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Experimental study on beam due to effect of coupling, lapping and welding in reinforcement

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Abstract

Manufacturing, fabrication, and transportation limitations make it impossible to provide full length continuous bars in some reinforced concrete structures. In general, reinforcing bars are stocked by suppliers in lengths of 12–18 m. For that reason, and because it is often more convenient to work with shorter bar lengths, it is frequently necessary to splice bars in the field.

Proper splicing of reinforcing bars is crucial to the integrity of reinforced concrete. ACI Code states: ‘‘splices of reinfor cement shall be made only as required or permitted on the design drawings, in the specifications, or as authorized by the engineer.’’ Great responsibility for design, specification, and performance of splices rests with the engineer who is familiar with the structural analysis and design stre sses, probable construction conditions and final conditions of service can properly evaluate the variables to select the mos t efficient and economical splice method.

Lap splicing, which requires the overlapping of two parallel bars, has long been accepted as an effective, economical splicin g method. In projects with smaller bar sizes such as f19 mm and smaller, lap splices have performed well over the long run. Continuing research, more demanding designs in concrete, new materials and the development of hybrid concrete/structural steel design have forced desig ners to consider alternatives to lap splicing such as welded splices. In this study, welding ,coupling is explored as an alternative to the traditional splicing methods.

Keywords: Welded splices; Reinforcing bars; Experimental

1. Introduction

There are three methods used for splicing reinforcing bars:, lap splicing, mechanical connections, and welded splices. Of the three, lap splicing is the most common and usually the least expensive. However, codes frequently require such long laps that steel becomes congested at splice location; sometimes the laps are truly impossible for lack of room. Location of construction joints, provision for future construction or a particular method of construction can also make lap splices impractical. In addition, ACI Code [2] does not permit lap splices of larger than f35 mm. Also of the three, mechanical connections are the most uncommon and expensive. Mechanical connections are made with proprietary splice devices. Performance information and test data should be secured directly from manu- facturers of the splice devices. It is the responsibility of the design engineer to indicate what types of splices are permissible, as well as their location and any special end preparation needed for the bars.

The objective of this study is to determine first the weld strength and then the weld length needed to satisfy the requirements of ACI Code about welded splices, in addition to the basic welding requirements given in AWS D1.4 [1], ‘‘Structural Welding Code-Reinforcing Steel’’, such as base metal, carbon equivalent, preheat and interpass temperature, structural details, workman- ship, welding process, etc.The effect of welding current on the tensileproperties of low carbon steel welded joint was investigated in this research. In this work mild steel plates were joined byshielded metal arc welding process which is also known asmanual metal arc welding used to examine optimum welding current. The welded samples were cut and machined to standardconfigurations for tensile tests. It was concluded that variation of current affect the tensile properties of the low carbon steel welded joint. As the current increases from 80A to 110A,the ultimate tensile strengths and yeild strength increases. The percentage elongation decreases with increase in welding current but increases at the welding current of 110A.

Steel structures are widely adopted in the constructionindustry due to their excellent mechanical performance, effective prefabrication, and rapid assembly. To date, retrofitting existing steel structures is commonly necessaryfor practice when they are required to resist loadsbeyond their designed capacity [1]. Within this field, one of the critical issues is to retrofit weak beam-to-column joints. The beam-to-column joint is a critical part of steel frames because itsfailure may lead to a significant loss of flexural rigidity andstrength of structures. The panel zone, defined as the columnweb area surrounded by the column flanges and the extension ofbeam flanges , is a vital component to resist complex loads .

2. Base metal

According to AWS D1.4., reinforcing steel base metal shall confirm to the following requirements.

2.1. Weldability

When the subject of welded reinforcing bars is discussed, the term of weldability is often mentioned; a metallurgist defines weldability in terms of the chemical composition of the steel; his measure is carbon equivalent content. A structural engineer probably thinks of weldability in terms of the strength achieved at a splice, while a welder or contractor considers it in terms of cost, welding method required and amount of preheat. The American Welding Society code, AWS, defines weldability as ‘‘the capacity of a metal to be welded under the fabrication conditions imposed into a specific suitably designed structure and to perform satisfactorily in the intended service.’’

Source of reinforcing bars

The reinforcing bars used in this study are manufactured at Consolidated Steel Lebanon, CSL, in Amchit, Lebanon. They are designed according to International Organization of Standardization [4], ISO 6935-2. This part of ISO 6935 specifies technical requirements for ribbed bars designed for reinforcing in ordinary concrete structures and for non-prestressed reinforcement in prestressed concrete structures.

Grade and dimensions

The reinforcing steel base metal used is of grade RB 500W, which are readily welded by conventional welding procedures: AWS D1.4-92. This reinforcing steel base metal also confirms to the requirements of ASTM [3] specifications A615/A615M, *Specification of Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*, of grade 400, which is approved by the ‘‘Structural Welding Code—Reinforcing Steel’’ (AWS D1.4-section 1.3). The dimensions of bars used are f12, 14, and 16 mm.

Chemical composition

According to the AWS D1.4-92: ‘‘All steel bars, except those designated as ASTM A706, the carbon equivalent shall be calculated using the chemical composition, as shown in the mill test report, by the following formula:

CE ¼ %C þ %Mn=6.

Since the standard rebar specifications ASTM A615/ A615M specifically state that ‘‘weldability of the steel is not part of this specification’’, there are no limits on the chemical elements included in the CE (the CE would typically exceed 0.55% for these bars). Therefore, the chemical composition is only provided upon request.

ISO 6935-2 states that the steel used for RB 500W, shall not contain quantities of the given elements higher than those specified in Table 1.

Table 1
Chemical composition—maximum values in percentage by mass

Steel grade	C	Si	Mn	P	S	N
RB 500W	0.24	0.65	1.7	0.055	0.055	0.013

Based on the above, the maximum value of carbon equivalent is:

CE ¼ %C þ %Mn=6,

CE ¼ 0:24 þ 1:7=6,

CE ¼ 0:523%.

3. Code requirements for welded splices

Splices in reinforcement at the point of maximumstress should be avoided, and when splices are used theyshould be staggered although neither condition is practical. According to ACI Code 12.14.3.3: ‘‘A full welded splice shall have bars butted and welded to develop in tension at least 125% of specified yield strength f_y of the bar.’’ The tensile strength requirementsof 125% of specified yield will insure sound welding. The maximum reinforcement stress used in design under the code is the yield strength. To insure sufficient strength insplices so that yielding can be achieved in a member and thus brittle failure avoided, the 25% increase above the specified yield strength was selected as both an adequateminimum for safety and a practicable maximum for economy. For tension splices where the area of the bar istwice that required by structural analysis, the splices can be designed for less than 125% of the specified yield strength.

AWS states that: ‘‘welded lap joints shall be limited to bar size 19 mm and smaller and lap joints made with double-flare-V-groove welds would be preferred, except that single-flare-V-groove welds may be used when the joint is accessible from one side only, and approved by the engineer, as the case done in this study.

4. Structural details

The AWS D1.4 code includes many types of welded splices. The reinforcing bars may be welded with direct or indirect butt joint, lap joints, or T-joints. Every type is suitable for specific projects, welding processes, field conditions, and bar diameters. For example, direct butt joints are preferable for bars greater than 19 mm, and welded lap joints shall be limited to bar size 19 mm and smaller. The types of joints and welds used in the project are described below

Joint type

The joint type used in the project are *full weldeddirect lap joints* with bars in contact. The lap joint is made with single-flare-V-groove welds, as shown in Fig. 1.

Effective weld areas, lengths, and sizes

- The effective weld area of flare-V-groove welds shall be the effective weld length multiplied by the effective weld size.
- The minimum effective weld length shall not be less than 2 times the bar diameter.
- The effective weld size for flare-V-groove welds shall be 0.6 of the bar radius *S* (Fig. 2).

5. Welding process

According to AWS D1.4, any welding process may be used when approved by the engineer, provided that any special qualification test requirements are met to ensure that welds satisfactory for the intended application will be obtained. Electrical welding process (Fig. 3) is utilized in this study, because it is commonly used in

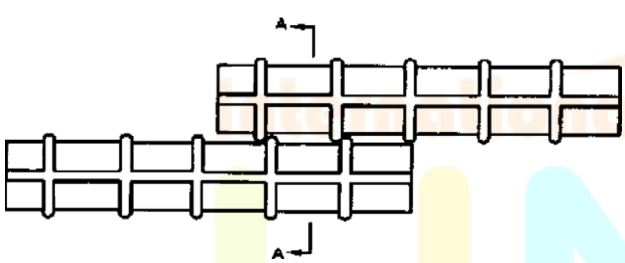

Fig. 1. Direct lap joint.

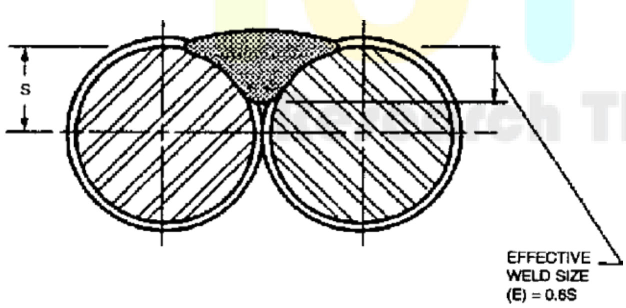

Fig. 2. Effective weld size for flare-V-groove welds.

Fig. 3. Electrical welding.

Lebanon and its cost (labor and electrodes) is not expensive. The electrodes for electrical welding used, are ‘‘Permanent Brand Welding Electrodes’’ of +2 ~ 300 mm.

6. Workmanship

Preparation of base metal

Surfaces to be welded shall be free from fins, tears, cracks, or other defects that would adversely affect the quality or strength of weld. Surfaces to be welded, and surface adjacent to a weld, shall also be free from loose or thick scale, slag, rust, moisture, grease, epoxy coating, or other foreign material that would prevent proper welding or produce objectionable fumes.

Control of heat

When welding is performed on bars or other structural components that are already embedded in concrete, allowance shall be made for thermal expansion of the steel to prevent sapling or cracking of the concrete or significant destruction of the bond between the concrete and the steel. The heat of welding may cause localized damage to the concrete.

Quality of welds

Welds that do not meet the following quality requirements shall be repaired by removal of unaccep-table portions or by rewelding, whichever is applicable:

- Welds shall have no cracks in either the weld metal or heat-affected zone.
- There shall be completed fusion between weld metal and base metal and between successive passes in the weld.
- All craters shall be filled to the full cross section of the weld.
- Welds shall be free from overlap

7. Minimum preheat and interpass temperature requirements

Minimum preheat and interpass temperature shall be in accordance with the carbon equivalent and the size of base metal. Since the standard rebar specification ASTM A615/615M has no limit on the CE (chemical equivalent) the minimum temperature varies as in Table 2.

In cases when the base metal is below 0 1C, thebase metal shall be preheated to at least 20 1C, or above, and maintained at this minimum temperature during welding.

According to the Mill test report given from the manufacturer of the base metal (CSL), CE is equal to 0.523. Therefore, from Table 3 for bar sizes up to 19 mm, a specified temperature is not required.

The American Welding Society states that welding shall not be done when the ambient temperature is lower than 18__1C. When the base metal is below the temperature listed for the welding process being used and the size and carbon equivalent range of the bar being welded, it shall be preheated (except as otherwise provided) in such a manner that the cross section of the bar for not less than 150 mm on each side of the joint shall be at or above the specified minimum temperature. Preheat and interpass temperature shall be sufficient to prevent crack formation. Also, after welding is complete, bars shall be allowed to cool naturally to ambient temperature. Accelerated cooling is prohibited. Finally, when it is impractical to obtain chemical analysis, the carbon equivalent shall be assumed to be above 0.75%.

Table 2
Minimum preheat and interpass temperature

CE range (%)	Size of base metal (mm)	Min. temp (1C)
Up to 0.40	Up to 36	None[1]
	43–57	10
0.40–0.45	Up to 36	None[1]
	43–57	40
0.45–0.55	Up to 19	None[1]
	22–36	10
	43–57	90
0.55–0.65	Up to 19	40
	22–36	90
	43–57	150
0.65–0.75	Up to 19	150
	22–57	200
Over 0.75	22–57	260

When the base metal is below 0 1C, the base metal shall be preheated toat least 20 1C, or above, and maintained at this minimum temperature during welding.

8. Testing the materials

The ‘‘Consolidated Steel Lebanon’’ manufacturer certifies that all ribbed reinforcing bars, manufactured at the factory in Amchit-Lebanon, fully confirm to (‘‘meet or exceed’’) the below-mentioned quality stan- dards.

According to ISO 6935:

- At least 95% of the population under consideration shall have tensile properties equal to or above the characteristic values specified.
- No single result shall be less than 95% of the characteristic value given in the preceding table.
- The values in the preceding table may be used as guaranteed minimum values.
- The ratio of tensile strength to yield stress specimen shall be at least 1.05.

In accordance with civil engineering philosophy, all materials must be tested to determine their actual properties. Yield and tensile strength of base metal are the major concerning properties in the project; tension tests are performed in the laboratory at the Lebanese American University. Three bars of each diameter (12, 14, and 16 mm) and of length 60 cm are selected randomly for testing. Tests are done according to ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products.

The yielding point is determined experimentally when the increase in load stops or hesitates. The ultimate tensile strength is calculated by dividing the maximum load the specimen sustains during a tension test by the original cross-sectional area of the specimen (Figs. 4 and 5).

The results of the tension test are shown in Table 4. If a comparison is done between the results of the tension tests (Table 4) and the requirements of ISO or ASTM (Table 3), it can be seen that the materials fully confirm to these requirements (Table 5).

Table 3
Characteristic values for yield stress, tensile strength, and ratio

Country	Standard	Norm	Grade	Yield (MPa)	Tensile (MPa)	Ratio (tensile/yield)
International	ISO	6935-2	RB 500W	500	550	1.05
USA	ASTM	A615M	400	400	600	n/a

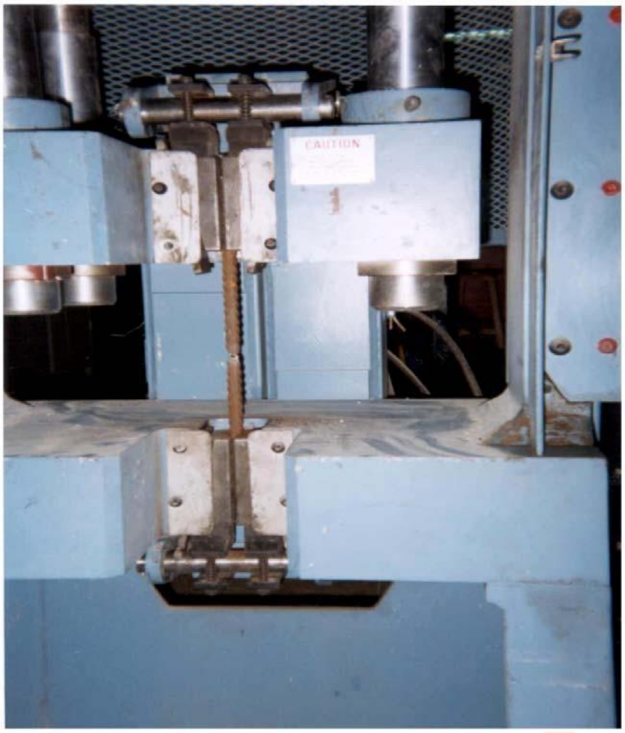

Fig. 4. Tension test of a single bar.

Fig. 5. Overloaded bar

Table 4
Yield and tensile strength of base metal

Test #	Diameter (mm)	Yield point (kg)	Maximum load (kg)	Yielding stress (MPa)	Tensile strength (MPa)
1	12	6236	7276	552	644
2	12	6227	7280	551	644
3	12	6223	7271	550	643
Mean (average)	12	6229	7276	551	644
1	14	8064	9733	523	632
2	14	8154	9729	529	632
3	14	8131	9740	528	632
Mean (average)	14	8116	9734	527	632
1	16	10931	13005	543	647
2	16	10752	13001	535	647
3	16	10819	12992	538	646
Mean (average)	16	10834	12999	539	646

9. Weld strength

As specified previously, one of the purposes of this study is to determine the acceptable weld length so that the welded bars can carry the maximum sustainable unwelded bar load.

In order to determine the weld strength, the following procedure is applied:

1. Join two bars, having the same diameter, of 40 cm length each with a direct lap joint with bars in contact, in a way to have a total length of 60 cm.
2. The lap joint shall be made with single-flare-V-groove welds of a weld length varying between 5 and 10 cm.
3. Measure exactly the weld length.
4. Apply a load at a constant rate by using the tension-testing machine.
5. Record the load at which the welds fail.
6. Calculate the weld strength by dividing the load in step 5 by the effective weld area.
7. Repeat this procedure 3 times (Figs. 6–8).

All data and values are tabulated in Table 6.

A safety provision should be applied to weld strength by utilizing strength reduction factors, +, which may

Table 5
Test results

Standard	ASTM A-615M 400 (min)	ISO 6935-2 RB-500W (min)	Diameter (mm)		
Grade			12	14	16
Yield, MPa	400	500	551	527	539
Tensile, MPa	600	550	644	632	646
Ratio, tensile:yield	n/a	1.05	1.17	1.13	1.20

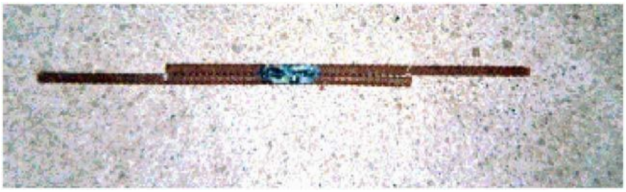

Fig. 6. Single flare-V-groove weld for 8 cm weld length.

Fig. 7. Testing of weld strength.

vary from 0.70 to 0.90, to follow ACI philosophy. Therefore, a strength reduction factor of 0.7 should be applied to the minimum weld strength obtained. From the preceding table, the minimum weld strength is equal to 1671 kg/cm^2. By using a reduction factor of 0.7, the effective weld strength becomes 1170 kg/cm^2.

10. Weld length

As stated before, ‘‘in a full welded splice the bars have to be butted and the splice must develop at least 125% of the specified yield strength of the bar.’’ Table 4 contains the calculated 125% of the specified yield strength for every bar diameter (Table 7).

The effective weld length is then calculated by dividing the 125% of the average yield point by the

Fig. 8. Failure of weld.

weld strength and the specified weld size:

125% of yield strength ðkgÞ ¼ weld strength ðkg=cm^{2}Þ
~ weld size ðcmÞ
~ weld length ðcmÞ.

The effective weld length for every bar diameter is tabulated in Table 8. From Table 8, we can conclude that the effective weld length determined is proportional to the bar size. As the bar diameter increases by 2 mm, a 3 cm more of splice must be welded. By plotting the effective weld length versus the bar diameter, it can be seen that the graph is a straight line of slope equal to 1.5 (Fig. 9):

effective weld length ðcmÞ ¼ 1:5 ~ bar diameter ðmmÞ.

Table 9 shows the effective weld length and size for bar sizes less than 19 mm.

11. Testing the effective weld length

In order to ensure that an overloaded spliced bar would fail by ductile yield in the region away from the splice, the procedure below is followed:

1. Join two bars, having the same diameter, of 45 cm length each with a direct lap joint with bars in

Table 6
Weld strength

Test #	Diameter (mm)	Weld length (cm)	Effective weld size (cm)	Effective weld area (cm^2)	Maximum load (kg)	Weld strength (kg/cm^2)
1	12	6	0.36	2.16	3772	1746
2	12	6	0.36	2.16	3700	1713
3	12	5	0.36	1.8	2796	1553
Mean (average) of ϕ12 mm						1671
1	14	7	0.42	2.94	5179	1762
2	14	8	0.42	3.36	5515	1641
3	14	6	0.42	2.52	4547	1804
Mean (average) of ϕ14 mm						1736
1	16	6	0.48	2.88	5022	1744
2	16	7	0.48	3.36	5833	1736
3	16	6	0.48	2.88	4883	1696
Mean (average) of ϕ16 mm						1725

Table 7
Design stress

Bar diameter (mm)	Average yield strength (MPa)	125% of yield (MPa)	Average yield point (kg)	125% of yield (kg)
12	551	689	6229	7786
14	527	659	8116	10145
16	539	674	10834	13543

Table 8
Effective weld length for ϕ12, 14, and 16

Bar diameter (mm)	125% of yield strength (kg)	Weld strength (kg/cm^2)	Weld size (cm)	Effective weld length (cm)
12	7786	1170	0.36	18
14	10145	1170	0.42	21
16	13543	1170	0.48	24

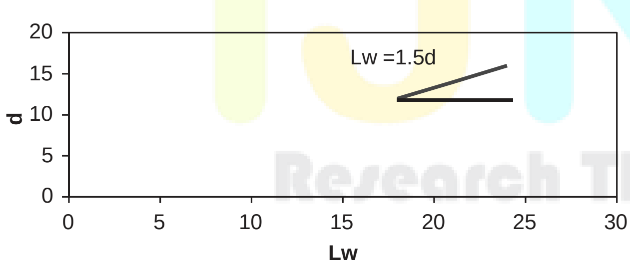

Fig. 9. Effective weld length (cm) vs. bar diameter (mm).

contact, in a way to have lap length equal to the effective weld length.
2. The lap joint shall be made with single-flare-V-groove welds.

Table 9
Effective weld length for bars less than 19 mm

Bar diameter (mm)	Weld size (cm)	Effective weld length (cm)
6	0.18	9
8	0.24	12
10	0.3	15
12	0.36	18
14	0.42	21
16	0.48	24
18	0.54	27

3. Apply a load at a constant rate by using the tension-testing machine.
4. Check that the overloaded spliced bars fail in the region away from the splice, rather than at weld.
5. Repeat this procedure 3 times.

The tests are done for the three different bar diameters 12, 14, and 16 mm. The results show that the overloaded spliced bars fail at a region away from the welded splice. The results of the tension test are shown in Table 10 (Figs. 10–12).

12. Lap splices in tension

The required length of lap for tension splices, established by the test, may be stated in terms of the development length L_d. In the process of calculating L_d the usual modification factors are applied except that the reduction factor for excess reinforcement should not be applied because that factor is already accounted for in the splice specification.

Table 10
Results of weld length tests

Bar diameter (mm)	Force at failure (kg)	Stress at failure (kg/cm^2)
12	7473	6613
12	7388	6538
12	7571	6700
14	9574	6217
14	9184	5964
14	9220	5987
16	12947	6441
16	13037	6486
16	13019	6477

Fig. 10. Welded lap joint.

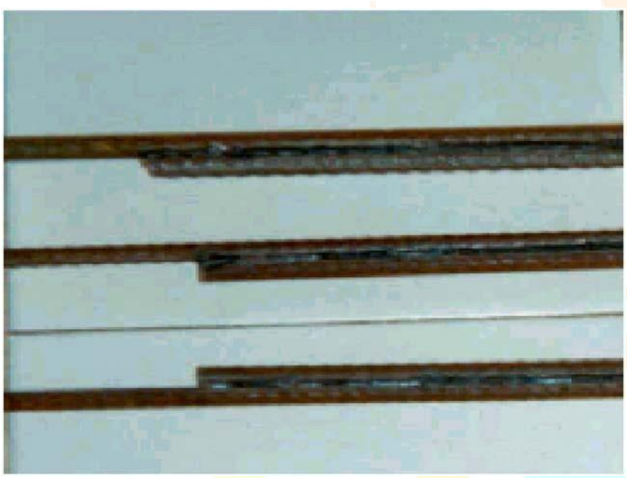

Fig. 11. Welded splices of ⌀12, 14, and 16.

Therefore, according to ACI Code 12.2.2, for deformed bars and deformed wire of 19 mm diameter and smaller, L_d/d_b shall be:

1. Clear spacing of bars being developed or spliced not less than d_b, clear cover not less than d_b, and stirrups or ties throughout L_d not less than the code minimum or clear spacing of bars being developed or spliced not less than 2 db and clear cover not less than d_b: (*case* 1):

$$\frac{L_d}{d_b} = \frac{12 f_y \alpha\beta\lambda}{25\sqrt{f'_c}}.$$

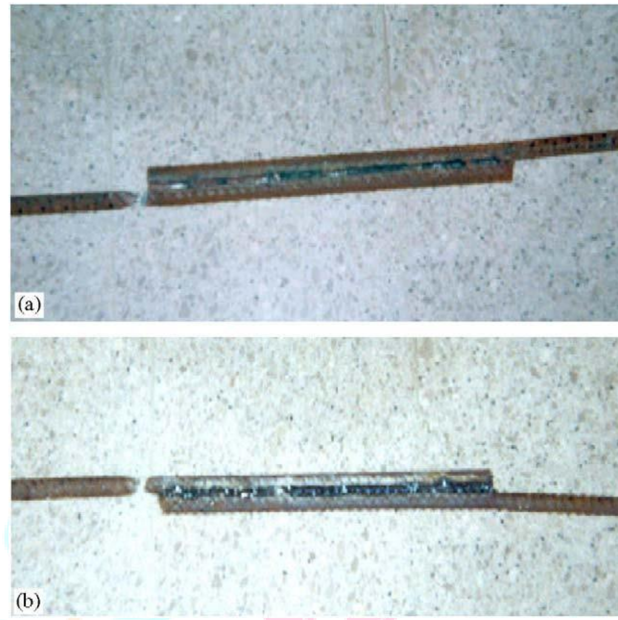

Fig. 12. (a) Failure by yield away from the splice, (b) failure of steel.

2. Other cases: (*case* 2):

$$\frac{L_d}{d_b} = \frac{18 f_y \alpha\beta\lambda}{25\sqrt{f'_c}},$$

where L_d is the required development length, d_b the bar diameter, f_y the specified yield strength of reinforcing bars, f'_c the specified compressive strength of concrete, a the reinforcement location factor, b the coating factor, and l the lightweight aggregate concrete factor.

Two different classifications of lap splices are established corresponding to the minimum length of lap required: a Class A splice requires a lap of $1.0L_d$, and a Class B splice requires a lap of $1.3L_d$. In either case, a minimum length of 30 cm applies. Lap splices, in general, must be Class B splices, according to ACI Code 12.15.2, except that Class A splices are allowed when the area of reinforcement provided is at least twice that required by analysis over the entire length of the splice and when one-half or less of the total reinforcement is spliced within the required lap length. The effect of these requirements is to encourage designers to locate splices away from the regions of maximum stress, to a location where the actual steel area is at least twice that required by analysis and to stagger splices.

Calculation of the required length of lap splices

The factors for use in the expressions of development length are defined according to ACI Code 12.2.4 as the following:

a ¼ 1:3 for ‘‘top’’ bars.

a ¼ 1:0 for ‘‘other’’ bars.

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b ¼ 1:0 for uncoated bars.
b ¼ 1:5 for epoxy-coated bars with concrete cover o3 d_b, or clear spacing o6 d_b.
b ¼ 1:2 for other concrete covers and clear spacing conditions of epoxy-coated bars.

The product of ab need not be taken greater than 1.7.

l ¼ 1:3 for lightweight aggregate concrete.
l ¼ 1:0 for normal-weight concrete.

Tabular values

The following tables give values of the development length, L_d, based on normal-weight concrete for uncoated reinforcing bars.

For case 1:

$$L_d \text{ ¼ } \frac{12 f_y abl \sim d_b}{25 \sqrt{f^0_c}}.$$

Notes:

1. Lengths are in centimeters.
2. Lap splice lengths are multiples of tension development lengths: Class A—1.0 L_d and Class B—1.3 L_d.
3. Top bars are horizontal bars with more than 30 cm of concrete cast below the bars.
4. For lightweight aggregate concrete, multiply the tabulated values by 1.3.

For case 2 (Table 12):

$$L_d \text{ ¼ } \frac{18 f_y abl \sim d_b}{25 \sqrt{f^0_c}}.$$

Welded vs. lap splicecostNotes:

1. Lengths are in centimeters.
2. Lap splice lengths are multiples of tension development lengths: Class A—1.0 L_d and Class B—1.3 L_d.
3. Top bars are horizontal bars with more than 30 cm of concrete cast below the bars.
4. For lightweight aggregate concrete, multiply the tabulated values by 1.3.

13. Welded vs. lap splicing

For many years the traditional method of connecting reinforcing bars has been with lap splicing. Some engineers and specifiers licensed that ‘‘The traditional lap splice is generally the most economical splice and welded splices generally require the most expensive field labor.’’ But as I have discovered, lap splicing has very few advantages and quite a few disadvantages when compared to welded direct lap joint.

13.1. Welded vs. lap splice length

For the comparison between these two methods of splicing, the same conditions applied in the determination of weld length must be used in the calculation of development length. These conditions are:

1. Area of reinforcement provided at splice is less than twice that required by analysis (Class B splices).
2. Using uncoated bars.
3. Using steel of grade 400.

Other factors that affecting development lengths are assumed in a way to reduce the value of lap splice lengths. These factors are:

1. Case 1 (see section XII-1).
2. Compressive strength of concrete is equal to 28 MPa.
3. Other than the top bars.
4. Normal-weight concrete.

Note: Except the Class B splices condition, the variables based on allow for shorter development lengths; see Table 11. Therefore, we compare the minimum lengths in lap splices with the required weld lengths in welded splices (Tables 12 and 13).

From Tables 9 and 11:

1. From the preceding table we can determine lap splice length as function of bar diameter based on the conditions and factors stated before L_d ¼ 4:9 ~ d_b.
2. In welded splicing less rebar is used: L_w ¼ 1:5 ~ d_b.

Cost of welded splices

The total cost of welded splice is the cost of weld in addition to the cost of steel for lap length.

Weld cost. Two weld contractors that were questioned on the cost of welds gave approximately the same prices. According to them, the weld cost consists of the cost of labor and the cost of electrodes as the following.

One package of ‘‘Permanent Brand Welding Electrodes’’ of ∔2.0 ~ 300 mm costs 3 dollars and able to weld:

1. For ∔12 bars, 15 m length.
2. For ∔14 bars, 14 m length.
3. For ∔16 bars, 13 m length.

The labor cost for welding one package of electrodes is approximately 18 dollars (including the cost of electricity) (Table 14).

The costs of welds for the required weld length for bars of ∔12, 14, and 16 are given in Table 15.

Table 11
Tension development and lap splice lengths

Normal-weight concrete F_y ¼ 4200 kg=cm^2		f_c^0 ¼ 210 kg=cm^2 Uncoated		f_c^0 ¼ 245 kg=cm^2 Uncoated		f_c^0 ¼ 280 kg=cm^2 Uncoated	
		Top	Other	Top	Other	Top	Other
+6	Class A	34	30	32	30	30	30
	Class B	45	39	41	39	39	39
+8	Class A	46	35	42	33	40	30
	Class B	59	46	55	42	52	40
+10	Class A	57	44	53	41	50	38
	Class B	74	57	69	53	64	50
+12	Class A	69	53	64	49	59	46
	Class B	89	69	83	64	77	59
+14	Class A	80	62	74	57	69	53
	Class B	104	80	96	74	90	69
+16	Class A	92	70	85	65	79	61
	Class B	119	92	110	85	103	79
+18	Class A	103	79	95	73	89	69
	Class B	134	103	124	95	116	89

Table 12
Tension development and lap splice lengths

Normal-weight concrete F_y ¼ 4200 kg=cm^2		f_c^0 ¼ 210 kg=cm^2 Uncoated		f_c^0 ¼ 245 kg=cm^2 Uncoated		f_c^0 ¼ 280 kg=cm^2 Uncoated	
		Top	Other	Top	Other	Top	Other
+6	Class A	51	39	48	36	45	34
	Class B	68	51	62	48	59	45
+8	Class A	69	53	63	50	60	45
	Class B	89	69	83	63	78	60
+10	Class A	86	66	80	62	75	57
	Class B	111	86	104	80	96	75
+12	Class A	104	80	96	74	89	69
	Class B	134	104	125	96	116	89
+14	Class A	120	93	111	86	104	80
	Class B	156	120	144	111	135	104
+16	Class A	138	105	128	98	119	92
	Class B	179	138	165	128	155	119
+18	Class A	155	119	143	110	134	104
	Class B	201	155	186	143	174	134

Table 13
Lap splice length vs welded splice length

Bar diameter (mm)	Lap splice length (cm)	Welded splice length (cm)
12	59	18
14	69	21
16	79	24

Table 14
Unit weld cost

Bar diameter (mm)	Weld length (m)	Labor cost ($)	Electrodes cost ($)	Unitweldcost ($/m$_{Length}$)
12	15	18	3	1.40
14	14	18	3	1.50
16	13	18	3	1.62

Table 15
Total weld cost

Bar diameter (mm)	Required weld length (cm)	Unit weld cost ($/m$_{Length}$)	Total weld cost ($)
12	18	1.40	0.25
14	21	1.50	0.32
16	24	1.62	0.39

Cost of steel for welded splices. According to ‘‘Consolidated Steel Lebanon’’, CSL (Steel Factory—Amchit), the cost of reinforcing bars is equal to 0.27 dollars per kg (RB 500W and RB 500

Table 16
Steel cost for welded splices

Bar diameter (mm)	Lap length (m)	Weight (kg)	Steel cost ($)
12	0.36	0.34	0.09
14	0.42	0.51	0.14
16	0.48	0.76	0.20

Table 17
Total cost of welded splices

Bar diameter (mm)	Weld cost ($)	Steel cost ($)	Total cost of welded splices ($)
12	0.25	0.09	0.34
14	0.32	0.14	0.45
16	0.39	0.20	0.59

Table 18
Total cost of lap splicing

Bar diameter (mm)	Lap length (m)	Weight (kg)	Total cost of lap splicing ($)
12	1.18	1.05	0.28
14	1.38	1.67	0.45
16	1.58	2.49	0.67

have the same price) and the weights of steel per unit length are:

- For ∔12, 0.887 kg/m_{Length}.
- For ∔14, 1.208 kg/m_{Length}.
- For ∔16, 1.578 kg/m_{Length}.

All calculations are tabulated in Table 16.

Note: Lap length is equal to double the effective weld length.

The total costs of welded splices are given in Table 17.

13.2.2. Cost of lap splicing

Lap splicing cost consists only of the steel cost for lap splices. Labor costs for installing lap splices are not counted because they are negligible.

Therefore, the cost of lap splicing is as shown in Table 18.

Notes:

1. Lap length is equal to double the lap splice length.
2. Weights of steel are: 0.887 kg/m_{Length} for ∔12, 1.208 Kg/m_{Length} for ∔14, 1.578 kg/m_{Length} for ∔16.
3. Cost of steel is 0.27 $/kg.

Table 19
Cost of welded vs lap splices

Bar diameter (mm)	Total cost of welded splices ($)	Total cost of lap splices ($)
12	0.34	0.28
14	0.45	0.45
16	0.59	0.67

13.2.3. Conclusions

According to the preceding table, for bars less than 14 mm diameter, lap splicing is more economical than welded splices. For bars greater than 14 mm diameter, welded splices are economical (Table 19).

Since our comparison on costs is based on the minimum values for development length in class B splices condition, we can conclude that lap splicing is not the most economical method.

Even in some cases and conditions when lap splicing may be economical, there exist many cases such as higher yield stress of steel (higher than 420 MPa), lower concrete strength (lower than 28 MPa), larger bar diameter (18 mm), splices of bundled bars, case 2 etc., in which the welded splicing method is more economical than lap splices.

Lap splicing	Welded splicing
Lap splicing double the number of bars leading to rebar congestion.	Welded splicing reduces rebar congestion.
Lap splicing inhibits concrete consolidation.	Welded splicing improves concrete consolidation.
The larger the bar, the longer the lap	Welded splicing eliminates lap splices in high stress regions.
The lower the concrete strength, the long the lap length required.	Requires special skills and codes (AWS).
Lap splices develop strength from interaction with concrete.	Splice strength developed independent of concrete.
The higher the yield stress, the greater the lap length required.	Provides significantly higher strength by design.
To prevent concrete splitting, additional rebar may be required.	Provides ductility independent of concrete condition.
Corrosion-resistant coated bars are expensive and longer lengths are used.	Accelerates construction schedules for optimal cost and efficiency.
Lap splicing involves time-consuming calculations, possible calculation mistakes.	Reduces material costs because less rebar is used.

14. Conclusions

Mechanical connections are seldom used in Lebanon because they are impractical. Traditional lap splicing techniques are unreliable (especially in flexure). This study suggests that welded splicing provides reliability, efficiency, and consistency that cannot be found with lap splicing. Therefore, welded splices can replace other methods of splicing.

References

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