

Cambers of prestressed precast bridge girders, prediction vs. reality

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ABSTRACT: This paper deals with investigation of reasons of deviations of actual cambers from predicted values that were observed on precast bridge girders where prestress transfer is divided into two stages. The first part of prestressing is introduced by pre-tensioned strands and usually starts only 18 hours after casting and the second part by three post-tensioned curved tendons stressed one or two month later. The problem was analyzed from structural and technological aspects.

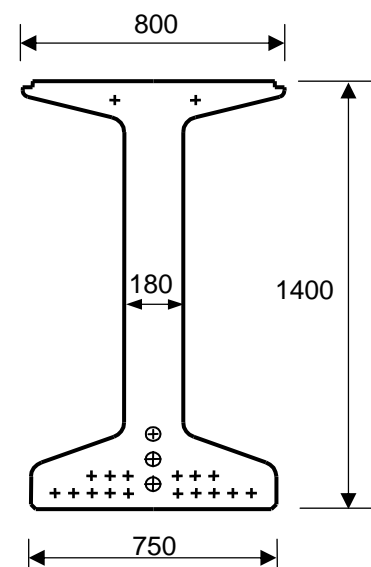
1 INTRODUCTION

Continuous slab-on-girder bridges with RC diaphragms belong to the most frequent option for construction of long elevated highways in Slovakia. These bridges are mostly composed of 32 m long precast beams with the depth of 1,4 m, see figure 1. Construction technology required dividing of prestressing into two parts. The first part is introduced by pre-tensioned strands 18 hours after beam casting and the second part through three post-tensioned curved tendons stressed one or two month later. Each tendon consists of four strands (strand sectional area is $141,6 \text{ mm}^2$ and $f_{pk} = 1800 \text{ MPa}$). During construction of the elevated 17 span highway in northern Slovakia, some important differences were found

between the cambers of erected beams. The cambers were ranging from - 40 mm to + 8mm deflection. The predicted value was -35 mm. The most frequently observed values were about - 22 mm. Inspectors responsible for quality control asked for explanation. They were afraid that the full part of pretension prestressing force could not develop due to partial loss of the bond between very young concrete and pre-tensioned prestressing strands. Although the load capacity of beams and bridge structure were proven by very strong in situ load tests, the producer decided to check the beam production in the precast plant and find out the reasons of this problem.



Figure 1. Beams at storage yard



2 MONITORING OF THE BEAMS

Monitoring of the beams consisted of in situ measurements and laboratory testing of some material properties. In situ measurements included:

- Measurements of the cambers
- Measurements of the prestressing forces
- Measurements of the concrete strains

Monitoring covered time interval limited by:

- Strand tensioning at the plant
- Stressing of four-strand tendons at the storage yard
- Partial time of storage.

Detailed monitoring was carried out on four precast beams with length of 32,1 m. Beams N1 and N2 were prestressed by 16 strands in the bottom part, see figure 3, and by 2 strands located in the upper flange. Beams N3 and N4 (on running solution of the problem) had the same strand lay-out, however upper strands were separated on the length of 20 m in the central section and they were cut shortly after prestress transfer. Moreover, beam displacement was measured on further three beams N01, N02 and N03.

2.1 Cambers

Cambers were monitored for all above mentioned beams. The first measurement was performed just after prestress transfer at the prestressing bed and the last one during stressing of post-tensioned tendons.

Measured deformations just after prestress transfer of pre-tensioned tendons are in figure 2. Applied prestressing forces that had always lifted beams and

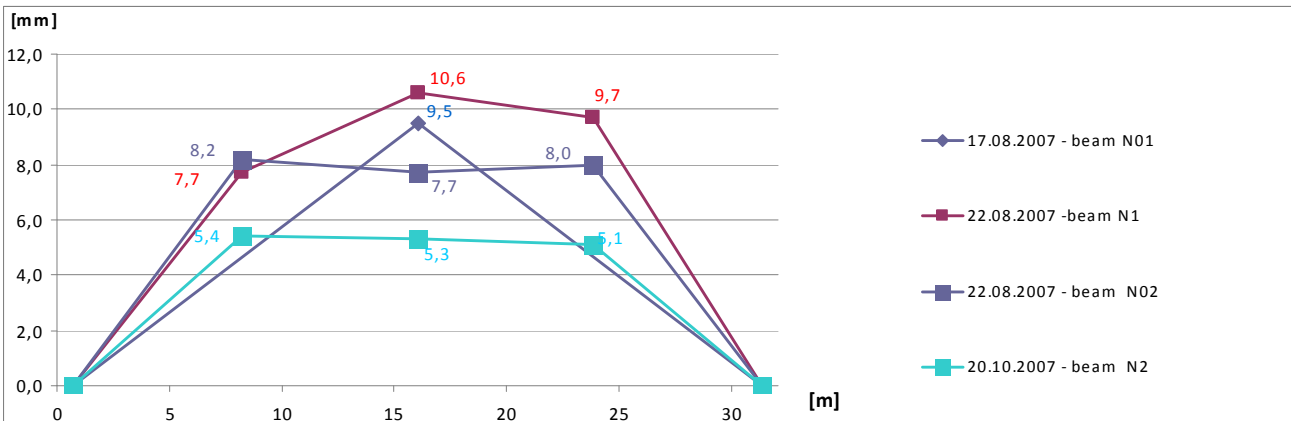


Figure 2 Cambers of the beams just after prestress transfer in formwork

measured cambers were even higher than the predicted value 7,5 mm for the most of the monitored

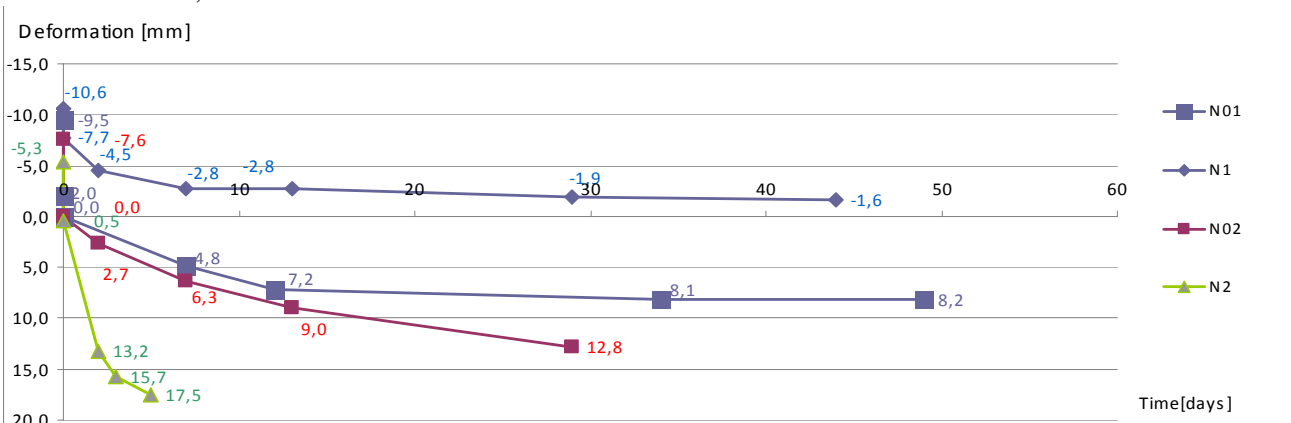


Figure 3 Development of cambers in the middle of the beams

beams. However beams began to loose their camber within several minutes, see figure 3, 4 and original cambers changed into deflection in many cases contrary to the prediction when increment of cambers was expected. The same behavior was observed on the beams N3 and N4 with separated upper strands. A large range of deformation was very typical.

Much better results were obtained during stressing of post-tensioned tendons. Measured deformation due to effect of three four-strand tendons is in figure 5. Increment of cambers was ranging between 22,7 mm and 23,2 mm. These results were also in very good coincidence with predicted values 22,8 mm. Assessment of beam deformation was carried out assuming mature high-performance concrete C55/67 and an average modulus of elasticity of 45 GPa. These values are proven by laboratory tests of more than 300 cube samples tested on strength and 50 prisms tested on modulus of elasticity.

2.2 Prestressing forces

The main goal of the measurements was to determine actual prestressing forces applied to the beams by strands and tendons and as well as monitoring of immediate and long-term prestress losses in the strands. Prestressing forces were measured by elastomagnetic sensors Projstar type PSS16, PSS20, PSS50 embedded on the strands in a section that was located the middle of the beam. All sensors were calibrated with precisions dynamometer DMS PAUL.

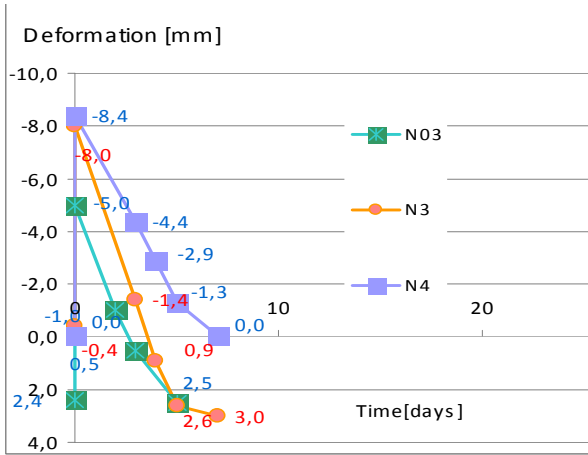


Figure 4 Development of cambers

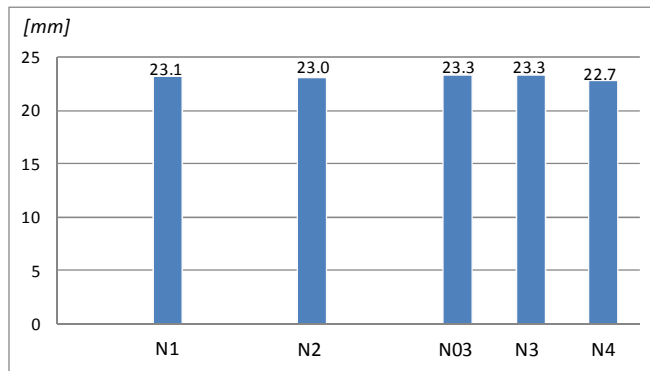


Figure 5 Deformations due to post-tensioned tendons

The comparison of prestressing forces in monitored pre-tensioned tendons located in bottom part of the beam is in figure 7. Average value of prestressing force before transfer was 198,4 kN, while minimum projected value 192 kN (used in design), average value just after transfer 191,7 kN. It means that immediate losses due to elastic shortening of concrete were in average -6,7 kN (-47 MPa). While predicted value was -6,9 kN (assumed modulus of elasticity for concrete 38 GPa and prestressing steel 190 GPa).

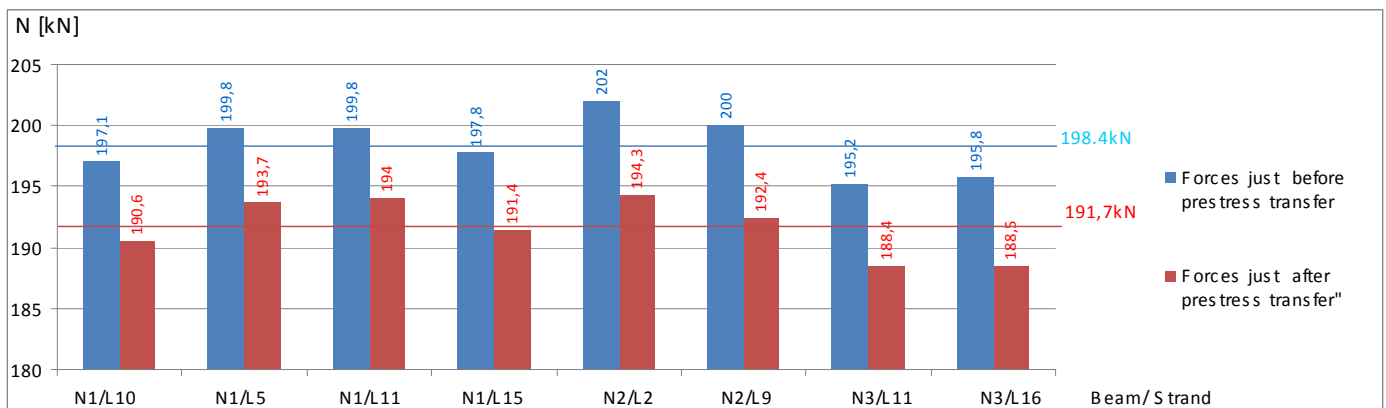


Figure 7 Measured prestressing forces in the bottom strands

Measured losses of upper strands were nearly -7 kN, while predicted ones only -5,7 kN. It shows much higher deformation of upper concrete layers than it was expected.

More detailed data dealing with prestressing forces in beam N2 are in table 1. Beam N2 was characte-

rized by a large increment of deflection that developed within 5 days. Deflection was also confirmed by a higher increment of prestress losses in the upper strands. In spite of lower predicted stresses/strains of upper concrete layers at prestress transfer an increment of prestress losses was nearly two times higher than in the lower strands. This phenomenon could not be explained by insufficient prestressing forces due to e.g. excessive prestress losses.

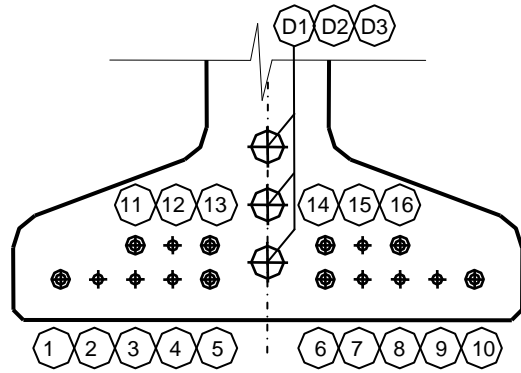


Figure 6 Tendon lay-out and designation

Table 1 Prestressing forces in kN

Stage	Lower strands		Upper strands	
	L2	L9	L24	L25
Before transfer	202,0	200,0	198,1	198,7
Just after transfer	194,3	192,4	191,1	191,9
Change	-7,6	-7,7	-7,1	-6,8
5 days after transfer	192,0	189,7	186,1	185,5
Change	-2,3	-2,7	-5,0	-6,4

Generally, monitoring of prestressing forces has shown good quality of prestressing works at the plant. Introduced prestressing forces by both pre-tensioned and post-tensioned tendons were within expected values or higher. Excessive deformations had to be caused by the other effects.

2.3 Concrete strains

Concrete strains were measured by highly sensitive strain gauges embedded in sections that were located in middle of precast beams. Position of the strain gauges in cross-section is in figure 8. Three strain gauges were used in beam N1, two in beams N2, N3

and N4 (TEN1 and TEN 3). Comparison of predicted values (P) and measured values (M) of the concrete strains at prestress transfer is in table 2. Theoretical strains were calculated with modulus of elasticity of 18-hours old concrete $E_{c,eff} = 38$ GPa. Corresponding stresses in the concrete were: top of the beam $-7,31$ MPa, bottom $-9,14$ MPa. In case of beams with separated upper strands $-4,27$ MPa and $-9,91$ MPa respectively.

Measured strains of upper concrete layers were always higher than the predicted ones, in spite of the fact that the projected value of prestressing force was introduced by pre-tensioned tendons. Even curvature of the monitored central cross-section had a different sign compare to the theory.

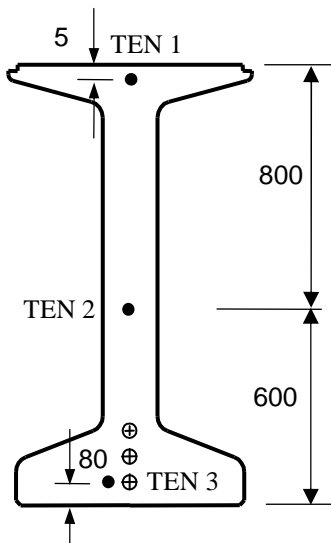


Figure 8 Position of tensometers

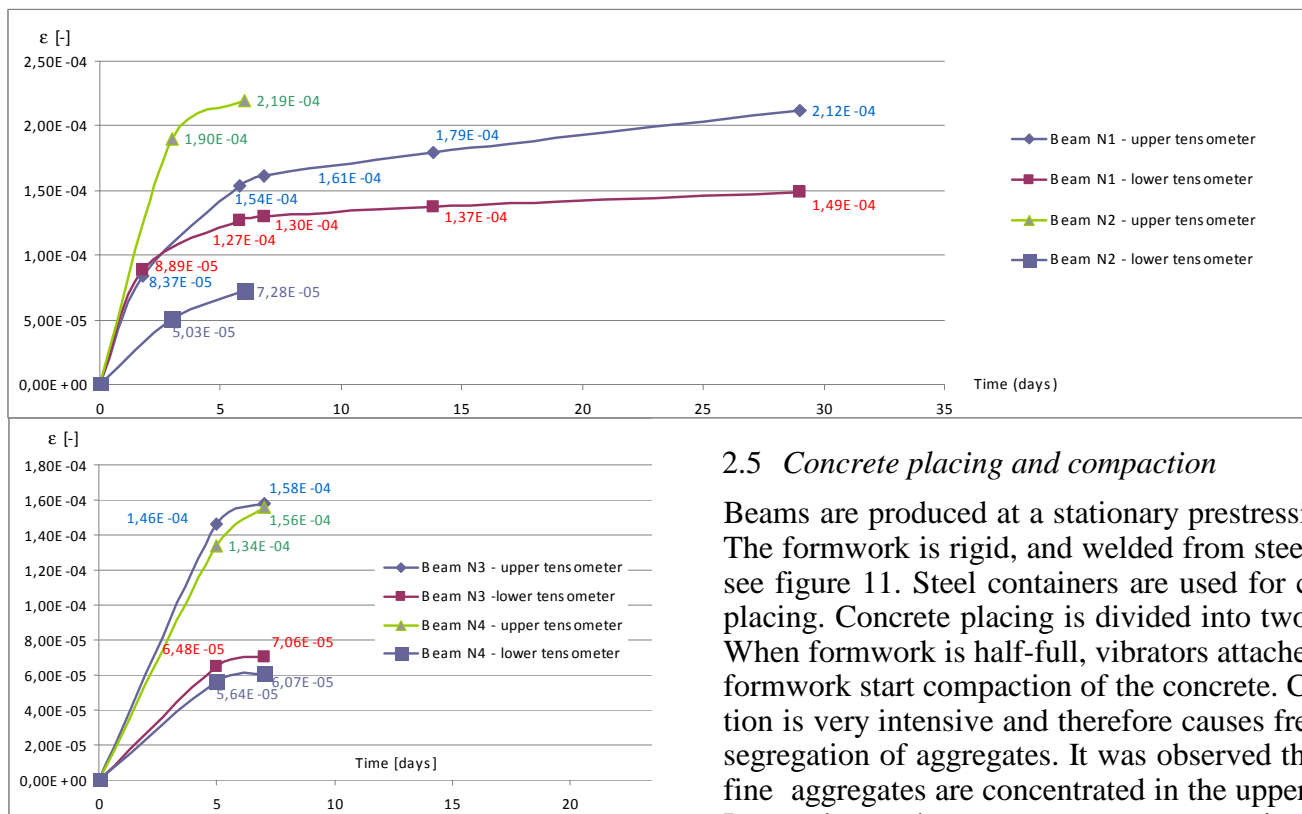


Figure 9 Time development of concrete strains

Time development of the concrete strains is in figure 9. Increment of strains (shortening) measured by upper strain gauges has always been larger than in lower ones. It confirmed development of deflection in the middle of the beams, see also figure 3, particularly for beam N2. These deflections were not result of long-term prestress losses, because e.g. the prestress losses in beam N2 were only -17 MPa within 5 days.

Table 2. Measured (M) and predicted values (P) of strain (stage – at prestress transfer)

Beam	TEN 1		TEN 3	
	P	M	P	M
N1	2,05	3,06	2,52	2,50
N2	2,05	2,47	2,52	2,50
	10^{-4}	10^{-4}	10^{-4}	10^{-4}

CONCRETE TECHNOLOGY

2.4 Concrete mix

The concrete used for pouring of the precast beam is C55/67 strength class. High strength concrete has been used in order to achieve required compressive strength within 18 hours. According to the long-term testing an average cube compressive strength was 45 MPa, and for modulus of elasticity 38 GPa in 18 hours. The 28-days average cube compressive strength was over 80 MPa and modulus of elasticity was between 45 and 50 GPa.

2.5 Concrete placing and compaction

Beams are produced at a stationary prestressing bed. The formwork is rigid, and welded from steel plates, see figure 11. Steel containers are used for concrete placing. Concrete placing is divided into two stages. When formwork is half-full, vibrators attached to the formwork start compaction of the concrete. Compaction is very intensive and therefore causes frequently segregation of aggregates. It was observed that more fine aggregates are concentrated in the upper flange. It makes the concrete cross-section non-homogeneous along the beam depth. This observation was also confirmed by further laboratory tests.

Table 3. Comparison of concrete properties after 18 hours

Specimen	Type	γ	$f_{c,cube}$	E_c
		kg/m ³	MPa	GPa
#1	upper layers concrete	2281	63	34,6
#2		2280	63	35,7
#3		2251	60	33,8
#1	reference concrete	2400	74	48,6
#2		2370	65	46,7
#3		2310	64	45,2

stressing was not the primary reason of these phenomena. All observed beams began to lose camber shortly after prestress transfer, contrary to the prediction when very small growth of cambers was expected.

Big differences between beams were observed in spite the fact that prestressing forces were ranging within 5 %, e.g. beam N1 lost 11 mm within 40 days, while beam N2 lost 22 mm within 5 days. A very similar situation has occurred with N3 and N4 beam where separation of upper strands was carried out. In spite of much higher lifting effects of prestressing the beams lost 8,4 and 11 mm within 6 days.

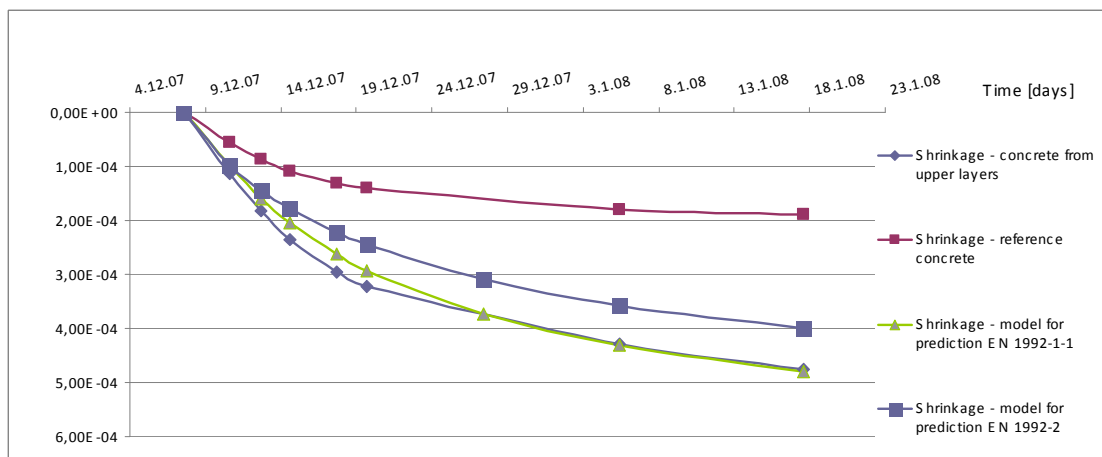


Figure 10 Strains due to shrinkage

Concrete samples were taken from upper layers of the beams just after intensive compaction and tested for shrinkage, modulus of elasticity, compressive strength and density. Results were compared with reference concrete, taken from the same concrete batch. The comparison of the results is in table 3. The results confirmed worse properties of concrete from upper layers compared to the normal concrete. The particular differences between shrinkage of both concrete casts are very significant. Shrinkage of concrete taken from upper flange was two times higher than shrinkage of reference concrete, see figure 10.

CONCLUSIONS

Differences between measured and predicted values of cambers in prestressed beams are very frequent. Moreover actual cambers have sometimes large scatter which may evoke doubts concerning of quality of precast products. Lower cambers are usually referred with insufficient prestressing and low quality of prestressing works.

However the problem is more complex and technological aspects may have even stronger influence on a beams behavior than structural ones. Monitored precast beams with the length of 32 m represent a very good example. The investigation of low cambers and large differences between beams has shown that pre-

According to our experience and our investigation the major role played here used the technology of concrete placing and the way of concrete compaction which makes the beam cross-section non-homogenized. Particularly when concrete is a young, big difference between shrinkage of upper concrete layers and lower ones lead to development of constant curvature and pushes beams downward. The shrinkage of upper concrete layers is amplified by the condition at the storage yard. Beams mature each side by side so only the upper surface is directly exposed to ambient conditions. Because shrinkage is a very random phenomenon measured cambers or displacement have large scatter. Additional deformation due to different shrinkage is permanent. This means that it becomes frozen in the beam forever. Further allowance of low cambers may be caused by different mechanical properties of the concrete along the beam depth. Higher modulus of elasticity of young concrete in the bottom part moves the centre of gravity downward, which makes bending effect of prestressing lower compared to the theoretical values.

The monitoring and research of this problem is still continuing. In order to separate different effects, we started with monitoring shrinkage on non prestressed segments of the beam (length 1 m). Continuous strands are separated by PE pipes. Segments are made along with a beam in the some formwork, us-

ing the original technology of placing concrete and intensity of vibrators (see figure 11). The results of measurement on the first segment are shown in the figure 12. It is clear that the upper part of segment is very sensitive to extensive shrinkage. Through simple calculation, this effect after 5 days on a 32 m long beam gives about 10 mm of deflection. By measuring shrinkage gradients over the height of segments and comparing them with the reference samples (as shown in chapter 3) we would like to find the answer for technological or technical solution of the camber loss. The first solution was increasing the bending effect of the first prestressing, by partial separation and cutting of upper strands.

Figure 12 Strains due to shrinkage measured on beam segment

7 ACKNOWLEDGEMENT

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