Strengthening of Reinforced Concrete Beam Subjected to Shear Loading using Deep Embedment Method

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Abstract. This research investigates the behaviour of non-engineered reinforced concrete (RC) beams strengthened with embedded steel bars. Two RC beams, namely control beam (Beam-A) and strengthened beam (Beam-B) were fabricated and tested under shear loading. Beam-B was strengthened with four 12 mm steel bars embedded in the core of the concrete beam. The results showed that Beam-A experienced shear failure while Beam-B failed in flexural tension where most cracks developed in the flexural span. The embedded steel bars were proven to shift failure mode from shear failure on Beam-A to flexural one on Beam-B. Furthermore, the shear capacity of the strengthened beam was enhanced by 31% compared to that of the control beam.

1. Introduction

A large number of newly-built and old structures are not performing according to their original purpose. To prevent such structures from collapse, several efforts to provide a practical and cost-effective solution to strengthen the element of the reinforced concrete (RC) structures have been proposed. This strengthening technique includes the conventional one, e.g. enlargement of the structural cross-sectional area [1] as well as steel and concrete jacketing [2-7], and the so-called strengthening technique with the application of high strength fibre reinforced polymer (FRP), namely externally bonded (EB) [8, 9] and near-surface mounted (NSM) [10, 11] FRP strengthening method. The aforementioned strengthening systems have been shown to provide significant enhancement to the strength of RC structures. However, those strengthening methods are labour-intensive and require tedious surface preparation and protection against vandalism and fire. Furthermore, the experiment also showed that an unanchored FRP strengthening system experienced premature debonding at a stress level of 20 to 30% of FRP’s ultimate strength [12].

A novel technique, called deep embedment (DE) [13, 14] formerly known as embedded through-section (ETS) [15] was introduced to overcome the drawbacks of the previous strengthening system. The DE method had been successfully implemented in strengthening shear-deficient RC beam-column joints [16, 17]. A parametric study conducted on shear-deficient RC beams also showed that the strength enhancement in the DE method was positively influenced by the concrete strength and the number of embedded bars installed in the shear span [18, 19].

Research investigating the behaviour of the DE strengthening method on a non-engineered RC beam is limited. This research explores the application of the DE strengthening method using reinforcement steel bars to enhance the shear capacity of the RC beam. The behaviour of the strengthened beam is presented in terms of crack propagation, failure mode and shear force capacity and compared with the control beam.
2. Experimental Program

2.1. Description of specimens
In this study, two RC beams, namely Beam-A (shear-deficient specimen) and Beam-B (strengthened specimen) were constructed. All specimens had the same dimension and reinforcement configuration as can be seen in Figure 1. The beams were reinforced with 2Ø12 mm and 2Ø6 mm steel bars as bottom and top longitudinal reinforcement, respectively. Ø6 mm stirrups were spaced at a distance of 600 mm from each supports to ensure that the specimens will fail in shear, whereas Ø6 mm stirrups were spaced at 50 mm centre-to-centre at both ends.

The strengthened specimen comprised four 12 mm diameter steel bars embedded in the core of the concrete beam. The embedded bars were spaced at 200 mm centre-to-centre at both shear regions (see Figure 1.b). To help to install the embedded steel bars, holes were prepared within the shear span of concrete’s core by installing acrylic rods before the concrete poured. Later, these acrylic rods were removed two days after casting and the holes were cleaned with the help of a wire brush and air compressor to remove any cement or aggregate residues. The lower end of the holes was sealed temporarily and high-strength epoxy resin was injected to fill two-third of the holes’ volume from the upper end of the holes. The embedded steel bars were covered with a thin layer of epoxy and then inserted into the holes.

![Diagram of beam specimens](image)

**Figure 1.** Details of the RC beam specimens—all dimensions in mm

The beams were simply supported on hinge and rollers and were tested under a four-point bending load system. During the test, instrumentations were mounted to measure load and displacement on the mid-span of the specimen. A 300 kN capacity load cell was used to measure the load and a 100 mm stroke of LVDT was utilized to measure the displacement at mid-span.

2.2. Material properties
RC beams were cast separately in different batch with a maximum aggregate size of 20 mm. A standard test conducted on a 150 mm x 300 mm concrete cylinder showed that the average concrete compressive strength of Beam-A and Beam-B was 17 MPa and 19 MPa, respectively. Based on tensile tests, the bottom longitudinal reinforcement and the embedded bars had yield and ultimate strengths of
362 MPa and 532 MPa, respectively, whereas the yield and the ultimate strength of top longitudinal reinforcement and the stirrups were 373 MPa and 500 MPa, respectively.

3. Results and Discussion

3.1. Crack propagation

Illustrations of crack propagation for both specimens are depicted in Figure 2. In general, the minor flexural crack was observed at mid-span specimen Beam-A (see Figure 2.a) during the early stage of loading while diagonal tension failure developed at the final stage of loading. The first crack in the vertical direction started to develop at mid-span where the moment bending is the highest. With increased loading, cracks propagated to the shear span forming flexural-shear cracks which were typically shown by inclined line at a certain angle from the beam’s bottom to the loading point. At the end of the test of Beam-A, shear cracks became wider and visible.

![Crack propagation at failure](image)

Similar to the control specimen, cracks on specimen Beam-B were initially observed at the mid-span, and with increased loading, these cracks developed in the moment region in the vertical direction and propagating towards the neutral axis of the specimen. Throughout the test, flexural cracks kept developing within the flexural span (See Figure 2.b). From the examination of Figure 2.a and Figure 2.b, it is possible to compare the cracks density of the two specimens. The embedded steel bars applied on the shear span of the strengthened beam prevents crack propagated to the shear span as the shear forced is transferred from the concrete to the embedded bars.

3.2. Failure mode

The control specimen experienced a shear diagonal-tension failure mechanism. This failure was characterised by shear damage in the form of diagonal cracks developed in the shear span accompanied by the splitting action along the concrete surface and triggered the spalling of concrete. On the other hand, the strengthened specimen showed the enhanced behaviour where it failed in
flexural tension failure in which most damages existed in the flexural span. The DE strengthening method was able to shift the failure from the shear failure on the Beam-A to the flexural failure on the Beam-B.

The maximum shear force capacity attained by the control specimen was 53.1 kN. A significant contribution of the embedded steel bars can be seen in the shear force that the strengthened beam can withstand. The shear force capacity of the strengthened specimen was 69.6 kN, showing an increase of 31% compared to that of the control specimen.

4. Conclusion
In this study, tests were conducted on the control beam as well as the strengthened beam. The control beam failed in shear whereas the strengthened beam failed in a ductile manner where most cracks propagated in the flexural span showing that the embedded steel bars were successfully shifted the failure mode from shear to flexure. Furthermore, the shear force capacity of the strengthened beam (Beam-B) was enhanced by about 31% compared to that of the control beam (Beam-A).

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