ARTICLE IN PRESS

HBRC Journal (2015) xxx, xxx–xxx

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

# Effect of bond loss of tension reinforcement on the flexural behaviour of reinforced concrete beams

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Received 5 November 2014; revised 22 December 2014; accepted 8 January 2015

**KEYWORDS**

Beams;
Reinforced concrete;
Bond loss;
Flexure;
Ultimate load;
Deflection

**Abstract** An experimental programme has been conducted in order to investigate the flexural behaviour of concrete beams with variable un-bonded length of tension reinforcement. A test series of six simple beams containing different nominal length without bond close to the support had been conducted in this investigation. The tested beams are of 2250 mm total span loaded at the middle third with two equal concentrated loads. The bond loss had been introduced with plastic tubes surrounding the longitudinal tension reinforcement leaving short bonded lengths over supports and at positions of stirrups crossing the longitudinal reinforcement. The effect of reinforcement bond loss on the response, cracking load, crack propagation, deflection, ultimate capacity, reinforcement strain at mid span and mode of failure of beams is examined in this paper. The cracking load, number of cracks in the flexural zone, and the crack width are affected significantly with increasing the area of bond loss. On the other hand, the reduction in the ultimate load capacity is surprisingly low even with 73% loss of bond. This refers to the creation of high bond forces at the small bonding areas at the crossing stirrups which compensates the high bonding loss in the longitudinal bars between stirrups.



## Introduction

The bond between the reinforcing steel and surrounding concrete depends primarily on the contact area, the surface texture of reinforcing bars, bar diameter and concrete cover. Therefore, it is expected that the shape, location, length, width and propagation of cracks as well as the load carrying capacity be affected by the un-bonded length of tensile reinforcement. This un-bonded length may be caused by construction errors. Honeycombed concrete resulting from bad compaction and the use of dry and rough formwork could remove the concrete cover. Washout also affects the bond properties of reinforcing steel bars embedded in underwater concrete [1]. Over and above, bond-loss is closely related to deterioration of structure. Corrosion of reinforcement, internal frost damage, and alkali-silica reaction are three deterioration mechanisms that have a negative influence on bond between concrete and reinforcement. Investigations had been conducted to explain the flexural strength, shear strength, and bond as function of corrosion

Peer review under responsibility of Housing and Building National Research Center.

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http://dx.doi.org/10.1016/j.hbrcj.2015.01.003

intensity [2–8]. Different studies had been performed by researchers to evaluate the effect of different degrees of reinforcement corrosion on the bond degradation using the pull-out test [6,9]. Review of literature showed that limited work on un-bonded length of reinforced concrete beams has been carried out. Nevertheless there are many studies on un-bonded post tension tendons prestressed beams [10–15].

The purpose of this research is to study the effect of the unbounded length of tensile reinforcement on the behaviour and reduction of flexural capacity of concrete beams. The loss of bond had been artificially introduced in the longitudinal reinforcement close to the supports and with varied length. The objective of this paper was to provide better understanding of the influence of loss of bond along the longitudinal tension reinforcement on the flexural behaviour of beams.

## Experimental programme

A test series of six beams had been designed in order to investigate the influence of bond loss along the longitudinal reinforcement close to the support, on the behaviour of this series under flexural static loading. The unbounded length was accurately created using a plastic tube with inner diameter slightly larger than the longitudinal reinforcement surrounded by these tubes. The ends of the plastic tubes were sealed with silicon and also surrounded with plastic tape. This method was chosen to simulate the unbounded length due to corrosion. One reference beam ($B_0$) was reinforced with two full bonded longitudinal bars at the bottom and without stirrups in order to examine the failure mode when compared with another reference beam with stirrups ($B_1$). The dimensions of the tested beams were 2250 mm length × 200 mm height × 120 mm width. The six tested beams were simply supported and loaded with two equal point loads at the middle third of the span. The bottom longitudinal reinforcement was 2Φ16 and the upper was 2Φ10 with 15Ø6/2100 stirrups as shown in Fig. 1a. For beams with stirrups the unbounded length varied from two spaces between stirrups close to each support, as in beam $B_2$ to six spaces, beam $B_4$. The bond is available at all intersections between stirrups and longitudinal reinforcement (∼20 mm), Fig. 1b. The bottom reinforcement in all beams studied was straight except in beam $B_5$ where it had 90° hook at the end in order to develop better anchorage of the longitudinal bars as shown in Fig. 2.

### *Material and concrete proportions*

Portland cement (CEM I 42,5N) was used in preparing the concrete mix of this programme. The fine aggregate used was natural siliceous sand with a fineness modulus of 2.6, specific gravity 2.63 and unit weight of 1750 kg/m$^3$, and the coarse aggregate was gravel of two sizes 10 mm and 20 mm. The grading of aggregates satisfied the requirements of the Egyptian specifications [16]. The superplasticizer used was the sulphated naphthalene formaldehyde condensate type. The used silica fume (SF) contains silica ($SiO_2$) of 95% and was of 20% of cement weight. The concrete mix chosen for casting the test beams was designed to be high strength concrete and its proportions are presented in Table 1. The compressive strength ($f_{cu}$) was tested for 150 mm cubes, the tensile strength ($f_{sp}$) was determined from splitting tension tests of 150 mm × 300 mm cylinders and the bond strength ($f_b$) was calculated from pull out tests on cylinders of 150 mm × 300 mm size with central ribbed bars of 16 mm diameter. In all cases at least six specimens were used. The following mean values were obtained: $f_{cu} = 67.32$ MPa, $f_{sp} = 4.53$ MPa, and $f_b = 8.97$ MPa, Table 1.

For the reinforcement, three specimens were tested for every bar diameter. The longitudinal reinforcement in tension consisted of two ribbed bars with diameter 16 mm at the bottom of the beam, with an average yield strength $f_y = 498$ MPa. The longitudinal compression reinforcement at the top of the beam consisted of two ribbed bars of 10 mm diameter, with an average yield strength of 427 MPa. Plain round bars of 6 mm diameter were used as stirrups with spacing 150 mm and with average yield strength of 300 MPa.

### *Specimen preparation and test procedure*

Six steel moulds were used for casting the specimens; they were stiff enough to prevent any significant movement during

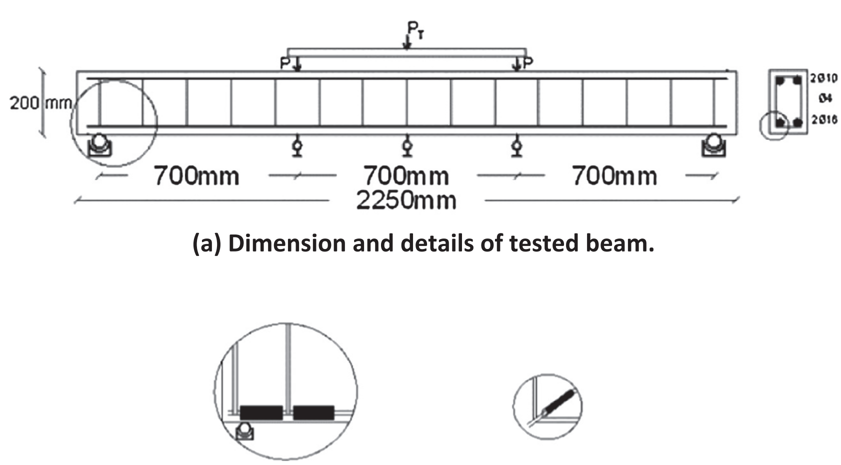


**Fig. 1** Concrete dimensions and details of tested beam and un-bonded zone.