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ANALYSIS OF DEFLECTION OF REINFORCED CONCRETE ELEMENTS AFTER DEMOULDING

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Abstract: *The content of this article is strut-and-tie modelling including the behaviour of early age concrete and analysis of deflections of reinforced concrete elements after demoulding. Mechanical properties of early age concrete are significantly influenced by ongoing hydration. Good knowledge of the behaviour of concrete at early age plays an important role in setting the deadline for removal of formwork and props. Material parameters and time-dependent deformation such as creep and shrinkage were in this work determined based on measurements and by using the microstructure development function. The results are deflections depending on the time of demoulding and the influence of support by props. The results are compared with the limit values. The proposed analysis of the instant of demoulding may be of practical use and can lead to proper intervals or technological breaks and can reduce the amount of formwork required for construction.*

Keywords: ***Deflection, development of microstructure, early-age concrete, formwork stripping, strut-and-tie model.***

1. Introduction

In building construction process, fast formwork dismantling is a very significant issue. There is always a purpose to reuse the formwork or to apply a load to the structure from the adjacent elements. The technological break between concreting and formwork removal and the time when structure can be loaded represents the most important time period in construction of reinforced concrete elements. Because of this, it is important to study the properties of concrete not only in long term, but also in early age just after formwork removal. Other criteria besides the speed of construction are the price of construction affected by the price of formwork rent, etc. Reduction of time necessary for formwork rent and minimizing of time necessary for technological breaks leads to cost savings.

The paper is based on work Štemberk & Tsubaki (2003) dealing with behaviour of concrete at early age and the microstructure development function. This work deals relatively deeply and correctly with the concrete behaviour in the beginning of hydration. Application of this function on particular construction is mentioned in Frantová (2007) where real numbers of short time strain of bridge deck loaded by concrete mix truck in early age of concrete only few hours are evaluated.

For particular application, analysis of elements using strut-and-tie models (STM) is used in the paper, which can be used for design of reinforced concrete structures because of their simplicity when obtaining results. The procedure of STM definition and calculations are available for instance in Reineck (2002).

2. Material model for early-age concrete

Mechanical properties of solidifying and afterwards hardening concrete are cardinally influenced by hydration when microstructure of concrete develops in this period very fast. When modelling the solidifying and hardening concrete it is important to take into consideration the influence of ongoing hydration that can be described by development of microstructure, which represents the process of solidifying and afterwards hardening of concrete. This process depends on various factors as is the

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composition of concrete mixture, the shape of structure and the external conditions such as temperature and the curing period. Strength of concrete grows exponentially in the early age but already after few days its exponential growth is over.

Mechanical properties of concrete at early ages are hard to be tested. Most of the researches made on microstructural evolution were based on data from pull-out and penetration tests, whose performance is rather difficult and time-consuming. Moreover, there are not many results that have been presented. Therefore, a reasonable estimation of concrete properties is a better alternative.

Generally, regarding modelling of mechanical properties, the type of equation is not a major point, but it is convenient to have such an equation as (1) for practical use.

$$h(t_n) = a_5 \cdot \left(\frac{a_3 t_n^{a_2}}{a_1 + a_3 t_n^{a_2}} \right)^{a_4} \tag{1}$$

Function (1) represents time-dependant evolution of microstructure, described in Štemberk & Tsubaki (2003). In this study it is used to define, firstly, compressive strength and, secondly, the modulus of elasticity of concrete at early age, which is necessary to know for STM calculations.

3. Application of material model for analysis of deflections

The element for application of assumptions is defined as a simply supported beam with the span of 6 metres and cross-section 0.3 x 0.6 m with lower reinforcement 6Ø20 and top reinforcement 2Ø12. Stirrups were for simplification assumed as two-legged Ø8 all over the length of the beam with the spacing of 200 mm. The strut-and-tie model was used. The calculation model was created using the 1D finite element method

$$K(t) \cdot u = \Delta f, \tag{2}$$

where $K(t)$ is the stiffness matrix that changes in time. This is caused by development of concrete properties, in other words, the modulus of elasticity in time.

Uniform loading due to self-weight was assumed as point loading acting in upper joints. Figure 1, where it was divided partially on Δf that was loading the construction step-by-step. Using this approach it was tried to increase the accuracy of the internal forces calculation of the deformed structure. However, assuming very small strains, the effect is negligible.

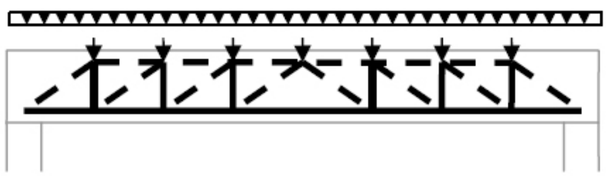

Fig. 1: Recalculation of loading to joints.

3.1. Formwork stripping of whole element

In the first case, the removal of formwork of whole element at the same time was assumed, see Figure 2. In Figure 3, deformations based on the removal of formwork at the time period 20 minutes are shown. If we assume the limit deflection L/250, construction complains the requirement at the time 9 hours after removal of formwork.

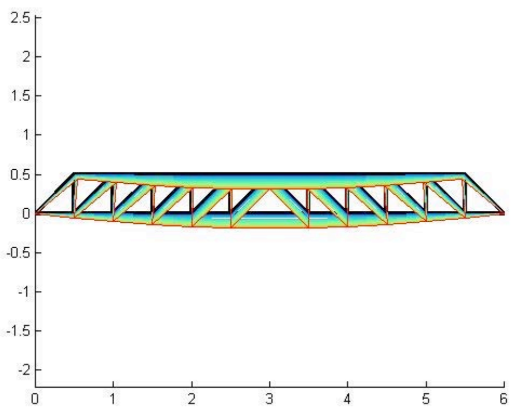

Fig. 2: Deflection after one-shot formwork removal (not in scale)

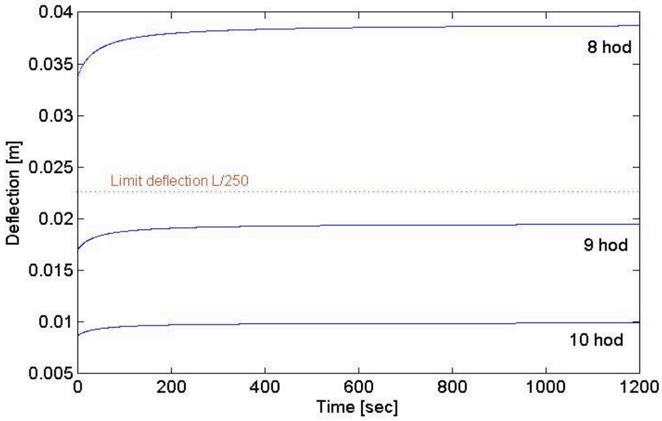

Fig. 3: Deflection after formwork removal

3.2. Step-by-step formwork stripping

In the practice, the beams demoulded are step-by-step based on the type of the formwork system. Separate states will appear after formwork removal, as can be seen in Figures 5, 6, 7 and 8 (deflections are not in scale). States are affected by the used formwork system.

In our case, it was opted for length of segment of 3 metres. It means two segments for the whole beam.

In Figure 5, removal of formwork from the left half of the beam is assumed while the right half is still being propped. The duration of this process is assumed 15 minutes. Immediately after beginning of the next step, the beam is supported by props in the first third of its length and the other half of the beam is demoulded. Similarly as in the first step, the period of 15minutes was assumed (Figure 6), after which the beam was supported by props in the second third (Figure 7). Now the beam is demoulded and left 15 minutes on the props. In the last step (Figure 8), removal of props follows. This is a theoretical option only, because from the experience it is known that props remain supporting the construction much longer. This is also visible from the Figure 9 in last stage of the formwork removal.

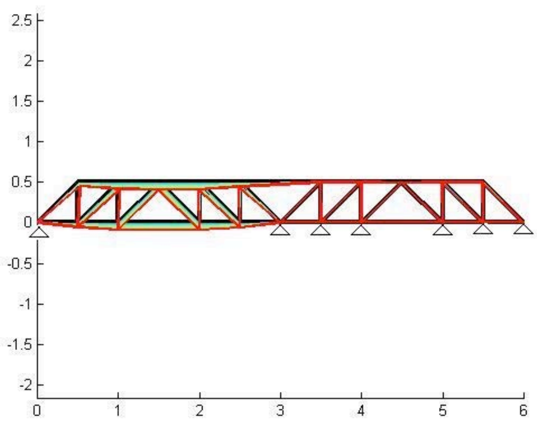

Fig. 5: Deformation after 15 minutes after demoulding from the left side

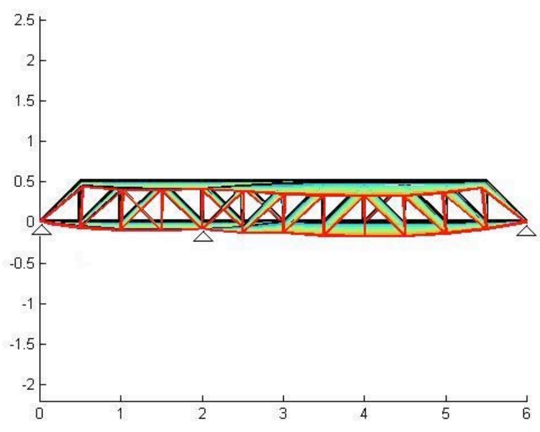

Fig. 6: Deformation after 30 minutes after propping in the first third of span and demoulding another half of the beam

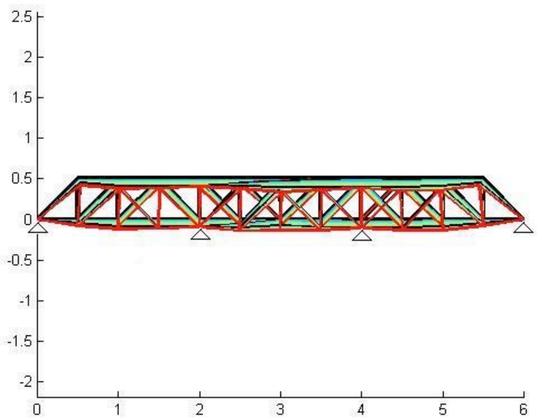

Fig. 7: Deformation after 45 minutes after propping in thirds of span

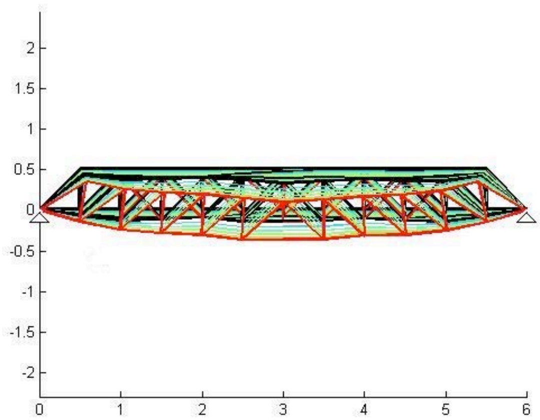

Fig. 8: Deformation after 60 minutes without props

Figure 9 expresses the largest deflections at individual time periods after demoulding. It is obvious that a big part of the deformation is caused directly by the last stage of demoulding. This is caused by higher stress in the struts that were not as big in the previous stages of demoulding. If additional possible loading was assumed, especially the period of the last stage would be very important and leaving the props on their positions would be decisive for the deflection.

So it means that leaving the props on their positions for a longer time period would cause the deflection not to change essentially as it can be seen in Figure 9. In the case of hasty removal of props, the deflection would be by 35% larger. However, also in the case of demoulding at the 8^{th} hour the deflection is close to the value of the limit deflection $L/250$, which is 24 mm.

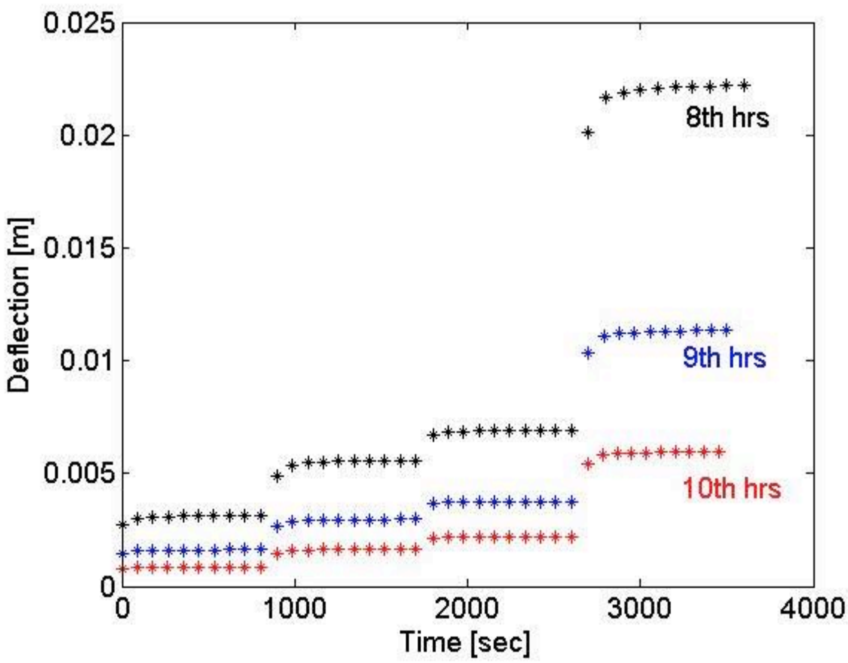

Fig. 9: Deflection based on the various time of demoulding

Values gathered by the proposed model provide very short values of time for possible demoulding. However, it should be kept in mind that the assumptions of experimental measurement were assumed, when the period of loading was 20 minutes and the level of loading was 30% of the concrete compression strength. It was tried to maintain these conditions. The model of the beam was simplified by the strut-and-tie model. Using this simplification, possible cracks are not taken into consideration, which would essentially influence the deflections. Also the cracks appearing on the verge of reinforcement and concrete might have played an important role.

4. Conclusions

In this study, a method to predict the earliest instant for formwork stripping is presented. Considering the early-age concrete, most of the final strength will be achieved after a relatively short time, though some further strength gain can occur according to the type of cement and admixtures. Therefore, the function of evolution of microstructure was used to define the time-dependent gain of concrete stiffness.

The studied element is a simply supported beam with 6 metres of span. That has been replaced by a strut-and-tie representation and was modelled using 1D finite element method. From the results of the presented work it can be seen that reinforced concrete elements loaded only by self-weight can comply with the deflection requirements already after a very short time after concreting. In the presented case it was the 8^{th} and 10^{th} hour. In the case of total formwork removal by one-shot, the value of 9 hours was approached. Respecting the process of formwork removal, one can speak about 8^{th} hours. If the props supporting the structure are left in place longer, the time for formwork removal would be even shorter and the structure could be also additionally loaded.

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