Early-Age Concrete Cracking in Composite Bridges

Thomas Bittermann
Structural Engineer
Univ. of Rostock,
Rostock, Germany
thomas.bittermann@hs-wismar.de

Thomas Bittermann, born 1974, received his civil engineering degree from the Univ. of applied science Wismar, Germany

Kersten Latz
Professor
Univ. of applied science
Wismar, Germany
kersten.latz@hs-wismar.de

Kersten Latz, born 1961, received his civil engineering degree from the Technical Univ. of Braunschweig, Germany

Summary

A numerical simulation of temperatures and stresses on a composite bridge, and during the first 4 days after casting, is presented in this paper. The thermo-mechanical methodology for this kind of nonlinear analysis is introduced first, describing the thermal field engendered in concrete by heat released during cement hydration and by meteorological conditions, the aging laws that reproduce the growth of mechanical properties during the early stages and the evaluation of concrete stresses. Attention is focused on an integrated consideration of external influences and mechanical structure to take into account the particularities of composite bridges. The developed 3D FE model is verified by a comparative calculation of a real case of damage. The results of simulations by using thermal insulation on concrete surface, and by lowering the supports to impress compression stress in the slab and so to avoid stress stages that may lead to premature cracks, are put forward at the end.

Keywords: composite bridge; hydration; early-age concrete; transverse cracking; smeared crack.

Short version

Composite bridges in steel and concrete are common structures in contemporary bridge construction. Problems often arise in composite bridges, which are due to the development of temperature during hydration of the cement in conjunction with adverse climatic and meteorological conditions. The restraints to which concrete is subjected, together with the differential temperatures that usually arise within the structural element, may lead to early-age thermal stresses capable of inducing premature cracks, or at least of creating a stress state of imminent cracking. Most commonly, early age thermal cracking poses durability problems related to an increased susceptibility of concrete to degradation phenomena (such as corrosion and carbonation), rather then causing structural concerns.

The development of temperature stages due to hydration and the aging of concrete have been thoroughly studied in the past. For determination of the hydration process, the heat production and growing concrete properties several well known models are used, eg. [1-5]. To specify the hydration progress, the effective concrete age τ_e and the degree of hydration α were applied.

As the meteorological conditions are of particular importance for the temperatur fields in the concrete slab, the interchange of heat between structure and environment has been considered by the Newton Cooling Law for convective heat transfer and by the Boltzmann Radiation Law for radiativ heat transfer [6]. The studies have shown the significant influence of solar radiation in particular.

Because the deck slab is restrained by the steel girder, the steel-concrete connection has a wide influence on the formation of cracks. Usually this connection is executed with headed studs, whose load bearing characteristics in hardened concrete have been thoroughly studied in the past and can be expressed by characteristic curves, e.g. [7]. To account for the hardening process of concrete, the concept of the degree of hydration is used to determine the stiffness by age-dependent characteristic curves for the headed studs.

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The thermal problem is dealt with by solving the heat diffusion equation, whereas the strains and stresses involved in the mechanical problem are computed based on the theory of viscoelasticity, with due allowance for concrete aging, which causes material properties to grow considerably during the early ages after casting, and for the pronounced creep behavior in young concrete [8,9].

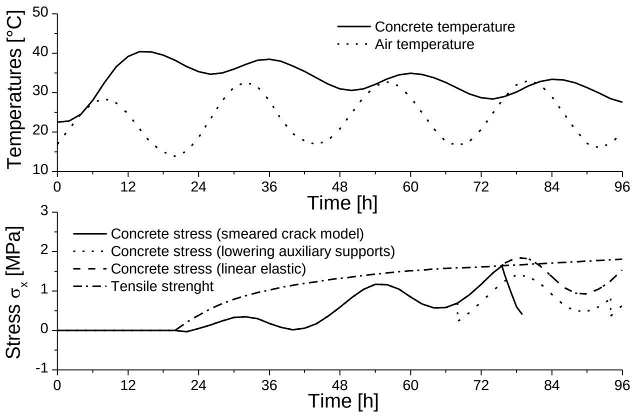

Fig. 1: Evolution of temperature and stress

In addition to these stress-dependent strains, autogenous and drying shrinkage are considered as stress-independent effects. Furthermore the brittle behavior of concrete under tensile stress will be considered by a fracture mechanical model. The used nonlinear smeared-crack-model takes into account the tension stiffening effect in accordance to [10], as well as a scalar damage model with exponential softening of the tensile strength.

To verify the applied methodology and the developed FE model, a computation of a two-span composite bridge was performed, which was damaged by cracking of the deck slab within 4 days after casting. Serving as example, in Fig.1 the temperature and stress evolution of a selected point in the core of the slab in midspan are illustrated. The results of simulation and observed case of damage coincide well, what leads to the conclusion that the risk of early age cracking can be reliably predetermined with the developed model.

Based on these simulations extensive parameter studies were made with various curing methods to analyze whether the early-age cracks could have been prevented. Besides a curing method with using thermal insulation, a method is introduced by which compressive stress can be impressed into the slab by lowering the auxiliary supports incrementally during the hardening process (see Fig. 1). For detailed information about the developed FE model and the results of parameter studies for prevention of early-age concrete cracking in composite bridges see [11].

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