

## **An overview of the service design of composite steel-concrete slabs**

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### **ABSTRACT**

Composite steel-concrete floors are widely used throughout the world for building applications. Their main advantage relies on the ability of the slab to be cast unpropped for spans usually up to 3 m (when considering conventional profiled steel sheeting) and to require intermediate propping for longer spans and for post-tensioned composite installations. Once the concrete hardens, the floor system becomes composite. The composite slab design is usually governed by serviceability limit state requirements associated with deflections. In this context, this paper provides a brief overview of the main factors influencing the service behavior of composite slabs and of a new design model capable of predicting their long-term deflections. Particular attention is devoted to the influence of the non-uniform shrinkage profile that develops through the slab thickness due to the inability of the concrete to dry from its underside for the presence of the profiled steel sheeting. The adequacy of the service deflection model is then outlined by comparing the long-term deflections calculated with the design procedure and those measured experimentally from long-term tests carried out on selected composite and post-tensioned composite slab samples that have been reported in the literature.

### **1. INTRODUCTION**

Composite steel-concrete slabs are widely used for building applications. One of the main advantages of this form of construction relies on the ability of the profiled steel sheeting to act as formwork during construction and as external reinforcement once the concrete has hardened. When considering typical composite floor systems, the governing criteria for design is related to the serviceability limit state associated with deflections. In this context, this paper focuses on the response of composite slabs subjected to time effects, such as creep and shrinkage, and introduces a design model for deflection calculations that has been included in the final version of the composite design code (AS2327, 2017). The particularity of this approach relies on its ability to account for the development of a non-uniform shrinkage profile that takes place in slabs

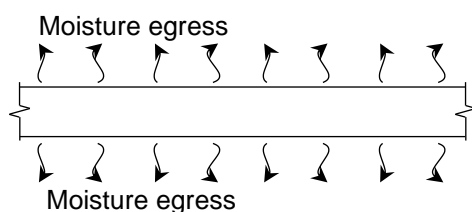
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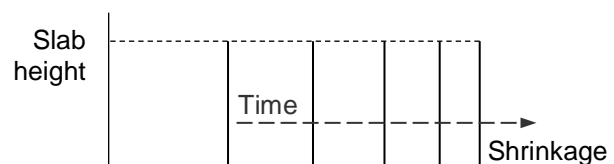
cast of profiled sheeting due to the inability of the concrete to dry from the slab underside. This behavior was first observed experimentally in long-term tests carried out on composite steel-concrete beams with composite slabs (Al-Deen et al, 2011) and this originated further work focussed on the time-dependent response of composite floors. This effort was articulated the preparation and performance of new long-term tests, e.g. (Shayan et al 2010, Ranzi et al 2013b, Al-deen et al 2015, Gholamhoseini et al 2014), and in the development of modelling procedures capable of accounting for the occurrence of a non-uniform gradient, e.g. (Ranzi and Vrcelj 2009, Bradford 2010, Ranzi et al 2013a,b, Gilbert et al 2012, Al-Deen and Ranzi 2015). The first part of the paper briefly outlines the time-dependent properties of the concrete associated with non-uniform shrinkage. This is then followed by the key features of the design model for service deflection calculations and some comparisons between its numerical predictions and experimental long-term measurements reported in the literature on selected composite and post-tensioned composite slab samples.

## 2. CONCRETE BEHAVIOUR: NON-UNIFORM SHRINKAGE PROFILES

The service behavior of concrete structures is influenced by concrete time effects, such as creep and shrinkage. Of particular interest to the scope of the paper, this section intends to outline the key features describing the development of non-uniform shrinkage profiles in composite floors. For this purpose, two unreinforced and unloaded concrete slabs are considered and differ for their exposure conditions, i.e. one slab being exposed to dry on both sides (Fig 1a) and one being exposed on one side and sealed on the other (Fig 2a). In the former case (Fig 1a), the slab is able to dry from both its top and bottom faces and it exhibits constant total deformations over time. For design purposes, it is well accepted to simplify the problem and to assume that these total deformations can represent the shrinkage distributions as depicted in qualitative terms in Fig 1b. In reality, the real shrinkage distribution is nonlinear, e.g. (Gilbert and Ranzi 2011). When considering the unreinforced slab with exposure conditions similar to those of a composite slab (Fig 2a), the asymmetric drying conditions produce a linearly varying total deformation profile over time. Under the assumption of using linear shrinkage profiles for design purposes, it is possible to relate the total deformations to a simplified shrinkage distribution, as shown qualitatively in Fig 2b. Also in this case, the real shrinkage profile would be nonlinear.



(a) drying conditions



(b) qualitative shrinkage distribution  
(plotted assuming a linear shrinkage profile)

Fig. 1 Drying conditions and qualitative shrinkage distributions for slab exposed on both sides.

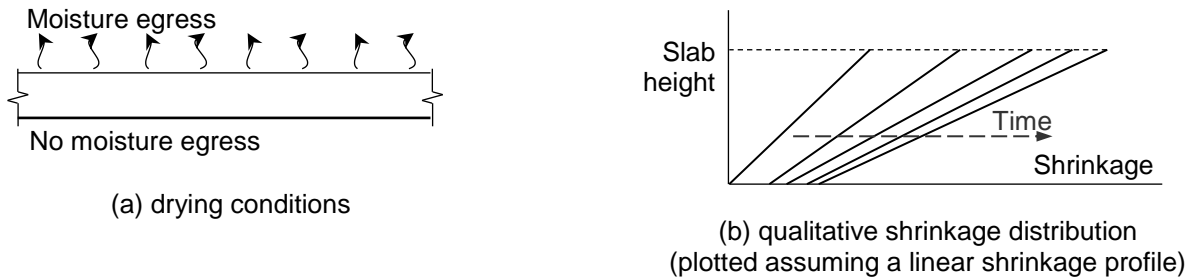


Fig. 2 Drying conditions and qualitative shrinkage distributions for slab exposed on one side only.

### 3. DESIGN MODEL

#### 3.1 Model description

The deflection predictions at service conditions account for the contribution of a number of components. These usually consist of the instantaneous deflection  $\delta_0$  produced by the short-term service loads, of the deflection  $\delta_{cc}$  produced by creep effects and of the component  $\delta_{cs}$  induced by shrinkage. This approach is also adopted in the design model proposed below for which further details can be found in (AS2327 2017, Ranzi 2017). In particular, the instantaneous deflection is determined performing an analysis of the composite slab adopting an effective flexural rigidity. The latter can be evaluated following common design specifications recommended for reinforced concrete slabs, as performed in the Australian guidelines (AS3600 2009). The creep deflection is calculated relying on the effective modulus method, e.g. (Gilbert and Ranzi 2011), and considering only the sustained part of the short-term service load. The remaining shrinkage deflection is obtained by evaluating the effects produced by a shrinkage-induced curvature  $\kappa_{cs}$  at different locations and calculated as a weighted value between the curvature exhibited under uncracked condition  $\kappa_{cs,uncr}$  and the one developed for cracked conditions  $\kappa_{cs,cr}$ . The weighting term in this case is the distribution coefficient  $\gamma_{cs}$  that considers the degree of cracking exhibited in the slab for the applied service load. Based on this, the shrinkage-induced curvature at a particular cross-section is determined as follows:

$$\kappa_{cs} = (1 - \gamma_{cs}) \kappa_{cs,cr} + \gamma_{cs} \kappa_{cs,uncr} \quad (1)$$

The shrinkage profile to be used in the design (assumed to be linearly varying) is determined based on a reference shrinkage value  $\epsilon_{sh}$  obtained from reinforced concrete guidelines, e.g. (AS3600 2009, EC2 2005), by adopting a hypothetical thickness equal to the thickness of the composite slab and assuming both sides of the slab to be exposed. The non-uniform shrinkage distribution is then defined considering a linearly varying profile possessing values of  $1.2 \epsilon_{sh}$  and  $0.2 \epsilon_{sh}$  at the top and bottom sides of

the slab, respectively. The definition of the shrinkage reference strain is a consequence of the fact that the top and bottom values of the non-uniform shrinkage profile have been calibrated experimentally against those exhibited by companion concrete slab samples exposed on both sides with same thickness as the composite specimens. Obviously, more refined representations could be considered and adopted for the shrinkage distribution.

### *3.2 Model validation*

The proposed model has been validated against long-term tests available in the literature on composite slabs and post-tensioned composite slabs. For the purpose of this paper only selected experimental tests have been selected and presented in Figs. 3-5. In particular, Fig. 3 reports a comparison between the values calculated with the design model and the experimental measurements recorded in a long-term test of a composite slab whose details can be found in (Gholamhoseini et al 2014, Gholamhoseini 2014). In this case, the results relate to a sample cast on a Fielders' KF70 profiled steel sheeting. A second long-term test carried out on a composite slab is depicted in Fig. 4. (Al-deen et al 2015) In this case, a Stramit Condeck HP profiled sheeting was used in the preparation of the specimen. The third comparison presented in this paper relates to a post-tensioned composite slab also cast on a Stramit Condeck HP profile and its comparisons are illustrated in Fig. 5. (Ranzi et al 2013b) In all cases, the model predictions based on the use of a non-uniform shrinkage profile well match the experimental deflections recorded over time, while the use of a constant shrinkage distribution underestimates the deformation.

## **4. CONCLUSIONS**

This paper has provided a brief overview of recent advances related to the serviceability limit state design of composite floor systems. In particular, it has presented a design model for the evaluation of deflections at service conditions. The particularity of this work relies on the ability of the proposed formulation to account for the development of a non-uniform shrinkage profile, observed in recent long-term experimental tests carried out on composite slabs and post-tensioned composite slabs, to occur due to the inability of the concrete to dry from its underside. The validity of the proposed approach has been validated by comparing the numerical calculated values to the measured deflections of selected composite and post-tensioned composite samples. In all cases, the adopted model implemented with a non-uniform shrinkage profile has shown to well match the experimental data while the use of a uniform shrinkage has underestimated the deformations.

## **5. ACKNOWLEDGEMENTS**

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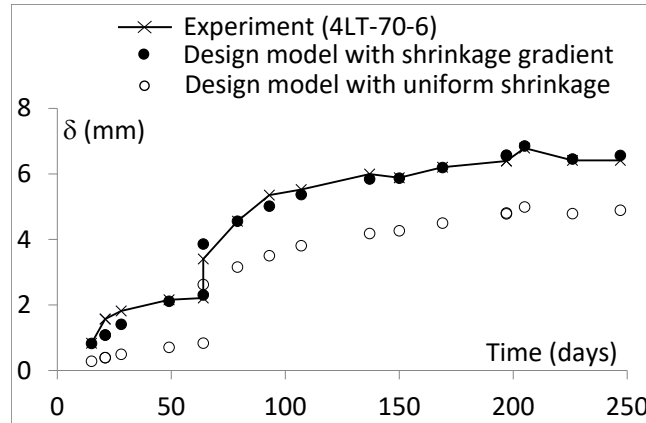


Fig. 3 Comparisons between experimental measurements and calculated values: sample 4LT-70-6. (Gholamhoseini et al 2014, Gholamhoseini 2014)

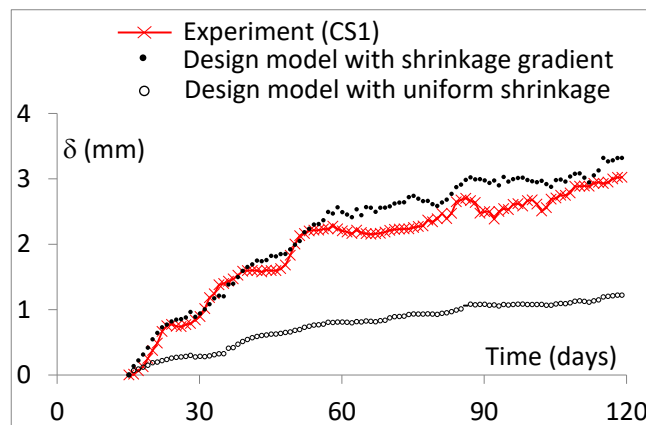


Fig. 4 Comparisons between experimental measurements and calculated values: sample CS1. (Al-deen et al 2015)

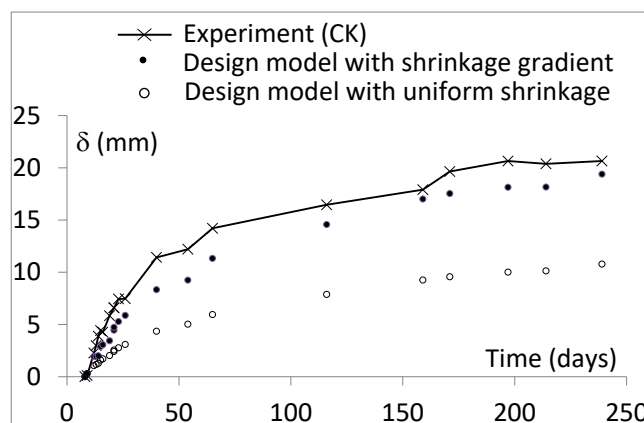


Fig. 5 Comparisons between experimental measurements and calculated values: sample CK. (Ranzi et al 2013b)

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