Engineering Structures 165 (2018) 1–10

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Proposal and assessment of an efficient test configuration for studying lap splices in reinforced concrete

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ARTICLE INFO

Keywords:
Lap splices
Reinforced concrete
Test setup
Bond-slip

ABSTRACT

Connecting reinforcement bars in their longitudinal direction is often needed in reinforced concrete structures. These connections must guarantee a correct stress transmission between bars without excessive cracking or inadmissible slips, and they are commonly executed by overlapping the reinforcement bars in a procedure known as a lap splice. In the absence of a standard or widely recognized test, three or four point bending tests are often used for the experimental study of lap-splices in tension. This test configuration shows inherent limitations, large costs and, usually, significant scatter.

In this paper the authors have selected, fine-tuned and evaluated a specific test configuration for studying lap splices in reinforcement bars submitted to tensile forces. The proposed experiment was designed to be flexible and affordable in terms of cost, time consumption and required testing equipment. Consequently, it is possible to carry out multiple reruns of the experiments, minimizing the uncertainty and providing a good starting point for applying statistic methodologies. In contrast to the regular test configurations, the selected setup makes possible to directly obtain the bond-slip curves of the spliced bars. The experimental work carried out to assess the reliability, sensitivity and scatter of the proposed configuration shows promising results.

1. Introduction

1.1. Bond between reinforcement bars and concrete

The complex combination of the different physical phenomena and chemical interactions that make possible the joint work between concrete and the reinforcements bars embedded in it are usually denominated as the bond properties. These interactions allow the transfer of forces between both materials, creating the composite material we usually refer to as reinforced concrete. In addition to the chemical adhesion between the concrete and the surface of reinforcement bars, which is often obviated due to its negligible contribution once a very small relative displacement takes place [1], the main bond mechanism is the development of mechanical stresses between the rebar ribs and the surrounding concrete, with the height and spacing between ribs having a strong impact in the bond-slip response of reinforcement bars [2].

Abrams developed a test method in which a single rebar embedded in a concrete prism is pulled out until failure, while the applied force and the slip at the free end of the rebar are simultaneously measured [3]. This experiment, named as the pull-out test, soon was adopted by several institutions and it was normalized by the RILEM as a standard method [4]. The pull-out test, represented in Fig. 1A, is affordable and provides a constitutive curve of the phenomenon, but it only takes into account the particular case of a single rebar embedded in concrete. Furthermore, the concrete around the bar is submitted to longitudinal compression whereas in the tension zone of a beam it is placed in tension, resulting in a different stress state and driving to more favorable and unrealistic confinement conditions [5,6]. Its lack of realistic conditions makes it unsuitable for determining the development length and, consequently, ACI Committee 408 recommends against it [7].

A more complex and time-consuming alternative experiment is the one named as beam-test, also adopted by the FIB and normalized by the RILEM [8]. This method, shown in Fig. 1B, emulates a concrete beam under a 4 point bending configuration, with reinforcement bars embedded in the tension zone of the cross-section.

1.2. Lap-splices

As structures grow in size and complexity the need to join different reinforcement bars in their longitudinal direction comes up. This necessity is imposed by the commercial length of rebars and also due to the requirement of connecting the reinforcement between different construction stages. Although there are many different ways to execute

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https://doi.org/10.1016/j.engstruct.2018.03.004
Received 4 September 2017; Received in revised form 5 January 2018; Accepted 5 March 2018
0141-0296/

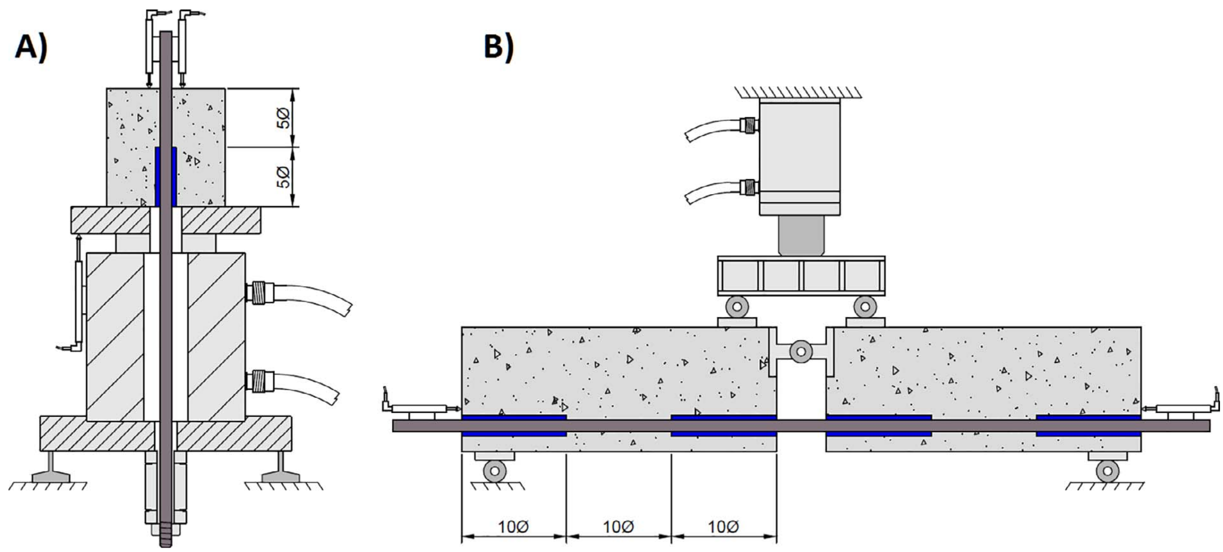

Fig. 1. Test configuration: (A) pull-out test and beam test (B).

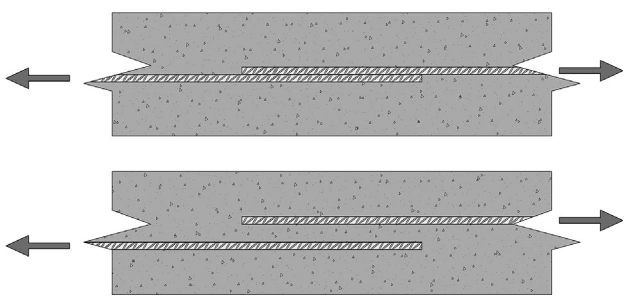

Fig. 2. Contact and non-contact lap splice.

rebar joints, including mechanical couplers and arc welding [9], overlapping the bars is the most frequent technique used to ensure reinforcement continuity, being both economic and fast to apply in most cases. In Fig. 2 typical configurations of overlapped bars in a concrete member are presented.

A lap splice constitutes a singularity within the structure and its functionality should be guaranteed by ensuring that stress transmission between rebars does not produce excessive cracking in concrete nor do inadmissible slips take place. Although the core mechanism in lap splices is the same as in the anchorage of a single rebar and remarkable analytical models have been proposed [10,11], there is yet no standard or widely recognized affordable test for the experimental study of lap-spliced rebars in tension. Researchers resort to expensive and complex 3-point or 4-point bending tests on beams, introducing lap splices and analyzing their influence on the load-bearing capacity. Full-scale beams with lapped bars provide a very realistic approach to the phenomenon, and outstanding experimental work has been carried out in this field regarding, for example, the study of the influence of percentage of bars lapped in the same section [12] or the comparison with bars in bundles [13]. The main limitation of these tests is that they are very expensive both in time-consuming and economic costs. Even though under certain conditions it is possible to measure the slip of the rebars in beam specimens [14], most times the obtained results are not a direct bond stress-slip relationship. Moreover, the results are affected by a remarkable uncertainty due to the lack of trials and to the way that numerical results are achieved since it is impossible to make a direct measurement of the rebar force.

1.3. *Tension specimens*

Tension specimens, shown in Fig. 3, have been occasionally used to study lap splices and overcome the limitations present in full-scale beam tests. First references to this configuration can be found in the experiments carried out by Goto and Otsuka to study the cracks formed in concrete around tensioned bars [15]. In the early 1990s, lap splices were studied at the Heriot-Watt University using specifically designed tension specimens [16]: the samples were constituted by a prismatic concrete prism of conventional concrete with four embedded reinforcement bars arranged in the same plane. Two reinforcement bars were clamped to a reaction frame while the remaining bars were submitted to a tensile load.

By means of an analogous test configuration, Richter carried out a large research work with a substantial number of experiments studying the strength of lap splices in reinforced concrete members [17]. Splice length and concrete cover were the main factors studied, and good correlation was found between results obtained in the tension specimens and in conventional beams. Recently, an equivalent test setup has been successfully used once again to investigate the stress distribution and the bond strength of lap splices in unconfined UHPFRC [11,18].

Despite the study of lap splices, tension specimens have also proved to be useful for studying the bond behavior of reinforcement bars embedded in concrete. This configuration allows to easily elude the introduction of spurious compressive stresses around the embedded area of the reinforcement bar, leading to a more realistic simulation of the tension zone of a bending beam [5,19]. Several references to this test can be found in the literature starting from the 70s [20,21], but with relevant differences in the geometry, in the number of reinforcement bars, in the test setup or in the measured parameters. Tension specimens show a tendency to experience brittle failure, commonly associated with the tensile stress state induced in the specimen. For this reason, additional reinforcement is often included, hampering the extrapolation of the obtained results. Nonetheless, bond in fiber reinforced concrete, with improved tensile strength and behavior, can be more realistically studied with this test setup [22–24].

1.4. *Aims and scope*

As a result of the absence of a widely accepted analytical model and an effective, affordable and normalized test method, formulations in different construction codes result in very heterogeneous overlap length requirements. If a comparison is made between the Model Code 90 [25], the ACI 318-08 [26], the Eurocode 2 [27] and the AASHTO code [28], differences that in some cases reach 50% or even 100% can be observed [29,30].