Chapter 5
Structural Behaviour

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Abstract Bonded cement-based material overlays and their substrates constitute a hybrid or composite structural system. The interaction of these two material layers (with different ages), with each other, with the external boundary conditions (foundations, supports) and possible joints, and under loading, defines the structural behaviour of this composite system.

The main actions governing this structural behaviour are (1) the differential deformations of the two layers due to autogenous shrinkage, thermo-mechanical effects due to cement hydration and/or external climatic influences and drying shrinkage, (2) settlements, and/or (3) imposed forces (dead loads, traffic loads). These actions give rise to stresses which depend on the stiffness of the substrate with respect to the new layer, and that eventually may result in failure either by transverse crack propagation, by debonding or both.

Composite structures formed of building materials of different kinds and ages are very common: slabs on grade, steel-concrete, wood-concrete, concrete-concrete, concrete repairs, cement-based overlays, etc. However, until now, the causes of distress in these composite structures and their design were mostly addressed by empirical approaches. This document shows how a common approach might treat all these applications on the unique basis of the mechanical description of the behaviour of composite structural members under restrained shrinkage.

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5.1 Introduction

Bonded cement-based material overlays and their substrates constitute a hybrid or composite structural system. The interaction under loading of these two material layers (with different ages), with each other and with the external boundary conditions (foundations, supports) and possible joints defines the structural behaviour of this composite system.

Composite structures formed of building materials of different kinds and ages are very common: slabs on grade, steel-concrete, wood-concrete, concrete-concrete, concrete repairs, cement-based overlays, etc. However, until now, the causes of distress in several of these composite structures and their design were mostly addressed by means of empirical approaches. This document shows how a common approach originally proposed by Sillfwerbrand [1, 2] can treat all these applications on the unique basis of the mechanical description of the behaviour of composite structural members under restrained shrinkage.

Composite structural members are subjected to actions such as: (1) the differential deformations of the two layers due to autogenous shrinkage, thermo-mechanical effects due to cement hydration and/or external climatic influences and drying shrinkage, (2) settlements, and/or (3) imposed forces (dead loads, traffic loads). These actions give rise to stresses which depend on the stiffness of the substrate with respect to the new layer, and that eventually may result in failure either by transverse crack propagation, by de-bonding or both. The early age effects such as the thermo-mechanical effects are difficult to approximate with simplified approaches, due to the rapidly changing material properties.

There is a complex interaction between the structural behaviour and the modes of failure. If de-bonding can be prevented, the hybrid structure behaves in a monolithic way and structural failure will happen by transverse cracking. Otherwise, if de-bonding occurs, near cracks or joints, complex failure patterns can be obtained.

In the case of restrained deformations of the overlay, a simplified approach is to summarize the parameters related to the structure using the notion of degree of restraint of the overlay. Maximum restraint is obtained when all degrees of freedom (flexural and axial) of the overlay are blocked, i.e. the worst case scenario. The degree of restraint represents the loading level of the overlay with respect to maximum restraint. This approach has been investigated by several authors with the hypothesis of elastic materials. In the most general case, the structural response of a hybrid element can only be determined by a finite element simulation taking into consideration all relevant boundary conditions and material properties. The viscoelastic behaviour of the overlay, and if applicable, of the substrate, significantly contributes to the stress relaxation under imposed deformations. It can be taken into consideration by comprehensive numerical analyses, or by means of simplified analytical models.

Both the simplified approach based on the degree of restraint and the advanced numerical simulations can be used to predict the structural performance of composite systems, under imposed deformations of the overlay, with the aim to select appropriate combinations of materials, thicknesses, reinforcements and joints.