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Detailing of concrete-to-concrete interfaces for improved ductility

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ABSTRACT

Recent research has shown that reinforced concrete (RC) beams with concrete-to-concrete casting interfaces where plastic hinges are likely to develop, may experience reduced ductility in comparison to similar structural elements casted at once, due to a potential shear slippage along the casting interfaces. Although of relevant importance for both precast and cast *in situ* RC structures, this problem is still not addressed in current codes and standards, which limit the safety check of casting interfaces to the verification of their strength based on improved expressions of the "*shear friction theory*", the latter proposed in the 60's. However, recent research has shown that friction strength of casting interfaces depends on interface width opening, and it is significantly reduced after the yield of the bending reinforcement. During the formation of plastic hinges, shear stresses run preferentially across the compressed zones of the interfaces, reducing their strength, and ultimately the specimens' ductility.

In this paper, different and alternative details for interfaces are proposed to improve global behaviour, and in particular, ductility of RC beams with casting interfaces located on plastic hinges regions. An experimental campaign was carried out to study the effect of: (i) epoxy and latex based adhesion promoters' usage between castings; (ii) web reinforcement; (iii) geometry of interfaces; (iv) and shear level.

Results show that both epoxy and latex based adhesion promoters, currently used in construction, hardly improve the tensile strength of casting interfaces, to a point that the interface presence has negligible impact on the cracking pattern. A much better result was observed from the use of a web reinforcement crossing the interface perpendicularly. Although this solution revealed itself also incapable to avoid preferential cracking along the interfaces, it proved to be efficient in limiting shear slippages. The adoption of inclined interfaces either perpendicular or parallel to the expected direction of shear cracks proved also to be an efficient solution. Finally, the likelihood of experiencing a shear slippage along the interface is strongly dependent on the existing shear level after the formation of a plastic hinge.

1. Introduction

In the design and construction of reinforced concrete (RC) structures, every time two concretes are cast against each other at different moments, and the hardening process of the older concrete is already finished, a concrete-to-concrete interface is created and an additional safety check is required, corresponding to the verification of the interface capacity to transfer loads across. The situation is recurrent in the construction of RC structures.

For cast-in-place structures, the concrete-to-concrete interfaces result essentially from the limited production resources or from the casting plans, which do not allow always a single cast per structure, but also from unforeseen events leading to interruptions in the erection process. Concrete-to-concrete interfaces are also recurrent in precasted RC construction in the connections between precasted elements or between cast-in-place and precasted elements.

The safety verification of these interfaces has been traditionally carried out using the shear "*shear-friction theory*", originally proposed by Birkeland and Birkeland [1] for the connections of the precasted construction. Later on, it was also adopted, with subsequent improvements, by the generality of codes and, in particular, by the Eurocode 2 [2] and the ACI 318–14 [3] or the very recent Model Code 2010 [4]. However, the "*shear-friction theory*", including the following changes, did not address the safety check of interfaces subjected to a combination of shear and bending moment as it was developed having in mind a shear failure as a slippage along a mode II crack, according to the classification of the mechanics of fracture [5], subjected to shear and normal forces. However, interfaces subjected to shear and bending moment, and where a shear slippage along a mode I crack can potentially occur, are also frequent in real practice, in both cast in place or

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Nomenclature

α	angle between shear reinforcement and the shear plane
β	coefficient allowing for angle of concrete diagonal strut
c	coefficient of cohesion
c_r	coefficient of interlocking effect
f_c	concrete compressive strength
f_{cm}	mean value of concrete compressive strength
f_{ctd}	design value of concrete tensile strength
f_{ctm}	mean value of concrete tensile strength
f_y	yield strength of reinforcement
f_{ym}	mean value of yield strength of reinforcement
k_1	Randl's coefficient of efficiency of reinforcement
k_2	Randl's dowel action coefficient
μ	coefficient of friction
ν	strength reduction factor
ν_u	ultimate shear friction strength
ρ	reinforcement ratio
σ_n	normal stress acting on interface due to external loading
A_{sl}^-	negative longitudinal reinforcement area
A_{sl}^+	positive longitudinal reinforcement area
A_{sw}	transversal reinforcement area
M_{Rm}	bending strength
P_{Rm}^M	expected ultimate testing load due to a bending failure
P_{Rm}^S	expected ultimate testing load due to a shear friction failure
P_{Rm}^V	expected ultimate testing load due to a shear failure
V_{Rm}^M	shear load at the time of a bending failure
V_{Rm}^S	shear friction strength
V_{Rm}^V	shear strength

precast structures. Some examples include: (i) the interfaces defined by the connection of precast beams elements to execute a continuous beam on the hogging region; (ii) the casting interface between columns and the foundations; (iii) and every casting interface, created accidentally or intentionally, on beams and columns of cast in place RC structures matching sections subjected simultaneously to shear and non-negligible bending moment.

Recent research work [6] has shown that the "*shear-friction theory*", including the design expressions of the Eurocode 2 [2] and the ACI 318–14 [3], are incapable to describe the physical mechanism behind the load transfer across an interface subjected to a normal stress gradient resulting from the combination of a shear force and a bending moment. Moreover, it was found that the presence of a vertical interface between two differently aged concretes is responsible for a ductility reduction in bending of a RC beam, in comparison to that of a beam produced in a single cast, thus without interfaces.

Following the research presented in [6], in particular the results suggesting the ductility reduction of a RC beam with vertical casting interfaces, in this paper different and improved design strategies are proposed and the corresponding behaviours are experimentally investigated..

2. Literature review

The behaviour of concrete-to-concrete interfaces subjected to shear or normal forces perpendicular to the interface, or a combination of both, where a shear slippage is possible to occur, has been the object of several research works published in the latter 50 years [7–22]. The "*shear-friction theory*", originally proposed in [1] and given by Eq. (1), has been used to predict the shear strength of concrete interfaces.

$$v_u = \mu\rho f_y \tag{1}$$

It has seen major improvements over the years, as a result of several research works, to take into account several different effects such as adhesion, aggregate interlock, dowel action, the weakest concrete, interface roughness, among others. It has been adopted in most design codes, in particular in the ACI 318–14 [3] (see Eq. (2)), Eurocode 2 [2] (see Eq. (3)) or the very recent Model Code 2010 [4] (see Eq. (4)).

$$v_u = \rho f_y(\mu\sin\alpha + \cos\alpha) \tag{2}$$

$$v_u = cf_{ctd} + \mu\sigma_n + \rho f_y(\mu\sin\alpha + \cos\alpha) \leqslant 0.5\nu f_c \tag{3}$$

$$v_u = c_r f_c^{1/3} + \mu(\rho k_1 f_y + \sigma_n) + k_2\rho\sqrt{f_y f_c} \leqslant \beta\nu f_c \tag{4}$$

However, and according to the crack classification of the fracture mechanics [5], the original theory has been developed for the hypothesis of having a shear slippage along a mode II crack, and not a mode I crack, resulting from tension stresses. Moreover, this fact has rarely been addressed in the subsequent improvements made to the original theory. The application of the "*shear-friction theory*", including the

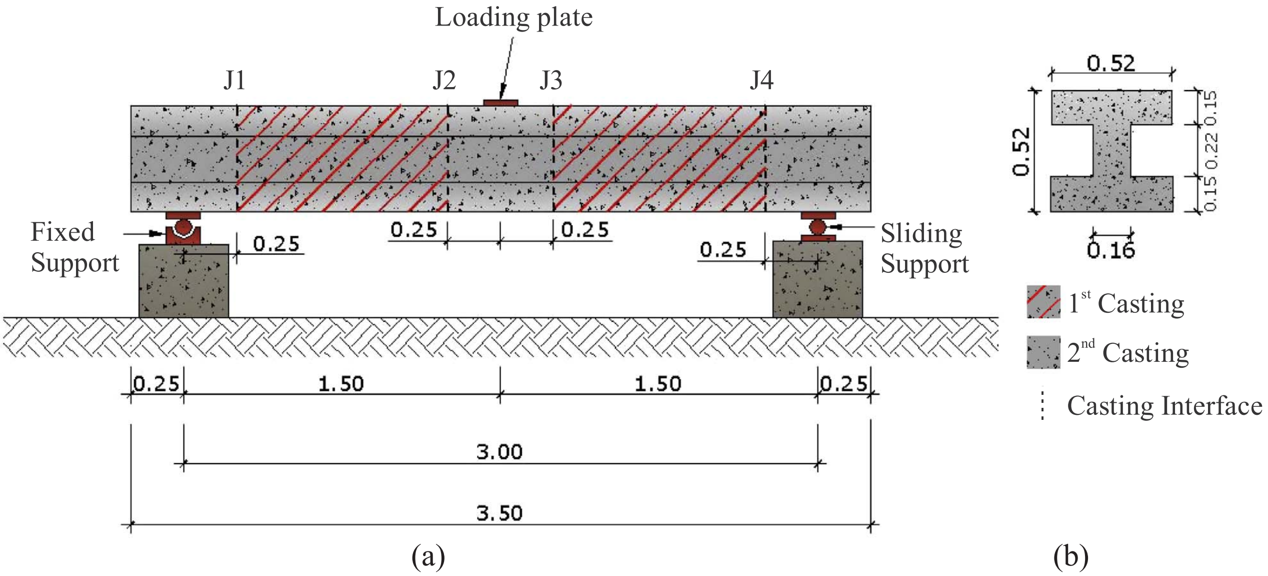

Fig. 1. Standard beam specimen: (a) side view; (b) cross section.