In consideration of the following, more time is requested for a task group to work through the proposed AC133 changes

BarSplice PRODUCTS INC.
A SUBSIDIARY OF FC INDUSTRIES INC.

STAGE 1 RESIDUAL SLIP TEST IS EXTREME. THERE IS NOTHING LIKE THIS IN THE US

- ISO 15835 loads to 90% of nominal yield strength for the first 20 cycles, therefore the residual slip test in proposed AC133 is more extreme than the ISO standard. Proposed AC133 is also much more extreme than DOT slip tests which perform one load cycle to 50% of specified yield strength.
- Keeping the maximum slip value the same regardless of bar size is not realistic. Caltrans has understood this and years ago implemented an increasing allowable slip value as the rebar size increases (see Caltrans Standard Specifications Section 52-6.02B(1)).
- Per ISO 15835 section 5.6, residual slip of a splice at cycle 20 shall not exceed the equivalent residual slip of an unspliced bar by more than 0.3mm (0.012 inch). It is not clear from Figure 1 that residual slip of the splice has the residual elongation (slip) of an unspliced bar subtracted from the measurement.

STAGE 1 RESIDUAL SLIP SHOULD BE REMOVED FOR TYPE 1 SPLICES

- Table 6 of the proposed changes states no requirement for a maximum residual slip for Type 1 splices. If there is no requirement to evaluate the test against, then the test creates an unnecessary financial burden on the report holder and should be removed.

STAGE 2 AND 3 RESIDUAL SLIP TESTS SHOULD BE REMOVED FOR TYPE 2 AND TYPE 2HS – REMOVE FIGURE 1B

- The current 2018 edition of ISO 15835 – 1 and – 2, does not evaluate residual elongation (slip) after cycles 24 and 28 (Stages 2 and 3). If ISO 15835 must be used as a foundation for the proposed AC133 changes, it should be the latest edition that has been approved for use in the industry, not an obsolete edition that has been **withdrawn** from circulation. Figure 1B should be removed.

A THIRD OPTION SHOULD BE ADDED TO THE TYPE 2HS SECTION 3.25 STRAIN DETERMINATION REQUIREMENT

- Similar to what Caltrans specify, a bar break in the reinforcing bar, clear of the splice affected zone, should be allowed in order to demonstrate compliance with the Stage 4 strain requirement.

More time is needed to evaluate the ramifications of AC133 proposed changes and develop an industry consensus on requirements

KEY CONCERNS – RESIDUAL SLIP

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Proposed Change:
Added a **residual slip limit** criteria for Type 2 Mechanical Splices, including the addition of Table 6 and Figure 1.

Key Concerns:

- Slip criteria should not be added to existing Type 2 Mechanical Splices.

- It is far too stringent and if there are concerns about the overall behavior over the splice length, the length of the coupler is a more important factor. Some slip actually helps performance of mechanical splices per Tazarv:

  - *Tazarv, M. and Saiidi, M.S. (2015) "Design and Construction of Bridge Columns Incorporating Mechanical Bar Splices in Plastic Hinge Zones," Center For Civil Engineering Earthquake Research, Department of Civil and Environmental Engineering, University of Nevada, Reno, Nevada, Report No. CCEER-15-07, 149 pp.*
  - *Tazarv, M. and Saiidi, M.S. (2016) "Seismic Design of Bridge Columns Incorporating Mechanical Bar Splices in Plastic Hinge Regions," Engineering Structures, DOI: 10.1016/j.engstruct.2016.06.041, Vol. 124, pp. 507-520.*

- Slip is often difficult to measure on rebar deformations of a cross-section that is more oval than circular with bars that are not perfectly straight. Allowing these bars to be mechanically coupled with an installation friendly product, will yield far better results in the field than restricting or complicating the system to minimize slip.

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KEY CONCERNS – RESIDUAL SLIP

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Key Concerns (cont.):

- Should slip still be introduced to AC133 due to serviceability concerns, it should be limited to the proposed Type 2HS, and the proven Caltrans slip criteria should be adopted to avoid the unnecessarily complicated and excluding criteria proposed.

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KEY CONCERNS – PRELOAD SLACK

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Proposed Change:

Added a definition for **preload slack** and its applicable condition of use to be included in the evaluation report

Key Concerns:

- Excessive preload slack could be a concern, but the proposed revisions need to be expanded upon to clearly define "any movements of the reinforcing bars within the mechanical splice" and how this movement is inspected/identified.

- Preload slack should only be identified and/or inspected after the mechanical splice is fully assembled per manufacturer's instructions.

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KEY CONCERNS – TYPE 2HS

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Proposed Change:
Added evaluation requirements for an optional **Type 2HS (High Strain)** Mechanical Splice, including the addition of Table 7 and Annex B.

Key Concerns:

- There is no room for error with this type of (ultimate) splice.
- Consideration needs to be given to the fact that types of devices needs to be practical so they can be fabricated and installed consistently in the fabrication shop and on the jobsite, not just for manufacturer prequalification tests.
- A Type 2HS should not be necessary in most applications, but we assume it will become the "standard". There is already a tendency to specify the Type 2 over Type 1 regardless of the application. Engineers will certainly be enticed to require the new Type 2HS even for applications where Type 2 is sufficient.

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KEY CONCERNS – TYPE 2HS

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Key Concerns (cont):

- In addition to acceptance criteria, careful consideration needs to be given to application limitations for this type of splice and bar material.

  - Consider "no-splice" zones like Caltrans has defined in addition to Ultimate & Service Splices. Maybe it is NOT a good idea to splice (or even use) grade 100 bars in a potential high strain region?

  - Caltrans projects are still limiting rebar in general to A706-60. Our experience is that ultimate performance is achievable for A706-80 as well, but ductility is reduced with increasing grades. Stronger material tend to be more sensitive to most or all bar end preps and transitions to couplers.

  - The combination of high strength and no safety factor (Type 2HS) should therefore be a concern to everyone.

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KEY CONCERNS – TYPE 2HS

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Key Concerns (cont.):

- If a high strain mechanical splice is desired, the AC133 acceptance criteria should adopt the Caltrans Ultimate Splice requirements which are both proven and viable from a cost and scheduling point of view.

  - Please note that while the current AC133 Type 2 testing is apparently ineffective for high strain locations, it is still also the most excluding criteria in our industry due to the high cost and limited laboratories capable of performing the cyclic testing. We have therefore limited the ICC-Es coupler testing to the product/size/grade that we think will generate sufficient sales, not products that are great for specific applications with limited or sporadic use.

  - Caltrans Ultimate has been the benchmark within the industry for decades already (A706-60).

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KEY CONCERNS – TYPE 2HS

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Key Concerns (cont.):

- If a type 2HS is ultimately approved and included in AC133, mechanical splice manufacturers with current Es reports should not be required to retest for Type 1 or Type 2 criteria. They should be allowed to submit existing test data that proves compliance with Type 2HS and no additional testing should be required. This should be made explicitly clear in AC133.

- Manufacturers with Ultimate Splice approved products should already have independent results that satisfies the intent of the proposed AC revision.

- However, as written the proposed AC doubles down on the prohibitive Type 2 cyclic test with a complicated, mostly irrelevant slip test.

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SUMMARY & HRC PROPOSAL

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Summary

- The proposed acceptance criteria revisions are not economically or practically viable.

- The intent of the proposed acceptance criteria revisions is satisfied more effectively by adopting the proven Caltrans Ultimate criteria for Type 2HS.

HRC Proposal

- Leave definitions and acceptance criteria for Type 1 and Type 2 mechanical splices alone.

- If a Type 2HS mechanical splice is desired in an effort to upgrade the acceptance criteria and product performance, this should be done by adopting the Caltrans Ultimate criteria. This addresses all concerns with slip & ductile behavior, uses a proven method and is economically feasible. This approach will also harmonize the bridge and building design communities.

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FINAL RECOMMENDATION

Proposed Revisions to the Acceptance Criteria for Mechanical Splice Systems for Steel Reinforcing Bars (AC133-1020-R1)

Final Recommendation

- Approve inclusion of HRC proposed changes from previous slide

  - OR -

- Find that further study is required

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nVent response to Revisions in AC133 -1020-R1 (MC/VC)

4 - Added evaluation requirements for an optional Type 2HS (High Strain) Mechanical Splice, including the addition of Table 7 and Annex B.

- nVent respectfully **OPPOSES** for the following reasons:
  - **Background**:
    - HSRB properties are not finalized and need to be agreed upon by industry
    - Type 2HS application needs clarity in proposed ICC AC133 and consistency with ACI 318
      - The proposed wording needs revision and industry experts inclusion
      - The current AC 133 protocol already provides the safeguards needed for strain response of the structure
    - Proposals in AC133 need to consider statistical variation in rebar properties
  - **Test Methods**:
    - Proposed test protocol cannot be completed due to buckling of sample
    - Currently there is no ASTM standard or ACI code that defines how to measure Uniform Strain
      - Testing protocol needs to be agreed upon by industry
  - **Practicality and Timing**:
    - RETESTING will be required, timing is UNREALISTIC for review and compliance
    - Previously proposed and rejected at ACI 318 in 2019 (last minute proposal)
      - Last minute proposals without proper research can be harmful to construction industry

nVent response to Revisions in AC133 -1020-R1 (MC/VC)

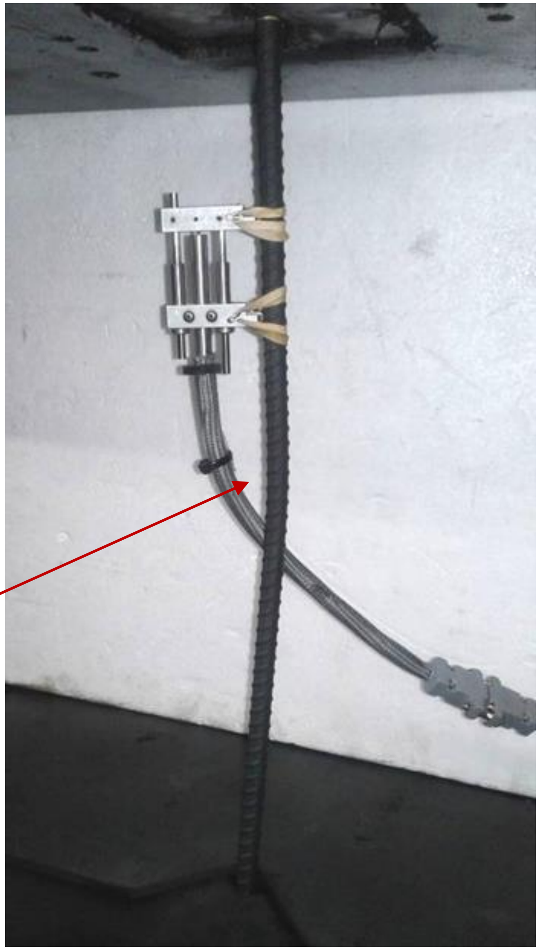
2 - Added a residual slip limit criteria for Type 2 Mechanical Splices, including the addition of Table 6 and Figure 1

- nVent respectfully **OPPOSES** for the following reasons**:**
  - Slip needs to be included for Type 1 splices – Measured at service loads
  - Simplified industry-accepted methods
  - Practicality and timing for revision and compliance is extreme

Proposed AC133 Sample Length Leads to Buckling

- Internal nVent testing confirmed buckling of rebar
- Mostafa Tazarv, PhD, PE of South Dakota State University wrote ICC-ES stating the concerns about buckling test samples
- Test protocol for Type 2HS cannot be run due to buckling of test samples

Rebar bent in compression when tested at required length in proposed AC133 protocol



Compressive loads of current proposed AC133 require changes

Proposed AC133 Sample Length Leads to Buckling

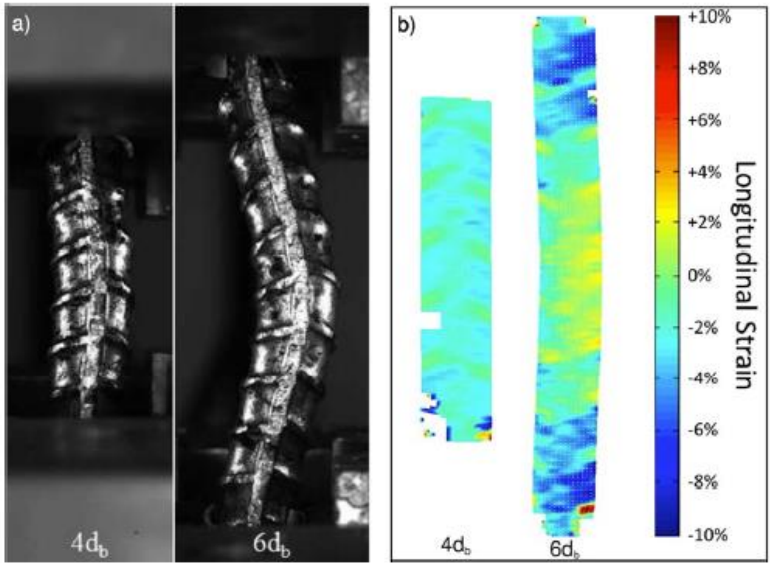


FIGURE 5-3: LOW CYCLE FATIGUE TESTS OF BARS GRIPPED AT SPANS OF 4 AND 6 BAR DIAMETER: A) PICTURES OF GRADE 100 BARS DURING TESTING B) MEASURED LONGITUDINAL STRAINS IN GRADE 80 BARS DURING TESTING (ADOPTED FROM GHANNOUM AND SLAVIN 2016)

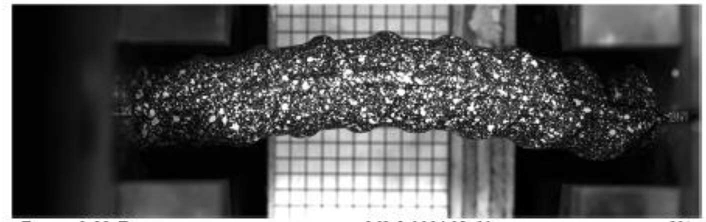


FIGURE 3-32: FINAL COMPRESSION CYCLE FOR A M2-3-100A08-6d$_b$ SPECIMEN UNDER THE +2% TO -2% STRAIN PROTOCOL

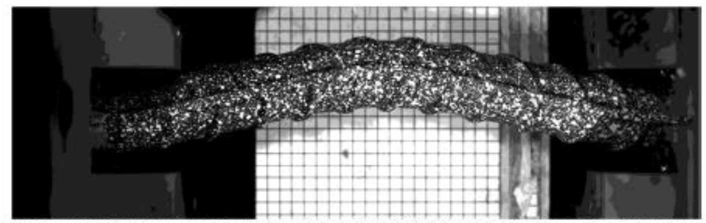


FIGURE 3-33: FINAL COMPRESSION CYCLE FOR A M2-3-100A08-8d$_b$ SPECIMEN UNDER THE +2% TO -2% STRAIN PROTOCOL

- **Possible solutions:**
  - Allow Monotonic Testing for Type-2HS Mechanical Couplers --- requires rewriting of AC133-2HS testing
  - Allow Type-2HS cyclic tension/compression per current AC133 protocol---requires rewriting of AC133-2HS testing

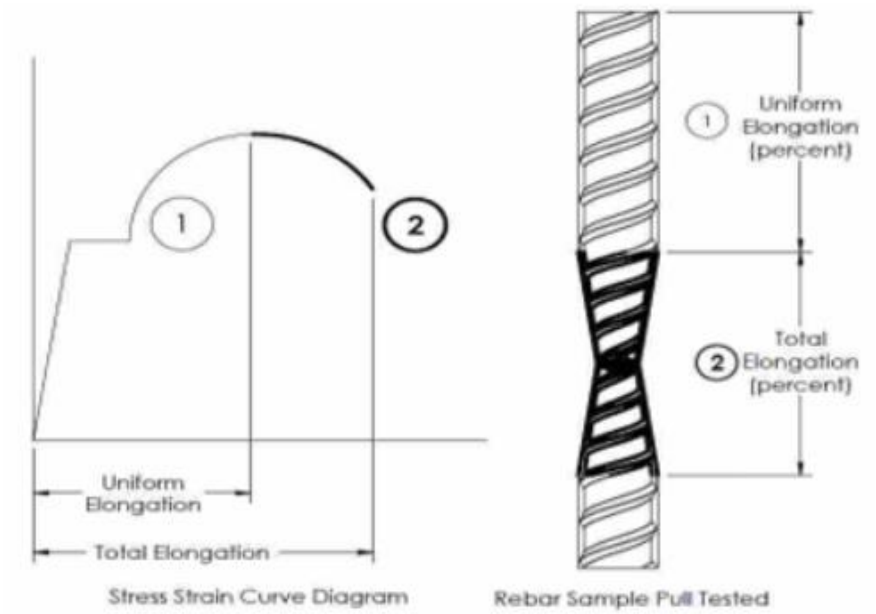
Bar Buckling is a SERIOUS concern

Ghannoum – Pankow Foundation Final Report 03-16, UT Austin, Aug 2019

No ASTM Standard nor ACI Code Defines Measurement of Uniform Elongation (Uniform Strain)

Proposed AC133 states: "*The Type 2HS splice is a mechanical splice with a minimum tensile strength and tensile strain capacity intended for use in seismic applications with reinforcing bar conforming to ACI 318-19 Section 20.2.1.3(b).*"

- ASTM A706 requires Total Elongation
- Uniform Elongation and Total Elongation are <u>two different measurements</u>. Refer to diagram
- Neither ASTM A706 nor ACI 318-19 define how to measure Uniform Elongation



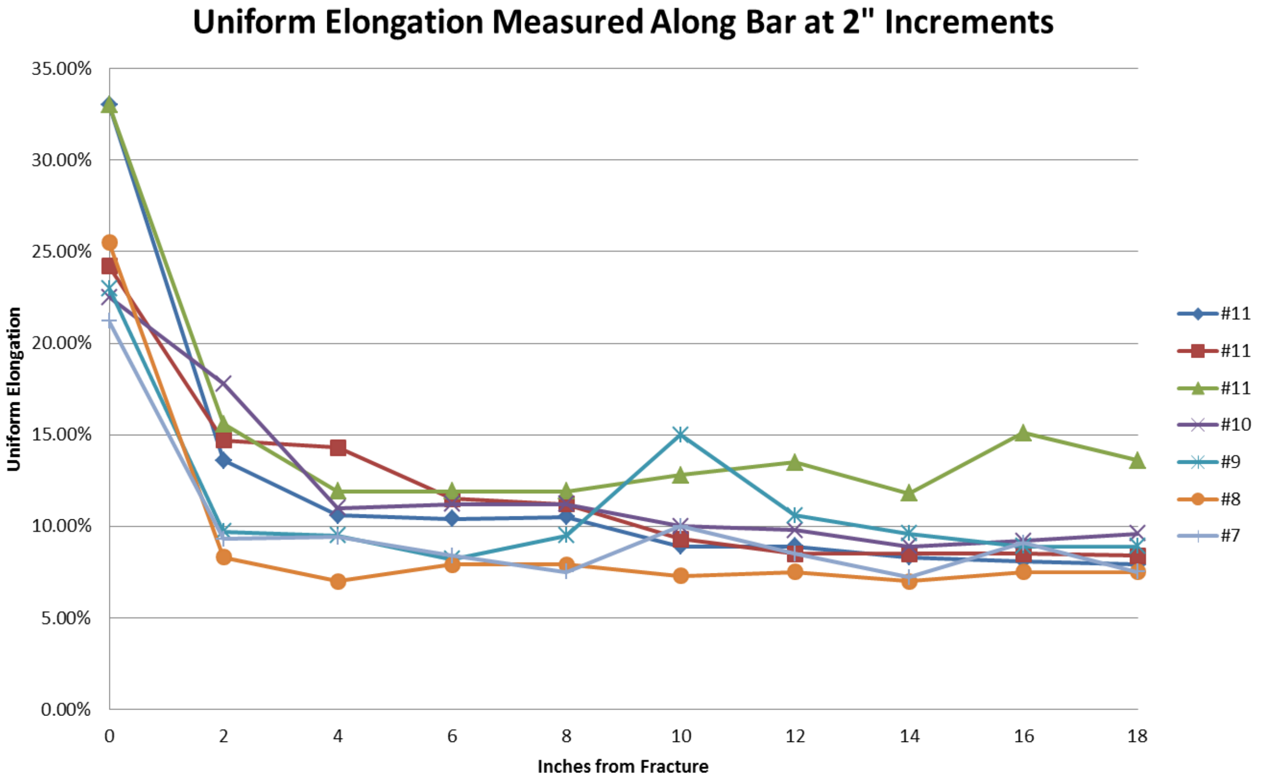
Uniform Elongation (as per ACI 318-19) = measured section 1
Total Elongation (as per ASTM A706) = measured section 2

There is no consensus in the industry on how to measure strain and/or uniform elongation

No ASTM Standard nor ACI Code Defines Measurement of Uniform Elongation (Uniform Strain)

➢ **Uniform Elongation requirement is not in ASTM A706**

- Due to an individual's interpretation and knowledge, Uniform Elongation will have wide variances due to measuring techniques



Both ASTM A706 and A615 are silent on how to measure Uniform Elongation and do not require reporting of Uniform Elongation

No ASTM Standard nor ACI Code Defines Measurement of Uniform Elongation (Uniform Strain)

- **Measuring and certifying Uniform Elongation is not a requirement in ASTM A706**
  - Uniform Elongation will have wide variances due to measuring techniques

Rebar Size	Test Program	Test Sample	Uniform Elongation Measured at Every 2" Punch Mark. Started at One Bar then measured into break									
			18 inch	16 inch	14 inch	12 inch	10 inch	8 inch	6 inch	4 inch	2 inch	0 inch
#11	Pull Test	Control Bar	7.9%	8.1%	8.3%	8.9%	8.9%	10.5%	10.4%	10.6%	13.6%	33.0%
#11	Pull Test	Control Bar	8.4%	8.5%	8.5%	8.5%	9.3%	11.2%	11.5%	14.3%	14.7%	24.2%
#11	Pull Test	Control Bar	13.6%	15.1%	11.8%	13.5%	12.8%	11.9%	11.9%	11.9%	15.6%	33.0%
#10	Pull Test	Control Bar	9.6%	9.2%	8.9%	9.8%	10.0%	11.2%	11.2%	11.0%	17.8%	22.5%
#9	Pull Test	Control Bar	8.9%	8.9%	9.6%	10.6%	15.0%	9.5%	8.2%	9.5%	9.7%	23.0%
#8	Pull Test	Control Bar	7.5%	7.5%	7.0%	7.5%	7.3%	7.9%	7.9%	7.0%	8.3%	25.5%
#7	Pull Test	Control Bar	7.5%	9.1%	7.2%	8.5%	10.0%	7.5%	8.4%	9.4%	9.3%	21.2%

How can a mechanical splice meet the requirements of Uniform Elongation of ACI 318-19 if the reinforcing bar does not meet Uniform Elongation?

No ASTM Standard nor ACI Code Defines Measurement of Uniform Elongation (Uniform Strain)

- Worldwide codes such as ISO are detailed on rebar strain measurements

- ASTM A706 require Total Elongation, not Uniform Elongation

- Due to measuring techniques, laboratories and fabricators attempting to measuring Uniform Elongation will result in wide variances

- As is done in other Worldwide Codes, ASTM A706 needs to define how Uniformed Elongation shall be measured

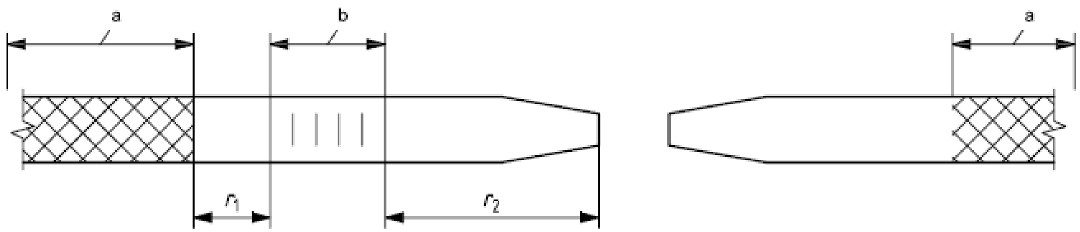
— if A_{gt} is determined by the manual method after fracture, A_{gt} shall be calculated from the following formula:

$$A_{gt} = A_g + R_m / 2\,000 \qquad (1)$$

where A_g is the percentage non-proportional elongation at maximum force.

The measurement of A_g shall be made on the longer of the two broken parts of the test piece on a gauge length of 100 mm, as close as possible to the fracture but at a distance, r_2, of at least 50 mm or $2d$ (whichever is the greater) away from the fracture. This measurement may be considered as invalid if the distance, r_1, between the grips and the gauge length is less than 20 mm or d (whichever is the greater). See Figure 1.

In case of dispute, the manual method shall apply.



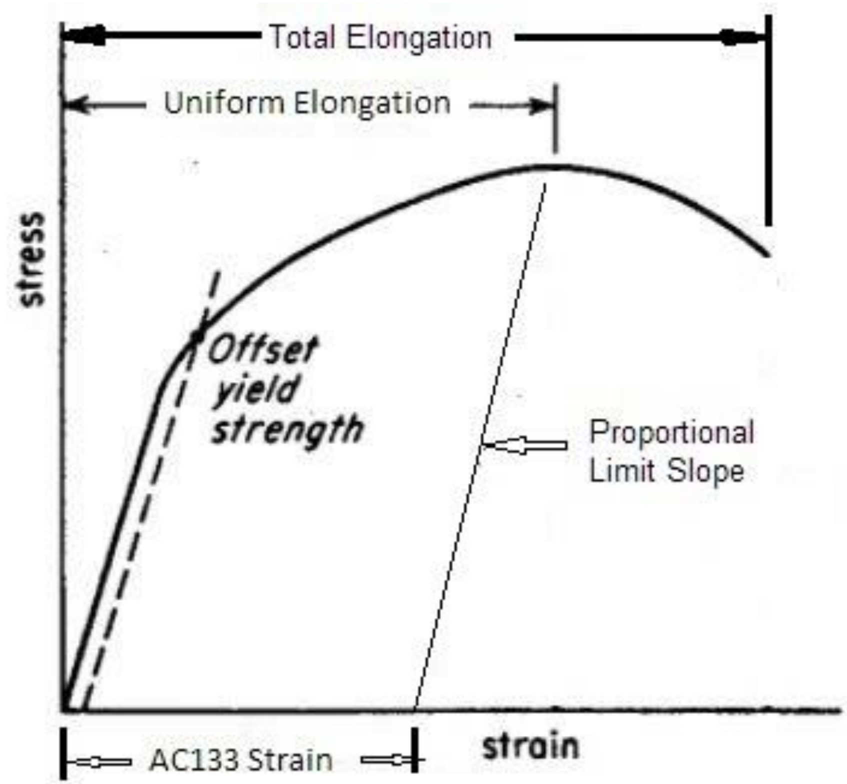
a Grip length.

b Gauge length 100 mm.

Worldwide codes are detailed on Strain measurements---proposed AC133 requires modifications

No ASTM Standard nor ACI Code Defines Measurement of Uniform Elongation (Uniform Strain)

➢ **Three different Standards/Codes with three different Elongation definitions**
- ACI 318-19 Requires Uniform Elongation
- ASTM A706 measures Total Elongation
- Proposed AC133 Measures Elongation after load



There is not a consensus in the industry on how to measure strain and/or uniform elongation

nVent response to Revisions in AC133 -1020-R1 (MC/VC)

4 - Added evaluation requirements for an optional Type 2HS (High Strain) Mechanical Splice, including the addition of Table 7 and Annex B.

- nVent respectfully **OPPOSES** for the following reasons:
  - **Background**:
    - HSRB properties are not finalized and need to be agreed upon by industry
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      - The proposed wording needs revision and industry expert's inclusion
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  - **Test Methods**:
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    - Previously proposed and rejected at ACI 318 in 2019 (last minute proposal)
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  - Simplified industry-accepted methods
  - Practicality and timing for revision and compliance is extreme

HSRB Properties

- **High Strength Rebar HSRB – Took ~10 years to develop**
  - Chemistries
  - Alloying additions, V
  - QTB steels
  - Deformation geometries required changes to avoid deleterious stress concentrations
  - Uniform Strain level capabilities and methodology
  - Realization - large portion of the ductility of rebar is needed for and consumed in fabrication (bending)
- **A706 HSRB not fully implemented by**
  - ASTM
  - DOT's
  - AASHTO
- **ACI 439.6R**
  - 3% Uniform Strain for Class B (2HS) connections A1035 Grade 100
  - Aligns with data provided in public comment by Dr. Tazarv

nVent took a leadership position in the development and support of HSRB

HSRB Properties

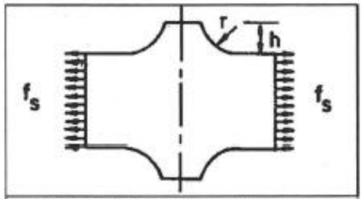
CR031 ACI 318 Sub R October 16, 2018

Submittal No.: CR031

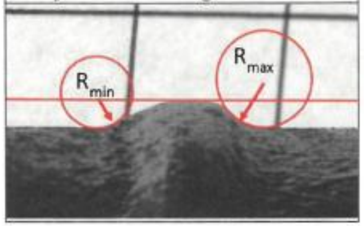
Subject: Deformation geometry requirements for ASTM A706 reinforcement

Motion: ACI Committee 318 recommends that the ASTM A706 standard be revised to include requirements that the ratio of the radius at the base of the deformation to the height of the deformation (refer to illustrations), r/h, be at least 1.5 for all deformations on a bar, including transverse lugs, longitudinal ribs, grade ribs, grade marks, and intersections between deformations. Conformance is to be assessed by measurements taken on newly-machined rolls used to manufacture reinforcing bars, in lieu of measurements taken on samples of bar.

Rationale: The parameter r/h is known to affect the magnitude of the strain localization that occurs at the juncture between the deformation and the barrel of the bar. This strain localization in turn influences inelastic fatigue and tensile fracture (ductility) performance of the bar[1].
While a number of parameters may adversely affect fatigue and tensile performance of reinforcing bars, Subcommittee 318-R and representatives of several producing mills reached a consensus that control of the deformation geometry ratio r/h should be included in the ASTM A706 standard as a rational and practical way for reducing inelastic fatigue and tensile fracture (ductility) performance-related issues in the future.



Above: Bar deformation parameters. Below: Up-close photo of transverse deformation on a bar, illustrating radii at base of the transverse lug



This motion recommends an r/h ratio of at least 1.5 to qualify bars for anticipated acceptable performance. The recommended value is based on consensus achieved within Subcommittee 318-R after considering inelastic fatigue performance of reinforcing bars (Slavin and Ghannoum, 2015)[1]; the test data indicates acceptable inelastic fatigue performance at ratio r/h=1.5 as measured on the bar. No significant gain in fatigue life performance is observed with values of r/h above 2.0 as measured on the bar. The results of the test program also indicated that location of the critical strain localization could occur not only at the base of the deformations, but also where deformations intersect with each other.

Producing mills were involved in the consensus discussion, and advised that, based on the design value of r/h used to machine the rolls that produced the reinforced bars used in the inelastic fatigue tests, a value of r/h=1.5 as measured on the rolls will result in an actual value of r/h of at least 1.5 on the bar, if not larger. The proposed limit applies to all deformations on the bar (transverse, longitudinal and grade markings).

CODE

(ii) Uniform elongation requirements for all grades of ASTM A706 reinforcement shall be as specified in Table 20.2.1.3(c), and uniform elongation shall be determined as the elongation at the maximum force sustained by the reinforcing bar test piece.

(iii) For all grades of ASTM A706 reinforcement, the radius at the base of each deformation shall be at least 1.5 times the height of the deformation. This requirement applies to all deformations, including transverse lugs, longitudinal ribs, grade ribs, grade marks, and intersections between deformations. Conformance shall be assessed by measurements taken on newly-machined rolls used to manufacture reinforcing bars, instead of measurements taken on bar samples.

Table 20.2.1.3(a)—Modified tensile strength and additional tensile property requirements for ASTM A615 reinforcement

	Grade 40	Grade 60	Grade 80	Grade 100
Tensile strength, minimum, psi	60,000	80,000	100,000	115,000
Ratio of actual tensile strength to actual yield strength, minimum	1.10	1.10	1.10	1.10

Table 20.2.1.3(b)—Tensile property requirements for ASTM A706 Grade 100 reinforcement

	Grade 100
Tensile strength, minimum, psi	117,000
Ratio of actual tensile strength to actual yield strength, minimum	1.17
Yield strength, minimum, psi	100,000
Yield strength, maximum, psi	118,000
Fracture elongation in 8 in., minimum, %	10

A706 Rebar Deformation Geometry Requires Modifications

Source ACI

Clarification Needed for Type 2HS Application

- **Proposed Type 2HS (optional) 3.2.1 (a)**
  - Unclear if the intent of the requirement is limited to Special Moment Frames and Special Structural Walls as defined in ACI or to all structures. ACI Is clear on this topic. Alignment is needed.
  - Clarity is needed if Type 2HS applies to only A706 and only to Grade 100 or Grade 80
  - 6.7 (c) (ii) Current wording requires 1.25fy, but unspliced the proposed Grade 100 does not meet the criteria ref ACI 318-19 Table 20.2.1.3(b)
    - ASTM A615-20 Note 1 limits grade 100 to 1.15 fy for mechanical splices
    - ASTM A615 -20 Changed from 1.25 T/Y ration to 1.10 T/Y ratio. Language needs added to address A615
  - Multiple public comments voicing concerns:
    - Is proposal is warranted
    - Need for a consensus development process
    - Inclusion of industry experts

Proposal Needs Significant Work

Clarification Needed for Type 2HS Application

- **ACI 318-19 – Mechanical Splices**

CODE

18.2.7.1 Mechanical splices shall be classified as (a) or (b):
(a) Type 1 – Mechanical splice conforming to 25.5.7
(b) Type 2 – Mechanical splice conforming to 25.5.7 and capable of developing the specified tensile strength of the spliced bars

18.2.7.2 Except for Type 2 mechanical splices on Grade 60 reinforcement, mechanical splices shall not be located within a distance equal to twice the member depth from the column or beam face for special moment frames or from critical sections where yielding of the reinforcement is likely to occur as a result of lateral displacements beyond the linear range of behavior. Type 2 mechanical splices on Grade 60 reinforcement shall be permitted at any location, except as noted in 18.9.2.1(c).

Mechanical Splices for HSRB not allowed in special moment frames or special structural walls within 2D

Statistical Variation in Rebar Properties

TABLE 3-1: MONOTONIC TENSION TEST RESULTS FOR ALL TEST SERIES

Manufacturing Process	Grade	Monotonic Properties: Yield Strength, ksi		Tensile Strength, ksi		T/Y ratio		Elastic Modulus, ksi		Elastic Limit Strain, %		Uniform Strain, %		Fracture Strain, %		Sample Size
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	
M1	60	63.3	68.8	93.4	97.2	1.39	1.50	25,300	33,100	0.2	0.3	9.8	12.3	13.5	22.7	12
	80	78.9	88.2	106.1	118.4	1.28	1.44	25,000	37,200	0.2	0.4	8.5	12.7	11.1	19.5	53
	100	100.5	111.3	126.9	135.6	1.21	1.27	26,800	34,700	0.3	0.4	7.6	9	9.5	14	9
	120	117.7	121.6	139.3	143.3	1.18	1.19	27,800	32,600	0.4	0.4	7.5	8.3	11.4	12.2	3
M2	60	61.1	72.6	91.1	104.4	1.34	1.69	23,700	33,300	0.2	0.3	9.5	12.3	13.8	20	15
	80	83.7	100.3	103.1	119	1.19	1.29	23,500	30,500	0.3	0.4	6.3	10	10.1	15.2	19
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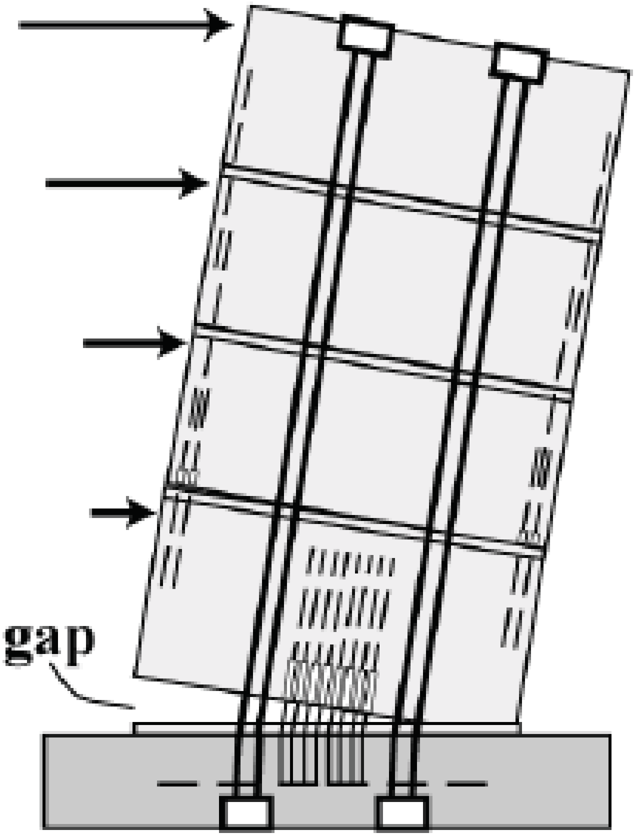

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HSRB Properties

- **High Strength Rebar HSRB – Took ~10 years to develop**
  - Chemistries
  - Alloying additions, V
  - QTB steels
  - Deformation geometries required changes to avoid deleterious stress concentrations
  - Uniform Strain level capabilities and methodology
  - Realization - large portion of the ductility of rebar is needed for and consumed in fabrication (bending)
- **A706 HSRB not fully implemented by**
  - ASTM
  - DOT's
  - AASHTO
- **ACI 439.6R**
  - 3% Uniform Strain for Class B (2HS) connections A1035 Grade 100
  - Aligns with data provided in public comment by Dr. Tazarv

nVent took a leadership position in the development and support of HSRB

HSRB Properties

CR031 ACI 318 Sub R October 16, 2018

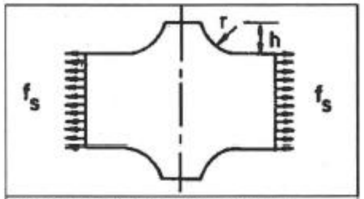
Submittal No.: CR031

Subject: Deformation geometry requirements for ASTM A706 reinforcement

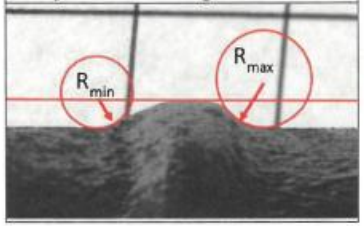
Motion: ACI Committee 318 recommends that the ASTM A706 standard be revised to include requirements that the ratio of the radius at the base of the deformation to the height of the deformation (refer to illustrations), r/h, be at least 1.5 for all deformations on a bar, including transverse lugs, longitudinal ribs, grade ribs, grade marks, and intersections between deformations. Conformance is to be assessed by measurements taken on newly-machined rolls used to manufacture reinforcing bars, in lieu of measurements taken on samples of bar.

Rationale: The parameter r/h is known to affect the magnitude of the strain localization that occurs at the juncture between the deformation and the barrel of the bar. This strain localization in turn influences inelastic fatigue and tensile fracture (ductility) performance of the bar[1].

While a number of parameters may adversely affect fatigue and tensile performance of reinforcing bars, Subcommittee 318-R and representatives of several producing mills reached a consensus that control of the deformation geometry ratio r/h should be included in the ASTM A706 standard as a rational and practical way for reducing inelastic fatigue and tensile fracture (ductility) performance-related issues in the future.



Above: Bar deformation parameters.
Below: Up-close photo of transverse deformation on a bar, illustrating radii at base of the transverse lug



This motion recommends an r/h ratio of at least 1.5 to qualify bars for anticipated acceptable performance. The recommended value is based on consensus achieved within Subcommittee 318-R after considering inelastic fatigue performance of reinforcing bars (Slavin and Ghannoum, 2015)[1]; the test data indicates acceptable inelastic fatigue performance at ratio r/h=1.5 as measured on the bar. No significant gain in fatigue life performance is observed with values of r/h above 2.0 as measured on the bar. The results of the test program also indicated that location of the critical strain localization could occur not only at the base of the deformations, but also where deformations intersect with each other.

Producing mills were involved in the consensus discussion, and advised that, based on the design value of r/h used to machine the rolls that produced the reinforced bars used in the inelastic fatigue tests, a value of r/h=1.5 as measured on the rolls will result in an actual value of r/h of at least 1.5 on the bar, if not larger. The proposed limit applies to all deformations on the bar (transverse, longitudinal and grade markings).

CODE

(ii) Uniform elongation requirements for all grades of ASTM A706 reinforcement shall be as specified in Table 20.2.1.3(c), and uniform elongation shall be determined as the elongation at the maximum force sustained by the reinforcing bar test piece.

(iii) For all grades of ASTM A706 reinforcement, the radius at the base of each deformation shall be at least 1.5 times the height of the deformation. This requirement applies to all deformations, including transverse lugs, longitudinal ribs, grade ribs, grade marks, and intersections between deformations. Conformance shall be assessed by measurements taken on newly-machined rolls used to manufacture reinforcing bars, instead of measurements taken on bar samples.

Table 20.2.1.3(a)—Modified tensile strength and additional tensile property requirements for ASTM A615 reinforcement

	Grade 40	Grade 60	Grade 80	Grade 100
Tensile strength, minimum, psi	60,000	80,000	100,000	115,000
Ratio of actual tensile strength to actual yield strength, minimum	1.10	1.10	1.10	1.10

Table 20.2.1.3(b)—Tensile property requirements for ASTM A706 Grade 100 reinforcement

	Grade 100
Tensile strength, minimum, psi	117,000
Ratio of actual tensile strength to actual yield strength, minimum	1.17
Yield strength, minimum, psi	100,000
Yield strength, maximum, psi	118,000
Fracture elongation in 8 in., minimum, %	10

A706 Rebar Deformation Geometry Requires Modifications

Source ACI

Clarification Needed for Type 2HS Application

- **Proposed Type 2HS (optional) 3.2.1 (a)**
  - Unclear if the intent of the requirement is limited to Special Moment Frames and Special Structural Walls as defined in ACI or to all structures. ACI Is clear on this topic. Alignment is needed.
  - Clarity is needed if Type 2HS applies to only A706 and only to Grade 100 or Grade 80
  - 6.7 (c) (ii) Current wording requires 1.25fy, but unspliced the proposed Grade 100 does not meet the criteria ref ACI 318-19 Table 20.2.1.3(b)
    - ASTM A615-20 Note 1 limits grade 100 to 1.15 fy for mechanical splices
    - ASTM A615 -20 Changed from 1.25 T/Y ration to 1.10 T/Y ratio. Language needs added to address A615
  - Multiple public comments voicing concerns:
    - Is proposal is warranted
    - Need for a consensus development process
    - Inclusion of industry experts

Proposal Needs Significant Work

Clarification Needed for Type 2HS Application

- ACI 318-19 – Mechanical Splices

CODE

18.2.7.1 Mechanical splices shall be classified as (a) or (b):
(a) Type 1 – Mechanical splice conforming to 25.5.7
(b) Type 2 – Mechanical splice conforming to 25.5.7 and capable of developing the specified tensile strength of the spliced bars

18.2.7.2 Except for Type 2 mechanical splices on Grade 60 reinforcement, mechanical splices shall not be located within a distance equal to twice the member depth from the column or beam face for special moment frames or from critical sections where yielding of the reinforcement is likely to occur as a result of lateral displacements beyond the linear range of behavior. Type 2 mechanical splices on Grade 60 reinforcement shall be permitted at any location, except as noted in 18.9.2.1(c).

Mechanical Splices for HSRB not allowed in special moment frames or special structural walls within 2D

Statistical Variation in Rebar Properties

TABLE 3-1: MONOTONIC TENSION TEST RESULTS FOR ALL TEST SERIES

Manufacturing Process	Grade	Monotonic Properties																Sample Size
		Yield Strength, ksi		Tensile Strength, ksi		T/Y ratio		Elastic Modulus, ksi		Elastic Limit Strain, %		Uniform Strain, %		Fracture Strain, %				
		Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.			
M1	60	63.3	68.8	93.4	97.2	1.39	1.50	25,300	33,100	0.2	0.3	9.8	12.3	13.5	22.7			12
	80	78.9	88.2	106.1	118.4	1.28	1.44	25,000	37,200	0.2	0.4	8.5	12.7	11.1	19.5			53
	100	100.5	111.3	126.9	135.6	1.21	1.27	26,800	34,700	0.3	0.4	7.6	9	9.5	14			9
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