Interactive Design of Prestressed Precast Bridge Beams from High Performance Concrete

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Summary

This paper deals with a monitoring of a set of pre-tensioned bridge beams with a length of 21 m made from high performance concrete C55/67. The monitoring included measurement of the actual prestressing forces (losses), concrete strains, cambers as well as testing of material properties of concrete as are compressive strength, modulus of elasticity, creep, shrinkage.

Keywords: bridge beams, composite; construction; camber; creep; curvature; high performance concrete; precast; prestressing; shrinkage.

1. Introduction

Design of structural members is usually based on inputs defined in relevant codes and standards. Because some precast members are produced in large numbers it is convenient to confront the actual parameters (strength, stresses and strains) with those used for design. Also new materials, e.g. an application of HPC, may lead to the different behaviour of prestressed concrete structures than expected particularly if they were designed according to older standards. Re-design based on the actual material properties, stresses and deformations allows to improve a quality of assembled structures. E.g. prestressed precast bridge beams are highly stressed structural elements, sensitive on deformation properties of concrete which can adversely influence final camber and thus an elevation of the bridge. In case of composite concrete-concrete bridges it may lead to the variable thickness of the topping, higher at the support region, lower in the middle of span and so to the higher concrete consumption compared to the list of quantities.

Doprastav a.s. started with production of the new pre-tensioned beams DPS-VP-97 for construction of composite bridges in September 2002. In order to improve quality of the products, the company has decided to perform a monitoring of the first six beams. The beams were divided into two groups. Monitoring of the first group (beams N1,N2,N3) included measurements of prestressing forces and cambers. More detailed monitoring was carried out for the second group (beams N4,N5,N6), where more over measurements of deformations in selected sections and testing of material properties of concrete were performed.

2. Description of the Precast Beams

Monitored precast bridge beams with a length of 21 m have an I –shaped cross-section with a depth of 0,95 m, see fig.1. Beams were prestressed by 16 strands in the lower flange and 2 strands in the upper flange. Low relaxation 7 – wire strands with a characteristic strength of 1800 MPa and sectional area 141 mm^2 were stressed between two stands spacing at 40 m. Beams were originally designed from concrete class C45/55 (B600) which is the highest available strength for concrete in used national design code. The higher quality of concrete (C55/67) was introduced in order to accelerate production cycle and to improve deformation properties (stiffness) of the beams.

Thickness of the topping is projected 0,20 m and precast beams are spaced at 1 m in bridge construction.

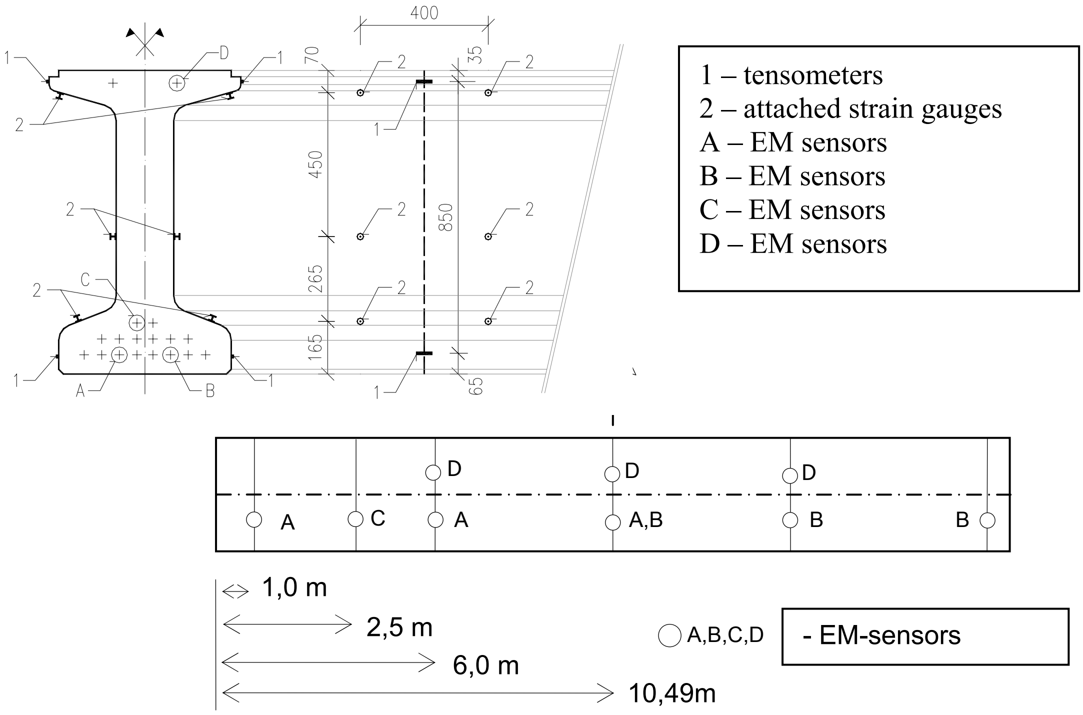

Fig.1 Position of the Strain Gauges and EM - sensors

3. Measurements

Detailed monitoring included in situ measurements of the set of three precast beams, (N4, N5, N6) , and laboratory testing of material properties of concrete that was used for their casting. Time interval of the monitoring was limited by erection of the beams to the bridge structure.

3.1 Laboratory Tests

The laboratory tests were focused on the material properties of concrete that influence behavior of the beams. Properties were investigated for concrete at age 1 day, 2 days , 3 days and 28 days. Cube compressive strength $f_{cm,cube}$, sectional modulus of elasticity E_{cm} , strains due to creep and shrinkage and density of concrete were measured. Results are summarize in tab.1

Table 1 Material Properties of Concrete

Properties	Units		Concrete age			
			1 day	2 days	3 days	28 days
Compressive strength $f_{cm}/f_{cm,cube}$	MPa	N4	32,0/40,0	43,4/54,2	48,2/60,2	57,0/71,3
		N5	34,2/42,7	42,8/53,5	50,0/62,5	57,3/71,6
		N6	31,4/39,3	44,5/55,6	52,0/65,0	61,3/76,6
Modulus of elasticity E_{cm}	GPa	N4	26,61	29,71	31,44	38,57
		N5	28,75	29,36	32,18	41,61
		N6	27,15	29,11	32,16	40,40
Density ρ_{cm}	kg/m^3	N4	2370	2380	2380	2372
		N5	2400	2370	2390	2383
		N6	2400	2390	2400	2400

Shrinkage and creep directly influence long-term prestressing looses. Therefore both parameters were investigated and finally compared with values used for design of the beams. In fig.2 are two charts with a comparison of measured and predicted strains due to the shrinkage. Two models for prediction were used. The first one is model from national code (used for design) and the second one is model EN1992-1-1. The charts show significant differences between the actual and predicted strains (national code). A shape of specimens was prism 100×100×400 mm ($h_0 = 50$ mm), RH = 60%, temperature 14°C, rapid hardening cement CEM 42,5R.

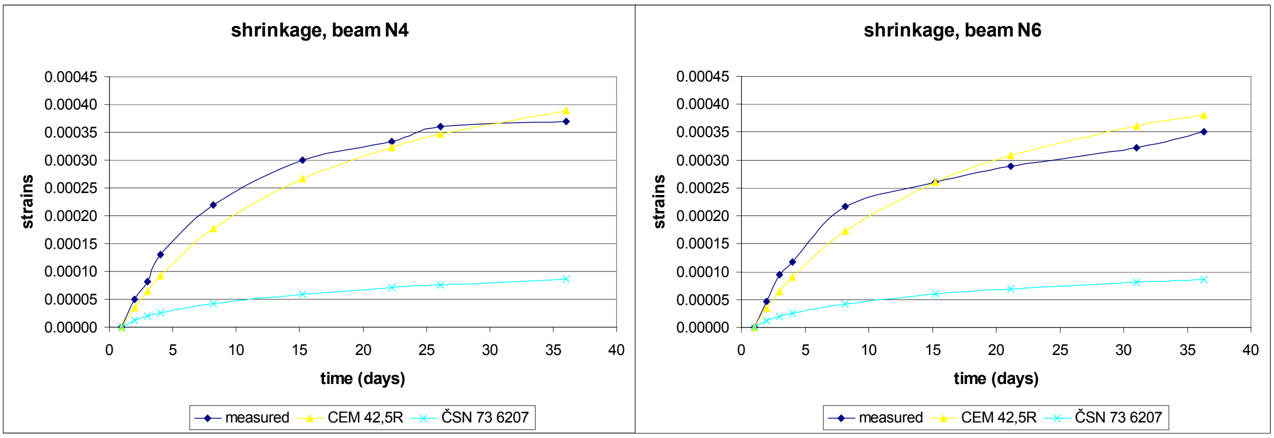

Fig.2 Comparison of Measured and Predicted Values of Shrinkage Strains

Creep was measured on three prisms 100×100×400 mm for each beam. Specimens were stressed on the average stress 20 MPa at age of concrete 2 days (N4,N6 beams) and 3 days (beam N5). The day of loading coincided with the age of concrete at prestress transfer. Ambient conditions were the same as for shrinkage measurement. Relation creep coefficient/time for concrete specimens (N4, N6) loaded at age of concrete 2 days is plotted in fig.3. Values were derived using formula (1):

$$\phi(t,t_0)=\frac{\varepsilon_{c,cr+sh}(t)-\varepsilon_{c,sh}(t,t_0)}{\sigma_c(t_0)}\times E_{c,28} \tag{1}$$

where: $\varepsilon_{c,cr+sh}(t)$ – measured overall strains,
$\varepsilon_{c,sh}(t,t_0)$ – measured strains due to the shrinkage,
$\sigma_c(t_0)$ – imposed compressive stresses,
$E_{c,28}$ – 28 – days modulus of elasticity of concrete,
t_0 – concrete age at loading.

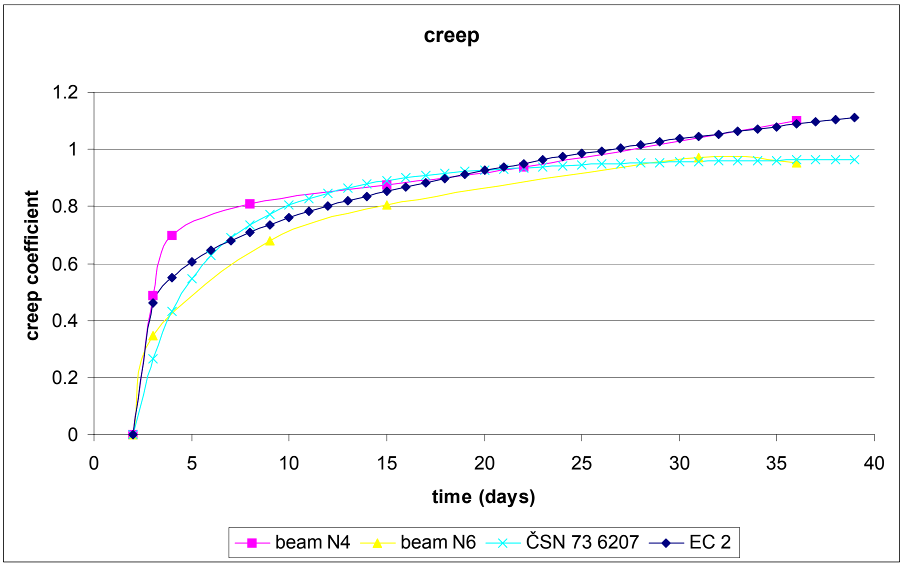

Fig.3 Comparison of Measured and Predicted Values of Creep Coefficient

Opposite to the shrinkage, function for prediction of the creep coefficient in national code rendered much better properties of concrete. National code was established in the sixties (last amendment 1993) and works with a very simple model for prediction of shrinkage and creep. Final values of shrinkage strain and creep coefficient are based only on relative humidity of environment and time function on the age of concrete measured from compaction of concrete in the mould.

3.2 In situ measurements

The first goal of in situ measurements was to determine actual prestressing forces applied to the beams. Forces were measured by three independent systems. 18 elasto-magnetic sensors were embedded on the strands just beside the mould (each strand was equipped). Further 9 EM-sensors were embedded on the strands directly in the form. Position of the sensors in the form is in fig.1. Sensors located out the form allowed to measure prestressing forces from stressing stage, including immediate losses, to the stage of prestress transfer. Internal EM-gages were used with intention to measure prestressing forces also after transfer stage. Precision of the measurement was ± 1 kN. The third system was represented by HBM50 dynamometer which was located between the stand and passive anchor of the selected strand. The dynamometer served also as a calibration unit during stressing.

An effect of prestressing and the other loads (self-weight) on the beams was investigated on the level of concrete strains and displacements (camber). Concrete strains were measured in 6 sections (both sides of the beams) by tensometers and attached strain gauges. Tensometers were used for measurement of strain at the transfer stage, while attached strain gauges allowed to measure beams also on the storage site. Following positions of the section were selected: in the middle of span, 6.0 m far from the head of beam (maximum effect of prestressing) and 1.0 m from the beam head (the end of transmission length). Within each section three different concrete fibers were measured in vertical directions: upper flange, center of gravity of concrete cross-section and lower flange.

3.2.1 Prestressing forces

The average values of the prestressing forces after anchoring for each of four strand layers are in tab.2. Introduced forces were measured by the first system of EM-sensors and checked by the other two systems. The forces varied from 180 kN to 190 kN, while jack force was 205 kN. Also further measurements confirmed that the immediate losses, as a parameter of the prestressing bed, range from 8 to 12 %. Because originally in design assumed prestressing forces were 195 kN it was necessary to re-check durability criteria of the beams. Lower values of prestressing force caused that the criteria for fully prestressed beams had to be abandoned and criteria for limited prestress were applied. Found out technical properties of the prestressing bed have also influenced development of the new pre-tensioned beams with a length of 24 m and 27 m, those design was accomplished this year.

Table 2 Average Values of Prestressing Force After Anchoring [kN]/[MPa]

Beam	1st layer	2nd layer	3rd layer	upper strands
	Force/Stress	Force/Stress	Force/Stress	Force/Stress
N4	186,4/1316	185,9/1313	187,0/1321	186,0/1314
N5	183,1/1293	182,7/1290	181,5/1282	184,0/1300
N6	183,3/1295	183,2/1294	180,5/1275	189,8/1341

3.2.2 Measurements of concrete strain

Measurements allowed to determine an axial deformation and curvature of the selected sections due to the loads at stage of prestress transfer and prestressing looses due to the creep and shrinkage. Elastic deformations of monitored sections (beam N5) just after prestress transfer are plotted in fig.4 (left). Time development of deformation of #3 section - located in the middle of span is in fig.4 (right).

Theoretical elastic deformations at prestress transfer were computed using known material properties (E_{cm} ,ρ_{con}) and prestressing forces and then they were compared with measured values. Comparison showed consistently (for all sections) lower measured values of curvature then were expected, differences varied from 3% to 8%. The reason was found out in lower stiffness of concrete in the upper flange due to the lower compaction of concrete here. It caused shift of the center of gravity downwardly and naturally slight fall of bending effect of prestress. Non linear deformations in fig.4 (left) belong to the #1 and #5 sections, which are located 1 m from the head of beam. Measurements showed that these sections lay still within so called dispersion length.

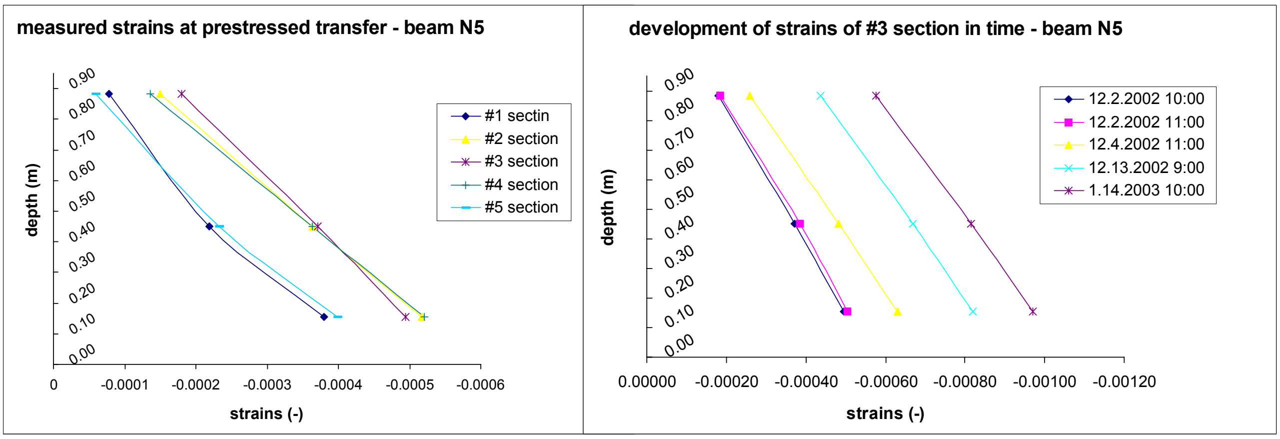

Fig.4 Measured Deformations of the Selected Sections

For proper elevation of the composite bridges assembled from pre-tensioned precast beams play an important role cambers at time of casting of the topping. Therefore the monitoring also focused on measurement of vertical displacements (cambers). Cambers were measured by electronic level and indirectly through the curvatures of measured sections. Time development of the cambers in fig.5. Measured values were used for calibration of the model for camber prediction. The model enables to calculate cambers for any time interval and thus allows to determine more precise an amount of concrete which is used for casting of the topping.

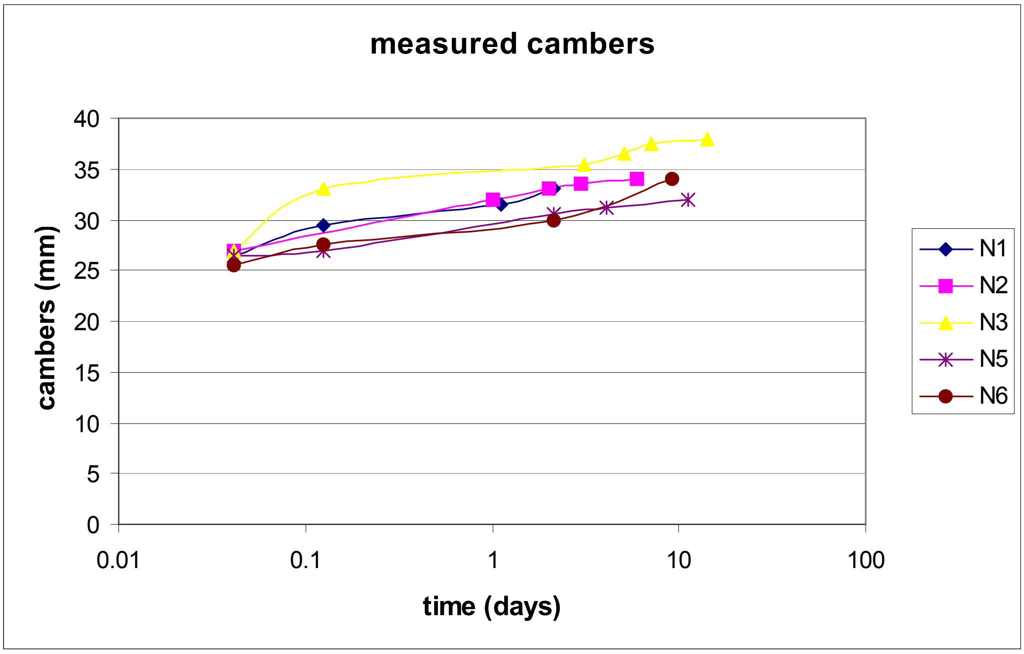

Fig.5 Measured Cambers – Development in Time

Conclusions

The results of the monitoring have had a very valuable contribution to the improvement of the quality of prestressed beams. It unveiled some shortages connected with a prestressing procedure, as well as technical parameters of the new prestressing bed that influence a magnitude of prestressing forces applied to the beams. Application of the concrete with a modern admixtures and rapid hardening cements influence magnitude and development of shrinkage and model for prediction in old national code has become absolutely unfit for further design. Contrary to the shrinkage, model for prediction of creep coefficient seems to be still acceptable. Knowledge obtained from the monitoring were also used in design of the new pre-tensioned beams, those production will start next year.
Introduced work shows how important role play monitoring and testing of parameters, which have a decisive effect on the proper behavior of prestressed precast members.

References

[1] CHANDOGA M., HALVONIK J., JAROŠEVIČ P. *The monitoring of DPS-VP-97 bridge beam*, Projstar PK Ltd., Bratislava, 2002.

[2] ČSN 736207: Design of prestressed concrete bridge structures, 1993

[3] prEN 1992-1-1: Design of concrete structures - Part 1.1: General rules and rules for Buildings