Mechanical splices of reinforcing bars

Proprietary couplers for tension and compression splices; ready and able when ordinary lap splices aren't suitable

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Manufacturing, fabrication, and transportation limitations make it impossible to provide full length continuous bars in most reinforced concrete structures. Therefore proper splicing of rebars becomes essential to the integrity of reinforced concrete. There are three basic ways to splice the bars:

- lap splices
- mechanical connections
- 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 the 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, the ACI Building Code (Reference 1) does not permit lap splices of #14 and #18 bars except in compression, and then only to #11 or smaller bars.

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. Thus if lap splices are impossible or impractical, the engineer will choose either welded or mechanical splices. The purpose of this article is to identify the different types of proprietary mechanical splices commonly available in the United States, and to outline some of their advantages and disadvantages. Welded splices were described in an earlier issue of CONCRETE CONSTRUCTION (Reference 2).

Most modern mechanical splicing devices align and secure the joined rebar ends in an in-line connection suitable to meet appropriate splice requirements. Both compression and tension splicing devices rely on mechanical interlock to accomplish this. The most popular methods or devices are:

- metal-filled sleeves
- mortar- or grout-filled sleeves
- swaging or forging, both hot and cold
- threading
- friction or clamping

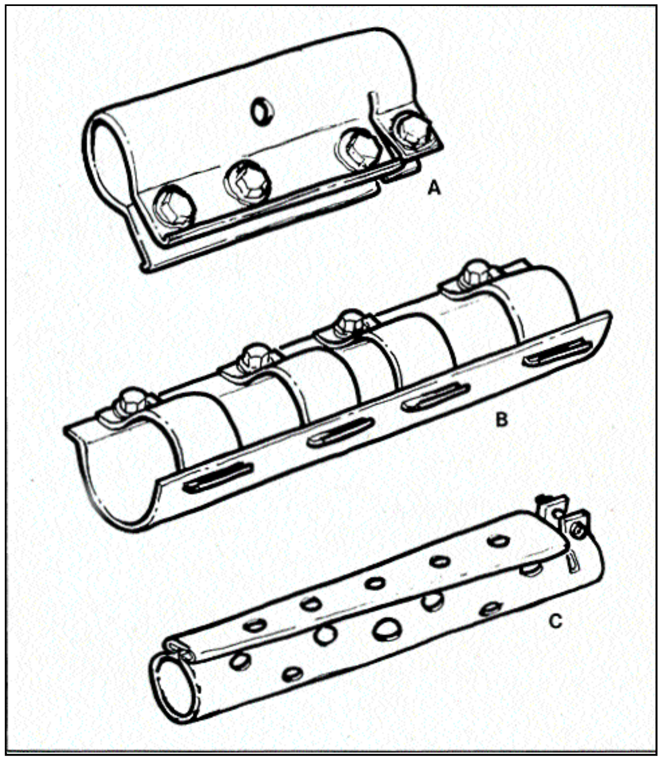

Figure 1. Compression splice sleeves. The two upper splices (A and B) are bolted steel sleeves. One is a cylindrical shell with bolted flanges at one side; the other is a half-cylinder with straps which clip into one side of the cylindrical shell and are bolted to the other edge. The bottom splice (C) tightens by wedge action. The cylindrical sleeve has a tapered opening with flattened collar flanges. A wedge-shaped piece with edges which wrap around the flanges slides into position, then is driven down with a hammer.

Splices transfer tension or compression loads from one piece of reinforcement to another, and splicing devices are classified accordingly. Many splice systems which are designed for tension capability also satisfy compression splice requirements, but the converse is not true. Compression splices do not generally meet tension splice requirements.

The ACI Code requires that "a full mechanical connection shall develop in tension or compression, as required, at least 125 percent of the specified yield strength of the bar." This has been regarded as a minimum necessary for safety to prevent brittle failures, and as a maximum for economy. However, some recent splice developments make it possible to achieve ultimate strength without sacrificing economy.

END-BEARING COMPRESSION SPLICES

Three types of compression splices shown in Figure 1 all work through friction-clamping interlock. They are commonly used for bars in columns, and in all three the bars are inserted so that the upper bar rests on the lower bar before the device is tightened. To obtain a proper fit in the field, bars must be cut by saw or otherwise to obtain a reasonably flat surface. This means that the bar ends must be within 3 degrees of full bearing after assembly.

These splices can only be used for transferring compression from bar to bar. Where these compression-only splices cannot be used due to limited access or requirements for cover and clear spacing between clustered bars, tension-type splices may have to be substituted.

TENSION SPLICE DEVICES

Metal filled sleeve

The first widely accepted commercial mechanical splice system was a metal-filled sleeve (Figure 2). Reinforcing bars are placed end to end in the metal sleeve, and a molten metal filler is introduced through the tap hole. The filler material flows between the bars and the sleeve, solidifying in the deformations of the rebar and in the internal ribs of the sleeve, forming a mechanical interlock. Normal length of this coupler is 7 inches when used as a tension splice for a #18 bar. It can also be used for compression-only splices, and then is normally 3 inches long. Tension splices are available in either full ultimate or 125 percent of yield strength.

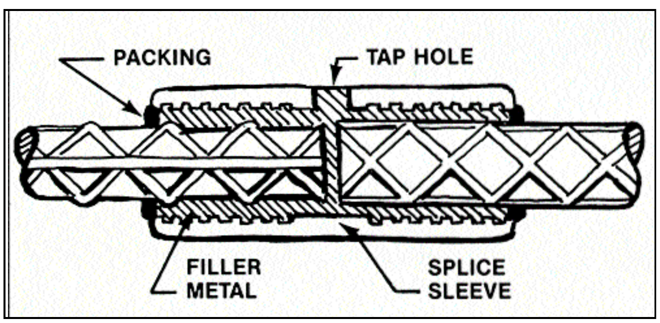

Figure 2. Metal-filled sleeve can be used for either tension or compression splice. Heated metal filler flows between rebar deformations and internal ribs of the sleeve, creating a mechanical interlock.

Bar ends must be clean and dry but require no special preparation. This method has the advantage of backfit capabilities; that is, it is able to correct oversights, to promptly meet schedule changes, and to make repairs following destructive quality control procedures. However, the interior of the splice cannot be inspected visually, and there are possible problems of labor costs, weather and environmental requirements at the job site, and the need for fire protection because of the heat given off in melting the metal filling.

Grout- or mortar-filled sleeve

Another splice system using a grout or mortar filler works much the same way as the metal-filled sleeve, by mechanical interlock. The sleeve is shaped like two cut-off cones butted together (Figure 3). It is larger than other splices—ten to fourteen bar diameters long with a maximum diameter of more than 4 inches for splicing #18 bars. A proprietary high strength grout pumped into the sleeve using a low pressure grout pump forms an interlock between rebar deformations and the internal ribs of the sleeve.

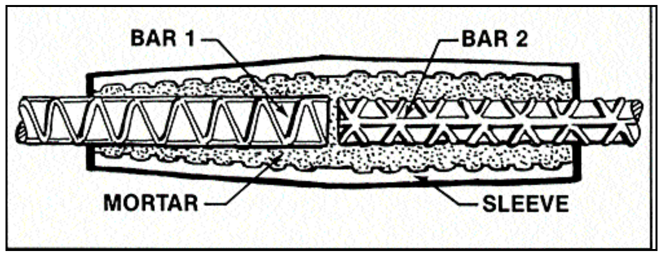

Figure 3. Grout- or mortar-filled splices have special applicability for precast concrete connections. The high strength grout is pumped between rebar and internal ribs of the sleeve to establish interlock.

Some disadvantages of this system are its bulkiness, special grout requirements, lack of heat resistance, and chemical reaction concerns. Setting time for the grout may be from 2 to 4 hours or more, depending on temperature. However, the system has special advantages for assembling precast concrete units without closure pours or formwork.

Splices based on hot or cold metal forming

Following development of the filler type splices came interlocking mechanisms using hot and cold metal forming techniques (Figure 4). These methods create interlock of the sleeve with rebar deformations by applying external pressure to the sleeve, forcing the walls of the sleeve to collapse and penetrate into the deformations of the reinforcement. The sleeves are long enough—9 to 12 inches for large bars—so that collapsing them against the bars provides adequate interlock.

Like the filled sleeves, they require special field equipment, sometimes cumbersome. Since the sleeves are manufactured from materials other than rebar and may have different machinability and formability, added

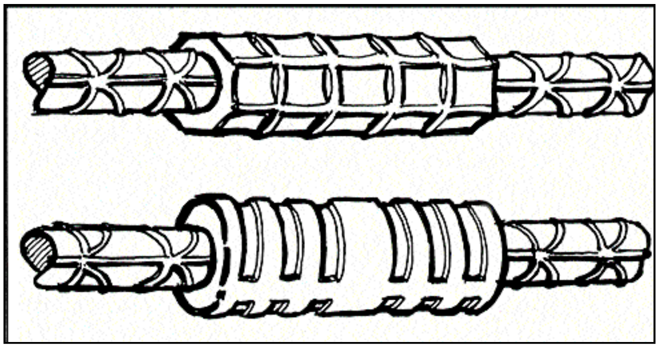

Figure 4. Metal forming splice techniques create interlock of coupler sleeve and rebar deformations by applying external pressure to the sleeve, forcing the walls of the sleeve to collapse and penetrate into the rebar deformations. One method is based on hot forging; another is based on cold swaging (upper sketch).

quality control procedures are required. Filler material and metal forming splice techniques also leave some doubt as to whether proper interlock has been achieved, since they cannot be visually inspected. They are not compatible with epoxy-coated rebar because coating deterioration may be caused by the physical processes required.

Hot forging—The earliest of the metal forming techniques was hot forging. The hot forged system requires a furnace and fuel source near the immediate work area. The sleeves are heated to about 2000 degrees F, removed from the furnace, and positioned over the end of the bar to be spliced. The adjoining bar is positioned in the opposite end of the splice, and the hot sleeve is forged into the deformations of both bars by a hydraulic ram. Contraction of the sleeve upon cooling improves bond and increases the splice strength.

Cold swaging and extrusion—The cold swaging process adapts forging techniques without heat. A seamless steel tube is placed over abutting ends of the bars to be spliced and is deformed to the bar configuration. For #14 and #18 bars a two-piece hydraulically powered extrusion press can be used to shape the sleeve to the bars. The press needed for the largest bars may weigh as much as 360 pounds. For #14 and smaller bars a one-piece side action hydraulic press is used. It is placed at one end of the sleeve, crushing the sleeve into the bar deformations for a limited distance. The crimping and squeezing operation is repeated until adequate deformation lengths are obtained. As a result, the sleeve is squeezed into the bar deformations just as with hot forging or extrusion. The one-piece presses weigh from 120 to 210 pounds.

Threaded couplers

A common older interlock system is the threaded coupler shown in Figure 5. With an ordinary system of threading, it is common to dress the ends of the rebar before cutting or rolling the threads, thereby reducing nominal bar area and lowering load capacity. There is little or no strength difference between cut and rolled threads of the same size.

Rebar ends may generally be threaded either in the fabricator's shop or in the field. Threaded bar ends must be protected against damage during shipping and handling until the splices are completed.

Splice systems that remove material during the threading operation must be used with care. If the design bar size is increased to the next larger bar size to compensate for material loss, splicing #11 and #14 bars is difficult and splicing #18 bars is impossible. An alternative to increasing bar size is to upgrade material specifications, such as using Grade 60 steel instead of Grade 40. Although some rebar material exceeds specified minimum properties—for example Grade 40 bars with more than 40,000 psi yield strength—this strength cannot be depended on to compensate for area lost in threading.

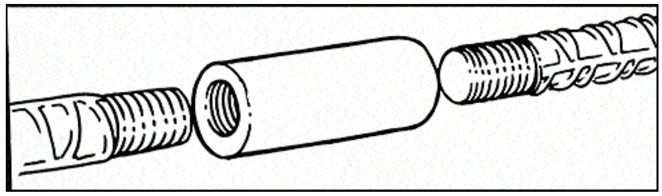

Figure 5. Typical threaded splice system requires rebar ends to be threaded, either in the fabricator's shop or in the field. Threaded bar ends must be protected against damage until splices are completed.

Tapered-thread splice—Figure 6 shows a tapered cut-thread splicing system, based on an idea borrowed from the oil industry for extending drilling pipe. Using a rebar coupler with tapered internal threads and matching external threads on the bars helps make good alignment and quick joining. Tapering threads also modifies the shear distribution across the threads and helps minimize the stress concentration effect caused by threading. Splicing of the two bars is achieved with only four or five turns of each bar. After fit-up each bar is tightened with a torque wrench. The combined effects of stress concentration and reduced net area make it impossible to achieve full ultimate strength of the spliced bars, but the code requirement of 125 percent of yield strength can be met.

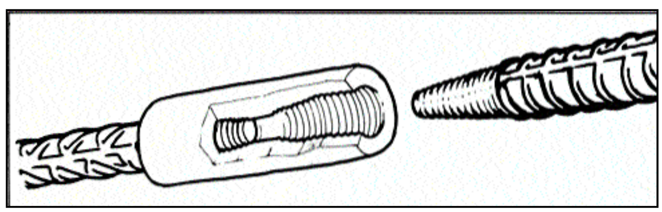

Figure 6. Tapering the cut-thread system helps make good alignment and quick joining of bars. Tapering also helps reduce stress concentration in the threaded regions.

Threaded sleeve for special bars—Another type of threaded splice (Figure 7) is available for reinforcing bars which have specially rolled thread-like deformations

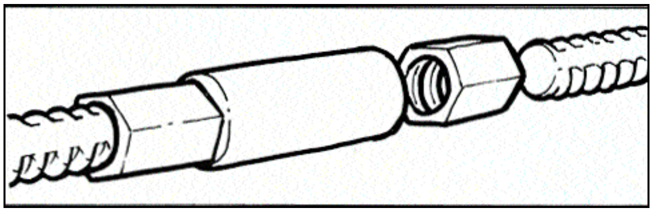

Figure 7. Threaded sleeve for special bars has internal threads to match the rolled thread-like bar deformations. Two lock nuts, one on either side of the coupler, are needed to eliminate slack in the completed splice.

over their entire length. Coupler sleeves are manufactured with internal threads to match the bar threads. The thread configuration is coarse and two lock nuts are needed to eliminate the slack. A splice is made by first placing a lock nut on each bar, then threading the coupler onto the end of one bar and advancing the other bar into the opposite end of the coupler. The coupler sleeve is centered over the bar ends by premarking the bars an equal distance from the ends before splicing. After the bars are correctly positioned in the coupler, the lock nuts are torqued with a hydraulic wrench.

This system requires a coupler, two lock nuts, and a wrench that can provide 1000 to 2000 foot-pounds torque for the largest bars. Mill markings and bar sizes are not rolled into the bar material (as required by United States standards), which may present problems in identification and traceability. However, there is no loss of reinforcement strength because there is no reduced area due to threading.

Swaged and threaded couplers

The splice shown in Figure 8 makes use of both threading and swaging and does not reduce the net area of bars being spliced. An internally threaded coupler is cold forged by octagonal dies onto the end of a rebar.

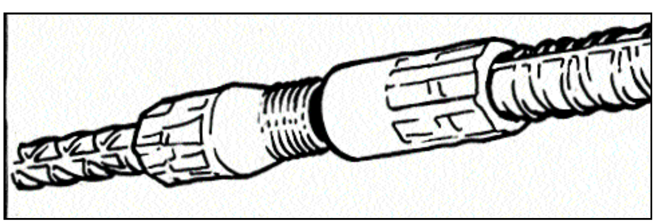

Figure 8. Using both threading and cold swaging, this coupler does not reduce the net area of bars being spliced. An internally threaded coupler is cold forged onto the end of one rebar. On the end of the second rebar, a prethreaded male adapter matching the internal threads of the coupler is also swaged into place. The two bars are then simply twisted together.

On the end of a second bar a prethreaded male adapter matching the internal threads of the coupler is swaged into place. When the two bars are aligned, they can be simply twisted together. The net area through the thread region equals or exceeds the nominal bar diameter and torquing is not needed. This swaging may be done in either shop or field, but not on the bar in place in the structure.

This method insures that the thread properties are adequate to meet the ultimate bar strength. As in ordinary cold swaging, the adapter materials are not as strong as the bar material, and increased wall thickness is used in the adapters to compensate. To splice two bars with this system, it is necessary to complete three connections. This increases labor as well as the number of possible points for error.

In a variation of this system, internally threaded couplers are swaged onto the ends of both bars to be joined. Then the connection is completed with a prethreaded steel stud, turning either the stud or the bar as convenient.

SPLICING AT CONSTRUCTION JOINTS

Reinforcing steel must frequently be continued across construction joints. Typically this means that rebars, either the main reinforcement or dowels used to provide a lap splice in the main reinforcement, project beyond

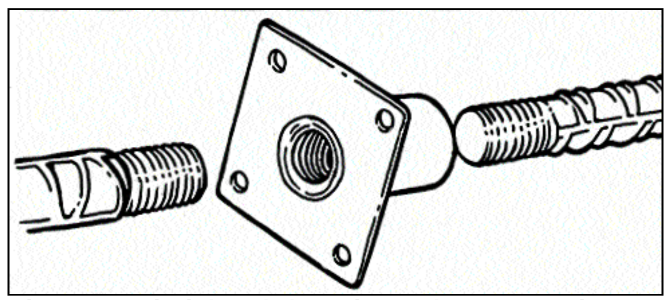

Figure 9. Typical threaded coupler used at construction joints. Threaded rebar or dowel is screwed into the coupler, and the flange plate is secured to the bulkhead form. When the forms have been stripped and steel is being set for the next placement of concrete, the connecting threaded bar or dowel is inserted into the coupler.

the first placement of concrete. Bulkhead forms are built around them, usually a tedious and expensive process, and the projecting steel is a hazard until it is enclosed in the forms for the next stage of the construction.

Specialized couplers for use at construction joints have been developed to help relieve forming costs and speed the stripping at such locations. Figure 9 shows one of these couplers. The internally threaded coupler has a flange plate which is nailed or screwed to the bulkhead form. The principal reinforcement may be prepared with threaded ends to screw into the coupler, or a specially threaded dowel splice piece can be inserted into the coupler. When the forms have been stripped and steel is being set for the next placement, either a threaded bar or dowel is screwed into the coupler. Positive stops inside the coupler assure getting the proper length of bar screwed into the coupler. Because threading reduces the bar cross section, a larger bar or dowel diameter than specified may be needed if the full mechanical strength of an equivalent nonthreaded splice is required.

A simpler integral threaded splice system (Figure 10) achieves a doweled splice at construction joints with only one connection. It does not require sleeves or couplers. It is manufactured from two pieces of rebar, one piece forged with a barrel tapped with standard coarse threads and finished with an integral flange. The thread size is larger than the nominal size of the main bar being spliced. The end of the adjoining piece of dowel is enlarged to match by upset forging and roll threading.

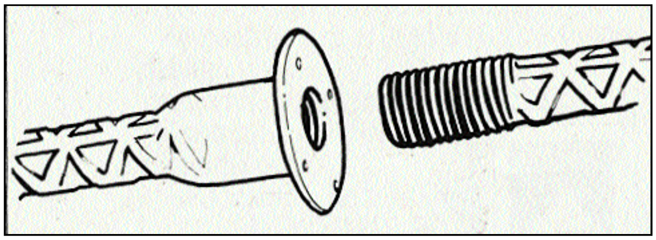

Figure 10. Integral threaded splice system achieves a doweled splice at construction joints with only one connection. It is manufactured from two pieces of rebar, one forged with a barrel tapped with standard coarse threads and finished with an integral flange. The end of the adjoining piece of dowel is enlarged to match by upset forging and roll threading.

The advantage of this splice system is that it develops the full ultimate bar strength. It needs no special tools or torquing. Since it creates the splice with only one connection, it saves labor and presents fewer possible failure points. The system is completely prepackaged, eliminating secondary field operations. However, male threads may be cut in the field to meet emergencies or schedule changes. This kind of splice works well with epoxy coated bars because torquing is not required. The one-piece barrel receiver and male dowel are joined when the coating is applied, then separated for installation. After field assembly, a light spray or paint touch-up is commonly applied at the mating seam.

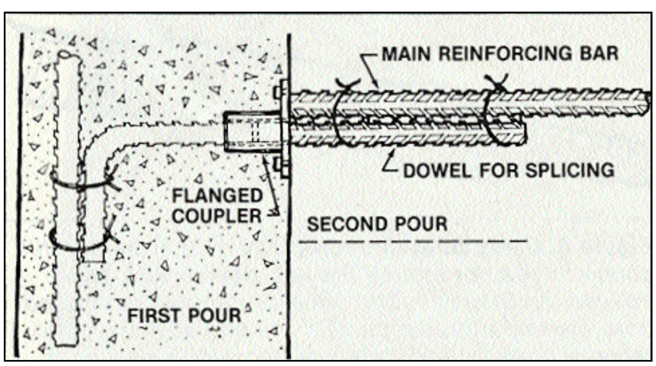

Figure 11. Substitute for standard dowel bar as used at construction joint (showing lap with main bars). A flanged coupler (shown) or integrally flanged dowel is attached to the form bulkhead for first placement of concrete. After forms are stripped, a threaded dowel of suitable length to complete the lap splice is inserted into the coupler.

Both the integral threaded dowel splice system and the flanged threaded coupler system are available with prefabricated hooked bars. When these systems replace standard splicing dowels, they provide a more efficient way to create a lap splice at the construction joint (Figure 11). Since codes prohibit lap splicing of #14 and #18 bars in tension, these splices therefore have limited applicability for the two largest reinforcing bar sizes.

Prefabricated dowel assemblies—generally #6 or smaller bars—with ends bent and concealed in protective boxes or plastic strips have been attached directly to bulkhead forms to meet certain reinforcement continuity needs. However, they are beyond the scope of this article.

CONCLUSIONS

As a result of changing concepts, ideas, and philosophies, a wide variety of rebar splicing methods has been developed—some better than others. We believe the ideal splice would have just one connection for one splice, although many of the devices described don't meet this condition. Many splice systems were developed to meet immediate needs with little thought for future possibilities. Others have been developed to allow for coated bars, unique customizing, and proper alignment of hooked bars. Construction teams are now finding it economical to splice across construction joints (dowel splicing).

Some design requirements have become more stringent. Both United States and Canadian nuclear codes require 90 to 100 percent of ultimate strength in splices, and they have more stringent limitations for load-displacement relationships. Corrosion effects have also had a significant impact on splice development. All of these things make it highly unlikely that any one splice system can effectively handle all applications. So, considerable care must be given in selection and use of a proper splice for best results.

References

1. “Building Code Requirements for Reinforced Concrete (ACI 318-83),” American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219.

2. Gustafson, David P. “Welded Splices of Reinforcing Bars,” CONCRETE CONSTRUCTION, October 1981, pages 807-811 and 842.

3. “Mechanical Connections of Reinforcing Bars (ACI 439.3R-83),” reported by ACI Committee 439; American Concrete Institute, P.O. Box 19150, Detroit, Michigan 48219.

4. “Reinforcement Anchorages and Splices,” Concrete Reinforcing Steel Institute, 933 North Plum Grove Road, Schaumburg, Illinois 60195. Second edition (1984) is now available.

For more information

Comprehensive generic information on many of the devices described in this article is available in References 3 and 4 from the American Concrete Institute and the Concrete Reinforcing Institute, respectively.