Assessment on Tension Bar Lap Splices of Concrete Reinforcement Steel

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Abstract. Splicing rebar with lap splices must be done in its implementation due to the influence on the methods of implementation and the availability of existing reinforcing steel length. Lap splices length (ld) serves to channel the force borne by the steel reinforcement. Lap splices length testing conducted to determine the distribution of force occurs. The test specimen lap splice using a class B which is 1.3 ld with concrete covers at least 3 cm. By using an experimental study in which the use of reinforcing steel D-10 with a lap splices length of 1.3 ld by 43 cm, 1.2 ld by 40 cm using K-400 concrete and calculation analysis produces the lap splices length 27 cm and 30 cm use quality of concrete K-400 and K-450. Tests using the tensile test equipment (Universal Testing Machine) in laboratory B2TKS BPPT. Results from this study is the length of the lap splices of 1.3 ld and 1.2 ld use quality of concrete K-400 is able to meet the mechanical properties of reinforcing steel for the collapse occurred in the reinforcing steel. With lap splices length 27 cm and 30 cm using quality of concrete K-400 occur in lap splice collapse after passing the yield stress of reinforcing steel 40 kg/mm². While the lap splices length 27 cm and 30 cm using the quality of concrete K-450 collapse there are a difference between the test specimens due to the tension that occur closer to the ultimate stress of rebar’s at 57 kg / mm²

Keywords: Lap splices length, collapse evidence, Bond stress ratio.

1. Introduction

Reinforced structural elements without bar lap splices are more resistant to large loads than when given a lap splice [1], however limitations of steel reinforcement lengths available from the plant (generally 12 m), causing the construction actors to splice the reinforcement. The simplest and easiest way is to make a lap splice, which made overlap by a certain length is called the length of lap splice bar. Although there are already concrete code that require a minimum length of lap splices, practitioners in the field still want concrete proof whether the terms of this splice length are within the minimum or too secure in all situation Experimental studies related to the length of lap splice bar by [2], [3] and [4] are done through the study of flexible beams on a real scale considering the limited costs to be spend for the study. With limited data, that is one specimen for each reinforcing bar size (16 and 20 mm) with 42.5 concrete grade, Turk, K, 2008 get that as the diameter of the steel bar increased from 10 to 20 mm the bond strength decreased regardless of concrete type. The ratio of bond strength to the root value of concrete compressive strength are 0.93 for 16 mm bar size and 0.90 for 20 mm bar size.

The question is, is this Turk phenomenon can be generalized? For that reason, a study that examines the length of lap splices reinforcing bars through a tensile test by using the Universal Testing Machine
in the B2TKS BPPT laboratory on small specimens so that it can be carried out at test specimens with more quantities.

Through this research, it can be assessed whether the phenomenon that the greater the diameter of reinforcement then the ratio of bond strength to the root of the concrete compressive strength becomes smaller can be generalized.

2. Experimental Programme

Splices Length (ls) corresponds with development length (ld) that increases according to increased strength. In the design of a construction, the value of the tensile strength of the reinforcing steel plan employed used a value of tensile strength without connection. In the implementation, not all could be installed without a connection.

Splices consisted of 2 types, namely the class A splice \( ls = 1.0 \text{ ld} \) and class B splice \( ls = 1.3 \text{ ld} \).

![Figure 1. Class A and Class B Splice](image)

We expected to get the development of tensile strength of reinforcing steel from class B splices and to know the class B splices required to meet the tensile strength of the reinforcement tensile strength. This research used splices class B reinforced steel with BjTS 40 D-10 quality threaded steel and K-400 normal concrete quality.

2.1. Tensile Strength of Reinforcement Steel

In construction, reinforcing steel works as the retaining force. The tensile strength of reinforcement should be in line with the plan. As stated in SNI 2054:2014 “Baja Tulangan Beton”, BjTS 40 should meet the minimum of the molten strength of 40 kgf/mm² and the tensile strength of at least 57 kgf/mm².

2.2. Development and Splicing of Reinforcement

The tensile force on the reinforcement at each cross section of the reinforced concrete structure must be channeled on each side of its cross section through the splices length. The reinforce splices length varies depending on the diameter of the reinforcement used. It is expected that the reinforce splices length is capable to develope the force. The calculation of development length of reinforcement was taken from SNI 2847:2013 “Persyaratan Beton Struktural Untuk Bangunan Gedung”.

The splicing shall comply with the appropriate class requirements but not less than 300 mm. The terms of each connection class are as follows

- Class A splicing \( ls = 1.0 \text{ ld} \)
- Class B splicing \( ls = 1.3 \text{ ld} \)

The splice of deformed bar and wire in a tensile condition is a class B splicing, however class A splicing allowed only when:

a) The area of reinforcement provided at least twice as required by the analysis along the overall length of the splices; and

b) Half or less of total reinforcement spliced in required length of the code.

2.3. Tensile Strength Test of Reinforcement Steel

The specimen test was carried out by clamping one end and continuously withdrawing the other end of the test rod with a force that grows larger until it breaks in order to determine the value of its tensile strength. Implementation of tensile tests shall use tensile testing machines that clearly perform maximum load readings and shall be calibrated according to the applicable test machine calibration.
requirements. The determination of the tensile strength value is the division of the maximum load in kgf and the cross-sectional area in mm².

The research was done in 2 stages. In the first stage of the study, the lap splices length was designed at 1.3 ld and 1.2 ld. At the second stage, the lap splices was design less than 1.3 ld, but greater than 1.2 ld. Hammer test was performed for uniformity of concrete quality and tensile strength of reinforcement steel carried out in Serpong Technological Assessment and Technology Agency (BPPT). At each stage, force when the sample collapses is observed, and the location of the collapse, whether collapse occurs in steel or concrete.

3. Results and Discussion

3.1. Specimen Splices 1.3 ld and 1.2 ld (Stage 1)

According to Indonesian Building Code Requirements for Structural Concrete [5], the development length of rebar for concrete grade K-400 (f′c = 33.2 Mpa) and 10 mm diameter of deformed rebar is as follows

\[ ld = \frac{f_y \psi_t \psi_e}{2,1 \lambda \sqrt{f_c'}} \cdot db = \frac{400 \cdot 1 \cdot 1}{2,1 \cdot 1 \cdot \sqrt{33.2}} \cdot 10 = 330.6 \text{mm} \]

Then for:

a. Splices length 1.3 ld
   \[ ls = 1.3 \cdot 1.3 \cdot 330.6 = 429.7 \text{mm} = 43 \text{cm} \]

b. Splices length 1.2 ld
   \[ ls = 1.2 \cdot 1.2 \cdot 330.6 = 396.7 \text{mm} = 40 \text{cm} \]

The specimen sizes are shown at Figure 2 and 3 below, (with 3cm concrete cover)

![Figure 2. The Size of specimen (stage 1)](image)

![Figure 3. Specimens for Stage 1](image)

The specimens were tested after curing for 28 days. The concrete uniformity was tested before specimen tests by BPPT hammer test equipment and researcher hammer test equipment by adopted the procedure from [6]. Results from hammer test are shown at Table 1 and 2 as followed.
Table 1. Results of hammer test by BPPT equipment (stage 1)

| Location spot | Specimen Code | Compressive Strength (kg/cm²) |
|---------------|---------------|-------------------------------|
|               | Location 1    | Location 2    | Location 3    | Average |
| 1             | 1.3 ld        | 176           | 158           | 204     | 179.33 |
| 2             | 186           |              | 216           |         | 177.33 |
| 3             | 173           | 207           | 218           |         | 199.33 |
| 4             | 1.2 ld        | 224           | 126           | 218     | 189.33 |
| 5             | 230           | 190           | 204           |         | 208.00 |
| 6             | 214           | 233           | 206           |         | 217.67 |

The Average of Compressive Strength: 195.17

Because of hammer test results show very low than compressive strength concrete grade:, a subsequent correlation test was conducted between standard test specimens (cube 15x15x15 cm) using universal concrete’s comprehensive strength test machine compare with the proposed specimen (10x10x50 cm) using hammer test of the same concrete mix with K-400 grade. The test was conducted in the lab of Teknik Sipil Universitas Mercu Buana (UMB). The results are shown at Table 3, 4 and 5.

The correlation test result showed that the concrete’s compressive strength with standard test specimens (cube 15x15x15 cm) using universal test machine was 354 kg/cm², meanwhile the result of hammer test with proposed test specimens (10x10x50 cm) was \( \frac{212.7+201}{2} = 206 \) kg/cm². Correlation number for concrete’s compressive strength between standard test specimen and research specimen was \( \frac{354}{206.8 + \frac{195.17+176.88}{2}} x 1.71 = 318 \) kg/cm²

Table 2. Results of hammer test by Researcher equipment test (stage 1)

| Location spot | Specimen Label | 1.3 ld | 1.2 ld | A | B | C |
|---------------|---------------|--------|--------|---|---|---|
|               |               | 1      | 2      | 3 | 1 | 1 |
| 1             | 20            | 20     | 20     | 20| 20| 18|
| 2             | 28            | 26     | 26     | 28| 23| 24|
| 3             | 22            | 22     | 25     | 24| 22| 23|
| 4             | 25            | 26     | 27     | 20| 26| 24|
| 5             | 20            | 18     | 18     | 19| 17| 17|
| 6             | 24            | 15     | 24     | 14| 35| 20|
| 7             | 26            | 22     | 30     | 22| 24| 26|
| 8             | 22            | 22     | 24     | 21| 26| 25|
| 9             | 34            | 28     | 21     | 25| 28| 26|
| 10            | 18            | 18     | 22     | 22| 26| 20|
| Average       | 23.9          | 21.7   | 23.7   | 21.5| 24.7| 22.3|
| (Average) + 6 | 29.9          | 27.7   | 29.7   | 27.5| 30.7| 28.3|
| (Average) - 6 | 17.9          | 15.7   | 17.7   | 15.5| 18.7| 16.3|
| Reading Average| 22.78         | 21.75  | 23.00  | 21.63| 24.38| 22.30|
| Tool’s Correction Factor | -0.2    | -0.2   | -0.2   | -0.2| -0.2| -0.2|
| Tool’s Direction Factor | 3.32    | 3.35   | 3.31   | 3.35| 3.27| 3.33|
| Correction Average | 25.89    | 24.90  | 26.11  | 24.78| 27.44| 25.43|
Compressive Strength (kg/cm²) | 178.52 | 164.57 | 181.65 | 162.87 | 201.66 | 172.03  
Compressive Strength Average (kg/cm²) | 176.88 

Table 3. Concrete compressive strength Results on cube specimen grade K-400 at UMB lab (stage 1)

| No | Device Reading | Surface Area | Calibration | Concrete’s Compressive Strength |
|----|----------------|--------------|-------------|---------------------------------|
| 1  | 720 kN         | 225 cm²      | 1.091       | 349 kg/cm²                      |
| 2  | 690 kN         | 225 cm²      | 1.091       | 335 kg/cm²                      |
| 3  | 700 kN         | 225 cm²      | 1.091       | 339 kg/cm²                      |
| 4  | 695 kN         | 225 cm²      | 1.091       | 337 kg/cm²                      |
| 5  | 695 kN         | 225 cm²      | 1.091       | 337 kg/cm²                      |
| 6  | 680 kN         | 225 cm²      | 1.091       | 330 kg/cm²                      |
| 7  | 770 kN         | 225 cm²      | 1.091       | 373 kg/cm²                      |
| 8  | 780 kN         | 225 cm²      | 1.091       | 378 kg/cm²                      |
| 9  | 765 kN         | 225 cm²      | 1.091       | 371 kg/cm²                      |
| 10 | 780 kN         | 225 cm²      | 1.091       | 378 kg/cm²                      |
| 11 | 750 kN         | 225 cm²      | 1.091       | 364 kg/cm²                      |
| 12 | 745 kN         | 225 cm²      | 1.091       | 361 kg/cm²                      |
|    | Average        |              |             | 354 kg/cm²                      |

Further experiments after concrete uniformity tests were tensile tests for stage 1 on 3 samples with lap splices length of bars were 1.3 ld and 3 samples with lap splices length of bars were 1.2 ld as shown at Figure 5. Experimental results in stage 1 are shown in Table 6.

Table 4. Results of hammer test from device in UMB lab (stage 1)

| R  | 1  | 2  | 3  | 4  | 5  |
|----|----|----|----|----|----|
| 1  | 27 | 26 | 23 | 27 | 26 |
| 2  | 21 | 23 | 25 | 24 | 25 |
| 3  | 22 | 25 | 25 | 21 | 22 |
| Reading Average | 23.3 | 24.7 | 24.3 | 24.0 | 24.3 |
| Compressive Strength (kg/cm²) | 194 | 204 | 204 | 199 | 204 |
| Average of Compressive Strength (kg/cm²) | 201 |

Table 5. Results of hammer test from testing device at UMB lab (stage 1)

| R  | 1  | 2  | 3  | 4  | 5  |
|----|----|----|----|----|----|
| 1  | 24 | 27 | 26 | 27 | 26 |
| 2  | 23 | 25 | 26 | 24 | 25 |
| 3  | 25 | 22 | 25 | 27 | 25 |
| Reading Average | 24.0 | 24.7 | 25.7 | 26.0 | 25.3 |
| Tool’s Correction Factor | -0.2 | -0.2 | -0.2 | -0.2 | -0.2 |
| Tool’s Direction Factor | 3.28 | 3.26 | 3.23 | 3.22 | 3.24 |
| Correction Average | 27.08 | 27.73 | 28.70 | 29.02 | 28.37 |
| Compressive Strength (kg/cm²) | 196.2 | 205.9 | 220.5 | 225.3 | 215.6 |
| Compressive Strength Average (kg/cm²) | 212.7 |

Based on the test results of 18 specimens of steel reinforcement diameter 10 grade 40 kg/cm² from 3 brands to be used in this experiment, it is obtained, the value of the real minimum, maximum and
average yield tensile stress ($f_y$) respectively 41.63 kg/cm², 49.39 kg/cm² and 44.36 kg/cm². It is mean the real value of the yield tensile stress ($f_y$) is greater than the steel reinforcement grade required that is 40 kg/cm². And the average of ultimate steel reinforcement ($f_u$) = 59.42 kg/mm². According to Indonesian code for steel reinforcement [7], for steel grade 40 kg/mm² and the ultimate stress is $f_u = 57$ kg/mm². Regarding to the data, researcher will use a minimum $f_u$ comparison with max $f_y$ to get the length of splices on the collapsed steel situation coinciding with the slip between concrete and steel, that is

$$\frac{x}{1,2 \times ld} = \frac{f_y \text{ min}}{f_u \text{ max}}$$

$$\frac{x}{1,2 \times ld} = \frac{40}{59,42}$$

$$x = 0.8078 \times ld = 0.8078 \times 330.6 = 267.1 \text{ mm} \approx 27 \text{ cm}$$

So, the bar length splice with expected situation that reinforcing steel and concrete will collapse at the same time is $x = 27 \text{ cm}$, or $ld_{\text{failure}} = 27 \text{ cm}$.

At that situation, $P_{\text{failure}}$ for steel bar diameter, $db = 10 \text{ mm}$, is: $ld \times \pi \times db \times \mu$

**Concrete bond stress**

If the $P_{\text{exp.}} = 45 \text{ kN} = 45000 \text{ N}$

$db = 10 \text{ mm}$

$ld = 1.2 \times ld = 400 \text{ mm}$

$$\mu = \frac{P_{\text{exp.}}}{\pi \times db \times Ld} = \frac{45000}{3.14 \times 100 \times 400} = 3.58 \text{ MPa}$$

$$f_u_{\text{exp.}} = \frac{P}{A} = \frac{45000}{0.25 \times 3.14 \times 400} = 572.95 \text{ MPa}$$

$$P_{\text{failure}} = \frac{f_y \text{ syarat}}{f_u \text{ terjadi}} \times P_{\text{terjadi}} = \frac{390}{572.95} \times 45000 = 30630.53 \text{ N}$$

$$\text{Ld}_{\text{failure}} = \frac{P_{\text{runtuh}}}{\pi \times db \times \mu} = \frac{30630.53}{3.14 \times 10 \times 3.58} = 272.2 \text{ mm} \approx 27 \text{ cm}$$

According to Turk, K (2008), the obtained result was $\sqrt{\frac{\mu}{f_{c'}}} = 0.93$. If the specimen used K-400, hence $f_{c'} = 33.2 \text{ MPa}$

$$\mu = 0.93 \sqrt{f_{c'}} = 0.93 \times \sqrt{33.2} = 5.36$$ it is expected that reinforcing steel and concrete will collapse at the same time.

$$ld = \frac{P}{\pi \times db \times \mu} = \frac{45000}{3.14 \times 10 \times 5.36} = 267.3 \text{ mm} \approx 27 \text{ cm}$$
Due to the requisite from [5] that no splices use under 300 m = 30 cm allowed, researcher would use splices with 27 cm and 30 cm long. Researcher used concrete K-450 this time to reach the requisite concrete’s compressive strength in 400 kg/cm².

**Specimen Splices 27 cm and 30 cm (Stage 2)**

![Image of splices](image1)

Figure 4. The Size of specimen 27 cm and 30 cm (stage 2)

![Image of splices](image2)

Figure 5. Specimen splices 27 cm and 30 cm (stage 2)

After curing, and concrete and concrete has reached the age of 28 days, concert uniformity test was done before tensile strength test. The results of the test hammer are as follows

**Table 6. Result of Compressive Strength of cube Specimen K-400 at UMB lab (stage 2)**

| No | Load | Surface Area | Calibration | Compressive Strength |
|----|------|--------------|-------------|---------------------|
| 1  | 705 kN | 225 cm²      | 1.091       | 342 kg/cm²          |
| 2  | 720 kN | 225 cm²      | 1.091       | 349 kg/cm²          |
| 3  | 765 kN | 225 cm²      | 1.091       | 371 kg/cm²          |
| 4  | 730 kN | 225 cm²      | 1.091       | 354 kg/cm²          |
| 5  | 715 kN | 225 cm²      | 1.091       | 347 kg/cm²          |
| 6  | 705 kN | 225 cm²      | 1.091       | 342 kg/cm²          |
|    | Average |            |             | 351 kg/cm²          |

**Table 7. Result of Reinforcing Steel of cube Specimen K-450 at UMB lab (stage 2)**

| No | Load | Surface Area | Calibration | Compressive Strength |
|----|------|--------------|-------------|---------------------|
| 1  | 760 kN | 225 cm²      | 1.091       | 369 kg/cm²          |
| 2  | 875 kN | 225 cm²      | 1.091       | 424 kg/cm²          |
| 3  | 850 kN | 225 cm²      | 1.091       | 412 kg/cm²          |
A test for tensile strength of reinforcing steel with splices then conducted after the uniformity test. The results were as followed:

Table 8. Tensile Strength of Reinforcing Steel with Splices (stage 2)

| No | Concrete Strength | Lap-Splices | A (mm²) | P (kN) | fu (kgf) | Mode of Failure |
|----|-------------------|-------------|---------|--------|----------|----------------|
| 1  | K-400             | 27 cm       | 78.5    | 41     | 4179     | Concrete failure |
| 2  | K-400             | 27 cm       | 78.5    | 41     | 4179     | Concrete failure |
| 3  | K-400             | 30 cm       | 78.5    | 39     | 3975     | Concrete failure |
| 4  | K-400             | 30 cm       | 78.5    | 43     | 4383     | Concrete failure |
| 5  | K-450             | 27 cm       | 78.5    | 45     | 4587     | Bar failure     |
| 6  | K-450             | 27 cm       | 78.5    | 45     | 4587     | Bar failure     |
| 7  | K-450             | 30 cm       | 78.5    | 46     | 4689     | Concrete failure |
| 8  | K-450             | 30 cm       | 78.5    | 42     | 4281     | Concrete failure |

Average: 417 kg/cm²

Analysis of lap-splices on reinforcing deform steel splices class B in 10 diameter

The results of test of the length of the passage on the reinforcement of the grade B tensile steel, the diameter of 10 threads obtained the tensile strength according to the standard of SNI where the collapse occurred in the base material of reinforcing steel. With a quality plan of K-400 concrete and 3cm deck concrete, the specimen is made 10 x 10 cm. The length of the class B connection is 1.3 ld and for comparison there is also a 1.2 ld connection as a result all the connections have collapsed in the reinforcing steel. From the result of concrete compressive strength obtained concrete actual compressive strength is ± 350 kg / cm². Actual concrete strength less than the K-400 concrete quality plan due to
concrete mold using multiplex formwork that can absorb water on cement paste. If the calculation for
splices length use concrete quality of 350 kg/cm² or $f_{c'} = 29$ MPa

$$ld = \frac{f_y \psi_t \psi_e}{2.1 \lambda \sqrt{f_{c'}^2}} \cdot db = \frac{400 \cdot 1 \cdot 1}{2.1 \cdot 1 \cdot \sqrt{29}} \cdot 10 = 353.7 \text{ mm} \approx 35 \text{ cm}$$

From the result shown above, splices length with lower concrete quality produced shorter result from
use planned $K-400 = 400$ kg/cm² or $f_{c'} = 33.2$ MPa, which was 33 cm.

After the first test using 1,3 and 1,2 ld, the collapse still happen on fu on reinforcing steel. Subsequently, researcher tried to look for splice length by comparing the minimal fy with 1,2 ld. The
calculation obtained the splice length of 27 cm. This length is less than the planned ld which was 33

cm. Reseracher also calculated the yield stress which was $(\mu) = 3.58$ MPa and $ld = 27$ cm. This result
showed different number compared with the study conducted by [2] which also test the yield stress that
obtained $\frac{f_{y,exp}}{\sqrt{f_{c'}}} = 0.93$. From that number, the obtained ld was = 27 cm.

Since the requisite of splices could not be less than 30 cm, on the stage 2 researcher used splices with
length of 27 and 30 cm. Also, because the result of concrete’s compressive strength in $K-400$ only
obtained the quality of 350 kg/cm², in the next stage researcher tried to use concrete $K-450$ to expect
result of 400 kg/cm².

Stage 2 generated variations of forces and yield stress.Datas obtained were as followed.
1. Splice with length of 27 cm with concrete $K-400$ generated the average $P = 41$ kN, $fu = 52.2$
kg/mm² with collapses on concrete.
2. Splices with length of 30 cm with concrete $K-400$ obtained the average $P = 41$ kN, $fu = 52.2$
kg/mm² with collapses on concrete.
3. Splices with length of 27 cm with concrete $K-450$ obtained the average $P = 45$ kN, $fu = 57.3$
kg/mm² with collapses on concrete.
4. Splices with length of 30 cm with concrete $K-450$, obtained the average $P = 44$ kN, $fu = 56$
kg/mm² with collapses on concrete.

On concrete’s compressive strength test, results obtained were as followed:
1. Concrete of quality plan $K-400$ obtained compressive strength of 351 kg/cm².
2. Concrete of quality plan $K-450$ obtained compressive strength of 417 kg/cm².

From the results above, splices had undergone period of yield wherein the yield stress of the
reinforcing steel was 40 kg/mm². Differences between 27 cm and 30 cm length of connection with $K-
400$ concrete produced the same fracture stress of 52.2 kg / mm². The collapse occurred in the concrete
because the reinforcing steel had not reached the fracture stress with the minimum requirement of $fu = \ 57$ kg / mm². While at the length of the connection of 27 cm and 30 cm, with $K-450$, concrete produced
ultimate stress respectively 57.3 kg / mm² and 56.02 kg / mm². The collapse occurred successively on
reinforcing steel and concrete. The collapse occurred because the stress that occured in the range of the
minimum ultimate steel reinforcement.

4. Conclusions
Based on the results of research both from the test results, data analysis and discussion, the following
conclusion were made:
1. Distribution of tensile strength of splices steel B grade: BJTS-40 D-10 has fracture stress of 57.3 kg/mm² has meet the mechanical properties of reinforcing steel requirement, that is the minimum fracture stress, \( f_u = 57 \text{ kg} / \text{mm}^2 \).

2. The ratio of the tensile strength of the grade B reinforcing splices to the the average mechanical properties of reinforcing steel strength is \( 58.19 / 59.42 = 0.98\% \).

3. Class B splices value of 1.3 \( ld \) has satisfied the mechanical properties of the reinforcing steel. The experimental value of the splices less than \( ld = 33 \text{ cm} \) ie 27 cm with the quality / compressive strength of 400 kg / cm² concrete has satisfied the yield stress requirement, \( f_y = 40 \text{ kg} / \text{mm}^2 \), but it is close to the fracture stress requirement, \( f_u = 57 \text{ kg} / \text{mm}^2 \).

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