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SOME DETAILS OF LONG-TERM ANALYSIS OF CONCRETE BRIDGES

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SUMMARY

Prestressed concrete bridges of large span often exhibit larger long-term deflections than it was assumed in the design calculations. The paper aims to illustrate some effects which influence the deflections growth with time. The effects of grouted tendons on the stiffness of the cross section, shear strains in webs and shear lag, and short-term temperature changes are briefly mentioned on the example of a real bridge.

Keywords: bridge, concrete, cracking, creep, deflection, shear, shear lag, temperature

1. INTRODUCTION

Cast in situ prestressed concrete bridges usually exhibit larger long-term deflections than it was assumed in the design analysis [1]. Many influencing factors may be found. The comprehensive research is necessary which evaluates the significance of the individual factors. Prestressed structures are subjected to the dead and live load and to the effect of prestressing which acts in the opposite direction than the load. The loading and prestressing are in certain extent balanced. The resulting deflection of the prestressed beam is a difference of the large deflections which would appear if the load and prestressing performed separately. If the uncertainties in loading, prestressing and structural stiffness are taken into account, it becomes clear that the deflections are extremely sensitive to the arbitrary variation of any of the actions or of the stiffness of the beam. The most important factors influencing the long-term growth of deflections seem to be creep of concrete, differential shrinkage of thick and thin parts of the cross section, cracking in tensile zones, effects of repeated loading induced by traffic and by temperature changes, underestimated prestress losses etc.

The aim of the research conducted at the Czech Technical University is to evaluate some factors leading to improvement of the prediction of long term deflections of prestressed concrete bridges. The paper deals with some parts of this research.

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2. CENTROID OF POST-TENSIONED CROSS SECTIONS

The cross section of box girder bridges develops progressively. Assuming that a segment of the box girder bridge is cast in one stage, the ducts prepared for the prestressed tendons remain initially empty (before grouting). The cross section area is reduced by the area of the ducts. In this stage the tendons are placed into the ducts and stressed. After some period the ducts are filled with grouting mortar and the cross section then acts as a composite section including concrete and steel. If the position of the centroid is calculated a significant difference may be observed between the two mentioned cases. In preliminary design stages the area of the cross section is assumed roughly neglecting the ducts and the prestressing steel. The difference in the position of centroid in the three cases (concrete section, reduced concrete section, composite concrete section) has been observed at the box girder of the bridge at Melnik in the Czech Republic (Fig. 1). The reference case is a concrete section. The difference of the centroidal axis along the girder related to the reference case is plotted in Fig. 2. The extreme difference in the cross sections over the supports where the tendons are concentrated reached about 170 mm, while at the midspan, where the number of tendons is relatively low the difference in the position of the centroid is smaller.

The long term deflections of the bridge were calculated taking the differential position of the centroid in individual cross sections into account. It has been concluded that the difference in final values of deflection is influenced by this effect only in a limited scale of several percents. The initial stage of prestressing which acts on the reduced cross section has only small effect on the long term deflection. If the influence of the changing area of the cross section is neglected the difference between predicted and measured deflections can be observed during construction which is compensated by rectification of segments.

3. SHEAR DEFORMATIONS AND SHEAR LAG

The beam models of box girders may suffer from incorrect modelling of their shear behaviour. The webs of the bridge box girders are rather thin and therefore sensitive to shear deformations. Axial stresses develops initially in webs and then in flanges. The shear deformation of flanges results in shear lag effect. In wide sections the shear lag may be rather significant and it should not be neglected. In the design practice it is usual to take the shear lag into account by means of the effective width concept. This concept is acceptable for reinforced concrete structures. At prestressed concrete structures the shear lag differs for loading and for prestressing. In some cases when there is no shear force induced by prestressing (e.g. straight tendons), there is no shear lag beside that induced by loading. Therefore the concept of effective widths may be used only if the designer is aware of the real performance of the prestressed beam.

An approximate method taking into account the shear lag effects in analysis of long-term behaviour of prestressed concrete bridges has been developed. As an example the deflections of the cast in situ bridge at Melnik are plotted in Fig. 3. The three calculations have been executed: (i) only the bending is considered, effects of shear strain in webs and shear lag is neglected, (ii) bending and shear deformations of webs are taken into account and shear lag is neglected and (iii) bending, shear strain of webs and shear lag are taken into account. The diagram in Fig. 3a shows the deflection of the free end of the first cantilever at the end of its erection (405 days) and before its connection with the second cantilever (685 days). If the shear effects are included in the analysis the deflection is approximately 24% higher than that calculated only according to bending theory.

Fig. 3b illustrates the increase of calculated deflection at the midspan during the 25 years of service life. If only bending is considered the deflection increases about 20 mm. If the shear effects are also taken into account the increase is about 32 mm, which is 56% more. It should be noted that no cracking is assumed in this analysis.

The example shows that although the final deflections are still smaller than the measured values the shear effects are important components of deformation and it is necessary to take them into account.

4. DAILY TEMPERATURE VARIATIONS

Prestressed concrete bridges are exposed to many repeated loads. Beside the traffic load, cyclic temperature changes during the day and year produce tensile stresses which finally may result in cracking and thus in reduction of stiffness. The experimental program has been designed and executed at the bridge at Melnik (Fig. 1).

The temperature variations were measured during the three independent days. The thermometers were located in the top flange in the webs and in the bottom flange. The air temperature was measured under the bridge. Two days in last Summer showed the behaviour in extreme temperatures, but the daily difference did not exceed 6 deg.C. The third day of measurement was in October when the difference between extreme temperatures was about 12 deg.C. The daily temperature variations of air, in the top and bottom flanges are plotted in Fig. 4. The diagram shows that the concrete of the bridge is heated with some delay and as expected, the top flange has higher temperature than the bottom flange.

The deflection line of the bridge was measured by optical levelling. The measurement was repeated three times a day. The morning measurement (10.00) was taken as a reference line. The afternoon levelling (15.30) and evening levelling (19.30) were related to the morning reference values. The relative deflection lines are plotted in Fig. 5. The horizontal axis is a longitudinal coordinate along the bridge. The points where no deflections are measured are over the supports (0, 72, 218 and 290 m). The afternoon measurement showed small increase of deflections, although the temperature were almost extreme due to the delay in heating of concrete. The magnitude of evening deflections was in order of 8.5 mm. In case of the simply supported beam the heating of the top flange would result in upward displacement of the midspan. In case of the continuous beam the deflection depends on the stiffnesses of individual spans. The deep sections over the interior supports and flexible section at the midspan lead to the deformation showing downwards deflection of the midspan. The response is similar to that of the bridges with hinges at the midspan.

The deflection line shows that the middle section is exposed to the positive bending (tensile stress in the bottom flange). The top flange is warmer than the bottom flange which makes the bending moment produced due to redundancy of the beam even higher. This confirms the estimate that the temperature variations may induce the tensile stress in the section (if not covered by prestressing), which can reduce the tensile strength of concrete due to many cycles during the service life.

5. CONCLUSIONS

The paper illustrates selected possible causes of excessive deflections of prestressed concrete bridges and the discrepancy between analysis and measured values. The analysis which is based on the beam elements can be improved if the designer is aware of the weaknesses and simplifications of such approach. The study of the effect of reduction of the section due to ducts before they are filled by grouting showed that this effect is not too important for of deflection analysis.

On the other hand the shear effects have to be taken into account. The example of the analysed bridge showed that shear strains in webs and shear lag cover about 50% of the long-term deflection due to bending effects.

The temperature effects during one day have been investigated experimentally. The measured temperature and deflection line showed that the effect of temperature is rather similar to that of traffic load. The tension is induced in the bottom flange at the midspan and in the top flange over the supports.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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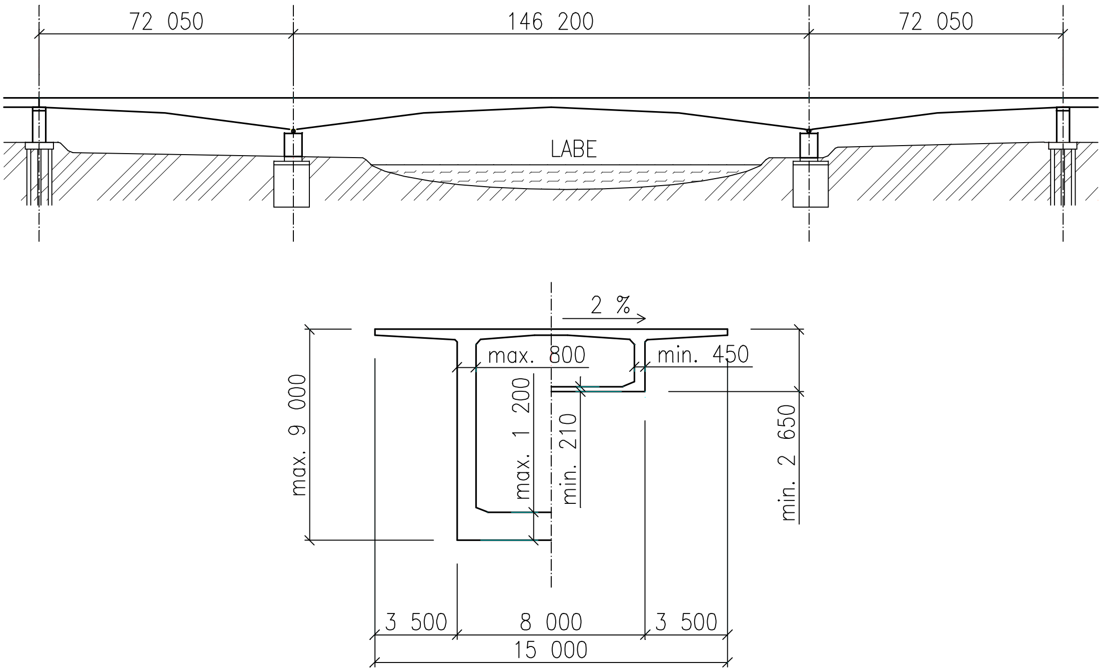

Fig. 1: Elevation and a typical cross section of the bridge at Melnik

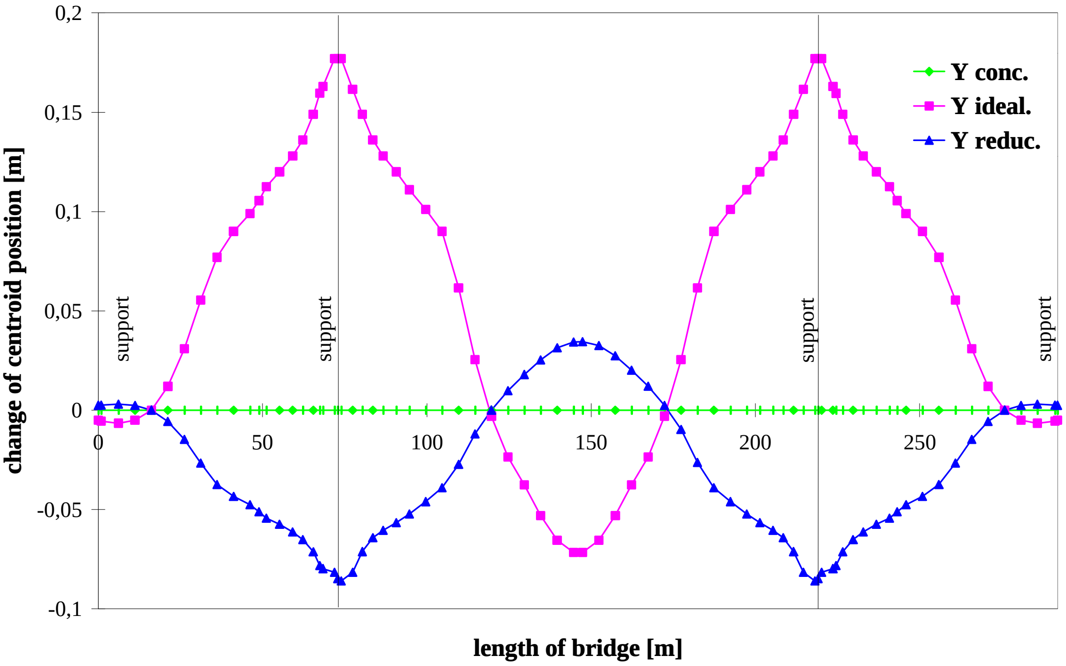

Fig. 2: Variation of the centroid axis along the beam
reference axis - concrete section
concrete section reduced by ducts
composite concrete section

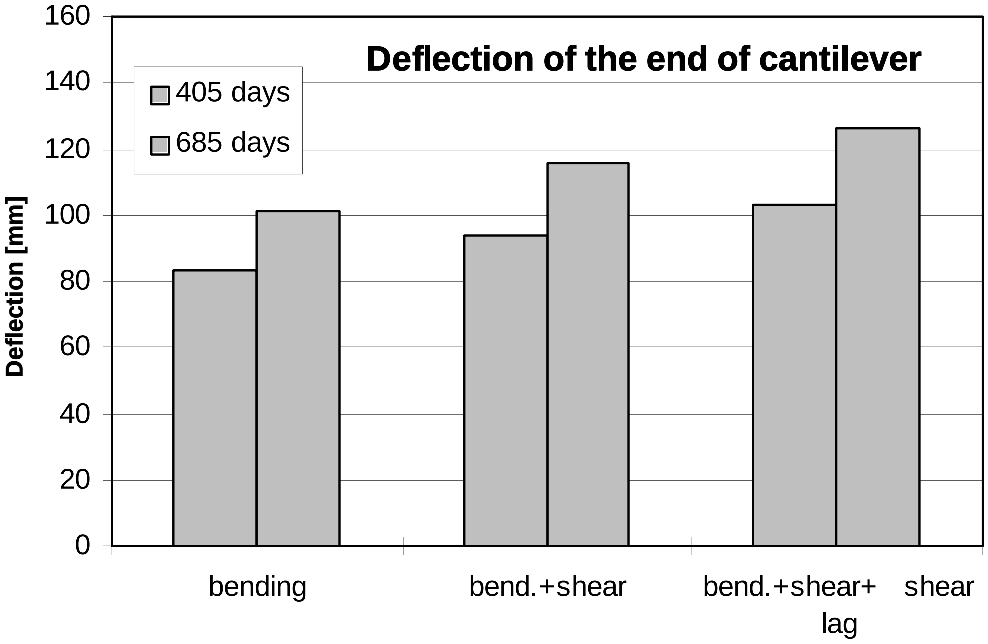

Fig.3a: Deflection increment of the end of the cantilever during construction

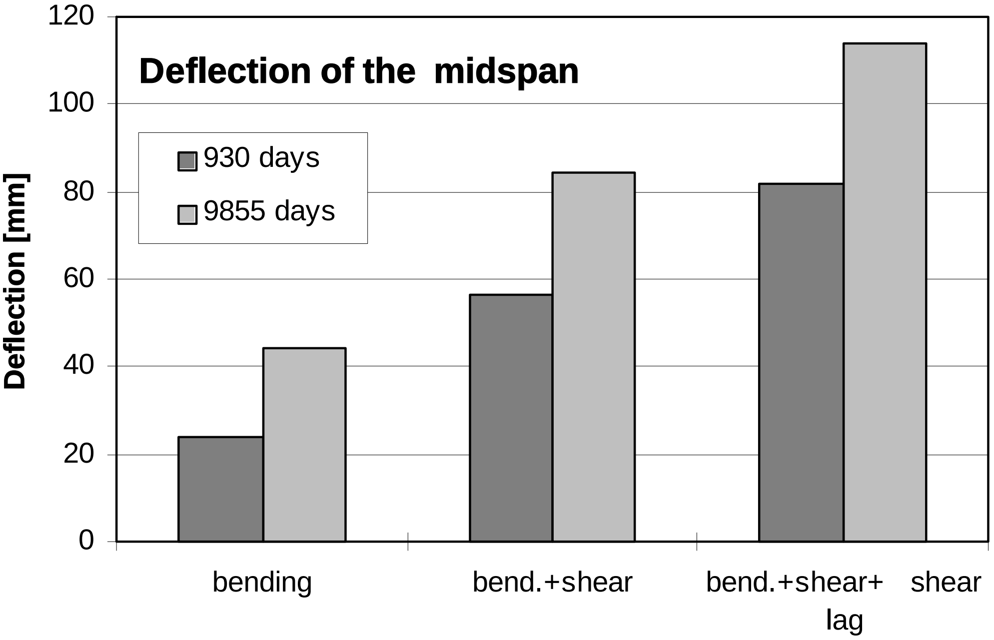

Fig. 3b: Deflection increment of the midspan after completion of the bridge

Fig. 3: a, b, 2 diagrams FIP report

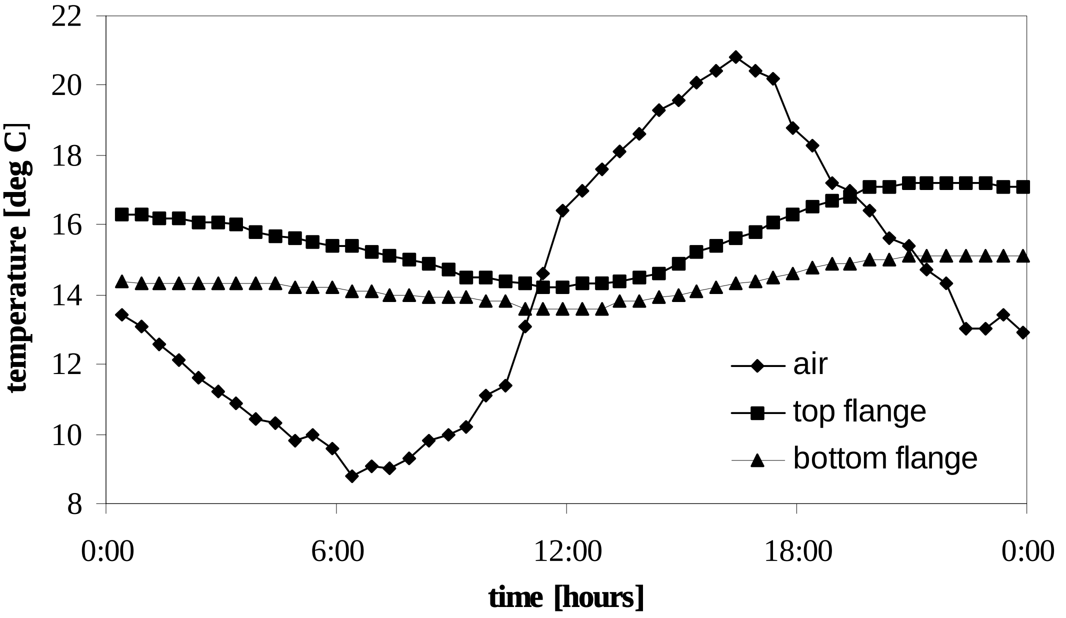

Fig. 4: Temperature variation during one day in the air, top and bottom flange

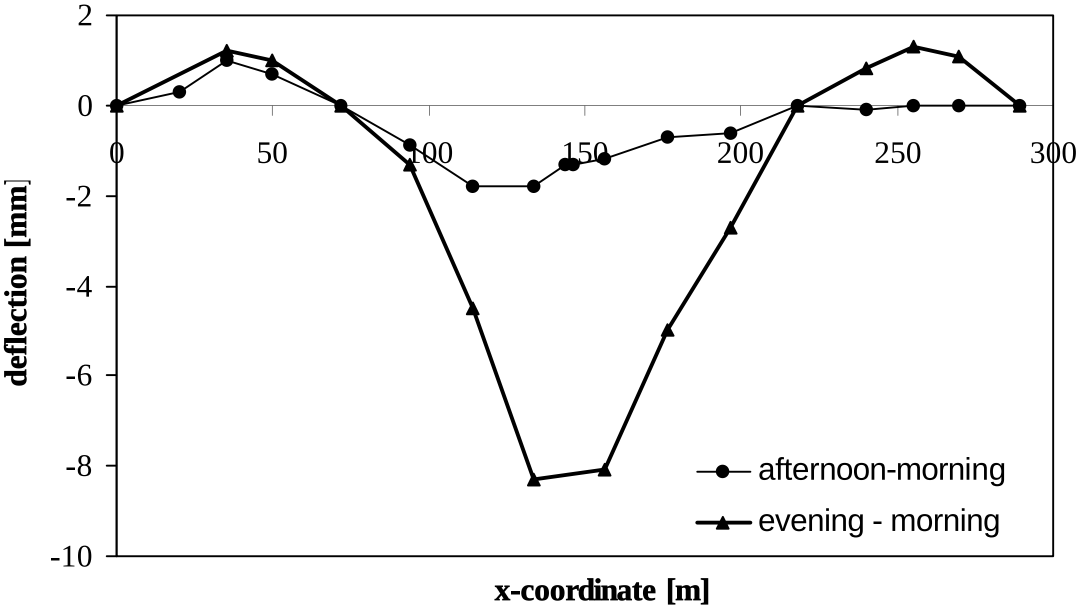

Fig. 5: Deflection variation in the afternoon and in the evening related to the morning longitudinal axis.