# Measurement of bridge body across the river Labe in Mělník

***Lukáš Vráblík*[1], *Martin Štroner*[2] a *Rudolf Urban*[3]**

***Měření mostního tělesa přes řeku Labe v Mělníku***

*Long-span concrete prestressed bridges are sensitive for long-term deflections growing. Bridge over the river Labe near Mělník is a typical example of this structural type. 15 years after bridge opening, midspan deflection still increases. Detail surveying of the superstructure was made to identify possible structure failure.*

***Key words***: *prestressed concrete bridge, deformed structure*

## Description of the bridge structure and its state

Long span prestressed concrete bridge across the river Elbe in Mělník (fig. 1) is the main part of the bridging transferring the I/16 communication. It was designed as a through girder with span length 72,05 + 146,2 + 72,05 m. With the main span length 146,2 m it is still biggest overhung concrete bridge in operation in Czech republic.

As well as other concrete bridges with large spans, this bridge is also characterized by permanent increase in deformations in time. The structure has been therefore permanently observed since its putting into operation in September 1994. The evaluation of monitoring results [4] clearly shows that even after almost 15 years since putting into operation it does not come to fixing of increase in deformations.

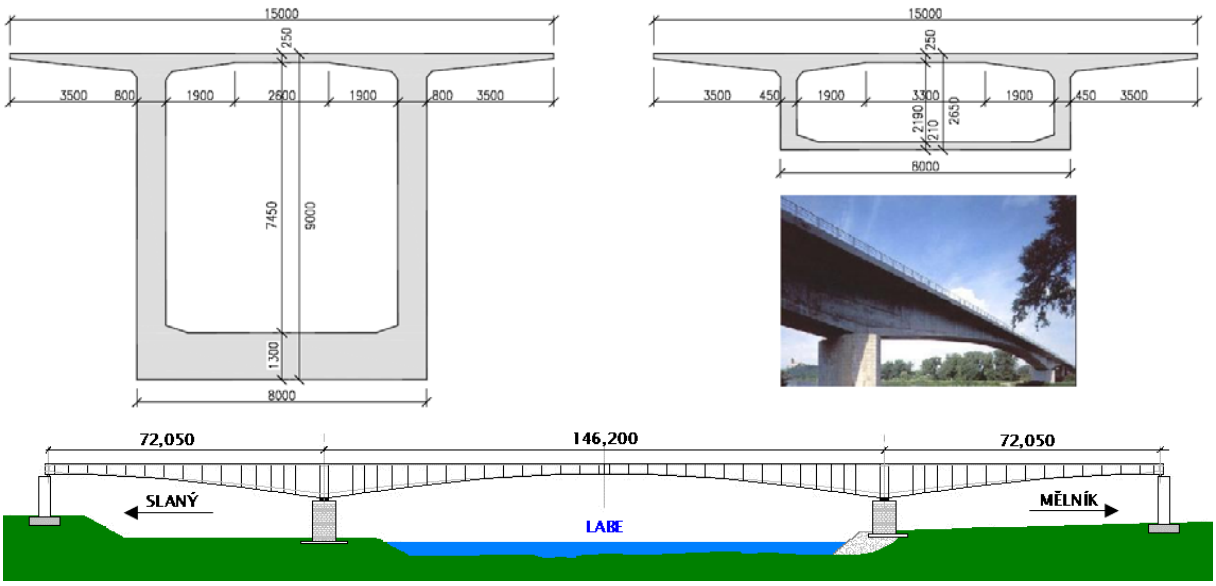


*Fig. 1. The bridge scheme.*

Long-term deformations are measured in fixed points on the structure (above supportings for analysis of their long-term settlement and in the intermediate points of the end span and middle span for observing long-term deformations of the prestrained concrete structure caused both by reological signs of concrete - creeping and shrinkage, and by other possible effects (e.g. decreases in prestress etc.).

[1] *Ing. Lukáš Vráblík, Ph.D.*, ČVUT in Prague, faculty of civil engineering, department of concrete and msonry structures, Thákurova 7, 166 29 Prague 6, lukas.vrablik@fsv.cvut.cz

[2] *Ing. Martin Štroner, Ph.D.*, ČVUT in Prague, faculty of civil engineering, department of special geodesy, Thákurova 7, 166 29 Prague 6, martin.stroner@fsv.cvut.cz

[3] *Ing. Rudolf Urban*, ČVUT in Prague, faculty of civil engineering, department of special geodesy, Thákurova 7 166 29 Prague 6, rudolf.urban@fsv.cvut.cz

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The result of such measuring is time development of the real shape of the structure – comprising both the starting shape and the deflection line – in the analyzed points.

So as to find out an exact shape of the deflection line, a detailed focusing of the deformed shape of the supporting structure in large amount of points was designed. Possible found „anomalies“ in the course of the deflection line might point to failures of the structure causing enormous long-term increase in deflections of this bridge structure.

## Technology, measuring and processing procedure

### Instrumentation and measuring technology

The Trimble S6 Robotic instrument ($\delta_{\square}$ = 0,3 mgon, $\delta_D$ = 1 mm + 1 ppm D) with a relevant omnidirectional reflection prism was used for the measuring. It is a total station with automatic observation of an aim and spacing, which also enables automatic focusing an omnidirectional reflection prism. Further we used a tape (50 m), a drilling kit, a hammer, driving plugs 6×30 mm (600Pcs), underlays (1000Pcs), a spray colour.

The bridge structure was focused by the space polar method. The measuring technology was determined in dependence on time change of the bridge structure shape and on accuracy requirements. The exact levelling technology, which would determine height of points with higher accuracy, could not be used for reason of extremely higher focusing time, which would cause a significantly bigger movement of the structure owing to temperature change and thereby a significantly higher measuring inaccuracies (the measuring would not be continual and a correction by means of a time sample would be infeasible).

*Fig. 3. Trimble S6 Robotic, a range pole with an omnidirectional prism.*

## Stabilization of points

Stabilization of points was carried out by means of the driving plugs with length of 30 mm. With respect to the amount of points and related elaborateness and economic demandingness of the whole project, it was not possible to plant the points with benchmarks and cartridge nails. Planting of the cartridge nails into the road asphalt bed was tested and it turned out to be very problematic as it is a very hard surface and when using a cartridge tool it is not possible to guarantee even approximately the same anchorage of the nails into the bridge deck.

The first 246 points were stabilized approximately 0,5 m from the safety fence in the direction of the communication into the asphalt surface, whereas the other half of the points were stabilized 0,5 m from the safety fence in the direction of the communication into the concrete underbed. The plug heads had to be increased by means of underlays (asphalt – 2 underlays, concrete – 1 underlay). The reference point for comparison of differences of the stage measuring was also stabilized with a plug and situated approximately 10 m behind the end of the buttress into the asphalt pavement (the checkpoint for attachment stabilized with a benchmark at the end of the bridge).

The total time of carrying out stabilization of all c. 500 points using the professional drilling kit took two workers 8 hours including dimensioning. The costs were significantly lower in comparison with standard stabilizations. With respect to the planned night measuring, the signalization was done with yellow colour placed directly onto the peg heads and their neighbourhood.

## Measuring configuration

The measuring configuration is situated in fig. 4. The standpoint was placed in the middle of the focused section of the bridge, because then all the 492 points could be focused from one standpoint. Eventual using of two or more standpoints would lower the total accuracy owing to attachment errors. The bridge structure shape was changing in the course of focusing. When designing the configuration measuring it was supposed that this systematic influence will be sufficiently suppressed by the „time sample“ method. The standpoint could be placed in a more stable place, but in this case it would not be possible to focus everything from one standpoint, the structure shape would also change systematically and therefore it would be necessary to implement a correction.

The used omnidirectional prism was fixed to the range pole in a stable way during the whole time of measuring approximately in the height of 1,5 m. The whole focusing was attached to a reference point by means of end points of both profiles (profile on asphalt point n. 1, profile on concrete point n. 492), which were independently focused four times at the end of focusing. The stable points from which both profiles were determined from height point of view are illustrated in fig. 4.

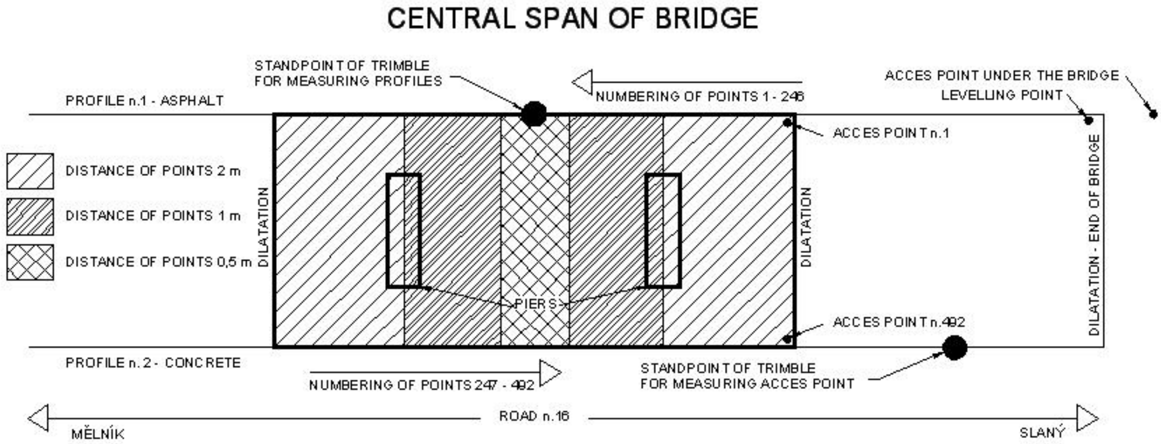


*Fig. 4. Measuring configuration.*

## Measuring procedure

At first we focused both profiles from the standpoint in the middle of the bridge in the sequence of points 1 to 492 (measuring time – 3,5 hrs, temperature at the beginning 12,5 °C, temperature at the end 8 °C). Then we determined a time sample that contained each fifth point of the profiles (measuring time – 45 min, temperature 8 °C, time temperature change is considered minimum). At the end we carried out focusing profile end points for attachment and attachment itself to a stable point at the end of the bridge from the other standpoint of the instrument (measuring time – 20 min, temperature 8 °C). The focused horizontal directions, zenith angles and oblique lengths were registered in the course of the measuring, and there were also registered three space coordinates in the local (chosen) system of coordinates for check purposes during the measuring.

**Statement of the reasons for the measuring and processing data procedure**

Determination of heights of such a large number of points (500) cannot be at present carried out from the technological point of view with standard deviation c. 1 mm – 2 mm in such a short time, so that the shape of the structure does not change owing to temperature changes in time during focusing the first and the last point. So as to minimize these undesirable changes, the measuring was carried out at night (22:30 hrs. – 4:00 hrs.), in spite of the fact that (as it will be showed further) there appeared a change in vertical direction by values of approximately 3 mm. That is why approximately 1/5 points (each fifth point) were refocused for check reasons in a significantly shorter time (c. 45 min) after finishing the first measurements. Changes between height determination of the first and the last point can be taken here for significantly smaller and the sample of points determined in this way can be used to determine a correction curve, by means of which it is possible to bring the measured points into the correct position and to suppress systematic errors.

**Analysis of height measuring accuracy**

With respect to the way of signalization of points for measuring (a range pole with a prism held by a lineman) it is possible to estimate standard deviation of point height determination (in the local system). The manufacturer states the standard deviation of the zenith angle measured in two positions amounting to 0,3 mgon. According to the standard deviation accumulation law [7], the standard deviation of the 2 x focused zenith angle in one position is 0,3 mgon. again. For maximum distance of the point from the standpoint of 150 m, the standard deviation of the determined height therefore equals 0,7 mm. Further it is suitable to consider influence of inaccurate setting of the range pole tip onto the point, which amounts to 1 mm with a sufficient reserve. Influence of inaccurate settlement of the spherical level on the target device (range pole nonverticality) on the determined height is insignificant for level sensitivity 4′ – 6′ and prism height 1,5 m. Standard deviation of height can be therefore estimated with value of 1,2 mm.

The standard deviation calculated from the repeated focusing when measuring height attachment was 0,5 mm for maximum distance of 50 m, which corresponds to the accomplished accuracy analysis.

**Determination of parallel profile axes and stationing of points on profiles**

When stabilizing such an amount of points it was not possible to dimension the position accurately, so that both profiles were mutually sufficiently parallel and all points lay exactly on these lines. Generally it is therefore possible to consider two lines of points that are deployed around two almost parallel lines. So that it were possible to determine the deflection line of the bridge deck, it was first necessary to adjust positions of points by a calculation so that two lines with condition of mutual parallelism were spaced through two groups of points (corresponding to the profiles) by the method of least squares ( MNČ – MLS) while keeping to the terms of orthogonal spacing and consequently stationing was determined, which was measured from the beginnings of the perpendiculars led from the line to the point profiles. The initial stationing was simultaneously determined the same for both profiles (by projecting the basepoint of the first profile onto the second one). So as to illustrate point stabilization accuracy it is possible to state that the average distance of a point from the levelled line was 13 mm (maximum 144 mm), the difference in stationing of the profile basepoints was 22 mm.

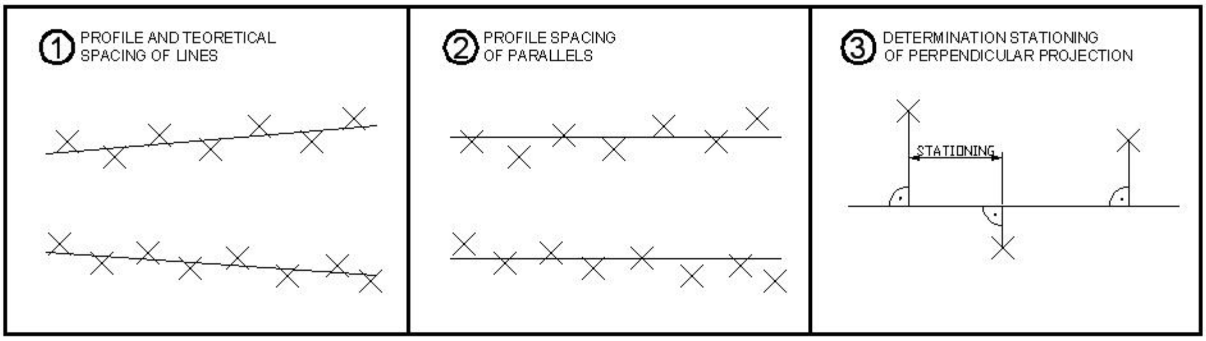


*Fig. 5. Profile levelling scheme.*

**Determination of correction from temperature change**

The chart in fig. 6 illustrating comparison of the determined heights (in the local system) when focusing all 492 points and when focusing time section points shows an evident change of the bridge body shape in dependence on time (the centre of the measured span descends together with the device, while ends of the span behind the pillars have tendency to ascend). When comparing heights of all points with heights of time section points, the result is a polygon in general. For further calculation of suppressing temperature change it was therefore necessary to space the polygon with a curve that is easily mathematically definable (n-th grade multinominal) and then it is possible to calculate a correction from shape change (owing to temperature change) for the individual stationings and thereby to get final heights for determining the curve that will characterize the bridge structure. Fig. 6 and fig. 7 illustrate differences of the determined heights dH in dependence on stationing s. A smooth curve illustrates a spaced function (6-th grade multinominal).

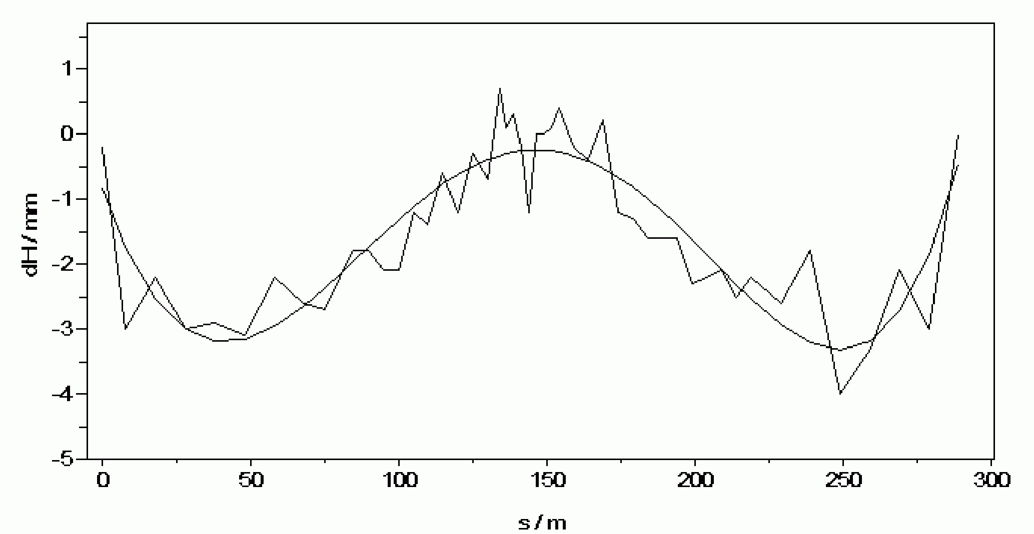


*Fig. 6. Chart of measuring differences and check measurement – profile n. 1.*

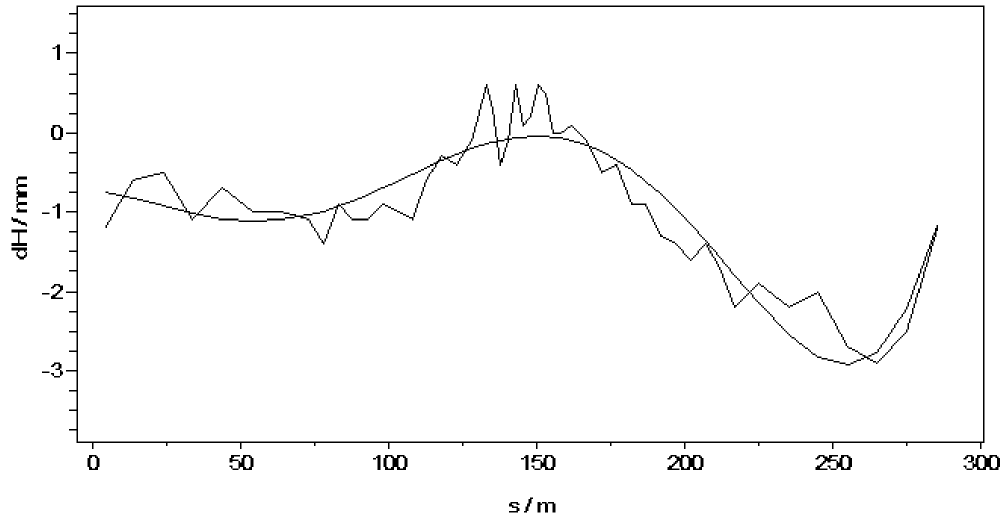


*Fig. 7. Chart of measuring differences and check measurement - profile n.2.*

**Determination of the bridge deck course curve**

It is a similar calculation as in processing the time samples, but with the difference that an approximate type of a curve is known, it is a tenth-grade multinominal in the form (1).

$$H_i = a_0 + a_1 s_i + a_2 s_i^2 + a_3 s_i^3 + \ldots + a_{10} s_i^{10}, \qquad (1)$$

where $s_i$ and $H_i$ are stationing and height of the i-th point.

The spacing can be carried out simply by the method of least squares, plan matrix of experiment J and vector of right sides l are defined:

$$\boldsymbol{J}(i,j) = s_i^{j\text{-}1}; \quad \boldsymbol{l}(i) = H_i, \qquad (2)$$

where j is 1,2,3, …, 11 and i is 1,2, … n, where n is number of focused points.

Vector of the unknown quantities a:

$$a = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_{10} \end{pmatrix}. \qquad (3)$$

For calculation of unknown coefficients $a_0$ to $a_{10}$, formula (4) will be used.

$$\boldsymbol{a} = \left(\boldsymbol{J}^T \boldsymbol{J}\right)^{-1} \boldsymbol{J}^T \boldsymbol{l} \qquad (4)$$

Vector of corrections v assigned to heights H is calculated from formula (5).

$$\boldsymbol{v} = \boldsymbol{J}\boldsymbol{a} + \boldsymbol{l}\,. \qquad (5)$$

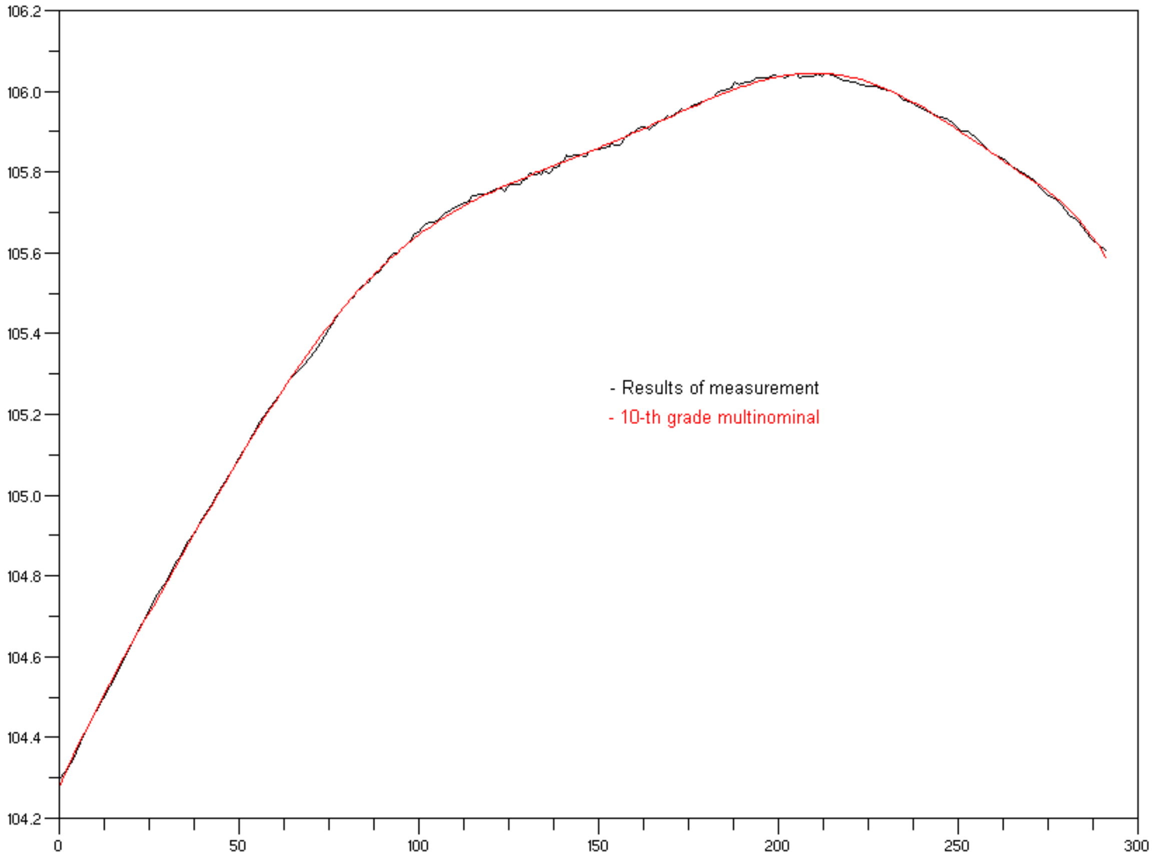


*Fig. 8. Spacing the measuring results with a multinominal.*

## Conclusion

A detailed focusing of the supporting structure surface with using large number of points (fig. 4) was therefore carried out. The result is a „smooth and continuous“ line approaching the current shape of the supporting structure (fig. 8), the detailed mathematical analysis of which, amended for example by visual check of state of the supporting structure, can reveal eventual failures of the supporting structure leading to excessive deflections that grow in time. When adopting assumption of linear creeping (level of pressure tensions is supposed to be e.g. according to ČSN ENV 1992-1-1 smaller than $0{,}45f_{ck}$)

and constant tension must be a found shape of deflection line „similar“ to shape of deformation gained by calculation when considering building procedure, changes in static system and development of deformations owing to concrete creeping.

The eventual found differences can therefore indicate places on the construction for example with reduced solidity caused by fissures in the structure. It is necessary to remind that if the real shape of deformation does not correspond to presumptions of the calculation, then even the lay-out of the inner forces defined by the calculation is not correct.

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