

# Yield Method: 0.2% Offset Ahead

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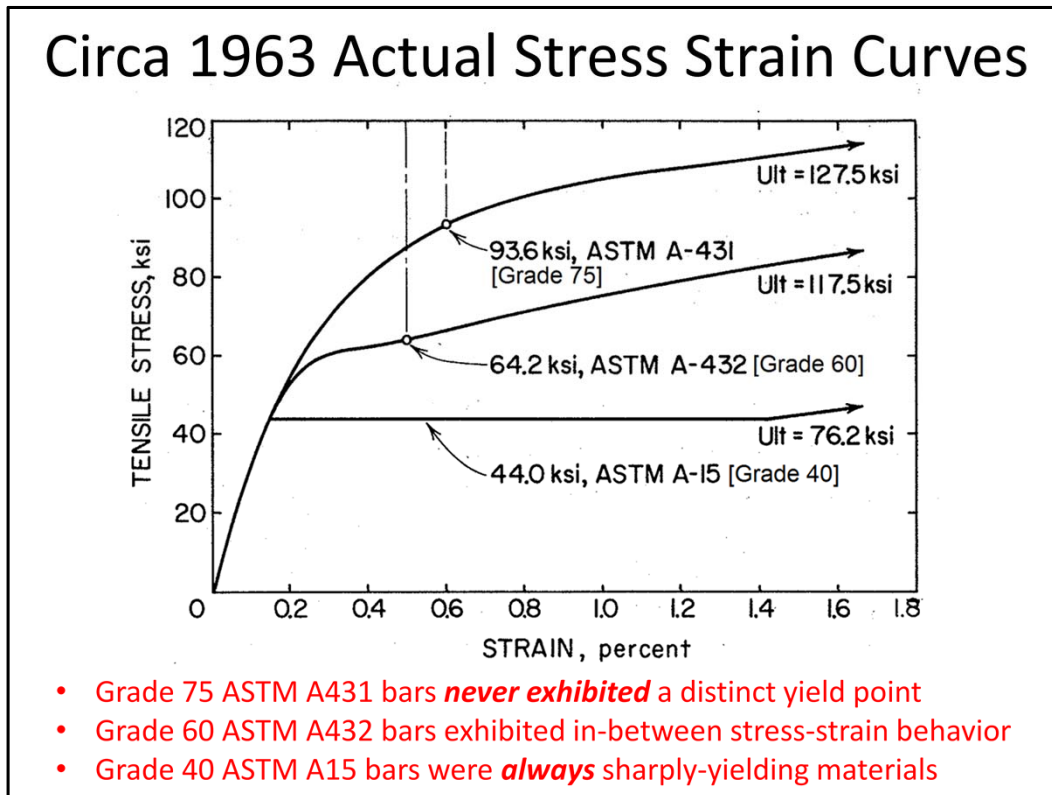
This presentation covers four aspects of the effort related to the change of yield method specified by the ACI 318 Code. The four aspects are:

1. Historical review. Why the “old” 0.35% EUL method came about, and the long-term results.
2. Some details about the CPF-sponsored research project that studied R/C sectional strength-related effects of the yield method.
3. The steps involved with changing the 318 Code provisions for yield method.
4. And finally, a look at “new business” for ACI Committee 318 and also for the CRSI Materials Properties committee, that are a result of the Code change and the related research.

# The (Former) 0.35 EUL Method

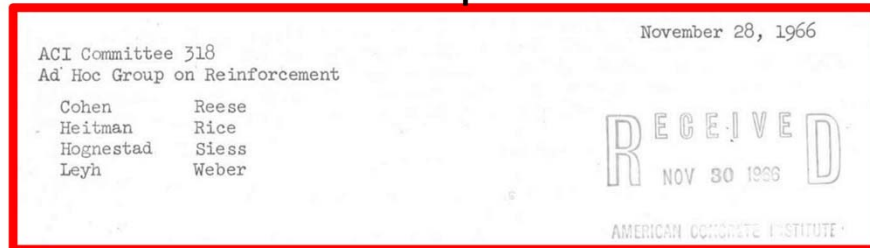
## Historical Review: Why were we where we were at?

Before moving forward, it always helps to know what happened in the past. For the topic at hand, that means answering the following question:  
“Why did ACI 318-71 specify that yield strength be measured using the 0.35% EUL method?”



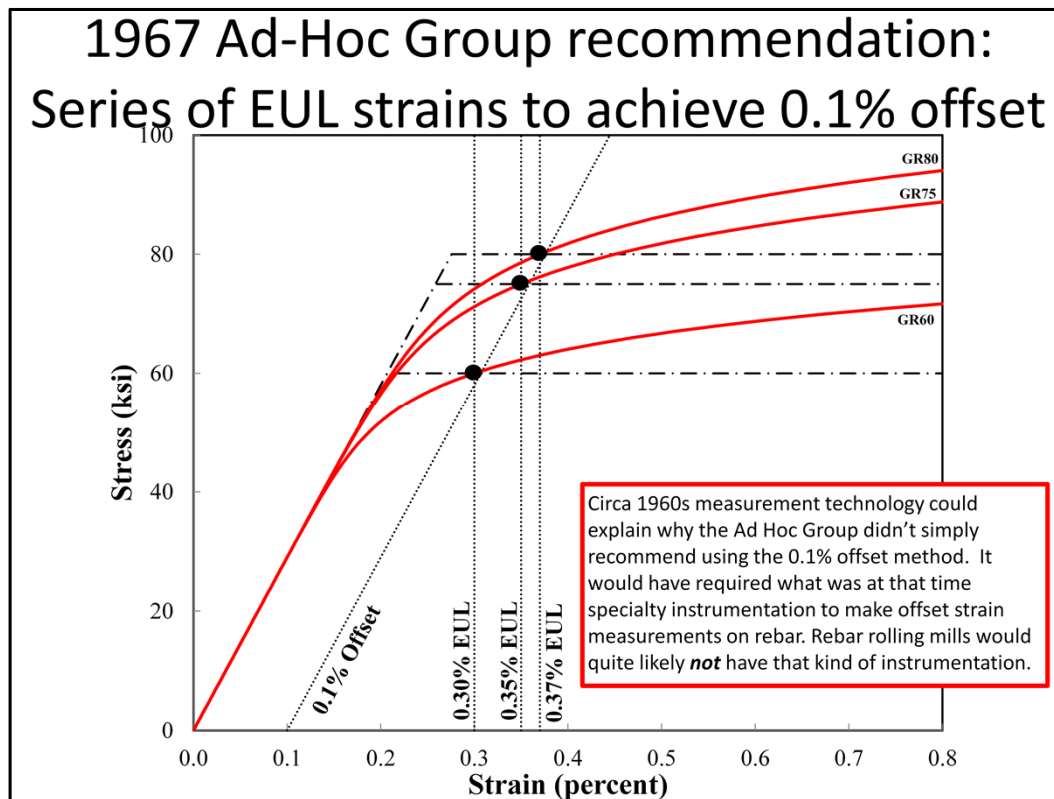
The history of the 0.35% EUL code provision goes back to the 1960s, and the actual stress-strain behavior (shown here) of the nonprestressed steel bar reinforcement as manufactured at that time. The behaviors of the three different grades of bar reinforcement are as described in the notes at the bottom of this slide.

## ACI 318 Ad Hoc Group on Reinforcement



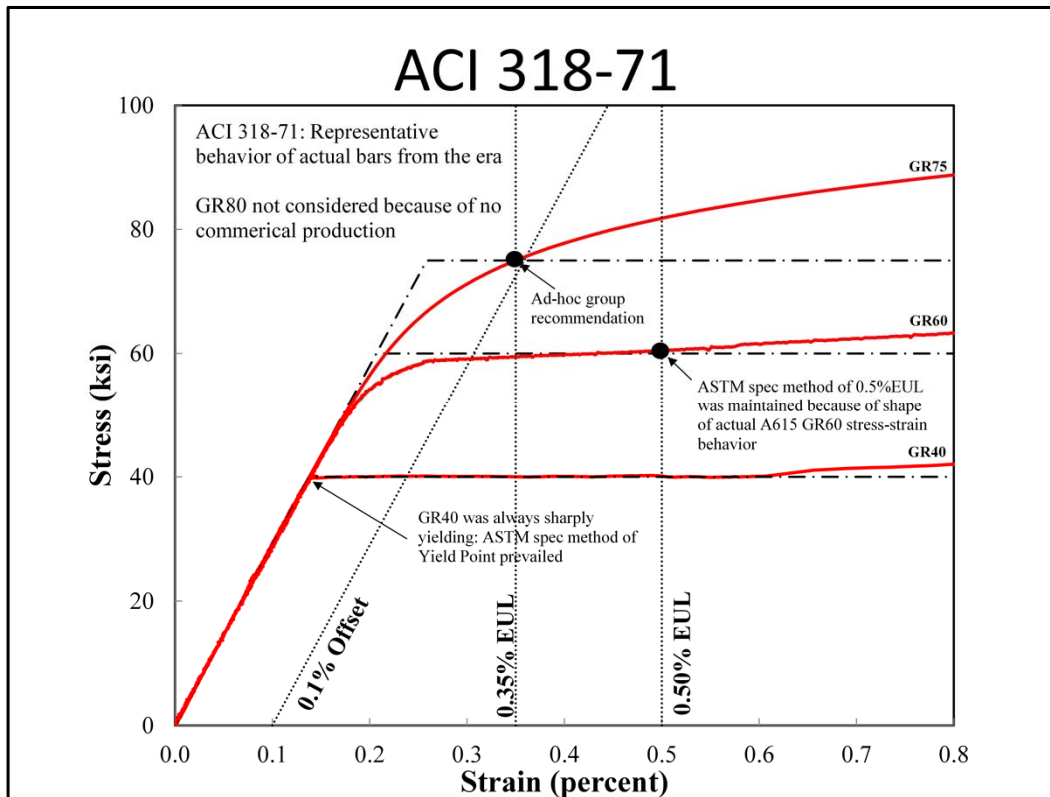
- In early 2013, the records of “Ad Hoc Group on Reinforcement” were found in the committee correspondence archives at ACI headquarters
- The ad hoc group appears to have operated during 1966, 1967, 1968
- “DRAFT of a Report” issued March 8, 1967
- “Report” issued April 10, 1967
- 1967 and 1968: Interaction with ASTM committees and follow-up laboratory testing; ad hoc group expanded in size at that time to include steel producers and others

Very instrumental to affecting the current (October 2013) code change (CB006) to the 0.2% offset method are certain historical records for ACI Committee 318, dating from the mid-1960s. It was not until early 2013 that ACI Subcommittee 318B became aware that these records existed. This historical record shows that, in the middle-to-late 1960s, an “Ad Hoc Group” of Committee 318 members studied several issues related to steel bar reinforcement, including how to establish yield strength of gradually yielding reinforcement. The 1960s Ad Hoc Group members includes several individuals who are historically known for significant contributions to structural engineering of reinforced concrete.



Regarding yield measurement method, the circa 1967 Ad Hoc Group decided that the yield strength of gradually-yielding reinforcement should be measured using the offset method at an offset of 0.1% strain. However, as explained in the insert box, strain measurement technology as employed circa 1960s in the steel mills for mill certification tests was not capable of directly making offset strain measurements. Therefore, the Ad Hoc Group developed a series of Extension Under Load (EUL) strain requirements for measuring yield. EUL measurements can be made using “low tech” approaches that don’t require electronic strain gages and stress-strain curves.

Notice that the Ad Hoc Group established a different EUL strain requirement for each different grade of reinforcement considered by them. This is an important point to remember for the several following slides.



Shown here is what made it into the ACI 318-71 Code, along with the stress-strain behavior for different grades of reinforcement as apparently assumed by the code authors. The following are relevant:

Grade 80: Not considered for the ACI 318-71 Code because Grade 80 is not included in any ASTM standard referenced by ACI 318-71.

Grade 75: The Ad Hoc Group's 0.35% strain requirement for Grade 75 recommendation is included in the ACI 318-71 Code. However, as written, the 0.35% EUL method is applied to "reinforcement with specified yield strength exceeding 60,000 psi." In 1971, the only grade of reinforcement "exceeding 60,000 psi" being manufactured at that time is Grade 75.

Grade 60: The Ad Hoc Group's 0.30% strain requirement for Grade 60 reinforcement did not make it into the ACI 318-71 Code. The reason is described in the 1971 Commentary to the code. In a nutshell, Grade 60 steel bar reinforcement has stress strain behavior, as shown here, that was almost elastic-plastic. Based on a study of several hundred recorded stress-strain curves, the yield strengths obtained by the 0.30% EUL, 0.35% EUL and 0.50% EUL were more or less the same value, typically, within 2 percent. The 0.50% EUL method was not specified by ACI 318-71, but instead is found in the underlying ASTM specification for Grade 60 reinforcement. Based on the study of the stress-strain curves, ACI Committee 318 chose not to take

an exception to the ASTM specification for Grade 60 reinforcement.

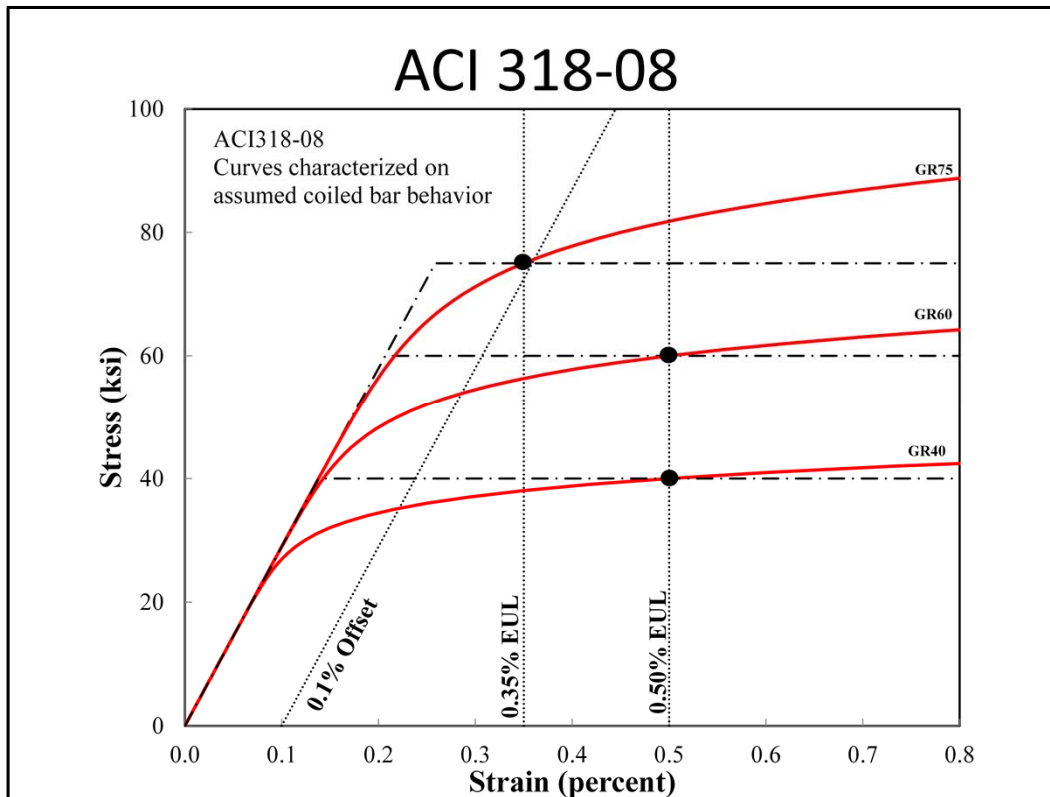
Grade 40: At that time, all Grade 40 reinforcement was sharply-yielding, and so yield strength was based on the observed yield point at the knee in the stress-strain curve. As a result, the Ad Hoc Group wasn't concerned at all with establishing a EUL strain criteria for Grade 40 reinforcement; neither was Committee 318.

NOTE: Here are some important points to keep in mind regarding what is summarized on this slide:

Given the ACI 318-71 code language as-written ("... specified yield strength greater than 60,000 psi...), the Ad Hoc Group's direct linkage between Grade 75 and the 0.35% EUL strain criteria became lost. Grade 80 reinforcement, when it was introduced in about 2009, ended up being assessed at 0.35% EUL. If there was such a thing as Grade 65 reinforcement existed, it would also be assessed at 0.35% EUL. The Ad Hoc Group's idea that the EUL strain should vary with the specified yield strength of the reinforcement is not apparent in the language used for the 1971 Code provision. Furthermore, the 1971 Commentary didn't explain this concept.

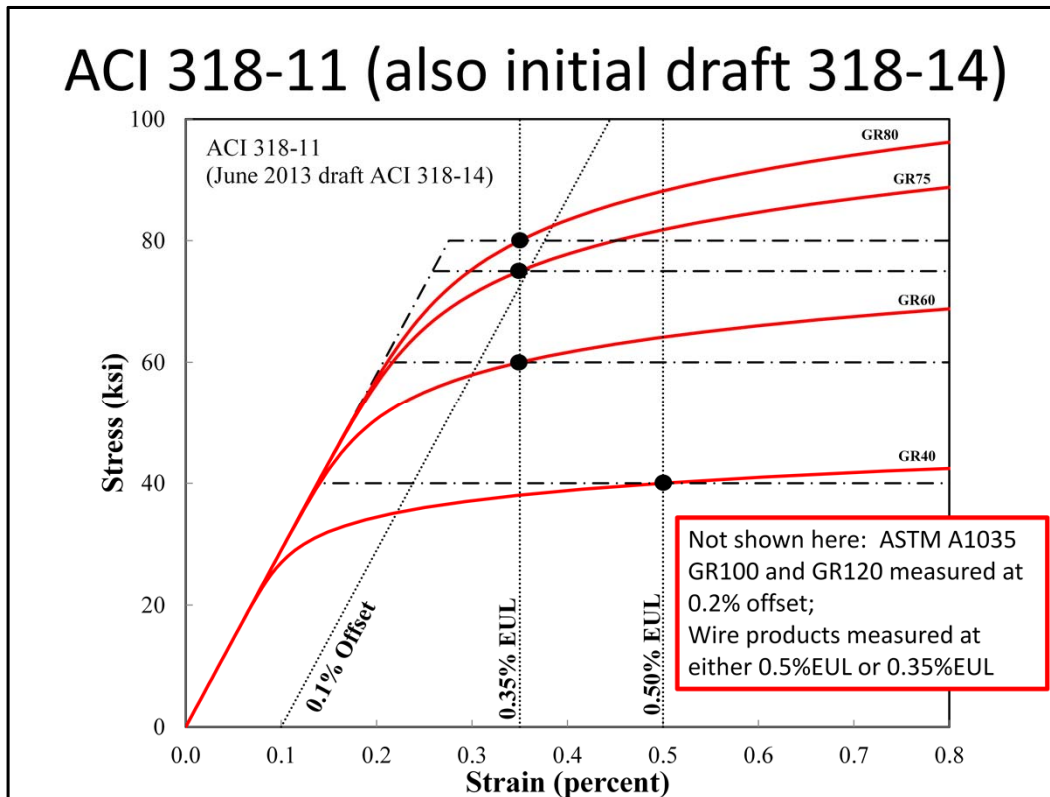
Regarding Grade 60, given that Committee 318 relied on the stress-strain behavior shown here, the use of the 0.50% EUL requirement implicitly assumes that all types of Grade 60 reinforcement have the stress-strain behavior shown here.

Regarding Grade 40, given the underlying logic, The ACI 318-71 Code implicitly assumed that all types of Grade 40 reinforcement are sharply-yielding.



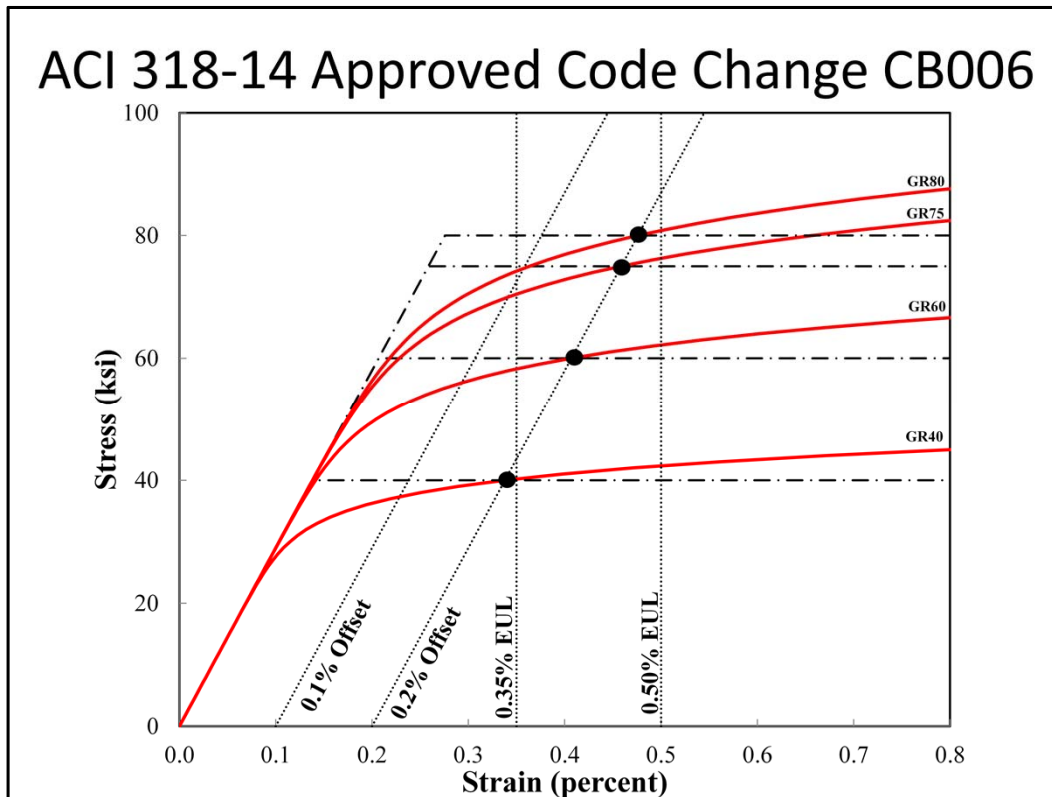
Fast forward to the ACI 318-08 Code. The underlying Code requirements for yield strength did not change: Grade 75 is assessed at 0.35% EUL, and Grades 60 and 40 are assessed at 0.50% EUL. But notice how the stress-strain curves for Grades 60 and 40 are now “roundhouse”-type characteristic, similar to that of Grade 75. By 2008, all grades of reinforcement had become available in coiled format for smaller-sized bars; coiled bars have stress-strain relationships not unlike that shown by the red curves on this slide. Notice how the stress-strain relationships for Grades 40 and 60 differ from that implicitly assumed by the 318-71 provisions. The available historical record does not have any evidence that ACI Committee 318 considered the actual stress-strain behavior of new steel reinforcement products (such as coiled bar, carbon wire, and stainless bar and wire) as they were introduced in the ACI 318 Code.





With the ACI 318-11 Code, a subtle change was made. For steel bar reinforcement, the 0.35% EUL requirement was extended downward to Grade 60 reinforcement. (This change, however, was not applied to steel wire reinforcement products.) At the time this change was made, however, the historical information (the reports of the 1960s Committee 318 Ad Hoc Group) that the EUL strain value should vary with specified yield strength was still “lost” in the committee archives, and so that code change was made without benefit of this crucial historical background. Additionally, notice that now a curve is shown for Grade 80 reinforcement, because this grade of reinforcement was introduced into the ASTM specifications in 2008. According to the provisions of ACI 318-11, Grade 80 is assessed against the 0.35% strain requirement, even though the circa 1967 Ad Hoc Group intended a different strain requirement.

In the end, under the provisions of ACI 318-11, only Grade 75 reinforcement is assessed against the historically-intended 0.1% offset requirement. The as-written provisions of ACI 318-11 diverge from the historical intent for all other grades of reinforcement.



This slide shows the state of affairs for ACI 318-14, following the approval of Code Change CB006 in October 2013. For the sake of simplicity, the red lines show roundhouse-like stress-strain behavior at all grades. Yield strength measurement method is now the 0.2% offset method for all grades of reinforcement. How this change came into being is the subject of the next section of this presentation.

# Determination of Yield Strength for Nonprestressed Steel Reinforcement

**Wiss, Janney, Elstner Associates, Inc.**

**WJE Project No. 2013.4161**

**Sponsored by**

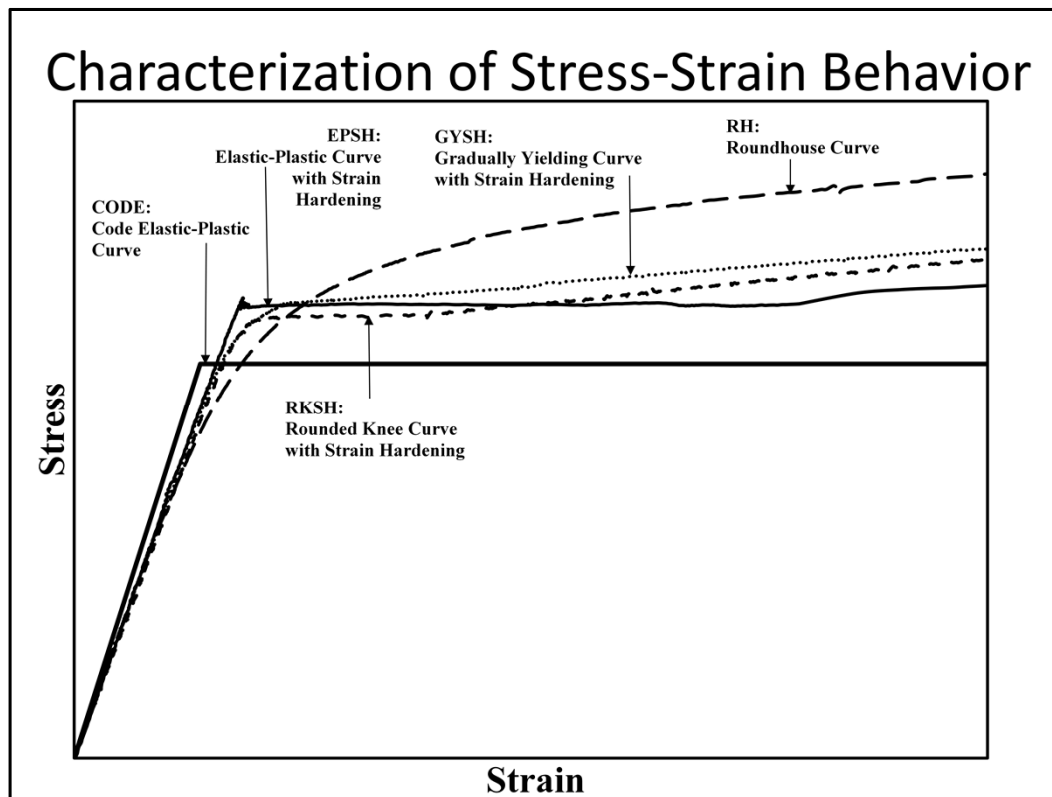
**Charles Pankow Foundation (CPF), as RGA 04-13**

This research project, sponsored by CPF, carried out the tasks of the ACI 318B Task Group (TG), as outlined in the TG mission statement dated July 23, 2013. The motivation for establishing the TG is described later in this presentation. Suffice it to say for now, it was essential that the TG mission be carried out to completion in order to substantiate the change from the 0.35% EUL method to the 0.2% offset method.

## CPF-WJE Research Project: Brief Outline

1. Review actual stress-strain behavior of many types of reinforcing bars: GR60, GR80, carbon, coiled, stainless
  - a) Only for specified  $f_y \leq 80,000$  psi
2. Develop “normalized” stress-strain curves for GR60 and GR80 bars, both sharply-yielding and gradually-yielding
  - a) “Normalized” curves established for each of 0.1% offset, 0.2% offset, 0.35% EUL and 0.5% EUL at each of GR60 and GR80
3. Select beam and column cross-sections, for a wide-range of reinforcement ratios and concrete strengths
4. Calculate “Code” nominal sectional strengths according to ACI 318 Code-permitted assumptions
5. Calculate “actual” strengths for these same sections using the “normalized” curves with strain hardening and also “realistic” concrete stress-strain behavior
6. Compare “Code” and “actual” strengths, looking for “strength loss” and “strength gain” relative to Code
7. Develop recommendations, based on the research results

This is a severely condensed overview of the research project. In the end, this outline represents a parametric study that includes sectional strength analyses for approximately 16,000 different R/C sections.



One important step was to characterize the stress-strain behavior that can be exhibited by the various types of nonprestressed steel reinforcement considered by the ACI 318 Code. This graphic illustrates the range of stress-strain characteristics observed when reviewing actual stress-strain curves.

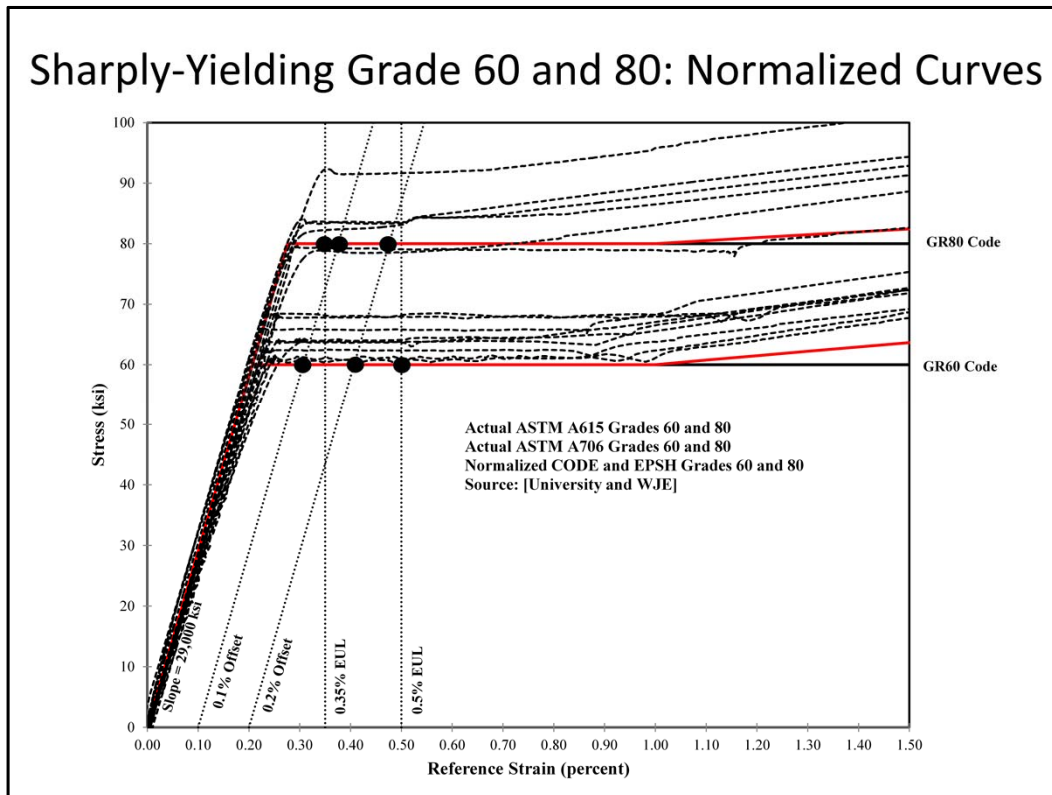
This graphic also shows the “CODE” stress-strain behavior for reinforcement, which is assumed to be elastic-perfect plastic, without strain hardening.

The actual curves illustrated represent the observed range of actual stress-strain behavior for nonprestressed steel reinforcement of all types. In the end, two curves “bracket” the range of behaviors:

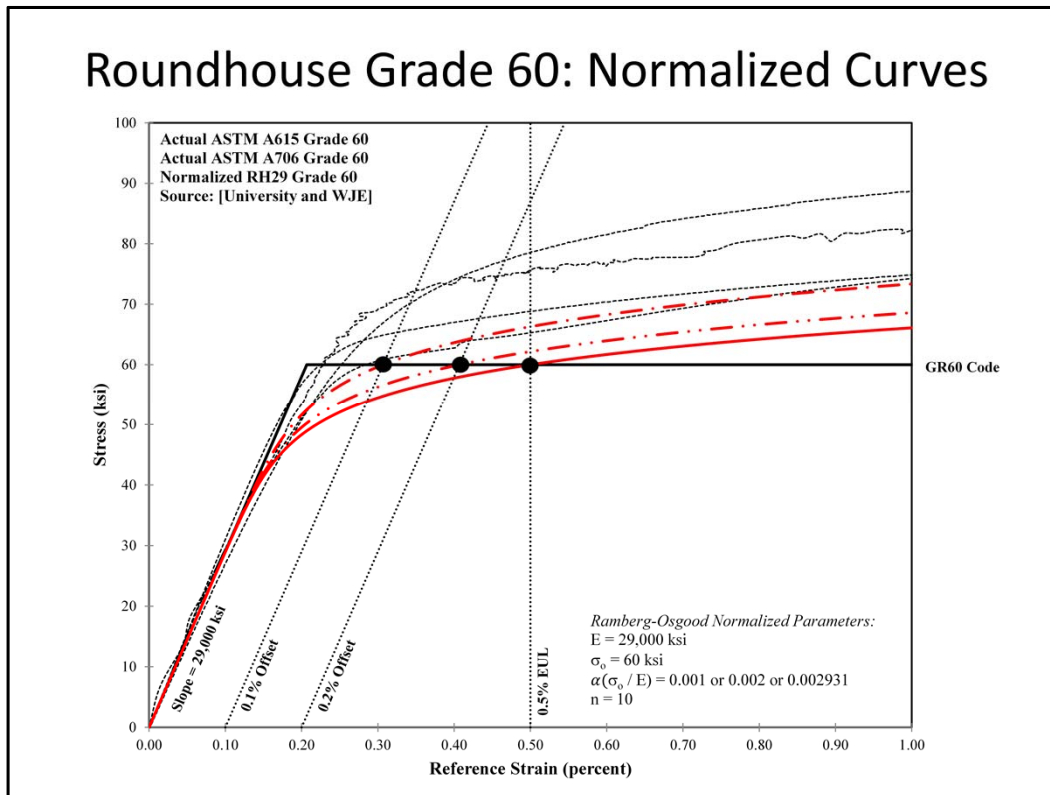
At one end of the range is the EPSH behavior, representing reinforcement stress-strain behavior which is, for all practical purposes, elastic-perfectly plastic, but is followed by strain hardening.

At the other end of the range of behaviors is the RH “roundhouse” behavior, also shown on this graphic.

For all practical purposes, the RKSH and GYSH behaviors are bracketed by the EPSH and RH behaviors. Consequently, the parametric study included the EPSH and RH stress-strain behaviors, and the RKSH and GYSH were not further considered.

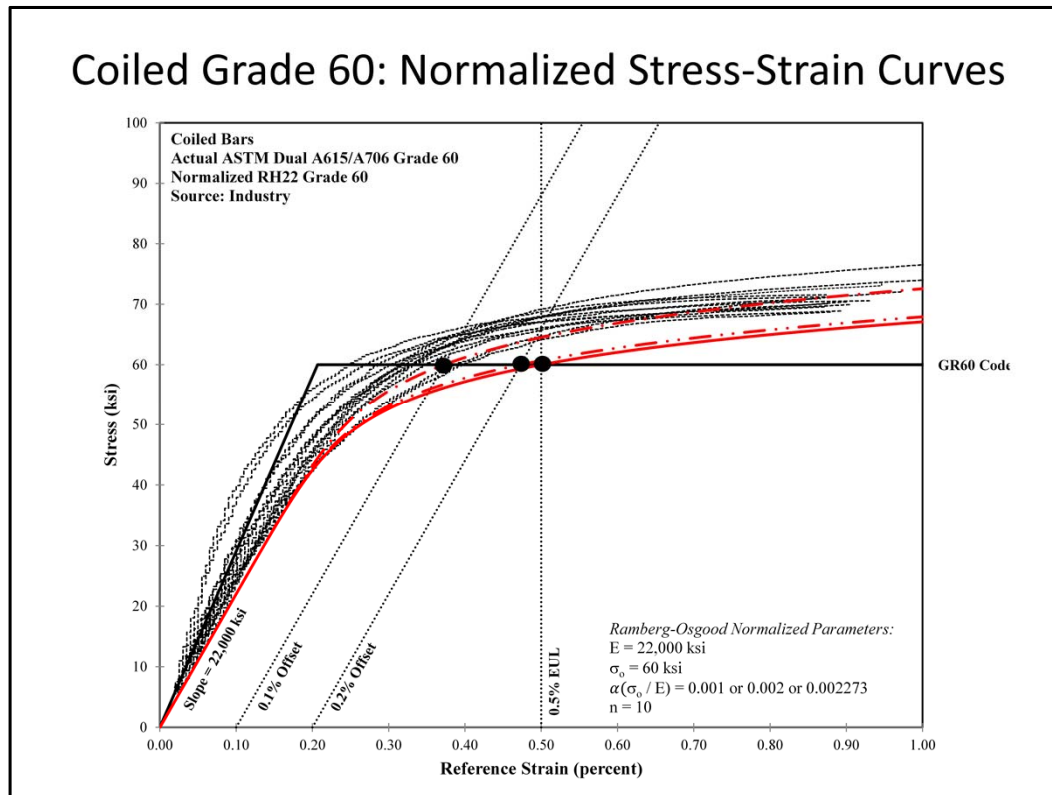


The solid red lines shown the “normalized” stress-strain behavior for sharply-yielding reinforcement, which is characterized as EPSH behavior. The onset of strain hardening is assumed to take place at 1.0% strain for the EPSH curves.



The approach used for the research project was to develop the “normalized” stress-strain curves based on lower-bound, visual-fit line that exhibits the general shape of the actual stress-strain curves in the range of zero to about 1% or 1.5% strain.

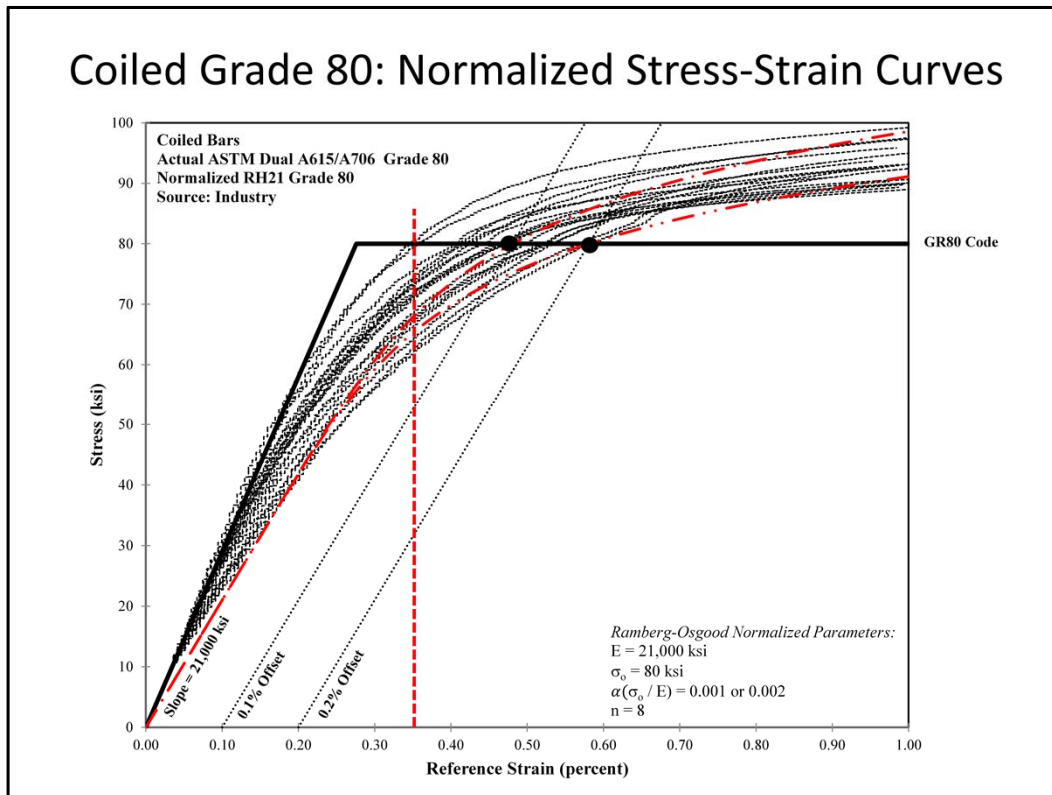
As an example, shown here with the dashed black lines are actual stress-strain curves for straight (that is, not coiled) reinforcing bars in Grade 60 that exhibited roundhouse-type stress-strain behavior. The red lines illustrate three different “normalized” curves. As used for the research project described in this presentation, “normalized” means that a gradually-yielding stress-strain curve develops exactly the specified yield strength when yield is measured according to the method being considered. Here, the different red lines represent Grade 60 roundhouse behaviors that are normalized to the 0.1% offset method, the 0.2% offset method, and the 0.5% EUL method. The normalized stress-strain curves follow the Ramberg-Osgood equation, using the parameters given on the slide.



This shows the normalized curves based on the actual stress-strain behavior for Grade 60 coiled steel bar reinforcement. Notice the wide range of initial tangent modulus for the linear-elastic region (initial straight line behavior commencing at the origin) of the stress-strain curve. The approach taken for the research project was to lower bound coiled bar stress-strain behavior, and so the normalized curves for coiled Grade 60 bar have a lower bound initial modulus of 22,000,000 psi.

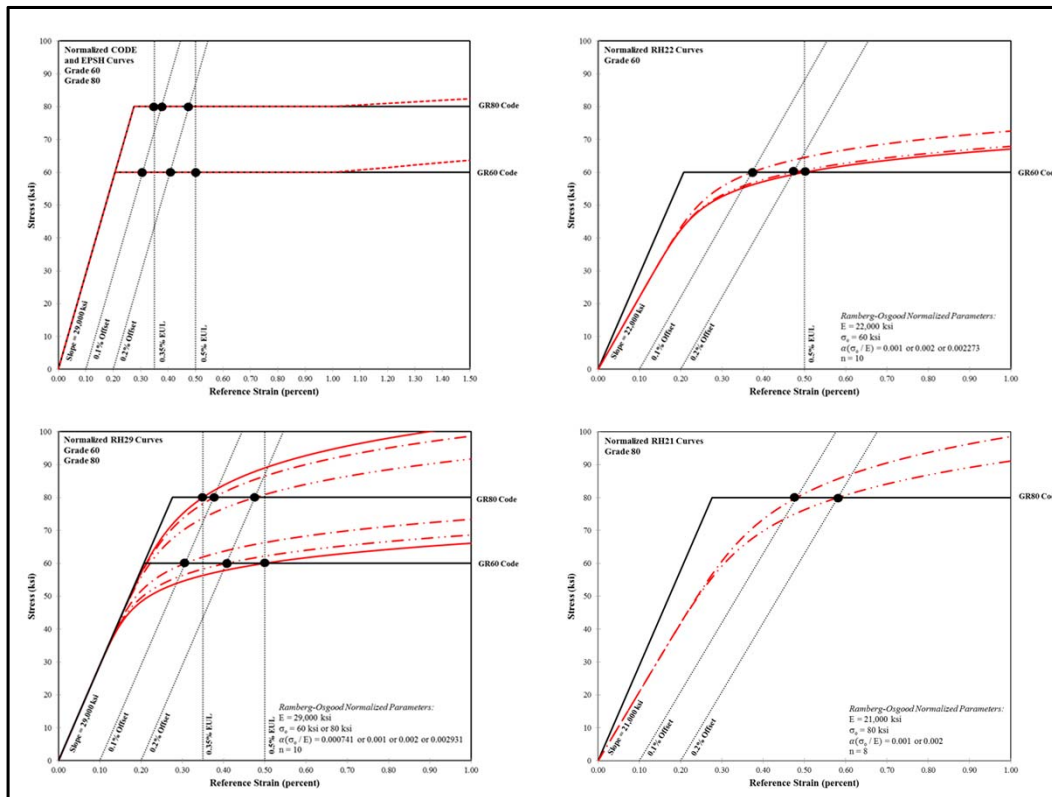
Notice that some of the actual stress-strain curves have an initial modulus that is significantly greater than the commonly-accepted value of 29,000,000 psi for steel, while the lower bound initial stiffness is significantly less than the commonly-accepted value. As discussed later in this presentation, this kind of scatter is likely attributable to the instrumentation used to measure and record the actual stress-strain curves shown here.





This shows the normalized curves based on the actual stress-strain behavior for Grade 80 coiled steel bar reinforcement. Again, notice the wide range of initial tangent modulus for the linear-elastic region (initial straight line behavior commencing at the origin) of the stress-strain curve. The normalized curves for coiled Grade 80 bar have a lower bound initial modulus of 21,000,000 psi.

The vertical, red dashed line represent the 0.35% EUL strain criteria. For Grade 80 reinforcement, the 0.35% EUL strain vertical line intersects the line representing the initial modulus of 21,000,000 psi at a stress that is less than 80,000 psi. This means that it is not possible to “normalize” Grade 80 coiled bar to the 0.35% EUL yield measurement method.



In the end, eight (8) different normalized curves were developed for Grade 60 and seven (7) different curves were developed for Grade 80. All of these normalized curves and the corresponding Ramberg-Osgood parameters are shown on this slide.

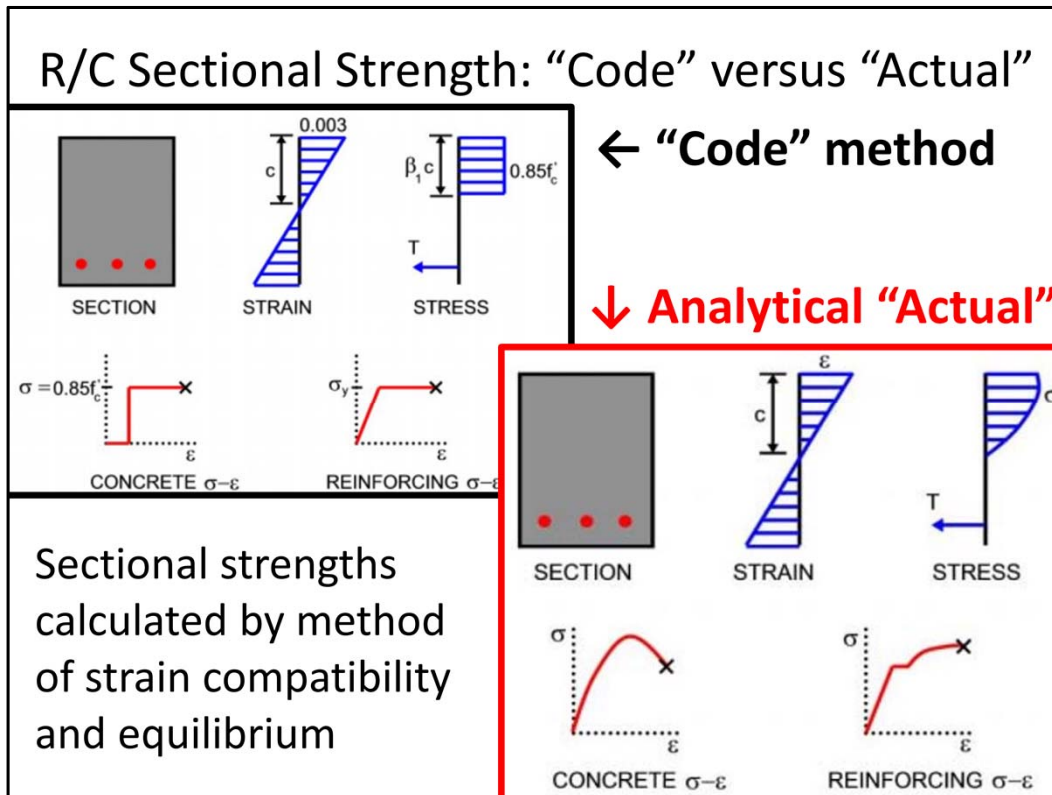
<b>“Suite” of Normalized Stress-Strain Curves</b>					
<b>Specified Minimum Yield Strength of Reinforcement, <math>f_y</math> (psi)</b>	<b>Yield Measurement Method</b>				
	<b>Observed Yield Point</b>	<b>Offset Method at 0.1% Offset</b>	<b>Offset Method at 0.2% Offset</b>	<b>0.35% Extension Under Load (EUL)</b>	<b>0.50% Extension Under Load (EUL)</b>
80,000	CODE EPSH	RH 29 RH 21	RH 29 RH 21	RH 29	N/A
75,000	Not included - bracketed by GR80 and GR60				
60,000	CODE EPSH	RH 29 RH 22	RH 29 RH 22	N/A	RH 29 RH 22
40,000	Non included because of limited production				

These same normalized curves are summarized here in tabular format, showing the notation used to identify different curves. All of these tabulated stress-strain curves were included in the parametric study.

Of note:

Grade 75 reinforcement was not included because its strength performance will be bracketed by that of Grade 80 and Grade 60 reinforcement.

Grade 40 reinforcement was not included because not very much Grade 40 reinforcement is currently produced.



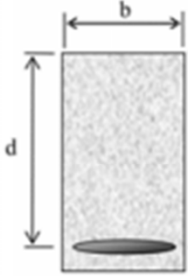
These diagrams graphically illustrate the assumptions made when calculating "Code" strengths, as compared to the assumptions made when analytically calculating "actual" strengths.

Both types of strength calculations employ the assumptions of strain compatibility and equilibrium.

For "Code" strengths, the stress-strain relationships for both concrete and reinforcement are simplified as shown here, as permitted by the ACI 318 Code.

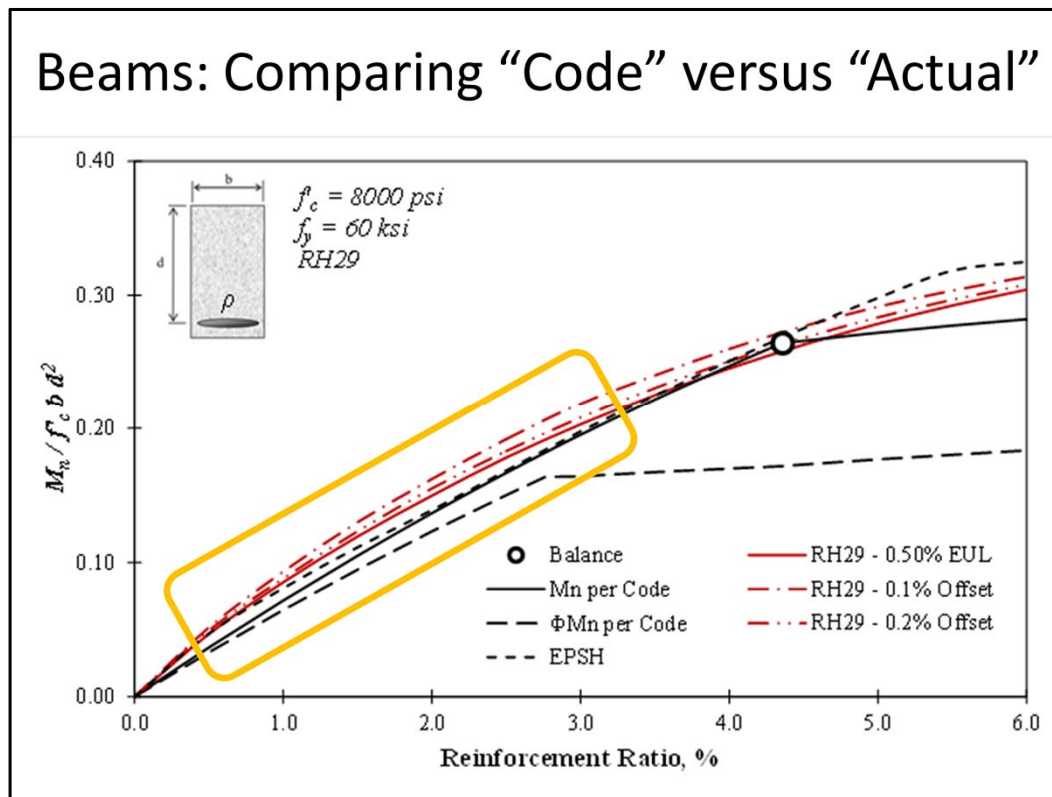
For "Actual" strengths, more sophisticated, non-linear, stress-strain relationships are included for both concrete and reinforcement.

## R/C Beam Sections Considered

Section	Concrete $f'_c$ (psi)	Reinforcement $f_y$ (psi)
 <p><math>\rho=0\%</math> to <math>6\%</math> by <math>0.5\%</math> increments, and also at <math>\rho_b</math></p>	5,000	60,000
	5,000	80,000
	8,000	60,000
	8,000	80,000

Multiply by 7 or 8 stress-strain relations (straight bars and coiled bars) for each grade of reinforcement, results in 390 different beam sections.

Here are the beam sections that were included in the parametric study. Considering all combinations and permutations, 390 different beam sections were analyzed.

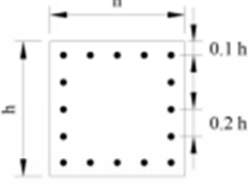
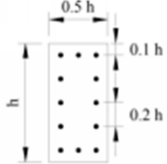
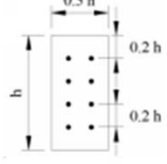


The “Nominal Per Code” and “Design Per Code” moments are calculated in accordance with the provisions of ACI 318-14.

The other curves are calculated using realistic, nonlinear stress-strain relationships for both steel and concrete. A moment-curvature curve is developed for a beam section having a given reinforcement ratio. The moment strength is then taken as the maximum moment on the moment-curvature curve.

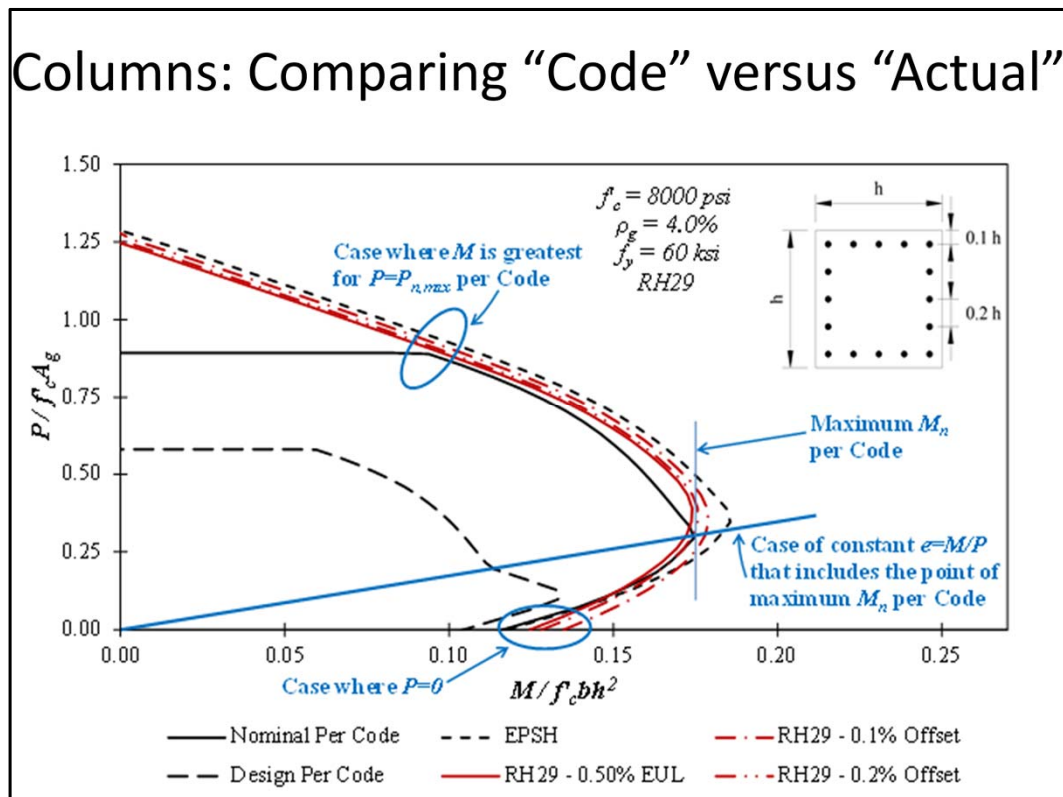
The region of interest (within the yellow rectangle shown on this slide) for beams is the range of reinforcement ratios between a minimum value of about 0.3% and maximum value of about 0.75 times the balanced reinforcement ratio. (The balanced reinforcement ratio is shown as the open circle on the “Mn per Code” curve.) Within this range of reinforcement ratios, all types of reinforcement stress-strain behaviors, whether straight bar (the RH29 curves shown here) or coiled bar (not shown here), provide analytical sectional strengths that exceed code-calculated nominal strengths (Mn curve). This occurred for all combinations of concrete strength, reinforcement yield strength, and reinforcement stress-strain relationships considered.

## R/C Column Sections Considered

Section	Concrete $f'_c$ (psi)	Reinforcement $f_y$ (psi)
Square with $\gamma=0.8$  $\rho=1\%, 2\%, 3\%, 4\%$	5,000	60,000
	5,000	80,000
	8,000	60,000
	8,000	80,000
	12,000	60,000
	12,000	80,000
Rectangular with $\gamma=0.8$  $\rho=1\%, 2\%, 3\%, 4\%$		
Rectangular with $\gamma=0.6$  $\rho=1\%, 2\%$		

At request of ACI Committee 318, additional column sections with  $\rho=6\%$  and  $8\%$  are also included (not shown). Multiply by 5 stress-strain relationships (“coiled” bars not included for columns) for each grade of reinforcement, results in about 380 different column sections. Multiply by 40 different axial load levels, results in approximately 16,000 different column strength analyses.

Here are the column sections that were included in the parametric study. Considering all combinations and permutations, including different magnitudes of axial load, 16,000 different column sections were analyzed.



The “Nominal Per Code” and “Design Per Code” interaction curves are calculated in accordance with the provisions of ACI 318-14.

The other curves are calculated using realistic, nonlinear stress-strain relationships for both steel and concrete. For a given column section and a given magnitude of assumed axial load acting on the column section, a moment-curvature curve is developed. The moment strength is then taken as the maximum moment on the moment-curvature curve.

There are three regions of interest in these column P-M interaction curves:

\*Pure flexural behavior, at the bottom of the graph, where  $P=0$ . This case was assessed qualitatively. For the most part, almost across the board, the strength provided by the EPSH behavior is about the same as that of CODE, and all of the RH behaviors provide strengths that exceed CODE.

\*High axial load, identified on the graph as case where  $M$  is greatest for  $P=P_{n,max}$  per Code. This case was also assessed qualitatively. In this region, the strengths provided by the various realistic reinforcement stress-strain behaviors were grouped close to one another. Sometimes the realistic curves exceed CODE, as illustrated here, and sometimes they were less than CODE, but typically the realistic curves moved as a group relative to the CODE curve.

\*At the “nose” of the CODE P-M curve, which is defined as the point of maximum  $M_n$  on the CODE curve. The “nose” region sees the greatest variation among strengths provided by the various realistic reinforcement stress-strain behaviors. The other strengths were assessed along the sloping line shown here that represents constant eccentricity  $e=M/P$ , where the point  $(M,P)$  is the point of maximum  $M_n$  on the CODE curve. The other strengths were numerically assessed relative to CODE strength, as shown on the following two slides.



## GR60 Square Columns: “nose” data

$f_y$ (psi)	$f'_c$ (psi)	Reinforcement Stress-Strain Relationship	Longitudinal Reinforcement Ratio, $\rho$			
			1%	2%	3%	4%
			Strength Ratio Relative to CODE (Note 1)			
60,000 (Note 2)	5,000	EPSH	1.04	1.03	1.03	1.02
		RH29-0.1% Offset	1.03	1.00	.99	.98
		RH29-0.2% Offset	1.01	.99	.97	.96
		RH29-0.5% EUL	1.01	.98	.96	.94
		CODE	1.00	1.00	1.00	1.00
	8,000	EPSH	1.07	1.08	1.06	1.05
		RH29-0.1% Offset	1.07	1.05	1.03	1.02
		RH29-0.2% Offset	1.06	1.03	1.01	.99
		RH29-0.5% EUL	1.06	1.03	1.00	.98
		CODE	1.00	1.00	1.00	1.00
	12,000	EPSH	.98	.99	.99	.99
		RH29-0.1% Offset	.97	.98	.97	.96
RH29-0.2% Offset		.97	.98	.96	.94	
RH29-0.5% EUL		.97	.97	.95	.93	
CODE		1.00	1.00	1.00	1.00	

Here are results for square columns with Grade 60 reinforcement. All strengths are given as ratios relative to the strength provided by CODE, hence CODE is always 1.0. From ACI 318-71 to ACI 318-08, inclusive, gradually-yielding ASTM A615 Grade 60 reinforcement was assessed using the 0.5% EUL criteria. The 0.2% offset relationship provides the same or slighter larger strengths.

It is also of interest to compare the various strengths to that provided by the EPSH stress-strain relationship, which represents the strength provided by most Grade 60 carbon bar reinforcement.

In the end, for the more economical column reinforcement ratios of 1% and 2%, there is not a great variation among or between the strengths provided by various relationships shown here.

## GR80 Square Columns: “nose” data

$f_y$ (psi)	$f'_c$ (psi)	Reinforcement Stress-Strain Relationship	Longitudinal Reinforcement Ratio, $\rho$			
			1%	2%	3%	4%
			Strength Ratio Relative to CODE (Note 1)			
80,000	5,000	EPSH	1.04	1.02	1.01	1.01
		RH29-0.35% EUL	1.02	.99	.99	.98
		RH29-0.1% Offset	1.01	.99	.98	.97
		RH29-0.2% Offset	1.00	.97	.96	.95
	CODE	1.00	1.00	1.00	1.00	
	8,000	EPSH	1.07	1.08	1.06	1.03
		RH29-0.35% EUL	1.06	1.07	1.03	1.02
		RH29-0.1% Offset	1.06	1.06	1.03	1.01
		RH29-0.2% Offset	1.06	1.05	1.01	.99
	CODE	1.00	1.00	1.00	1.00	
	12,000	EPSH	.98	.98	.99	.99
		RH29-0.35% EUL	.97	.97	.98	.97
RH29-0.1% Offset		.97	.97	.98	.96	
RH29-0.2% Offset		.97	.97	.97	.95	
CODE	1.00	1.00	1.00	1.00		

Here are results for square columns with Grade 80 reinforcement. All strengths are given as ratios relative to the strength provided by CODE, hence CODE is always 1.0. From ACI 318-71 and onward, gradually-yielding Grade 80 reinforcement was, inadvertently, assessed using the 0.35% EUL criteria; recall that, historically, 0.35% EUL was actually meant for only Grade 75 reinforcement.

It is also of interest to compare the various strengths to that provided by the EPSH stress-strain relationship.

In the end, for the more economical column reinforcement ratios of 1% and 2%, again, there is not a great variation among or between the strengths provided by various relationships shown.

## Research Finding: Recommend 0.2% Offset

“It is recommended that the yield measurement method for gradually-yielding nonprestressed steel reinforcement as specified by ACI 318-14 become the offset method using an offset of 0.2 percent.”

“As demonstrated by the findings of the parametric study of sectional strength as reported, the change would not adversely affect the structural safety of reinforced concrete members.”

The main finding of the CPF-WJE research project is a recommendation that the ACI 318 Code-specified yield measurement method become the 0.2% offset method. The next section of this presentation describes how this recommendation moved forward as Code Change Submittal CB006 within ACI Committee 318.

# The “New” 0.2% Offset Method and ACI 318 Building Code Requirements for Structural Concrete

**How was this code change accomplished  
within ACI Committee 318?**

The CB006 ballot brought forward other technical concerns with the ACI 318 Code that ended up being procedurally unrelated to the topic of the CB006 submittal, which was specifically limited to the yield measurement method. These other technical concerns are nonetheless important for future consideration by Committee 318.

## Things actually can happen quickly! (1 of 2)

- March 2013: The historical record from the mid-1960s ACI Committee 318 “Ad Hoc Group on Reinforcement” is located at ACI HQ
- April 15, 2013: 318B Subcommittee member Paulson presents a summary of the 1967 Ad Hoc Group’s historical reports to ACI Subcommittee 318B – attracts much interest throughout all of ACI Committee 318
- April 15, 2013: The Chair of ACI Subcommittee 318B, Cathy French, appoints “ACI 318B Task Group on Yield Strength Determination for Nonprestressed Steel Reinforcement”
- July 23, 2013: The ACI 318B TG reviews and finalizes its Mission Statement and List of Tasks
- August 15, 2013: Charles Pankow Foundation (CPF) approaches WJE, asking for proposal to carry out the tasks of the ACI 318B TG as a commercial research project
- August 18, 2013: CPF gives WJE notice to proceed

It is very rare that this kind of Code change happens as quickly as it did. But it is nonetheless possible when the proposed change makes sense and has wide support among the membership of Committee 318.

All of the steps shown here were necessary for completing the Code change. Two of these steps are particularly important for completing the Code change in such a short time:

\*The first step: finding historical records that explain why the 0.35% EUL method was used. These records were summarized earlier in this presentation. Until these historical records were located, it was not possible to clearly and authoritatively explain why the 0.35% EUL method was written into the ACI 318 Code in 1971. These historical records made it clear that the Code provision specifying the 0.35% EUL method was obsolete, and so the new Subcommittee 318B Task Group (TG) was appointed in April 2013.

\*The fifth step: sponsorship of a commercial research project by the CPF to carry out the tasks of the TG. If left to the volunteer activities of the TG, it would have taken two or three calendar years to accomplish the tasks. As commercial research, this was accomplished within a few weeks.

## Things actually can happen quickly! (2 of 2)

- August 30, 2013: WJE structural analyses substantially complete; reporting is underway
- September 11, 2013: Code Change CB006, proposing that ACI 318 change to 0.2% offset method, is prepared and submitted to ACI Committee 318
- September 13, 2013: Ballot LB13-6 issued; includes CB006
- October 11, 2013: Ballot closes; proposed change CB006 draws 12 negative votes
- October 22 and 23, 2013: extensive discussion of CB006 during ACI 318B meeting and before the ACI 318 Main meeting; 10 negatives resolved
- October 23, 2013: during the 318 Main meeting, discussion on the floor resolves the remaining two negatives: **CB006 passes.**
- 2014: ACI 318-14 will specify use of the 0.2% offset method for measurement of yield strength of all nonprestressed steel reinforcement

With the structural analyses and findings of the CPF-sponsored research project in hand as technical evidence, code change Submittal CB006 was put forward. There was considerable debate about CB006 during ACI Subcommittee 318B and ACI Committee 318 meetings. In the end, all negative ballots were resolved, and CB006 was accepted as a technical code change for ACI 318-14.

## Approved CB006 Code Change

20.2.1.2 — Yield strength of nonprestressed bars and wires shall be determined by either (a) or (b):

(a) the offset method, using an offset of 0.2 percent; or

(b) the yield point by the halt-of-force method, provided the nonprestressed bar or wire has a sharp-kneed or well-defined type of yield point.

Shown here is the as-approved final language for the CB006 submittal code changes.

## Approved CB006 Commentary Language

R20.2.1.2 — The majority of nonprestressed steel bar reinforcement exhibits actual stress-strain behavior that is sharply yielding or sharp-kneed (elasto-plastic stress-strain behavior). However, reinforcement products such as bars of higher strength grade, steel wire, coiled steel bar, and stainless steel bars and wire, generally do not exhibit sharply-yielding stress-strain behavior, but instead are gradually-yielding. The method used to measure yield strength of reinforcement needs to provide for both types of reinforcement stress-strain relationships.

A study<sup>20.XX</sup> considering reinforcement manufactured during 2008 through 2012 found that the offset method, using an offset of 0.2%, provides for a reasonable estimate of the strength of reinforced concrete structures.

The yield strength is determined by the manufacturer during tensile tests performed at the mill on samples of reinforcement. Test methods for determining yield strength of steel, including the offset method and yield point by halt-of-force method, are referenced in the ASTM standards for nonprestressed bars and wire.

Shown here is the as-approved final language for the CB006 submittal commentary changes. In the second paragraph, Reference 20.XX is the report for the CPF-WJE research project.



**Recommended “New Business” for the  
consideration of ACI Committee 318,  
arising out of the CB006 ballot**

The CB006 balloting process brought forward other possible technical concerns with the ACI 318 Code that ended up being procedurally unrelated to the CB006 yield methodology, but are nonetheless important for future consideration by Committee 318.

## Suggested New Business for Committee 318

- Coiled bars: Is the initial tangent modulus of coiled bar reduced because of the cold-working related to coiling and straightening? If yes, does the 318 Code need to recognize this?
- “Excessively” overstrength reinforcement: Does the 318 Code need to specify a maximum yield strength for each grade of reinforcement, as a general provision for all reinforcement?
- Code reliability calibration: Consider extending Code calibration to separately include Grade 80 reinforcement, in addition to Grade 60
- Substitution of ASTM A615 GR60 for ASTM A706 GR60 in seismic applications: Revise Code to require the substitute A615 to also satisfy final elongation requirements of A706

Shown here are items of new business that arose during the course of resolving negative ballots on CB006. Negative ballots were cast around the technical items shown here. It was pointed out to the individuals casting these negative votes that these topics are actually unrelated to the method used for measuring yield strength. It was proposed that these topics be put forward as new business for the next code cycle, and so the related negative votes were withdrawn.

Concrete Reinforcing Steel Institute (CRSI)  
Materials Properties Committee

**Recommended “Action Items” for  
the consideration of the Committee**

Because the CB006 code change applies to steel reinforcing bars, the code change balloting process (and also the CPF-WJE research project) brought forward a number of technical concerns that should be considered by the CRSI Materials Properties Committee.

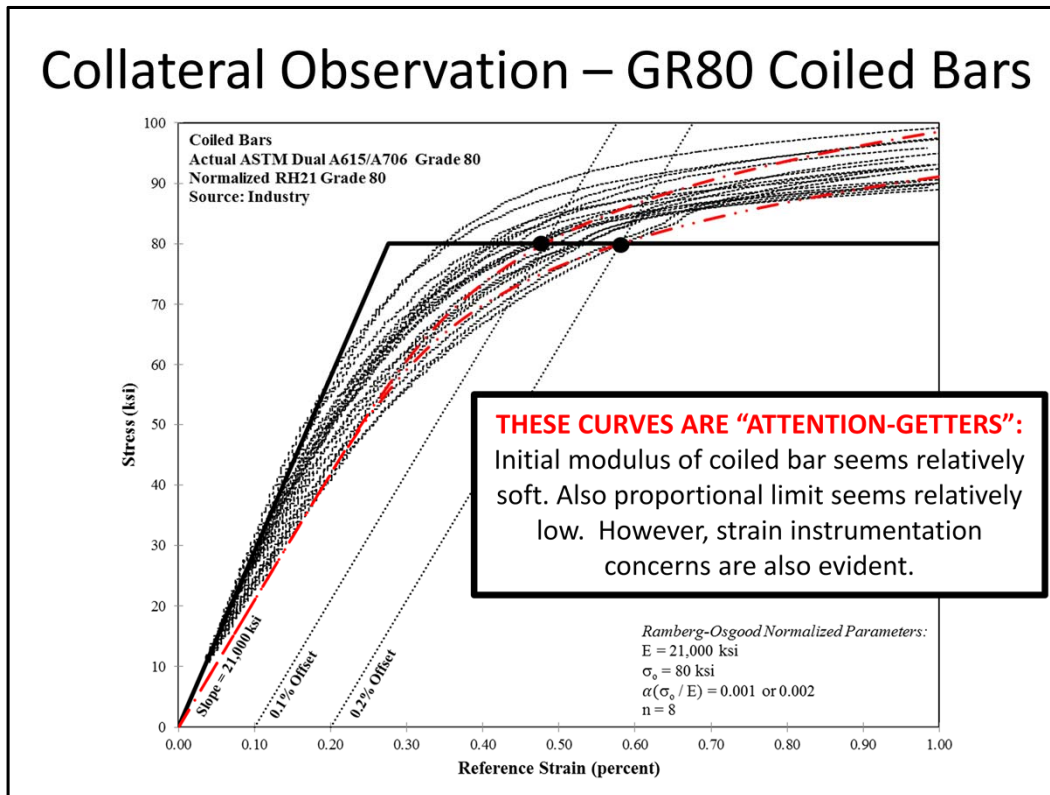
**“Action Item” for CRSI Mat’ls Prop. Committee:  
Work to Modify All ASTM Specs Cited in ACI 318-14**

- Bars:
  - ASTM A615 (carbon steel)
  - ASTM A706 (low-alloy steel)
  - ASTM A996 (axle steel and rail steel)
  - ASTM A955 (stainless steel)
- Wire:
  - ASTM A1064 (carbon steel)
  - ASTM A1022 (stainless steel)
- NOTE: ASTM A1035 (low-carbon chromium steel) already uses 0.2% offset, so no need to change A1035
- NOTE: Coordinate similar changes with CSA spec

It is anticipated that CRSI will work with the appropriate ASTM Committees to implement the change to the 0.2% offset method in a timely manner. The Canadian standard for reinforcing bar also uses the 0.35% EUL method, and so there should also be coordination with the Canadian reinforcing bar manufacturing specifications. Additionally, there needs to be coordination with the Canadian reinforced concrete design code body, so that they are informed about the ACI Code change.

The following slides illustrate items of long-term interest to the CRSI Materials Properties Committee

These long-term items were identified as “collateral observations” in the CPF-WJE research report. These collateral observations are not strictly related to methods used to measure yield, but nonetheless became evident as significant technical concerns during the course of carrying out the CPF-WJE research project.

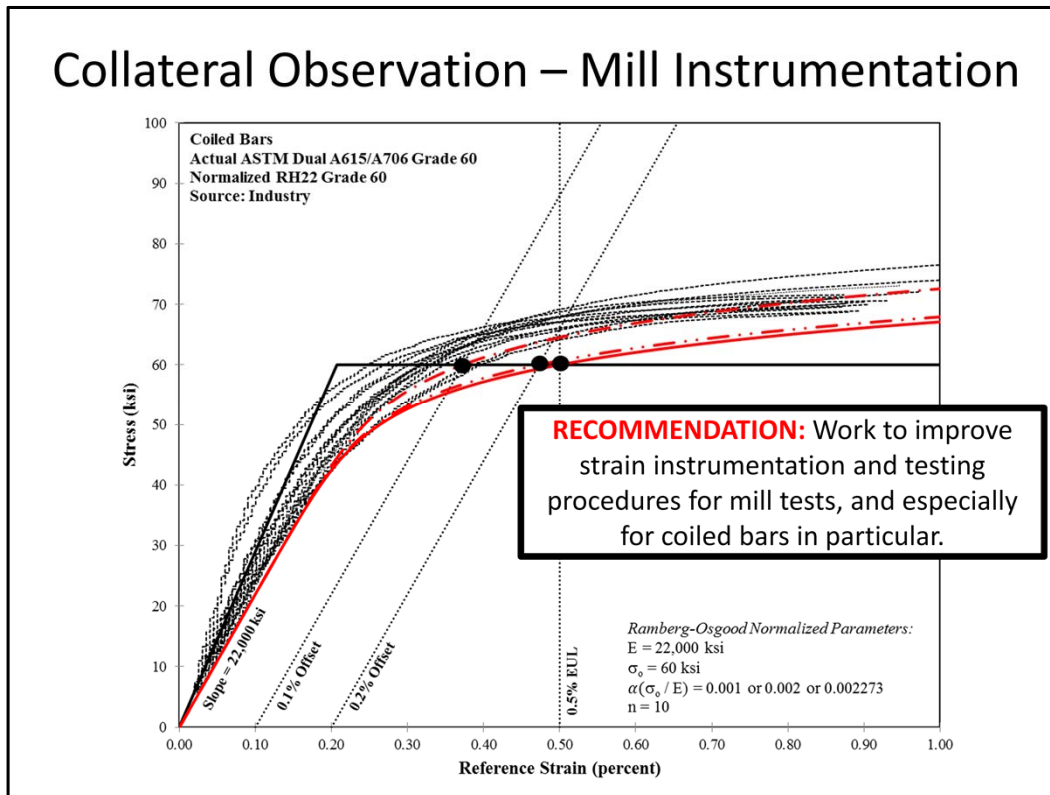


The stress-strain curves for coiled reinforcing bars are “attention-getters” because of the wide variation to the initial tangent modulus of the stress-strain curves. The curves shown here were provided by the reinforcement manufacturing industry. These curves were generated at the mill during tensile testing of the bar yield strength of the reinforcement as reported on certified mill test reports.

These results suggest that there is some “softening” of the initial tangent modulus. Considering that the test samples used for generating these curves are coiled bars that have been physically straightened out, some “softening” of the elastic modulus would not be unexpected. This part of the “softening” might be attributable to cold-working during the coiling process and subsequent straightening prior to testing.

However, keep in mind that the mills typically use a single extensometer mounted to the test sample. Inevitably, coiled bar samples are still slightly curved, even after being straightened for the tensile tests shown. So, sometimes the extensometer might be mounted on the “inside” of the curved bar, and sometimes on the “outside”. Therefore, much of the variation appearing in the curves shown here is probably attributable to single-sided instrumentation being mounted on a curved sample.

See also the next slide showing curved Grade 60 reinforcement, where instrumentation is further discussed.

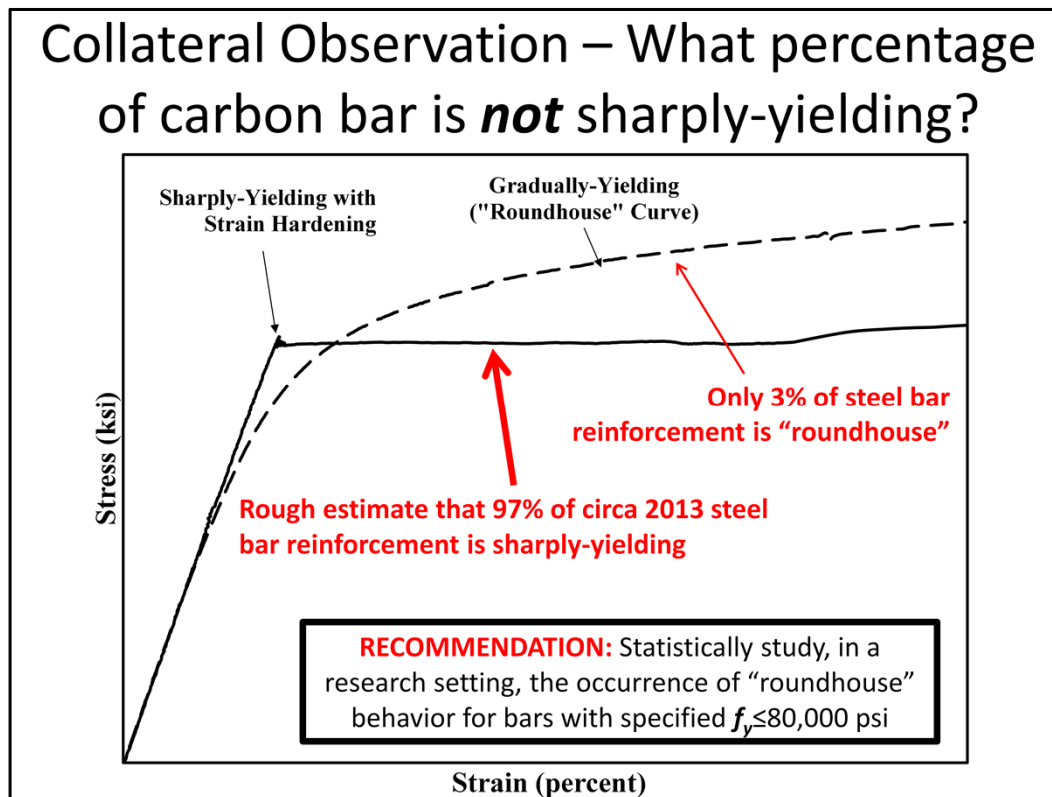


Here is a similar curve for Grade 60 reinforcement. Notice that many samples have an initial tangent modulus that is stiffer than the commonly-accepted modulus of elasticity of 29,000,000 psi for steel. Again, this is more evidence that single-sided instrumentation mounted onto a curved test sample is a significant contributor to the variation shown.

The curves shown on this slide and the previous slide are adequate for purposes of measuring yield strength, particularly when the measurements are made by the offset method. If the measurements are made by the EUL method, then these curves are likely inadequate, because the EUL method typically assumes that the initial elastic modulus is 29,000,000 psi.

Furthermore, these curves are not adequate for purposes of accurately measuring the stress-strain behavior in the initial, elastic portion of the stress-strain curve. This is due to both instrumentation being used (it is a single extensometer; instead, “averaging” extensometers should be used) and the slightly curved sample being tested. Consult ASTM E111, “Standard Test Method for Young’s Modulus, Tangent Modulus, and Chord Modulus,” for more details.

If the producing mills wish to rely on these kinds of curves for purpose of assessing elastic modulus of the reinforcement, then the instrumentation and test methods used should conform to ASTM E111 requirements. This will require upgrading of instrumentation and procedures in the typical rebar steel mill.



An important question, in particular related to its possible affect on reliability statistics, is given here. Based on a survey conducted as part of the CPF-WJE research project, it is estimated that on the order of 3% of Grade 60 carbon bar exhibits “roundhouse”-type stress-strain behavior. However, the survey may not have captured reinforcement production from throughout the entire U.S.

Consequently, it is recommended that a research project be undertaken to examine this topic using a systematic, statistically significant approach.

Since this kind of research involves recorded stress-strain curves, this topic could be just one of several other topics related to stress-strain behavior that could be studied. Other important topics include: upper yield versus lower yield, onset of strain hardening, uniform elongation by autographic method versus manual (scribe mark) method, total elongation and relationship to uniform elongation, and laboratory-measured static yield strength versus mill-certificate reported yield strength.



## Proposed Code Change – ACI 318-14 CB040/LB13-7 ASTM A615 in Seismic Applications

**20.2.2.5** — Deformed nonprestressed longitudinal reinforcement resisting earthquake-induced flexure, axial force, or both in special moment frames, special structural walls, and all components of special structural walls including coupling beams and wall piers shall be in accordance with (a) or (b):

(a) ASTM A706, Grade 60

(b) ASTM A615 Grades 40 if (i) and (ii) are met and ASTM A615 Grade 60 reinforcement if (i) through (iii) are met.

(i) the actual yield strength based on mill tests does not exceed  $f_y$  by more than 18,000 psi

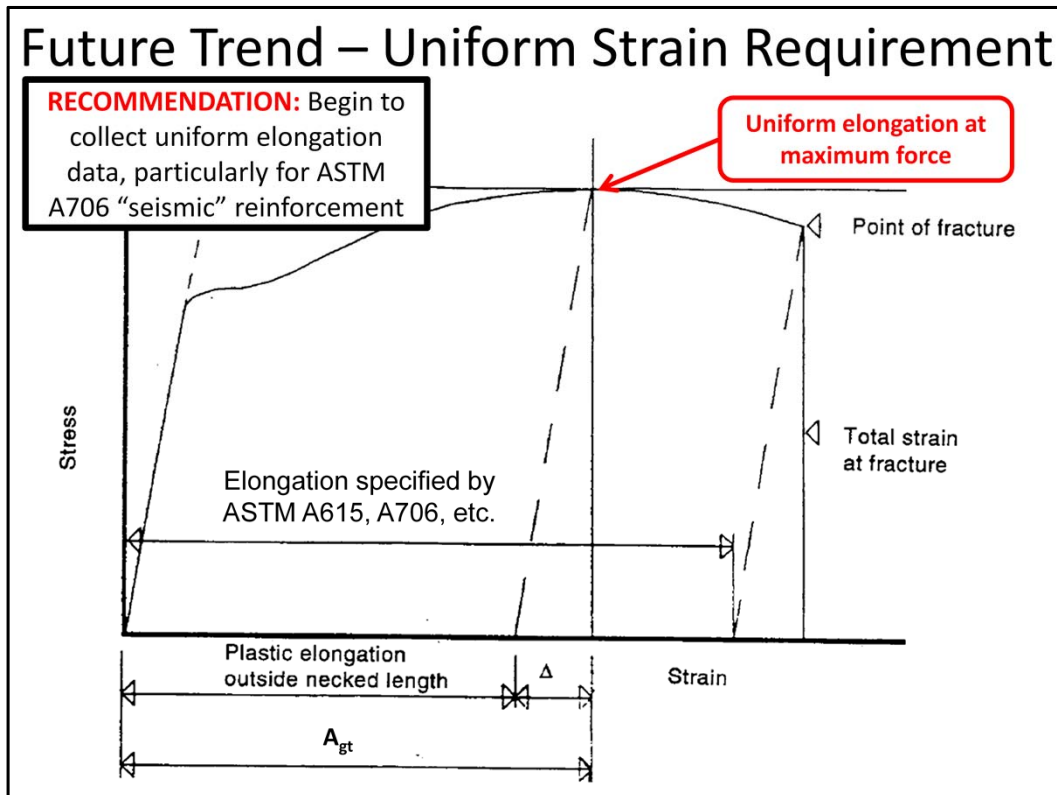
(ii) ~~and~~ the ratio of the actual tensile strength to the actual yield strength is at least 1.25.

(iii) the minimum elongation in 8 in. shall be at least 14 percent for bar sizes No. 3 through No. 6, at least 12 percent for bar sizes No. 7 through No. 11, and at least 10 percent for bar sizes No. 14 and No. 18.

As of early November 2013, code change Submittal CB040 has been included as an item in LB13-7, which is essentially the last of the Committee 318 letter ballots related to the ACI 318-14 code. The CRSI Material Properties Committee should track this code change submittal. It is one of the items that was agreed to be taken up as new business, in order to resolve negatives on the CB006 submittal related to the 0.2% offset method.

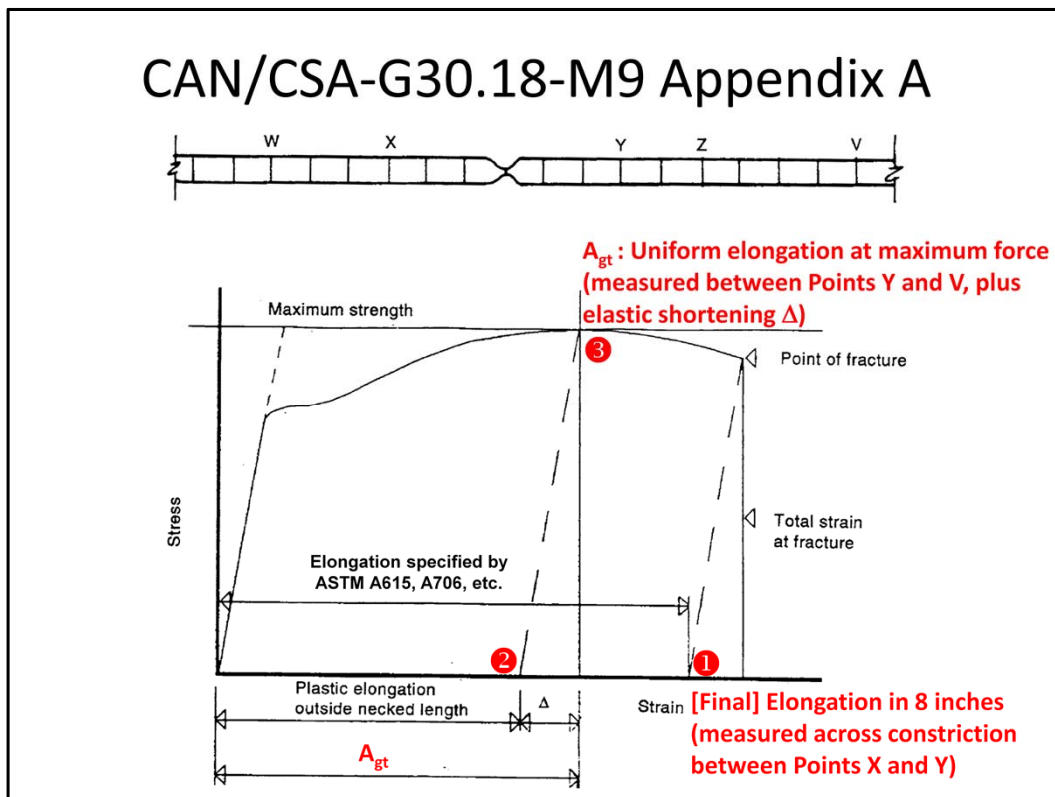
Code change Submittal CB040 asks that ductility requirements be added to the “escape clause” that otherwise permits ASTM A615 Grade 60 reinforcement to be used in special seismic systems. This code change has strong support within Committee 318 and stands a good chance of eventually passing. Provisions 20.2.2.5(b)(i) and (ii) have been in the Code for a long time. The added elongation requirements in provision 20.2.2.5(b)(iii) are exactly the same as the elongation requirements found in ASTM A706 for Grade 60 reinforcement.

If CB040 passes and is accepted into ACI 318-14, the CRSI Materials Properties Committee should considering working within the ASTM committees to modify the ASTM A615 standard to introduce two “new” grades: Grade 40D and Grade 60D. Grade 40D would include requirements (b)(i) and (b)(ii) shown on this slide, and Grade 60D would include requirements (b)(i), (b)(ii) and (b)(iii). The suffix letter “D” is taken from the first letter of the word “Ductile”.



Uniform elongation is becoming an increasingly important parameter for seismic structural engineering design. However, to date, uniform elongation is little studied in the North American setting. ASTM specifications for reinforcement do not include uniform elongation among the tensile properties required to be recorded and reported on the mill certificate.

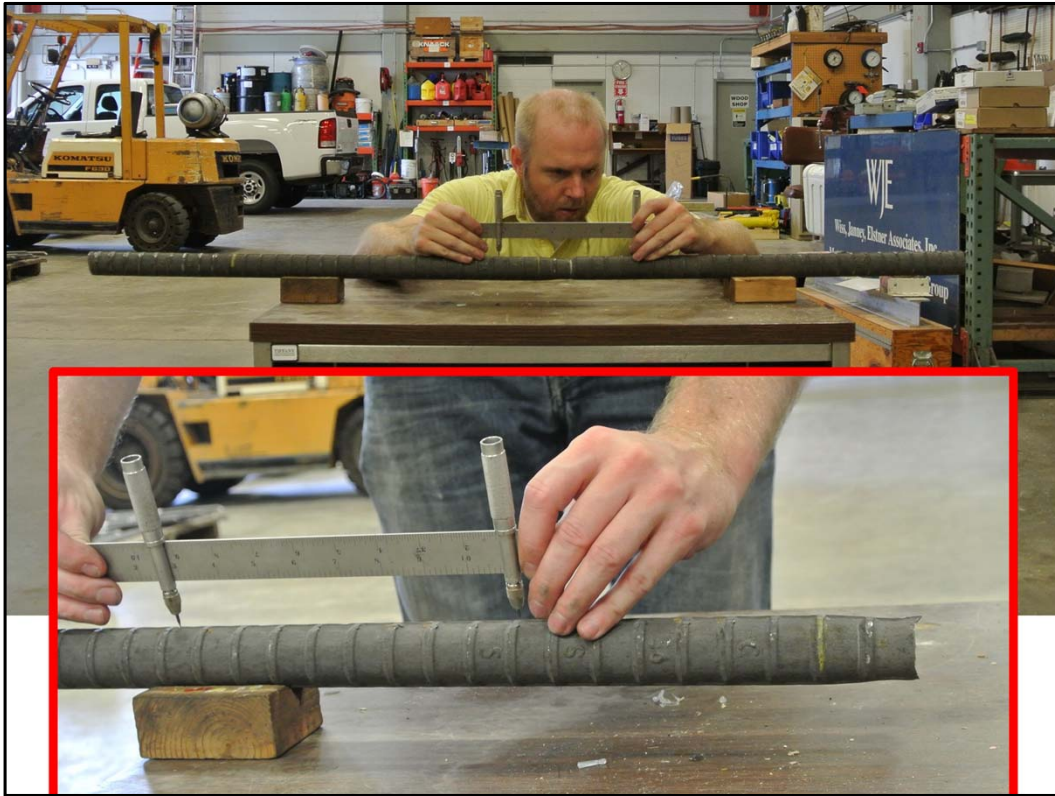
The reinforcement producing industry should anticipate requests in the near future from the structural engineering community for reliable information about uniform elongation provided by reinforcement presently produced by the industry. Therefore, it is recommended that the ASTM specifications be modified to require reporting of uniform elongation. At this time, there would be no need to establish any acceptance or rejection criteria related to uniform elongation. Rather, the actual value achieved should simply be reported.



The request to report uniform elongation really isn't a burdensome request. It does not require an extensometer, but instead can be measured using scribe or punch marks, using the same equipment and the same test piece as is used for elongation across the fracture. This stress-strain curve illustrates where uniform elongation occurs on the stress-strain curve, and the corresponding strains that can be measured on the fractured test piece (schematically illustrated at the top of this slide).

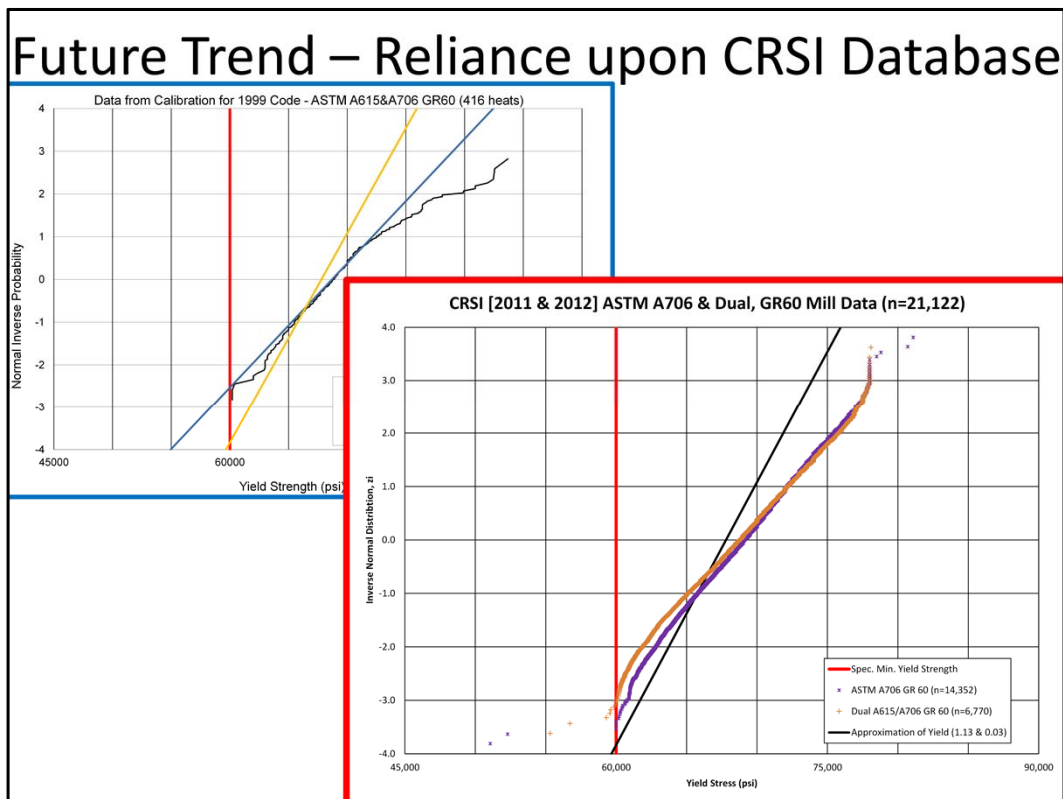
Point 1 is the elongation across the necked-down region that includes the fracture, measured between points X and Y on the test piece shown here.  
 Point 3 is the uniform elongation at the peak of the stress-strain curve, developed before any necking of the test piece takes place.  
 Point 2 is approximately the uniform elongation achieved at Point 3, measured between locations Y and V on the test piece shown here.

Consult the Canadian standard cited above for detailed instructions for these procedures. ISO standards also include similar approaches.



Here is an example of the traditional, manual method for measuring elongation. The upper photo illustrates measuring final (total) elongation across the fracture. The lower, inset photo illustrates measuring uniform elongation on the bar away from the fracture.

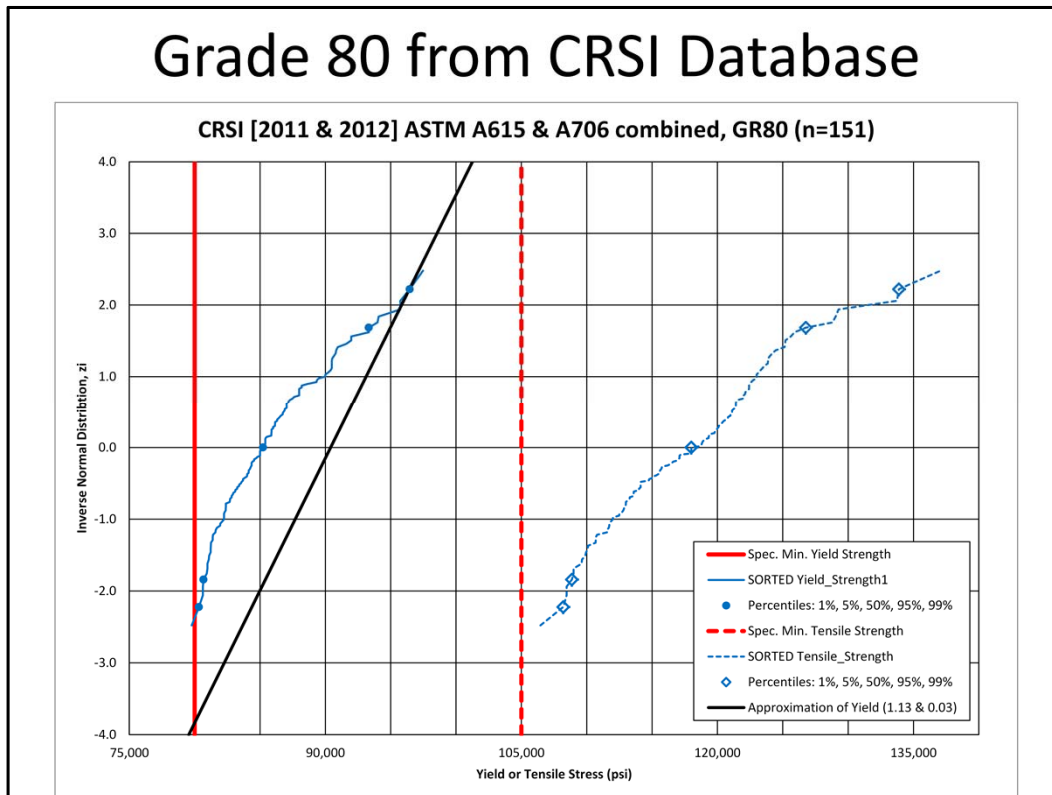
The same techniques and equipment are used for both measurements.



The CRSI database of tensile properties, compiled by CRSI from data reported on certified mill test reports, is a very helpful tool. The database will play an important role in future code calibration efforts.

In the upper-left graphic, the data shown here by the jagged, black line in the plot at the upper left are the yield strength data used in the 1999 ACI 318 Code calibration. The blue line is the probability fit assumed on the basis of that data. The yellow line is the updated probability fit, developed from circa 2005 data not shown here, for the 2008 ACI 318 Code calibration.

In the lower right plot, the yield strength data are for ASTM A706 Grade 60 and A615/A706 dual-certified Grade 60, from the CRSI database. The solid black line is the probability fit line for the 2008 Code calibration (same as the yellow line on the other plot). This suggests that with the next Code calibration, there might be the need to update the assumed probability fit for reinforcing bar yield strength based on type of bar within a given grade.



In the same probability curve format, here is an “early look” at Grade 80 yield strength and tensile strength data. The black line is again the assumed probability fit line used for the 2008 ACI 318 Code calibration. This comparison suggests that yield strength statistic for Grade 80 could be different from those of Grade 60.

## CRSI: Keeping up with Future Trends (1 of 2)

- **RECOMMENDATION:** If CB040 passes, work to modify the ASTM A615 standard to include “ductile” Grades 40D and 60D
- **RECOMMENDATION:** Add uniform elongation to the set of *reported* data for a mill cert in the ASTM specs
  - At this time, do not establish any numerical requirement – simply record and report the value for informational purposes

These two recommendations are to “collateral observations” given earlier in this presentation.

## CRSI: Keeping up with Future Trends (2 of 2)

- **RECOMMENDATION:** Keep contributing to and maintaining the CRSI database of mill test report tensile properties data
- **RECOMMENDATION:** Consider participation in the funding of the next ACI 318 “code calibration”
- **RECOMMENDATION:** The producing mills should *immediately* get involved with ACI Committee 439 on Steel Reinforcement

These recommendations are in addition to the “collateral observation” recommendations given in the preceding slide.



## Acknowledgements (1 of 2)

- ACI Sub-Committee 318B “Reinforcement and Development,” and its “Task Group on Yield Strength Determination for Nonprestressed Steel Reinforcement”
  - Thanked for developing the outline of tasks for the study of yield determination methods
  - Cathy French, Chair of 318B, is thanked for sponsoring Code Change CB006 under the auspices of 318B
- Charles Pankow Foundation (CPF), for providing the funds to carry out the study
  - Mr. Mark Perniconi, Executive Director, CPF
  - Prof. David Darwin, Univ. of Kansas, retained by CPF as External Peer Reviewer of the WJE report

Acknowledgements (1 of 2).

The accomplishments described in this presentation were the result of the combined efforts of many different persons and organizations (undoubtedly, the list given here has missed someone).

## Acknowledgements (2 of 2)

- The Concrete Reinforcing Steel Institute (CRSI)
  - Coordinated the collection of industry-recorded stress-strain curves, which were anonymously contributed by several CRSI producer members
- Wiss, Janney, Elstner Associates project staff
  - Conrad Paulson, Principal Investigator
  - Scott K. Graham, Project Engineer
  - Jeff Rautenberg, Project Engineer
  - Gary Klein, WJE Internal Project Advisor

### Acknowledgements (2 of 2)

The accomplishments described in this presentation were the result of the combined efforts of many different persons and organizations (undoubtedly, the list given here has missed someone).

## Thank You! Any Questions?

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Please feel free to contact Conrad Paulson at WJE if you have any question.

### Revision history for this presentation:

Rev. 0: First presented to the CRSI Materials Properties Committee on November 5, 2013, at the fall committee meeting held in Chicago, Illinois.

Rev. 1: DRAFT FOR REVIEW, November 17, 2013. "Talking points" text added to the notes sections of most slides, along with general revisions and some reorganization of slides.

Rev. 2: FUTURE: Submitted to CPF on November XX, 2013, for posting to their web site.