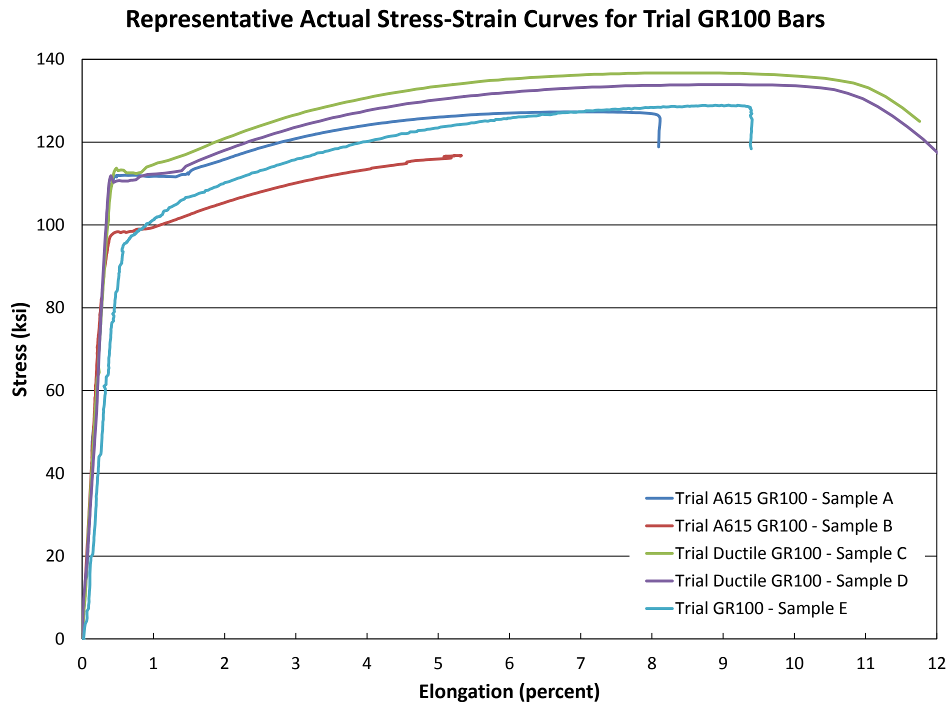
CHARLES PANKOW FOUNDATION - RGA #03-14
Proposed Specification for Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement

Vancouver, Washington



Final Report
July 10, 2015
WJE No. 2014.3158

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WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

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Proposed Specification for Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement

EXECUTIVE SUMMARY

As the primary activity funded by a research grant from the Charles Pankow Foundation (CPF), Wiss, Janney, Elstner Associates, Inc. (WJE) developed a complete draft of a proposed manufacturing specification for deformed steel reinforcing bars with controlled ductile properties having specified minimum yield strengths of up to 100,000 psi (690 MPa). This effort is in support of CPF's research project in the area of High Strength Steel Bar Reinforcement (High Strength Rebar). Considerable in-kind assistance was provided by the Concrete Reinforcing Steel Institute (CRSI), its Material Properties and Bar Producers Committee, CRSI producer members, and various CRSI task groups.

The proposed specification pertains to deformed steel bars with controlled ductile properties that are intended primarily for reinforcement in members of special seismic systems made of reinforced concrete. The proposed specification is different from current specifications for ductile deformed reinforcing bars in that it provides for ductile bars with specific minimum yield strengths as large as 100,000 psi (690 MPa). Additionally, in the proposed specification, the primary measure of ductility is the uniform elongation (uniform strain) developed in the bar, coincident with the attainment of actual tensile strength. This is in contrast to current industry practice, which measures elongation across the fracture point (the constricted or necked-down region) of the expended test piece.

The proposed specification provides tentative (“placeholder”) values for certain tensile property requirements for bars with minimum yield strengths of 80,000 psi and 100,000 psi, including specified minimum uniform elongation, specified minimum tensile strength-to-yield strength ratio, and pin diameter for bend testing. The tentative values were established on the basis of currently-available engineering information, from original research and from structural engineering publications. Laboratory tests on trial production of Grade 100 ductile reinforcing bars indicates that the industry is capable of manufacturing reinforcing bars that conform to the proposed specification. Final values for these tensile property requirements are anticipated to be established in the future on the basis of engineering research that is presently (mid-year 2015) underway and whose research results are anticipated to be available during 2016. It is also presently anticipated that this specification will enter into the consensus standardization process at ASTM International (ASTM) n the near future and be published as a new ASTM standard as early as 2017.

INTRODUCTION

As requested by the Charles Pankow Foundation (CPF), Wiss, Janney, Elstner Associates, Inc. (WJE) has developed a draft of a proposed manufacturing specification for deformed steel reinforcing bars with controlled ductile properties having specified minimum yield strengths of up to 100,000 psi (690 MPa). The development of the proposed specification was carried out as a part of CPF RGA #03-14, which was awarded to WJE on June 2, 2014 and subsequently amended on October 14, 2014. This research effort is in support of CPF's research project in the area of High Strength Steel Bar Reinforcement (High Strength Rebar).

The proposed specification pertains to deformed steel bars with controlled ductile properties that are intended primarily for reinforcement in members of special seismic systems made of reinforced concrete. The proposed specification is different from current specifications for deformed reinforcing bars in that it provides for ductile bars with specific minimum yield strengths as large as 100,000 psi. The proposed specification also provides for a measure of ductility that is different from the measure employed by current specifications. This report summarizes relevant background information, describes the development of the proposed specification, and presents the final CPF-funded draft of the proposed specification.

BACKGROUND

To establish the context under which the proposed specification was developed, this section: defines the terminology used for the various tensile properties of steel reinforcement; provides a brief summary of relevant historical and current manufacturing specifications for deformed steel reinforcing bars; and describes key differences between existing specifications and the proposed specification.

Stress-Strain Curve Terminology

The typical manufacturing specification for steel reinforcing bar specifies requirements for various tensile properties of the bar, such as yield strength, tensile strength and elongation, among others. The definitions for these parameters are perhaps best understood in the context of the relationship between stress and strain of a reinforcing bar. An idealized curve representing the tensile stress-strain relationship for sharply-yielding reinforcing steel, which is also generally applicable to any steel, is given in Figure 1. Key features are illustrated on the stress-strain curve and identified by notation, and definitions for the notation are given in a table appearing on the figure itself. The definitions are generally taken from ASTM E6 “Standard Terminology Relating to Methods of Mechanical Testing” and ASTM E8 “Standard Test Methods for Tension Testing of Metallic Materials,” with some minor modifications. The following properties will be mentioned frequently in this report:

- Yield Strength
- Tensile Strength
- Uniform Elongation
- Elongation after Fracture
- T/Y Ratio

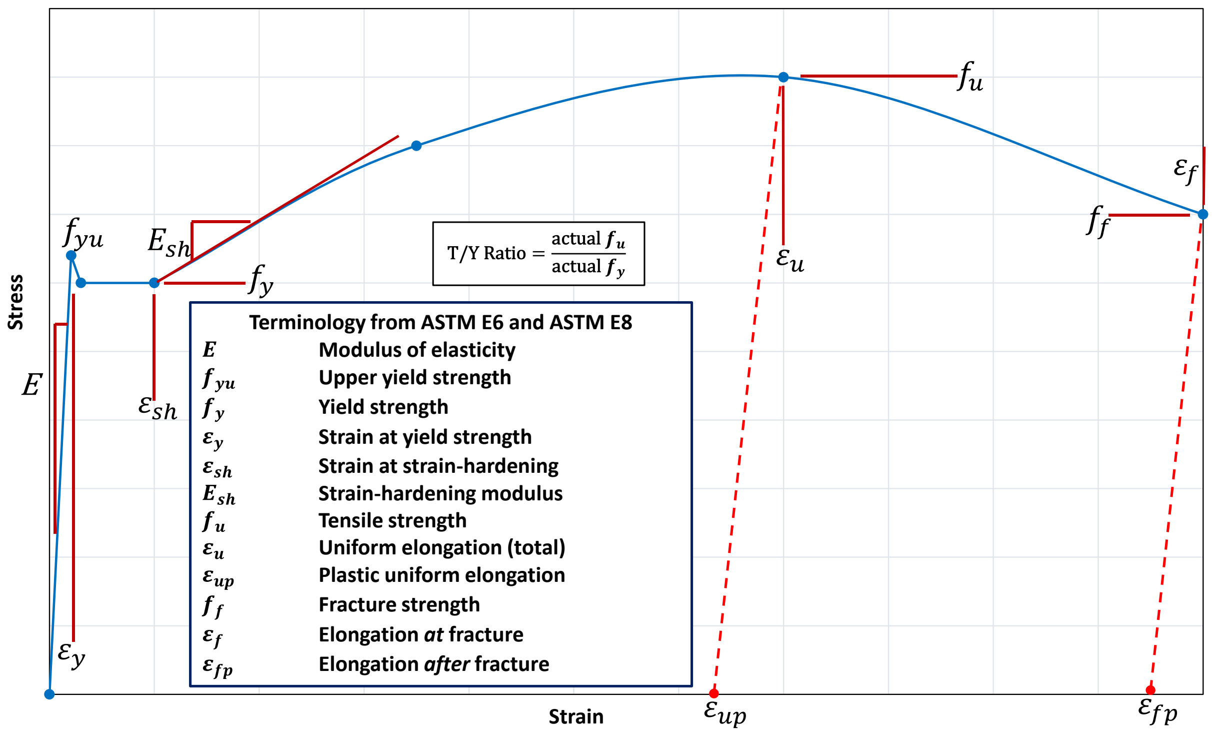

Figure 1. Notation for key features on the tensile stress-strain curve for ductile reinforcing bar, and definitions for the notation.

Historical Review

The first consensus-based manufacturing specification in the United States for reinforcing bar, "Standard Specification for Steel Reinforcement Bars," was adopted on August 21, 1911, by the American Society for Testing Materials, the predecessor organization of the American Society for Testing and Materials, and of today's ASTM International (ASTM). This specification provided for deformed bars of two grades: Structural Steel Grade having specified minimum yield strength of 33,000 psi, and Hard Grade having specified minimum yield strength of 50,000 psi. Ductility was specified to be measured as elongation after fracture using a gauge length of 8 inches, with specified minimum values for elongation being a function of the actual tensile strength of the bar. This specification eventually received the serial designation ASTM A15.

By 1962, ASTM A15 was modified. The 1962 edition of the specification included deformed bars of three grades: Structural Steel Grade having specified minimum yield strength of 33,000 psi, Intermediate Grade having specified minimum yield strength of 40,000 psi, and Hard Grade having specified minimum yield strength of 50,000 psi. Requirements for ductility remained generally the same as those of the earliest editions of the specification.

On February 14, 1968, Specification ASTM A615, "Deformed Billet-Steel Bars for Concrete Reinforcement," was adopted. This specification replaced ASTM A15. The 1968 edition of ASTM A615 included deformed bars of two grades: Grade 60 having specified minimum yield strength of 60,000 psi and Grade 75 having specified minimum yield strength of 75,000 psi. Ductility continued to be specified to be measured as elongation after fracture using a gauge length of 8 inches. However, the specified values for minimum elongation varied with size (diameter) and grade of the reinforcing bar. The 2015 edition of ASTM A615 includes five grades: Grade 40, Grade 60, Grade 75, Grade 80 and Grade 100, having specified minimum yield strengths, respectively, of 40,000 psi, 60,000 psi, 75,000 psi, 80,000 psi and 100,000 psi. Requirements for ductility in ASTM A615-15 remain generally the same as those of the earlier editions of the specification.

A reinforcing bar for applications where welding, ductility, or both are of importance was approved in 1974 under the designation ASTM A706, "Low-Alloy Steel Deformed Bars for Concrete Reinforcement." The first edition of this specification included only a single grade of reinforcement having specified minimum yield strength of 60,000 psi. As a result, the specification did not include any grade designation identifier. Nonetheless, the single grade of reinforcement become commonly referred to as Grade 60. The 2015 edition of ASTM A706 includes two grades: Grade 60 having a specified minimum yield strength of 60,000 psi and Grade 80 having a specified minimum yield strength of 80,000 psi. Beginning with the first edition of ASTM A706, requirements for ductility and for strain hardening have been specified: elongation after fracture measured using a gauge length of 8 inches; and the tensile-to-yield ratio (T/Y ratio), specified to be determined as the actual tensile strength divided by the actual yield strength. As with ASTM A615 reinforcement, the specified value for minimum elongation varies with size and grade of the reinforcing bar; the specified value for T/Y ratio, however, is a minimum of 1.25 for all sizes and grades of bar.

Proposed Specification

The proposed specification is for deformed steel bars with controlled ductile properties primarily intended for seismic applications. As described later in this report, the proposed specification provides for greater minimum yield strength than the current ductile, deformed bar specification (ASTM A706), and provides for a new measure of ductility, namely, uniform elongation. The proposed specification also places an emphasis on ductility over weldability, by making weldability requirements a purchaser-specified optional requirement. Arguably, the proposed specification represents the next step in the evolution of ductile, deformed steel reinforcing bars.

The consideration of seismic applications leads to the following requirements in the proposed specification:

1. A maximum yield strength is specified in addition to a minimum yield strength, in part to accommodate proportioning of reinforced concrete members according to the principles of capacity design;
2. A minimum T/Y ratio is specified to promote the spread of plasticity in members that are expected to behave inelastically; and
3. Requirements for minimum uniform elongation, coincident with the attainment of tensile strength, are specified, instead of elongation after fracture, because this is the maximum usable strain in the design of members expected to behave inelastically.

Further elaboration as to why these particular properties are relevant to seismic applications are beyond the scope of this report. The reader interested in these matters is referred to textbooks about seismic design of reinforced concrete structures, such as *Seismic Design of Reinforced Concrete Structures*, by Jack Moehle (New York: McGraw Hill Education, 2015), among others.

DEVELOPMENT OF THE PROPOSED SPECIFICATION

The proposed specification was developed during 2014 with the collaboration of the High Strength Bar Task Group of the Concrete Reinforcing Steel Institute (CRSI). The organization of the proposed specification is generally the same as that of ASTM A615-15 and ASTM A706-14. Common requirements, such as dimensions, deformations, purchasing, packaging and many others, are essentially unchanged from ASTM A615 and ASTM A706, except for a number of relatively minor changes made at the suggestion of the CRSI task group.

The January 29, 2015 draft of the "Proposed Standard Specification for Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement" is given in Appendix A. Significant changes and additions to requirements found in the proposed specification, relative to what is specified by ASTM A706 or ASTM A615, generally relate to aspects that are particular to ductile reinforcement and high-strength reinforcement. The following is a summary of these significant changes and additions:

1. The measure of ductility employed by the proposed specification is uniform elongation, or the strain at the peak of the engineering stress-strain curve, identified as ε_u in Figure 1. The proposed specification has no requirement related to elongation after fracture, identified as ε_{fp} in Figure 1, which is the measure of ductility employed by the current editions of ASTM A615 and ASTM A706.
2. Two methods for measurement of uniform ductility are included in the proposed specification: an autographic method and a manual method. Provisions of ASTM E8 are cited for the autographic method. The manual method described in Annex A1 of the proposed specification was developed as part of this research project.
3. At the suggestion of the CRSI task group, requirements related to weldability of the reinforcement have become a purchaser-specified optional requirement. The weldability requirements are generally modeled after those of ASTM A706, with some minor modifications.
4. The proposed bar mark for this type of ductile reinforcing bar is the letter D. The grade marks are the same as those used by ASTM A615-15, which now includes Grade 100 reinforcement.
5. A comprehensive set of tensile requirements and bend test requirements are included. These particular requirements, while believed to be realistic values that can be achieved in production today, should be considered tentative, "placeholder" values that are subject to change for reasons described later in this report.

Additional details about the development of the proposed specification are given in the following sections of this report, and also in the presentation slides given in Appendix B of this report.

Nominal Weights, Dimensions, and Deformation Requirements

Table 1 of the proposed specification, reproduced below, includes requirements related to nominal weights, nominal dimensions and deformation requirements. These requirements are unchanged from those specified in ASTM A706 and ASTM A615, except that the table does not include Bar Designation No. 20 that now appears in ASTM A615-15.

TABLE 1 Deformed Bar Designation Numbers, Nominal Weights [Masses], Nominal Dimensions, and Deformation Requirements

Bar Designation No.	Nominal Weight, lb/ft [Nominal Mass, kg/m]	Nominal Dimensions A			Deformation Requirements, in. [mm]		
		Diameter, in. [mm]	Cross-Sectional Area, in.^{2} [mm^2]	Perimeter, in. [mm]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5 % of Nominal Perimeter)
3 [10]	0.376 [0.560]	0.375 [9.5]	0.11 [71]	1.178 [29.9]	0.262 [6.7]	0.015 [0.38]	0.143 [3.6]
4 [13]	0.668 [0.994]	0.500 [12.7]	0.20 [129]	1.571 [39.9]	0.350 [8.9]	0.020 [0.51]	0.191 [4.9]
5 [16]	1.043 [1.552]	0.625 [15.9]	0.31 [199]	1.963 [49.9]	0.437 [11.1]	0.028 [0.71]	0.239 [6.1]
6 [19]	1.502 [2.235]	0.750 [19.1]	0.44 [284]	2.356 [59.8]	0.525 [13.3]	0.038 [0.97]	0.286 [7.3]
7 [22]	2.044 [3.042]	0.875 [22.2]	0.60 [387]	2.749 [69.8]	0.612 [15.5]	0.044 [1.12]	0.334 [8.5]
8 [25]	2.670 [3.973]	1.000 [25.4]	0.79 [510]	3.142 [79.8]	0.700 [17.8]	0.050 [1.27]	0.383 [9.7]
9 [29]	3.400 [5.060]	1.128 [28.7]	1.00 [645]	3.544 [90.0]	0.790 [20.1]	0.056 [1.42]	0.431 [10.9]
10 [32]	4.303 [6.404]	1.270 [32.3]	1.27 [819]	3.990 [101.3]	0.889 [22.6]	0.064 [1.63]	0.487 [12.4]
11 [36]	5.313 [7.907]	1.410 [35.8]	1.56 [1006]	4.430 [112.5]	0.987 [25.1]	0.071 [1.80]	0.540 [13.7]
14 [43]	7.65 [11.38]	1.693 [43.0]	2.25 [1452]	5.32 [135.1]	1.185 [30.1]	0.085 [2.16]	0.648 [16.5]
18 [57]	13.60 [20.24]	2.257 [57.3]	4.00 [2581]	7.09 [180.1]	1.58 [40.1]	0.102 [2.59]	0.864 [21.9]

A The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight [mass] per foot [metre] as the deformed bar.

Tentative Tensile Requirements and Bend Requirements

The draft of the proposed specification includes specific numerical values for the tensile requirements given in Table 2 of the proposed specification, reproduced below, and for bend test requirements given in Table 3 of the proposed specification, also reproduced below. The numerical values listed in these two tables should be considered tentative, "placeholder" values that are intended to be revised in the future based upon the results of physical testing of prototype, Grade 100 ductile deformed reinforcing bars, including tests of reinforced concrete members fabricated using the prototype Grade 100 bars. The supporting research is presently being carried out simultaneously at several institutions, with results of the research anticipated to be available towards year-end 2015 or early 2016. The origin of the tentative values that appear in the specification are described in the following paragraphs.

TABLE 2 - Tensile Requirements

	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
Tensile strength, min, psi [MPa]	80 000 [550]	100 000 [690]	120 000 [830]
Yield strength, min, psi [MPa]	60 000 [420]	80 000 [550]	100 000 [690]
Yield strength, max, psi [MPa]	78 000 [540]	98 000 [675]	118 000 [815]
Ratio of actual tensile strength to actual yield strength (T/Y), min.	1.25	1.21	1.17
Uniform elongation, min, %	8	7	6

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for 180 degree Bend Tests A		
	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
3, 4, 5 [10, 13, 16]	3*d*	3-1/2 *d*	4*d*
6, 7, 8 [19, 22, 25]	4*d*	5*d*	5*d*
9, 10, 11 [29, 32, 36]	6*d*	7*d*	7*d*
14, 18 [43, 57]	8*d*	9*d*	9*d*

A *d* = nominal diameter of specimen.

In Table 2 of the proposed specification, the specified minimum yield strength, specified maximum yield strength, and the specified minimum tensile strength listed for Grade 60 and Grade 80 are the same as those for Grade 60 and Grade 80, respectively, as specified in ASTM A706. The specified strengths given in the table for Grade 100 are 20,000 psi larger than those of Grade 80.

The T/Y ratio of 1.25 for Grade 60 is the same as that specified for Grade 60 in ASTM A706. For Grade 100, NIST GCR 14-917-30, *Use of High-Strength Reinforcement in Earthquake-Resistant Concrete Structures*, National Institute of Standards and Technology (NIST), March 2014, suggested that the Japanese requirement for a maximum yield-to-tensile (Y/T) ratio of 0.85 with metric Grade 685 [yield strength of 685 MPa, or 99.3 ksi] might be applied to ductile Grade 100 reinforcement for U.S. seismic applications.

Taking the reciprocal of 0.85 and truncating the result to two digits past the decimal point leads to the value of 1.17 for Grade 100 as listed in Table 2 of the proposed specification. Interpolation between the T/Y values for Grade 60 and Grade 100 leads to the value of 1.21 for Grade 80.

Uniform elongation tests were performed during 2014 at various producing mills under a test program coordinated by the Uniform Elongation Measurement Task Group of CRSI that was organized for the purpose of implementing trial methods for measuring uniform elongation. The resulting uniform elongation test data were analyzed to provide guidance for establishing tentative values for specified minimum uniform elongation in the proposed Table 2. The value of 8 percent strain for uniform elongation of Grade 60 was established on the basis of the 5 percent fractile of the uniform elongation measurements from 233 samples of bars produced as conforming to ASTM A706 Grade 60. An approximate analysis of a more limited set of measurements from 13 samples of ASTM A706 Grade 80 bars produced an estimated value of 7 percent strain for the 5 percent fractile of the test results. The data analyses are presented graphically in Figure 2. The 5 percent fractile values for Grades 60 and 80 were extrapolated to arrive at the value of 6 percent uniform elongation strain listed in the proposed Table 2 for Grade 100 ductile reinforcement.

Bend diameter requirements for Grade 60 and Grade 80 in proposed Table 3 are the same as those specified in ASTM A706 for Grade 60 and Grade 80, respectively. The bend diameter requirements for Grade 100 in the proposed Table 3 are the same as those of Grade 80, with the exception of that of the group of smallest bar sizes, which was increased slightly from the Grade 80 requirement, using the same incremental increase of bend diameter as presently exists when going from Grade 60 to Grade 80 in ASTM A706.

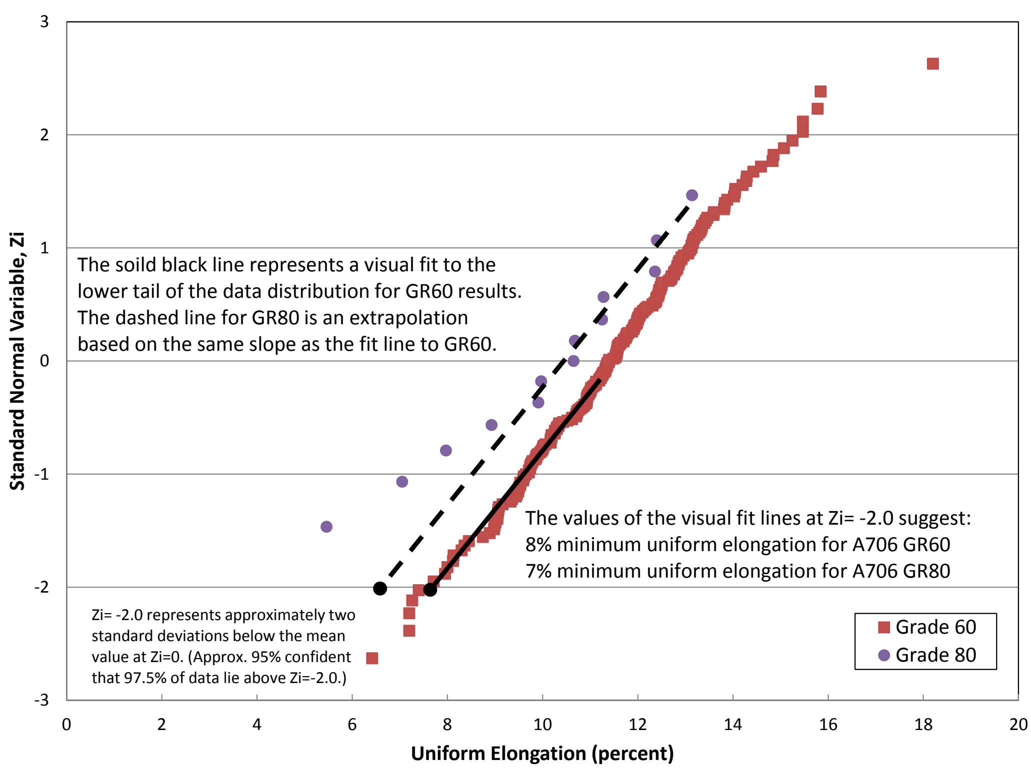

Figure 2. Results of uniform elongation measurements on ASTM A706 deformed bar reinforcement, Grade 60 and Grade 80, produced during 2014.

Manual Measurement of Uniform Elongation

While ASTM E8 includes requirements for autographic measurement of uniform elongation, there is no manual methodology for measurement of uniform elongation in steel bar reinforcement specified in any ASTM specification. Consequently, it was necessary to develop a manual measurement method for inclusion in the proposed specification. The manual method found in Annex A1 of the proposed specification was adapted from the manual methods described in International Standard ISO 15630-1, "Steel for the Reinforcement and Prestressing of Concrete - Test Methods - Part 1: Reinforcing Bars, Wire Rod and Wire," Second edition, October 15, 2010, and in Annex A of Canadian Standards Association G30.18-09, "Carbon Steel Bars for Concrete Reinforcement."

The manual method in the proposed specification relies upon a series of gauge marks placed upon the bar prior to testing, made in the same manner that gage marks are made for the existing manual method for measuring elongation after fracture, at a specified interval of one inch between marks and over a gauge length of at least 16 inches. The bar is then tested to destruction during a monotonic tension test, and after the test, a measurement is made between two marks, located suitably away from the point of rupture and outside of the necking zone, for which the distance between the same two marks before the tensile test was at least 4 inches. This is illustrated in Figure A1.1 of the proposed specification given in Appendix A to this report. The percentage uniform elongation, ε_u, at maximum force is specified in the proposed specification to be calculated using the formula:

$$\varepsilon_u = \left[\frac{L - L_0}{L_0} + \frac{f_u}{E}\right] \times 100$$

STATUS OF PROPOSED SPECIFICATION

Appendix A of this report provides the draft dated January 29, 2015 of the "Proposed Standard Specification for Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement." This draft of the proposed specification represents the completion of the tasks under CPF RGA #03-14 that are related to development of a manual method for measuring uniform elongation and to the development of a proposed standard for ductile, high-strength reinforcing bars.

Formal Standardization

Further development of the proposed specification is intended to be taken up by the Bar Producers and Material Properties Committee of CRSI. Presently (mid-year 2015), members of this committee who are also members of ASTM intend to apply to ASTM to develop a new standard specification for ductile, deformed reinforcing bars, based on the January 29, 2015 draft of the proposed specification.

Establishing Final Tensile and Bend Test Requirements

At the present time (mid-year 2015), engineering research under the sponsorship of the CPF is underway at the University of California Berkeley, the University of Texas at Austin, and at the University of Kansas to provide data to be used for selection of final values in the proposed specification for specified minimum T/Y ratio, specified minimum uniform elongation, and specified pin diameter for bend tests. Other tensile property parameters listed in the proposed specification may be adjusted based on these and other engineering research results. It is anticipated that the research results will become available towards the end of 2015 or the beginning of 2016.

ACTUAL STRESS-STRAIN CURVES FOR TRIAL GRADE 100 BARS

During 2013 and 2014, producer members of CRSI voluntarily manufactured trial batches of various types of Grade 100 deformed steel reinforcing bars. Some bars were intended to be ductile reinforcement, similar to bars conforming to the Grade 100 requirements of the proposed specification described in this report, and some bars were intended to conform to what is now specified as Grade 100 in ASTM A615-15. Samples of the trial batch reinforcing bars were submitted to WJE for purposes of monotonic tensile testing to record actual stress-strain curves. The tests were carried out in general conformance to ASTM A370, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products". A representative selection of actual stress-strain curves are given in Figure 3. These laboratory tests indicate that the industry is capable of manufacturing ductile Grade 100 reinforcing bars that conform to the proposed specification, including the tentative tensile requirements for uniform elongation and T/Y ratio listed in Table 2 of the proposed specification.

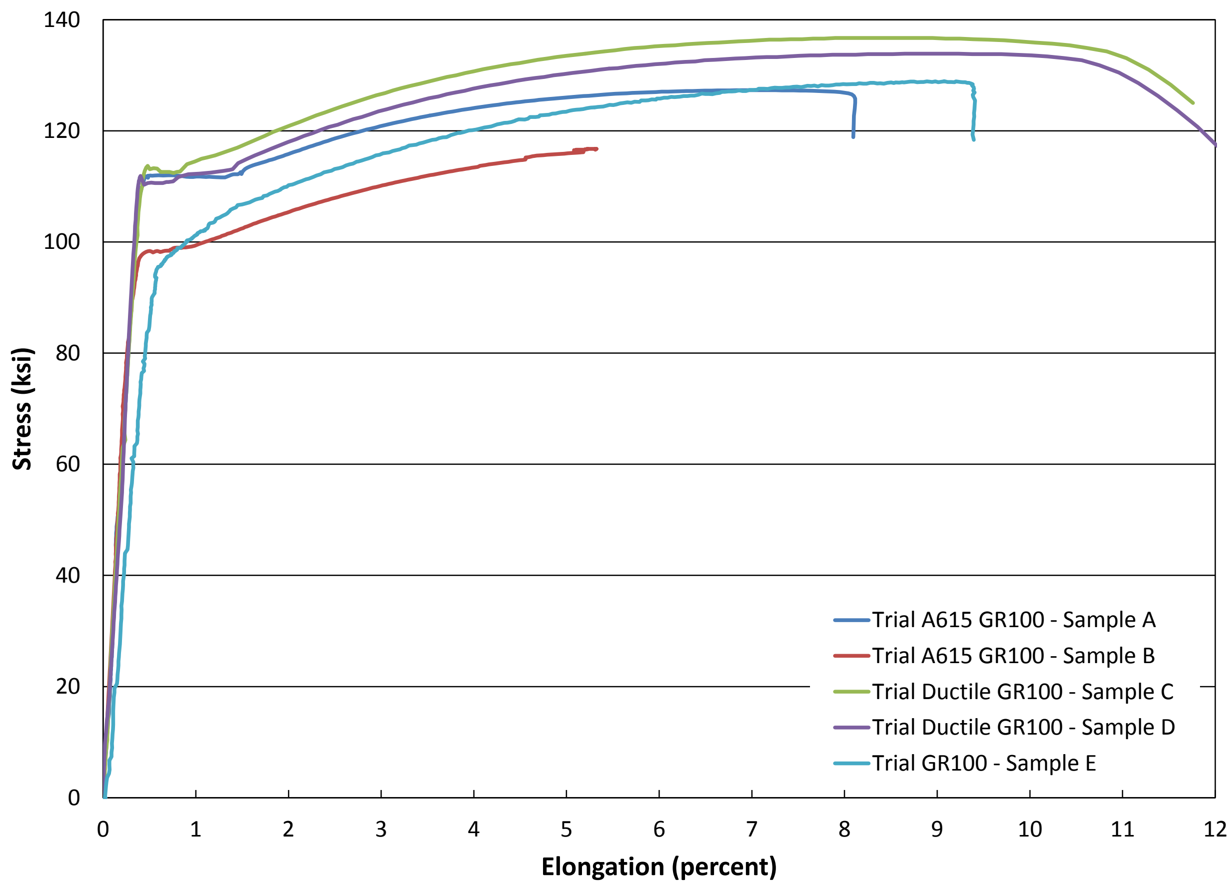

Figure 3. Actual stress-strain curves from representative samples of trial production Grade 100 deformed steel reinforcing bars.

SUMMARY

Under funding provided by the Charles Pankow Foundation, Wiss, Janney, Elstner Associates, Inc. developed a complete draft of a proposed standard specification for manufacturing of deformed steel reinforcing bars with controlled ductile properties having specified minimum yield strengths of up to 100,000 psi (690 MPa). This effort is in support of the Foundation's research project in the area of High Strength Steel Bar Reinforcement (High Strength Rebar). Considerable in-kind assistance was provided by the Concrete Reinforcing Steel Institute, its Material Properties and Bar Producers Committee, its producer members, and its various task groups.

The requirements for controlled ductile properties in the proposed specification are intended to provide steel bar reinforcement that is suitable for applications in special seismic systems made of reinforced concrete. The proposed specification is different from current specifications for ductile deformed reinforcing bars in that it provides for ductile bars with specific minimum yield strengths as large as 100,000 psi (690 MPa). Additionally, in the proposed specification, the primary measure of ductility is the uniform elongation (strain) developed in the bar at attainment of actual tensile strength. This is in contrast to current industry practice, which measures elongation across the fracture point (the constricted or necked-down region) of the expended test piece.

The proposed specification includes tentative ("placeholder") values for certain tensile property requirements, including specified minimum uniform elongation, specified minimum tensile strength-to-yield strength ratio, and pin diameter for bend testing. The tentative values were established on the basis of currently-available engineering information, from original research and from structural engineering publications. Laboratory tests on trial production of Grade 100 ductile reinforcing bars indicate that the industry is capable of manufacturing reinforcing bars that conform to the proposed specification. Final values for the tensile property requirements are anticipated to be established in the future on the basis of engineering research that is presently (mid-year 2015) underway and whose research results are anticipated to be available during 2016. It is also presently anticipated that the proposed specification will enter into the consensus standard development process at ASTM International in the near future and be published as a standard as early as 2017.

APPENDIX A:

DRAFT OF PROPOSED STANDARD AS OF JANUARY 29, 2015

DRAFT of a Proposed Standard Specification for Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement

1. Scope

NOTE 1—This draft of a proposed standard specification has not been reviewed or accepted under any standardized consensus process. The user of this specification assumes any and all risk associated with its use.

1.1. *General*—This specification covers deformed steel bars in cut lengths and coils for concrete reinforcement intended for applications where restrictive mechanical properties are required for compatibility with controlled tensile property applications. Where specified by the purchaser, additional restrictive chemical composition is required to enhance weldability. The standard sizes and dimensions of deformed bars and their number designations are given in Table 1.

NOTE 2—This specification does not include plain bar because it is not anticipated that plain bars will be used as longitudinal reinforcement in concrete members that comprise a seismic force-resisting system.

TABLE 1 Deformed Bar Designation Numbers, Nominal Weights [Masses], Nominal Dimensions, and Deformation Requirements

Bar Designation No.	Nominal Weight, lb/ft [Nominal Mass, kg/m]	Nominal Dimensions[A]			Deformation Requirements, in. [mm]		
		Diameter, in. [mm]	Cross-Sectional Area, in.^{2} [mm^2]	Perimeter, in. [mm]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5 % of Nominal Perimeter)
3 [10]	0.376 [0.560]	0.375 [9.5]	0.11 [71]	1.178 [29.9]	0.262 [6.7]	0.015 [0.38]	0.143 [3.6]
4 [13]	0.668 [0.994]	0.500 [12.7]	0.20 [129]	1.571 [39.9]	0.350 [8.9]	0.020 [0.51]	0.191 [4.9]
5 [16]	1.043 [1.552]	0.625 [15.9]	0.31 [199]	1.963 [49.9]	0.437 [11.1]	0.028 [0.71]	0.239 [6.1]
6 [19]	1.502 [2.235]	0.750 [19.1]	0.44 [284]	2.356 [59.8]	0.525 [13.3]	0.038 [0.97]	0.286 [7.3]
7 [22]	2.044 [3.042]	0.875 [22.2]	0.60 [387]	2.749 [69.8]	0.612 [15.5]	0.044 [1.12]	0.334 [8.5]
8 [25]	2.670 [3.973]	1.000 [25.4]	0.79 [510]	3.142 [79.8]	0.700 [17.8]	0.050 [1.27]	0.383 [9.7]
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11 [36]	5.313 [7.907]	1.410 [35.8]	1.56 [1006]	4.430 [112.5]	0.987 [25.1]	0.071 [1.80]	0.540 [13.7]
14 [43]	7.65 [11.38]	1.693 [43.0]	2.25 [1452]	5.32 [135.1]	1.185 [30.1]	0.085 [2.16]	0.648 [16.5]
18 [57]	13.60 [20.24]	2.257 [57.3]	4.00 [2581]	7.09 [180.1]	1.58 [40.1]	0.102 [2.59]	0.864 [21.9]

[A] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight [mass] per foot [metre] as the deformed bar.

1.2. *Grade*—Bars are of three minimum yield strength levels: namely, 60 000 psi [420 MPa], 80 000 psi [550 MPa], and 100 000 psi [690 MPa], designated as Grade 60 [420], Grade 80 [550], and Grade 100 [690], respectively.

1.3. *Controlled Tensile Properties*—This specification limits tensile properties (Table 2) to provide the desired yield/tensile properties for controlled tensile property applications. Uniform elongation is used as the primary measure of ductility. Methods for measuring uniform elongation are presented in mandatory Annex A1. (See Note 3.)

NOTE 3—The yield and tensile properties of this specification (Table 2) are established in part with consideration for seismic applications. This consideration leads to the use of uniform elongation as the measure of ductility; measurement of elongation after fracture is not a requirement of this specification.

1.4. *Weldability*—Requirements for additional limits on chemical composition and carbon equivalent to enhance the weldability of the material are presented in Annex A2. The requirements in Annex A2 only apply when specified by the purchaser (see 4.2.4).

1.5. Requirements for alternate bar sizes are presented in Annex A3. The requirements in Annex A3 only apply when specified by the purchaser (see 4.2.3).

1.6. The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes, excluding those in tables, shall not be considered as requirements of this specification.

1.7. This specification is applicable for orders in either inch-pound units or in SI units.

1.8. The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with this specification.

1.9. This specification does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this specification to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1. ASTM Standards:

A6/A6M Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
A370 Test Methods and Definitions for Mechanical Testing of Steel Products
A510/A510M Specification for General Requirements for Wire Rods and Coarse Round Wire, Carbon Steel, and Alloy Steel
A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
A700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Shipment (Withdrawn 2014)
A706/A706M Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement
A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
E6 Terminology Related to Methods of Mechanical Testing
E8/E8M Test Methods and Definitions for Mechanical Testing of Steel Products
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

2.2. AWS Standard:

AWS D1.4/D1.4M Structural Welding Code—Reinforcing Steel

2.3. U.S. Military Standard:

MIL-STD-129 Marking for Shipment and Storage

2.4. U.S. Federal Standard:

Fed. Std. No. 123 Marking for Shipment (Civil Agencies)

3. Terminology

3.1. Definitions of Terms Specific to This Specification:

3.1.1. *deformations, n*—transverse protrusions on a deformed bar.
3.1.2. *deformed bar, n*—steel bar with protrusions; a bar that is intended for use as reinforcement in reinforced concrete and related construction.

3.1.2.1. *Discussion*—The surface of the bar is provided with lugs or protrusions that inhibit longitudinal movement of the bar relative to the concrete surrounding the bar in such construction. The lugs or protrusions conform to the provisions of this specification.

3.1.3. *plain bar, n*—steel bar without protrusions.
3.1.4. *rib, n*—longitudinal protrusions on a deformed bar.

3.2. In addition, the following common terms from Test Methods E8 are defined:

3.2.1. *uniform elongation*, ε_u, [%], *n*—the elongation determined at the maximum force sustained by the test piece just prior to necking or fracture, or both.

3.2.1.1. Discussion—Uniform elongation includes both elastic and plastic elongation.

3.2.2. *elongation after fracture, n*—the elongation measured by fitting the two halves of the broken specimen together.
3.2.3. *elongation at fracture, n*—the elongation measured just prior to the sudden decrease in force associated with fracture.

4. Ordering Information

4.1. Orders for controlled-ductile-steel bars for concrete reinforcement under this specification shall contain the following information:

4.1.1. Quantity (weight) [mass],
4.1.2. Bar designation number (size) of deformed bars,

4.1.3. Cut lengths or coils,
4.1.4. Grade, and
4.1.5. ASTM designation and year of issue.

4.2. The purchaser shall have the option to specify additional requirements, including but not limited to, the following:

4.2.1. Special package marking requirements (20.2),
4.2.2. Other special requirements, if any,
4.2.3. Optional requirements of Annex A2, if applicable, and
4.2.4. Optional requirements of Annex A3, if applicable.

5. Material and Manufacture

5.1. The bars shall be processed from properly identified heats of mold-cast or strand-cast steel. The steel shall be made by any commercially accepted process.

6. Chemical Composition

6.1. The chemical analysis of each heat of steel shall be determined in accordance with Test Methods, Practices, and Terminology A751. The manufacturer shall make the analysis on test samples taken preferably during the pouring of the heat. The percentages of carbon, manganese, phosphorus, and sulfur shall be determined. (Note 4.)

Note 4: If the purchaser has optionally specified the additional requirements of Annex A2 for weldability, then the chemical composition requirements of A2.2 apply.

7. Requirements for Deformations

7.1. Deformations shall be spaced along the bar at substantially uniform distances. The deformations on opposite sides of the bar shall be similar in size, shape, and pattern.

7.2. The deformations shall be placed with respect to the axis of the bar so that the included angle is not less than 45°. Where the line of deformations forms an included angle with the axis of the bar from 45 to 70°, inclusive, the deformations shall reverse alternately in direction on each side, or those on one side shall be reversed in direction from those on the opposite side. Where the line of deformation is over 70°, a reversal in direction shall not be required.

7.3. The average spacing or distance between deformations on each side of the bar shall not exceed seven-tenths of the nominal diameter of the bar.

7.4. The overall length of deformations shall be such that the gap (measured as a chord) between the ends of the deformations shall not exceed 12.5 % of the nominal perimeter of the bar. Where the ends terminate in a rib, the width of the rib shall be considered as the gap between these ends. The summation of the gaps shall not exceed 25 % of the nominal perimeter of the bar. The nominal perimeter of the bar shall be 3.1416 times the nominal diameter.

7.5. The spacing, height, and gap of deformations shall conform to the requirements prescribed in Table 1.

8. Measurements of Deformations

8.1. The average spacing of deformations shall be determined by measuring the length of a minimum of 10 spaces and dividing that length by the number of spaces included in the measurement. The measurement shall begin from a point on a deformation at the beginning of the first space to a corresponding point on a deformation after the last included space. Spacing measurements shall not be made over a bar area containing bar marking symbols involving letters or numbers.

8.2. The average height of deformations shall be determined from measurements made on not less than two typical deformations. Determinations shall be based on three measurements per deformation, one at the center of the overall length and the other two at the quarter points of the overall length.

8.3. Insufficient height, insufficient circumferential coverage, or excessive spacing of deformations shall not constitute cause for rejection unless it has been clearly established by determinations on each lot (see Note 5) tested that typical deformation height, gap, or spacing do not conform to the minimum requirements prescribed in Section 7. No rejection shall be made on the basis of measurements if fewer than ten adjacent deformations on each side of the bar are measured.

NOTE 5—As used within the intent of 8.3, the term "lot" shall mean all the bars of one bar size and pattern of deformations contained in an individual shipping release or shipping order.

9. Tensile Requirements

9.1. The material, as represented by the test specimens, shall conform to the requirements for tensile properties prescribed in Table 2. (See Notes 6 and 7.)

NOTE 6—The tensile properties requirements listed for Grade 60 in Table 2 are the same as those specified for Grade 60 reinforcement in Specification A706/A706M, except that elongation in Table 2 is uniform elongation and the elongation specified in Specification A706/A706M is elongation after fracture. Regardless of the difference in the definition of elongation, Grade 60 reinforcement conforming to the requirements of Table 2 are anticipated to also conform to the requirements for Grade 60 reinforcement specified in Specification A706/A706M.

NOTE 7—The tensile properties listed in Table 2 are preliminary ("placeholder") values and are subject to change. The values listed have been established as follows. The requirements for Grade 60 [420] are the same as those for Grade 60 [420] manufactured according to Specification A706, with the exception of uniform elongation. Uniform elongation for Grade 60 [420] was established on the basis of the 5% fractile of uniform elongation data from tests on bars produced as conforming to Specification A706 Grade 60 [420]. The tests were performed during 2014 at the producing mills under a test program coordinated by a task group of the Concrete Reinforcing Steel Institute (CRSI). The values listed for Grade 100 [690] are based in part on NIST GCR 14-917-30, *Use of High-Strength Reinforcement in Earthquake-Resistant Concrete Structures*, National Institute of Standards and Technology (NIST), March 2014, with adjustments made to several recommended values. Grade 80 values are interpolated between the values for Grade 60 [420] and Grade 100 [690].

TABLE 2 - Tensile Requirements

	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
Tensile strength, min, psi [MPa]	80 000 [550]	100 000 [690]	120 000 [830]
Yield strength, min, psi [MPa]	60 000 [420]	80 000 [550]	100 000 [690]
Yield strength, max, psi [MPa]	78 000 [540]	98 000 [675]	118 000 [815]
Ratio of actual tensile strength to actual yield strength (T/Y), min.	1.25	1.21	1.17
Uniform elongation, min, %	8	7	6

9.2. The yield point or yield strength shall be determined by one of the following methods:

9.2.1. The yield point shall be determined by the halt-of-the-force method, where the steel tested has a sharp-kneed or well-defined yield point.

9.2.2. Where the steel does not have a well-defined yield point, the yield strength shall be determined by the offset method (0.2 % offset) as described in Test Methods and Definitions A370.

9.3. When material is furnished in coils, the test specimen shall be taken from the coil at a location away from the "hot rings" of the coil and shall be straightened prior to placing it in the jaws of the tensile testing machine. (See Note 8.)

NOTE 8—Straighten the test specimen to avoid formation of local sharp bends and to minimize cold work. Insufficient straightening prior to attaching the extensometer can result in lower-than-actual yield strength readings.

9.3.1. Test specimens taken from post-fabricated material shall not be used to determine conformance to this specification. (See Note 9.)

NOTE 9—Multiple bending distortion from mechanical straightening and from fabricating machines can lead to excessive cold work, resulting in higher yield strengths, lower elongation values, and a loss of deformation height.

9.4 The uniform elongation shall be as prescribed in Table 2 and shall be determined by the methods prescribed in Annex A1. (See Note 10.)

NOTE 10—There is no method prescribed in this specification for measurement of elongation at fracture or elongation after fracture. If the bar produced under this specification is to be also certified as conforming also to Specification

A615/A615M, Specification A706/A706M, or both, then there will be the need to additionally measure elongation after fracture because these specifications include a requirement for elongation after fracture.

10. Bending Requirements

10.1. The bend test specimen shall withstand being bent around a pin without cracking on the outside radius of the bent portion. The requirements for degree of bending and sizes of pins are prescribed in Table 3. When material is furnished in coils, the test specimen shall be straightened prior to placing it in the bend tester.

TABLE 3 Bend Test Requirements

Bar Designation No.	Pin Diameter for 180 degree Bend Tests [A]		
	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
3, 4, 5 [10, 13, 16]	3*d*	3-1/2 *d*	4*d*
6, 7, 8 [19, 22, 25]	4*d*	5*d*	5*d*
9, 10, 11 [29, 32, 36]	6*d*	7*d*	7*d*
14, 18 [43, 57]	8*d*	9*d*	9*d*

[A] *d* = nominal diameter of specimen.

10.2. The bend test shall be made on specimens of sufficient length to ensure free bending and with apparatus that provides:

10.2.1. Continuous and uniform application of force throughout the duration of the bending operation,

10.2.2. Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate,

10.2.3. Close wrapping of the specimen around the pin during the bending operation.

10.3. It is permissible to use more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fixed pin. When failures occur under more severe methods, retests shall be permitted under the bend-test method prescribed in 10.2.

11. Permissible Variation in Weight [Mass]

11.1. Deformed reinforcing bars shall be evaluated on the basis of nominal weight [mass]. The weight [mass] determined using the measured weight [mass] of the test specimen and rounding in accordance with Practice E29, shall be at least 94 % of the applicable weight [mass] per unit length prescribed in Table 1. In no case shall overweight [excess mass] of any deformed bar be cause for rejection.

12. Finish

12.1. The bars shall be free of detrimental surface imperfections.

12.2. Rust, seams, surface irregularities, or mill scale shall not be cause for rejection, provided the weight [mass], nominal dimensions, cross-sectional area, and tensile properties of a hand wire brushed test specimen are not less than the requirements of this specification.

12.3. Surface imperfections or flaws other than those specified in 12.2 shall be considered detrimental when specimens containing such imperfections fail to conform to either tensile or bending requirements. Examples include, but are not limited to, laps, seams, scabs, slivers, cooling or casting cracks, and mill or guide marks.

NOTE 11— Deformed reinforcing bars intended for epoxy coating applications should have surfaces with a minimum of sharp edges to achieve proper coverage. Particular attention should be given to bar marks and deformations where coating difficulties are prone to occur.

NOTE 12— Deformed reinforcing bars destined to be mechanically-spliced or butt-spliced by welding may require a certain degree of roundness in order for the splices to adequately achieve strength requirements.

13. Number of Tests

13.1. One tension test and one bend test shall be made of each bar size rolled from each heat.

13.2. One set of dimensional property tests including bar weight [mass] and spacing, height, and gap of deformations shall be made of each bar size rolled from each heat.

14. Retests

14.1. If the results of an original tension test specimen fail to meet the specified minimum requirements and are within 2000 psi [14 MPa] of the required tensile strength, within 1000 psi [7 MPa] of the required yield strength, or within one percentage unit of the required uniform elongation, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

14.2. If a bend test fails for reasons other than mechanical reasons or flaws in the specimen as described in 14.4.3 and 14.4.4, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification. The retest shall be performed on test specimens that are at air temperature but not less than 60°F [16°C].

14.3. If a weight [mass] test fails for reasons other than flaws in the specimen as described in 14.4.4, a retest shall be permitted on two random specimens from the same lot. Both retest specimens shall meet the requirements of this specification.

14.4. If the original test or any of the random retests fails because of any reasons listed in 14.4.1, 14.4.2, 14.4.3, or 14.4.4, the test shall be considered an invalid test:

14.4.1. The uniform elongation property of any tension test specimen is less than that specified and the fracture occurs within 2 inches [50 mm] or 2*d*, whichever is greater, from the grip.

14.4.2. When using the manual method of Annex A1, the location of the fracture does not permit a valid 4-inch minimum length for the uniform elongation measurement zone as defined in A1.5.3;

14.4.3. Mechanical reasons such as failure of testing equipment or improper specimen preparation;

14.4.4. Flaws are detected in a test specimen, either before or during the performance of the test.

14.5. The original results from a test found invalid according to 14.4.1, 14.4.2, 14.4.3, or 14.4.4, shall be discarded and the test shall be repeated on a new specimen from the same lot.

15. Test Specimens

15.1. All mechanical tests shall be conducted in accordance with Test Methods and Definitions A370 including Annex A9.

15.1.1. Uniform elongation shall be measured by the methods prescribed in Annex A1.

15.2. Tension test specimens shall be the full section of the bar as rolled. The unit stress determination shall be based on the nominal bar area.

15.3. Bend test specimens shall be the full section of the bar as rolled.

16. Test Reports

16.1. The following information shall be reported on a per heat basis. Report additional items as requested or desired.

16.1.1. Chemical analysis including the percentages of carbon, manganese, phosphorus, and sulfur. If the purchaser has optionally specified the additional requirements of Annex A2 for weldability, additionally include the percentages of silicon, copper, nickel, chromium, molybdenum, and vanadium.

16.1.2. If the purchaser has optionally specified the additional requirements of Annex A2 for weldability, additionally include carbon equivalent in accordance with A2.2.4.

16.1.3. Tensile properties.

16.1.4. Bend test results.

16.2. A Material Test Report, Certificate of Inspection, or similar document printed from or used in electronic form from an electronic data interchange (EDI) transmission shall be regarded as having the same validity as a counterpart printed in the certifier's facility. The content of the EDI transmitted document shall meet the requirements of the invoked ASTM standard(s) and conform to any EDI agreement between the purchaser and the manufacturer. Notwithstanding the absence of a signature, the organization submitting the EDI transmission is responsible for the content of the report.

NOTE 13—The industry definition invoked here is: EDI is the computer to computer exchange of business information in a standard format such as ANSI ASC X12.

17. Inspection

17.1. The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works that concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities to satisfy the inspector that the material is being furnished in accordance with this specification. All tests (except product (check) analysis) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be conducted so as not to interfere unnecessarily with the operation of the works.

17.2. *For Government Procurement Only*—Except as otherwise specified in the contract, the contractor shall be responsible for the performance of all inspection and test requirements specified herein and shall be permitted to use one's own or any other suitable facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the purchaser at the time of purchase. The purchaser shall have the right to perform any of the inspections and tests at the same frequency as set forth in this specification where such inspections are deemed necessary to assure that material conforms to prescribed requirements.

18. Rejection and Rehearing

18.1. Any rejection based on testing undertaken by the purchaser shall be promptly reported to the manufacturer.

18.2. Samples tested that represent rejected material shall be preserved for two weeks from the date rejection is reported to the manufacturer. In case of dissatisfaction with the results of the tests, the manufacturer shall have the right to make claim for a rehearing within that time.

19. Marking

19.1. When loaded for mill shipment, bars shall be properly separated and tagged with the manufacturer's heat or test identification number.

19.2. Each manufacturer shall identify the symbols of their marking system.

19.3. All bars produced to this specification shall be identified by a distinguishing set of marks legibly rolled onto the surface of one side of the bar to denote in the following order:

19.3.1. *Point of Origin*—Letter or symbol established as the manufacturer's mill designation.

19.3.2. *Size Designation*—Arabic number corresponding to bar designation number of Table 1.

19.3.3. *Type of Steel*—Letter *D* indicating that the bar was produced to this specification.

19.3.3.1. If the bar is produced to both the main part of this specification and Annex A2 for weldability, conformance to the weldability requirements of Annex A2 shall be documented in the test report with no additional requirement for physically marking the bar.

19.3.4. *Minimum Yield Strength Designation*—For Grade 60 [420] bars, the marking shall be either the number 60 [4] or a single continuous longitudinal line through at least five spaces offset from the center of the bar. For Grade 80 [550] bars, the marking shall be either the number 80 [6] or three continuous longitudinal lines through at least five spaces. For Grade 100 [690] bars, the marking shall be one of the following: the letter C; the number 100 [7]; or four continuous longitudinal lines through at least five spaces.

19.3.5. It shall be permissible to substitute an inch-pound size bar of Grade 60 for the corresponding metric size bar of Grade 420, an in-pound size bar of Grade 80 for the corresponding metric size bar of Grade 550, and an inch-pound size bar of Grade 100 for the corresponding metric size bar of Grade 690.

19.3.5.1. It is not permissible to substitute any alternatively sized bar produced according to Annex A3 for an inch-pound size bar or for a metric size bar. (See Note 14.)

Note 14— This restriction is established with consideration for seismic applications where actual maximum yield force (actual yield strength multiplied by bar nominal area) developed by a bar may be a design consideration.

20. Packaging and Package Marking

20.1. Packaging, marking, and loading for shipment shall be in accordance with Practices A700.

20.2. When specified in the purchase order or contract, and for direct procurement by or direct shipment to the U.S. Government, marking for shipment, in addition to requirements specified in the purchase order or contract, shall be in accordance with MIL-STD-129 for military agencies and with Fed. Std. No. 123 for civil agencies.

21. Keywords

21.1. ductile steel; concrete reinforcement; deformations (protrusions); steel bars; uniform elongation

ANNEXES

(Mandatory Information)

ANNEX A1. METHOD FOR MEASURING UNIFORM ELONGATION

A1.1 *Scope*

A1.1.1 This annex contains testing requirements that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail.

A1.2 *Test Specimens*

A1.2.1 All test specimens shall be the full section of the bar as rolled.

A1.3 *Tension Testing*

A1.3.1 *Test Procedure*— The tension testing shall be conducted in accordance with Test Methods and Definitions A370 including Annex A9. In the case of conflict between requirements provided in this annex and those found in Test Methods and Definitions A370 including Annex A9, the requirements of this annex shall prevail.

A1.3.2 *Test Specimen Length*— Specimens for tension tests shall be long enough to provide a free length that is sufficient for the measurement required by A1.5.3, plus the distances between any gauge mark and the grips as specified in A1.5.3, plus sufficient additional length to fill the grips completely leaving some excess length protruding beyond each grip. See also A1.5.1.

A1.3.3 *Gripping Device*— The grips shall be shimmed so that no more than 1⁄2 in. [13 mm] of a grip protrudes from the head of the testing machine.

A1.4 *Uniform Elongation*

A1.4.1 Uniform elongation shall be determined by either the manual method or by the autographic method. The test report shall indicate the method of determination (manual or autographic) used for uniform elongation.

A1.4.2 The manual method shall be as described in A1.5.

A1.4.3 The autographic method shall be as described in 7.9 of Test Methods E8. The gauge length for the extensometer used shall be a minimum of 4 inches [100 mm]. Longer gauge lengths are permitted.

A1.4.4 Uniform elongation shall include both plastic and elastic elongation.

A1.4.5 Where there is a conflict between results of uniform elongation measured by the manual method and measured by the autographic method, the results of the manual method shall prevail.

A1.5 *Manual Method for Uniform Elongation*— Measurement of uniform elongation by the manual method shall be as follows:

A1.5.1 Gauge marks shall be provided to determine the uniform elongation by the manual method. The free length between grips shall be marked every 1 in. [25 mm] along a gauge length that is at least 16 in. [400 mm] long. Longer gauge lengths may be necessary to accommodate the measurement described in A1.5.3. (See Note A1.1.) The tolerance on the distance between the marks shall allow the distance between any two marks to be measured with a tolerance of 0.02 inch [0.5 mm].

Note A1.1— The length of the test sample between grips should be made long enough to account for the possibility that the point of rupture will be near the middle of the test sample while also provding adequate length of bar between the necking zone and one of the grips to make the measurement specified in A1.5.3. The minimum gauge length specified in A1.5.1 may be insufficient for larger-diameter bars.

A1.5.2 The punch marks shall be put on one of the longitudinal ribs, if present, or in clear spaces of the deformation pattern, with the marks placed along a line parallel to the longitudinal axis of the bar. The punch marks shall not be put on a transverse deformation. Light punch marks are desirable because deep marks severely indent the bar and may affect the results. A bullet-nose punch is desirable.

A1.5.3 Select two marks, *y* and *v*, between which the distance before the tensile test was at least 4 inches [100 mm]. Both marks shall be on that side of the necking zone where the grip zone is farthest from the point of rupture. Neither mark shall be nearer to a grip than 2 inches [50 mm] or 2*d*, whichever is greater. In addition, neither mark shall be nearer to the point of rupture or center of the necking zone than 2 inches [50 mm] or 2*d*, whichever is greater. See Figure A1.1.

A1.5.4 The percentage uniform elongation, ε_u, at maximum force is calculated using the formula:

$$\varepsilon_u = \left[\frac{L - L_0}{L_0} + \frac{f_u}{E}\right] \times 100$$

where:

L=	length, in inches [mm], between selected marks, *y* and *v*, after fracture, shown in Figure A1.1
L_0=	distance, in inches [mm], between the same marks, *y* and *v*, before the test
f_u=	actual tensile strength, in psi [MPa]
E=	modulus of elasticity, taken to be 29,000,000 psi [200,000 MPa]

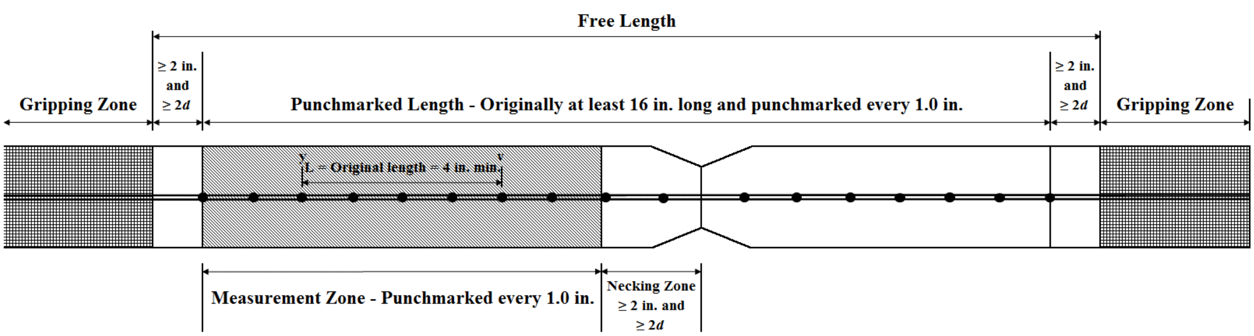

Figure A1.1 — Uniform elongation measurement.

ANNEX A2. CHEMICAL COMPOSITION TO ENHANCE WELDABILITY

A2.1 *Scope*

A2.1.1 This annex limits chemical composition (A2.2.2) and carbon equivalent (A2.2.4) to enhance the weldability of the material. When this steel is to be welded, a welding procedure suitable for the chemical composition and intended use or service should be used. The use of the latest edition of AWS D1.4/D1.4M Welding Code is recommended. AWS D1.4/D1.4M describes the proper selection of the filler metals, preheat/interpass temperatures, as well as, performance and procedure qualification requirements.

A2.1.2 This annex contains testing requirements that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail.

A2.2 *Chemical Composition to Enhance Weldability*

A2.2.1 The chemical analysis of each heat shall be determined in accordance with Test Methods, Practices, and Terminology A751. The manufacturer shall make the analysis on test samples taken preferably during the pouring of the heat. The percentages of carbon, manganese, phosphorus, sulfur, silicon, copper, nickel, chromium, molybdenum, and vanadium shall be determined.

A2.2.2 The chemical composition as shown by heat analysis shall be limited by the following:

Element	max, %
Carbon	0.30
Manganese	1.50
Phosphorus	0.035
Sulfur	0.045
Silicon	0.50

A2.2.3 Choice and use of alloying elements, combined with carbon, phosphorus, and sulfur to produce the mechanical properties prescribed in Table 2 and Table 3, shall be made by the manufacturer. Elements commonly used include manganese, silicon, copper, nickel, chromium, molybdenum, vanadium, columbium, titanium, and zirconium.

A2.2.4 The heat analysis shall be such as to provide a carbon equivalent (C.E.) not exceeding 0.55 % as calculated by the following formula:

$$\mathrm{C.E.} = \%\,\mathrm{C} + \frac{\%\,\mathrm{Mn}}{6} + \frac{\%\,\mathrm{Cu}}{40} + \frac{\%\,\mathrm{Ni}}{20} + \frac{\%\,\mathrm{Cr}}{10} - \frac{\%\,\mathrm{Mo}}{50} - \frac{\%\,\mathrm{V}}{10}$$

A2.2.5 *Product (Check) Verification Analysis*—A product check analysis made by the purchaser shall not exceed the following percentages:

Element	max, %
Carbon	0.33
Manganese	1.56
Phosphorus	0.043
Sulfur	0.053
Silicon	0.55

ANNEX A3. ALTERNATE BAR SIZES

A3.1 The following requirements shall apply only when specified in the purchase order or contract. When specified, the following Table A3.1, Table A3.2, and Table A3.3 replace Table 1, Table 2, and Table 3, respectively.

TABLE A3.1 - Deformed Bar Designations, Nominal Weights [Masses], Nominal Dimensions, and Deformation Requirements

Bar Designation No.[A]	Nominal Weight, lb/ft [B] [Nominal Mass, kg/m] [C]	Nominal Dimensions [D]			Deformation Requirements, in. [mm]		
		Diameter, in. [mm]	Cross-Sectional Area in.^{2} [mm^2]	Perimeter, in. [mm]	Maximum Average Spacing	Minimum Average Height	Maximum Gap (Chord of 12.5 % of Nominal Perimeter)
10	0.414 [0.617]	0.394 [10.0]	0.12 [79]	1.237 [31.4]	0.276 [7.0]	0.016 [0.40]	0.151 [3.8]
12	0.597 [0.888]	0.472 [12.0]	0.18 [113]	1.484 [37.7]	0.331 [8.4]	0.019 [0.48]	0.181 [4.6]
16	1.061 [1.578]	0.630 [16.0]	0.31 [201]	1.979 [50.3]	0.441 [11.2]	0.028 [0.72]	0.241 [6.1]
20	0.657 [2.466]	0.787 [20.0]	0.49 [314]	2.474 [62.8]	0.551 [14.0]	0.039 [1.00]	0.301 [7.7]
25	2.589 [3.853]	0.984 [25.0]	0.76 [491]	3.092 [78.5]	0.689 [17.5]	0.049 [1.25]	0.377 [9.6]
28	3.248 [4.834]	1.102 [28.0]	0.95 [616]	3.463 [88.0]	0.772 [19.6]	0.055 [1.40]	0.422 [10.7]
32	4.242 [6.313]	1.260 [32.0]	1.25 [804]	3.958 [100.5]	0.882 [22.4]	0.063 [1.60]	0.482 [12.2]
36	5.369 [7.990]	1.417 [36.0]	1.58 [1018]	4.453 [113.1]	0.992 [25.2]	0.071 [1.80]	0.542 [13.8]
40	6.629 [9.865]	1.575 [40.0]	1.95 [1257]	4.947 [125.7]	1.102 [28.0]	0.79 [2.00]	0.603 [15.3]
50	10.36 [15.41]	1.969 [50.0]	3.04 [1963]	6.184 [157.1]	1.378 [35.0]	0.098 [2.50]	0.753 [19.1]
60	14.91 [22.20]	2.362 [60.0]	4.38 [2827]	7.421 [188.5]	1.654 [42.0]	0.106 [2.70]	0.904 [23.0]

[A] The bar designations are based on the number of millimetres of the nominal diameter of the bar.
[B] The assumed weight of a cubic foot of steel is 490 lb/ft3 in accordance with Specification A6/A6M.
[C] The assumed mass of a cubic metre of steel is 7850 kg/m3 in accordance with Specification A6/A6M.
[D] The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same weight [mass] per foot [metre] as the deformed bar.

TABLE A3.2 - Tensile Requirements

	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
Tensile strength, min, psi [MPa]	80 000 [550]	100 000 [690]	120 000 [830]
Yield strength, min, psi [MPa]	60 000 [420]	80 000 [550]	100 000 [690]
Yield strength, max, psi [MPa]	78 000 [540]	98 000 [675]	118 000 [815]
Ratio of actual tensile strength to actual yield strength (T/Y), min.	1.25	1.21	1.17
Uniform elongation, min, %	8	7	6

TABLE A3.3 Bend Test Requirements

Bar Designation No.	Pin Diameter for 180 degree Bend Tests		
	Grade 60 [280]	Grade 80 [550]	Grade 100 [690]
10, 12, 16	3*d*	3-1/2 *d*	4*d*
20, 25	4*d*	5*d*	5*d*
28, 32, 36	6*d*	7*d*	7*d*
40, 50, 60	8*d*	9*d*	9*d*

[A] *d* = nominal diameter of specimen.

APPENDIX B:

SLIDE PRESENTATION, APRIL 1, 2015

CPF RGA 03-14:
Draft of a Proposed Specification for

Deformed Steel Bars with Controlled Ductile Properties for Concrete Reinforcement

April 1, 2015

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Principal
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Overview

- Participants
- Stress-Strain Curve Terminology
- General Development of the Proposed Specification
- Selection of "Placeholder" Specified Tensile Properties and Bend Test Pin Diameters
- Actual Stress-Strain Curves for Trial Grade 100 Bars
- Summary
- Appendix: Draft of Proposed Ductile Bar Spec

Participants

Participants

- Charles Pankow Foundation (CPF)
  - Sponsor for development of proposed specification
- Wiss, Janney, Elstner Associates, Inc. (WJE)
  - Consultant to CPF, composed the draft specification, coordination among participants
- Concrete Reinforcing Steel Institute (CRSI)
  - CRSI Materials Properties Committee
  - CRSI High Strength Bar (HSB) Task Group
  - CRSI Uniform Elongation (UEL) Measurement TG
- Various producing mills

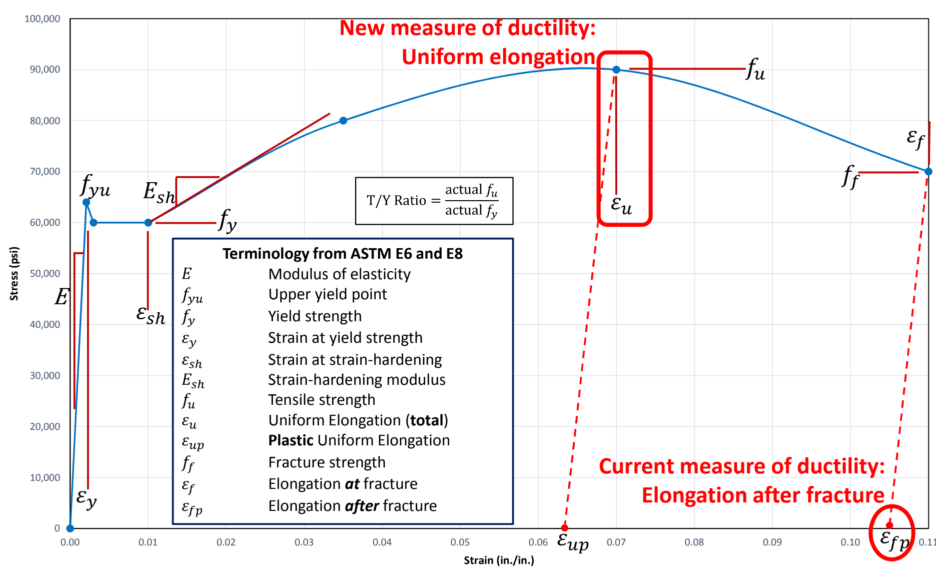
Suggested terminology for key points on the stress-strain curve

Compiled from:

ASTM E8 Test Methods for Metallic Materials

ASTM E6 Terminology for Mechanical Testing

Representative Stress-Strain Curve



Important Parameters for New Ductile Bars

- T/Y Ratio = $\frac{\text{actual } f_u}{\text{actual } f_y}$
  - Determined from the results of a monotonic tension test, such as the mill test
- Uniform Elongation: ε_u
  - Strain at the peak of the engineering stress-strain curve
  - Determined from results of a monotonic tension test, such as the mill test
    - Electronic method – autographically determined from a recorded stress-strain curve
    - Manual method – measurement on the fractured test piece, including a mathematical adjustment for elastic strain

General Development of the Proposed Specification

Overview

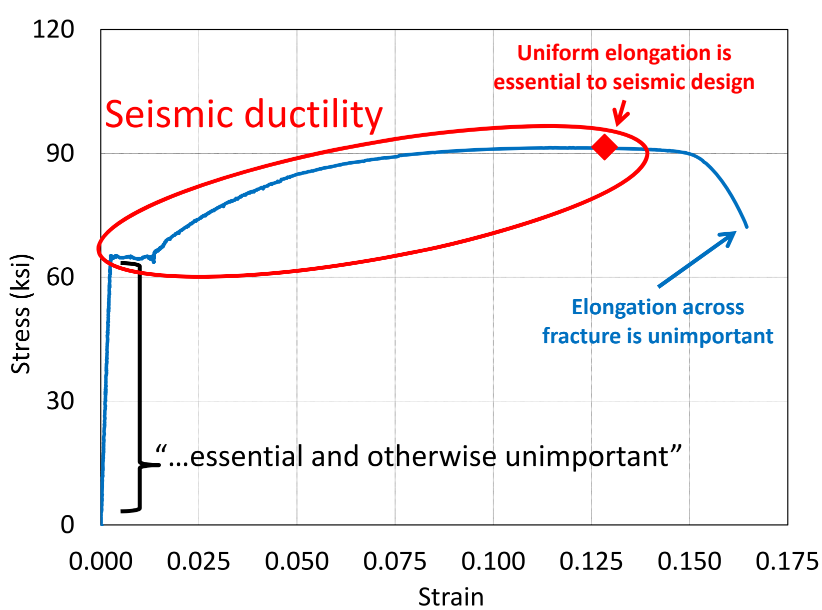
- ASTM A615 and ASTM A706 used as “boilerplate”
  - Same general organization of sections
  - Same language used within many sections
  - Minor wordsmithing throughout
- Certain technical changes to “boilerplate” language made at suggestion of CRSI’s HSB TG
  - Refer to next slide for details
- Changed measure of ductility from fracture elongation (FEL) to uniform elongation (UEL)
  - Second slide following explains why
- Added a mandatory annex specifying procedures for measuring uniform elongation (UEL)
  - Extensive details later

Suggestions from CRSI HSB TG

- Requirements to report chemistry analysis are included, but removed limit on phosphorus
  - No limits on chemistry are included, other than with purchaser-specified weldability option
- Weldability is an option to be specified by the purchaser
  - Weldability requirements are provided in an annex
  - Weldability requirements modelled after ASTM A706 chemistry requirements
- Limits on location of test sample for coiled bar
  - Cannot sample from the so-called “hot rings” of the coil

Why use Uniform Elongation?

- Requirements for elongation across fracture (or fracture elongation, FEL) were first established more than 100 years ago
- FEL is useful as a production quality check for the ductility of the as-rolled reinforcing bar
- However, the useful structural engineering parameter is the uniform elongation (UEL)
  - UEL is the strain at the peak of the stress-strain curve (strain coincident with tensile strength)
- There is no reliable correlation between FEL and UEL
  - This makes FEL of little use to structural engineers



Actual stress-strain curve for representative sample of ASTM A706 Grade 60 bar

Measurement of Uniform Elongation (UEL)

- Electronic method by use of a strain extensometer:
  - E8/E8M Test Methods and Definitions for Mechanical Testing of Steel Products
- Manual method not covered by an existing ASTM standard test method applicable to rebar
  - New manual method developed for this spec
  - Based in part on Canadian and ISO procedures for measuring UEL of steel bar reinforcement
  - Adaptations made to accommodate U.S. rebar mill practices

UEL Electronic Method: ASTM E8

7.9 *Uniform Elongation:*

7.9.1 Uniform elongation shall include both plastic and elastic elongation.

7.9.2 Uniform elongation shall be determined using autographic methods with extensometers conforming to Practice E83. Use a class B2 or better extensometer for materials having a uniform elongation less than 5 %. Use a class C or better extensometer for materials having a uniform elongation greater than or equal to 5 % but less than 50 %. Use a class D or better extensometer for materials having a uniform elongation of 50 % or greater.

7.9.3 Determine the uniform elongation as the elongation at the point of maximum force from the force elongation data collected during a test.

7.9.3.2 Stress-strain curves for some materials exhibit a lengthy, plateau-like region in the vicinity of the maximum force. For such materials, determine the uniform elongation at the center of the plateau as indicated in Fig. 27.

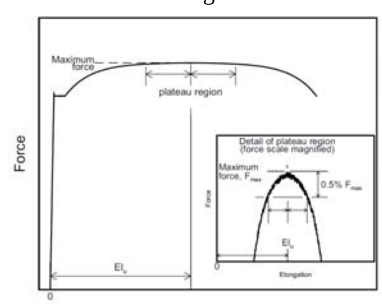


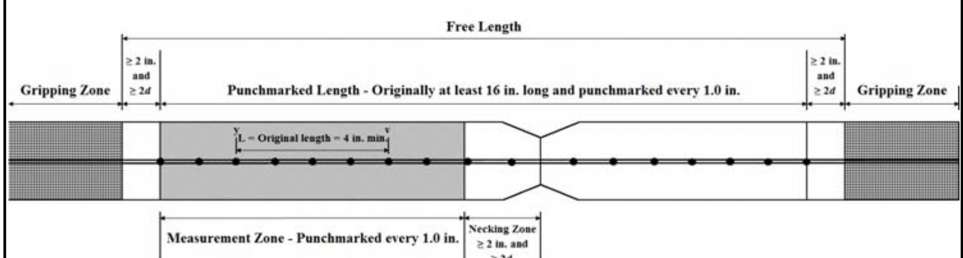
FIG. 27 Force-Elongation Diagram for Determination of Uniform Elongation of Steel Sheet Materials Exhibiting a Plateau at Maximum Force

UEL Manual Method

- Place a series of marks at equal intervals in the free length of the bar between grips
- Load the sample in monotonic tension to destruction
- Measure uniform plastic elongation away from the fracture and away from the grips
- Compute total uniform elongation as:

$$\varepsilon_u = \left[\frac{L - L_0}{L_0} + \frac{f_u}{E}\right] \times 100$$

UEL Manual Method



Feedback from UEL Manual Method Trials

- Punch/ scribe marks can be at 1” intervals, and gauge length can be as short as 4”
  - Results at 4” gauge are consistent with longer gauges
  - Short gauge length has the advantage that the multi-step Canadian method can be avoided
- Still need to examine the data in detail to verify proposed requirements for:
  - how closely a valid gauge point can approach a grip
  - how closely a valid gauge point can approach the necking zone
  - what is a reasonable tolerance on placement of original scribe/punch mark

“Placeholder” Values for Specified Tensile Properties and Bend Diameter

Final specified values will be based upon in-concrete testing and other research

"Placeholder" Tensile Properties

- Proposed ductile GR60 requirements generally based upon current A706 GR60 tensile properties
  - Exception: uniform elongation (details later)
- For GR80 and GR100, considered also the recommendations of:
  - NIST GCR 14-917-30, *Use of High-Strength Reinforcement in Earthquake-Resistant Concrete Structures*, National Institute of Standards and Technology (NIST), March 2014

"Placeholder" Bend Diameters

- The bend diameters for mill tests are more severe that ACI-specified minimum bend diameters
  - They serve different purposes, so they can be different
- Bend test pin diameter for ductile GR60 and GR80 the same as those for ASTM A706 GR60 and GR80
- Ductile GR100 bend diameters generally the same as A706 GR80
  - Exception: bend test pin radii for the smallest bars increased from 3.5 ***d*** to 4 ***d*** (***d***=bar nominal diameter)

"Placeholder" Yield and Tensile Strengths

- Minimum yield, maximum yield, and minimum tensile strengths as follows:
- Proposed ductile GR60 same as ASTM A706 GR60
  - 60,000 psi; 78,000 psi; 80,000 psi
- Proposed ductile GR80: simply add 20,000 psi to the strength values proposed for GR60
  - 80,000 psi; 98,000 psi; 100,000 psi
- Proposed ductile GR100: simply add 20,000 psi to the strength values proposed for GR80
  - 100,000 psi; 118,000 psi; 120,000 psi

"Placeholder" Tensile-to-Yield (T/Y) Ratios

- Proposed ductile GR60:
  - Minimum T/Y=1.25, same as ASTM A706 GR60
- Proposed ductile GR100:
  - NIST GCR 14-917-30: adopt Japanese practice of minimum Y/T=0.85 for GR100 ductile bars
  - This becomes T/Y = 1/0.85 = 1.1764 ≈ 1.17 (truncate to become odd-numbered value)
- Proposed ductile GR80:
  - Interpolate between proposed T/Y for GR60 and that proposed for GR100
  - Minimum T/Y=1.21

Uniform Elongation (UEL)

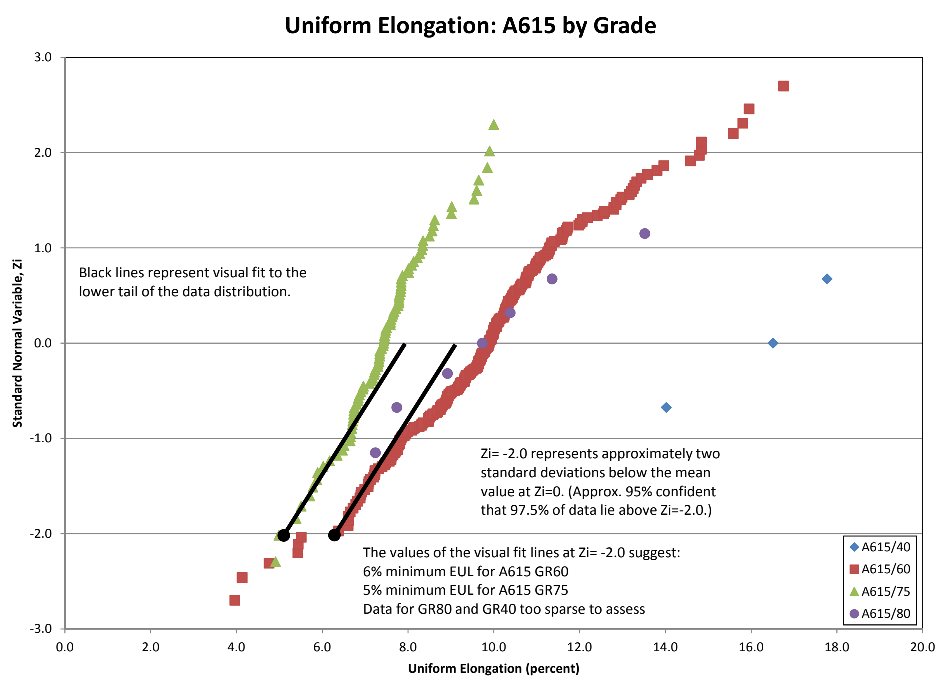
- Currently, ASTM A706 and ASTM A615 specify requirements for ***fracture*** elongation (FEL), not for ***uniform*** elongation (UEL)
- There is no consistent correlation between FEL and UEL
  - This is in part due to the method used to measure FEL: results are inconsistent because in part gauge length is not a function of bar diameter
- CRSI established a UEL Task Group to implement UEL testing on a trial basis
  - Results were used to preliminarily establish specified minimum values for UEL of ductile bars

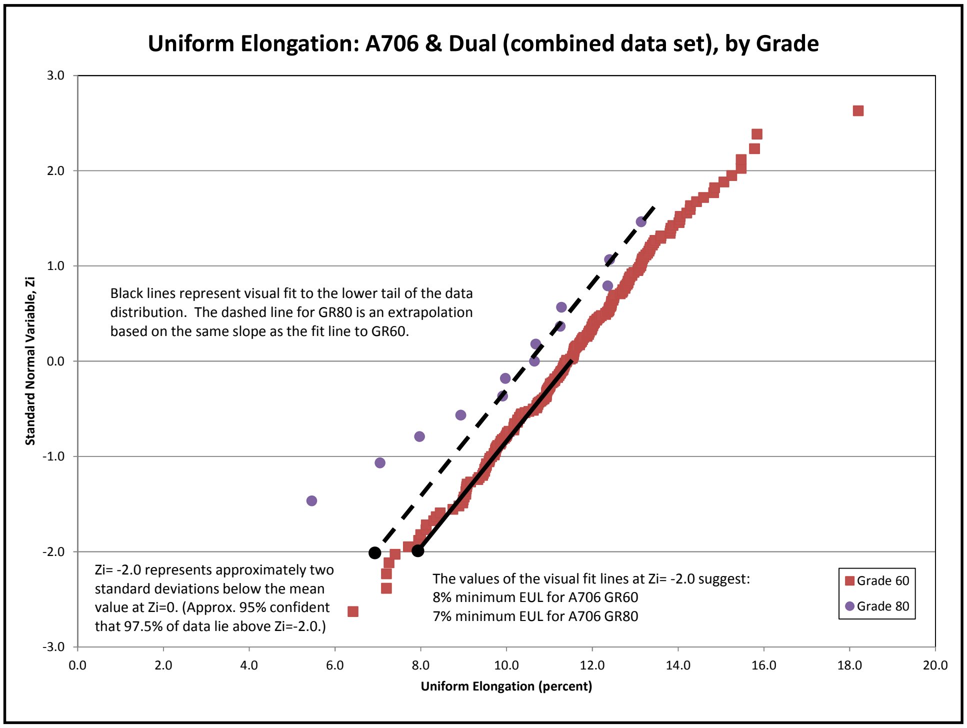
CRSI UEL Task Group

- Task group operates under the auspices of the CRSI Materials Properties Committee
- Sampled ASTM A615 (GR 40, 60, 75, 80) and A706 bars (GR 60, 80) produced during the first two quarters of 2014
  - Contributions from multiple producing mills
- Participating mills implemented a trial method for measuring uniform elongation (UEL) at the mill

CRSI UEL TG Test Results

- Probability plots of UEL for both ASTM A615 and ASTM A706 bars are given in the following slides
- Sample sizes for A615 GR60, A615 GR75, and A706 GR60 are large enough to produce suitable probability plots
- Smaller sample sizes for A615 GR80, A615 GR40, and A706 GR80 provide "sparse" plots
  - A706 GR80 results were interpreted in light of the results for A706 GR60





Resulting "Placeholders" for UEL

- Currently-produced ASTM A706 GR60 bars achieve a lower bound (5% fractile) UEL of 8%
  - This same value is taken as the specified minimum requirement for UEL of the proposed ductile GR60
- Based on the interpretation of test data shown on the previous slide, currently-produced ASTM A706 GR80 bars appear to achieve a lower bound UEL of 7%
  - This same value is taken as the specified minimum requirement for UEL of the proposed ductile GR80
- It then follows that proposed ductile GR100 might reasonably be expected to achieve a lower bound UEL of 6% (extrapolation)

Proposed Rev 2.0 "Placeholder" Values

TABLE 2 - Tensile Requirements

	Grade 60 [420]	Grade 80 [550]	Grade 100 [690]
Tensile strength, min, psi [MPa]	80 000 [550]	100 000 [690]	120 000 [830]
Yield strength, min, psi [MPa]	60 000 [420]	80 000 [550]	100 000 [690]
Yield strength, max, psi [MPa]	78 000 [540]	98 000 [675]	118 000 [815]
Ratio of actual tensile strength to actual yield strength (T/Y), min.	1.25	1.21	1.17
Uniform elongation, min, %	8	7	6
~~Elongation after fracture in 8 in. [200 mm], min, %~~	~~Not Regulated~~	~~Not Regulated~~	~~Not Regulated~~

Values subject to change based on results of in-concrete seismic-related research utilizing prototype ductile HSB

Establishing ***Final*** Tensile Properties

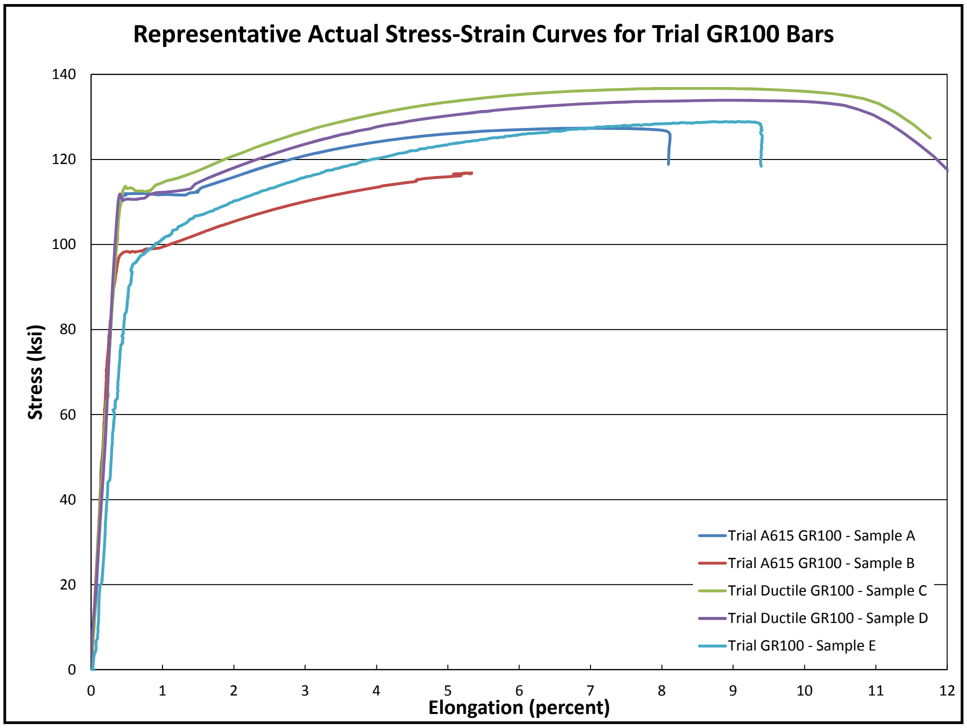
- CPF-sponsored research is underway using trial ductile GR100 HSB in concrete member test samples
  - Some testing using GR80 bars is also included
- Ductile GR60 will generally be consistent with current A706 GR60 tensile properties
- Research results will be used to rationally establish ductile GR100 values for:
  - Lower bound T/Y ratio to promote spread of plasticity at plastic hinges, for both seismic and gravity load applications
  - Minimum uniform elongation to provide seismic ductility
- Ductile GR80 will be established by "interpolation" between GR60 and GR100, and will also be supported by some in-concrete research

CPF-Funded Research Underway

- Anchorage
  - Development Lengths – Univ. of Kansas (Darwin)
- Tensile Properties
  - Gravity Beams – U.C. Berkeley (Moehle)
  - Seismic Beams – U.C. Berkeley (Moehle)
  - Seismic Columns – U.T. Austin (Ghannoum)
  - Seismic Walls – Univ. of Kansas (LePage)
- Physical Properties
  - Bar Bending – U.T. Austin (Ghannoum)

Actual Stress-Strain Curves for Trial Grade 100 Bars

Monotonic tensile tests on trial production of A615 Grade 100 and Ductile Grade 100 bars


Representative Actual Stress-Strain Curves for Trial GR100 Bars
Stress (ksi)
Elongation (percent)
0
20
40
60
80
100
120
140
0
1
2
3
4
5
6
7
8
9
10
11
12
Trial A615 GR100 - Sample A
Trial A615 GR100 - Sample B
Trial Ductile GR100 - Sample C
Trial Ductile GR100 - Sample D
Trial GR100 - Sample E

Summary

Proposed Ductile Reinforcing Bars

- The "placeholder" values for tensile properties, across all grades, are believed to be reasonably achievable by multiple mills
- Reasonably achievable using multiple manufacturing processes
- Trial results suggest that commercial production of the proposed new ductile GR100 bars is technically feasible
- Commercial viability of Grade 100 new ductile bars will inevitably be determined by supply versus demand
  - Strategic changes to the ACI 318 Code can spur demand

ASTM Version of Ductile Bar Spec

- The "football" has been passed from CPF to CRSI
- CRSI intends to formally apply to ASTM, during April 2015, for approval to develop a completely new specification for ductile reinforcing bars
- If all goes well, in-concrete test results will be available by the end of 2015 to help inform selection of final tensile properties values
- It is conceivable that the proposed ductile bar spec could be issued by ASTM in 2016 or 2017

Path to Implementation

- Option 1:
  - New ductile bar spec includes GR60, GR80, GR100
  - Eventually, ASTM A706 is withdrawn from use
  - Weldability handled by user-specified optional purchasing requirements (welability annex) in ASTM A615 and the new ductile bar spec
- Option 2:
  - New ductile bar spec includes GR80 and GR100
    - The new ductile bar will not be intended to be weldable
  - A706 GR60 will be both weldable and ductile
    - GR80 is removed from ASTM A706

Planned Relationship among ASTM Specs (opt 1)

Specification	**Measure of Ductility**	**Weldable?** **(Note 3)**	**GR60**	**GR80**	**GR100**	**GR120** (Note 5)
A615 **(Note 4)**	Fracture EL	By supplement	Yes	Yes	Yes	TBD
~~A706~~ **(Note 1)**	~~Fracture EL and T/Y Ratio~~	~~Yes~~	~~Yes~~	~~Yes~~	~~No~~	~~No~~
AZZZZ Ductile Bar **(Notes 2,4)**	Uniform EL and T/Y Ratio	By supplement	Yes	Yes	Yes	No
AYYYY	Uniform EL and T/Y Ratio	TBD	No	No	No	Yes

Note 1: The intention is to withdraw A706 under a program of "planned obsolescence". A706 will remain in place so that it can be cited by ACI 318 Supplement 2016. A706 will be withdrawn when AZZZZ is cited by ACI 318-19.

Note 2: Development schedule for the new ductile bar specification AZZZZ is targeted so that AZZZZ is published by ASTM in 2016 or 2017. If completed by then, it can be cited by ACI 318-19.

Note 3: By the time A706 is withdrawn, weldable bar will be covered by purchaser-requested annex supplements to A615 and AZZZZ.

Note 4: By the time the new ductile bar spec AZZZZ is published, tensile properties requirements for A615 and AZZZZ will be coordinated so that AZZZZ can be readily substituted for A615. Additionally, new ductile bar spec AZZZZ GR60 should be substituted for A706 GR60 to provide for continuity.

Note 5: GR120 is shown here as a placeholder – the intent is to resolve outstanding concerns with GR100 before working on GR120.

TBD = To Be Determined

Planned Relationship among ASTM Specs (opt 2)

Specification	Measure of Ductility	Weldable?	GR60	GR80	GR100	GR120 (Note 5)
A615 (Note 4)	Fracture EL (Note 3)	No	Yes	Yes	Yes	TBD
A706 (Note 4)	Fracture EL (Note 3) and T/Y Ratio	Yes	Yes	~~Yes~~ No (Note 1)	No	No
AZZZZ Ductile Bar (Notes 2,4)	Uniform EL and T/Y Ratio	No	No	Yes	Yes	No
AYYYY	Uniform EL and T/Y Ratio	No	No	No	No	Yes

Note 1: The intention is to remove Grade 80 from A706. A706 will remain in place as both a ductile bar and a weldable bar, but only in Grade 60.

Note 2: Development schedule for the new ductile bar specification AZZZZ is targeted so that AZZZZ is published by ASTM in 2016 or 2017. If completed by then, it can be cited by ACI 318-19.

Note 3: Over time, the industry may choose to change the measure of elongation in ASTM A706 and ASTM A615 to become uniform elongation instead of fracture elongation.

Note 4: By the time the new ductile bar spec AZZZZ is published, tensile properties requirements for A615, A706 and AZZZZ will be coordinated so that A706 and AZZZZ can be readily substituted for A615.

Note 5: GR120 is shown here as a placeholder – the intent is to resolve outstanding concerns with GR100 before working on GR120.

TBD = To Be Determined

Implementation of New Spec (Option 1)

NOTE: Grades of bar **highlighted with red text** indicate recognition by the ACI 318 Code.

Year of Publication by ASTM	General Bar: ASTM A615	Old Seismic Ductile Bar: ASTM A706	New Seismic Ductile Bar: ASTM AZZZZ	Coordinate with ACI 318 Edition
2013/ 2014	**GR 40, 60, 75, 80**	**GR 60**, 80	Draft compiled (GR 60, 80, 100)	318-14
2015/ 2016	**GR 40, 60,** ~~75,~~ **80**, 100 (add GR100, withdraw GR75)	**GR 60, 80**	Formal ASTM spec under development	318 Supplement 2016 recognize ductile A706 GR80 for seismic; remove A615 GR75
2016/ 2017	**GR 40, 60, 80, 100**	GR 60, 80	**GR 60, 80**, 100	318-19 recognize A615 GR100 for general use; remove A706; recognize AZZZZ
2020 and beyond	**GR 40, 60, 80, 100**	Withdrawn	**GR 60, 80, 100**	318-19 and 318-24 recognize AZZZZ GR100 for seismic

As of November 3, 2014

Implementation of New Spec (Option 2)

NOTE: Grades of bar **highlighted with red text** indicate recognition by the ACI 318 Code.

Year of Publication by ASTM	General Bar: ASTM A615	Current Ductile Bar: ASTM A706	New Ductile Bar Spec	Coordinate with ACI 318 Edition
2013/ 2014	**GR 40, 60, 75, 80**	**GR 60**, 80	Draft compiled (GR 80, 100)	318-14
2015/ 2016	**GR 40, 60,** ~~**75,**~~ **80**, 100 (add GR100, withdraw GR75)	**GR 60**~~, 80~~ (withdraw GR80)	Formal ASTM spec under development	318 Supplement 2016 recognize ductile A706 GR80 for seismic; remove A615 GR75
2016/ 2017	**GR 40, 60, 80, 100**	**GR 60**	**GR 80**, 100	318-19 recognize A615 GR100 for general use; recognize new ductile GR80
2020 and beyond	**GR 40, 60, 80, 100**	**GR 60**	**GR 80, 100**	318-19 and 318-24 recognize new ductile GR100 for seismic

Option proposed March 4, 2015