Ductility of Reinforced Concrete Beams With Lap Splices

By

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1. Abstract
This research studies experimentally the ductility behaviour of reinforced concrete beams with different number of lap spliced bars at the zone of maximum bending. The effect of the transmitted force in the spliced bars by bonding through the surrounding concrete on the ductility of these beams is illustrated. The experimental study comprises ten different reinforced concrete beams. The beams were tested under the action of two symmetrically concentrated loads. The main variables are the number of lap spliced bars and the type of reinforcing steel. The yield load, the ultimate load, the deflection, and the strain were determined. The results of the experimental program are analyzed and discussed. Conclusions based on the executed study are drawn and recommendations are suggested.
1- **Introduction**

Ductility may be defined as the ability to undergo deformations without substantial reduction in the capacity of the member [1,2,3]. The behaviour of the reinforced concrete beams containing lap splices bars was studied previously [4,5,6,7]. These previous experimental researches were up to the ultimate loads. The behaviour of beams containing lap splices beyond the ultimate loads needs to be investigated.

The aim of this research is to show the effect of lap splice bars in the zone of maximum bending on the ductility of reinforced concrete beams. The variables of the study are the number of lap spliced bars and the type of reinforcing steel. To achieve this aim, ten reinforced concrete simply supported beams were tested under the action of two symmetrically concentrated loads up to the ultimate load and beyond it. The lap splices were at the middle of these beams inside the pure bending zone. The experimental measurements include the yield load, the ultimate load, the deflection, and the strain.

2- **Experimental test program**

The test program consists of two groups of simply supported reinforced concrete beams as shown in table (1). Each group contains 5 reinforced concrete beams with a rectangular cross section (12 cm width and 25 cm depth). The total length of each beam is 320 cm and the clear span is 300 cm. The variables of the test program are the following:

   i- The type of tension reinforcement which includes two grades of steel:
      a- Normal mild steel (24/35) (Group N)
      b- High tensile steel (36/52) (Group H)
   ii- The number of lap spliced bars which varies from zero (all bars are continuous) to four lap spliced bars (all bars are spliced) as illustrated in table (1)
The lap splice length is calculated according the Egyptian Code of practice were the lap length for normal mild steel bars (group N) is 62 cm (52\(\phi\)) and the lap length for high tensile steel (group H) was 54 cm (54\(\phi\)). The percentage of spliced bars at the same zone is greater than that recommended by the Egyptian Code of practice to the study its effect on the ductility behaviour of the tested beams.

3- Test setup and measurements

Vertical steel frame with a 20 ton mechanical screw jack was used to apply the required loads on the tested beams. The load was incrementally applied up to and beyond the ultimate loads of tested beams which are subjected to two symmetrical concentrated loads, as shown in Fig.(1). The distance between these two symmetrical loads was 65 cm apart. This distance makes the lap splices to lie inside the pure bending zone for both groups of beams. The loads were measured through two load cells each of maximum capacity of 10 ton. Deflections were measured using three dial gauges with an accuracy of 0.01 mm at the bottom face of the beam (tension side). Two of the dial gauges were putted under the two acting concentrated loads while the third one was located at the middle of the beam span. The strains were measured using electrical strain gauges which were stixed on the surface of tension steel reinforcement. The Gauge length was 10 mm. The beam cracks were also determined.

4- Experimental results and discussion

Based on the experimental results, the behaviour of the tested beams is discussed in terms of, yielding and ultimate loads, the load-deflection relationships, and the crack patterns.

4-1 The yielding and ultimate loads

Table (2) gives the yielding loads (Py) and the ultimate loads(Pu) for the tested beams. From this table one can notice that for group N, the yielding load is constant for all beams of the group. The lap splices,
whatever its number, doesn't affect the yielding load. On the other hand the ultimate load was not reduced with the increase of the number of the spliced bars. This result doesn't conform with the results reported in ref.[4] and that is because the lap splice length used in this research is more than that one used in ref.[4]. The ultimate load of beams BN2 and BN3 is slightly higher than the ultimate loads of other beams in group (N). This phenomenon may be attributed to the dual action of the increase in steel reinforcing area due to the lap splice of some bars and the continuity of the other bars at the same location. For group (H), the variation of both the yielding, load and the ultimate load is insignificant. This means that the lap splices don't affect the yielding and ultimate loads. The ultimate load of beams BH2 and BH3 is slightly higher than the ultimate load of other beams in group (H). This may be also attributed to the dual action of the increase in steel reinforcing area due to the lap splices of some bars and the continuity of the other bars as mentioned before for group N.

4-2 Load-Deflection curves

Figures (2) to (6) show the load-deflection curves for beams of group (N). It can be noticed from these figures that the five beams have almost the same elastic behaviour up to the point of the yield of reinforcing steel in tension side. The curves show that the maximum deflection generally decreases with the increase of the number of spliced bars and that is because the behaviour of spliced bars depends mainly on the bond between the concrete and the steel reinforcement.

The figures show also that there is a sudden drops in load for some beams containing spliced bars and that is due to the slip of these bars at the spliced zone. Figures (7) to (11) show the load-deflection curves for beams of group (H). From the figures, it can be noticed that the behaviour of the five beams is almost similar up to the point of yield of reinforcing steel. As shown in figures the maximum deflection decreases with the increase of the number of spliced bars as was observed previously for beams of group (N). It is noticed also that the slope of the descending portion of the load deflection curve for beams containing spliced bars is
more steeper than that for beams without spliced bars. This is because of the loss of bonds of these spliced bars.

4-3 The final ductility factor

The final ductility factor is defined as the ratio between the final deflection (the deflection when the load decreases to 80% of its ultimate value along the descending branch of the load deflection curve) and the deflection at the point of yield of reinforcing steel (2). The final ductility factors for the tested beams are shown in table (3) and its variation with the percentage of spliced bars are plotted in figure (12). From table (3) and figure (12) it is appeared that the final ductility factors for beams of group (N) are almost twice the corresponding values of beams in group (H). This is a totally expected observation due to the evident ductility of normal mild steel used in beams of group (N) over the high grade steel used in beams of group (H) and also due to the lower of yield of tension reinforcing steel used in group (N) and hence the lower of its stresses at yield than that tension reinforcing steel used in group (H). Generally the final ductility factor decreases with the increase of the number of spliced bars in both groups. The slightly increase in the final ductility factor for beams BN2 and BH2 compared with those for beams BN1 and BH1 respectively is due to the lowering of deflection at yield load for the first two beams than that ones for the second two beams while the deflection at 0.8 Pu is almost the same. For group (N) by increasing the percentage of number of spliced bars from zero in beam BN1 (no spliced bars) to 100% in beams BN5 (all bars are spliced) the final ductility factor decreases from 12.07 to 7.64 (see table 3). The ratio between the final ductility factor for beams BN3, BN4, and BN5 (which have percentage of spliced bars equal to 50%, 75%, and 100% respectively) and the final ductility factor for beam BN1 (which has percentage of spliced bars equal to zero) are 0.97, 0.71, and 0.63 respectively. For group (H) by increasing the percentage of number of spliced bars from zero in beam BH1 (no spliced bars) to 100% in beam BH5 (all bars are spliced), the final ductility factor decreases from 6.42 to 2.76. The ratios between the final ductility factor for beam BH3,
BH4, and BH5 (which have percentage of spliced bars equal to 50%, 75%, and 100% respectively) and the final ductility factor for beam BH1 (which has percentage of spliced bars equal to zero) are 0.86, 0.56 and 0.43. It is noticed from the above results that the percentages decrease in the final ductility factors for beams in group(H) are higher than the similar ones for beams in group(N) and that is because the excess in bond stresses for beams in group(H).

4-4 Crack Patterns

Figures (13),(14) show the crack patterns of the tested beams at the end of test. Generally the number of cracks for beams in group (H) is greater than the number of cracks for the corresponding beams in group(N). This observation may be attributed to the fact that tensile stresses in the reinforcement of the beams of group(H) are higher than those in the corresponding beams in group (N). For beams without spliced bars (BN1, BH1) the cracks are mainly distributed along and around the maximum bending zone while for beams with spliced bars the cracks are distributed outside the splice zone (maximum bending zone) because of the doubletication of bars in this zone due to the overlap and also because of the enough length of the lap spliced. The major cracks for these beams are located at the beginning and the end of the splice.

5-Conclusion

Based on the analysis of the results of the experimental program carried out in the present research over the simply supported reinforced concrete beams with the spliced bars in the zone of maximum bending moment, the following conclusion can be drawn:

1- The yielding and ultimate loads of the tested beams seem to be approximately unaffected by using lap splices of reinforcing bars in the zone of maximum bending with lengths equal to the recommended by the Egyptian Code whatever is the type of steel used.
2- By increasing the percentage of spliced bars over 0.25 of the total bars, the ductility of the beams decreases for both types of tension steel used in the tested beams.

3- The final ductility factor decreases by 3%, 29%, and 37% relative to non-spliced bars by using percentage of spliced bars equal to 50%, 75%, and 100% respectively for beams with normal mild steel bars as a tension reinforcement. For beams with high grade steel bars the above reduction in the final ductility factor becomes 14%, 44%, and 57% respectively for the corresponding beams.

4- The number of cracks for beams with high grade steel as a tension reinforcement are more than their numbers for the corresponding beams with normal mild steel as a tension reinforcement.

5- For beams with spliced bars the major crack concentrate at the beginning and end of the splice.

6- Recommendations

Despite the excess of the percentage of lab spliced bars more than 25% from the total bars at the same section does not cause a decrease in ultimate load of a beam but it cause a decrease in its ductility, so it is recommended to use a percentage of lab splice not exceed 25% of the total bars and that agrees with the recommended by the Egyptian code.

7- References


Table (1) Properties of tested Reinforced concrete beams

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Beam No.</th>
<th>Ccu</th>
<th>Tension Reinforcement</th>
<th>Compression Rft.</th>
<th>Stirrups</th>
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<tbody>
<tr>
<td></td>
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<td>Kg/cm²</td>
<td>As</td>
<td>ly</td>
<td>No of spliced bars</td>
</tr>
<tr>
<td>N</td>
<td>BN1</td>
<td>275</td>
<td>4 4 12</td>
<td>3.0 t/cm²</td>
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<td></td>
<td>BN2</td>
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<tr>
<td>H</td>
<td>BH1</td>
<td>280</td>
<td>4 4 10</td>
<td>4.4 t/cm²</td>
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<td></td>
<td>BH2</td>
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<td>BH5</td>
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Fig. (13) Crack-Pattern of tested beams in Group (N)

Fig. (14) Crack-Pattern of tested beams in Group (H)
Fig. (12) FINAL DUCTILITY FACTOR V.S. PERCENTAGE OF SPLICED BARS.

GROUP N (N.M.S. BARS)

GROUP H (H.G.S. BARS)