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Sustainability of Lap Splice in Near Surface Mounted Bars of Reinforced Concrete Beam

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ABSTRACT

The Near Surface Mounted (NSM) is a method to strengthen and rehabilitate components of the reinforced concrete (RC) flexural and shear strength in the tension side of the concrete, it consists of positioning the reinforcement bars in grooves scratched into the concrete shell. The goal of this research program is to investigate the sustainability of near-surface mounted reinforcing bar tension lap splices in reinforced concrete members subject to monotonic loading. Nineteen concrete beams reinforced with and without spliced deformed reinforcement bars were tested in a four-point bending condition with a constant moment along the mid-span splicing region. The study's main variables were the splice length, type of splice, and diameter of the bars. The structural strength and failure modes of the tested beams are presented and addressed, the splice butt joint showed little notice before failure for none or sufficient splice duration, the adequate splice length improved the rigidity of the beam reinforcement, delayed crack forming and decreased deflection. It is found that the epoxy agent significantly reduces the length of the splice compared to that used in the Egyptian code.

Keywords: R C beams, flexural, rehabilitation, strengthening, NSM, splice

1 INTRODUCTION

During the lifetime of the RC beams, they may be affected by numerous factors that have not necessarily been taken into account such as increased traffic loads or reinforced in bending beams, the problem often arises of insufficient flexural and shear strength, and the beams are in desperate need of reinforcement. The use of Near Surface Mounted (NSM) Reinforced Bars is a technique to increase flexural strength and shears of deficient reinforced concrete members. Several shear and flexural reinforcement (NSM) researches have been studied and the ambition has been achieved [1-7].

The (NSM) methodology relies on the positioning of the reinforced bars in grooves scratched in the concrete cover in the concrete member's stress side, the reinforced bars are bound with epoxy paste in grooves concrete. Lap splices were used to maintain the integrity of reinforcement within the structural components in order to transfer force between the lapped bars through the bonding power of the concrete over the lap length, the lap splice length depends on the fact that the splice bars are lodged in the concrete paste and limited to the concrete around the reinforcement and the amount of transverse reinforcement.

Several research studies have studied the main parameters that influenced the performance of lap splice and determined the lap splice length of bars, known as the parameter; concrete strength, bar diameter, concrete cover, transverse steel distribution, steel bar yield strength, and spacing between splices [8-10].

In many implementations, there is a need to lap the reinforcement bar used to strengthen using (NSM) technique, a few research works based on the lap splice using externally bonded, Stallings et al reported repairing a reinforced concrete T-beam highway bridge using CFRP laminates bonded to the bottom face with lap splicing of each patch [11].

J. Michael and Nathan used assemblies to test the lap splice of (CFRP) plates [12]. Y. Mohamed experimentally researched the flexural efficiency of RC beams with stress reinforcement lap splice reinforced with various techniques in the splice area using externally bonded FRP. The results showed that all reinforcement strategies used were successful in enhancing the bond strength of the lap splices, and Load-deflection action of the checked beams, in particular when strips were mounted over the splice region. This analysis accepted that the NSM methodology made employability more prominent [13].

Several researches has focused on the lap splice for concrete embedded reinforcement bars, the study of the lap splice of externally bonded reinforcement bars (NSM) is limited. The goal of this research is to classify the lap splice of deformed externally bonded reinforcing bars (NSM) and the better splice sort

2. RESEARCH SIGNIFICANT

This research focuses on measuring the lap splice length of the deformed bars reinforcing bars bonded utilising (NSM) for strengthening In order to find the best type of splice through mechanism of failure and the ductility of strengthened beams.

3. CODES RECOMMENDATION

The Egyptian code (2001)[14] requires anchorage and splice length of embedded reinforcement bars specified by bar diameter multiples.

Typically, the multiplication factor depends on the type of steel bar, bar shape, concrete strength around the anchorage, and concrete cover.

The equation for determining a development length and splice length (Ld) for bars in tension is:

$$Ld = \Phi \alpha \beta \lambda (fy / 1.15) / (fbu) \quad (1)$$

Where Φ is the bar diameter; α β, λ are variables depending on the steel type, shape of bar and concrete cover; fy and fbu are the yielding strength of steel the ultimate concrete bonding strength (0.3 $\sqrt{}$ (f cu/1.15) respectively.

4. TEST PROGRAM

After 28 days, under the four-point bending test, nineteen reinforced concrete beams 100 x 200 mm in cross section and 2200 mm long with cube strength 27.8 N / mm2 were tested, the reinforcement consisted of two 8 mm diameter mild steel bars at the bottom of the beam with 240 MP yielding load and two 10 mm high-grade steel bars at the top of the beam with 360 MP yielding load.

The web reinforcement consisted of closed stirrups with a diameter of 8 mm, spaced 60 mm between the point load and the point support. The descriptions of the test specimens are illustrated in Figure. 1.

Three beams were tested without strengthening (BC) and used as the control specimens for comparison. Two beams (BF10, BF12) were strengthened using (NSM) with full length of deformed bar 10 mm and 12 mm without splice for comparison with the strengthen beams with lap splice.

Six beams (B1010, B2010, B3010, B4010, B6010, B8010) were strengthened using (NSM) with deformed bar 10 spliced at the constant moment region with splice lengths 10, 20, 30, 40, 60, and 80 time the bar diameter respectively. Six beams (B1012, B2012, B3012, B4012, B6012, B8012) were strengthened using (NSM) with deformed bar Ø 12 spliced at the constant moment region with splice lengths 40, 60, and 80 time the bar diameter respectively.

Two beams (Bb4012, Bb6012) were strengthened using (NSM) with deformed bar 12 spliced at the constant moment region with spliced length butt 40, and 60 time the bar diameter respectively.

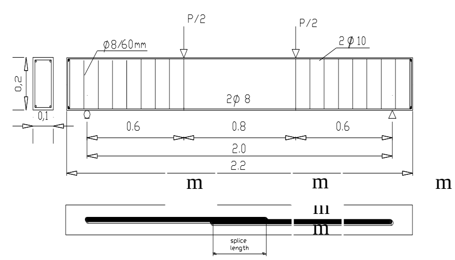


Figure 1: Reinforcement details of the beam and plan view

5. PREPARATION OF STRENGTHENED BEAMS

Sixteen beams were cast in the longitudinal direction between the supports of the beam specimens on the tension side of them with groove into the concrete cover. The groove was formed during the casting by placing a piece of foam along the beam specimen measuring 35x15 mm. The groove was cleared from the foam and any fine particles after 28 days to ensure contact between the concrete and the epoxy adhesive. The groove was lined with epoxy adhesive halfway through the groove; the reinforcement bar is put in the groove and squeezed gently. More paste fills the groove and flattened the floor.

6. EXPERIMENTAL SETUP

All beams were tested as simply supported beams with a total span of 2200 mm under four-point bending and a shear span of 600 mm using a dial gage with 0.001 mm accuracy to measure deflections. The beams were loaded in increments of 5 kN, the deflection of the mid span was recorded under point load, cracking sequence, cracking load and ultimate loads. Figure. 2 displays the beam check configuration.

Figure. 2: Setup of beam test

7. RESULTS AND DISCUSSION

7.1 Failure Mode

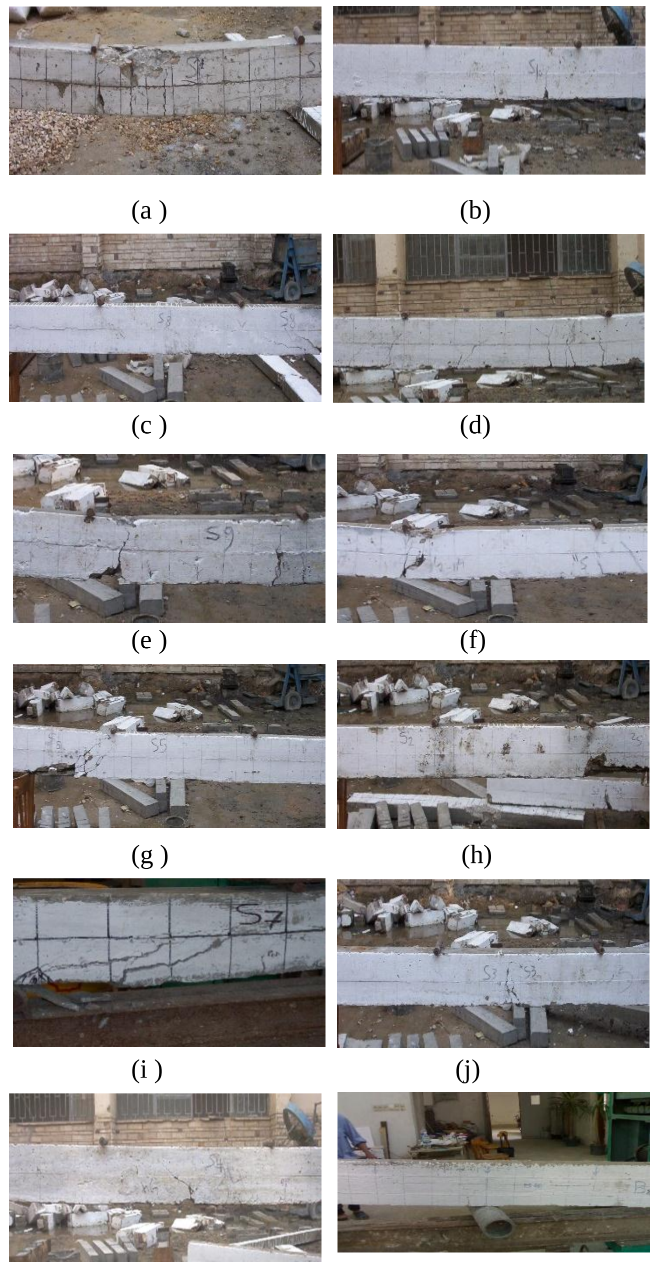
The control specimen BC, beam failed in tension failure through the yielding moment at the constant moment region, the cracks appeared at the tension zone undermost the point load and propagated in the constant moment region due to the yielding of the added steel bars and the reinforcing bars.

For the strengthened specimen (BF10) with full length of deformed bar 10 mm and without splice, the cracks appeared at the tension zone with similar behavior for the control specimens, whereas the strengthened beam (BF12) with full length of deformed bar 12 mm and without splice, before the failure, a hair diagonal cracks appeared between the point loads and the supports with splitting of the epoxy paste in which the NSM bar was embedded. As the load increased the width of diagonal increased and shear peeling failure occurred due to the losses of the shear resistance.

For the beams (B3010, B4010, B6010, and B8010), the first cracks appeared under the location of the point load, approximately, during increasing the load, the cracks propagated between the point load and the end of splice and increased and became wider, the failure load is occurred due to the yielding of the steel bars ((flexural failure). For the beams (B1010 and B2010), the first cracks appeared under the location of the point load. During the increasing of load, a sudden failure occurred at the end of splice due to the bond slip for both beams.

For the beams (B3012, B4012, B6012, and B8012), a peeling failure concomitant with shear cracks between the support and the point load, it was noticed that, the failure cracks was far from the splice zone, this behavior indicates that the splice length is enough to resist the bond slip. For the beams (B1012 and B2012), the first crack appeared under the point load at tension side, as the load increased, the propagated at the splice. A slip bond occurred at the splice ends with sudden failure at the failure load.

For the beams (BB4012 and BB6012), that were strengthened using (NSM) with deformed bar 12 spliced at the constant moment region with butt splice of lengths 40, and 60 time the bar diameter respectively were failed at the mid span (at the butt joint) with sudden failure associated with noise. The failure crack progressed toward the top of beam associated with inclination. Figure 3 shows the failure cracks for the tested beams.



(a) (b)
(c) (d)
(e) (f)
(g) (h)
(i) (j)
(k) (l)

Figure. 3: The cracks failure for the tested beams, a) BC, b) BF12, c) BF10, d) B4010, e) B6010, f) B8010, g) B4012, h) B6012, i) B8012, j) BB4012, k) BB6012 and l) B1010

7.2 Load- Deflection

The actual deflection at mid- span was measured and plotted against the actual load for the control specimen (CB), and the strengthened beams with full length bar without splicing (BF10 and BF12) as shown in Figure. 4. B2010 specimens failed in flexural mode at approximately 28 KN with maximum deflection 8.9, and 8.56 mm respectively, at the maximum capacity a sudden failure occurred at the splice. The percentage of increase with respect to the control specimen (CB) was 40%, whereas, there is a reduction in accepted strength of strengthened specimens in comparison with specimen BF10 (64%). Due to inadequate splice length for both specimens B1010 and B2010, a bond failure with splitting cracks at the end of splice occurred with sudden reduction in the load capacity and stiffness.

For specimens B3010, B4010, B6010 and B8010, the ultimate load and the cracking behavior are similar to the Specimen BF10, the first crack appeared at the end of constant moment region and with increasing load, cracks appeared simultaneously and the first crack propagated and widened. It can be seen that various splices lengths of the bar were sufficient to prevent the bond slip failure and the specimens failed in flexural due to yielding of steel reinforcement, the failure loads are approximately similar to the specimen BF10. As shown in Figure 4, as the spliced length of specimens increased the flexural rigidity and the stiffness increased

The control specimen failed in tension failure with ultimate load 20 KN., and maximum deflection 13.18 mm, at mid span. For the specimens BF10 and BF12, the ultimate loads reached 43.6 and 47.8 KN. with maximum deflection 20.28 and 9.45 mm. respectively, the percentage of increase was 218 % and 239 % respectively of the control specimen. No significant increase for BF12 with respect to BF10, due to the early debonding of the external bar (NSM) between the point load and the support point for specimen BF12 (shear-peeling failure). Specimens BF10 and BF12 provided significant increase in stiffness.

Figure 5 shows the loads capacity- deflection at mid span of strengthened beams using one NSM steel deformed bar 10 mm diameter with and various splice lengths. B1010 and B2010 specimens failed in flexural mode at approximately 28 KN with maximum deflection 8.9, and 8.56 mm respectively, at the maximum capacity a sudden failure occurred at the splice. The percentage of increase with respect to the control specimen (CB) was 40%, whereas, there is a reduction in accepted strength of strengthened specimens in comparison with specimen BF10 (64%). Due to inadequate splice length for both specimens B1010 and B2010, a bond failure with splitting cracks at the end of splice occurred with sudden reduction in the load capacity and stiffness.

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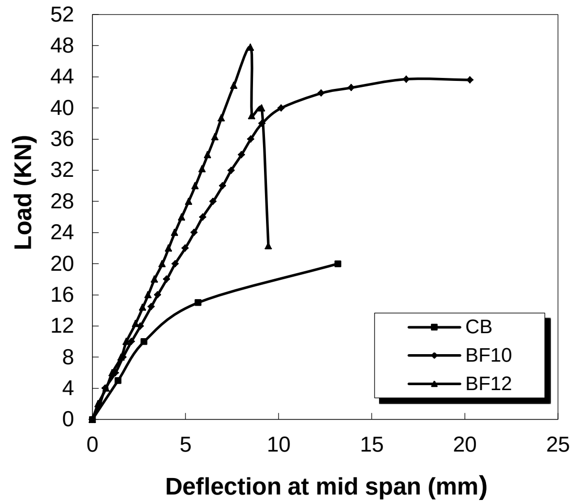

Figure 4: The Load-Deflection at Mid Span.

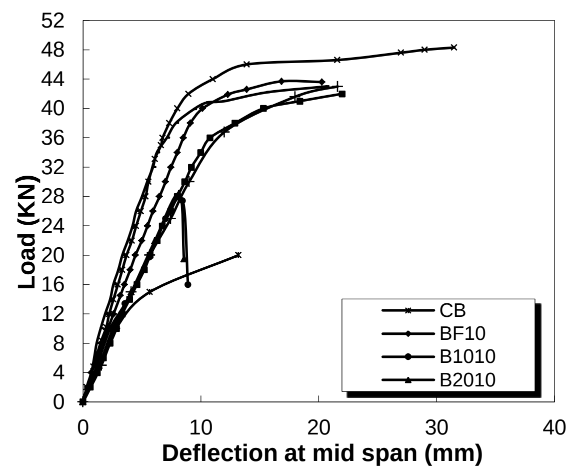

Figure 5: The Load-Deflection at Mid Span

Figure 6 shows the load capacity- deflection at mid span of strengthened beams using one NSM steel deformed bar 12 mm diameter with various splice lengths. due to inadequate the splice length, The specimens B1012 and B2012 failed in flexural mode with sudden failure at the maximum capacity 25.7 and 26.4 KN. respectively with maximum deflection 9.3, and 9.6 mm respectively, the first cracks appeared under the location of the point load, during the testing, a sudden failure occurred at the splice due to the bond slip for both beams. The percentage of increase with respect to the control specimen (CB) was 27%, whereas, there is a reduction in accepted strength of strengthening specimens comparison with specimen BF12 (54%).

For specimen B3012, the first crack was observed under the location of the applied point load, as the load increased, the cracks propagated horizontally associated with inclination between the support and the point load, the failure mode was shear diagonal cracks which was associated with separation of NSM steel bar in shear span zone, the ultimate load reached 41.4 KN., with maximum deflection 10.11 mm.

For the specimens B4012, B6012, and B80,12, the failure modes were similar to the specimen B3012 and the ultimate loads reached to 32.8, 47.8, and 50,2 KN., respectively, with maximum deflection at mid span 11.19, 9.76, and 9.49 mm respectively.

The failure modes indicated that, the splice lengths are sufficient to satisfy the bond between the spliced bars in concrete, which are responsible to transfer the tensile force from one bar to another through the surrounding epoxy paste. As the splice length increased, the stiffness of the strengthened beams increased and their deflection and cracks widths reduced and delayed the formation of new cracks.

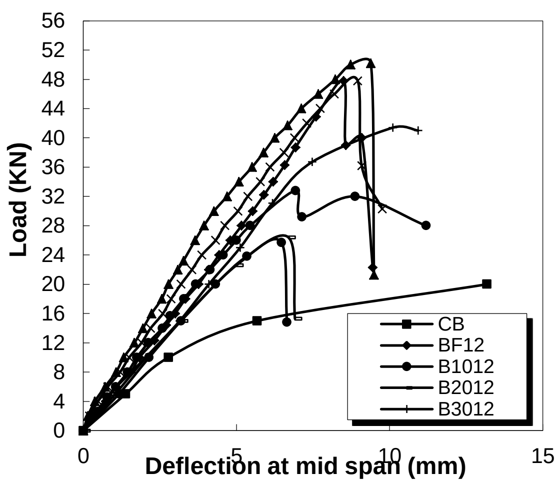

Figure 6: The Load-Deflection at Mid Span.

Figure 7 shows the loads capacity –deflection at mid span of the strengthened beams using one NSM steel deformed bar 12 mm with and various splice lengths and types. For specimen BB4012 (Butt joint), before the ultimate load, no crack was observed, at the ultimate load which reached 38.9 KN., a sudden failure occurred associated with noise at the mid span with maximum deflection 9.68 mm. For specimen BB6012 (Butt joint), the first crack occurred under the location of the point load, as the load increased, the first crack widened, during the testing, the failure occurred suddenly at mid of span and the failure load reached 43.9 KN with maximum deflection 10.93 mm. As shown in Figure 7, the drawback of butt joint is the sudden failure that occurred for specimens without any cautionary events.

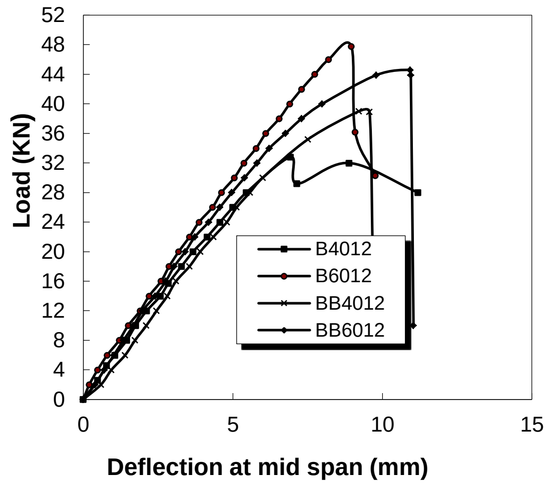

Figure 7: The Load-Deflection at Mid Span.

CONCLUSION

It has been shown the efficacy of using near-surface mounted (NSM) reinforcement bar with splice to stabilize concrete beams and splice forms. The following conclusions were drawn on the basis of the experimental results:

1- No splitting bond failure occurred for specimens with splice length equal or more than 30 bar diameter.
2- The Egyptian code equation for spliced bars in tension is twice the needed splice length for NSM bars, due to the high bond strength of the epoxy agent.
3- The splice butt joint did not exhibit any warning prior to failure for various splice lengths.
4- As the splice length increases, the ductility of the beam increases.
5- For adequate splice length (30 bar diameter), the major problem of NSM bars is the peeling failure away of the splice region.
6- The adequate splice length (30 bar diameter) increased the stiffness of the strengthened beams, delayed the formation of cracks and reduced the deflection.

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Credit Authorship Contribution Statement

Khaled F. Khalil: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Software, Writing – original draft, Writing – review & editing.

Mohamed A. Farouk.: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing.

Azza I. Anan.: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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