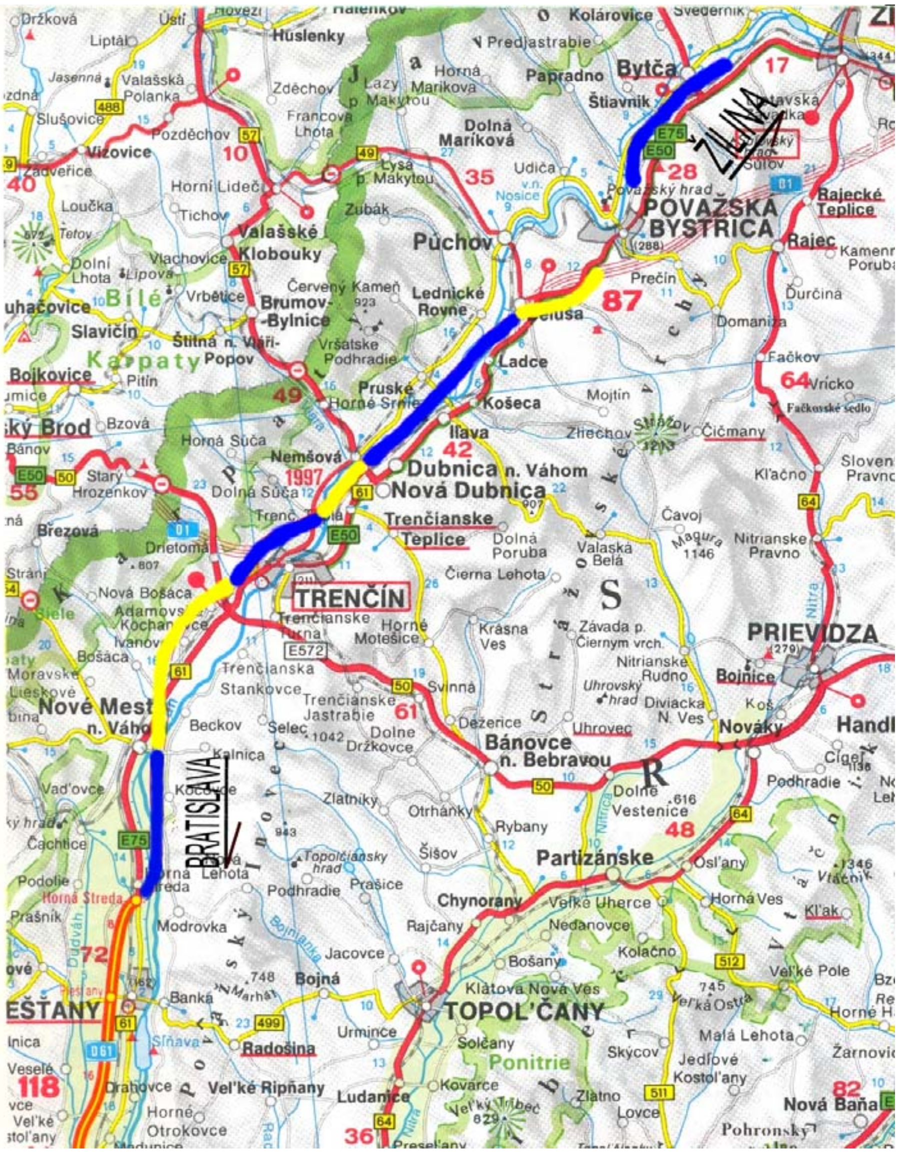

Fig. 1

In 1997-2005 were inspected highway sectors, on which were realized base deformation measurements of all bridges, see tab.1.

Tab. 1

BUILDING	LENGTH OF SECTOR	LENGTH OF BRIDGE	FIELD NUMBER	CONTRIBUTION OF BRIDGES
	m	m		%
D61 HORNÁ STREDA – NOVÉ MESTO NAD VÁHOM	13900	1223	37	9%
D61 NOVÉ MESTO NAD VÁHOM - CHOCHOLNÁ	15000	1490	37	10%
D61/D1 CHOCHOLNÁ – SKALA	10300	750	24	7%
D1 SKALA – NEMŠOVÁ	6700	1598	38	24%
D1 NEMŠOVÁ – LADCE	16600	1656	53	10%
D1 LADCE - SVEREPEC	9900	4776	136	48%
D1 VRTIŽER - HRIČOVSKÉ PODHRADIE	12900	4040	112	31%
HIGHWAY CONDUIT PÚCHOV	6500	617	19	9%
HIGHWAY CONDUIT TRENČÍN	1700	722	19	42%

Before these measurements it was necessary to prepare „Design deformation measurement“ and consecutive shoulder of measuring signs according to the [2]. Article 225 STN [2] defines situation of observed points, eventually measurement signs on the individual parts of bridge.

On bridge bearers and bearings we usually shoulder dowel elevation signs. On bearing construction (bridge deck) with range of 20m to 50m we usually shoulder three nail elevation signs but on bearing construction with range of 50m and more it is necessary to use five nail elevation signs, for monitoring of permanent deformation of bearing construction. Particular regulation dictates in which places on bridge deck should be situated observed points. Article 225 [2] dictates situation of observed points on bearers of object, for monitoring of sinking of lower building.

Overview about base parameters of bridge objects of the last two highway sectors are in the following tables:

Tab. 2

D1 Ladce - Sverepec						
Highway object	Length of object	Number of fields	Situation to the highway	Base points	Observed points	
					Bridge deck	bearers
201	33.2	1	on	4	12	8
202	21	1	on	3	12	8
203	16.3	1	on	4	12	8
204	38.8	1	on	4	12	8
205	284.8	7	on	5	60	56
206	380.8	10	Limb A	7	42	40
207	354.8	9	Limb B	6	38	36
208	234.8	6	Limb C	6	26	24

210	205.8	7	Limb B	5	30	28
213	32.5	1	on	5	12	8
214	61.2	4	above	5	18	10
215	29.8	1	on	4	12	8
216	62.2	4	above	4	18	10
217	917.2	23	on	12	188	96
219	102	6	outside	5	26	14
220	512.3	11	on	7	88	88
221	215.9	6	on	6	52	48
222	330.1	5	on	7	68	40
223	298.8	9	on	7	76	40
230	40.1	1	Limb A	4	6	4
291	192.2	6	outside	6	26	14
292	46	4	outside	6	14	8
294	26.1	1	on	4	12	8
297	230.8	7	on	6	30	14
298	73.2	3	outside	5	14	8
299	35.2	1	on	5	12	8

Tab. 3

Building: D1 VRTIŽER - HRIČOVSKÉ PODHRADIE						
Highway object	**Length of object**	**Number of fields**	**Situation to the highway**	**Base points**	**Observed points**	
					Bridge deck	**bearers**
201-00	348.1	11	Limb A	6	54	34
202-00	89.35	3	Limb D	5	12	6
204-00	784.24	16	on D1	8	164	136
205-00	47.4	1	on D1	4	12	8
206-00	688.95	20	on D1	8	196	168
207-00	44.52	1	on D1	4	12	8
208-00	24.72	1	on D1	4	12	8
209-00	310	10	on D1	6	84	80
210-00	603.7	20	on D1	8	168	160
211-00	301.5	7	Limb A, B, C	6	63	28
212-00	284.15	9	Limb A	6	34	18
216-00	271	6	above D1	6	26	8
217-00	43.32	1	on D1	4	12	8
219-00	198.6	6	above D1	5	26	14

Summary about lengths of particular highway sectors as well as lengths of bridge objects on the given sector presents Fig.2.

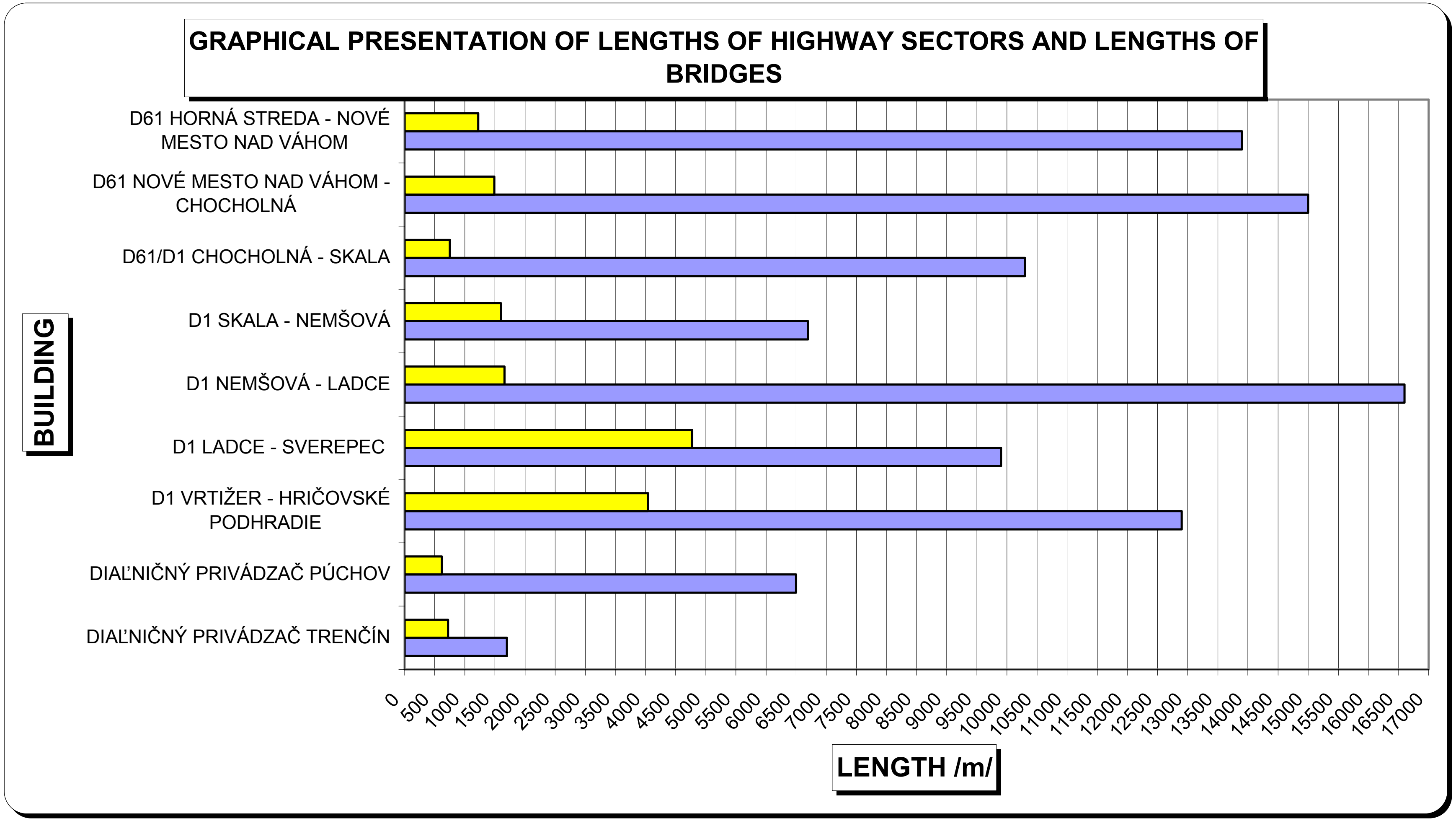
GRAPHICAL PRESENTATION OF LENGTHS OF HIGHWAY SECTORS AND LENGTHS OF BRIDGES
BUILDING
D61 HORNÁ STREDA - NOVÉ MESTO NAD VÁHOM
D61 NOVÉ MESTO NAD VÁHOM - CHOCHOLNÁ
D61/D1 CHOCHOLNÁ - SKALA
D1 SKALA - NEMŠOVÁ
D1 NEMŠOVÁ - LADCE
D1 LADCE - SVEREPEC
D1 VRTIŽER - HRIČOVSKÉ PODHRADIE
DIAĽNIČNÝ PRIVÁDZAČ PÚCHOV
DIAĽNIČNÝ PRIVÁDZAČ TRENČÍN
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
14500
15000
15500
16000
16500
17000
LENGTH /m/

Fig. 2

7. CONTENT OF REALIZATION OF BASE DEFORMATION MEASUREMENT OF BUILDING STRUCTURE

Subject of geodetic measurements on bridge structures was **base vertical deformation measurement by method of very precise levelling** in the following division:

- vertical deformation measurements of observed points of bridge bearings and bearers,
- vertical deformation measurements of observed points of bearing construction (bridge deck),
- measurement eventually connection to the base elevation points,
- temperature measurement of: bridge bearings, bearers, bearing construction and near sorrounding (see Fig. 3),
- processing and evaluation of measured data.

Measurement of vertical deformations of observed points on bridge bearing and bearers we realized according to the "Observation plan of measurement", which creates graphical attachement to the particular bridge structure. For stabilization of observed points were determined dowel elevation signs according to the STN 73 0416.

Measurement of vertical deformations of observed points of bearing construction (bridge deck) we realized analogous according to the individual "Observation plan of measurement", which created graphical attachement of bridge structure. For stabilization of observed points of bridge deck were used mainly nail elevation signs according to the STN 73 0416.

Connection to the base elevation points we realized in both directions according to "Observation plan of measurement", which was common also fot measurement of observed points of lower building. As base points were usually used points of highway staking out network, which were max. 400 m from bridge structure and which have suitable underground stabilization.

For vertical deformation measurement of base and observed points of particular bridge structures we used TRIMBLE DiNi 12T digital levelling instrument and code levelling rods. Particular instrument was before measurement verified and also code levelling rods were compared before measurement. Measured data were recorded direct to the instrumetn thanks what we could immediately after closing of levelling series to check closures and in case of need to repeat measurement.

Together with vertical deformation measurement we measure also temperature of:

- near sorrounding,
- bridge bearings and bearers,
- bearing construction,

and that in places signalized on Fig.3. Measurement was realized by digital temperature TESTO, which internal accuracy is 0,5 degree.

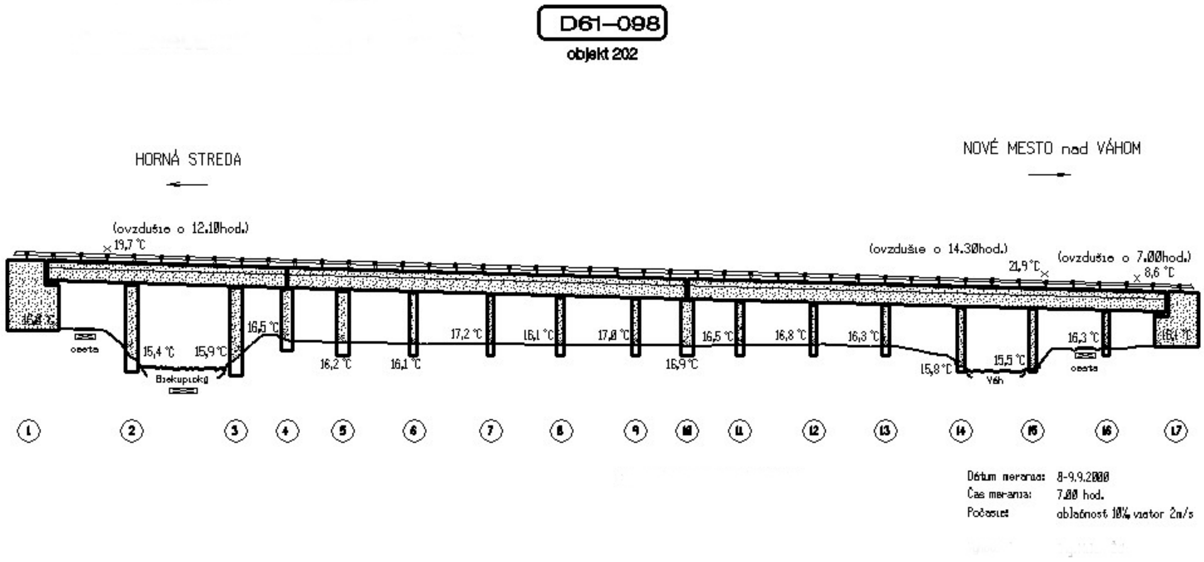

Fig. 3

8. PROCESSING OF MEASURED DATA AND DOCUMENTATION OF RESULTS

Processing and valuation of measured data we realized by NIVE-VNS software, to which we own user rights. It is modular program system, which consists of five modules of VLS, which is appropriate for acquisition, inspection and processing of large levelling data in elevation point field as well as for all accurate engineering surveying works by vertical deformation measurement and changes of various building structures as bridges, dams, nuclear power plants, minings etc.

Program system used the newest knowledge from mathematical statistics, probability and error theory. Network adjustment (estimate of the first and second order) is realized on a base of the second linear model (non-direct measurement of vector parameter) which is following:

$$\Delta \hat{\Theta}(\eta) = (A^T J^T \Sigma^{-1} J A)^{-1} A^T J^T \Sigma^{-1} \eta \ ,$$

$$\mathrm{var}(\Theta_0 + \Delta \hat{\Theta}(\eta)) = (A^T J^T \Sigma^{-1} J A)^{-1} \ ,$$

where:

$\Delta \hat{\Theta}(\eta)$ -vector of estimated parameters,

A -plan matrix,

J -configuration matrix,

Σ -covariance matrix,

η -observation vector,

$\mathrm{var}(\Theta_0 + \Delta \hat{\Theta}(\eta))$ - variance matrix of estimated parameter.

Estimate realized like this can be characterized as unbiased jointly efficient and consistent and therefore fulfils conditions of estimate for Least Square Methods (LSM).

Levelling series for individual structures were adjusted as a complex where importance of measurement input into calculation in dependence on length of levelling series. Elevations of all base and observed points were determined in altitude system Baltic after adjustment.
Resulting calculation protocols [3], [4], [5], [6], [7], [8], [9], [10], [11], consist from:

- list of estimated elevations of points,
- formation of levelling measurements,
- protocol of estimated .measured data.

Components of delivered protocols were also:
- technical report,
- list of measured temperature with prompted place of measuring,
- observation plan.

9. CONCLUSION

Realized base vertical deformation measurements of particular bridge structures are according to the STN 73 0405 initial base for long-time periodical measurement and monitoring of stability, function and operation competence of bridge structure. Author collective solved problem as a complex with use of modern methodic and instrumental technics and with the newest processing equipment.

The following stage vertical deformation measurement will be necessary to realize:
- in purview of technical department regulation MDPT SR: TP 09B /2005 Inspections, maintenance and reparations of roads,
- TP 04/2003 Import and output of bridge diagnostic. Statute , SSC: 2003,
- TP 05/2002 Prognosis of perturbation influence to loading of bridges and designation of rest vitality of bridges. Methodical handbook, SSC: 2002,
- our projects "Project of deformation measurement", it means in purview of methodical process, which was elected by base (zero) deformation measurements,
- according to the time requirements of manager of particular bridge structures – National Highway Society.

Bigger bridge structures like mentioned bridge structure will be in the next stages possible to measure only out of working what will demand early preparation but also coordination of manager but also creator or executor of concrete measurement. Forasmuch as all graphical, tabular as well as text protocols were submitted also in digital form and that presentation is transparent we can say that elaborated documents can create a base for information system of highway bridge structures in Slovakia.

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BIOGRAPHICAL NOTES

Štefan Lukáč

Academic experience:
Dipl. Ing. Faculty of Civil Engineering Slovak University of Technology.

Practical experience:
Civil Engineering, Deformations Measurements of Nuclear Power Plants, of Highway Bridge Structures, of Dams in Slovakia.

Activities in home and International relations:
President of Slovak Union of Surveyors 1997-…,
Vicepresident of Chamber of Surveyors and Cartographer 2001-…,
National Delegate to FIG, Commision 1: Profesional Standards & Practice,
Editor in Chief of Bulletin Slovak Surveyor and Cartographer,
Editorial Board of Slovak Journal of Civil Engineering,
Editorial Board of Geodetic and Cartographic Journal (CZ - SK).

Milan Žák

Academic experience:
Dipl. Ing. Faculty of Civil Engineering Slovak University of Technology.

Practical experience:
Civil Engineering, Deformations Measurements of Nuclear Power Plants, of Highway Bridge Structures, of Dams in Slovakia.

CONTACTS

Štefan Lukáč
Department of Surveying,
Faculty of Civil Engineering,
Slovak University of Technology Bratislava,
Radlinského 11
813 68 Bratislava
SLOVAKIA
Tel. + 421 2 59274388
Email: stefan.lukac@stuba.sk

Milan Žák
Geoland Trnava
J. Bottu 2
917 00 Trnava
SLOVAKIA
Tel. + 421 33 5531732
Email: zak@in.slovanet.sk