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Behavior of tension lap spliced sustainable concrete flexural members

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Abstract. The use of spliced reinforcing bars in sustainable concrete members to manage inadequate bars length is a common practical issue which is may be due to some limitations. The lap splicing means two bars overlapped in parallel with specified length called the splice length in order to provide the required bond between the two bars. The bond between sustainable concrete and spliced steel bars is another important issue. The normal strength sustainable concrete specimens of sizes 1700×150×150 mm with tension reinforcement lap spliced were selected according to testing device length limitations. These members were designed to fail in flexure in order to investigate the lap spliced tension bars effect. The selected lap spliced tension bars were of 10 mm size with smooth and deformed surfaces in order to investigate the surface nature accompanied with the splice nature. The sustainable concrete mechanical properties and mix workability were also studied. This study reveals that the effect of number of spliced bars on the response of beams reinforced with smooth bars is found to be more obvious than deformed one. Finite element modeling in three dimensions was carried out for the tested beams using ABAQUS software. A parametric study is carried out using finite elements on considering the following parameters, concrete compressive strength, load type and opening in cross section (hollow section) for weight reduction purposes.The laboratory and numerical results show good agreements in terms of ultimate load and deflection with an average difference of 10% and 15% in ultimate load and deflection respectively.

Keywords: sustainable concrete; beams; experimental test; finite element analysis; lap-spliced

1. Introduction

Concrete is a building material widely used in construction projects all over the world. The production of raw materials such as cement and aggregates which used to produce concrete is considered as a major concern environmental problems. The emission of CO_2 during the production of cement and the waste results from construction process and demolition are examples of such problems. Concrete that used lower cement content through using pozzolanic materials such as silica fume or metakaolin to replace cement with or without recycled aggregate is considered as a sustainable concrete. The problem of lap splicing of steel bars is a common construction issue which is used in concrete structures to overcome the continuous reinforcement bars requirements for long concrete elements. Other reasons for using lap splicing are sometimes referred to transportation limitation or designer reinforcement detailing. Lap spliced length and number of permissible lap spliced bars limitations recognized in codes must be discussed and studied.

The bars surface nature mentioned in codes focused on using deformed bars only in order to achieve the required bond between lap spliced bars and concrete which is an impotent issue. For flexural members, their strength depends on different physical parameters such as concrete strength in compression, steel reinforcement yield strength, beam dimensions and amount of reinforcement ratio. The result of these parameters will be the member stiffness. If the members are supported on spans larger than (12 m), the lap spliced technique is selected to reinforce the longer span members, however this technique should be carried out in accordance to the international design codes. The American Concrete Institute 318 (2014) has recommended the overlap splice with the minimum length of 40 multiplied by nominal diameter of bar (d_b). Knowing that, the reinforcing steel bars splice length must be longer than the development length in compression reinforcement in case of compression member (l_{dc}). While it should be longer than the development length in tension reinforcement in case of tension member. The Canadian Standard CSAA23.3 (2004) suggests an equation for the bond strength prediction which is similar to the ACI one. In 2000, Esfahani suggested an equation for the ductility criteria of spliced high strength concrete members subjected to monotonic loading as previous equations are applicable to normal concrete. Esfahani and Kianoush (2005) investigated the effect of web reinforcement quantity or ratio continuously provided along the spliced bars on the flexural member ductility. They concluded that the bond strength and ductility are increased with increasing web reinforcement quantity. But the increase in the splice length (l_d), does not affect the bond of spliced bars for high strength members.

Allam (2013) investigated the external strengthening of flexural members having short lap splice length for flexural tensile bars. Six members with identical dimensions and steel ratio were used in the laboratory specimens. Two reference members were tested. The first member was

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without any splice while the second one had a spliced bar with length of 240 mm (20 times the bar diameter). The other four members were identical to the second reference member but including near surface mounted strengthening techniques. Both carbon fiber bars and deformed steel bars were considered for the strengthening technique. The strengthening technique shows a more ductile failure for the four members in comparison to the second reference one.

Rakhshanimehr *et al*. (2014) investigated experimentally the flexural ductility of spliced bars members. The study comprises the design and cast of Twenty-four laboratory members. The main experiment parameters were the concrete strength in compression, web reinforcement quantity along the splice length, and the tension reinforcement bar size. The ductility ratio of tested members is calcultaed based steel reinforcement yield strain measurements. The strength of concrete and the web reinforcement quantity along spliced length were the major parameters the effected the experiment ductility results. If the members are provided with suitable quantity of web reinforcement, the flexural ductility with acceptable response is achieved for different concrete grades. The obtained results were compared and discussed with CSA-A23.3 (2004) Standard limitations for the ductility and bond of spliced members. The experiments revealed that the code limitation is adequate in calculating the spliced bond strength. The code is found to give non satisfactory response for ductility measurements. The study suggested an equation to achieve the suitable ductility.

Mousa (2015) carried out laboratory tests on flexural members with different splice lengths. The splice lengths were varied from zero to 700 mm. The specimen's dimensions were 200 mm depth, 250 mm width and 2200 mm length and tested under two point loads. The concrete grades were; 55, 65 MPa in order to produce high strength one. Two deformed bars were used as tension reinforcement and were spliced in the constant moment zone. Results showed that using shear reinforcement gave, a satisfactory ductility response with excellent correlation to reference nonspliced beam.

Alyousef *et al*. (2015, 2016) studied the response and bond strength of spliced members under monotonic and repeated loading strengthens with fiber-reinforced polymer FRP sheet wrapping. The experiments consist of cast and test of 53 members under monotonic and repeated loading. The samples were divided into three categories or groups. The first group consists of members with concrete cover of 20 mm. The second and third groups contain members with 30 and 50 mm concrete cover respectively. The minimum splice length (300 mm) was chosen using the ACI and the Canadian provisions in order to obtain bond failure before the yields of reinforcement. Each group contains three flexural members tested under static loading while the other samples were tested under repeated loading. The bars were spliced at the constant moment zone in order to investigate the effect of FRP strengthen on the bond strength of spliced bars. The repeated load was applied in the test with a minimum of 10% of the ultimate static load. Members tested with a million cycles without reaching failure were tested again with a higher load level.

The effect of fatigue loading on the bond between reinforcement and concrete, and the response and ductility of the tension lap splice beams strengthen with fiber-reinforced polymer (FRP) sheets were investigated by Alyousef *et al*. (2018). The fatigue life or repeated cycle of the spliced members was calculated using developed crack growth model. The analysis results were compared with the previous laboratory results of 53 beams tested in 2015 under repeated (fatigue) and static loading. There is a good correlation between the estimated number of cycles and the experimental fatigue life data for all members with 7% difference.

Mabrouk. and Mounir (2018) carried a laboratory test on 16 flexural spliced members. The main variables were the web reinforcement diameter, shape and distribution in different graded concrete members. The members have rectangular section 150×250 mm and simple supports with 1800 mm span. The tension reinforcing bars were lap spliced at the constant moment zone span. The bond strength in self-compacting concrete members is found to be higher than vibrated concrete members for the same concrete compressive strength.

Wu *et al*. (2018) investigated experimentally the response of spliced members cast with ordinary and self-compacted concrete. Six members were tested under two point load in order to study the bond strength. The obtained results revealed that the self-compacted concrete member and ordinary concrete member shows identical bond strength at the tension spliced bars. The limitations for spliced self-compacted concrete member are mentioned in the current code which is verified in that research. The ordinary and self-compacted concrete members exhibited the same ductile flexural response at the zone of spliced length.

Sharbatdar *et al*. (2018) used a technique called forging process of reinforcement that will be lap spliced in flexural members and comparison was made between members reinforced with them. The laboratory program consists of testing four concrete flexural members with identical member dimension and steel ratio. The first one is made as a reference which has no splices and the other three members with different splices (100% welded in the middle of splice length, 50% welded, and not welded lap splices). This study revealed that welding method for splicing bars on entire splice length have given a good results almost 75% of ultimate load carried by reference member.

Many research works has been made selecting different variables which expected to influence the bond strength of spliced members but limited research has been focused on the effect of spliced tension bars surface nature accompanied with utilizing continuous web reinforcement along the splice length for sustainable concrete members which may have hollow sections. This study comprises two main parts. The first one is carrying a laboratory testing program for seven RC members tested at the structural laboratory (Faculty of Engineering /Al-Nahrain University). While, the second part consist of carrying numerical analysis for tested beams with similar and different parameters. A parametric study is carried out using finite elements on considering the following parameters, concrete compressive strength, load type and opening in cross section (hollow section).

Table 1 Designation and properties of test specimens

Beam No.	Tension bars	Spliced bars	Top Bars deformed	Stirrups Deformed
B0	3#10 deformed	Non-spliced	2#6	#8@100
B1	3#10 deformed	Middle bar spliced	2#6	#8@100
B2	3#10 smooth	Middle bar spliced	2#6	#8@100
B3	3#10 deformed	2 outside bars spliced	2#6	#8@100
B4	3#10 smooth	2 outside bars spliced	2#6	#8@100
B5	3#10 deformed	All bars spliced	2#6	#8@100
B6	3#10 smooth	All bars spliced	2#6	#8@100

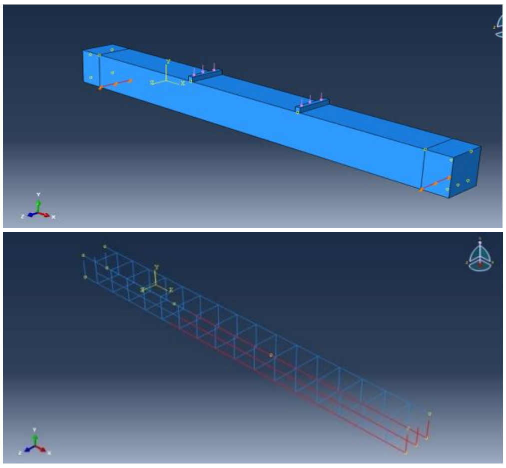


Fig. 1 Beam specimens

Fig. 2 Testing machine

Table 2 Properties of concrete mix and strength

Water/cement ratio	0.36
Water (kg/m^3)	126
Cement (kg/m^3)	350
Sand (SA) (kg/m^3)	800
Gravel (GA) (kg/m^3)	1000
Metakolin (kg/m^3)	60
Superplasticizer (SP) (lit/m^3)	6.5
Compressive strength (MPa)	38
Modulus of Rupture (MPa)	3.9

Table 3 Reinforcement tensile test results

Bar size (mm)	Yield stress (MPa)	Ultimate Strength (MPa)	Elongation %
6	480	620	25
8	400	750	14
10	650	760	9

2. Research program

2.1 Experimental study

All beam specimens were simply supported with square cross section of (0.15 m) and member length of (1.7 m) subjected to two points loading. The beam span was 1.5 m center to center of support and the shear span was 0.5m. The shear span divided by the effective depth (a/d) is made constant 3.7 for all tested members as shown in Figs. 1 and 2. The spliced length of main tension reinforcement is assumed to be 620 mm (60 d_b). All beams were loaded with small increments gradually until failure was reached. The experimental part of the study focused on the flexural response of the seven sustainable concrete members with constant flexural and shear reinforcement and concrete compressive strength, as shown in Fig. 1 and Table 1. The beams were designed in accordance with ACI-318 (2014) code. The reinforcement ratio value was chosen in order to obtain bending failure. The used tension reinforcement was (3φ10 mm) (steel ratio 1.16%) and the top compression reinforcement was (2φ6 mm). The beams had stirrups of (φ8@100 mm *c/c*).

2.1.1 Used materials

The concrete mix comprise the use of type I cement (ordinary Portland cement) complies with the requirements of ASTM C150 (2016), crushed gravel (CG), and sand (SA). The size of used gravel was less than 10 mm. Also, the used natural sand was of partial size of 4.75 mm. The gradation of them are confirmed to the Iraqi Standards No. 45 (1984) and ASTM C33 (2016). The Metakolin is used to replace the cement in order to produce sustainable concrete through reducing cement content.

2.1.2 Concrete mix

One set of sustainable mix was designed through adding superplastsizer of 1.8% by weight of cement paste, metakolin to replace cement and with 0.36 water cement ratio as given in Table 2. The mechanical properties were obtained as the average of three specimens.

Tensile test of steel bars was executed on reinforcement bars and the Table 3 shows that bars applicable with the ASTM A615 (2016).

2.2 Finite element study

Finite element method is very important tool that is selected to solve real structures with high material nonlinearity and complicated geometry. Three dimensional (3D) simulation is used to model the flexural members in this research. The ABAQUS 6.16 software is used in the simulation in which 20 node brick elements is used to model members and 3 node bar elements to simulate the spliced and non- spliced tension bars, compression and web reinforcement. The member mesh in finite elements is shown in Fig. 4. The concrete material is simulated using damage plasticity model and the spliced bars are simulated as elastic perfectly plastic. The parameters used in ABAQUS are taken from the experimental work.

3. Results and discussion

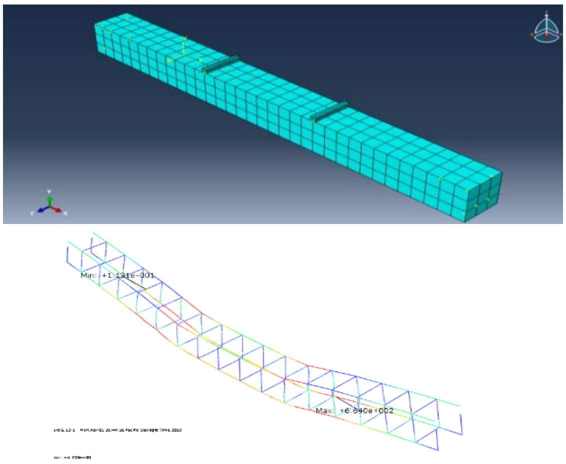


Fig. 3 Finite element mesh

B0

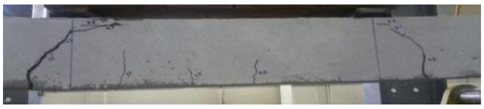
B1

B2

B3

B4

B5



B6

Fig. 4 Crack pattern for the tested beams

3.1 Experimntal study

Fig. 4 shows the crack development of the reinforced concrete beams during the test. It can be seen that all beams were failed in flexure due to lap splice bond slippage.

The specimens were failed gradually in the test as the cracks starts at the bottom face of the members and developed at the end of splice length and then propagate towards the compression zone combined with bond slip for spliced bars and smooth bars. The ratio of the cracking load capacity to the ultimate one of the tested beams ranged from 0.29 to 0.42. While the ratio of cracking deflection to the ultimate one ranged from 0.13 to 0.21 for the same tested beams. These variations depend on the spliced bars numbers and the nature of bars surface (smooth or deformed) as shown in Table 4.

Table 4 Tested beams results (flexural and bond mode of failure)

Beam No.	P_{cr} (kN)	Δ_{cr} (mm)	P_u (kN)	Δ_u (mm)	P_{cr}/P_u	Δ_{cr}/Δ_u
B0	24.3	6.2	81.6	25.5	0.30	0.24
B1	23.3	5.2	79.75	24.8	0.29	0.21
B2	23	3.8	58.2	21.1	0.39	0.18
B3	25.4	4.2	77.06	23.98	0.33	0.18
B4	23.7	3.1	56.60	18.9	0.42	0.16
B5	26.7	3.5	76.91	23.65	0.35	0.15
B6	22.5	2.4	53.22	17.8	0.42	0.14

where P_{cr} is the cracking load, P_u is the ultimate load Δ_{cr} is the cracking deflection, Δ_u is the ultimate deflection.

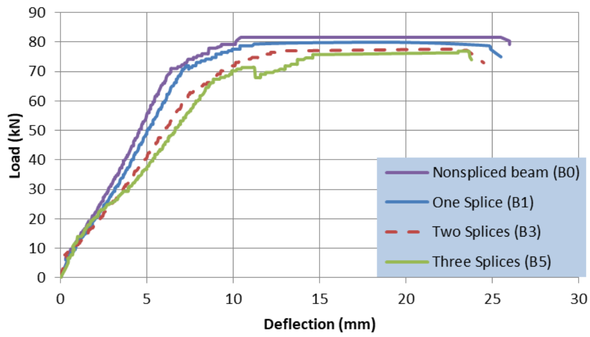


Fig. 5 Load deflection curves for the tested beams reinforced with deformed bars

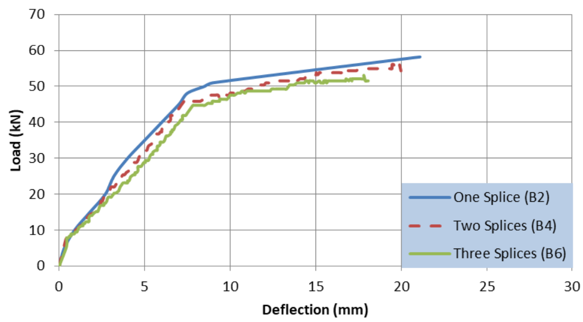


Fig. 6 Load deflection curves for the tested beams reinforced with smooth bars

The effect of number of spliced bars on the load deflection behavior for beams reinforced with deformed bars is shown in Fig. 5. It can be seen that, all beams had same behaviour till first crack was appeared. Beams had less number of splices show higher stiffness. That could be explained by the bond-slip between the reinforcement. Where beams had less number of splices developed less slip in the constant moment zone. Also, the ultimate load was increased with the decreased in the number of the splices. In this figure it can be seen also B3 and B3 has almost same

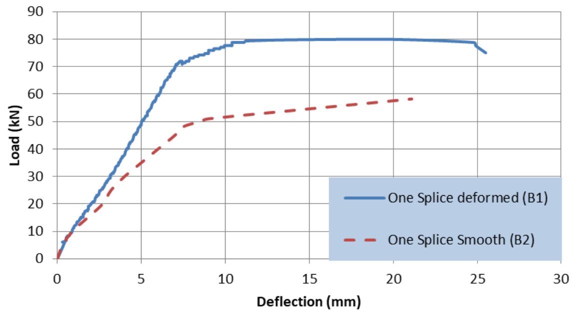


Fig. 7 Load deflection curves for the tested beams reinforced with single spliced bar and the two bars non-spliced

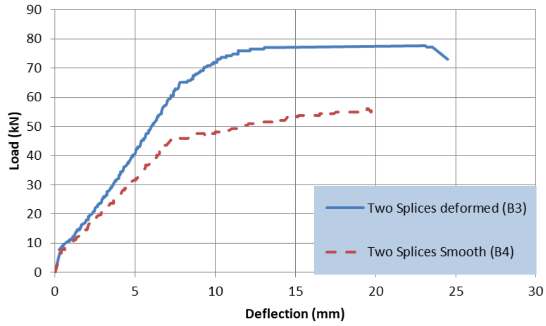


Fig. 8 Load deflection curves for the tested beams reinforced with two spliced bars and single bar non-spliced

behaviour which means a certain number of spliced leads to deterioration in tension zone concrete.

The effect of number of spliced bars on the behaviour of beams reinforced with smooth bars was presented in Fig. 6. It can be seen that all beams developed same deflection in the first 20 kN load (39% of the ultimate load). After that load, bar slip and spliced slip occurred. It can be seen also, beam had one spliced bar developed relatively less deflection the other two beams for the same loading amount.

Figs. 7,8 and 9 illustrate the load deflection behaviour of beams where the splices reinforcement condition was the main parameter. i.e., smooth and deformed. Form these figures it can be seen that all beams have the comparable cracking load. After beams visible crakes appear, the beams having deformed bar get more stiffness and load carrying capacity than the smooth bars. That is because the bound between the concrete and deformed bars is higher than that of smooth bars. According to ACI 318, deflection limits should be L/360. In Fig. 7. The service load of B1 was 48 kN which was almost the same of that of B0 i.e., 50 kN as shown in Fig 5. However, service load was 38 kN and 35 kN for beams B3 and B5 respectively. For beams with smooth bar spliced, the service load was almost the same for all beams 30 kN which was about 40% less than that of beams with no spliced. The ratio of ultimate deflection of deformed. Cracks were initiated for B1, B3 and B5 at about 29%, 33% and 35% respectively of ultimate load. While cracks were developed for B2, B4 and B5 at about 39%, 42% and 42% respectively. This is probably due to the effete of tension stiffening. Where beams with smooth

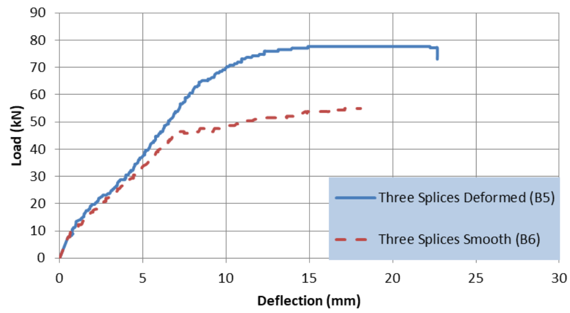


Fig. 9 Load deflection curves for the tested beams reinforced with three spliced bars

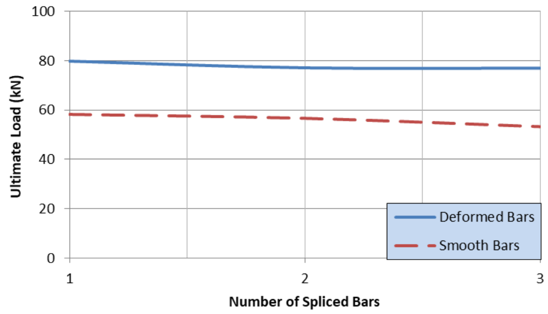


Fig. 10 Effect of number of spliced bars on ultimate loads

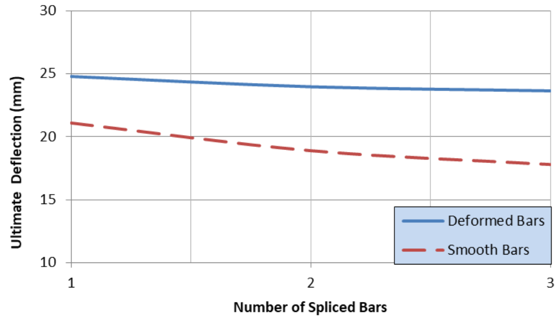


Fig. 11 Effect of number of spliced bars on ultimate deflection

reinforcement had less bond between the steel rebar and concrete in tension zone.

The effect of number of spliced bars on ultimate loads for the tested beams is shown in Fig. 10. This effect is found to be small for deformed bars beams (3%) and more significant for smooth bars (9%). The effect of bar surface on ultimate load is found to be larger (27-31%), the larger percentage is for the three bar spliced. The effect of number of spliced bars on ultimate deflections for the tested beams is shown in Fig. 11. This effect is found to be smaller for deformed bars beams (5%) and larger for smooth bars (15%). The effect of bar surface on ultimate load is found to be in the range of (15-25%), the larger percentage is for the three bar spliced. The effect of number of spliced bars on energy absorbed (area under load deflection curve) for the tested beams is shown in Fig. 12. For deformed bars, as the number of splice bars increased from 1 to 3 the energy absorbed decreases by 17%. This means that the one spliced deformed bar beam is the more ductile specimen. For the smooth bars, if the number of spliced bars increased from 1 to 3, the energy absorbed decreases by 26%. This means that the one spliced bar beam is

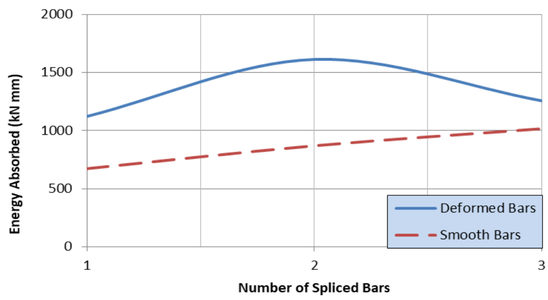


Fig. 12 Effect of number of spliced bars on energy absorbed

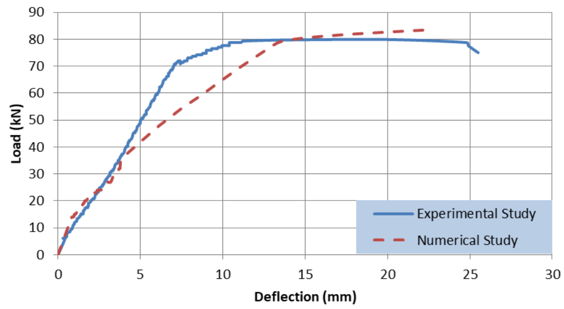


Fig. 13 Load deflection curves for the tested beam B1

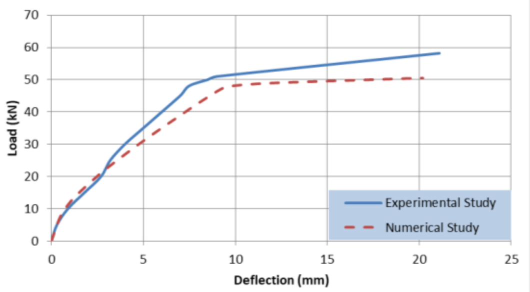


Fig. 14 Load deflection curves for the tested beam B2

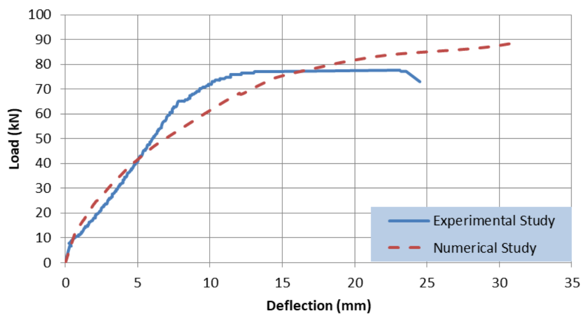


Fig. 15 Load deflection curves for the tested beam B3

the more ductile specimen for this case. The spliced deformed bars beam has an absorbed energy greater than the smooth one by (44-51%), the larger difference is obtained for the case of three spliced bars beam.

3.2 Finite element study

The experimental results were set against the values predicted by the finite element software to check the accuracy of the adopted finite element model and to trace the full behaviour with experimental beam test. Figs. 13 to

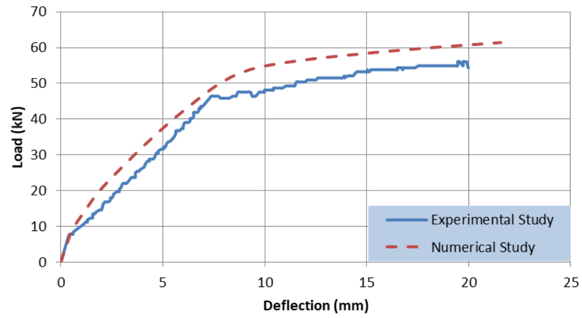


Fig. 16 Load deflection curves for the tested beam B4

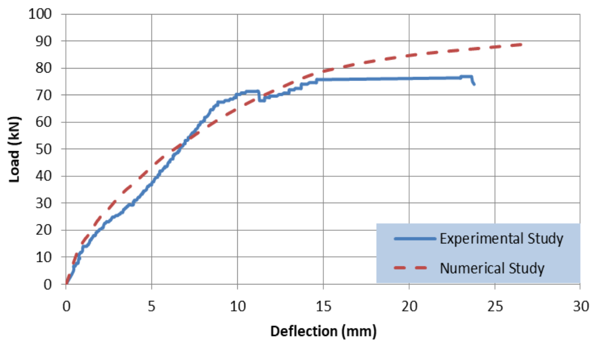


Fig. 17 Load deflection curves for the tested beam B5

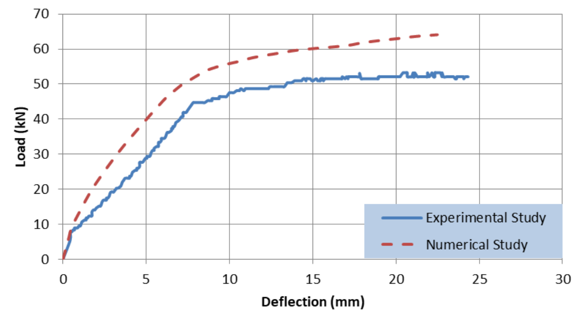


Fig. 18 Load deflection curves for the tested beam B6

18 show the load deflection curves obtained from experimental and finite elements. Good agreements were obtained. In general, all beams had higher numerical ultimate load than that of experimental beams within expectable percentage error i.e., less than 20%. For the smooth reinforcement beams it can be seen that the behaviour of both finite element and experimental results are identical. Whereas the load of the simulated deformed beams was continued to the crash of the concrete.

3.2.1 Effect of the compressive strength.

The first parameter considered in this study was the compressive strength. B1, B2, B3 and B4 were selected in this section expect that compressive strength was varied (25, 38 and 55 MPa). Figs. 19, 20, 21 and 22 show the influence of compressive strength on load deflection response of spliced bars specimen. For most members, as the compressive strength increased, the failure load enlarged while the ultimate deflection reduced and therefore flexural ductility reduced. For the case of deformed reinforcement, (Fig. 19 and Fig. 21), the ultimate load was

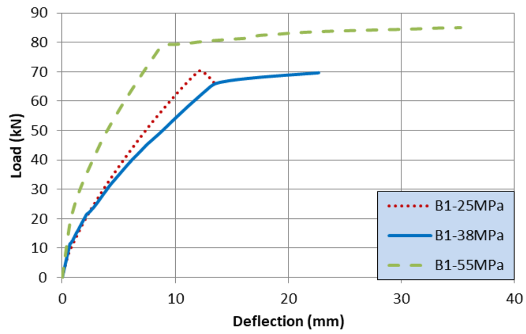


Fig. 19 Effect of compressive strength on the behavior of single spliced deformed bars beams

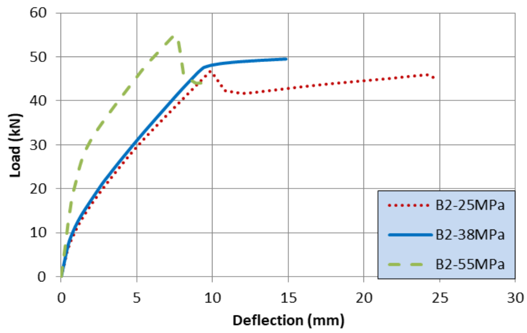


Fig. 20 Effect of compressive strength on the behavior of single spliced smooth bars beams

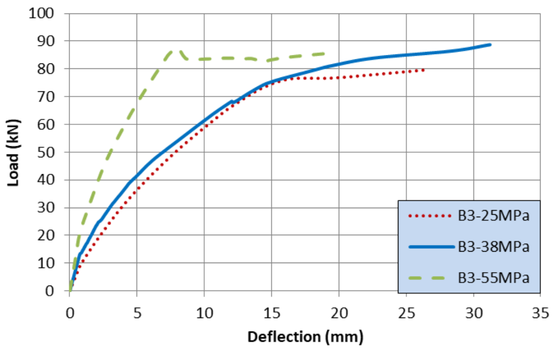


Fig. 21 Effect of compressive strength on the behavior of two spliced deformed bars beams

increased by 20% by increasing the compressive strength from 25 MPa to 55 MPa in case of single splice. While compressive strength had less effect on the ultimate load in case of two splice i.e., ultimate load increased only 12%. This could be explained by the tension stiffening where tension stiffening increases with the increases of the compressive strength.

3.2.2 Effect of the loading types

In this section, the effect of loading types on the load-deflection behaviour were studied. Two extra kinds of loading were selected in addition to the two point loads i.e. uniformly distributed load and one point load as shown in Figs. 22, 23, 24 and 25.

For both cases smooth and deformed bars, it can be seen the failure mode of uniform distributed load is similar for both cases (one and two splices). It can be notice also

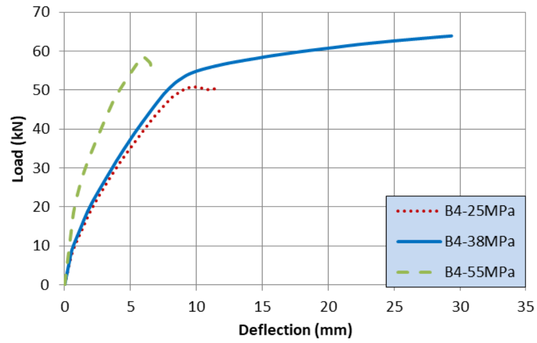


Fig. 22 Effect of compressive strength on the behavior of two spliced smooth bars beams

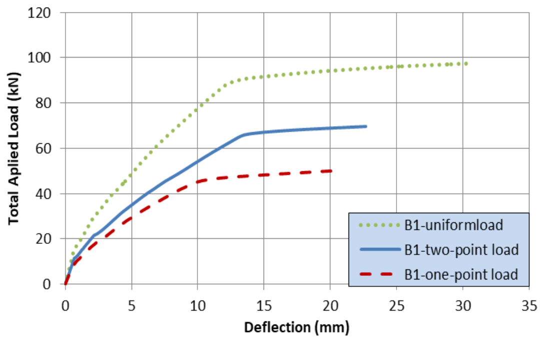


Fig. 23 Effect of load type on the behavior of single spliced deformed bars beams

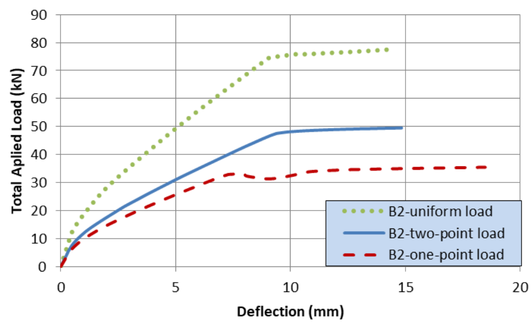


Fig. 24 Effect of load type on the behavior of single spliced smooth bars beams

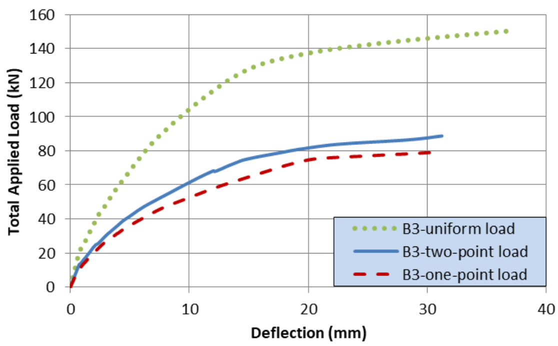


Fig. 25 Effect of load type on the behavior of two spliced deformed bars beams

ductility is higher in case of uniform distributed load than the other two cases. The ultimate load in case of uniformly distributed load is almost twice than that of one point load

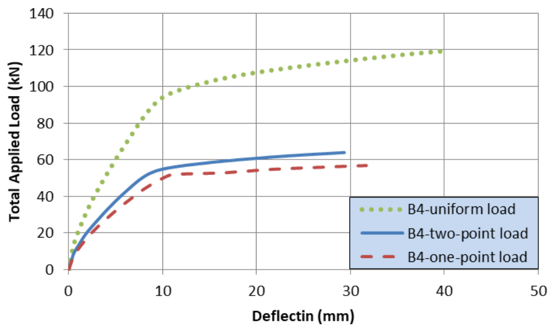


Fig. 26 Effect of load type on the behavior of two spliced smooth bars beams

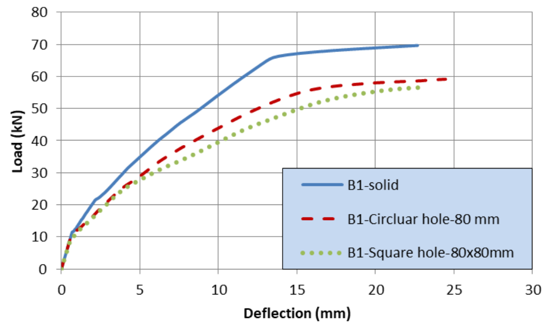


Fig. 27 Effect of hole shape on the behavior of single spliced deformed bars beams

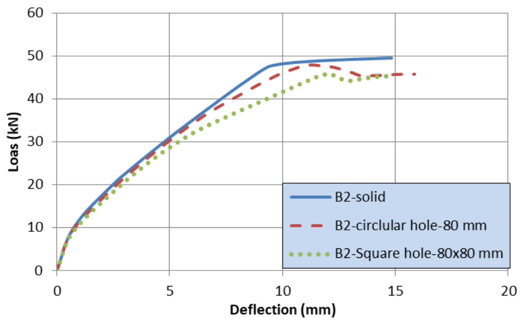


Fig. 28 Effect of hole shape on the behavior of single spliced smooth bars beams

in all beams (smooth and deformed).

For the case of deformed beams, the ultimate deflection in case of uniformly distributed beams was increased by 150% as in Fig. 23 (single splice). While this increase was less in case of two splice (110%)

3.2.3 Effect of the hollow shape.

The third parameter were used in this study was an opening along the beam. Same beams were selected except that the cross section is assumed hollow with square or circular hole along the beam length with equal size. Figs. 27 to 30 illustrate the effect of hole shape in cross section on load deflection behavior of spliced bars specimen. Fig. 26. and Fig. 28. show that, beams with soled section hold 115% more ductility than the hollow beams and once the hollow area increase the ductility decrease and it was noticeable in two splice beams. Whereas in case of beams smooth reinforcement (Figs. 28 and 30), hole in beam cross-section

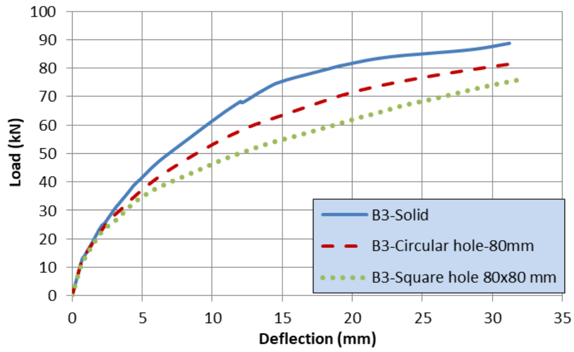


Fig. 29 Effect of hole shape on the behavior of two spliced deformed bars beams

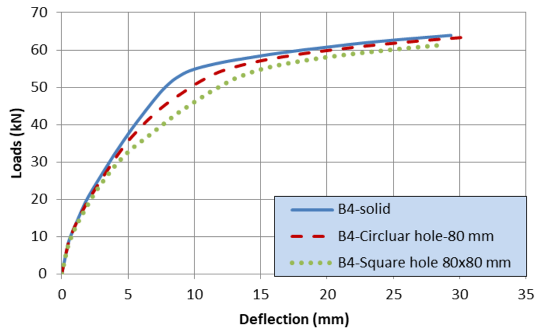


Fig. 30 Effect of hole shape on the behavior of two spliced smooth bars beams

does not have a significant effects on the behaviour

4. Conclusions

Seven reinforced concrete beams were used to investigate the flexural behaviour of tension lap spliced members. Comparisons were made between the experimental results and the nonlinear finite element data. Parametric studies were adopted to get a better understand of the flexural behaviour of tension lap spliced members under certain conditions. This study immerged the following the main conclusions:

- The laboratory and numerical results show good agreements in terms of ultimate load and deflection with an average difference of 10% and 15% in ultimate load and deflection respectively.
- The ratio of the cracking load capacity to the ultimate one of the tested beams ranged from 0.29 to 0.42. While the ratio of cracking deflection to the ultimate one ranged from 0.13 to 0.21 for the same tested beams. These variations depend on the spliced bars numbers and the nature of bars surface (smooth or deformed)
- The effect of number of spliced bars on the load deflection behavior for beams reinforced with deformed bars is studied. It can be seen that, all beams have same behaviour till they reached first crack then beams having lower number of splices show higher stiffness. This could be explained by the weakness in tension reinforcement which is lap spliced in the constant moment zone. Also, the ultimate load is increased with

the decrease in the number of the splices and this due to the slip between spliced bars.

• For beams reinforced with smooth bars, the load deflection behaviours were similar for all tested beams with smooth bars until loads 20 kN (39% of ultimate load). After that, the bar slip and spliced slip occur and the one spliced bar specimen shows more ductile behaviour than the others.

• The effect of bars surface nature (deformed or smooth) accompanied with splice is studied. The spliced deformed bars beams show higher initial stiffness than spliced smooth bars regardless of number of spliced bars. it can be seen that all beams have the comparable cracking load. After beams visible crakes appear, the beams having deformed bar get more stiffness and load carrying capacity than the smooth bars. That is because the bound between the concrete and deformed bars is higher than that of smooth bars

• The effect of number of spliced bars on ultimate loads is found to be small for deformed bars beams (3%) and more significant for smooth bars (9%). The effect of bar surface on ultimate load is found to be larger (27-31%), the larger percentage is for the three bar spliced.

• The effect of number of spliced bars on ultimate deflections is found to be smaller for deformed bars beams (5%) and larger for smooth bars (15%). The effect of bar surface on ultimate load is found to be in the range of (15-25%), the larger percentage is for the three bar spliced.

• The effect of number of spliced bars on energy absorbed for the tested beams is studied. For deformed bars, as the number of splice bars increased from 1 to 3 the energy absorbed decreases by 17%. This means that the one spliced deformed bar beam is the more ductile specimen. For the smooth bars, if the number of spliced bars increased from 1 to 3, the energy absorbed decreases by 26%. This means that the one spliced bar beam is the more ductile specimen for this case. The spliced deformed bars beam has an absorbed energy greater than the smooth one by (44-51%), the larger difference is obtained for the case of three spliced bars beam.

• If the concrete compressive strength was varied (25, 38 and 55 MPa) in finite elements for the spliced bars specimen, the failure load enlarged while the ultimate deflection reduced and therefore flexural ductility reduced for most members. Except for single spliced deform bars, the 55 MPa compressive strength beam shows ductile behavior and the 25 MPa compressive strength beam shows brittle one.

• If the type of loading was changed from two point loads to distributed load and to single point load at mid span in finite elements, the ultimate load and deflection were increased for case of distributed one and therefore ductility increased.

• If the cross section of the beam is assumed hollow with square or circular hole along the beam length with equal size of 80 mm in finite elements, the ultimate load and deflection were decreased. Similar behaviors were obtained in comparison to the solid section beams. The circular hollow section is the most preferred hollow shape in this study.

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