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INFLUENCE OF CONCRETE AGE ON A COMPOSITE CONCRETE SECTION BEHAVIOR

Composite concrete beams made of prefabricated prestressed element and cast in place reinforced concrete slab become very popular in nowadays bridge engineering. The two concrete composite parts are cast at different times, under different conditions. As a consequence, they have different concrete strengths and moduli of elasticity, as well as different rheological properties. The latter is responsible for stress redistribution within the composite section. The objective of the paper is to evaluate the influence of different concrete age between the girder and the in-situ slab on the behavior of composite concrete beams. Numerical study was performed on a real example of composite beams that are part of a multi-span continuous highway bridge. Four age differences between the precast girder and the in-situ slab were considered: 30, 90, 365 and 730 days. The numerical results indicate that different creep and shrinkage properties arising from the age difference between the concrete parts can significantly affect the stress redistribution, as well as the final deflections of the composite concrete beams.

Keywords: composite beams, creep and shrinkage, construction stages, redistribution

1. INTRODUCTION

Composite concrete beams become very popular in present-day bridge construction, especially for short- and medium-span bridges [1]. They are usually made of two concrete elements, a precast pretensioned beam and an in-situ deck slab (Fig.1). These two concrete parts are bonded together and form stiff composite bridge deck. Apart from providing a significant increase to the strength and stiffness of the prestressed girder, the in-situ slab can also provide continuity and lateral stability to the precast elements.

However, there are some specific aspects arising from the construction process that should be carefully considered in the design. The two concrete elements that form the composite section are cast at different times and under different conditions. Inevitably they have different concrete strengths, different moduli of elasticity and different creep and shrinkage properties (Fig.1).

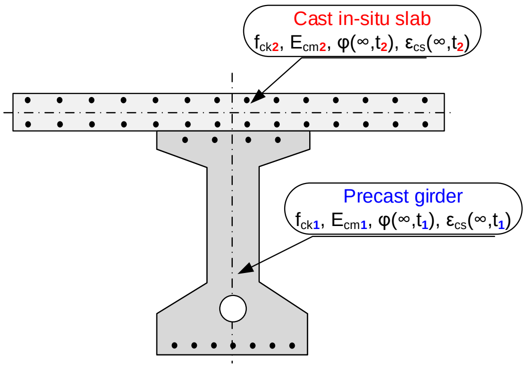


Figure 1. Typical concrete composite section

The concrete in the precast element is generally of better quality than the concrete in the cast in-situ element. It usually has higher specified target strength and experiences better quality control during construction [2]. Furthermore, the precast part is cast sometime prior the deck slab. With the concrete in the precast element being older and of better quality than the in-situ concrete, a redistribution of stresses within the composite section arises. Certain shrinkage amount of the girder occurs before setting the in-situ slab. Therefore, the subsequent shrinkage of the girder will be less than the shrinkage of the slab. Since the two concrete parts are bonded, the bigger shrinkage in the slab part is restrained by the girder. This internal restrain often results in tensile stresses in the deck slab, redistribution of the girders' stresses and increase in curvature of a section.

At the design stage, the designer has little control over the precast girders' age at which the in-situ slab will be placed. Usually, it is assumed that the age difference between the girder and the slab is within 60 and 90 days. However, there are many cases in practice when this difference is even more pronounced and less cases when it is less pronounced. For instance, in multi-span bridges, the age difference between the slab and the girders placed in the first span sometimes can be significantly large.

2. STRESSES AT STAGES OF LOADING

The history of construction and service stages influences the ultimate and serviceability limit states of composite concrete elements [3]. It is very likely that some intermediate construction stage can even be decisive in the choice of concrete strength class, tendon layout or reinforcement area in the deck slab. Therefore, the construction stages should be carefully treated in the design.

For composite sections, usually the following loading stages need to be considered [2]:

- Transfer of the initial prestress to the precast element – involves calculation of the elastic stresses due to the initial prestress and the self-weight of the precast element (line 1 in Fig.2).
- Period before casting the in-situ slab – requires time analysis to calculate the redistribution of the stresses caused by creep and shrinkage in the precast element (line 2 in Fig.2).
- Casting the in-situ concrete before composite action - requires short-term analysis of the precast element to calculate the instantaneous effects of the superimposed dead load prior to the composite action (line 3 in Fig.2).
- Immediately after the establishment of the composite action - involves short-term analysis of the composite cross section to determine the stresses for all the remaining loads (e.g. additional dead loads, live loads etc.) (line 4 in Fig.2).
- Period after the establishment of the composite action: - involves time analysis for the composite cross section until time infinite.

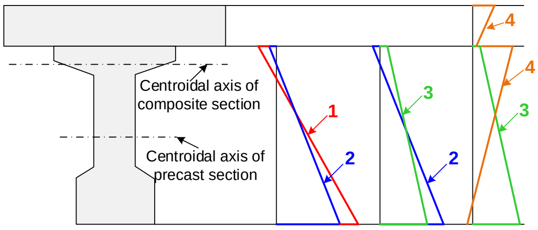


Figure 2. Concrete stresses at various load stages

3. ANALYSIS OF COMPOSITE CONCRETE BRIDGE BEAM – CASE STUDY

The influence of different age of precast concrete girder and in-situ concrete slab is evaluated through a numerical study on a real example of composite bridge beams. Five-span continuous bridge with composite concrete deck was analysed. This structure is chosen to demonstrate the above-mentioned effect due to the type of its structural system that is sensitive to the effects caused by creep and shrinkage. In addition to this, the age difference between the prestressed girder and the cast in-situ slab was approximately 2 years that is beyond the age difference treated in the design.

In the paper, the analysis was performed for various age differences: 30, 90, 365 and 730 days.

3.1 GENERAL BRIDGE DATA

The subject structure is five-span continuous bridge (41.89 m + 3 x 42.79 m + 41.89 m) with composite concrete deck. The superstructure is composed of five precast pretensioned girders (C40/50) continued in a second phase through deck slab reinforcement, cross girders above the piers (C35/45) and cast in-situ concrete slab (C35/45). The characteristic distance between the main girders is 2.20 m (fig. 3).

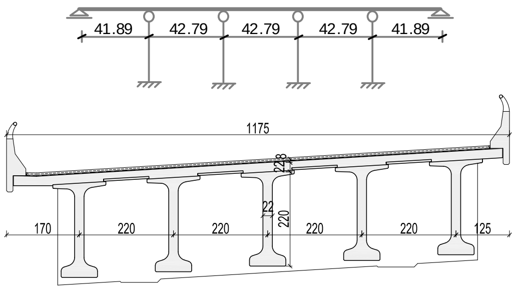


Figure 3. Structural system and typical cross-section

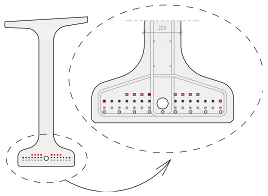


Figure 4. Prestressing arrangement

The main girders are pretensioned with 36 straight strands and additionally with one parabolic tendon (1600/1860MPa). The arrangement of the prestressing reinforcement is presented in Fig.4.

3.2 NUMERICAL MODEL

The numerical model, built in FEM software Sofistik, consists of composite girders from two adjacent spans. The model considers the composite action between the precast girder and the in-situ slab, as well as the transformation of the structural system from simple supported to continuous beam. The analysis is done for two phases:

- Phase I: the prestressed girders are acting independently with a structural system simple supported beam (Fig.5 top).
- Phase II: the prestressed girders and the cast in-situ slab are acting compositely with a structural system continuous beam (Fig.5 bottom).

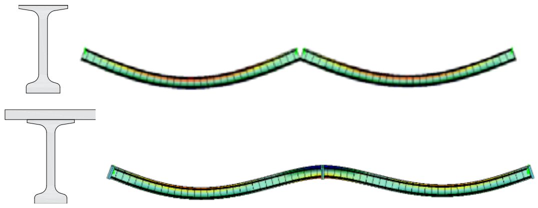


Figure 5. Phase I (top) and Phase II (bottom)

Construction Stage Manager (CSM) tool in Sofistik was used to simulate the history of construction and service stages of the bridge. The following stages were considered in the analysis (Fig.6):

1. Prestress of the 36 strands at $t_1 = 3$ days

2. Self-weight activation of the girders at $t_1 = 3$ days

3. Creep and shrinkage until stressing the parabolic tendon (duration $\Delta t_1 = 11$ days)

4. Prestress of the tendon at $t_2 = 14$ days

5. Creep and shrinkage until casting the in-situ slab (duration $\Delta t_2 = 16/76/351/716$ days)

6. Casting the in-situ slab at $t_3 = 30/90/365/730$ days

7. Hardening of the slab

8. Removing the temporary and placing the final supports

9. Creep and shrinkage until placing the asphalt and other additional loads (duration $\Delta t_3 = 90$ days)

10. Application of additional dead loads at $t_4 = 120/180/455/820$ days

11. Creep and shrinkage until the end of service life.

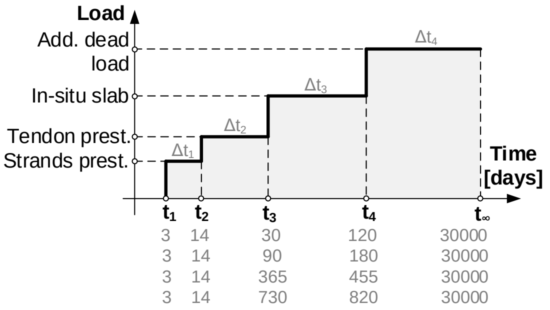


Figure 6. History of construction stages

In order to calculated the concrete stresses in the stages that require time analysis (stages

3.,5.,9. and 11.), different creep and shrinkage sources were used:

- Real creep and shrinkage strains based on measurements performed on concrete test specimens (provided by the Contractor)
- Available creep and shrinkage models implemented in Sofistik (Eurocode 2, fib Model Code 2010, CEB-FIP Model Code 1990 and Rusch's summation model)

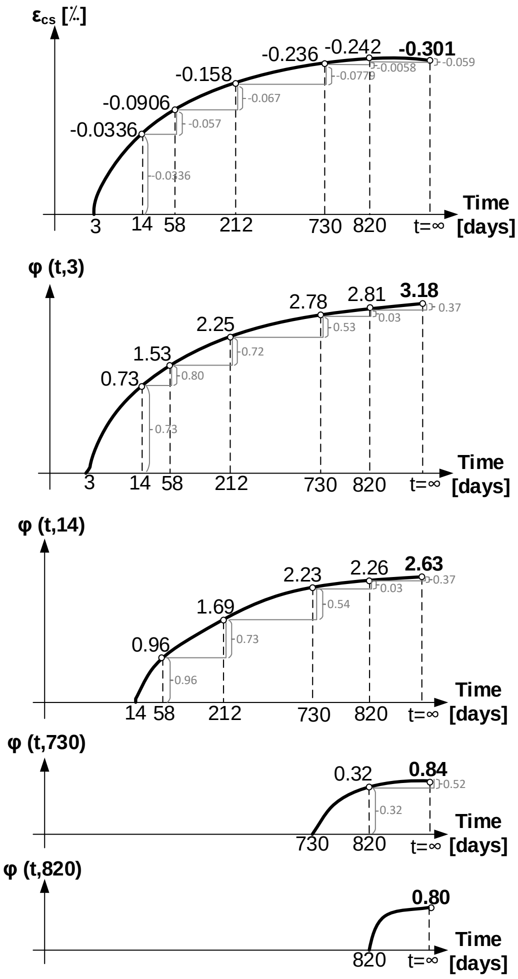


Figure 7. Creep and shrinkage curves for the prestressed girder (age difference 730 days)

For each concrete age at which immediate change in stresses appeared, different creep curves were developed separately for the girder and the slab:

- Creep coefficient for the precast element when the prestressing of the strands is applied: $\varphi(\infty, t_1) = \boldsymbol{\varphi}(\infty, \mathbf{3})$;
- Creep coefficient for the precast element when the prestressing of the tendon is applied: $\varphi(\infty, t_2) = \boldsymbol{\varphi}(\infty, \mathbf{14})$;
- Creep coefficient for the precast element when the in-situ slab is casted: $\varphi(\infty, t_3) = \boldsymbol{\varphi}(\infty, \mathbf{30/90/365/730})$;
- Creep coefficient for the precast element when additional dead loads are applied: $\varphi(\infty, t_4) = \boldsymbol{\varphi}(\infty, \mathbf{120/180/455/820})$;
- Creep coefficient for the deck slab when the additional dead loads are applied: $\varphi(\infty, t_4) = \boldsymbol{\varphi}(\infty, \mathbf{90})$;

Fig.7 presents the creep and shrinkage curves calculated according to one of the above-mentioned methods and indicates the values necessary for each load step.

On-site measurements of the girders deflections nearly before setting the in-situ slab were on disposal. The measured deflections are result of prestressing forces, self-weight of the girder and creep and shrinkage effects before placing the in-situ slab.

Table 1 contains comparison between the measured and the calculated deflections for the section at the middle of a span.

Table 1. Mid-span deflection of the girders

		Mid-span deflection at t=730 days [mm]
Measured		117.3
Calculated	Real creep and shr.	108.1
	EC2	100.4
	CEB-FIP MC90	107.4
	fib MC10	108.0
	Rusch's method	115.2

The comparison between the measured and the calculated deflections shows relatively good agreement. It suggests that the numerical model is sufficiently accurate to be used for the further analyses.

3.3 RESULTS OF THE ANALYSIS

3.3.1 Stresses

Stresses at different stages of loading were calculated for the varied age differences between the concrete parts (30, 90, 365 and 730 days). An age difference of 90 days was chosen as a reference, since it is usually assumed in the design. Figs. 8 and 9 summarize the calculated stresses in two characteristic cross-sections for the reference age difference. In the presented diagrams, sign "-" corresponds to compression. For the sake of clarity, the stresses are presented for each subsequent load stage. However, only the results in the stages affected by the considered effect will be discussed.

Right after the establishment of the composite action between the concrete parts (II.2), tensile stresses developed in the in-situ slab. They are more pronounced for the section at the intermediate support (Fig.9). The reason for development of such stresses without any external load effect lies in different creep and shrinkage properties between the concrete parts. Having in mind that 50% of the total shrinkage generally takes place in the first 3 months after casting, it will be clear that at this stage the in-situ slab is shrinking at a faster rate than the precast girder. On the other hand, the precast concrete at the element interface is creeping more than the in-situ slab due to the higher initial compressive stresses. This complex interaction between the concrete parts is responsible for the tensile stresses in the slab and redistribution of the stresses in the girder.

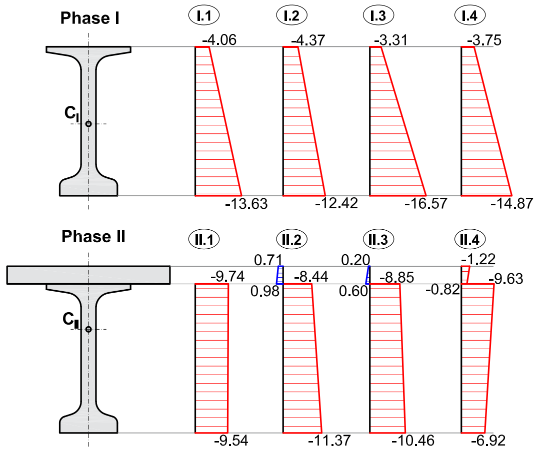
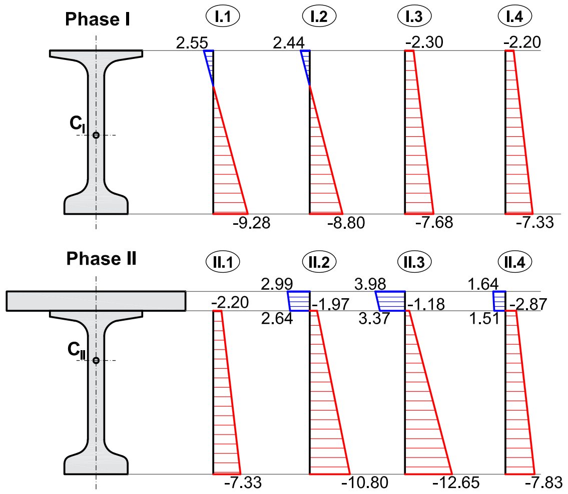


Figure 8. Concrete stresses for age difference of 90 days at mid-span section



LEGEND:
I.1 - self-weight and prestressing of 36 strands
I.2 - creep and shrinkage until prestressing the tendon
I.3 - prestressing the tendon
I.4 - creep and shrinkage until casting the in-situ slab
II.1 casting the in-situ slab
II.2 - creep and shrinkage until placing the additional dead loads
II.3 - additional dead loads
II.4 - creep and shrinkage until the end of service life

Figure 9. Concrete stresses for age difference of 90 days at intermediate support

The comparison between the stresses in the last two stages (II.3 and II.4) indicates that the creep and shrinkage effects increase the compressive stresses at the top fibre of the girder and reduce the stresses at the bottom one.

The influence of various age differences on the redistribution of concrete stresses is presented in Figs. 10-12. The stresses are normalized in terms of the chosen reference age difference. Figs. 10 and 11 show the relation between the age difference in the concrete parts and stresses in the precast girder, while Fig.12 presents the same relation for the stresses in the in-situ slab.

Fig.10 clearly indicates that the compressive stresses at the mid-span section has a tendency to increase with increasing the age difference. However, this tendency is less pronounced for the stresses at the top fiber. For the considered age differences in the study, the maximum increase in the girder stress can reach 25 % in terms of the reference one.

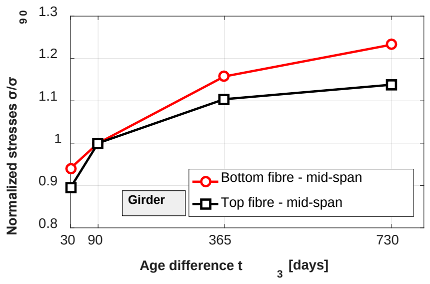


Figure 10. Relation between age difference and noramalized stresses for mid-span section

The similar trend is observed for the stresses at the bottom fibre of the support section (Fig.11). Unlike the bottom fibre, the stresses at the top fibers are reducing for up to 50 % by increasing the age difference. The reduction in concrete compressive stresses means that creep and shrinkage effects induce tensile stresses that increase with age difference.

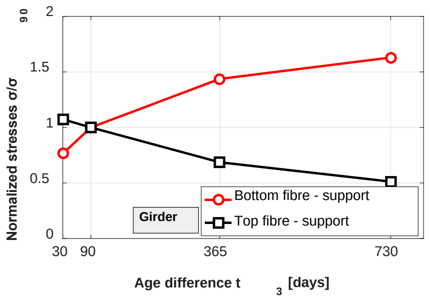


Figure 11. Relation between age difference and noramalized stresses for support section

Such variation in the prestressed girders' stresses due to different ages of the concrete parts may lead to difficulties in satisfying the serviceability checks for stress limitations.

The age difference has the biggest impact on the development of tensile stresses in the slab part. This is especially pronounced at the intermediate support (Fig.12). The relationship presented in Fig.12 suggests that the deck slab is the most sensitive part of the composite section to the considered effect. For the analysed age differences, the tensile stresses in the slab can be even 3 times bigger than the ones calculated with the reference age difference.

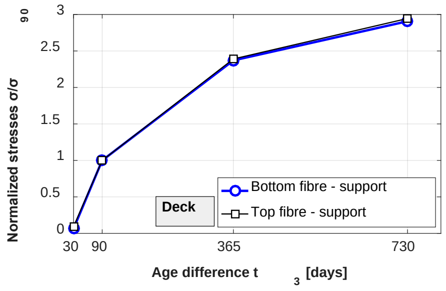


Figure 12. Relation between age difference and noramalized tensile stresses for concrete deck slab

Usually, these tensile stresses are carried by the reinforcement in the concrete slab. The results here suggest that bigger age difference than considered in the design may result in insufficient amount of reinforcement in the slab.

3.3.2 Deflections

Another limit state that has been examined on the effect of different age of concrete parts was the long-term deflections.

Fig. 13 presents the relationship between the age difference between the concrete parts and the mid-span deflections for some characteristic load stages. The deflections in the diagram are presented as normalized values in terms of the deflections calculated for the reference age difference.

It has to be mentioned that the calculated deflections at the end of service life remained positive values (upwards) for all analysed cases. The relations presented in Fig. 13 show that the deflections increase proportionally to the age difference. It means that if bigger age difference than the one considered in the design occurs, then the structure will suffer bigger positive deflections. For the biggest age difference considered in the study, the increase in deflections is somewhat more than 20% during the construction and around 15% at the end of service life.

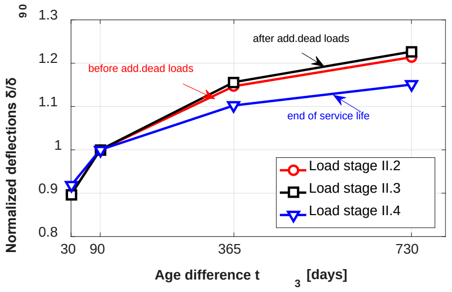


Figure 13. Relation between age difference and noramalized deflections

A misprediction of the positive deflections can be responsible for several serviceability issues. Additionally, it can contribute to many difficulties during the final activities of the bridge construction. Most common issues arising from over- or underestimation of deflections at construction stages are: disability of reaching the designed road level, difficulties in providing the designed asphalt depth and consequently providing correct waterproofing details.

CONCLUSIONS

Based on the results from the numerical study and the on-site measurements of deflections for the composite concrete bridge beams, the following conclusions are drawn:

- The age difference between the concrete parts has significant effects on the composite beams' behavior.
- Bigger age difference between the girder and the in-situ slab produces bigger compressive stresses in the girder. An exception is the top fibre of the intermediate support section.
- In-situ slab at the intermediate support section suffers several times higher tensile stresses for increased age differences between the composite elements.
- The positive deflections at the end of a construction process, as well as, at the end of a service life are bigger as the age difference between the concrete parts is pronouncer.

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