MORE REPRESENTATIVE ESTIMATION OF RHEOLOGIC EFFECTS IN CONTINUOUS STEEL-CONCRETE COMPOSITE BEAM

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Abstract

The paper presents a model for the time-dependent rheological determination of continuous composite structures of steel and concrete. A two-span composite beam is considered. Except a uniformly distributed load, the prestressing by middle support displacement was used. A comparison of the results obtained from the proposed simply analysis of rheological effects with both non-linear FEM analysis and some experimental values is presented.

Physical model and experimental measurement

In order to measure time-depend changes in strain of composite structure, a real model of continuous beam with spans 2.5 + 2.5 m was prepared. Steel part of the cross-section was made of a rolled beam IPE 300 of steel S235. The concrete part was cast in place concrete with compressive strength f_{cm} = 39,1 MPa. Concrete slab was reinforced with bars of diameter ϕ = 6 mm and quality 10 425 (V). Curing was carried out during first five days after casting, and the load was placed in the time of 44 days. Loading consists of two steps. Firstly, the beam has acted as simply supported with span of 5 m in order to obtain some prestressing in concrete slab. Secondly, when the middle support was provided, the additional uniformly distributed load was applied on deformed beam and kept up till age of concrete of 230 days. The changes in strain were measured by gauges in chosen fibres of two characteristic cross-sections (in the middle of a span and near middle support).

FEM numerical model

For better simulation of rheologic effects, the steel part in theoretical model in ANSYS programme was discredited into SOLID45 finite elements and reinforced concrete slab consisted of SOLID185 elements [1]. Using hard steel block elements as shear connectors, connection between top steel flange and concrete slab was modelled as rigid. The symmetry of the model was used for saving memory space and computing time. Loading was considered according to real procedure.

The program allows considering creep effects by several functions. For the time less than 230 days, the rate of creep based on EC 2 [2] could be quite well approximated by the functions

$$\frac{d\varepsilon}{dt} \approx \frac{\Delta\varepsilon_i}{\Delta t_i} = C_1.\sigma.t^{C_2} \ . \tag{1}$$

The constants, C_1 and C_2 in (1), were obtained from non-linear regression of exponential relationship for given set of $\Delta\varepsilon_i$ and Δt_i. Time increments Δt_i were chosen from 0,25 during first day of period up to 10 days at the end of the considered time. More information can be found in [3].

Shrinkage was applied as strain increments to the concrete elements calculated according to EC2 at each time step. Other material non-linearity has not been taken into account. Considering the fact that the steel and concrete part was worked fairly under its elastic strength, linear stress-strain diagram for a momentary load step was sufficiently accurate.

Approximative procedure for rheological effects assessment

A simply estimation of rheological effects consists of two main steps. At first, the primary effects of stress redistribution through cross-section caused by creep are calculated. For this purpose, the Age Adjusted Effective Modulus Method with combination of Relaxation Method across the section is commonly used. Afterwards, secondary creep effects are involved by deformation of structure elements caused by primary effects. These deformations can be derived as normal deformation of unit element

$$\Delta(t) = -\frac{N_c(t_0)\cdot\varphi(t,t_0)}{E_s\cdot A_i(t)\left[1+\chi(t,t_0)\cdot\varphi(t,t_0)\right]} \qquad [m/m`], \qquad (2)$$

and its rotation, respectively

$$\omega(t) = -\frac{\left[M_c(t_0)+N_c(t_0)\cdot a_{c,i}(t)\right]\cdot\varphi(t,t_0)}{E_s\cdot I_i(t)\cdot\left[1+\chi(t,t_0)\cdot\varphi(t,t_0)\right]} \qquad [rad/m`]. \qquad (3)$$

Therefore, the corresponding deformations **Chyba! Neplatné prepojenie.** and **Chyba! Neplatné prepojenie.** are considered as an additional load, which produces further modification of stress state along beam length. This method is given in detail in paper [4].

In addition, the shrinkage stresses can be similarly estimated by similar way, too.

Comparison of results in the middle of a span

Because of space limitation, only results in the cross-section in the middle of a span will be given. Partial results in cross-section near middle support are detailed discussed in [3].

Time-dependent development of strains across the height of beam is shown in fig. 1. ANSYS strains are presented as an average from points though width at certain vertical position.

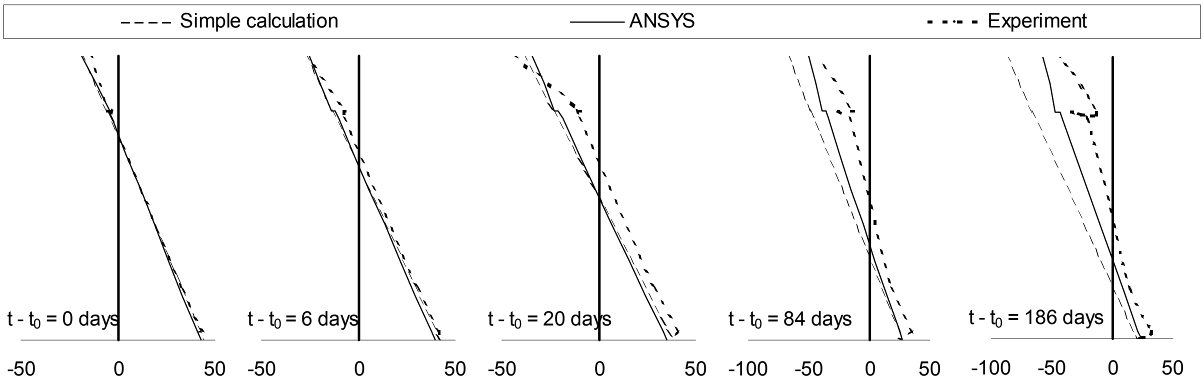

Fig. 1 Total strains though the height of the beam ($\varepsilon_{total}\cdot 10^6$)

It is evident from the picture that difference between measured strains and calculated ones, and between two analyse approaches respectively, is growing in time.

However, this conclusion does not fit with comparison of results shown in fig. 2 where the calculated strains without shrinkage effects are compared. It can be seen that the strains due to uniformly distributed load and middle support displacement are very close to the theoretical values. Therefore, the simple approach seems to be suitable for estimation of an effect of external actions.

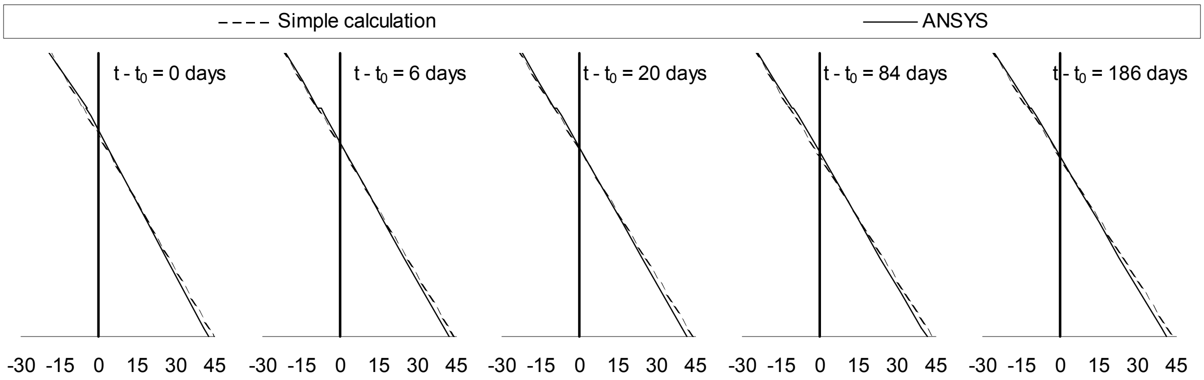

Fig. 2 Strains due to load though the height of the beam ($\varepsilon_{load} \cdot 10^6$)

After detailed analyse of strains due to shrinkage, the considerable differences increasing in time can be stated. These variations might express the fact that either the model of shrinkage or its application for this case was not accurate enough. The comparison between simple approach and ANSYS results is presented in fig. 3.

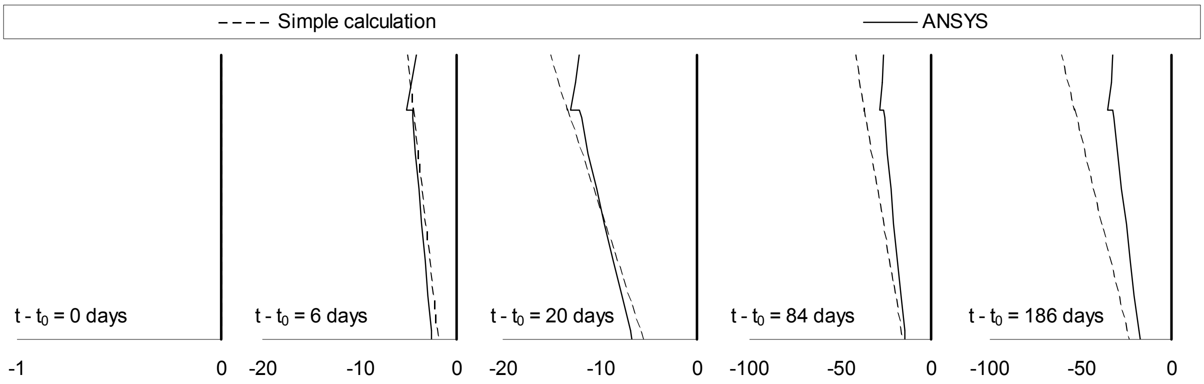

Fig. 3 Strains due to shrinkage though the height of the beam ($\varepsilon_{shrink} \cdot 10^6$)

The first set of curves in fig. 4 corresponds to the top fibres of concrete slab with width of 800 mm in distance 50 mm and 300 mm from longitudinal axis, respectively (indexes middle and edge, respectively). As it can be seen, the ANSYS strains suit well with measured ones. The differences may be produce by not only computing procedure or principles, but may be concrete non-homogeneity and additional strain due to eventual torsion as well. Similarly, accordingly to our expectations, results from manual calculation by using simplified methodology produce overcame strains towards the end of considered period.

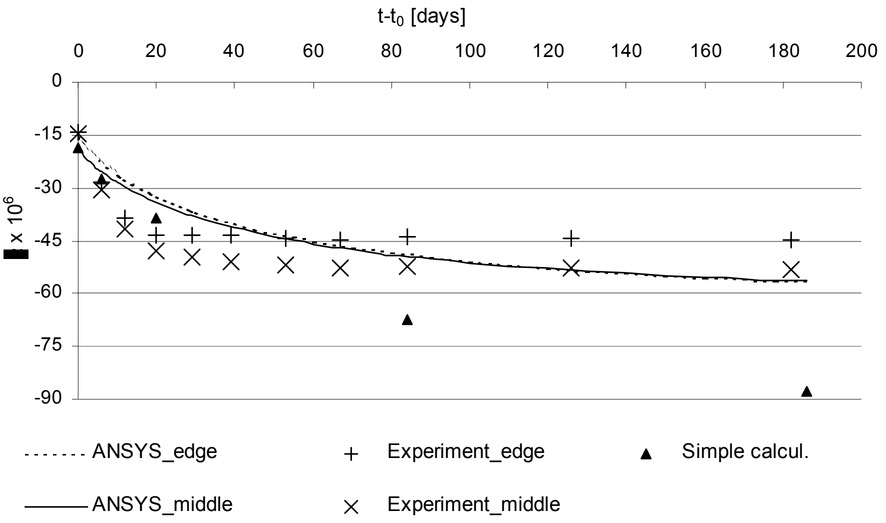

Fig. 4 The strain comparison at the top of concrete slab

At the bottom flange of rolled steel beam (fig. 5) it is obvious very good correlation of total strains. The differences are not such significant as in the case of concrete slab. Greater variation can be seen in other fibres of both steel and concrete part of cross-section not in detail presented here. However, in all considered fibres of chosen cross-sections the same tendency of $\varepsilon \rightarrow t$ relationship was observed. The simplified approach overestimates the strains in all cases.

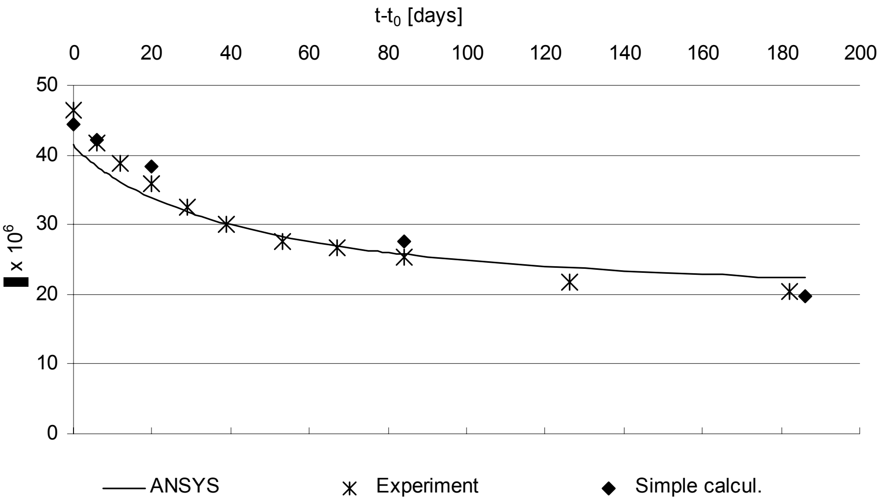

Fig. 5 The strain comparison at the bottom flange of rolled steel IPE beam

The curves at fig. 6 represent relative good concordance of theoretically declared stresses due to external load at the top fibres of concrete slab. The shrinkage stress calculated in simple way cannot be very precisely determined. Differences in comparison with time-dependent numerical analysis are more apparent with age of concrete. Accuracy of this method may be increased by two or more time steps in calculation procedure

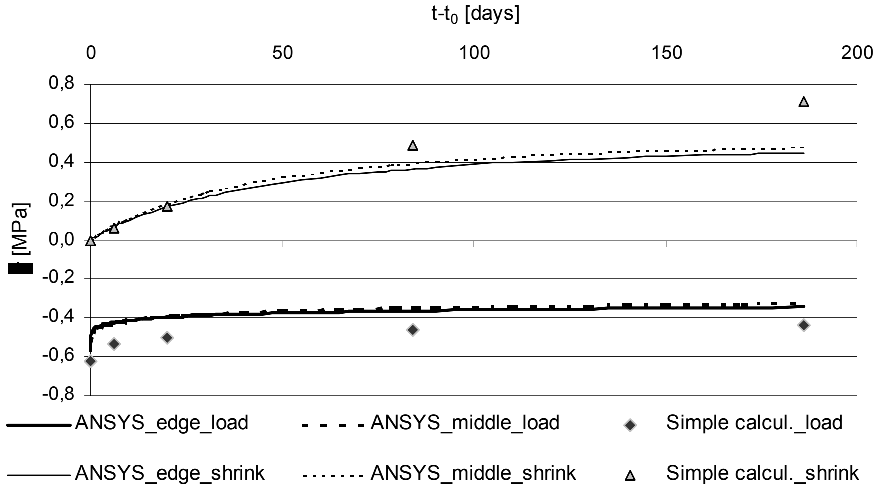

Fig. 6 The stress comparison at the top of concrete slab

Similarly, stresses due to shrinkage at bottom fibres of the steel beam (fig. 7) are overestimated too. In analyse of effects for uniformly distributed load and middle support displacement a good agreement in stresses and a similar curve tendency can be stated.

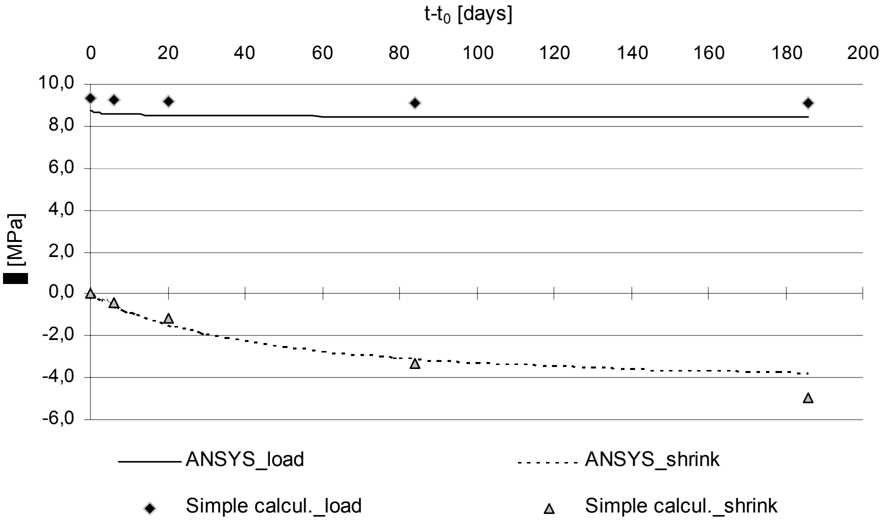

Fig. 8 The stress comparison at the bottom flange of rolled steel IPE beam

Conclusions

In conclusion, we can observe good approximation of time-dependent modification of strains by non-linear FEM modelling of composite beam. The presented results confirm that in the time range of 200 days, Eurocode approach of creep can predict real behaviour of concrete part of cross-section in composite structures. From simplified manual approach a similar results can be obtained, but this approach overestimates the strain and stress in both concrete and steel part of cross section.

Both theoretical approaches, especially simplified one, produced differences in comparison with measured strains. From particular analyse of these differences among results showed that magnitudes of this variations are close to differences obtained from shrinkage effects calculation. Therefore, these errors are produced not only by calculating procedure as it was mentioned above, but also by insufficient assessment of shrinkage phenomena.

Consequently, with reference to the results in certain time, it can be concluded that if the shrinkage effects are separated, the presented simplified method could be sufficiently exact for determination of influence of external load effects and forced displacement on stress or strain development.

References

[1] ANSYS ver. 5.7 – Theory, Manual & Guide. SAS IP, Inc., 1999.

[2] Eurocode 2: Design of Concrete Structures – Part 1: General Rules and Rules for Building. CEN, Brussels, 1992.

[3] Bujňák J. – Odrobiňák J.: Some Design Problems of Composite Structural Elements. Proceedings of the 3rd international conference „Concrete and Concrete Structures“. Žilina, 2002, pp. 369-374.

[4] Bujňák J. – Odrobiňák J.: Influence of Concrete Creep on Stresses and Deformations of Composite Beams of Steel and Concrete. Proceedings of the 19th Czech and Slovak International Conference “Steel Structures and Bridges 2000”. The High Tatras - Štrbské Pleso, 27 - 30 September 2000, pp. 341-346.