A PROFESSOR'S PERSPECTIVE

NONCONTACT SPLICES

Strut-and-tie method, history, and a few additional thoughts

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Noncontact splices are frequently encountered in bridge substructures and designed according to the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] These specifications limit the splice offset (shown in Fig. 1) in flexural members to one fifth of the required splice length or 6 in. For columns with longitudinal bars that anchor into oversized shafts, this spacing restriction is waived, provided that a sufficient amount of transverse reinforcement is provided in the shafts. The splice offset limits for flexural members referenced above exist in recognition of the limitations that exist in the available test data. The supplementary requirements that exist for the specific case of column to shaft connections stem from test data for one specific application that became available after the introduction of original provisions. Lack of a broad range of test data on noncontact splices notwithstanding, within this article I would like to use the load transfer mechanism in noncontact lap splices to show the transparency in using the strut-and-tie method (STM) and provide a brief historical context.

Figure 1 shows the mechanics of the load transfer in a typical noncontact splice. As can be observed in this figure, the development of a compression field between the longitudinal bars that are involved in the force transfer is necessary. The inclination of this compression field (or struts) is a function of the tension force in the bars *T*, the quantity of transverse reinforcement provided A_{tr}, the splice length, and the splice offset *s*. With that stated, let us examine some of these variables. To begin, we must recognize that the length of a noncontact splice is adversely influenced by the splice offset distance *s*. As the splice offset gets larger, so does the splice length. In a case where the diagonal compression field makes a 45-degree angle with the longitudinal bars, the splice length is equal to the summation of basic development length "$l_d + s$."

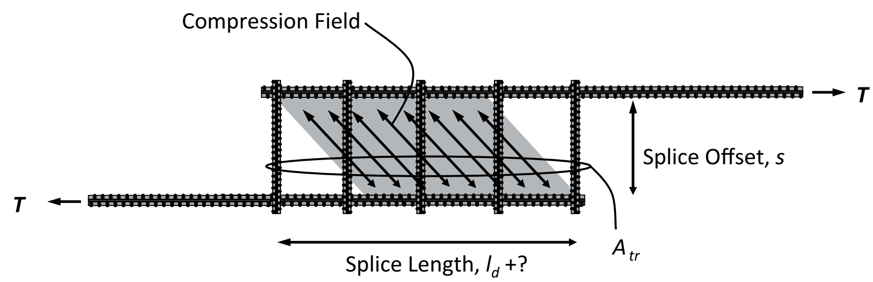

Figure 1. Mechanics of load transfer in noncontact splices. All Figures: Oguzhan Bayrak.

The force triangles presented in Fig. 2 clearly demonstrate the role of additional transverse reinforcement. When the quantity of transverse reinforcement is doubled, the angle between the compression field and the longitudinal reinforcement increases (for example, $\theta_2 > \theta_1$). As this angle increases, the overall length of the noncontact splice decreases, as can be inferred from Fig. 1. In other words, a designer can use a shorter noncontact splice length by using an increased amount of transverse reinforcement. Conversely, a lesser quantity of transverse reinforcement can be used, if the structural geometry allows for the use of a greater splice length.

Additional observations that can be made by examining the force transfer mechanism shown in Fig. 1 and 2 include: as the tension force *T* gets larger, that is, as the size of the bar being spliced gets larger, so does the splice length; and small portions at the ends of the bars being spliced do not contribute to the force transfer, as dictated by equilibrium. It is important to note that the qualitative discussion provided previously did not include any hard limits placed on the splice offset distance or on any other aspect of noncontact splice design. Rather, the discussion was based on first principles.

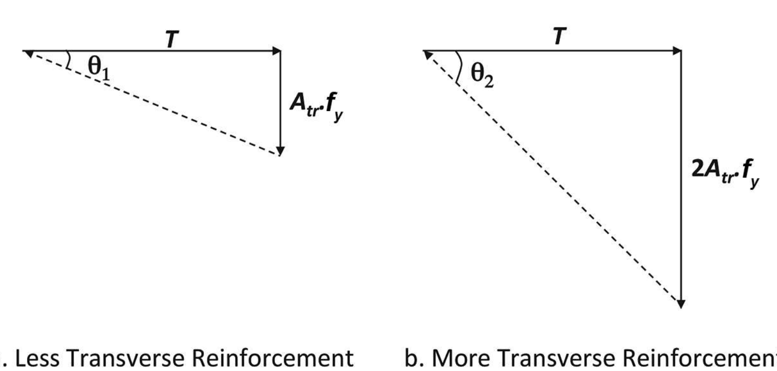

Figure 2. Force triangles for noncontact splice: influence of transverse reinforcement.

Typically, the limits placed on code provisions reflect the bounds of our understanding and/or the limits of test data available. In this context, ACI 408R-03[2] provides an informative summary of the historical developments that surrounded the evolution of reinforcing bar splicing in the United States. According to this reference document, until the 1963 edition of ACI 318, contact splices were not permitted and a minimum reinforcing bar offset (that is, the distance between the spliced bars) of $1.5d_b$ was required in ACI 318-47.[3] In 1951, the minimum bar offset requirement was reduced to a value of $1.0d_b$ and then in the 1963 edition of ACI 318, both contact and noncontact splices were allowed. In 1971, a maximum reinforcing bar offset requirement of 6 in. or one fifth of the required spliced length was introduced into ACI 318. The thinking behind this provision was that, with this conservative limit in place, a zig-zagging crack with 1:5 inclination could not form and structural safety in a noncontact splice would be ensured. More importantly, it is essential to appreciate that the commentary provided in ACI 318 openly acknowledges the fact that the 6 in. maximum spacing (that is, the limit placed on the spliced bar offset) was introduced because "most research available on lap splices of deformed bars was conducted with reinforcement within this spacing."

Moving forward, the benefits of generating additional data to fill the gaps in our knowledge cannot be overlooked. With that stated, the benefits of looking at the noncontact splice problem with the STM are also clear. These observations provide support to the increased emphasis placed on the use of the STM in the *AASHTO LRFD Bridge Design Specifications*. Consistent with that emphasis, I will cover this topic with a few more examples in upcoming articles.

References:

1. AASHTO. 2010. *AASHTO LRFD Bridge Design Specifications*, 7th ed. with 2015 and 2016 interim revisions. American Association of State Highway and Transportation Officials, Washington, D.C.
2. ACI 408R-03. 2012. *Bond and Development of Straight Reinforcing Bars in Tension*. Reported by ACI Committee 408, reapproved. American Concrete Institute (ACI), Farmington Hills, Mich.
3. ACI 318. 1947, 1963, 1971, 2014. *Building Code Requirements for Structural Concrete and Commentary*. ACI, Farmington Hills, Mich.

EDITOR'S NOTE

Dr. Bayrak's research group at the University of Texas at Austin assembled a large data set of concrete shear tests to validate the strut-and-tie code provisions. This research forms the basis of new strut-and-tie modeling design provisions in the AASHTO LRFD Bridge Design Specifications. *He will be sharing other research findings regarding modeling and the intricacies of node and strut definitions in upcoming articles. If you have a question about strut-and-tie modeling, please submit your question at the* ASPIRE *website.*