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ORIGINAL ARTICLE

Effect of tension lap splice on the behavior of high strength self-compacted concrete beams

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Abstract Construction using concrete is spreading widely and there is a need for concrete that is capable of flowing under its own weight without mechanical vibration or compaction and fill the places between reinforcement and the complicated form shapes. From here, Self-Compacted Concrete (SCC) appears for the first time. Limited attention has been directed toward the bond between High Strength Self-Compacted Concrete (HSSCC) and spliced bars in beams [1–8].

This research studies the bond between HSSCC and spliced tension bars in beams. It is focused on observing the effect of some factors such as; reinforcement bar diameter and ratio, splice length and casting position on the beam flexural behavior. An experimental program consisting of sixteen simply supported beams divided into four groups is considered. All beams are of 1800 mm span and 200 × 400 mm cross-section cast with HSSCC. In twelve beams, the tensile steel was spliced in the constant moment zone, and four control beams without splice for comparison purpose. During testing; ultimate capacity, deflection, crack pattern and mode of failure have been recorded. Test results had been compared with proposed values in the Egyptian code of practice, other international design codes and recorded values of other researchers.

1. Introduction

Adequate bond between concrete and reinforcing bars in a splice is an essential requirement in the design of reinforced concrete structures. In the last 25 years, The Interest in HSSCC grows rapidly and now it is widely used in bridges and high rise building construction. This concrete was described as high-strength concrete (HSC) since it has higher strength than the usual normal-strength concrete (NSC) that has been produced for almost a century with 28-days strength in the range of 20–40 MPa. A typical application example of Self-compacting concrete is the two anchorages of Akashi-Kaikyo Bridge opened in April 1998 and the

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suspension bridge with the longest span in the world (1991 m).

Many researches were reported on bond strength between concrete and deformed bars for both normal strength and high strength concrete. Experimental tests were done and analytical equations were proposed by some researchers.

Various investigations have been carried out in order to make self-compacting concrete a standard one [9]. The items to be solved are summarized as, self-compactability testing method, mix-design method including, acceptance testing method at job site, and new type of powder or admixture suitable for self-compacting concrete. The European Guidelines for Self-Compacting Concrete [3] represents a state of the art document addressed to those specifiers, designers, purchasers, producers and users who wish to enhance their expertise and use of SCC. The Guidelines have been prepared using the wide range of experience and knowledge available to the European Project Group.

During the last ten years, few researches were conducted on bond strength of self-compacting concrete [1–7]. In 1990, Atorod Azizinamini et al. [1] tested a total of 18 beam specimens with two or three bars spliced. The main variables were (a) Concrete compressive strength f'_c, (b) Splice length; and (c) Casting position. The results showed that normalized bond strength decreases as concrete compressive strength increases with a rate of decrease increases as the splice length increases. In the case of normal strength concrete, the top bar demonstrated approximately 8% reduction in bond capacity compared to bottom cast bars. As indicated by comparison with the results, top bars, as defined by the ACI 318-11 [10], produce higher bond capacity when HSC is utilized.

Yerlici and Özturan [2] conducted a research program for testing 53 eccentric pullout test specimens. Tested specimens were divided into four groups, where only a single parameter varied in each group. For the first three groups, the variable parameters were the concrete compressive strength, the reinforcing bar diameter, and the thickness of clear concrete cover. These parameters varied as 60, 70, 80, and 90 MPa (8700, 10,150, 11,600, and 13,050 psi), 12, 16, 20, and 26 mm (No. 4, 5, 6, and 8), and 15, 20, 25, and 30 mm (5/8, 3/8, 1, and 1-1/8 in.), respectively. The variable parameter of the fourth test group was the amount of web reinforcement that was made up of three closed stirrups spaced at 30 mm (1-3/16 in.), center-to-center, transversely crossing the anchorage length of the longitudinal bars. The amount of web reinforcement varied from none to having stirrups made of 3, 4, and 6 mm (D-1, D-2, and D-4) diameter steel wires. It was indicated that the average anchorage bond strength varies with the compressive strength of concrete, as $(f'_c)^{2/3}$. The ACI Code slightly underestimates the effect of concrete strength on anchorage bond resistance when extended to HSC, while it overestimates the effect of concrete cover on anchorage bond resistance when extended to HSC.

The research project of Chan et al. [4] included the testing of a full-scale RC wall as the pullout specimen in which pullout reinforcing bars and transverse reinforcement were installed, some walls were SCC while others were cast from ordinary compacted concrete. The main variables were; (a) Concrete compressive strength f'_c, (b) Height of pull out bar (effect of top bar), and (c) Age of Concrete from 17 h to 28 days. It was concluded that compared to normal concrete NC, SCC exhibits higher bond to reinforcing bars and lower reduction in bond strength due to the top-bar effect. The slow development of compressive strength and bond strength in SCC at early age is generally due to the retarding effect of the carboxylic high-range water-reducing admixture used.

Almeida et al. [5] tested 66 special set up beam specimens made from 3 SCC mixes. The main variables were (a) Maximum aggregate size, and (b) SCC fluidity. It was found that the bond resistance was not affected by the SCC lack of fluidity. It was also found that high performance concretes have a fragile rupture of the bond connection. Also, unless some confinement reinforcement is provided, the splitting of the concrete surrounding the bar will occur as the concrete tension strength is reached. Finally, the desirable failure mode, with yielding or slip of the bar, will not occur. The behavior of the beams was similar in the 3 series of tests, even considering the low fluidity of one of the 3 mixes.

Twelve full-scale beam specimens (2000 × 300 × 200 mm) were tested in positive bending [6] with the loading system designed to determine the effect of self-compacting concrete (SCC) and the diameter of reinforcement on bond–slip characteristics of tension lap-slices. The specimens of lap-splice series were tested with lap-spliced bars centered on the midspan in a region of constant positive bending. The results showed that load transfer within the tension lap-spliced bars embedded in SCC in a reinforced concrete beam was better than that of the tension lap-spliced bars embedded in NC. The beam specimens produced from SCC had generally longer cracks in length than the beams produced from NC regardless of the reinforcing bar diameter.

The project of Cattaneo and Rosati [7] included the testing of 27 pullout specimens containing one embedded reinforcement bar. The main variables were reinforcement bar diameter, fiber existence and confinement. Two types of tests were considered: unconfined and confined pullout. The tests showed a significant size effect on bond strength: the smaller bar diameter exhibited a higher strength than the larger one. The bond strength of self-consolidating concrete was found to be higher than normal strength concrete. The concrete cover, 4.5∅, where ∅ is the bar diameter, was not sufficient to prevent splitting failure in SCC.

2. Experimental work

This research is a part of an experimental investigation [8] which studies bond between high-strength self-compacting concrete (HSSCC) and reinforcing bars in splices in beams. A total of sixteen concrete beams were fabricated and tested in this experimental program. The specimens were divided into four groups each has four specimens. The objectives of this program are to examine the effect of some factors such as; reinforcement bar size, reinforcement ratio, tension lap splice length and casting position on the beam flexural behavior.

A three-part notation system was used to indicate the variables of each beam. The first part of the notation indicates the casting position: B and T for bottom and top casting respectively. The second part indicates the splice length as a factor of the bar diameter with two different bar diameters: $LM \times N$ for splice length of M times bar diameter and N is the diameter of reinforcement bar. The third part is the reinforcement ratio: R.295 and R.424 for $A_S/(b \times d)$ equal to 0.295% and 0.424% respectively. The specimens with no splice are referred to as the control specimens. The objectives of this

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