A P P E N D I C E S

NCHRP 12-105

Standard Method of Test for

Mechanically Spliced Steel Reinforcing Bars

AASHTO Designation: M xxx-yy[1]

Technical Section: No., Name

Release: Group n (Month yyyy)

American Association of State Highway and Transportation Officials
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1. SCOPE

1.1. These test methods cover monotonic, cyclic, and dynamic testing procedures for the determination of mechanical properties of mechanically spliced A615 and A706 Grade 60 steel reinforcing bars that are used in the plastic hinge region of ductile members, such as bridge columns subjected to moderate and high seismic loads.

1.2. In addition to satisfying the criteria specified in this document, mechanical splices shall meet the requirements for non-seismic loads.

2. REFERENCED STANDARDS

2.1. *AASHTO Standards*:

- T244, Standard Method of Test for Mechanical Testing of Steel Products

2.2. *ASTM Standards*:

- ASTM A 370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products
- ASTM A 615, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
- ASTM A 706, Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement
- ASTM A 1034, Standard Test Methods for Testing Mechanical Splices for Steel Reinforcing Bars
- ASTM E 4, Standard Practices for Force Verification of Testing Machines
- ASTM E 8, Standard Test Methods for Tension Testing of Metallic Materials
- ASTM E 83, Standard Practice for Verification and Classification of Extensometer Systems
- ASTM E 2309, Standard Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines

3. TERMINOLOGY

3.1. *Definitions of Terms Specific to This Standard:*

3.1.1. *Bar Region*–A length of the spliced bar outside the coupler region (Figure 1) that is utilized for the strain measurement of spliced bars.

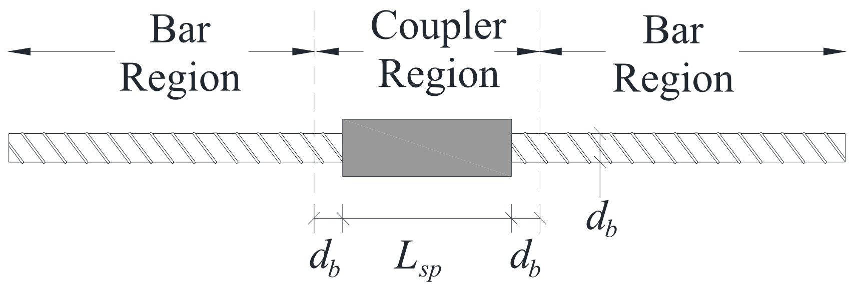


Figure 1—Coupler and bar regions

3.1.2. *Coupler*–Device for joining reinforcing bars for the purpose of providing transfer of either axial compression or axial tension or both from one bar to the other. The terms "coupler" and "splice" are interchangeable in this document.

3.1.3. *Coupler Region*–A length consisting of the total length of the coupler (L_{sp}) plus one bar diameter on each end of the coupler (Figure 1).

3.1.4. *Coupler Rigid Length Ratio (β)*–A ratio that represents the rigidity of a coupler. Rigidity of a coupler depends on the anchoring mechanism of the coupler and includes the effect of coupler elongation, bar elongation inside the coupler, and the slippage of the spliced bars inside the coupler.

3.1.5. *Fracture*–Physical rupture or breaking of bars or couplers.

3.1.6. *Lot*–A lot includes 150 count, or fraction thereof, of the same type of either reinforcing bars or mechanical bar splice for each bar size and bar deformation pattern.

3.1.7. *Mechanical Bar Splices*–Mechanical devices that are used to connect two reinforcing bars. The term "coupler" is frequently used for mechanical bar splices.

3.1.8. *Necking*–The onset of nonuniform or localized plastic deformation, resulting in a localized reduction of cross-sectional area

3.1.9. *Plastic Range*–A strain range between the yield and the ultimate points in the stress-strain relationship of a reinforcing bar or splice.

3.1.10. *Samples*–Reinforcing bars from the same lot.

3.1.11. *Seismic Splices*–Couplers that are not longer than $15d_b$ and exhibit bar fracture outside the coupler region with a strength that is at least 95% of the tensile strength of a corresponding "unspliced specimen" as defined below. All the spliced test specimens shall meet these requirements to be considered as a "seismic splice."

3.1.12. *Spliced Specimen*–A specimen including a coupler and two spliced bars connected to the coupler.

3.1.13. *Strain*–The ratio of the elongation of the test specimen within the initial gauge length to the initial gauge length, per ASTM E 6.

3.1.14. *Stress*–The ratio of the applied load to the sample nominal cross-section area, see ASTM E 6.

3.1.15. *Ultimate Tensile Strength*–Per ASTM E 6, the maximum tensile stress a mechanically spliced bar is capable of sustaining.

3.1.16. *Ultimate Strain*–The strain corresponding to the maximum tensile stress in a stress-strain relationship.

3.1.17. *Unspliced Specimen*–A single-bar specimen used to determine benchmark mechanical properties of bars.

4. SAFETY PRECAUTIONS

4.1 The test samples are heavy and may contain sharp edges or burrs. Sample fracture may involve brittle fractures and ejection of sample fragments. Use appropriate safety measures.

4.2 It is the responsibility of the user of this test method to establish appropriate safety practices and determine the applicability of regulatory limitations prior to use. Prior to handling, testing or disposing of any materials, testers must be knowledgeable about safe laboratory practices and personal protective apparel and equipment.

5. MATERIALS, TESTING APPARATUS AND OPERATIONS

5.1. *Testing Machines*–Tensile testing machines shall conform to the requirements of ASTM E 4. Components of testing machines such as grips, measurement devices, and calibration of the machines shall conform to the requirements of ASTM E 8 and ASTM A 370.

5.2 *Displacement Measuring Devices*–Displacement measuring devices such as dial indicators and LVDTs shall conform to the requirements of Class-A ASTM E 2309.

5.2.1 *Extensometers*–Extensometers used in strain measurement shall conform to the requirements of ASTM E 83. Use Class B2 or better extensometers.

5.2.2 *Caliper*–A calibrated caliper with an accuracy of 0.001 *in*. or better.

5.3 *Samples*–Each test sample shall conform to the following requirements:

5.3.1 Sample length: For No. 9 bars and smaller, sample length must be at least 5 *ft*. For No. 10 bars and larger, sample length must be at least 7.5 *ft*.

5.3.2 Spliced specimen length: The lab may shorten, machine, or otherwise alter the submitted sample length to meet the configuration of its testing equipment. The minimum length of the spliced specimen between the grips of the tensile testing machine shall be $L_{sp} + 16d_b$, where L_{sp} is the coupler length, and d_b is the nominal bar diameter of the larger spliced bar. The center of the coupler shall be located at the center of the test specimen. The unspliced and spliced specimens for each test shall be taken from the same lot.

5.5.3 Alignment: The alignment along the test sample must be straight to within 0.5 *in*. along any 3 *ft* of the length of the sample.

MONOTONIC TEST

6. SAMPLING AND NUMBER OF SPECIMENS

6.1. Monotonic tensile testing of unspliced and spliced specimens is required for each bar size and shall be performed according to ASTM A 370. Additional requirements for spliced specimens are referenced in ASTM A 1034. Test four samples for each lot.

7. UNSPLICED SPECIMEN - PROCEDURE

7.1 Apply an axial tensile load to the unspliced specimen to fracture. Follow ASTM E 8 and AASHTO T244 speed testing guidelines.

7.2 A full stress-strain curve can be obtained using continuous measurement (e.g. 8-*in*. extensometer and data acquisition system) (Figure 2a) or discontinuous measurement (dial or digital indicators) (Figure 2b).

7.3 Steps for the discontinuous method are:

7.3.1 Measure the initial gauge length using a caliper. An 8-in. gauge length is recommended.

7.3.2 Mount the unspliced specimen in the tensile test machine.

7.3.3 Attach two displacement measuring devices so that their indicators are 180° apart.

7.3.4 Apply an axial stress of 30 *ksi*. Maintain this stress until a stable reading is obtained from both indicators. Record the two indicator readings then take the average of the two readings. Increase the stress to 90% the nominal yield strength and record the average of the two indicator readings.

7.3.5 After the two initial readings in the elastic rage, more frequent reading is needed to properly capture the plastic range of the stress-strain diagram. At least 10 data points are needed in the plastic range. The appropriate readings (force in the plastic range) may be obtained when the indicators show values corresponding to strains equal to 0.005, 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, and 0.01 *in./in*. Readings with an interval of 0.01 *in./in*. should be continued until bar fractures.

7.3.6 Remove the displacement measuring devices.

7.3.7 Report the full-stress-strain curve for the unspliced specimen (Figure 3)

Note 1— For an unspliced specimen, the measurement is valid only when the bar fractures within the instrumented gauge length.

(a) Unspliced Specimen – Continuous Reading (b) Unspliced Specimen – Discontinuous Reading

Figure 2—Test setup and minimum length requirements for unspliced specimens

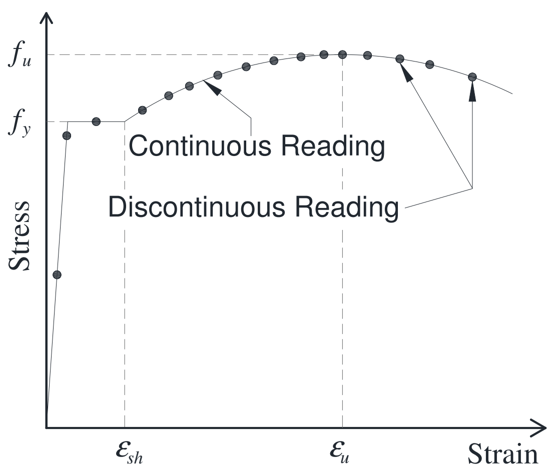


Figure 3—Measured stress-strain diagram for unspliced specimens

8. SPLICED SPECIMEN – PROCEDURE

8.1 Apply an axial tensile load to the spliced specimen to fracture. Follow ASTM E 8 and AASHTO T244 speed testing guidelines.

8.2 A full stress-strain curve can be obtained using continuous measurement (e.g. LVDT or coupler extensometer and data acquisition system) (Figure 4a), or discontinuous measurement (dial or digital indicators) (Figure 4b).

8.3 Steps for the discontinuous method are:

8.3.1 Measure the initial gauge length using a caliper. The gauge length shall be taken as $L_{cr} = L_{sp} + 2\alpha d_b$, where Alpha shall not exceed two. Alpha equal to 1.0 is used in Figure 4.

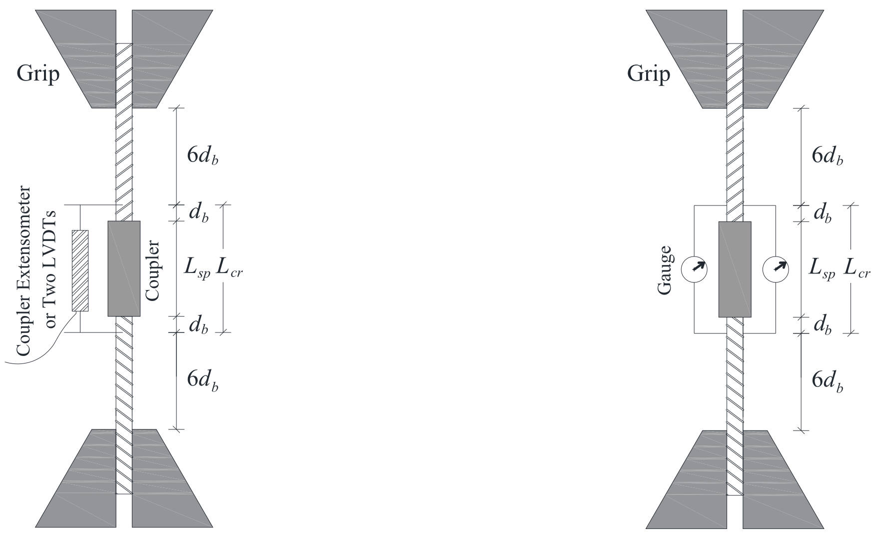
8.3.2 Mount the spliced specimen in the tensile test machine as shown in Figure 4b.

8.3.3 Attach two displacement measuring devices so that their indicators are 180° apart.

8.3.4 Once the setup is complete, stress the smaller spliced specimen to 3 *ksi* in the bar then zero out both indicators.

8.3.5 Apply an axial stress of 30 *ksi* in the smaller spliced bar. Maintain this stress until a stable reading is obtained from both indicators. Record the two dial indicator readings then take the average of the two readings. Increase the stress to 90% the nominal yield strength and record the average of the two indicator readings.

8.3.6 After two initial readings in the elastic rage, more frequent reading is needed to properly capture the plastic range of the stress-strain diagram. At least 10 data points are needed in the plastic range. The appropriate readings (force in the plastic range) may be obtained when the indicators show values corresponding to strains equal to 0.005, 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, 0.05, and 0.055 *in./in.* Readings with an interval of 0.005 *in./in.* should be continued until bar fractures.



(a) Spliced Specimen – Continuous Reading (b) Spliced Specimen – Discontinuous Reading

Figure 4—Test setup and minimum length requirements for spliced specimens

8.4 Remove the displacement measuring devices.

8.5 Report the mode of failure (bar fracture, bar pullout, or coupler fracture) and the location of the failure.

8.6 Report the full-stress-strain curve for spliced specimen (Figure 5).

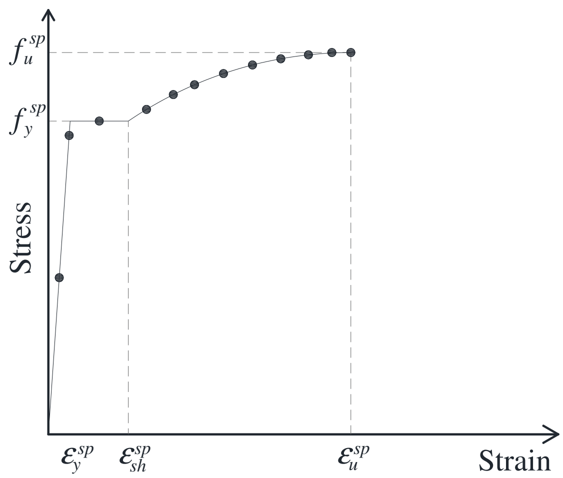


Figure 5—Measured stress-strain diagram for the spliced specimens

8.7 Superimpose the stress-strain curve of the spliced specimen with that measured for the unspliced specimen (Figure 6). Draw two vertical lines, one at the start of strain hardening (Line 1) and the other at the ultimate points of the stress-strain diagram for the spliced bar (Line 5). Draw additional three vertical lines between the two with equal spacing and determine the stresses (f_i) and strains (ε_{sp}^i) at five points on the diagram, with the first and last being the yield and ultimate points. Using the stresses (f_i), determine the associated strains on the stress-strain diagram for the unspliced bar (ε_s^i). This will lead to five strain values each for the spliced and unspliced bars. Calculate the coupler rigid length ratio, β_i, for each pair of strains:

$$\beta_i = (1 - \frac{\varepsilon_{sp}^i}{\varepsilon_s^i})(\frac{L_{cr}}{L_{sp}}) \qquad (1)$$

Calculate the coupler rigid length ratio, β, for spliced specimen as

$$\beta = \frac{1}{N}\sum \beta_i \qquad (2)$$

where N is the number of the data points. Round up the calculated coupler rigid length ratio to the nearest 0.05 (e.g. 0.76 will be 0.80). The minimum and maximum calculated coupler rigid length ratios shall be 0.5 and 1.0, respectively ($0.5 \leq \beta \leq 1.0$).

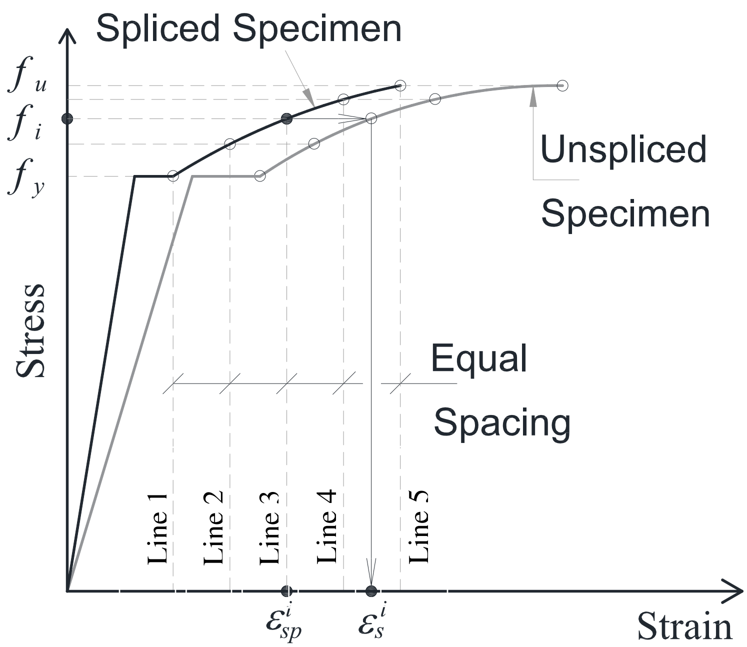


Figure 6—Calculation of coupler rigid length ratio based on stress-strain relationships

8.8 Report all β_i and β. The design value for the coupler rigid length ratio may be taken as the average for all the test specimens.

Note 2— When testing facility allows continuous measurement with multiple channels using a data acquisition system, the stress-strain curve for the unspliced bar may be measured during the testing of a spliced sample. A pair of extensometers, one for each potential bar fracture zone outside the coupler region, may be used for this purpose. In this case, the ratio of the coupler region strain to the bar region strain can be directly calculated using the continuous dataset but utilizing the strain data for the extensometer in which the spliced bar fractures. Subsequently, the coupler rigid length ratio can be calculated according to Equation 1 then Equation 2. All requirements such as number of specimens, testing device accuracy, testing speeds, results, etc., remain the same as those discussed in Sections 6 to 8.

Note 3— When the yield stress in the spliced and unspliced specimens is different due to scatter in data, use the strain at the start of strain hardening of the unspliced bar for ε_s^1.

Note 4— When the ultimate tensile strength in the spliced and unspliced specimens is different due to scatter in data, use the ultimate strain of the unspliced bar for ε_s^5.

Note 5— Ignore any point at which the stress in the spliced bar exceeds the ultimate tensile strength of the unspliced bar. This could occur due to data scatter.

8.9 Report whether or not the coupler meets the requirements of the "seismic splice" under monotonic loading

Note 6— A coupler is not qualified as a seismic splice if the failure mode in any of the four samples is bar fracture inside coupler, bar pullout, or coupler failure. For a spliced specimen, the strain measurement is valid only when the bar fractures outside the coupler region and outside the grip. When bar raptures outside the coupler but within the coupler region (defined as the coupler length plus one bar diameter on each side), another spliced specimen may be tested solely to obtain reliable strain data. Report measured data and mode of failure for all five specimens.

CYCLIC TEST

9. DESCRIPTION, SAMPLING AND NUMBER OF SPECIMENS

9.1 Cyclic tensile testing of spliced specimens is required for product verification of a new coupler or that which has not been tested according to the cyclic test procedure presented herein, and that is intended to be used in the plastic hinge region of ductile members, such as bridge columns, see ASTM A 1034 for further information.

9.2 Test four samples for each lot. Continuous measurement as explained in the previous section is recommended. A cycle in this document refers to a half-cycle and consists of applying tensile axial loading to the specimen to a target stress or strain and unloading to zero force (or a small tensile forces).

10. PROCEDURE

10.1 Cyclically load the spliced specimen at 10%, 30%, 50%, 70%, 80%, 90%, and 100% of the ultimate tensile strength (f_u) of the spliced bar. Repeat each cycle of loading four times. Use a constant rate of prior-to-yielding or post-yielding specified in ASTM E 8.

Note 7— To avoid buckling of the test sample under accidental compressive loads, the tensile stress on the unloading branch of each cycle does not need to be less than 3 *ksi* in the larger of the spliced bar.

Note 8— The measured stress-strain data from a spliced specimen with the same coupler type, bar size, and reinforcement properties tested under monotonic loading may be used to determine the strains corresponding to the target cyclic stresses.

10.2 Report the mode of failure (bar fracture, bar pullout, or coupler fracture) and whether the fracture occurred inside or outside the coupler region. If continuous measurement is utilized, report the cyclic stress-strain graphs for the spliced specimens.

10.3 Report whether or not the coupler meets the requirements of the "seismic splice" under cyclic loading.

DYNAMIC TEST

11. DESCRIPTION, SAMPLING AND NUMBER OF SPECIMENS

11.1 Dynamic tensile testing of spliced specimens is required for product verification of a new coupler or that which has not been tested according to the dynamic test procedure presented herein, and that is intended to be used in the plastic hinge region of ductile members, such as bridge columns, see ASTM A 1034 for further information.

11.2 Test four samples for each lot. Continuous measurement as explained in previous sections is recommended

12. PROCEDURE

12.1 Load the spliced specimen with a strain rate of 30,000 micro-strain/sec (3.0%/sec) to fracture. The strain rate may be converted to the machine head displacement rate using a length which is equal to the grip-to-grip clear distance minus βL_{sp}. An error of up to 25% between the target and the achieved strain or displacement rate shall be allowed.

12.2 Report the mode of failure (bar fracture, bar pullout, or coupler fracture) and whether the fracture occurred inside or outside the coupler region. If continuous measurement is utilized, report the stress-strain graphs for the spliced specimens.

12.3 Report whether or not the coupler meets the requirements of the "seismic splice" under dynamic loading.

13. REPORT

13.1 A "Test Report" shall be developed including the items specified in the present document for each loading type. See ASTM A 1034 for additional requirements needed for the test report.

14. KEYWORDS

14.1. Mechanical splices; reinforcing bar testing; plastic hinge region.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLES OF STRAIN MEASURING DEVICES

X1.1. Photographs of different strain measuring devices for mechanical bar splices are presented in Figure X1.1.

(a) Device with dial indicators (California Test 670)

(b) Device with extensometer

(c) Device with two LVDTs

(d) Device with coupler extensometer

Figure X1.1—Different strain measuring devices for mechanical bar splices