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Bond and Development of Straight Bars in Compression

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ABSTRACT

In high-strength concrete, a compression lap splice may be calculated to be longer than a tension lap splice according to ACI 318-14. From the regression analyses of 94 tests that failed in splitting including the data in the literature, an equation was developed with l_s/d_b to predict the splice strength. Using a 5% fractile coefficient, a design equations for the splice length was derived. The proposed equation provide shorter lengths than the splice length in tension as given by ACI 318-14. Based on the tests, Korea Concrete Institute amended the code provisions of splice lengths in compression and provided a new design equation. The KCI equation can remove the anomaly that a design compression lap splice can be longer than a design tension lap splice. From the comparison of these data and the proposed splice lengths, it is found that the KCI equation has a sufficient margin of safety.

1. INTRODUCTION

The compression lap splice criteria in ACI 318-14 (2014) were based on just 11 column tests (Pfistere and Mattock 1963) conducted over 50 years ago using concrete with a maximum compressive strength of 29.0 MPa. Lap requirements for compression splices have remained the same since the 1963 Code. Due to end bearing, the splice length in compression is shorter than the length in tension to develop the specified yield strength of reinforcing bars. However, a design compression lap splice could be longer than a design tension lap splice according to ACI 318-14, as concrete strength becomes higher, as shown in Fig. 1 (Chun et al. 2010a). This anomaly arises because the provisions for compression splices do not properly consider the effects of the compressive strength of the concrete and end bearing. To enhance the efficiency of high strength concrete, new criteria for compression lap splices are required. This study provides the model for strength of compression splices based on statistical analyses from the tests (Chun et al. 2010a, 2010b, 2010c, 2011). In addition, the amended KCI

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code provisions of lap slices in compression are introduced and compared with the provisions of ACI 318.

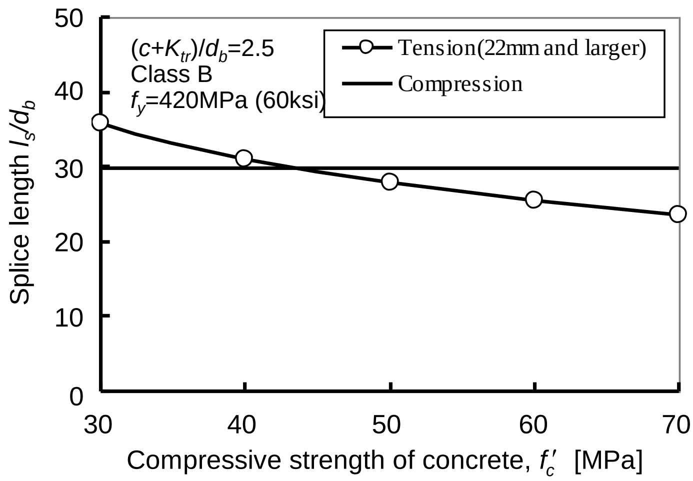

Fig. 1 Comparison of calculated splice lengths with varying concrete compressive strengths. (Chun et al. 2010a)

2. MODEL FOR STRENGTHS OF COMPRESSION SPLICES

A new model for predicting the splice strength, in high-strength concrete of 100 MPa and less without transverse reinforcement, was developed on the basis of the experimental results. Chun et al. (2011) suggested an equation for unconfined compression splices from a regression analysis for 58 tests.

$$f_{sc,p,uncon} = \left(1.59\frac{l_s}{d_b} + 34.5\right)\sqrt{f_c'} \tag{1}$$

To develop a simple design equation, a linear relationship between the splice length and the splice strength was assumed and, in addition, the splice the splice strength was assumed to be proportional to $\sqrt{f_c'}$. The slope of Eq. (1) was found to be sensitive to the range of the splice length of database and, therefore, Eq. (1) is only valid for splice lengths longer than the minimum splice length of the data.

In Eq. (1), the contributions of the bond and the end bearing cannot be recognized. The effects of the transverse reinforcement are not divided into bond and end bearing contributions, either. Therefore, the increase in the splice strength by transverse reinforcement can be expressed by multiplying Eq. (1) with a modification factor. The modification factor is assumed to be proportional to the value of K_{tr}/d_b. A regression analysis was conducted and the following equation was developed to predict the mean strengths of the compression splices, $f_{sc,p}$.

$$f_{sc,p2} = \left(1 + 0.11\frac{K_{tr}}{d_b}\right)\left(1.59\frac{l_s}{d_b} + 34.5\right)\sqrt{f_c'} \tag{2}$$

where K_{tr}/d_b cannot be greater than 1.76.

The splice strengths predicted by Eq. (2) were compared to the test values for 94 specimens in Fig. 2. The coefficient of variation (COV) for the ratios of the test to the predicted values is 9.8%, which is the same as that of Eq. **오류! 참조 원본을 찾을 수 없습니다.**. Within the tested conditions for concrete strength, splice length, and transverse reinforcement amount, Eq. **오류! 참조 원본을 찾을 수 없습니다.** can predict the splice strength as accurately as Eq. **오류! 참조 원본을 찾을 수 없습니다.**.

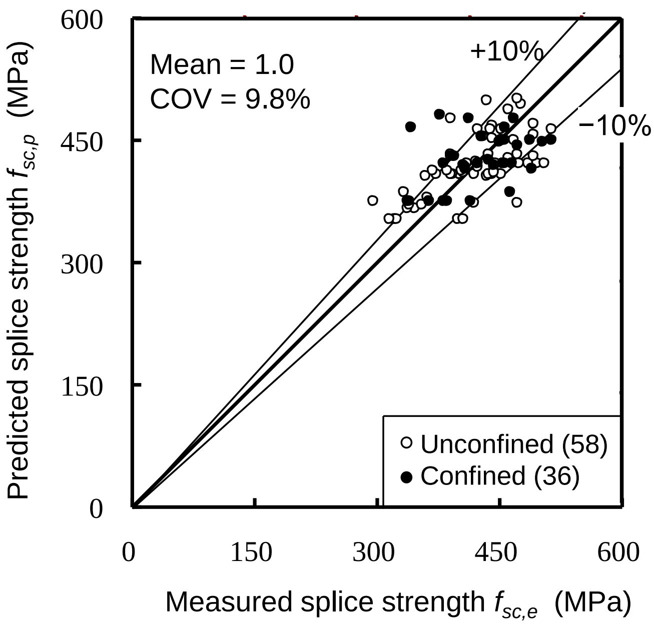

Fig. 2 Comparison of test results and predicted values.
(Note: ( ) is the number of specimens.) (Chun et al. 2011)

A 5% fractile coefficient (Natrella 1966), $n_{5\%}$, corresponding to a 90% confidence level, was introduced to determine the design strength ($f_{sc,d}$) from the mean strength of a compression splice ($f_{sc,p}$). A value of 0.82 was calculated for $n_{5\%}$ using the COV of 9.8% and the number of specimens as 94. For design purposes, it is desirable to determine the splice length rather than the splice strength. The current equation of ACI 318-14 can be used as the upper limit of the splice length because it has been practically verified for normal–strength concrete. Equation (2) can be solved for l_s by incorporating the $n_{5\%}$ of 0.82. In addition, in the case that the splice length is less than 16d_b, it is possible that there is no transverse reinforcement within the splice length. Therefore, it is conservative to ignore the effect of the transverse reinforcement in case of the splice length of 16d_b or less.

$$\frac{l_s}{d_b} = \frac{f_y}{1.3\psi_{sc}\sqrt{f_c'}} - 21.7 \le 0.071 f_y$$
$$\psi_{sc} = 1 + 0.11\frac{K_{tr}}{d_b} \qquad (3)$$

where the upper limits are replaced with $(0.13f_y - 24)$ if f_y is greater than 420 MPa, and K_{tr}/d_b should be taken as zero if l_s/d_b is equal to or less than $16d_b$.

Equation (3) has the same term $f_y / \sqrt{f_c'}$ as the current code provisions and can simply and easily provide the splice length in compression. The constant term of 21.7 in Eq. (3) represents the end-bearing contribution within the tested conditions, but this value does not directly relate the end-bearing strength without the bond or the splice strength of zero length. The splice lengths given by Eq. (3) are compared with 94 tests. All tests except 3 give conservative results.

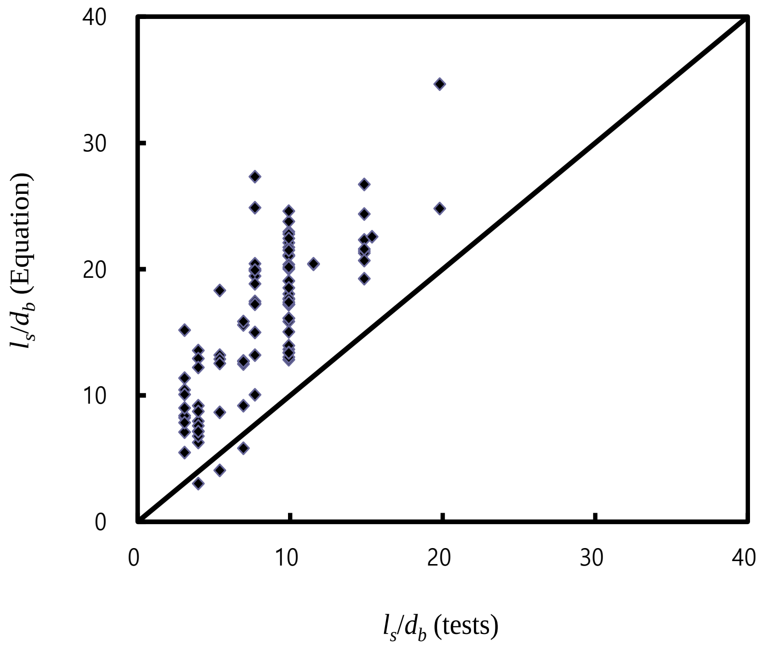

Fig. 3 Calculated l_{sc}/d_b vs. measured for results reported by Chun et al. (2011)

In 2012, Korea Concrete Institute amended the code provisions of splice length in compression based on Chun et al.'s study (2010b) and provides a new design equation of Eq. (4) for the splice length in compression. The splice lengths given by KCI (2012) are compared with the lengths given by ACI 318-14 in Fig. 4. The KCI equation can remove the anomaly that a design compression lap splice can be longer than a design tension lap splice. In addition, the data of tests, which gave splice strengths higher than a specified yield strength of reinforcement of 420 MPa, are also shown in Fig. 4. From the comparison of these data and the proposed splice lengths, it is found that the KCI equation has a sufficient margin of safety.

$$\frac{l_{s,KCI}}{d_b} = \frac{1.4 f_y}{\sqrt{f_c'}} - 52 \quad (4)$$

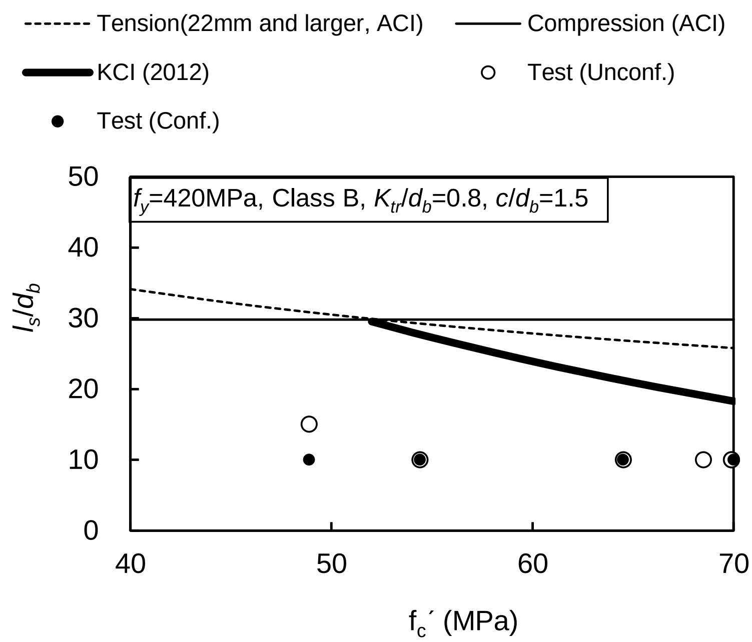

Fig. 4 Splice lengths by ACI 318 (2014) and by KCI (2012) (Chun et al. 2010b)

3. CONCLUSIONS

A compression splice can be longer than a tension splice, when observing ACI 318-14 with high-strength concrete. By reevaluating the test results of compression splices and performing a regression analysis, a simplified design equation was developed for splice length in compression. Based on the tests, Korea Concrete Institute amended the code provisions of splice lengths in compression and provided a new design equation. The KCI equation can remove the anomaly that a design compression lap splice can be longer than a design tension lap splice. From the comparison of these data and the proposed splice lengths, it is found that the KCI equation has a sufficient margin of safety.

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