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Shrinkage Behaviour of SFRC Industrial Ground Floors

Naeimeh Jafarifar[1], Alireza Bagheri Sabbagh[2]

[1] School of Architecture and Built Environment, Robert Gordon University, Aberdeen, AB10 7QB, UK

[2] School of Engineering, University of Aberdeen, Aberdeen, AB24 3UE, UK

ABSTRACT

Restrained shrinkage is an important issue in design of concrete industrial ground floors, although it is often overlooked. This paper studies shrinkage behaviour of a SFRC floor subjected to static racking load, through FE simulation. The ultimate load bearing capacity and cracking of the floor is assessed. It is shown that shortly-spaced surface micro-cracks are formed due to shrinkage. These cracks are not initially visible, but get longer and wider after loading. As a result, the load-carrying capacity of the floor reduces significantly, and the equivalent crack opening increases by up to10 times.

Keywords: Shrinkage; SFRC; Industrial floors; Load bearing

1. Introduction

Shrinkage is an important issue in design of industrial floors, as repairs and maintenance are costly and disruptive. All concretes shrink and many factors affect shrinkage of industrial floors. Racking equipment has been developed to hold more with an increasing height. This can result in greater contact pressure and flexural stresses. Increasing paste content to obtain higher strength concretes, and limited good quality aggregates increase shrinkage potential of concrete mixes.

Shrinkage can lead to cracking when there exists restraint. It causes decreased load-carrying capacity and has a serious impact on structural and durability performance of concrete floors. Ground slabs are more vulnerable to shrinkage cracks than other kinds of structural members, due to their large surface area relative to thickness and being restrained by racking bases and frictional resistance of the ground which causes differential shrinkage, and shown in Figure 1(a) and 1(b), respectively.

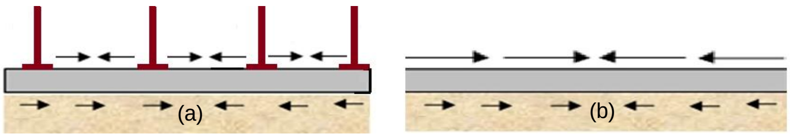


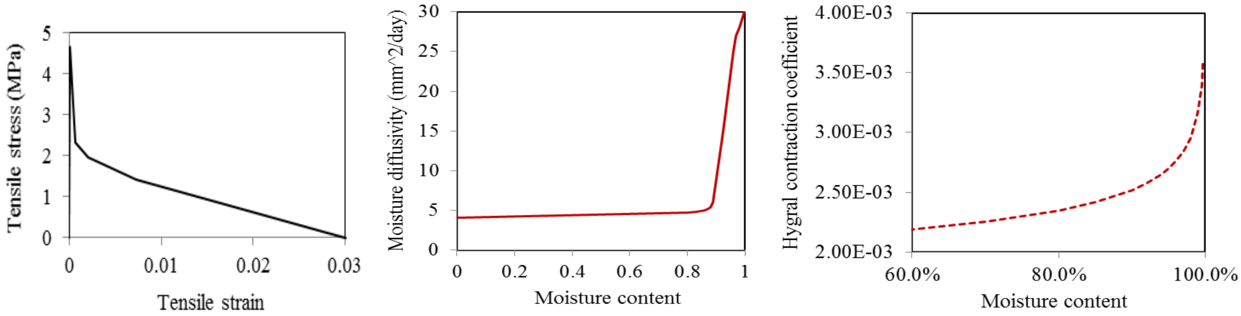
Figure 1 Differential shrinkage due to (a) restraint from racking bases; (b) restraint from frictional resistance of the foundation

This paper studies restrained shrinkage of a typical SFRC industrial floor subjected to static racking load, through numerical FE simulation. The effect of shrinkage distress on the load-carrying capacity is quantified. Dowel bars are modelled as well as a multi-layered foundation with the ability of developing friction, cohesion and separation between the slab and the base.

2. Mechanical, moisture transport and shrinkage properties of the studied concrete

A typical SFRC mix is studied in this paper, with a compressive strength of 32.0 MPa and an elastic modulus of 31 GPa. This mix incorporates 2.5% of fibres (by mass) and its tensile behaviour is presented in Figure 2(a).

To formulate transport of moisture and shrinkage in concrete, based on assuming the diffusion theory [1, 2, 3, 4, 5], three material properties of concrete need to be known: (1) diffusion coefficient, K_C; (2) the relationship between moisture loss and free shrinkage strain (Hygral contraction coefficient), $\beta_C(C)$; (3) convective moisture transfer coefficient (also called surface or film factor), *f* [6]. In this study, typical values are assumed for this parameters, from the experimental studies of Jafarifar et al. [6], as shown in Figure 2(b) and 2(c), as well as a surface factor of 5 mm/day.

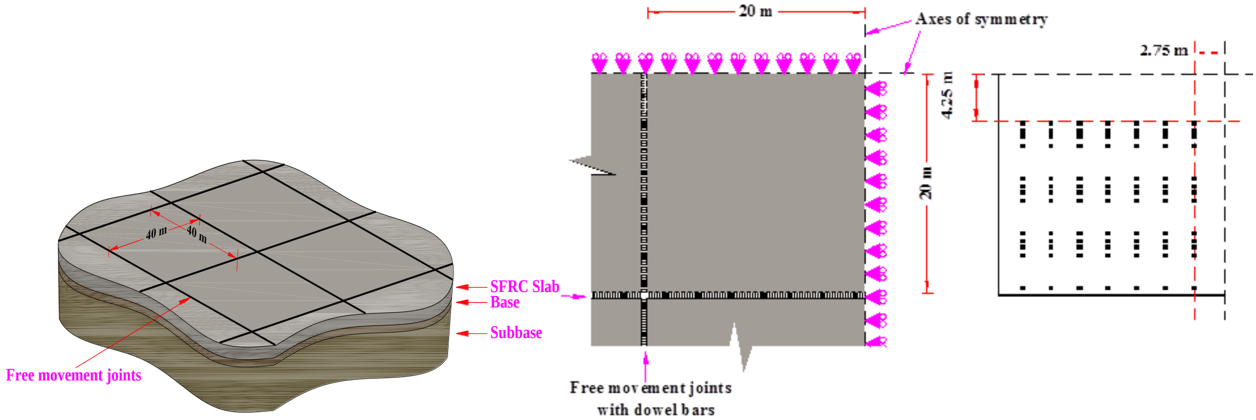


(a) (b) (c)

Figure 2 (a) Tensile behaviour of the studied SFRC; (b) Moisture diffusivity [6]; (c) hygral contraction coefficient [6]

3. FE Modelling of the SFRC ground floor and loading configuration

An industrial ground floor is analysed in a 3D model, including a concrete slab and a multi-layered foundation, as illustrated in Figures 3(a). In this model, moisture transport analysis is first carried out and spatial moisture profiles are calculated as functions of time. This is then coupled with a structural analysis in which shrinkage strains are used to assess stresses and predict crack development at the pre-loading stage. Finally, the slab is analysed under racking load and the performance of the slab is discussed. For this purpose, smeared crack approach is used based on Concrete Damaged Plasticity model formulated in Abaqus FE package [7].



(a) (b)

Figure 3 (a) Industrial ground slab and the foundation layers; (b) Modelling details and configuration of racking bases

The concrete floor consists of 40×40 m segments connected with free-movement joints (see Figure 3(a)) in which dowel bars are installed to maintain shear-transfer ability between the adjacent segments. The slab thickness is 175 mm. In the FE analysis, the contact between the slab and the foundation is modelled such that any relative movement is allowed. The base layer is modelled as an elastic solid body with 150 mm thickness and 7 GPa modulus of elasticity. The subbase is modelled as a Winkler foundation acting like vertical springs with 0.025 N/mm^3 modulus of reaction. The friction coefficient between the slab and the base layer is assumed equal to 1.0 with no cohesion. The modelling details and the loading configuration is presented in Figure 3(b).

It is assumed that the concrete slab is fully saturated after casting and the ambient humidity is 60%. Moisture convection occurs from the top surface. In the FE model moisture transport is simulated using heat transfer equation.

4. Results and discussion

The results show that for the studied SFRC mix, after 180 days of drying, shrinkage micro-cracks occur with an average opening density of 0.35 mm/m on the top surface. These micro-cracks penetrate only up to 20% of the slab depth. Based on a hypothesis proposed by Bazant et al. [8, 9] and assuming a minimum crack spacing in the range of the maximum aggregate size, at the stabilised state of drying and prior to applying the racking load, for the studied SFRC slab crack spacing is in the range of 20-60 mm and crack opening is in the range of 0.007-0.02 mm. The tensile strength of concrete slab on the top surface reduces to 60%, due to the effect of shrinkage.

When racking load is applied, surface cracks localise in the critical zones. Figure 4(a) shows crack localisation areas and critical cracks at the ultimate limit state, under the combined effect of racking load and shrinkage.

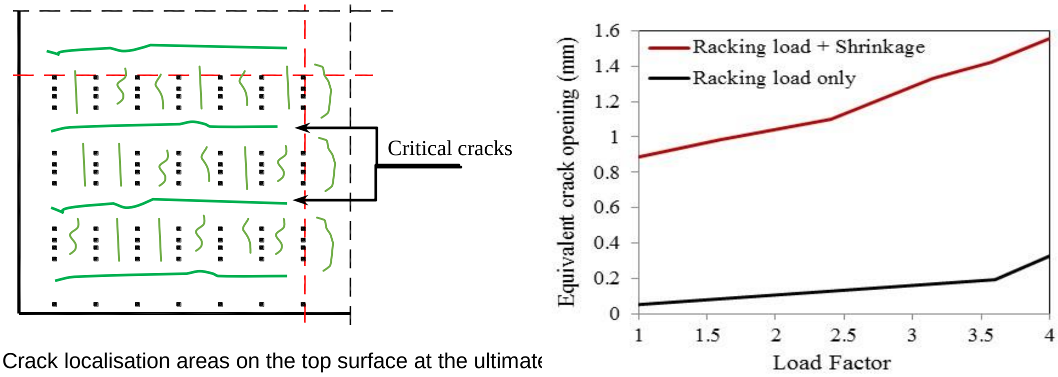


Figure 4 (a) Crack localisation areas on the top surface at the ultimat

In Figure 4(b), the equivalent opening of the critical cracks is compared with the case of ignoring shrinkage, for various load factors. Table 1 presents the load levels at which localised cracking is seen at the top surface of the concrete slab, and the values that cause penetration of the localised cracks to the half depth.

The results show that, due to the effect of shrinkage, crack openings can increase by more than 10 times, and this can seriously influence the serviceability and durability of the structure and significantly reduce the load-carrying capacity from 360 kN to 240 kN (at the ultimate limit state).

Table 1. Load-carrying capacities

Level of failure	Racking load only	Racking load + shrinkage
Crack localisation at the top	240 kN (Load Factor = 2.4)	20 kN (Load Factor = 0.2)
Crack penetration to half depth	360 kN (Load Factor = 3.6)	240 kN (Load Factor = 2.4)
Equivalent crack opening for load factor= 1.5	0.08 mm	0.96 mm

5. Conclusions

The shrinkage performance of a typical SFRC industrial slab was assessed through FE simulation. It was shown that although shrinkage cracks are localised, tiny, shallow in depth and rarely visible, they reduce the load bearing capacity of the floor to 66% and can increase the equivalent crack opening by more than 10 times.

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