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Estimation of bond strength envelopes for old-to-new concrete interfaces based on a cylinder splitting test

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ABSTRACT

The number of existing structures under rehabilitation has significantly increased over the past two decades; these structures typically require performance improvements including repair and strengthening. Currently, reinforced concrete is widely used in interventions for the rehabilitation of bridges and buildings. Here, we present a method for the estimation of failure envelopes for old-to-new concrete interfaces based on plasticity theory. The proposed Carol-type failure envelope uses the simple splitting tension test, also known as the Brazilian test. The relevant parameters of the envelope—f_t', the tensile strength, c', cohesion and ϕ', the friction angle—are assessed by experimentation, a rational formulation and a bibliographic study, respectively.

1. Introduction

The ageing of existing concrete structures demands work in maintenance, repair and strengthening measures. Cementitious materials, either mortar or concrete, are widely used in the rehabilitation of bridges and buildings; a common practice involves the addition of a thin concrete layer, ranging from 20 to 100 mm, either alone or reinforced with steel bars or metallic or synthetic fibres. The patching or substitution of concrete overlay in floors or decks and the use of structural concrete jacketing columns are two common examples of the application of cementitious materials in strengthening.

The aim of this study was to provide a criterion for evaluating the bond strength between newly added and existing concrete in such applications. For this purpose, we developed a simple method to estimate the bond strength of the interface between old and new concrete using a failure envelope based on the theory of plasticity. An experimental campaign using the splitting tensile test was developed to assess the tensile bond strength between old concrete and a micro-concrete repair.

2. Examples of shear stresses at interfaces

There are some typical stress states at interfaces that must be considered in assessing the suitability of a failure envelope. The interface between the substrate concrete of existing slabs and newly poured concrete is subject to a self-equilibrated state of tension combined with shear (Fig. 1-I). These stresses, which appear in the serviceability state, are mainly located at the borders and are caused by restrained drying shrinkage. Bridge retrofitting work is sometimes necessary in repairing and strengthening slender stems of box girder decks, generally due to a lack of shear reinforcement (Fig. 1-II A). In these cases, the interfaces between new and old concrete are under shear stress due to variations in the overall bending moment once the new dead load and the live load act together. Columns strengthened by means of high-performance concrete jackets have a transference zone along which the longitudinal forces are transferred through interface shear stresses from the old cross-section to the new cross-section (Fig. 1-III). Pure tension stresses are rather unusual in strengthening structures; however, tension stress with low eccentricity can occur in some circumstances, as shown in Fig. 1-II (point 'B'). Here, a partially demolished and then widened bridge deck is shown, where the critical section is located at the junction of the old and new concrete.

3. Failure criteria of the interface

We begin by assuming that the failure mechanism of an interface between two concrete bodies occurs under a plane deformation field and, additionally, that crack formation is initiated when the normal σ and tangential τ stress components reach a certain cracking failure envelope. Then, according to Mohr's failure hypothesis, the stresses are assumed to satisfy the condition:

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Nomenclature

f'_t	tensile strength of the interface, estimated from the splitting tensile test
$f'_{c,t}$	compressive stress concomitant with the splitting tensile strength
Pu	ultimate or peak load registered during the splitting tensile test
a	width of the bearing strip used to distribute the load applied to the cylinder
B	length of the cylinder used as a test specimen in the Brazilian test
D	diameter of the cylinder used as a test specimen in the Brazilian test
y	coordinate associated with a point located on the cylinder radial plane, measured from the edge of the cylinder
cov	coefficient of variation of the splitting tensile strength, defined as the ratio of the standard deviation to the mean value
ϕ'	internal friction angle of the interface material
c'	cohesion of the interface material (parameter defined for concrete plasticity corresponding to the pure shear resistance of the interface)
σ_x	transverse stress acting along the normal of the radial plane of the cylindrical splitting test specimen
σ_y	compressive stress parallel to the radial plane in the cylindrical splitting test specimen
$\sigma_{1,i}$	the highest-tension principal stress (e.g., in the splitting tensile test, this corresponds to the splitting tensile stress), located at i in Mohr's circle
$\sigma_{3,i}$	the highest-compression principal stress (e.g., in slant shear tests, it corresponds to the uniaxial compression stress), located at i in Mohr's circle
σ	normal stress at the interface
τ	shear stress at the interface
τ_u	ultimate shear stress at the interface

$$F(\sigma, \tau) = 0 \quad (1)$$

For the interface failure condition—as a special case of Mohr's theory—concrete is here, as it often is, assumed to be a Coulomb material. Furthermore, if the tensile strength is taken into account for the interface failure condition, a modified Coulomb material can be used (Fig. 3, line B). Therefore, a repair or construction joint interface failure envelope can be modelled using three parameters: the tensile strength, f'_t, the cohesion, c', and the internal friction angle, ϕ'. The term failure refers to cracking of the interface. Theoretically, there are three cracking failure modes: sliding, pure tension and a mixed mode. The sliding mode occurs when the shear strength limit is reached while the interface is under high compressive stress, whereas cracking under pure tension occurs with tensile stress but with zero shear stress. Between these two limiting conditions, e.g., in the case of low compressive stresses or when mainly under tension, shear failure occurs as a mixed mode of cracking.

For a qualitative analysis of the resistance mechanisms of bond strength in interfaces between old and new concrete, we employed a 2D version of the graphical model for the evolution of a cracking envelope proposed by Carol [1] for normal/shear cracking in quasibrittle materials. This model was originally proposed to differentiate between 'bond-adhesive' and 'bond-cohesive' mechanisms.

The 'adhesive' mechanism is related to the chemical forces acting at the micro-scale, which are responsible for the embedding action between the reactive matrix materials of the new concrete repair and the substrate of old repaired concrete. Xie and Xiong [2] presented a micromodel (see Fig. 2b) based on the existence of a three-layer interface between the substrate and overlay. The first layer, termed the 'penetration layer' (consisting mainly of prickly C–S–H with smaller amounts of AFt or $Ca(OH)_2$) is formed inside the concrete substrate and contains young constituents that

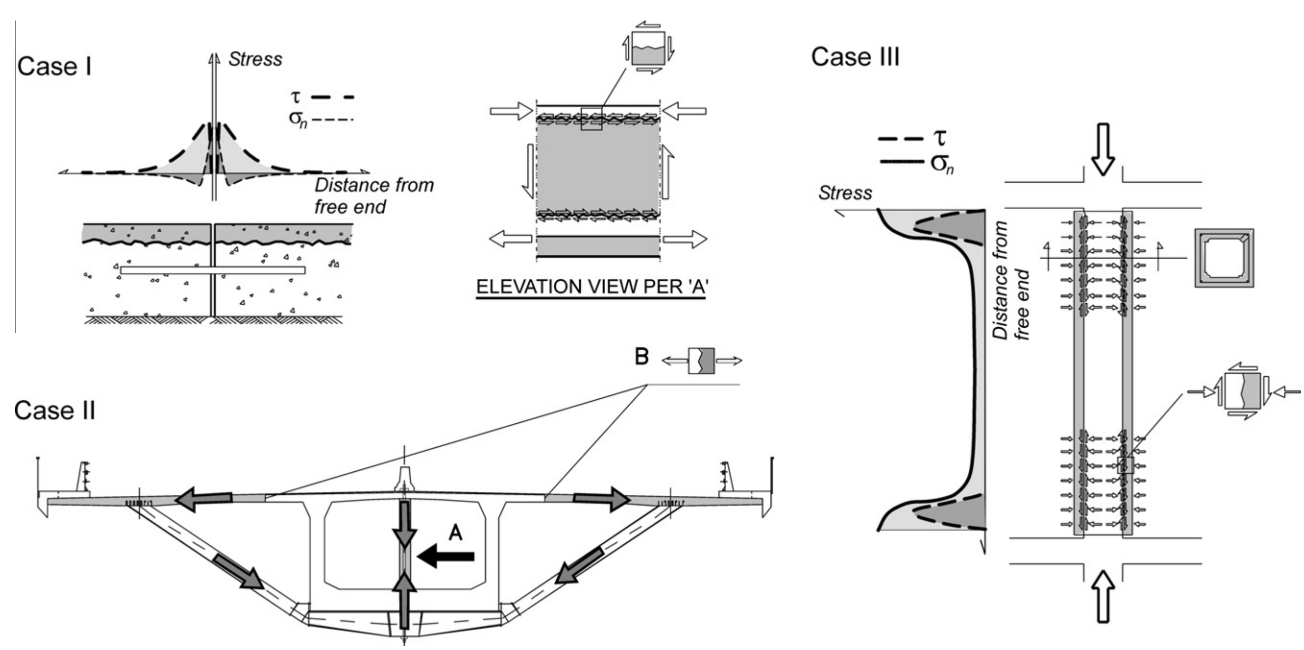

Fig. 1. Several examples of repair and retrofitting interventions of existing concrete structures using high-performance concrete.