Analysis for Behavior of Reinforcement Lap Splices in Deep Beams

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Abstract

The present study includes an experimental and theoretical investigation of reinforced concrete deep beams containing tensile reinforcement lap splices at constant moment zone under static load. The study included two stages: in the first one, an experimental work included testing of eight simply supported RC deep beams having a total length (L = 2000 mm), overall depth (h= 600 mm) and width (b = 150 mm). The tested specimens were divided into three groups to study the effect of main variables: lap length, location of splice, internal confinement (stirrups) and external confinement (strengthening by CFRP laminates). The experimental results showed that the use of CFRP as external strengthening in deep beam with lap spliced gives best behavior such as increase in stiffness, decrease in deflection, delaying the cracks appearance and reducing the crack width. The reduction in deflection about (14-21) % than the unstrengthened beam and about (5-14) % than the beam with continuous bars near ultimate load. Also, it was observed that the beams with unstrengthened tensile reinforcement lap splices had three types of cracks: flexural, flexural-shear and splitting cracks while the beams with strengthened tensile reinforcement lap splices or continuous bars don't observe splitting cracks.

In the second stage, a numerical analysis of three dimensional finite element analysis was utilized to explore the behavior of the RC deep beams with tensile reinforcement lap splices, in addition to parametric study of many variables. The comparison between the experimental and theoretical results showed reasonable agreement. The average difference of the deflection at service load was less than 5%.

Keywords: Lap splices, Deep beam, Finite element analysis

الخلاصة

يتضمن البحث الحالي دراسة عملية ونظرية لتصرف الأعتاب الخرسانية المسلحة العميقة الحاوية على وصلات التعاقب في منطقة العزم الثابت تحت تأثير الأحمال الساكنة. هذه الدراسة تتضمن مرحلتين: في المرحلة الأولى، تضمن العمل التجريبي فحص ثمان نماذج من العتبات الخرسانية المسلحة العميقة تمتلك طول كلي (2000 ملم)، ارتفاع (600 ملم) وعرض (150 ملم). تقسم نماذج الفحص الى ثلاث مجموعات لدراسة تأثير المتغيرات الرئيسية: طول وصلة التعاقب، موقع وصلة التعاقب، التقوية الداخلية (من قبل الاطواق) والتقوية الخارجية (من قبل شرائح (CFRP)). النتائج العملية تبين بان استخدام ألياف الكاربون البوليمرية كتقوية خارجية في العتب العميق الحاوي على وصلات التعاقب يعطي أفضل تصرف كزيادة الصلابة، نقصان في الهطول، تأخير ظهور الشقوق وتقليل عرض الشق. النقصان في الهطول حوالي (21-14) % مقارنة بالعتب الغير المقوى وحوالي (14-5) % مقارنة بالعتب المحتوي على قضيب مستمر. كذلك لاحظنا ان الاعتاب الحاوية على وصلات التعاقب الغير مقوى تمتلك ثلاث انواع من الشقوق: شقوق انحناء، شقوق انحناء- قص وشقوق انشقاق بينما الاعتاب الحاوية على وصلات التعاقب المقوى والحاوية على القضيب المستمر لا يلاحظ فيها شقوق الانشقاق.

في المرحلة الثانية (التحليل العددي)، تم استعمال التحليل اللاخطي بواسطة العناصر المحددة ثلاثية الأبعاد للتحري عن سلوك الأعتاب العميقة الحاوية على الوصلات المتعاقبة. المقارنة بين النتائج العملية والنظرية بينت بشكل واضح توافق معقول. حيث كان معدل الاختلاف في الهطول قرب الحمل الاقصى اقل من 5%.

الكلمات المفتاحية: الوصلات المتعاقبة، عتب عميق، تحليل العناصر المحدودة.

1. Introduction

Reinforced concrete deep beams are commonly used in many structural applications including transfer girders, pile caps, foundation walls, shear walls and offshore structures (ACI-318-2008). Deep beams are structural members loaded in a way that a significant part of the load transfer to the supports in through direct compression struts or tied-arch action (Moran, 2008).

On the other hand, the design of modern reinforced concrete structures has become more advanced. The designed shapes of structures have become increasingly complicated and have large spaces. This leads to discontinuity of reinforcing bars which often encountered even with the length of a single element. This is due to the fact that rebars are manufactured in standard lengths of 6,9,12 meters. Therefore; in concrete structures which have large spans such as bridges, shells, walls and concrete tanks; discontinuity of reinforcing bars may well exist but, by splicing bars, the reinforcement is effectively made continuous (Hamad, 2004). Three methods may be used to splice reinforcing bars: lap splices, mechanical splices and welded splices. Lap splicing of reinforcing bars is the most common method (Bravo, 1990).

Although the previous studies include many factors that influence the reinforcement splice performance, such as the bar size, concrete strength and cover, etc, but there has not been a considerable discussion about using lap splices in the deep beams. Such as (Ali, 1990) tested thirteen specimens on three series of simply supported reinforced concrete beams subjected to reversed cyclic loads to evaluate the behavior of reinforcing steel lap splices and to study the parameters namely, concrete cover, reinforcing bar diameter and intensity of load reversals. The test results showed that beams with lap splices is aggravated with the use of large bar diameters (16, 19 mm) and the increasing of concrete edge cover about (4-6) times bar diameter can be compensate for the transverse reinforcement. Also, (Kadhum, 2009) analyzed the behavior of steel fiber reinforced by concrete beams with reinforcement lap splices by finite element method. The parameters included in this research are fiber content of lap splices length. The results show that increasing the fiber content from (0-2) % leads to an increase in the ultimate load by about 32% and decreasing the stresses generated in the reinforcing bar by about 16%.

2. Objective of Research

The basic objective of the present work is to study the effect of tensile reinforcement lap splices on strength and the overall behavior of simply supported reinforced concrete deep beams under static loads. Also, study the effect of the length, location of tensile reinforcement lap splices and internal confining reinforcement (stirrups) in lap region. As well as investigate experimentally the efficiency of CFRP laminates in lap region of deep beams containing tensile reinforcement lap splices. Then evaluate the validity and accuracy to carry out finite element model to analyze the nonlinear behavior of RC deep beam with tensile reinforcement lap splice up to failure by using ANSYS (version 11.0) computer program.

3. Description of Specimens

The experimental program included preparation and testing of eight simply deep beams. Tested specimens having a total span (L=2000 mm), overall depth (h= 600 mm) and width(b = 150 mm), with shear span to effective depth ratio (a/d) about 1.0 to ensure that tied-arch action of deep beam would be developed. All beams were tested under two points top loading at a distance of (550 mm) from the support to produce a region of constant moment zone (700 mm) where lap splices were placed. Four Ø12 mm deformed bars were provided as longitudinal tension reinforcement and the steel bar had a 90° hook of length (12×Ø) at each end, in addition to longitudinal compression reinforcement (2-Ø10). The vertical and horizontal shear reinforcement (Ø8 mm) were provided. The ends of all beams extended 100 mm beyond the support's centerlines to prevent splitting failure and any local failure. Figure (1) illustrates all details of geometry and loading schemes of the tested specimens.

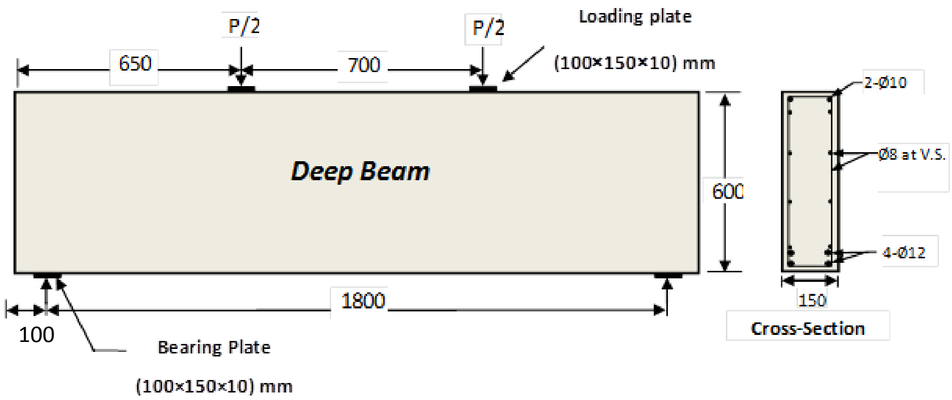

Figure (1) Geometry and Loading Scheme of Tested Specimens

In this study, one specimen (P) was considered as pilot beam to overcome the errors of casting and teaching the test. One control deep beam (DC) without lap splices for comparison with others beams. While others beams containing lap spliced bars include: one specimen (DB-1) was tested for comparison with all beams, three specimens (DT-1, DB-2, DB-S1) with different of the location, the length of lap splices and the presence of stirrups in the lap region and two specimens (DB-F1, DB-U1) was strengthened by CFRP laminates. All specimens are identified in Table (1).

Table (1) Identify of The Test Specimens

Specimen	***Identification***
P	The pilot deep beam.
DC	Deep control beam without lap splice (continuous bars).
DB-1	Deep beam with lap splice length of (ℓs = 1.0 ℓd = 420 mm) in bottom row of tension reinforcement, located at the center of beam.
DT-1	Deep beam with lap splice length of (ℓs = 1.0 ℓd = 420 mm) in top row of tension reinforcement, located at the center of beam.
DB-2	Deep beam with lap splice length of (ℓs = 1.3 ℓd = 540 mm) in bottom row of tension reinforcement.
DB-S1	The same of DB-1 but, strengthened with stirrups in the lap region.
DB-F1	The same of DB-1 but, strengthened in longitudinal direction with two strips of CFRP at bottom tension face.
DB-U1	The same of DB-1 but, strengthened laterally (as U-shape) by two strips of CFRP near ends of splicing region.

The specimen (**DB-F1**) was provided with one layer of CFRP by two strip having (1700) mm length, (50) mm width installed at bottom tension face. The specimen (**DB-U1**) was designated of its symbol by (U) was wrapped partially by two strips of CFRP sheet having (50) mm width installed at ends of splicing region as shown in Figure (2).

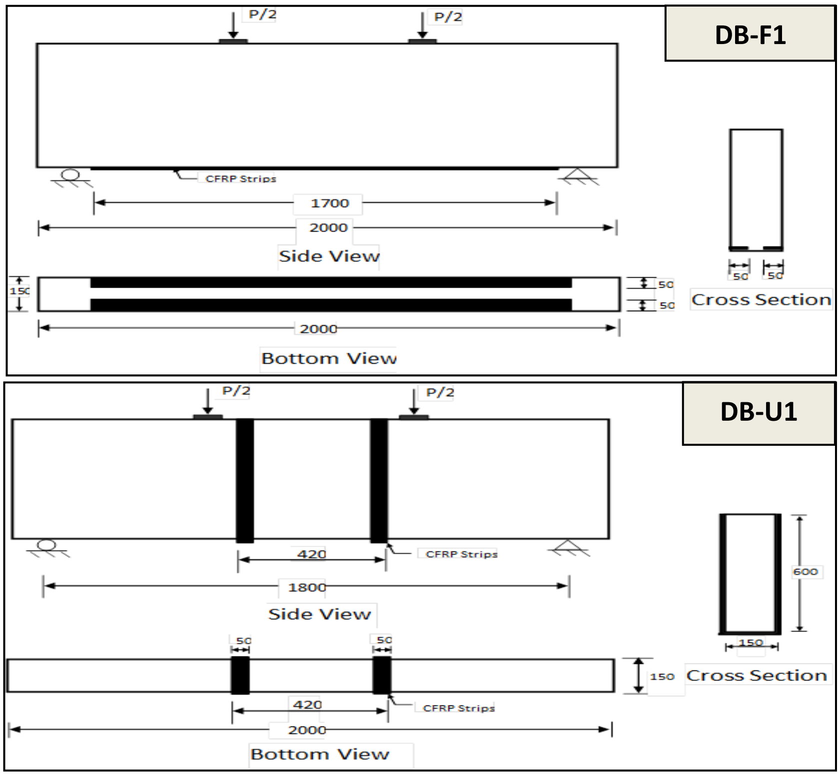

Figure (2) Details of Strengthened Beams With Lap Splices: DB-F1, DB-U1

4.Material Properties

The cement used in casting all the specimens was Ordinary Portland cement company commercially known (Tasluja-Bazian). Also, natural sand from (Al-Akaidur) region was used as fine aggregate. The fine aggregate was sieved at sieve size (2.38mm) to separate the aggregate particle of diameter greater than 2.36mm. Natural crushed gravel of maximum size 14 mm was used in this investigation. It was brought from (Al-Nebai) region. Clean tap water of Babylon, was used for casting and curing of all the specimens. Normal weight concrete was used to cast all specimens. The mix was by weight at 1:1.6:2.4 for cement, sand and gravel respectively. The water cement ratio was equal to 0.47 and cement content was 450 kg/m^3. The compressive strength concrete about 27 MPa at age 28 days. Also, the yield strength of steel (fy) for bar size (12, 10, 8 mm) was (580, 577, 526 MPa) respectively. The mechanical properties of the CFRP sheet are given in Table (2) according to manufacturing specifications of Sika company.

Table (2) Properties of Carbon Fiber Fabric Laminate

Fiber Orientation Deg.	*Density Kg/m^3*	*Thickness mm*	*Tensile Strength MPa*	*E-modulus MPa*	*Elongation %*
0^o	1760	0.131	4300	238000	1.8

5. Test Setup

All deep beam specimens were tested under two concentrated point loads. Two 30 mm heavy duty steel rollers were used to support the beams. A steel bearing plate of (150 ×100 ×10 mm) was inserted between the concrete and steel roller to prevent local failure at the supporting and loading points. The concentrated load is subjected on specimen by a hydraulic jack of the testing machine as shown in Figure (3). All tests were carried out in the laboratory of Civil Engineering department of the University of Al-Kufa.

Figure (3) Testing Machine.

6. Experimental Results

6.1 Cracking Pattern

During testing, flexural, flexural-shear and splitting cracks formed. It was observed that the beams with unstrengthened tensile reinforcement lap splices had three types of cracks: flexural, flexural-shear and splitting cracks while the beams with strengthened tensile lap splices or continuous bars don't observe splitting cracks.

In specimen **DC**, the tension reinforcing bars was continuous along span of the beam (i.e. no including lap splices). The first crack was observed at load about (140 kN) and occurred in constant moment region near center of the beam. As the load was increased, flexural cracks increased in number and width. When applied load reached to about (300 kN), a sudden inclined cracks propagate near the support upward to the point load. After the beam reached near ultimate load the formation of new cracks and flexural crack increase in width while inclined crack stay the same width.

In the beam **DB-1** (beam with spliced bars in bottom row of tension reinforcement of length $\ell s=\ell d$), the first visible crack appeared at the ends of the lap region when the load reached a level about (100 kN). When the applied load reached (150 kN) the flexural-shear crack appeared in the beam. When increasing the load to (480 kN) the formation of splitting cracks in constant moment region occurred in a direction parallel to the reinforcing bars. When the applied load reached the level about (540 kN) the splitting cracks became wider.

The deep beam **DB-2** with spliced bars in bottom row of tension reinforcement of length ($\ell s=1.3\ell d$). First crack occurred at a load of (120 kN) at the splice ends. Inclined cracks observed between point load and support at load (150 kN). As the load was increased, new cracks formed and widened. When the applied load reached (500 kN), a splitting cracks generally propagated from flexural cracks. When the increasing applied load was observed the side splitting cracks widened. The addition in length of lap splices causing to increase bond strength between concrete and reinforcing bars.

In the beam **DT-1** (deep beam with lap splices (ℓs=ℓd) in top row of tension reinforcement), the initial crack observed at (120 kN) and formed in the constant moment region at near lap splice end. As the load was increased, new inclined and flexural cracks formed and widened. When applied load reaches (500 kN) formed new longitudinal splitting cracks that occurred in a parallel was to the tensile reinforcement bars in top row. The splitting cracks became wider near ultimate load.

The beam (**DB-S1**) is the same beam (**DB-1**) but it includes 4-Ø8mm stirrups in the lap region. The first cracks occurred at a load of about (140 kN) near the ends of the splices The number of flexural and inclined cracks outside the splice region was more than other beams. The inclined crack increased in width with increment of the load. The presence of stirrup to confine the splices exhibited large number of smaller cracks width and prevented early failure. In addition, it does not observe any splitting cracks.

The specimen **DB-F1** was strengthened with two strips of CFRP sheet having 1700 mm length, 50 mm width was installed at edges of the tension bottom face. First crack was observed at a load of (150 kN) and formed between the support and point load. When the applied load reach (200kN), the flexural crack of the concrete observed near lap splice end. As the load was increased further, several flexural-shear cracks initiated in the tension face at intervals along the span and move upwards but it does not observe the presence of any splitting crack in this beam.

The deep beam **DB-U1** was strengthened with two wrap of CFRP sheet having 50 mm width as a U-jacket at the ends of the lap splice of the deep beam. First crack was appeared at load about (130 kN) out of the lap region. As the load increased the cracks go around the constant moment zone. When applying load reached about (200 kN) flexural crack near center of the beam is observed. As the load increased the number of cracks outside the splice region was more than other beams.

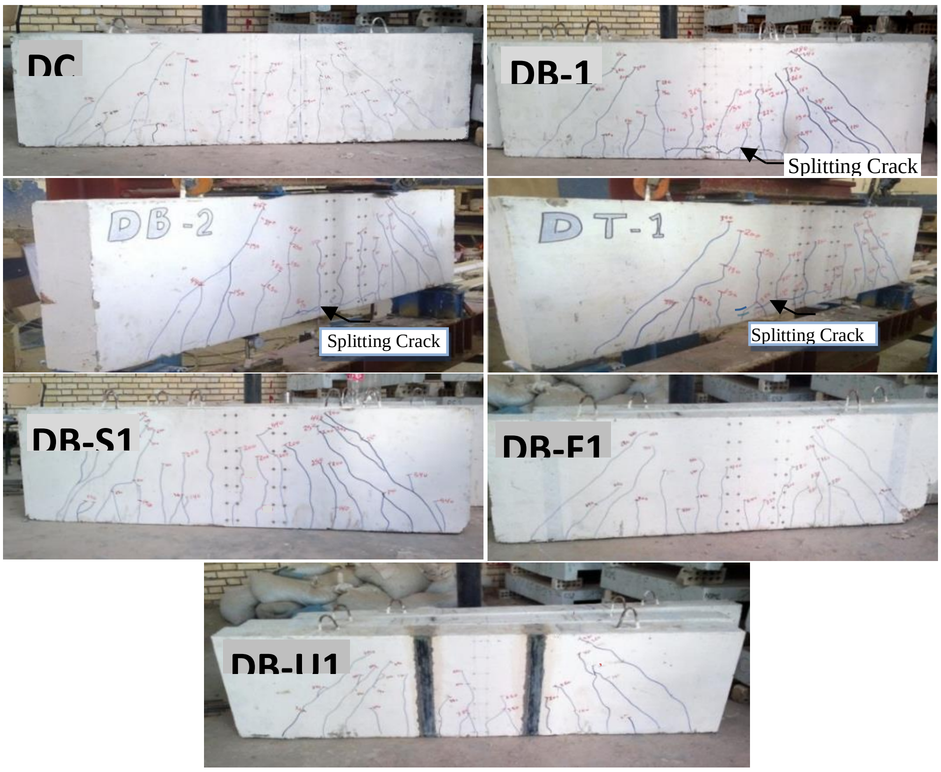

Figure (4) Cracking Pattern For All Specimens.

From comparison of cracks of the tested specimen, it can be noticed that beams with CFRP laminates had improvement in cracking pattern and also eliminating of splitting cracks. This can be attributed to contribution of CFRP laminates in enhancement the bond strength between concrete and reinforcing bars.

6.2 Crack Width

Cracking occurs when the concrete tensile stress in a beam reaches to the tensile strength. The formation of the first crack was monitored throughout the test to recording the width of this crack with increasing load (at each 100 kN) until near the failure of all specimens to know the difference between types of beams. The relation between load and maximum crack width for all beams is shown in Figures (5).

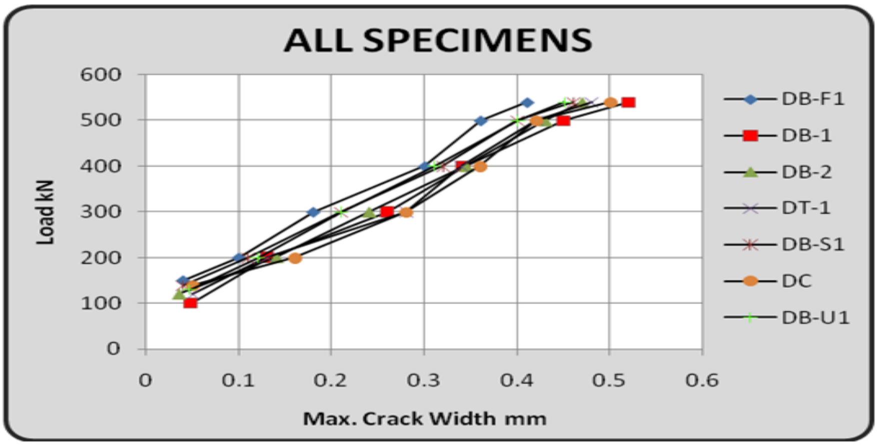

Figure (5) Crack Width For All Specimens

6.3 Load-Deflection Curves

The load-deflection behavior at mid span for each specimens was examined to evaluate the effect of lap splice and type of strengthening on the load carrying capacity and deformation ability of the specimens.

The load-deflection behavior of these beams to have three distinguished stages: Elastic stage, Elastic-plastic stage and Plastic stage as shown in Figure (6). It can be noticed that the stiffness of the beams containing lap splices DB-1 nearly equal the beam with continuous bars. Also, It was shown that DB-F1 have the best behavior where give a decrease in deflection and an increase in stiffness than other beams. The reduction in the deflection was 16% at mid span than control beam DC and 21% lesser than beam DB-1.

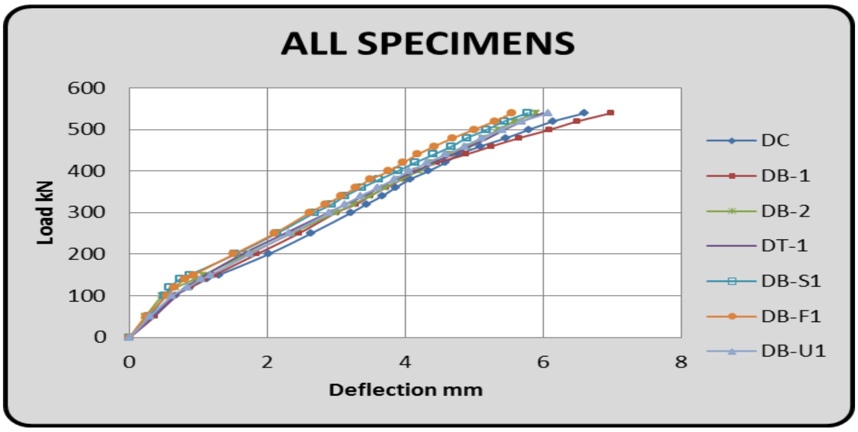

Figure (6) Load - Deflection Curve For All Specimens

7. Numerical Analysis

The aim of the present section is to make a comparison between the finite element model results and the experimental results to study the adequacy of elements type, material modeling, real constants and convergence criteria to model the response of the reinforced concrete deep beams with tensile reinforcement lap splices.

All beam models were modeled in **ANSYS** (V.11) taking the advantage of symmetry. In the finite element model, solid elements, (Solid 45) was used to model the steel plates at the support and loading point. In addition, (Solid 65) was used to model concrete. Link8 element was employed to represent the steel reinforcement. Shell 41 is used to model CFRP sheet. Bond mechanism between the concrete and steel reinforcement was assumed by using interface element (Contac52) in a constant moment region because of found lap splices in beam.

8. Description of Specimen in Finite Element

Symmetry in the geometry of the concrete beams and loadings was utilized in the **ANSYS** finite element models and only one half of each beam was modeled as shown in Figure (7). The properties of materials and the input data adopted in the analysis illustrated in appendix A.

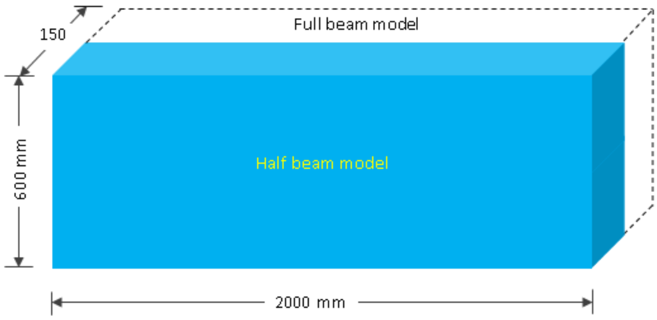

Figure (7) Half Beam Finite Element Model

An important step in finite element modeling is the selection of the mesh density. When an increase in the mesh density has a negligible effect on the results. Therefore, in this finite element modeling, a convergence study is carried out to determine an appropriate mesh density (Wolanski, 2004). Five types of mesh are used to find the best mesh size for **DB-1**.

From the result of the convergence study on mid span deflection, it was found that model with number of elements (7889) for **DB-1** had a negligible effect on mid span deflection as shown in Figure (8).

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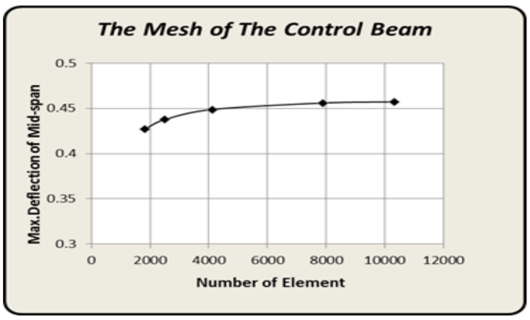


Figure (8) Max. Deflection at Mid-Span Versus Number of Elements Relation Ship

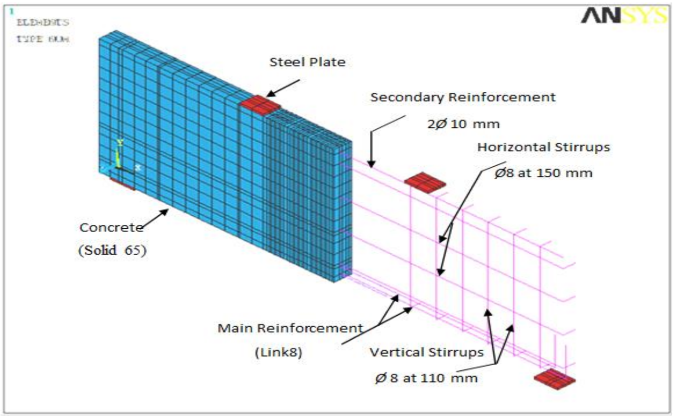


Figure (9) Details Modeling of Beam Models

Displacement boundary conditions are needed to constrain the model where the supports exist to ensure that the model acts the same way as the experimental beams. The external distributed applied load was represented by dividing the total distributed load on the top nodes according to area rounded of each node to represent the distributed load in ANSYS program. Figure (10) shows the details of boundary conditions and applied loads.

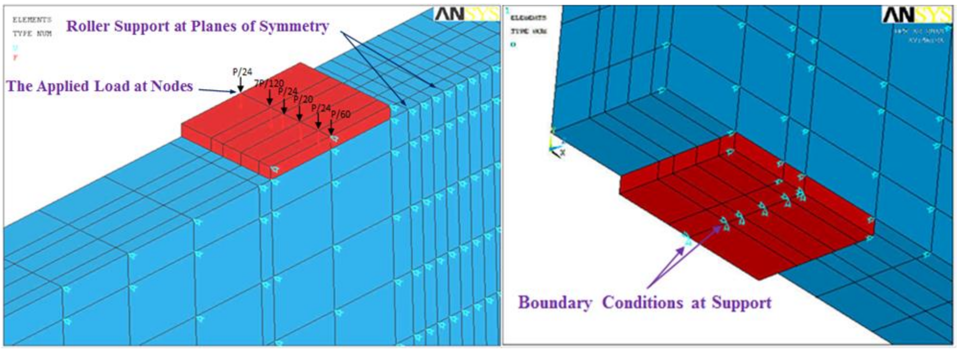


Figure (10) Details of Boundary Conditions of (Symmetry, Supports and Loads)

9. Finite Element Results

9.1 First cracking load

In the finite element model by ANSYS program, it can be noticed that the first cracks happen at the end of the lap region in all beam models with lap splices such as specimen (DB-1), while beam with continuous bars had first crack at mid span, as shown in Figure (11).

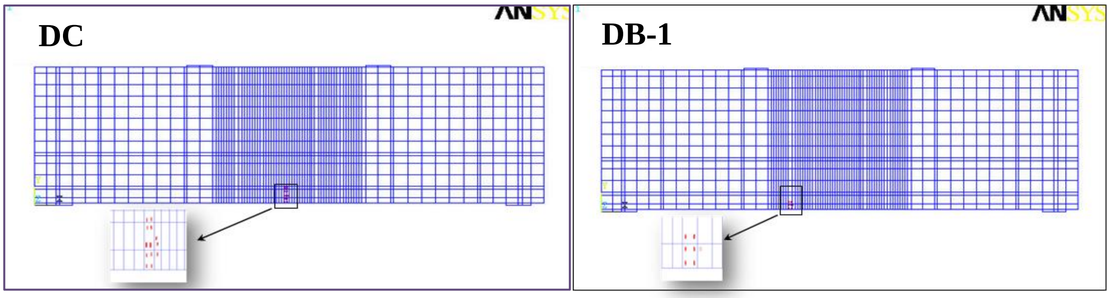


Figure (11) Crack Pattern at First Crack Load For DC and DB-1

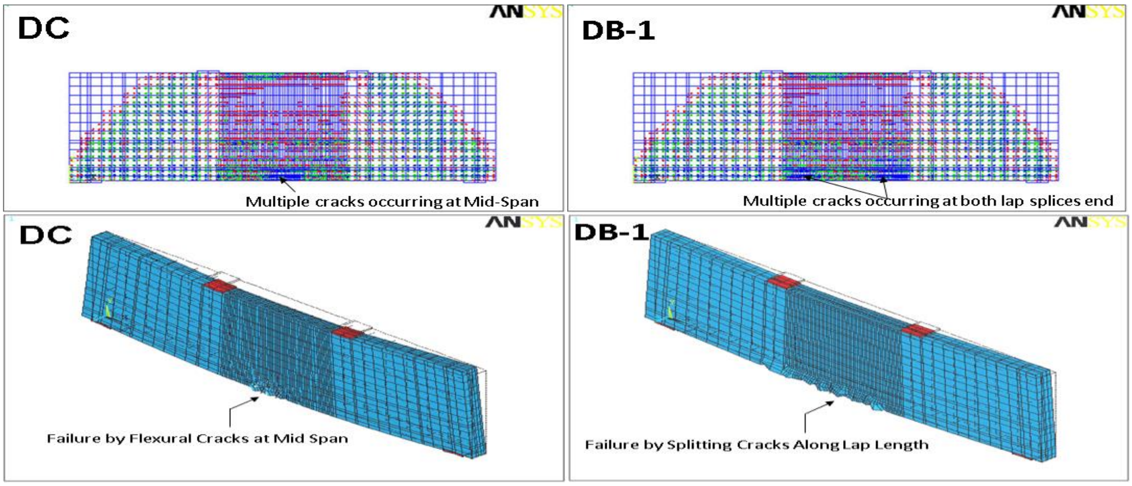
The comparison between experimental and numerical results of the first cracking load is shown in Table (2).

Table (2): Experimental and Numerical First Cracking Loads

SPECIMENS	***FIRST CRACKING LOAD (KN)***		$\frac{P_{cr})num.}{P_{cr})exp.}$
	Experimental $P_{cr})exp.$	***Numerical*** $P_{cr})num.$	
DC	140	138	0.98
DB-1	100	98	0.98
DT-1	120	98	0.82
DB-2	120	98	0.82
DB-S1	140	124	0.89
DB-F1	150	134	0.89
DB-U1	130	124	0.95
The Average			0.90

9.2 Deflected Shape and Cracking Pattern

The deflection shape and crack patterns at the ultimate load show that the failure mode for unstrengthened beam with tensile reinforcement lap splices by splitting cracking at lap splice region while the control beam with continuous bar by flexural cracking at mid span. The cracking pattern and deflection shape at ultimate load for DC and DB-1 is shown in Figure (12).



Figure(12)Deformed Shape and Cracking Pattern at Ultimate Load For DB-1 &DC

9.3 Load-Deflection Response

All tested beams (DC to DB-U1) have been analyzed by using ANSYS computer program to determine the validity of this numerical method for the analysis of deep beams with tensile reinforcement lap splice.

The load versus deflection curves obtained from the numerical study by using perfect bond and partial bond analysis together with the experimental plots are presented and compared in Figure (13). But partial bond results (containing the effect of the bond slip) best than perfect bond. From the load-deflection behavior of all beams can be noticed that results of experimental work and theoretical analysis have three regions, elastic-uncracked, elastic-cracked and elasto-plastic, the first region terminate when the cracks occur.

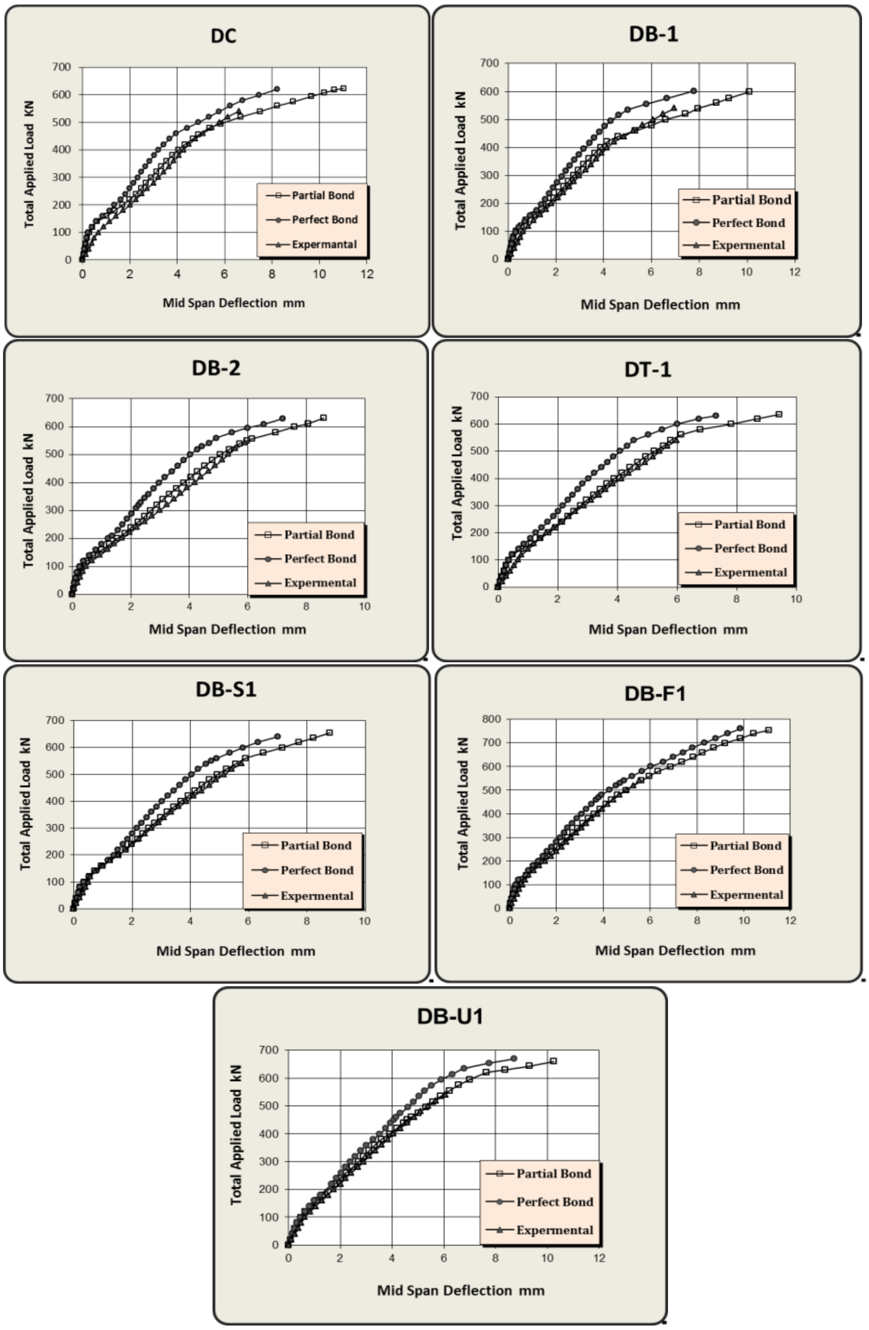


Figure (13) Load-Deflection Curve For All Specimens

9.4 Deflection at Service and Ultimate Load

A comparison between mid-span deflections at service load of the experimental tested beams with numerical mid span deflection from finite element models.

Table (3) Comparison Between Mid Span Deflection at Service Load For Experimental and Numerical Analysis

Beam	**Ultimate Load (kN)** $P_u)num.$	**Service Load*** Ps **(kN)**	**Mid Span Deflection (mm) at Service Load**			
			$\Delta)num.$ **(Perfect Bond)**	$\Delta)num.$ **(Partial Bond)**	$\Delta)\exp.$	$\frac{\Delta)num}{\Delta)\exp}$ **for Partial Bond**
DC	623.40	436	3.64	4.61	4.72	0.98
DB-1	599.23	420	3.46	4.13	4.45	0.93
DB-2	631	442	3.45	4.34	4.67	0.93
DT-1	635	445	3.50	4.48	4.75	0.94
DB-S1	655.24	459	3.63	4.40	4.66	0.94
DB-F1	754	528	4.73	5.30	5.42	0.98
DB-U1	660.11	462	4.20	4.78	4.85	0.99
The Average			3.80	4.58	4.79	0.95

(*): *Ps = 0.7 Pu*

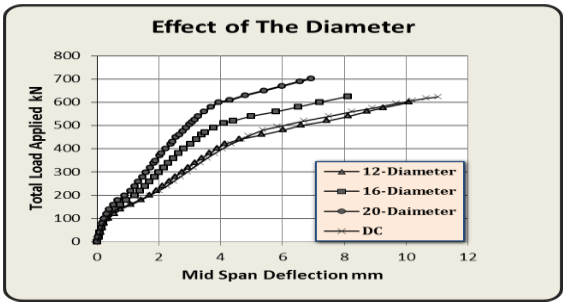
From Table (3) shows that the partial bond result seems efficient and gives good accuracy through comparison with the experimental results where the average difference of the deflection at service load was less than 5%.

10. Parametric Study

The effect of some selected parameters on behavior of beams containing tensile reinforcement lap splices are decided to study as follows:

10.1 Effect of The Bar Diameter

When the diameter of tension bar increase to (16, 20 mm) causing increment in the stiffness of the beam and then lead to failure at high level of ultimate load but at low level of ultimate deflection due to increasing in splitting bond stresses. Therefore, the increment in ultimate load for beams with 16, 20 diameter is about (4%, 17%) respectively, while the reduction in deflection less about (20%, 31%) than the beam **DB-1**.



Figure(14)Load-Deflection Curve of Beams With Different Diameter of Spliced Bar

10.2 Effect of Bar Orientation

The purpose of this study is to examine analytically the behavior of both splice orientations (a side-by-side configuration or an offset configuration) as shown in Figure (15).

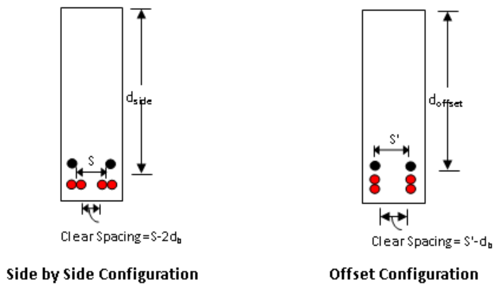


Figure (15) Clear Spacing Between Splices

Test results showed that offset splices consistently had higher bond than side-by-side splices. Offset splices beam was increased in ultimate load approximately(5%) than side-by-side splices beam (**DB-1)** and it had stiffness more than and **DB-1** as shown in Figure (16).

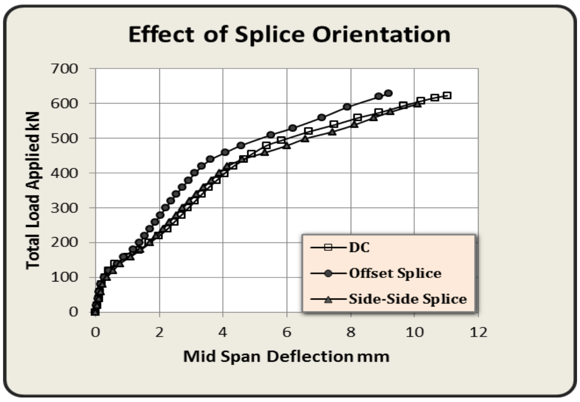


Figure (16) Load-Deflection Curves of Beams With Different Splice Orientations

10.3 Effect of Lap Length

To study the effect of lap length on behavior of R.C. deep beams with lap splices selected four values for length of lap splices (0.5 *ℓd*, 0.75 *ℓd*, 1.0ℓd and 1.3ℓd). It was found that increased the length leads to increase in ultimate load as shown in Figure (17).

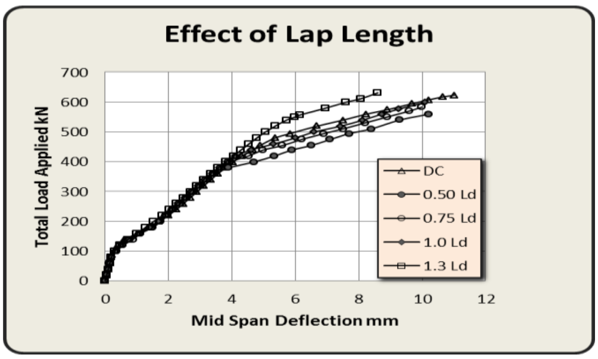


Figure (17) Load-Deflection Curves of Beams With Different Lap Length

11. Conclusions

11.1 Conclusions from Experimental Work

1. It was observed that the beams with unstrengthened tensile reinforcement lap splices had three types of cracks: flexural, (diagonal) flexural-shear and splitting cracks while the beams with strengthened tensile reinforcement lap splices or continuous bars didn’t observe splitting cracks.
2. The beam without internal confinement of stirrups in the lap splice region gives little number of wide crack width. While the beam with internal confinement reinforcement exhibited large number of smaller cracks width.
3. The use of CFRP laminates as external strengthening in longitudinal and lateral confinement as U-wrapping had a significant effect on crack pattern of the reinforced concrete deep beam by delaying the crack appearance and reducing the crack width, and eliminating of splitting cracks.
4. Using CFRP in the longitudinal direction of tensile reinforcement lap splices in deep beam gives a better behavior by increasing stiffness and decreasing deflection when compared with others beams. Therefore, the reduction in deflection near the ultimate load was about (21%) less than the unstrengthened beam.
5. The reinforced concrete beam with tensile reinforcement lap splices and strengthened with wrapping CFRP laminates (as U shape) showed decrease in deflection near the ultimate load was about (14%) less than the unstrengthened beam.
6. The increase in the length of the lap spliced bars had a significant effect on the behavior of the lap splices in the deep beam where the increase from ℓd to 1.3 ℓd causing increment in the first cracking load about 20% and reduction in deflection near the ultimate load about 16%.
7. It was found that the beam with top row of tensile reinforcement lap splices causing increment in the first cracking load of 20% and reduction in deflection near the ultimate load was about 14% compared with the beam of bottom row of tensile reinforcement lap splices.
8. In deep beams strengthened by internal (stirrups) along the lap region, the reduction in deflection near the ultimate load was about 18% less than the unstrengthened beam and about 10% less than the beam with continuous bar.

11.2 Conclusions From Finite Element Analysis

1. The deflection shape and crack patterns at the ultimate load showed that the failure mode for unstrengthened beam with tensile reinforcement lap occur by splitting cracking at lap splice region while the control beam with continuous bar by flexural cracking at mid span.
2. The partial bond result (including bond-slip phenomena of tensile reinforcement lap splices) seemed efficient and gave good accuracy through comparison with the experimental results where the average difference of the deflection at service load was less than about 5%.
3. Neglecting bond-slip phenomena in F.E. analysis of R.C. beams with tensile reinforcement lap splices leads to overestimation in; load-deflection response

through post-cracking stage and eliminating both the possibility of splitting bond failure and splitting cracks.

4. The deep beam strengthened by internal (stirrups) in the lap splice region failed slowly and gradually. The ultimate load for this beam increasing about 9% more than the unstrengthened beam and about 5% than beam with continuous bar.
5. The external longitudinal (CFRP sheet) are very effective in increasing the interaction between the CFRP and the concrete section and improving the structural behavior of the strengthened beams.The beam with longitudinal CFRP sheet was better than the beam with U-warp where the first beam increased 8% and 14% in cracking load and ultimate load, respectively.
6. Increasing the diameter of spliced bars had significant effect on the behavior of reinforced concrete beam where due to increase in ultimate load for beam with (16-20 mm) diameter about (4 % and 17%) and reduction in ultimate deflection about (20% - 31%) respectively.
7. It was found that the bar orientation effect on behavior of deep beam containing tensile reinforcement lap splices where causing the increment in ultimate load for beam with the offset splices approximately (5%) more than beam with side-by-side splices.

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