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# TIME DEPENDING DEFORMATION OF PRE-POST TENSIONED BEAMS

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Abstract

**The paper deals with investigation 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 only 18 hours after casting and the second part by three post-tensioned drapped tendons stressed one or two month later. The problem is analyzed from structural and technological aspects.**

Streszczenie

**W artykule przedstawiono badania odchyleń rzeczywistych strzałek odwrotnych od wartości przewidywanych, jakie obserwowano na prefabrykowanych dźwigarach mostowych w których przekazanie siły sprężającej następowało w dwóch etapach. Pierwsza część sprężenia była realizowana przez cięgna sprężające zaledwie w 18 godzin po zabetonowaniu, a druga część przez trzy osłonięte kable sprężane jeden lub dwa miesiące później. Zagadnienie analizowano zarówno z konstrukcyjnego, jak i technologicznego punktu widzenia.**

Keywords: **Cambers; Bridge girders; Pre-tensioned; Post-tesioned; Strain; Curvature.**

## 1. INTRODUCTION

Continuous slab-on-girder bridges with RC diaphragms over the intermediate piers belong to the most frequent options of long elevated highways construction in Slovakia. These bridges were mostly composed of 32 m long precast beams DPS VP I-04, see Fig. 1.

**Figure 1.**
**Elevated highway built from DPS VP I-04 beams in the city of Poprad**

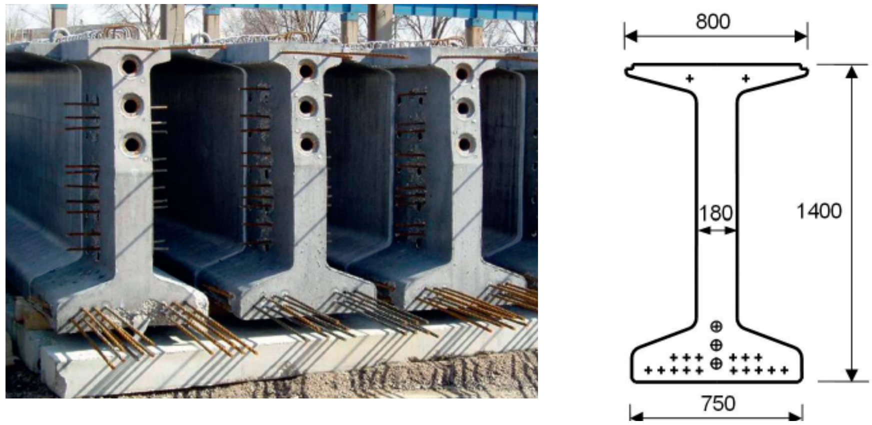


**Figure 2.**
**Beams DPS-VP I04 at storage yard**

DPS VP I-04 beams were originally designed as pre-tensioned members for simply supported structural systems where prestress transfer is introduced in one sequence. In order to achieve continuity over the intermediate supports it was necessary to divide pre-stressing into two parts. The first part is introduced by pre-tensioned strands 18 hours after beam casting and the second one by three post-tensioned drapped tendons tensioned one or two month later. Each tendon consists of four strands (strand sectional area is 141.6 mm$^2$ and $f_{pk}$ = 1800 MPa), see Fig. 2. However, during construction of the 17 spans elevated highway composed of DPS VP I-04 beams in the city of Poprad large differences were found between the cambers of the erected beams. Cambers were ranging from +40 mm to deflection -8 mm.

Predicted value was 35 mm. The most frequently observed values were 24 mm. Inspectors responsible for quality control stopped further construction of works, because there were doubts concerning sufficiency of prestressing. They were afraid that the part of prestressing force could not develop due to partial loss of the bond between very young concrete and prestressing steel. Consequently contractor has decided to check its beam production in the plant and find out the reasons for this problem. Because production of the beams was continuing, it was necessary to prepare very quickly possible comprehensive plan of the investigation. Load test of selected beam from the storage yard which was prestressed only by pre-tensioned tendon was proposed as well as detailed monitoring of several new beams.

## 2. LOAD TESTS

### 2.1. Goals of the load test

Load test was performed on selected beam pre-stressed only by pre-tensioned tendon. Prestressing, self weight and testing load should generate tensile stresses up to 3 MPa in the extreme fibres if pre-stressing force is fully introduced in beam. Because beams were cast of concrete C55/67 no cracks were expected at that moment. Opposite, if prestressing is not properly introduced due to e.g. loss of the bond, the cracks should have developed. Tested beam had deflection of -2 mm while predicted camber was +8 mm.

**Figure 3.**
**Load test of the 32 m long DPS VP I-04 beam**

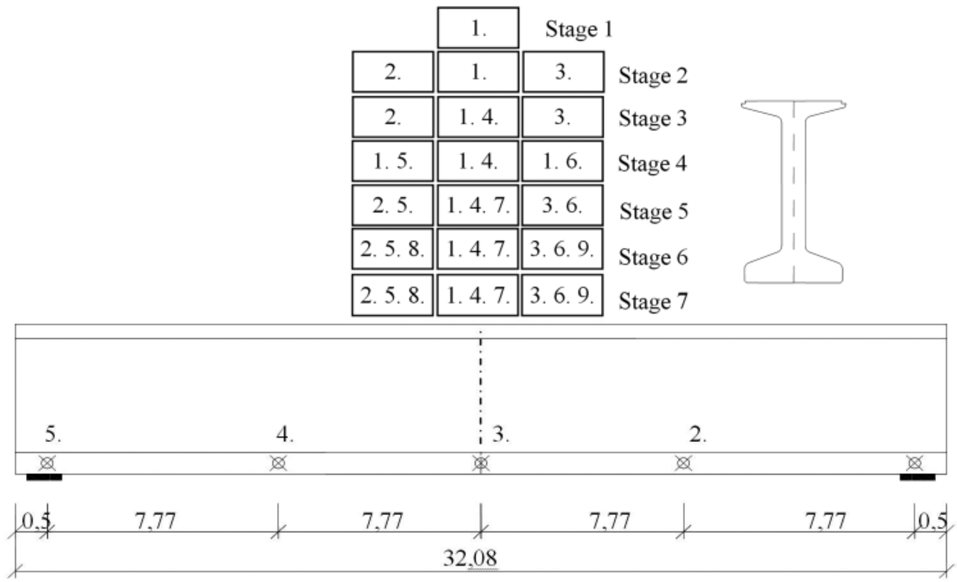


**Figure 4.**
**Arrangement of testing load**

### 2.2. Testing loads

Testing load consisted of nine steel plates with dimensions of 2.1×0.85×0.21 m each having weight 2.93 metric tons (29.3 kN). The maximum load (stage 6, 7) represented 41.85 kN/m on the length of 6.4 m. The maximum load was kept on the beam for 60 minutes. Load arrangement is presented in Fig. 4.

### 2.3. Results of the load test

Predicted deflection due to full testing load was 28.9 mm at mid span if modulus of elasticity $E_c$=45 GPa is assumed. The value of $E_c$ was determined based on the long-term measurements of modulus of elasticity which were carried out by manufacturer for used concrete C55/67. Measured deflection 32.3 mm was 11.7 higher than predicted value. Concrete strains were measured at mid-span section together with deflection. Attached strain gauges were used. Measured values are shown in Fig. 5. Measured value of 210 microstrains in the bottom shortly after full loading was lower than predicted value of 240 microstrains. Opposite measured deformation of 320 microstrains in the top was higher than predicted value of 300 microstrains.

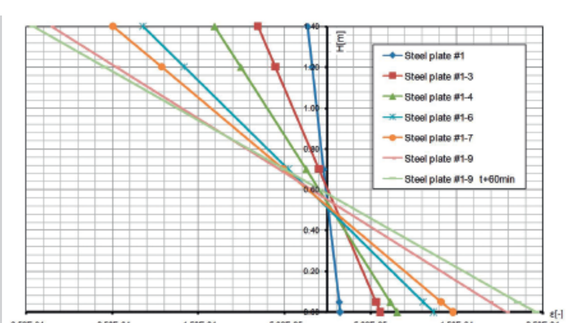


**Figure 5.**
**Strain distribution due to testing load**

The measurements indicated non-homogeneity of cross-section along the beam depth and explained larger deflection than it was predicted. Visual control of the bottom flange did not reveal any cracks in the tested beam.

## 3. 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.
- Measurements of the curvature on the 1 m long beam segments.

Monitoring covered time interval limited by strand tensioning at the plant and stressing of four-strand tendons at the storage yard.

Detailed monitoring was carried out on four 32.1 m long precast beams. Beams N1 and N2 were prestressed with 16 strands in the bottom flange and with 2 strands located in the upper flange, see Fig. 2. Beams N3 and N4 had the same strand lay-out,

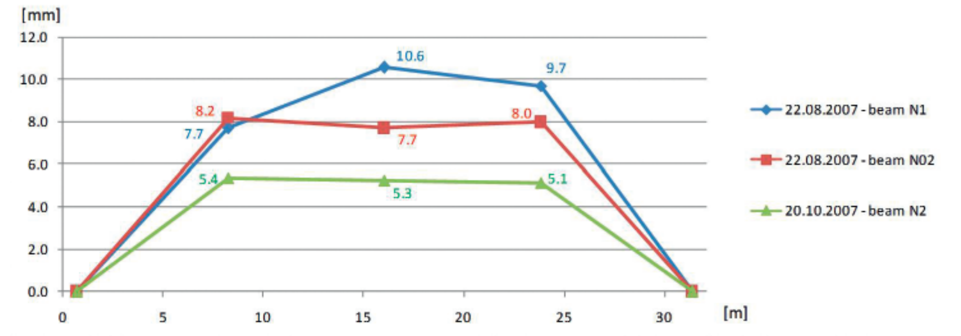


**Figure 6.**
**Cambers of the beams just after prestress transfer in formwork**

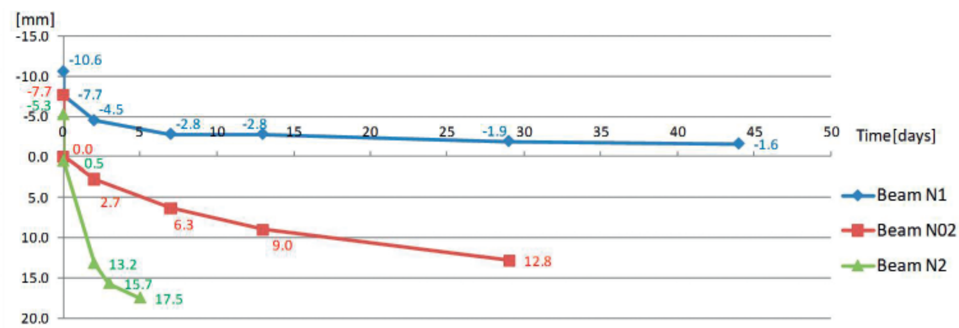


**Figure 7.**
**Development of cambers in the mid-span of the beams**

except for upper strands that were separated on the length of 20 m in the mid part of beams. Separated part of strands was removed from beams shortly after prestress transfer. Moreover, beam cambers were measured on further three beams N01, N02 and N03.

### 3.1. 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 presented in Fig. 6.

Applied prestressing forces had always lifted beams at the mid-span and measured cambers were even higher than the predicted value of 7.5 mm for several monitored beams. However, beams began to loose their camber within several minutes, see Fig. 7 and Fig. 8 and original cambers changed into deflection in many cases contrary to the prediction when incre-

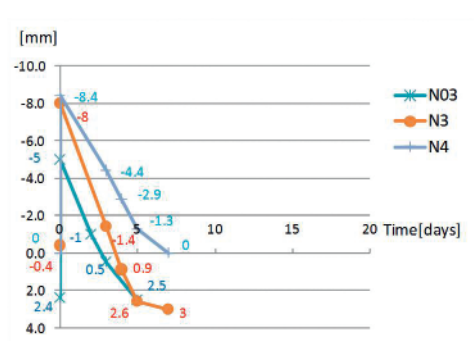


**Figure 8.**
**Development of cambers**

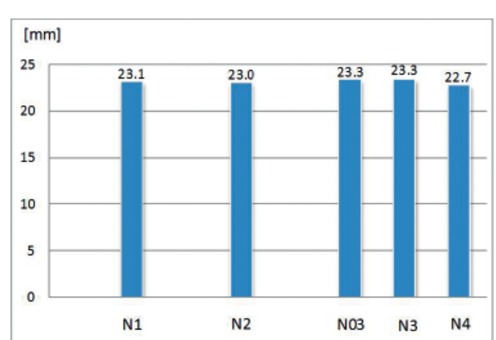


**Figure 9.**
**Deformations due to post-tens. tendons**

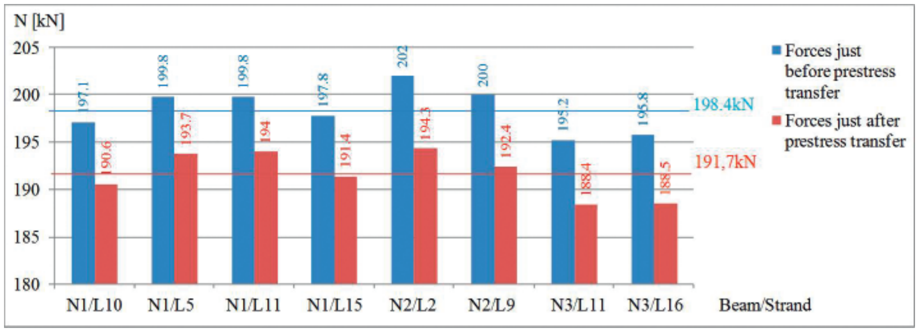


**Figure 10.**
**Measured prestressing forces in the bottom strands**

ment of cambers was expected. The same behaviour was observed on the beams N3 and N4 with separated upper strands. Very typical was large scatter of deformation. Much better results were obtained during stressing of post-tensioned tendons. Measured deformation due to effect of three four-strand tendons is shown in Fig. 9. Increment of cambers was ranging between 22.7 mm and 23.2 mm. This results were also in very good coincidence with predicted values 22.8 mm. Assessment of beam deformation was carried out assuming high-performance concrete C55/67 and average modulus of elasticity 45 GPa.

### 3.2. Prestressing forces

The main goal of the measurements was to determine actual prestressing forces applied to the beams by strands and tendons as well as monitoring of immediate and long-term prestress losses in the strands. Prestressing forces were measured by elasto-magnetic sensors Projstar type PSS16, PSS20, PSS50 that were embedded on the several strands in sections located at the mid-span.

Comparison of prestressing forces in monitored pre-tensioned tendons located in bottom flange is shown in Fig. 10. Average value of prestressing force per strand before transfer was 198.4 kN, while minimum projected value was 192 kN (used in design). Average value just after transfer was 191.7 kN. It means that immediate losses due to elastic shortening of concrete were on average -6.7 kN (-47 MPa), while predicted value was -6.9 kN.

Measured losses in upper strands were nearly -7 kN, while predicted ones were 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 included in table 1. Beam N2 was characterized by large increment of deflection that developed within 5 days. Deflection was confirmed also by higher increment of prestress losses in the upper strands. In spite of lower calculated compressive stresses/strains in upper concrete layers increment of prestress losses was nearly two times higher than in the bottom strands. This phenomenon could not be explained by insufficient prestressing forces due to e.g. excessive prestress losses.

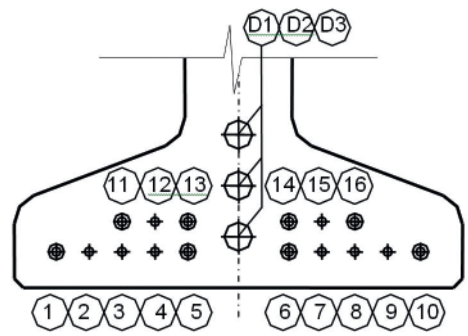


**Figure 11.**
**Development of cambers**

**Table 1.**
**Prestressing forces in kN**

| | Lower strands | | Upper strands | |
|---|---|---|---|---|
| Stage | 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 been caused by other reasons.

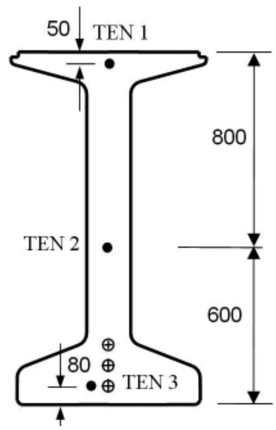


**Figure 12.**
**Position of tensometers**

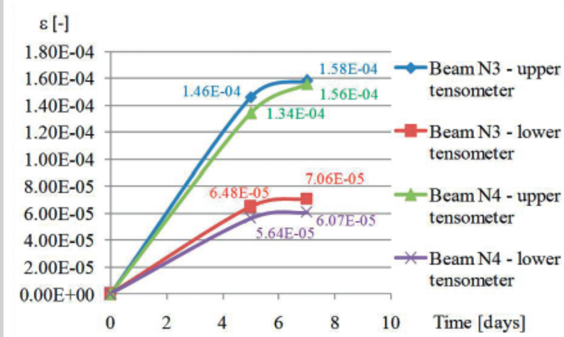


**Figure 13.**
**Time development of concrete strains**

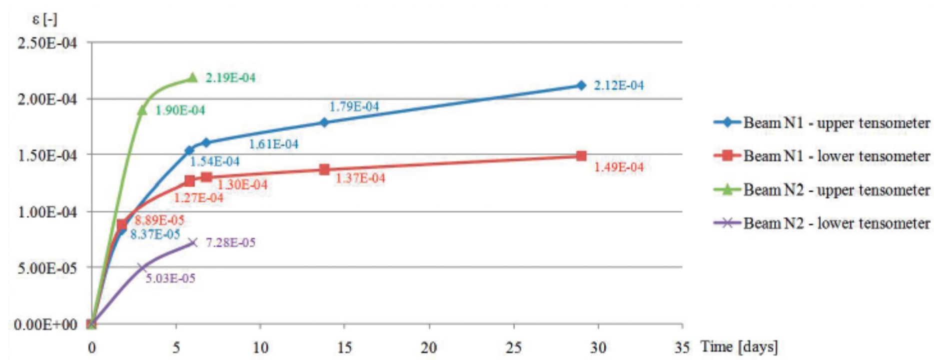


**Figure 14.**
**Time development of concrete strains**

### 3.3. Concrete strains

Concrete strains were measured with highly sensitive strain gauges embedded in sections that were located at mid-span of precast beams. Position of the strain gauges in cross-section is shown in Fig. 12. Three strain gauges were used in beam N1, two in beams N2, N3 and N4 (TEN1 and TEN 3). 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 predicted ones. in spite of the fact that introduced prestressing forces have always reached projected values. Even curvature of monitored mid-span cross-sections had a different sign compare to the theory.

Time development of the concrete strains is shown in Fig. 13 and Fig. 14. Increment of strains (shortening) measured by upper strain gauges has always been larger than in lower ones. It confirmed development of deflection of beams see also Fig. 7, particularly for beam N2. These deflections were not result of long-term prestress looses, because e.g. the prestress losses in beam N2 were only -17 MPa within 5 days.

### 3.4. Curvature due to uneven shrinkage

Three 1 m long segments were cast together with precast beams. Segments had the same cross-section as actual beams, see Fig.15 and they remained non-prestressed. Three tensometers were embedded in each segment. The first one was located in the bottom flange 60 mm far from the surface, the second one in the web – upper flange connection and the last one 40 mm far from the top of the beams. Difference between strains measured by upper and lower tensometer allowed us to determine curvature due to uneven

Figure 15.
**Segment in prestressing bed before casting and segment at the storage yard**

shrinkage of the concrete along the beam depth.

An example of time development of the strains in segment #3 is presented in Fig. 16. Measurements have shown differences between strains of the upper and lower flange, strains in upper flange were larger than in the bottom flange for all three segments. Differences were ranging from 100 to 130 micro-strains and thus curvature was ranging from $7.7 \cdot 10^{-5}$ m$^{-1}$ to $10 \cdot 10^{-5}$ m$^{-1}$. Displacement due to the uneven shrinkage more than -11 mm was determined by numerical integration.

## 4. CONCRETE TECHNOLOGY

### 4.1. Concrete mix

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. 28-days average cube compressive strength was over 80 MPa and modulus of elasticity between 45 and 50 GPa. Following concrete composition has been used: Portland cement CEM I – 520 kg. water 135 liters. aggregates (0-4 mm) – 660 kg, (4-8 mm) – 200 kg and (8-16 mm) – 810 kg, microsilica 18 kg and superplasticizer HP1 7.6 kg. Water/cement ratio is 0.27, but value might be variable, because of natural moisture of aggregates.

### 4.2. Concrete placing and compaction

Beams DPS VP I-04 are produced at stationary pre-stressing bed. Formwork is rigid. welded of steel plates, see Fig.15. Steel containers are used for concrete placing. Concrete placing is divided into two

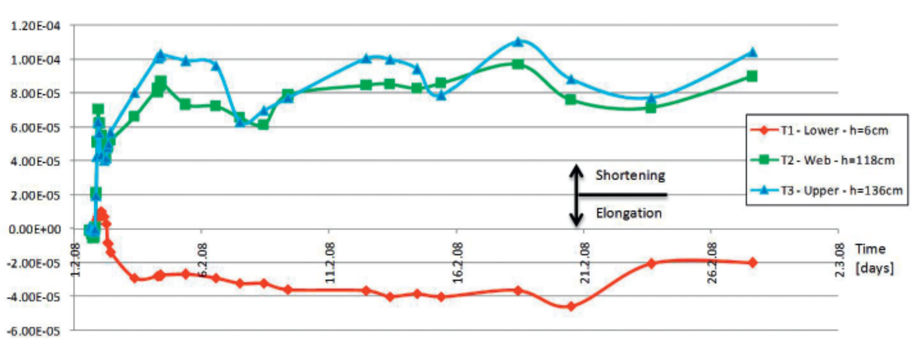


Figure 16.
**Time development of concrete strains in 3 segment**

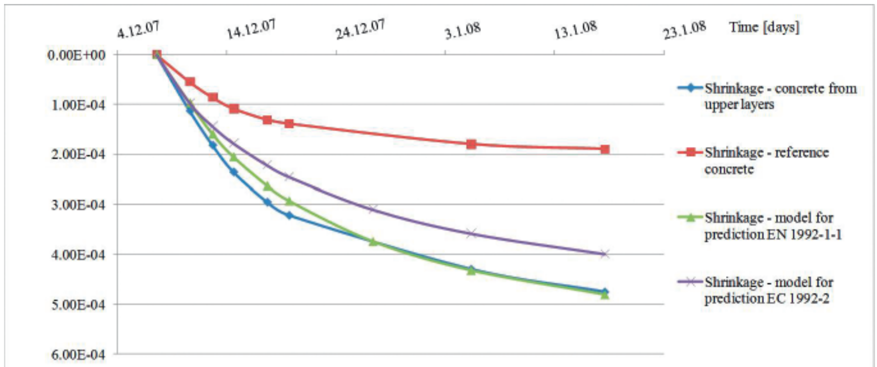


**Figure 17.**
**Strains due to shrinkage**

stages. When formwork is half-full, vibrators attached to formwork start compaction of the concrete. The same procedure is used when formwork is full. Compaction is very intensive and therefore causes frequently segregation of aggregates. It was observed that fine aggregates concentrate in the upper flange with thin layer of water on the upper surface (the concrete looks more like mortar after hardening), and sedimentation of larger aggregates occurs too. It makes concrete cross-section non-homogeneous along the beam depth. This observation was confirmed also by further laboratory tests.

**Table 2.**
**Comparison of concrete properties**

| Specimen | Type | $\gamma$ | $f_{c.cube}$ | $E_c$ |
|---|---|---|---|---|
| | | 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 |

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. Comparison of the results is presented in table 2. Results confirmed worse properties of concrete from upper layers compared to the normal concrete. Very significant are particularly differences between shrinkage of both concretes. Shrinkage of concrete taken from upper flange was two times higher than shrinkage of reference concrete, see Fig. 17.

## 5. 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 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 beam behavior than structural ones. Precast beams DPS VP I-04 with the length of 32 m set very good example. The investigation of low cambers and large differences between beams has shown that insufficient prestressing was not the primary reason of these phenomena. All observed beams began to loose 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. 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.

According to our experience and our investigation the major role played here used technology of concrete placing and the way of concrete compaction which makes beam cross-section non homogeneous, particularly when concrete is young. Big differences between shrinkage of upper concrete layers and lower ones lead to development of constant curvature and pushed beams downward. It was confirmed by test of three 1 m long non prestressed segments with the same cross-section as precast beams (having the same notional size). Deflection over 10 mm associated with developed curvature due to uneven shrinkage was in good coincidence with measurements of beam deformations. The shrinkage of upper concrete layers can be amplified by condition at the storage yard. Beams mature each side by side so only upper surface is directly exposed to ambient conditions. Because shrinkage is very random phenomenon measured cambers or displacement have large scatter. Additional deformation due to uneven shrinkage is permanent. It means that 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 neutral strain axis (centre of gravity) downward, which makes bending effect of prestressing lower compared to the theoretical values.

## ACKNOWLEDGEMENT

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