Technical Note

Engineering Technical Note
ETN-E-1-13

Introduction to Steel Reinforcing Bar Splices

Objective

The purpose of this Technical Note is to offer an introduction to steel reinforcing bar splices and is intended primarily to readers with limited experience with this subject. A more in-depth discussion can be found in the references listed at the end of this technical note, including CRSI's publication *Reinforcing Bars: Anchorages and Splices* (2008), where extensive design tables and detailed design examples can be found.

Background

The structural analysis of reinforced concrete structures subjected to various external loads and internal forces is generally predicated on the assumption that the individual structural members behave monolithically, as a unit. Due to practical limitations, the actual structure must be built piece-by-piece, story-by-story, and connected together. Just as it is physically impossible to place all concrete in one continuous operation, it is impossible to provide full-length, continuous reinforcing bars throughout any sizeable structure. Splices of reinforcing bars are unavoidable. Properly designed splices are a key component in a well-executed design.

Because splices are essential to the monolithic behavior of the finished structure, the Licensed Design Professional (LDP) should be familiar with the practical limitations of furnishing and installing reinforcing bars. These limitations occur during manufacture, fabrication and transportation to the jobsite and installation at the jobsite. Most steel mills produce reinforcing bars to a standard maximum stock length of 60 feet [18.3 m]. Longer lengths generally require special arrangements with the fabricator and mill. The absolute maximum length varies from mill to mill.

Steel reinforcing fabricating shops, using the stock on hand, are normally limited to bar lengths of 60 feet [18.3 m]. Bending equipment and its location in the shop may also impose limitations on the length of bent bars.

When shipping bars by truck, physical limitations for maximum length and width must be considered. Maximum length, in addition to mill and fabricating shop limits, is based on the number of bars involved, the route from the fabrication shop to the jobsite, the availability of trucking equipment as well as material handling limitations at the jobsite.

Splicing of Reinforcing Bars

The *Building Code Requirements for Structural Concrete,* ACI 318-11 (2011) defines splice requirements in terms of the type of load on the splice – tension or compression. The minimum requirements associated with lap splices, mechanical splices and welded splices are also outlined for each type of splice method.

Lap Splices – Tension

In a tension lap splice the force in the reinforcing bars is transferred to the concrete by bond which in turn transfers the force back to the adjacent reinforcing bars resulting in a continuous line of reinforcement. As a result of this interaction the length of the lap splice varies depending on concrete strength, grade of steel reinforcement, bar size, location and spacing. CRSI's *Reinforcing Bars: Anchorage and Splices* manual includes tables of required tension lap splice lengths based on these variables.

Tension splices should be confined with transverse reinforcement and if possible, located in zones of low tensile stresses, such as inflection points (i.e., location of curvature reversal with zero flexural moment). This is intended to mitigate splice failure at the end of the splice resulting from splitting stresses in the concrete and associated loss of cover due to the outwardly radial force transfer between the bar and the concrete.

Tension lap splices are designated as Class B splices with a splice length of 1.3 x ℓ_d (development length), except where Class A splices (1.0 x ℓ_d) are permitted, according to Section 12.15.2 of ACI 318.

Tension splices are further divided into Contact lap splices and Non-Contact lap splices. The former is a type of lap splice in which the bars touch and are wired together – are preferred because they are more secure against displacement during construction while the latter is a type of lap splice where the spacing between the bars should not exceed a maximum of 1/5 of the lap length, but not more than 6 inches [150 mm], as shown in Figure 1.

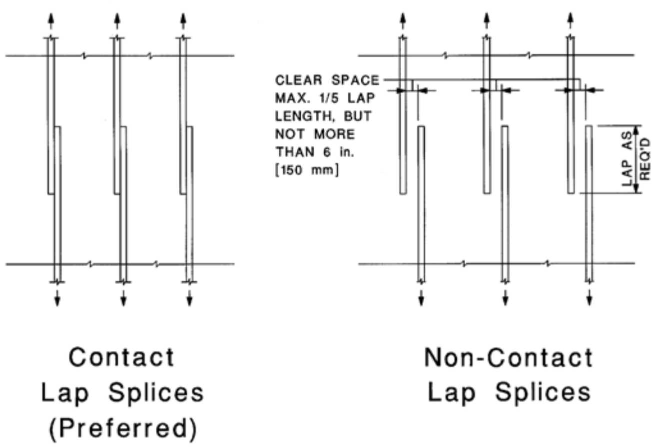

Figure 1 — Contact and non-contact tension lap splices

For lap splice design and construction, ACI 318 requires the Engineer to indicate locations and lengths of all lap splices on the structural drawings.

Where reinforcing bars of two sizes are lap-spliced in tension, ACI 318 requires the lap splice length to be the larger of the tension lap splice length for the smaller bar, or the tension development length for the larger bar. The current ACI 318 does not permit tension lap splices of #14 and #18 bars. For these sizes, mechanical or welded splices must be used. Although it isn't common, in compression only, #14 and #18 bars can be lap spliced to #11 bars and smaller.

Lap splices of bundled bars should be based on the lap splice length recommended for individual bars of the same size, and individual splices within the bundle should not overlap each other. The length of lap should be increased 20 percent for a 3-bar bundle and 33 percent for a 4-bar bundle. Lap splices of bundled bars should be securely wire-tied together to maintain the alignment of the bars and to provide minimum concrete cover.

Lap Splices – Compression

In a compression lap splice, the force transfer mechanism occurs primarily through bearing at the end of the bar. Given this type of transfer and the fact that no splitting stresses are present due to the compression nature of the force in the bar, this type of splice requires much shorter lengths as compared to tension lap splices. When bars of different sizes are lap-spliced in compression, the lap splice length must be the larger of the compression development length of the larger bar and the compression lap splice length of the smaller bar.

Mechanical Splices

There are two basic categories of mechanical splices:
- **Tension-compression**, which can resist both tensile and compressive forces, and
- **Compression only**, which are also known as "end-bearing" mechanical splices and transfer compressive force from bar to bar.

The designs of mechanical splices are proprietary. These splices are supplied by a number of manufacturers across the United States. Most mechanical splices can be supplied as uncoated, epoxy coated or galvanized to match the bars they are coupling. The various types of mechanical splices available include the types described in the following sections.

Tension-Compression Mechanical Splices

Cold-Swaged Coupling Sleeve – The cold-swaged coupling sleeve uses a hydraulic swaging press with special dies to deform the sleeve around the ends of the spliced reinforcing bars to produce positive mechanical interlock with the reinforcing bars. Bars to be spliced are inserted equal distances into the sleeve. Bars may be shear-cut, flame-cut, or saw-cut, however, a bar-end check is recommended. Bars of different sizes can be spliced with this system. This mechanical splice can also be used for joining reinforcing bars to structural steel members. Longer sleeves are required for splicing epoxy-coated reinforcing bars. Figure 2 illustrates a typical cold-swaged coupling sleeve.

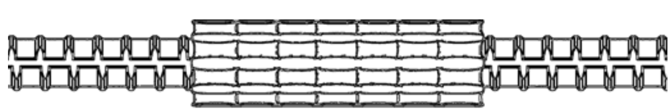

Figure 2 — Cold-swaged coupling sleeve

Cold-Swaged Threaded Coupler – The cold-swaged threaded coupler consists of pre-threaded male and female components, which are swaged onto the reinforcing bars using a swaging press with special dies. No special preparation is required on the bar ends. Splicing of the bars is completed by installing one pre-threaded component into the other. A three-piece position coupler is available for splicing bent bars that cannot be rotated. Optional details include transition couplers for splicing different bar sizes, couplers used to connect bars to structural steel members and couplers with flanges having nail holes. Threads are sealed and protected for future extension applications. Figure 3 shows a cold-swaged threaded coupler, with the top illustration showing the two components before they are screwed together and the bottom illustration showing them attached.

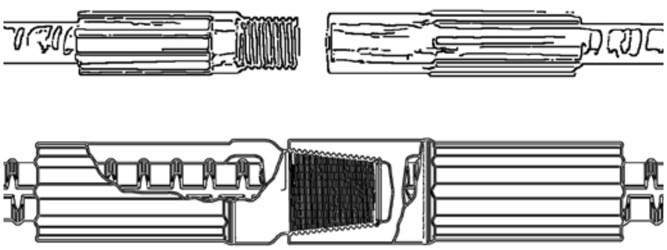

Figure 3 — Cold-swaged threaded coupler

Combination Grout-Filled/Threaded Coupler – Primarily used for precast construction, this type of mechanical splice combines two common mechanical splicing techniques. One end of the sleeve is attached and secured to a reinforcing bar by means of threading. The splice is then completed when the other bar end is inserted into the sleeve and the space between the bar and the sleeve is filled with high-strength grout. The wide mouth opening of the sleeve allows for minor bar misalignment. The wide mouth also allows for transitioning between different bar sizes. Figure 4 illustrates a combination grout-filled/threaded coupler, with the bar on the left threaded and the bar on the right grouted in place within the coupler.

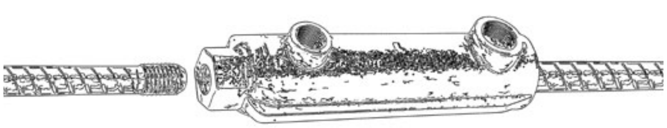

Figure 4 — Combination grout-filled/threaded coupler

Mechanical Lap Coupling Sleeve with Wedge – Designed primarily for splicing smaller bars, sizes #3 through #6, the coupling sleeve is oval in cross-section permitting the overlapping of two reinforcing bars of the same diameter in the sleeve. Each bar extends out of the sleeve about one bar diameter. After the sleeve is correctly positioned, a wedge-shaped round pin is driven through a hole in the flat face of the sleeve. The wedge passes between the bars and extends through a hole opposite the hole of insertion. The wedge pin is driven with a hand-held hydraulic ram. No special bar end preparation is required.

Mechanical Lap Coupling Sleeve with Shear Screws – This coupling sleeve consists of a ductile iron sleeve with two internal wedges. Two series of cone-pointed screws are arranged along the sleeve length, opposite a wedge-shaped profile in the sleeve. Each reinforcing bar extends out of the sleeve by approximately one bar diameter. No special bar end preparation is required. As the screws are tightened, they indent into the surface of the bars, and wedge the bars into the converging sides of the sleeve profile. Screws are recommended to be tightened using a suitable impact wrench. The heads of the screws shear off at a prescribed tightening torque. Bar sizes #3 through #6 plus bars of different sizes either uncoated or epoxy-coated can be spliced using this coupling sleeve. Figure 5 shows two types of mechanical lap coupling sleeves. The illustration on the top shows a mechanical lap coupling sleeve with shear screws, and the illustration at the bottom shows a mechanical lap coupling sleeve with wedge.

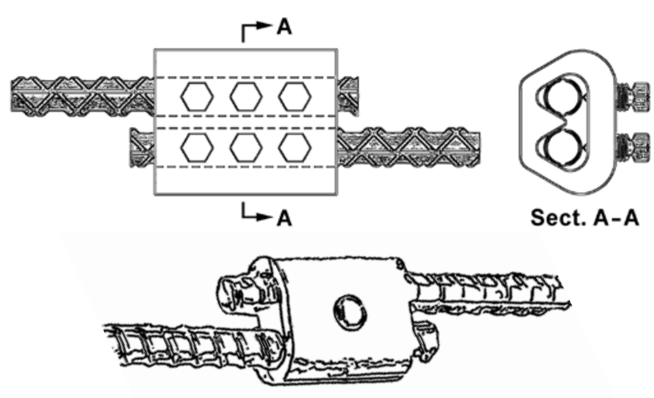

Figure 5 — Mechanical lap coupling sleeves

Grout-Filled Coupling Sleeve – The double frustrum-shaped coupling sleeve is filled with a cement based, non-shrink, high-early strength grout. Reinforcing bars to be spliced are inserted into the sleeve to meet at the center of the sleeve. The space between bar and sleeve is filled with non-shrink grout to transfer stress between the external deformations on the bar and internal deformations in the sleeve. No special end preparation of the bars is required. The relatively wide sleeves also can accommodate minor bar misalignments, and combinations of different size bars. Figure 6 illustrates a typical grout-filled coupling sleeve.

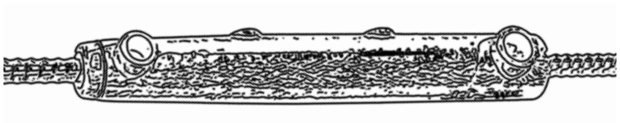

Figure 6 — Grout-filled coupling sleeve

Shear Screw Coupling Sleeve – This type of mechanical splice, as shown in Figure 7, consists of a coupling sleeve with shearhead screws which are designed to shear off at a specified torque. The reinforcing bars are inserted to meet at a stop at the center of the coupling sleeve and the screws are tightened. The tightening process embeds the pointed screws into the bars.

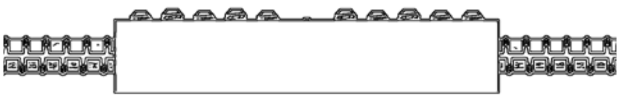

Figure 7 — Shear screw coupling sleeve

The heads of the screws shear off at a prescribed tightening torque. The screws are recommended to be tightened using a pneumatic impact wrench. For making a splice between two fixed bars, coupling sleeves without a center stop are available. This sleeve can be slipped completely onto one bar and subsequently repositioned over the two bar ends.

Steel-Filled Coupling Sleeve – The steel filled coupling sleeve is a mechanical splice in which molten metal or "steel filler" interlocks the grooves inside the sleeve with the deformations on the reinforcing bar. Special details permit use as end anchorages or connections to structural steel members. An illustration of a steel-filled coupling sleeve is shown in Figure 8.

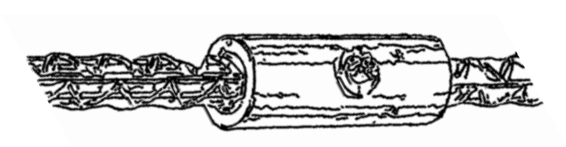

Figure 8 — Steel-filled coupling sleeve

Shear-cut, flame-cut, or saw-cut ends of the bar can be used as the "steel filler" fills the space between the ends of the bars, however, a bar-end check is recommended.

Straight Thread Coupler with Upset Bar Ends – This mechanical splice consists of forming heads on the ends of the reinforcing bars to be connected using a hydraulic machine from the splice manufacturer. This splice is designed to fit between closely-spaced bars. The upset bar ends are butted up to each other and are held in place using a male and female straight threaded coupler that is positioned onto the bars prior to forming the heads. The coupler is installed by turning either the male or female component and tightening to the manufacturer's recommended torque; no rotation of the bar is required. Bent or curved bars can be spliced with the same mechanical splice. Adaptations permit use for end anchorages in concrete or connections to threaded rods. Bar ends may be sheared, flame-cut or saw-cut. Figure 9 shows a straight thread coupler with upset bar ends, with the illustration on the left showing the components before they are screwed together and the illustration on the right showing the components attached.

Figure 9 — Straight thread coupler with upset bar ends

Taper-Threaded Coupler – This is a mechanical splice consisting of a taper-threaded coupler that joins two reinforcing bars with matching taper threads. The coupler is installed by turning the bar or sleeve with wrenches to the manufacturer's specified torque. For splicing bent or curved bars, special three-piece position couplers are used. Adaptations permit use for end anchorages in concrete or connections to structural steel members. Bar ends require taper threading over a specified length. The illustration in Figure 10 shows a taper-threaded bar on the left, which will be screwed into the coupler on the right.

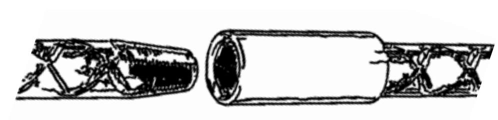

Figure 10 — Taper-threaded coupler

Upset Straight Thread Coupler – This is a mechanical splice consisting of a coupler with internal straight threads at each end that joins two upset end reinforcing bars with matching external threads. Upsetting the bar ends permits the cross-sectional area in the threaded portion to be greater than the bar cross-sectional area.

This type of splice can either be in three pieces (the two bar ends and internally threaded coupler) or in two pieces with the coupler integrally forged or pre-assembled onto one bar end. These systems are also available as weld-on couplers, transitional couplers, positional couplers, and headed bars.

Figure 11 shows an upset straight thread coupler in which the two bar ends are screwed into the coupler at the center of the figure.

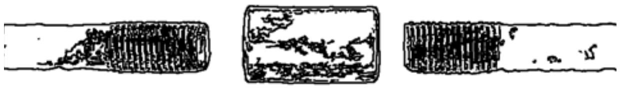

Figure 11 — Upset straight thread coupler

Non-Upset Straight Thread Coupler – This is a mechanical splice consisting of a coupler with internal straight threads at each end that joins two reinforcing bars with matching external threads.

Since the cutting of threads reduces the net cross-sectional area of the reinforcing bar, some manufacturers use bars one size larger while other manufacturers use bars with tensile and yield strengths sufficient to overcome the loss of net area by thread cutting. This type of splice is in three pieces (the two bar ends and the internally threaded coupler). These systems are also available as weld-on couplers, transitional couplers, and positional couplers. The coupler in Figure 12 of a non-upset straight thread coupler is similar to Figure 10, except that the bar ends in Figure 12 are straight threaded and the ends were not built up.

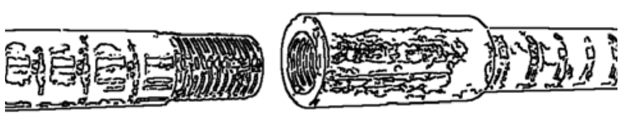

Figure 12 — Non-upset straight thread coupler

Dowel Bar Mechanical Splices – This is a mechanical splice used to avoid reinforcing bars from penetrating or protruding from forms. All of the various systems available consist of several components. The coupling component, initially embedded in concrete, is internally threaded and another component, installed after stripping the forms, is externally threaded. The internally threaded component is normally designed to fasten directly to the form face and is usually encased in the first concrete placement. These systems are available in a variety of designs, configurations, sizes and shapes. See Figure 13 for an example of this type of splice.

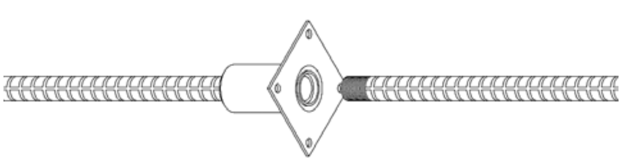

Figure 13 — Dowel bar mechanical splice

Compression-Only Mechanical Splices

Figure 14 shows an example of this type of splice utilizing a bolted strap coupling sleeve.

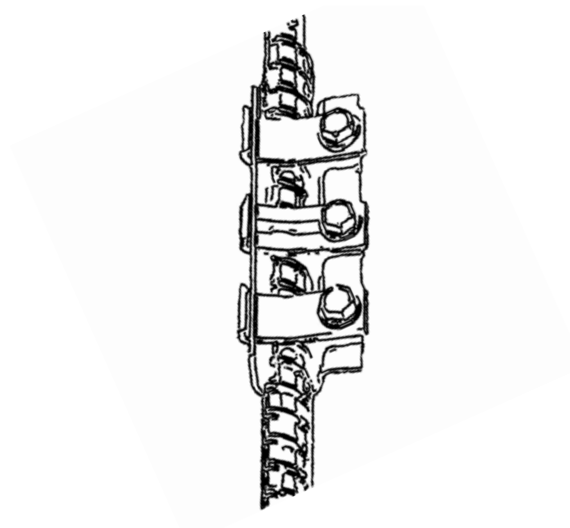

Figure 14 — Bolted strap coupling sleeve

Welded Splices

In general, CRSI recommends against manual arc welding in the field. However, if necessary, field-welded splices are accomplished by electric arc welding prepared ends of the reinforcing bars together. Welding should conform to AWS D1.4/D1.4M, *Structural Welding Code - Reinforcing Steel* (2011). The "weldability" of steel is established by its chemical composition. Usage of low-alloy reinforcing bars conforming to ASTM A706 (2009) ensures the chemistry for weldability. The most widely used type of reinforcing bars is carbon-steel conforming to ASTM A615 (2012), but its chemistry must be verified prior to attempting to weld these types of bars.

CRSI recommends against connecting crossbars by small arc welds, known as "tack welds." Tack welding is a factor associated with fatigue crack initiation and brittle failure of reinforcing bar assemblies.

Additional Resources

CRSI's *Reinforcing Bars: Anchorages and Splices* manual is the definitive resource for information on development and splicing of reinforcing bars. It includes extensive tables of development and lap splice lengths, information on mechanical splices and welded splices. It is based on ACI 318 and AASHTO bridge specifications (2012).

References

American Concrete Institute - ACI Committee 318 (2011), *Building Code Requirements for Structural Concrete* (ACI 318-11) and *Commentary*, American Concrete Institute, Farmington Hills, Michigan, 503 pp.

American Association of State Highway and Transportation Officials – AASHTO (2012), *AASHTO LRFD Bridge Design Specifications*, U. S. Customary Units, 6th Edition, American Association of State Highway and Transportation Officials, Washington, D. C., 1672 pp.

American Welding Society – AWS D1.4 (2011), *Structural Welding Code – Reinforcing Steel* (AWS D1.4/D1.4M: 2011), American Welding Society, Miami, Florida, 85 pp.

ASTM International – ASTM A615 (2012), *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement* (ASTM A615/A615M-12), ASTM International, West Conshohocken, Pennsylvania, 6 pp.

ASTM International – ASTM A706 (2009), *Standard Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement* (ASTM A706/A706M-09b), ASTM International, West Conshohocken, Pennsylvania, 6 pp.

Concrete Reinforcing Steel Institute – CRSI (2008), *Reinforcing Bars: Anchorages and Splices*, 5th Edition, Concrete Reinforcing Steel Institute (CRSI), Schaumburg, Illinois, 64 pp.

Wight, J.K., and MacGregor, J.G. (2012), *Reinforced Concrete – Mechanics and Design*, 6th Edition, Pearson Education, Inc., Upper Saddle River, New Jersey, 1176 pp.

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