



Effect of Lap Splice Length on Flexural Behavior of Reinforced Concrete Beams

Abbas H. Mohammed^{1*}, Samar Shoker¹, Taha K. Mohammed Ali¹, Ali K. Hussein¹, Thanaa Ghazi Abed¹,
Kamran S. Abdullah²

¹ Civil Engineering Department, University of Diyala, Diyala 32001, Iraq

² Department of Civil Engineering, Faculty of Engineering, Tishk International University, Sulaimani 46001, Iraq

Corresponding Author Email: abbas_Mohammed_eng@uodiyala.edu.iq

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ABSTRACT

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Due to the limited length of steel bars and the presence of construction joints, the use of bar splices in reinforced concrete (RC) members is often necessary. Steel reinforcement can be spliced using a variety of methods, including mechanical couplers, welding, and achieving lap-splices with length specified by design codes. This paper describes an experimental study of the behavior and strength of RC beams with a tension reinforcement lap splice. The effect of lap splice length was investigated using four simply supported RC beams. The test was carried out on four concrete beams with dimensions of (0.15 × 0.2 × 1.15) m. The lap-splice lengths considered were 38, 43, and 48 cm, and the results were compared with a control beam without a lap splice. The flexural behavior of specimens was investigated. The samples were tested using a four-point setup. One specimen served as the control and contained no lap-spliced bars. The results indicate that the beam with a 48 cm lap splice achieved the highest ultimate load (93 kN). In addition, the beam with a 38 cm lap splice exhibited the largest maximum deflection.

1. INTRODUCTION

This experimental study investigates the effect of lap splicing on the behavior of reinforced concrete (RC) beams and highlights its role in structural integrity and performance. Lap splicing is a method of connecting reinforcing bars that is particularly useful when rebar lengths are limited. Understanding the effectiveness of this technique is critical because inadequate lap-splice lengths can have serious consequences for load distribution and overall beam strength, jeopardizing the durability and the safety of concrete structures [1, 2]. This research focuses on the various factors that influence the RC beams' behavior, including splice length, fire resistance, and reinforcement methods [2]. Lapped splices are typically employed in RC members that are longer than the available length of reinforcing bars [3-5].

Experimental studies have demonstrated that increasing the ductility and bond strength of lap-spliced regions can significantly improve the load properties of RC beams [6]. Furthermore, the use of advanced materials, such as fiber-reinforced polymers (FRP), has shown the ability to improve the structural performance of lap splices and can mitigate the limitations of traditional methods. Notably, the study addresses major debates about the design and application of lap splices in RC, particularly in high-stress conditions such as seismic activity [6].

To transfer stress properly in a structural lapped splice, the reinforcing bar length must be sufficient. Based on test data, empirical formulas were created to calculate the necessary

lapped splice lengths [7, 8]. Current design codes, guidelines, and lap-splice length recommendations highlight the requirement for revised standards that account for technique and material advancements, confirming improved reliability in construction practices [9]. This experimental study contributes to structural engineering knowledge by providing insights that can inform best practices in RC beam design, improving the flexibility of concrete structures in a wide range of applications [9].

Rakhshanimehr et al. [8] explored how the number of shear connections across lap splices affects beam ductility. They discovered that extending the lap splice length does not always increase ductility or bonding strength, particularly in concrete beams. They did, however, determine that supplying an adequate number of shear linkages can result in a considerable increase in bonding strength and ductility. The findings of Rakhshanimehr et al. [8], who looked at how the shear connections across the lap splice joint affected beam ductility, were in line with those of Micallef and Vollum [10].

Steel and concrete are the two most widely used materials in construction. When Steel and Concrete are employed separately, there are disadvantages, such as concrete's inability to withstand tensile stress and the susceptibility of steel sections to buckling under compression. However, when they are combined to produce a composite construction, the advantages of steel and concrete are most used. The effectiveness of composite materials is greatly improved when steel is used in tension and concrete is used for compression. Furthermore, concrete offers corrosion resistance and fire

protection to steel sections while reducing the susceptibility of steel sections to buckling [11].

The main advantage of RC members is that the cross-sectional area can be greatly reduced when composite activity between concrete and steel is achieved. Because bonding may be inadequate for composite action, steel-concrete composite action can be accomplished using a variety of shear connection techniques. However, the full interaction cannot be obtained because the steel-concrete members exhibit incomplete interaction performance due to sliding and interface deformation when force is applied [12].

The behavior of RC elements in the moment zone with lap-splices has been studied over the past few decades. These investigations sought to establish the strength of lap splices while also gaining a better understanding of the various reported splitting-failure modes. Lap-splice length, the presence of confining steel, compressive strength, rebar diameter, and concrete cover are among the parameters evaluated. Beams with extensive confinement performed similarly to beams with weakly confined lap splices. The number of lap splices and anchoring length required are controlled not only by the efficacy of the anchorage, but also by the forces in the bars that can be developed or transferred.

Rezansoff et al. [13] investigated how confining reinforcement affects lap splice bond strength in RC beams. The purpose was to study the effect of confining steel on lap-splice performance, which may allow for lower lap splice lengths than are now required. In the zone of constant moment, 48 beams with lap-splices in the tension zone underwent a four-point bending test.

To study the effect of shear connections in the stress zone, Pandurangan et al. [14] carried out seventeen experiments on concrete beams. Among the properties studied are the number of shear links inside the lap-splice zone, the links' shape around the spliced length, compressive strength, and lap splice length. Their results demonstrated that the cause of failure changed to flexural failure as the splice's shear link length grew. Additionally, their research showed that shear connections along the splice length significantly improved final deflection and displacement ductility. Additionally, their study's findings showed that a failure mode of splitting without ductility and a reduced final stress were the outcomes of shortening the lap splice's shear link length. The results they obtained are in agreement with those of Mabrouk and Mounir [15], Rakhshanimehr et al. [8], Pandurangan et al. [14], and Osifala et al. [16].

Mabrouk et al. [15] conducted an experimental program using 16 RC beams. The shape, diameter, and distribution of the transverse reinforcement were investigated using self-compacting, high-strength, and normal-strength concrete. Two steel bars (400/600) with a 10 mm diameter comprised the main reinforcement. The reinforcements were lap-spliced in the moment zone. They found that the splitting without ductility and a decrease in ultimate load capacity occur when the lap splice length is reduced by lowering the shear connections.

The lap-splice's strength in ordinary concrete and self-compacted beams was studied by Wu et al. [17]. Lap splice experiments were implemented on six beams in the maximum moment zone. The bonding strength of self-compacted concrete beams and ordinary concrete beams was found to be comparable.

Hussain et al. [18] used low-cost cotton and hemp ropes in their design, proposing a bond strength-based methodology.

26 RC beams were evaluated with varying NFRP layers and lap splice lengths. The findings reveal that cotton and hemp configurations are successful in increasing ultimate capacity, with hemp demonstrating higher ductility, particularly for 28db lap splices.

Ghalla et al. [19] conducted numerical and experimental studies to investigate the RC beams' behavior with inadequate lap-splice lengths of steel bars reinforced using different methods. The behavior of eleven RC beams was studied to determine the effect of reinforcing anchorage and strengthening methods. The suggested strengthening techniques can greatly reduce the ultimate and cracking loads of the defective beams, according to experimental results.

Micallef and Vollum [20] compared the failure mechanisms with virus lap splice lengths to study the impact of lap-splice on ductility and strength. According to their research, increasing splice length reduces lap splice strength while increasing ductility. Additionally, the length of longitudinal splitting fractures and the average bonding stress between lap-splice ends were almost entirely unaffected by lap-splice length.

Fakhrany and Hussein [21] investigated the flexural properties of twenty-two lap-spliced beams with different lengths of lap splices and compared them to four conventional strength concrete beams. The concrete type, splice end shape, lap splice length, cover, and bar diameter were all investigated. This study's findings showed an average increase of 76% in ductility and 32% in load capacity.

Many studies may focus on specific splice lengths, but a more extensive exploration of how varying splice lengths impact the beam's flexural capacity might be missing. The objective of the present study is to investigate the effect of lap-splice lengths on the flexural behavior of RC beams. Four simply supported RC beams were tested to investigate the effect of the length of lap splices. The test was carried out on four beams with dimensions of (0.15 × 0.2 × 1.15) m. The lap splices considered in this study are (38 cm, 43 cm, 48 cm) and compared with the beam without a lap splice.

2. EXPERIMENTAL PROGRAM

The experiment program consists of four RC beams. The beam's dimensions are 115 × 20 × 15 cm, as shown in Figure 1. In this study, lap-splices with 38 cm, 43 cm, and 48 cm are considered. The lap splice is located at the midspan of the beam. The properties of the lap splice considered are illustrated in Table 1.

Table 1. Lap-splice lengths considered in this study

Beam	Steel Bar Diameter (mm)	Lap-Splice (cm)
B0	10	-
B1	10	38
B2	10	43
B3	10	48

The concrete mix percentage that was developed and used was 1:2:2.3:0.55 (cement: fine aggregate: coarse aggregate: water).

Coarse aggregate, as crushed gravel with a larger size of 12 mm, and fine sand with a size interval of 0-4 mm, were used in the concrete mix design. The cement is (Type I) Ordinary Portland Cement. All types of concrete were made using the same mix with 350 kg/m³ cement. Cylinders with a 150 mm

diameter and a 300 mm height were cast for the test of compressive strength. The concrete compressive strength at 28 days is 33 MPa.

Reinforcing steel having a 10 mm diameter was used in the longitudinal direction in the lower part of the beam to resist the stresses resulting from the flexural moment. Reinforcing steel with an 8 mm diameter was used in the longitudinal direction in the upper part of the section. Table 2 shows the Steel reinforcement properties. Stirrups with an 8 mm diameter were used in the transverse direction, and a lap splice was placed as shown in Figure 1.

The loading and geometry for the four beams are illustrated in Figures 1-4.

This paper discusses the effect of lap splices on concrete beam bending behavior. The tests were conducted on four RC beams with steel bars and were designed to fail in the tension zone, which was subjected to additional load until failure. In each increase, the cracks were observed and distinguished, and

the deviation was continuously recorded, and the spread of the crack was drawn through loading the beam. The test setup of the beam B0 is illustrated in Figure 5.

Mid-span deflections were computed using a linear variable differential transducer (LVDT) with a 25 mm stroke. The data collection system recorded the load and LVDT readings in the mid-span of the beam. The experiment was carried out using a displacement control scenario test system at a deflection rate of 0.25 mm/min.

Table 2. Steel reinforcement properties

Nominal Diameter (mm)	10	8
Bar area (mm ²)	78.5	50.3
Yield strength (MPa)	515	517
Tensile strength (MPa)	624	654
yield strain	0.00258	0.00201

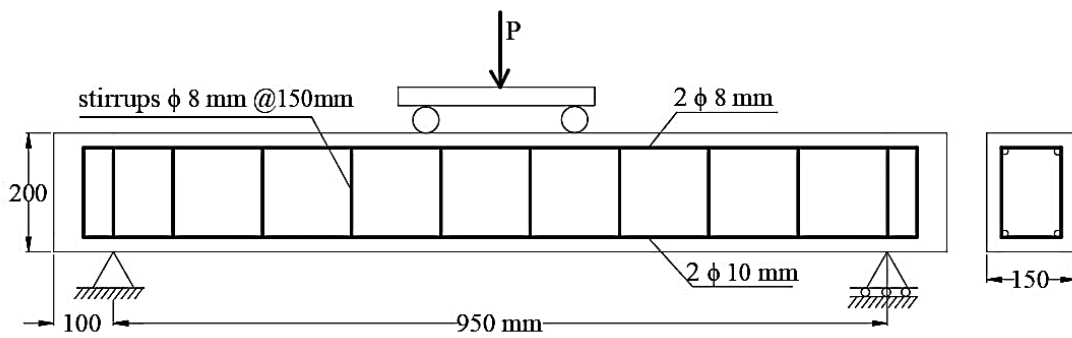


Figure 1. Loading and geometry for B0

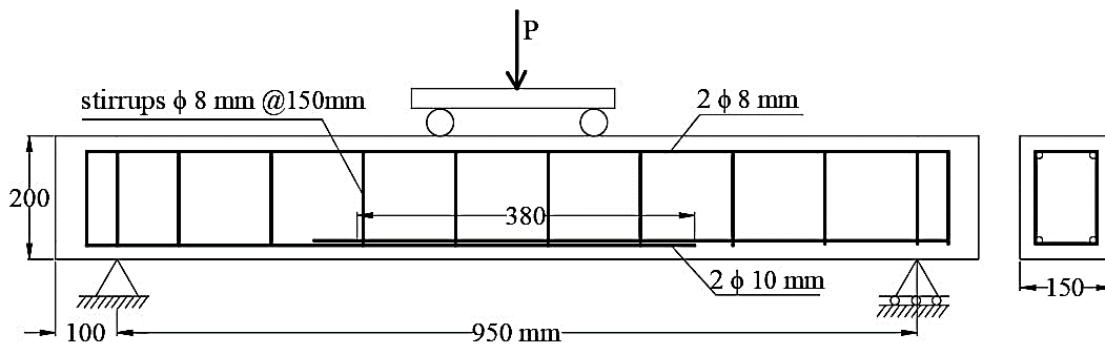


Figure 2. Loading and geometry for B1

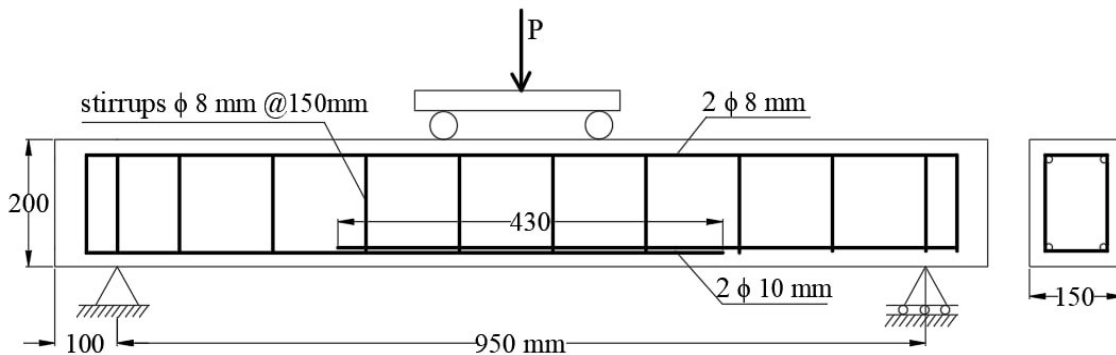


Figure 3. Loading and geometry for B2

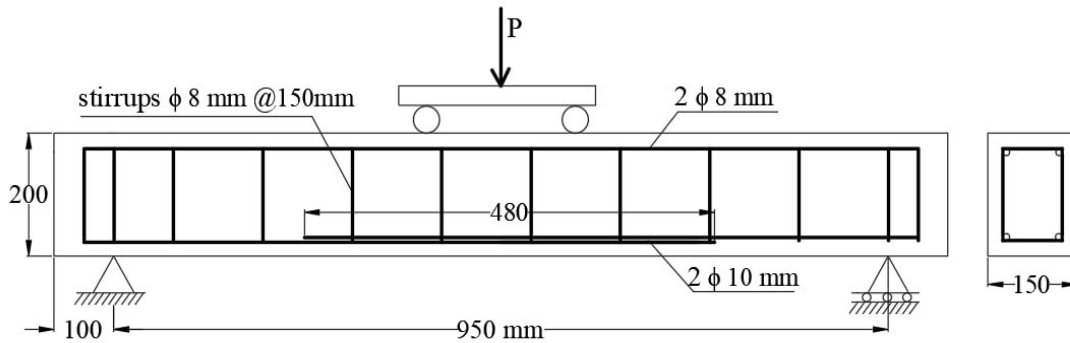


Figure 4. Loading and Geometry for B3



Figure 5. Test setup of beam B0

The splice location has no adverse effect on test results or introduces boundary effects. The beam length of 115 cm, with a lap-splice length of 38-48 cm, was designed so that the splice remained completely within the region where flexural stresses govern, away from the supports and load points. Proper spacing was maintained to prevent the splice zone from interfering with load introduction points or support reactions. As a result, boundary effects, such as localized stress concentrations from supports or loads, had no impact on splice performance. The failure mode and observed behavior are therefore attributed solely to the lap splice's flexural response and bond characteristics, with no unintended interference from boundary conditions.

3. RESULTS AND DISCUSSIONS

Results of tests conducted on beams are shown and discussed. Table 3 lists the ultimate load and maximum deflection of the B0, B1, B2, and B3 beams, and Figures 6-9 show the load-deflection curves. The corresponding failure loads for beams B0, B1, B2, and B3 were 85.53, 84.75, 84.85, and 93.19 kN, respectively. The beams' ultimate loads of B1, B2, and B3 were 99%, 99%, and 109% of that of beam B0, respectively.

From Table 3, it can be noticed that beams B1 and B2, which had lap splice lengths of 38 and 43 cm, had failure loads that were close to reference beam B0, which had no splice. The failure load was 9% higher than that of beam B0 when the lap length was 48 cm (beam B3), because the contact area of the lap-splice bars of beam B3 is bigger than that of beam B0.

Figures 6-8 illustrate the load-deflection curves for B1, B2, and B3 beams, respectively.

From Figures 6-8, it can be noticed that beams B1, B2, and B3 have smaller deflections than beam B0 under identical load levels within the elastic range.

Table 3. Ultimate load and maximum displacement

Beam	Lap-Splice (cm)	Ultimate Load (kN)	Max. Displacement (mm)
B0	—	85.53	9.74
B1	38	84.75	13.95
B2	43	84.85	7.36
B3	48	93.19	8.56

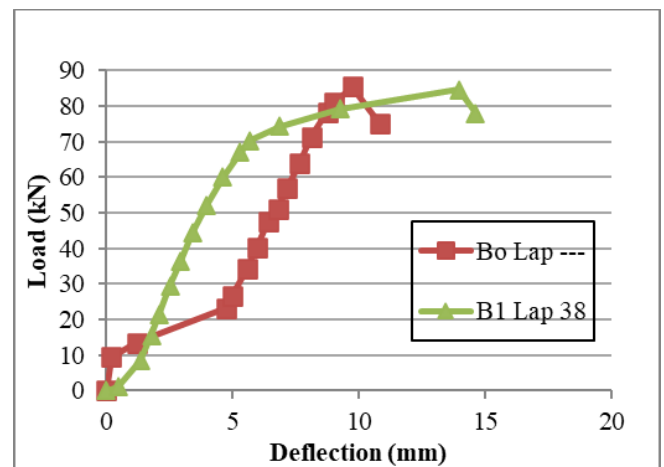


Figure 6. Load-deflection curve for beam B1

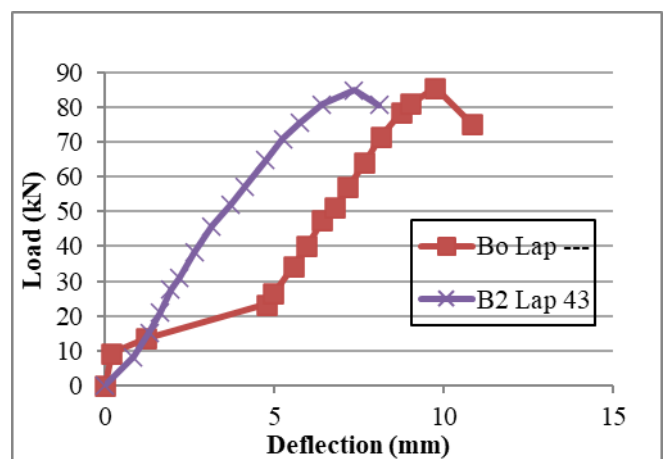


Figure 7. Load-deflection curve for beam B2

From Figure 9 and Table 3, it is found that the ultimate load increases with the lap-splice. In comparison to B1, the ultimate load of B2 and B3 beams has increased by 0.1% and 10%, respectively, due to the bond strength increase with increasing lap-splice. Lap-splice of bars has a bigger contact area

between the bar and concrete for a similar degree of confinement, therefore, that achieve more total bonding strength than a smaller bar lap-splice. In addition, the bar lap-splice plays an important role in confining transverse strengthening to bond strength. As a larger lap-splice, higher strains and therefore more stress are mobilized and better contained in the transverse reinforcement system.

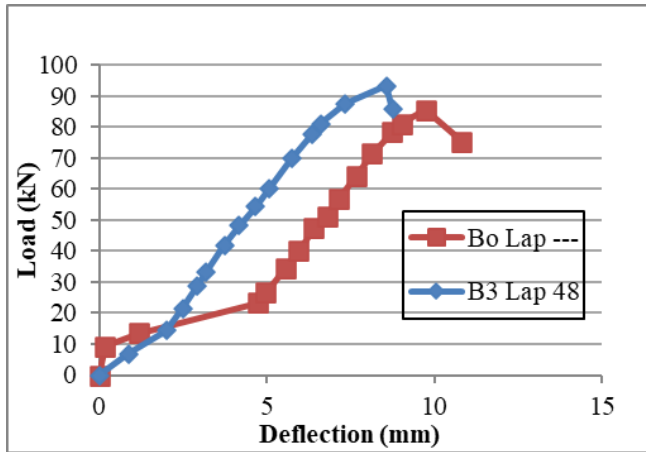


Figure 8. Load-deflection curve for beam B3

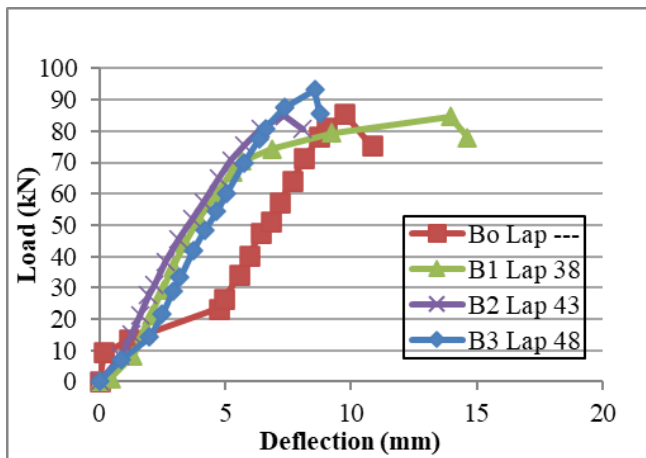


Figure 9. Load-deflection curves

As shown in Table 3, the maximum recorded mid-span deflection of specimen B1 before failure was approximately 143% that of beam B0, due to the lesser stiffness of beam B1. Beam B1 had the shortest lap length with 38 cm.

At failure load, the mid-span deflection of beam B2 (with lap splice length 43 cm) was approximately 24% lower than that of beam B0 (without splice).

Figure 9 shows that the load deflection curves for beam B1 with a lap splice of 38 cm and beam B2 with a lap splice of 43 cm were identical. However, after the first cracking loads, beams B1 and B2 exhibited less stiffness than beams B0 and B3. The results show that using a lap splice of 38 cm increased the maximum deflection. The use of a lap splice of 43 and 48 cm decreased the maximum deflection.

The lap splice can reduce the ultimate load of a beam if the splice length is not enough to develop the full tensile strength of the reinforcing bars. The reduction in strength is often attributed to the ineffective stress transfer at the splice, as well as the possibility of premature failure due to inadequate bond strength or crack formation.

Figures 10-13 show the crack patterns for the tested beams

at different loading stages. From these figures, it can be seen that the random sequence of crack initiation has been observed. This is due to the constant moment that has been applied, and the cracks grew upward as the applied load increased.



Figure 10. The patterns of cracks for the beam B0



Figure 11. The patterns of cracks for the beam B1



Figure 12. The patterns of cracks for the beam B2



Figure 13. The patterns of cracks for the beam B3

From the figures, it can be noticed that within the second third of the specimens of the beam, the formation of cracks was mostly vertical due to the pure moment that can be applied at this part. Beyond this region, inclined cracks are observed as a result of the existence of shear forces, besides the moment where the cracks were only flexural. The cracks always initiate within the second or third zone (middle), which has the highest applied moment within this zone.

The patterns of cracks for each beam are shown in Figures

10-13. For all beams, the average crack width was greater at the bottom of the beams than at the top of the beams at different stress levels. This is due to concrete bleeding, which resulted in low-quality concrete beneath the reinforcement in the splice region. The failure of beam B1 occurred as a result of a quick and brittle longitudinal splitting fracture in the tension side bottom cover, immediately under the splice zone. With the exception of preventing splitting fractures from forming, splice length had no effect on either failure mechanism or crack pattern.

The lap-splice length is an important factor in determining crack behavior in RC beams. The short lap-splice length significantly increases crack spacing and width, especially at the mid-span of the beam. Long lap-splice length has little impact on crack behavior in beams.

If the lap length is insufficient or the reinforcement is not properly aligned, cracks might widen at the splice location, compromising the overall stability and serviceability of the beam.

4. CONCLUSIONS

An experimental program was adopted in the paper to study the effect of bar lap-splice on the flexural behavior of RC beams. Four bar lap-splice was considered, which are 38, 43, and 48 cm. The following conclusions were obtained:

- The beam B3 with a bar lap splice of 48 cm has a higher ultimate (93.17 kN).
- In comparison to B1, the beams ultimate load of B2 and B3 has increased by 0.1% and 10%, respectively.
- The bar lap - splice contributes significantly to enhancing the strength of the bond between the bar and concrete.
- Within the second third of specimens of the beam, the formation of cracks was mostly vertical due to the pure moment that can be applied at this part.
- The results show that a lap-splice length of 38 cm increases the maximum deflection at failure. In contrast, lap-splice lengths of 43 and 48 cm reduce the maximum deflection at failure.
- The failure load of beams B1 and B2 with lap splice lengths of 38 and 43 cm, respectively, was close to that of the reference beam B0. Using a lap length of 48 cm in beam B3 caused an increase in the failure load by 9% than that of reference beam B0.
- Crack pattern and failure mode were unaffected by lap-splice length, with the exception that increasing splice length avoids the formation of splitting cracks.

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