

# Proposed Code Provisions for Anchoring Reinforcing Bars with Standard Hooks and Heads

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# Outline

- ACI Provisions
- What We've Learned
- Comparison of Test Data with ACI
- Descriptive Equations
- Proposed Design Provisions
  - Compressive strengths to 16 ksi
  - Yield strengths to 120 ksi

# ACI Equations

- Hooks: 
$$\ell_{dh} = \left( \frac{f_y \psi_e \psi_c \psi_r}{50 \lambda \sqrt{f'_c}} \right) d_b$$

- Heads: 
$$\ell_{dt} = \left( \frac{0.016 f_y \psi_e}{\sqrt{f'_c}} \right) d_b$$

## Modification factors

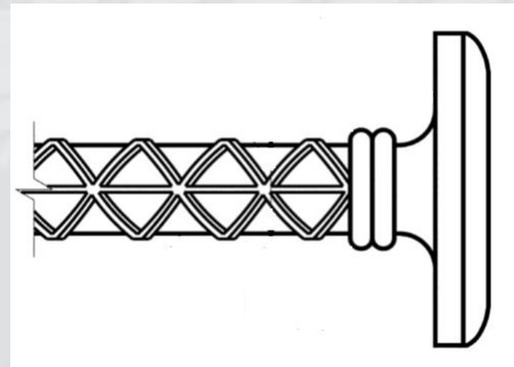
- Epoxy-coated reinforcement:  $\psi_e = 1.2$
- Cover\*:  $\psi_c = 0.7$
- Confining reinforcement\*:  $\psi_r = 0.8$
- Lightweight concrete\*:  $\lambda = 0.75$
- Excess reinforcement\*:  $\frac{(A_s \text{ required})}{(A_s \text{ provided})}$

\* Hooks only

# Limitations on $f'_c$ and $f_y$ and Head Size

- Hooks:  $f'_c \leq 10,000$  psi;  $f_y \leq 80,000$  psi
- Heads:  $f'_c \leq 6,000$  psi;  $f_y \leq 60,000$  psi

$$A_{brg} \geq 4A_b$$



# Limitations on bar spacing and size

- Headed bars:
  - Cover = as required for straight bars  $\geq 2d_b$
  - Clear spacing – horizontal layer  $\geq 4d_b$
  - Clear spacing – vertical layers  $\geq 4d_b$
  
- Bar size  $\leq$  No. 11

## Proposed Design Equations

- Hooks: 
$$\ell_{dh} = \left( 0.003 \frac{f_y \Psi_e \Psi_{cs} \Psi_o}{\lambda f_c'^{0.25}} \right) d_b^{1.5}$$
- Heads: 
$$\ell_{dt} = \left( 0.0024 \frac{f_y \Psi_e \Psi_{cs} \Psi_o}{f_c'^{0.25}} \right) d_b^{1.5}$$

# Range in Variables

Parameters	Range
Bar Size	No. 5, 6, 8, 11
Hook Bend Angle	90°, 180°
Head Size, $A_{brg}$	$3.8A_b$ to $14.9A_b$
Concrete Compressive Strength, $f_{cm}$ (ksi)	4 to 16.5
Center-to-Center Spacing of Bars	$2d_b$ to $11.5d_b$ ( $< 1.3d_b$ for splices)
Stress at Failure, $f_{su}$ (ksi)	23 to 153

# Headed Bars



Cold-Swaged Threaded  
Coupling Sleeve

Friction-  
Forged

Taper-  
Threaded

Cold-  
Swaged

## What we've learned – 1

- Hooked and headed bars behave a lot alike
- For the same embedment length, headed bars provide a higher anchorage force than hooked bars
- Closely spaced hooked and headed bars are weaker, individually, than widely spaced hooked and headed bars

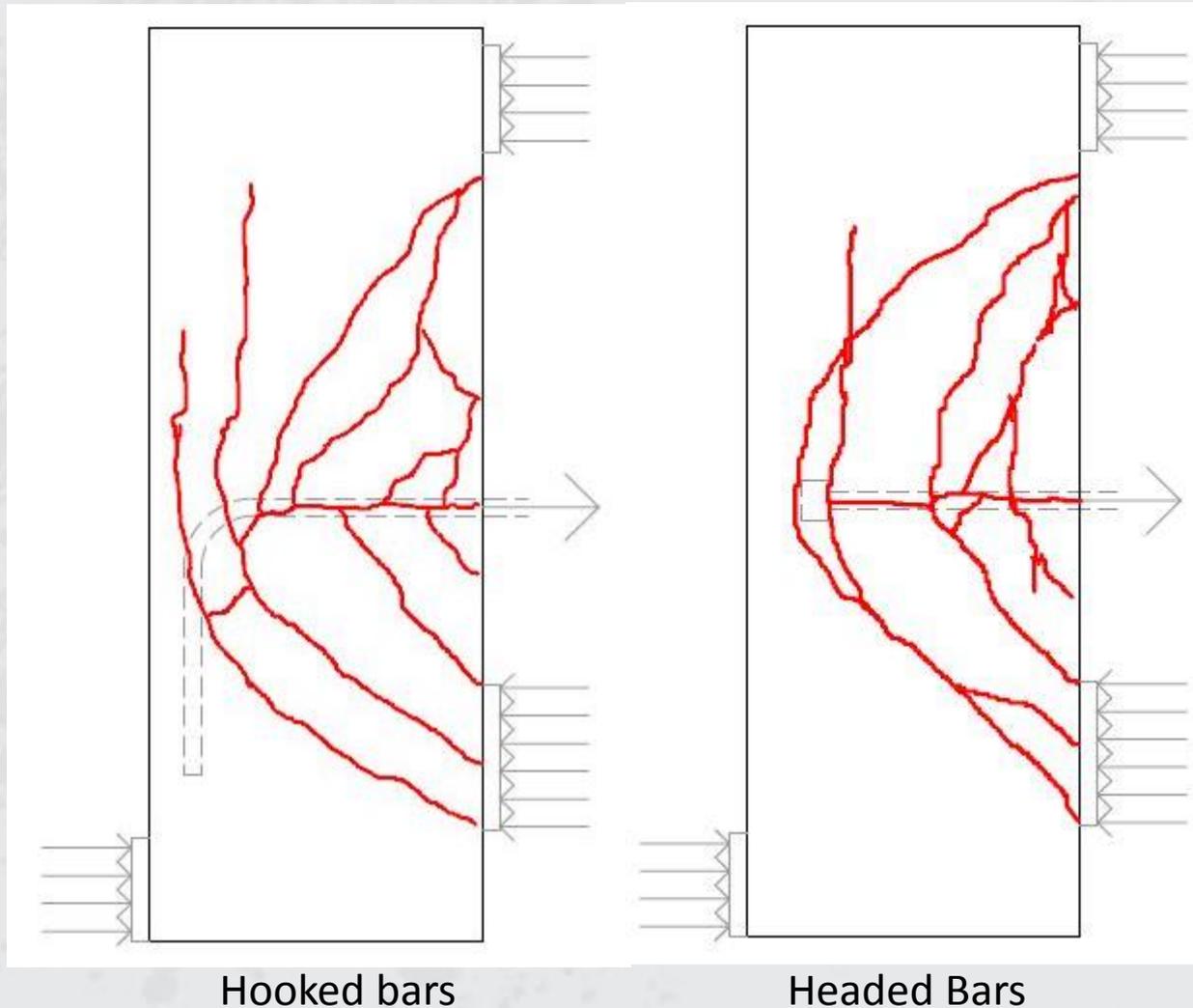
## What we've learned – 2

- Hooked bars with 90° and 180° degree bends have similar anchorage strengths
- Confining reinforcement parallel to the bar increases anchorage strength of hooked and headed bars
- Confining reinforcement perpendicular to the bar increases anchorage strength of hooked but not headed bars

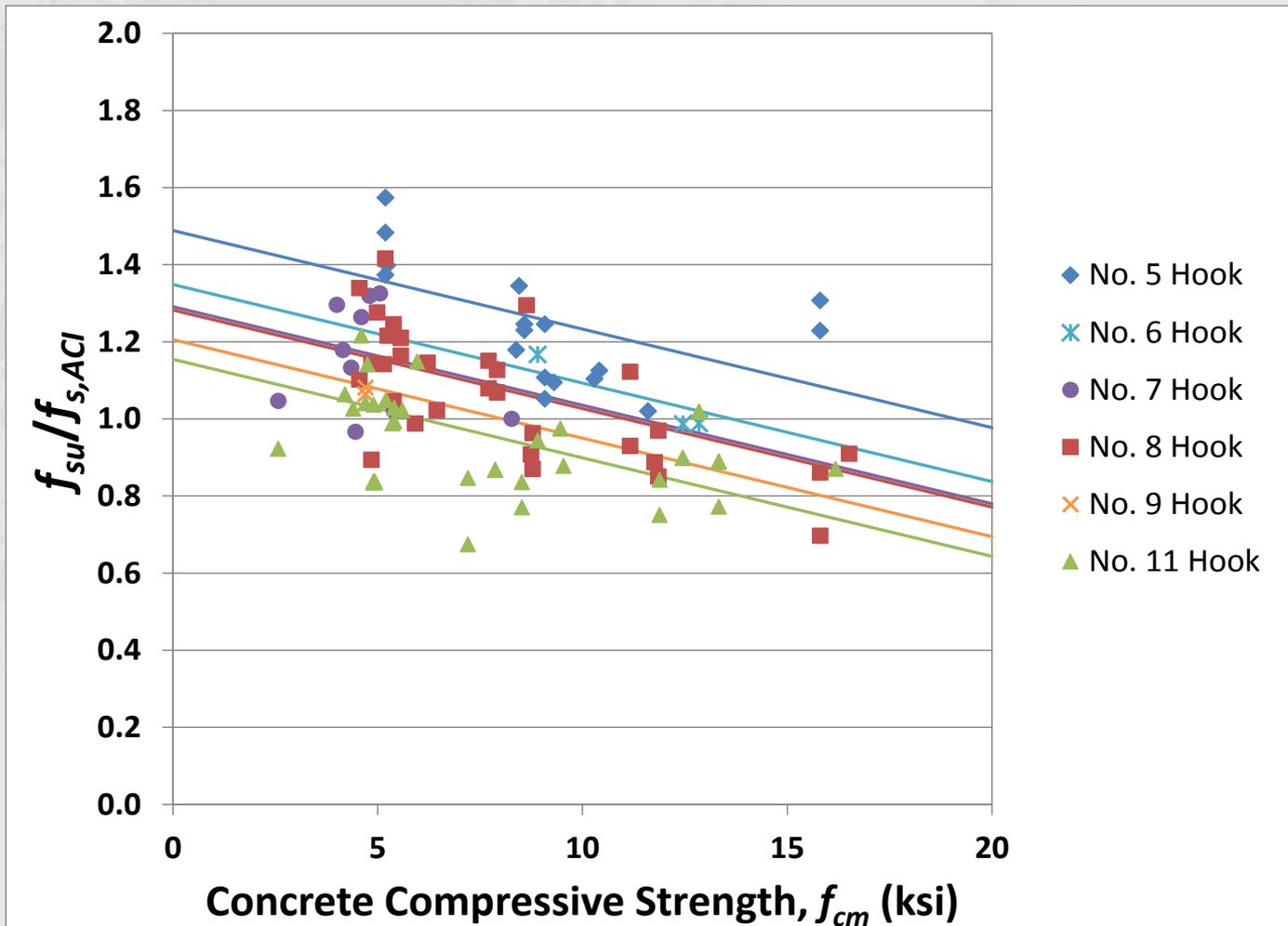
## What we've learned – 3

- The ACI Code does not accurately represent the anchorage capacity of hooked or headed bars in terms of the effect of bar size and the contribution of concrete compressive strength
- More!

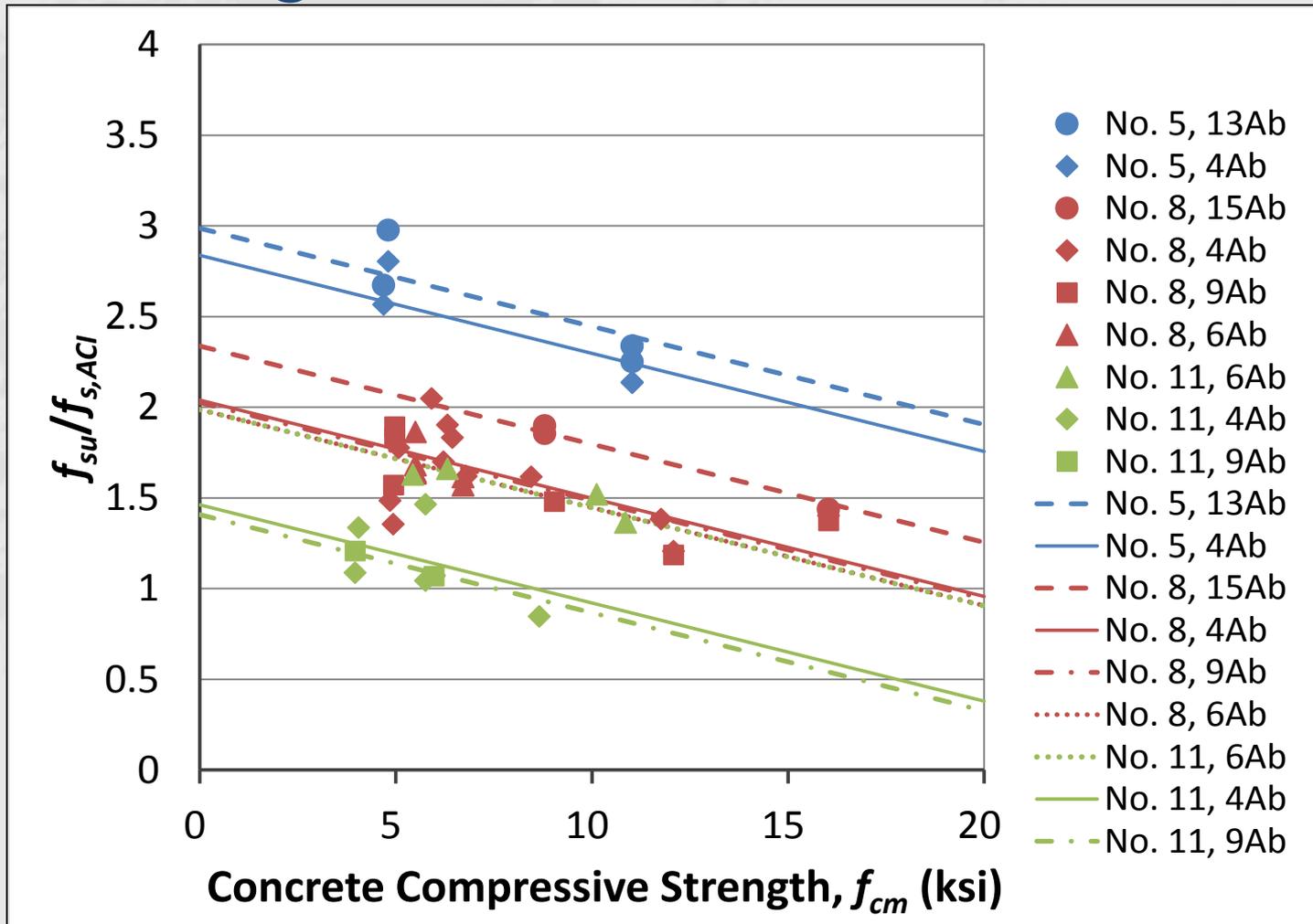
# Comparison of Crack Patterns



# Comparison to ACI – Two hooked bars No Confining Reinforcement



# Comparison to ACI – Two headed bars No Confining Reinforcement

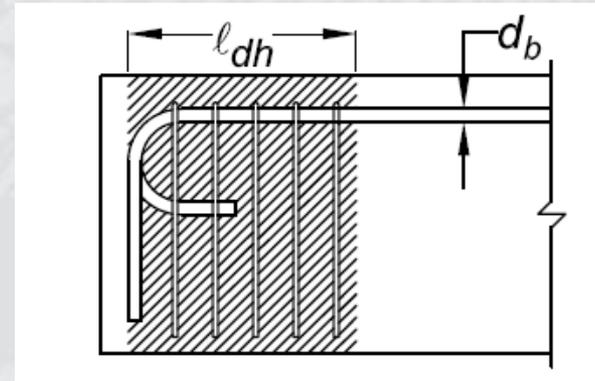
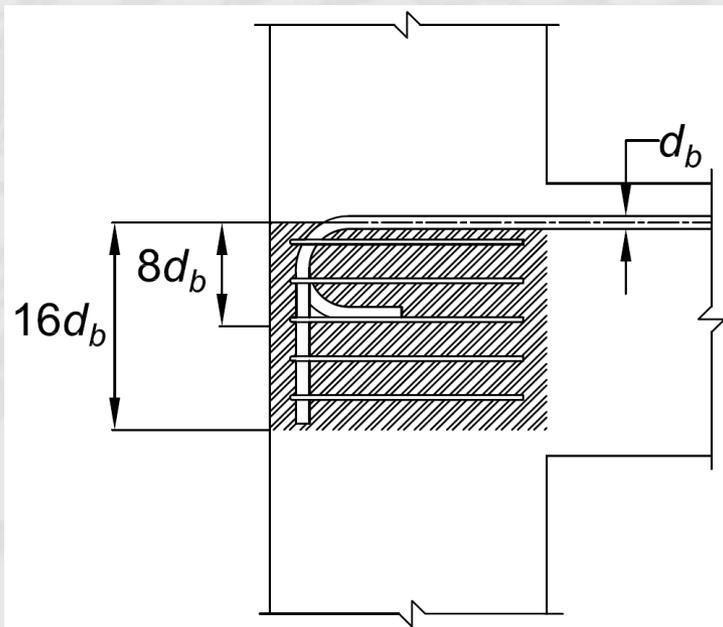




# Descriptive Equation – Hooked Bars

Two widely-spaced hooked bars:

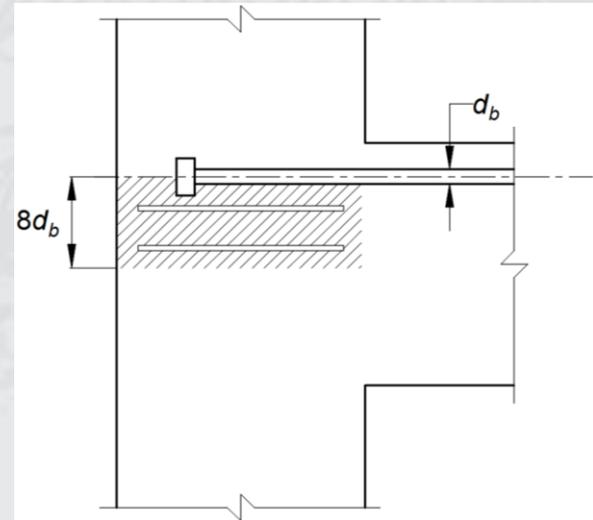
$$T_h = A_b f_s = 294 f_{cm}^{0.295} \ell_{eh}^{1.085} d_b^{0.47} + 27,500 \left( \frac{A_{th}}{n} \right)^{1.02} d_b^{0.73}$$



# Descriptive Equation – Headed Bars

For two widely-spaced headed bars with confining reinforcement oriented parallel to the bar:

$$T_h = A_b f_s = 781 f_{cm}^{0.24} \ell_{eh}^{1.03} d_b^{0.35} + 48,800 \left( \frac{A_{tt}}{n} \right) d_b^{0.88}$$



## Design Approach

- Convert descriptive equation to one for development length  $\ell_{dh}$  or  $\ell_{dt}$
- Modify equation for bar spacing of  $2d_b$ , and then account for
  1. wider bar spacing
  2. confining reinforcement
  3. bar location within the member
- Incorporate a reliability-based  $\phi$ -factor

## Design Equation – Hooked Bars

$$\ell_{dh} = \left( 0.003 \frac{f_y \psi_e \psi_{cs} \psi_o}{\lambda f_c'^{0.25}} \right) d_b^{1.5}$$

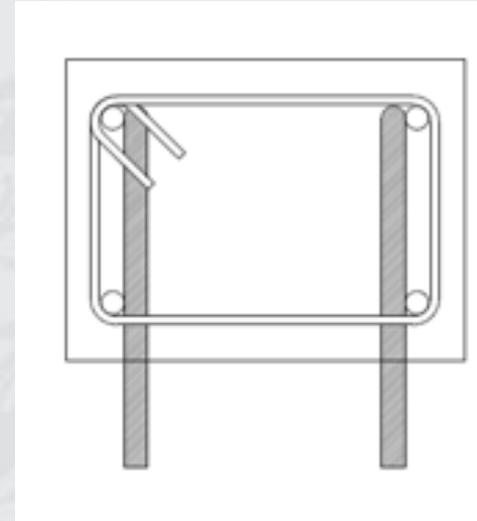
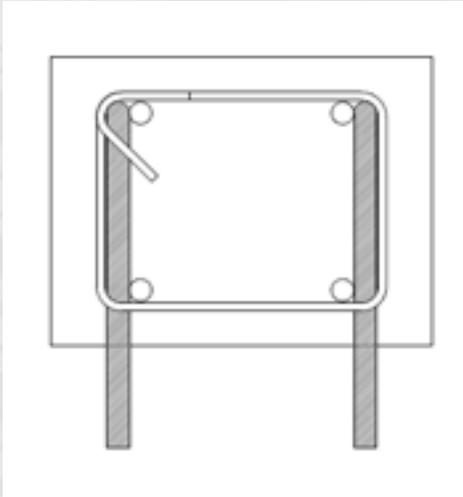
$\psi_{cs}$  = confinement and spacing factor

$\psi_o$  = location factor

# Confinement and Spacing Factor $\psi_{cs}$

Confinement level	c-c Spacing	
	$2d_b$	$\geq 6d_b$
<u>For No. 11 bar and smaller hooks with</u> $A_{th}/A_{hs} \geq 0.4$	0.7	0.5
<u>For No. 11 bar and smaller hooks with</u> $A_{th}/A_{hs} = 0$	1.0	0.6
<b>Other</b>	1.0	0.6

# Bar location factor $\psi_o$



$$T_{\text{outside}} \sim 0.80 T_{\text{inside}}$$

Hooks within a column core with side cover  $\geq 2.5$  in.  
or other member with side cover  $\geq 6d_b$ :  $\psi_o = 1.0$

Otherwise:  $\psi_o = 1.25$

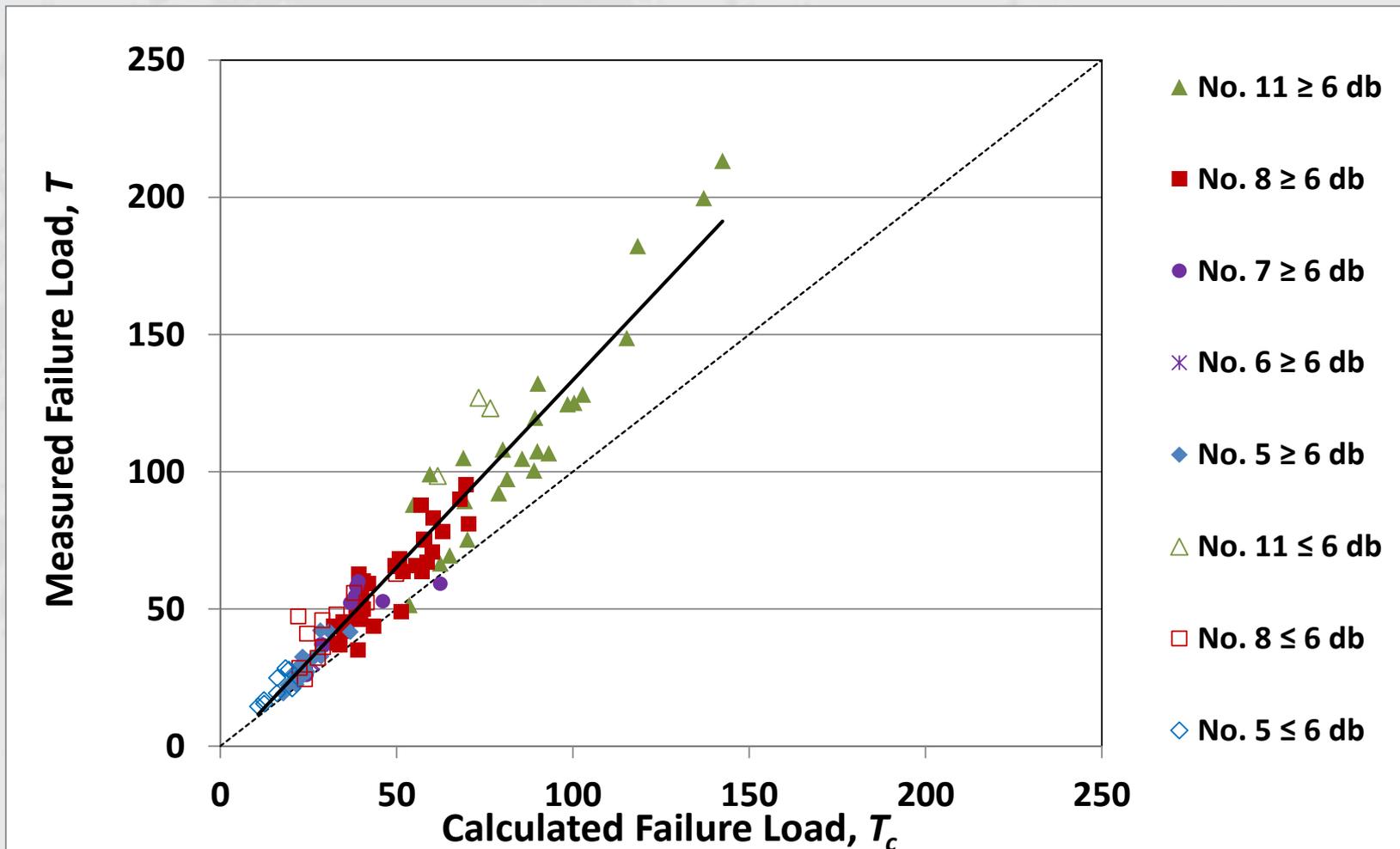
# Drop Excess Reinforcement Factor for Hooks

~~$$\left( A_{s,required} \right) / \left( A_{s,provided} \right)$$~~

because  $T$  is proportional to  $\ell_{eh}^{1.085}$

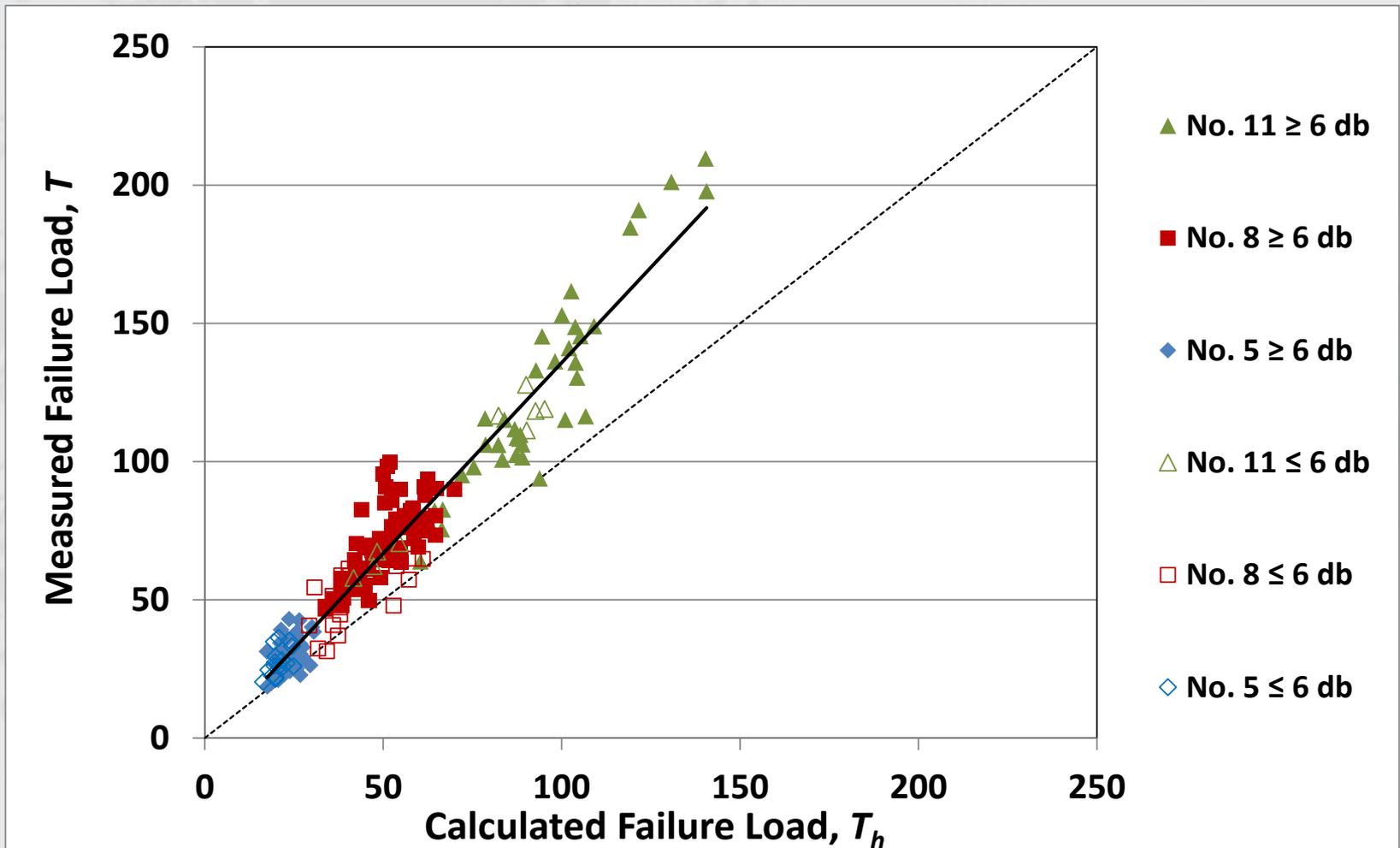
# Design Equation

For hooked bars without confining reinforcement



# Design Equation

For hooked bars with confining reinforcement



## Design Equation – Headed Bars

$$\ell_{dt} = \left( 0.0024 \frac{f_y \psi_e \psi_{cs} \psi_o}{f_c'^{0.25}} \right) d_b^{1.5}$$

$\psi_{cs}$  = confinement and spacing factor

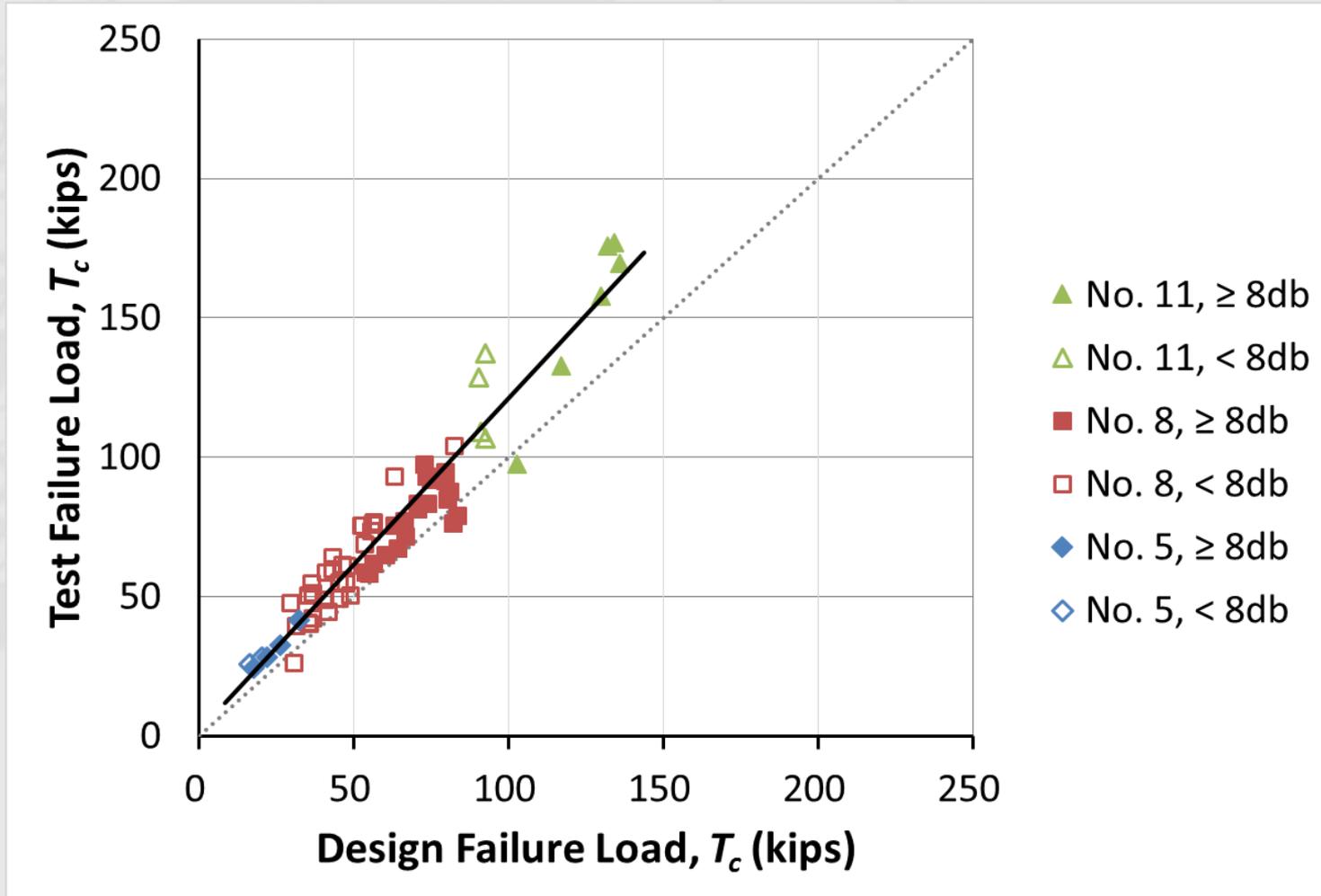
$\psi_o$  = location factor

# Confinement and Spacing Factor $\psi_{cs}$

Confinement level	c-c Spacing	
	$2d_b$	$\geq 8d_b$
$A_{th}/A_{hs} \geq 0.3$	0.7	0.4
$A_{th}/A_{hs} = 0$	1.0	0.5

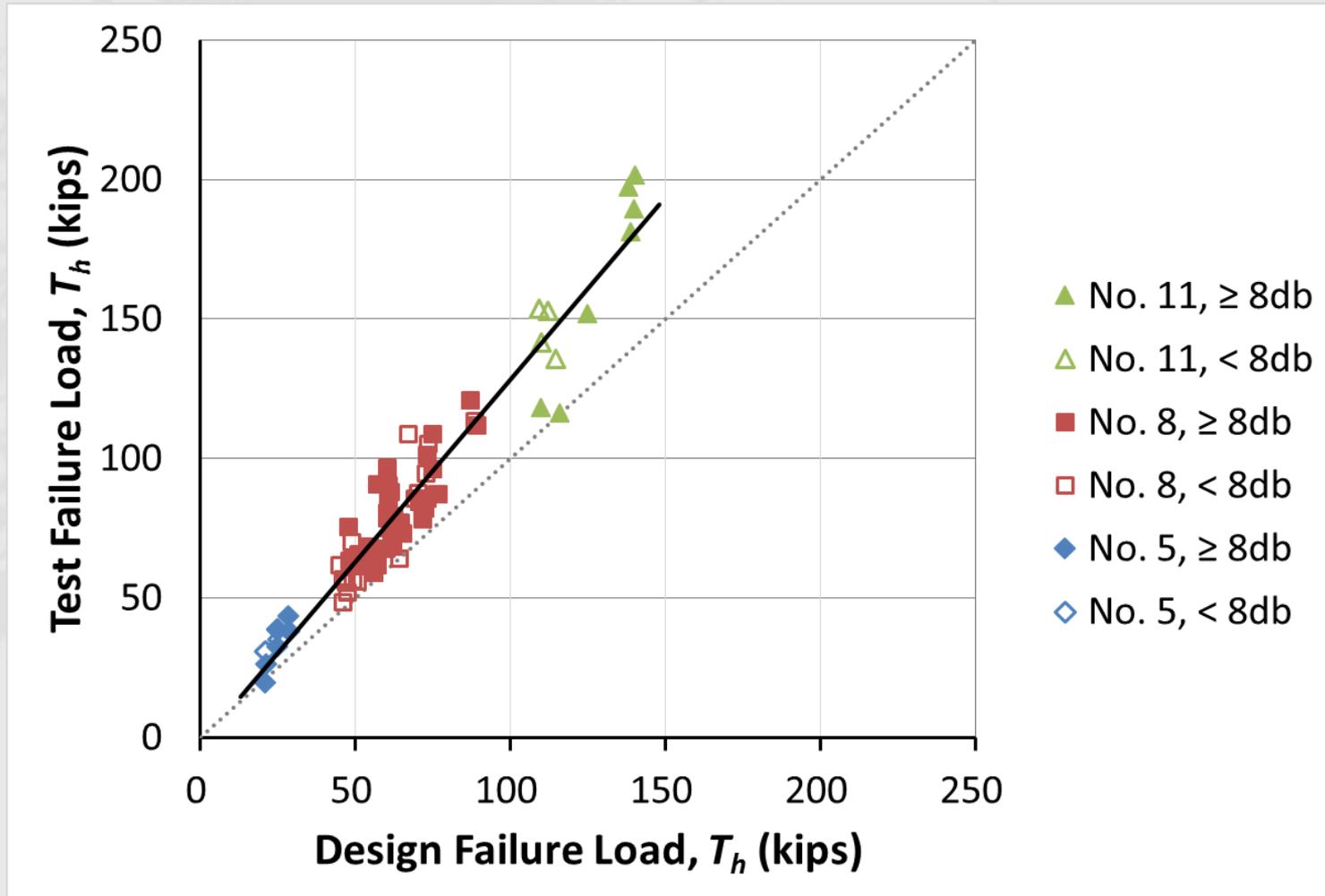
# Design Equation

For headed bars without confining reinforcement



# Design Equation

For headed bars with confining reinforcement



# Proposed design provisions for hooked and headed bars apply to:

- Compressive strengths to 16 ksi
- Yield strengths to 120 ksi

# Sponsors





# The University of Kansas

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