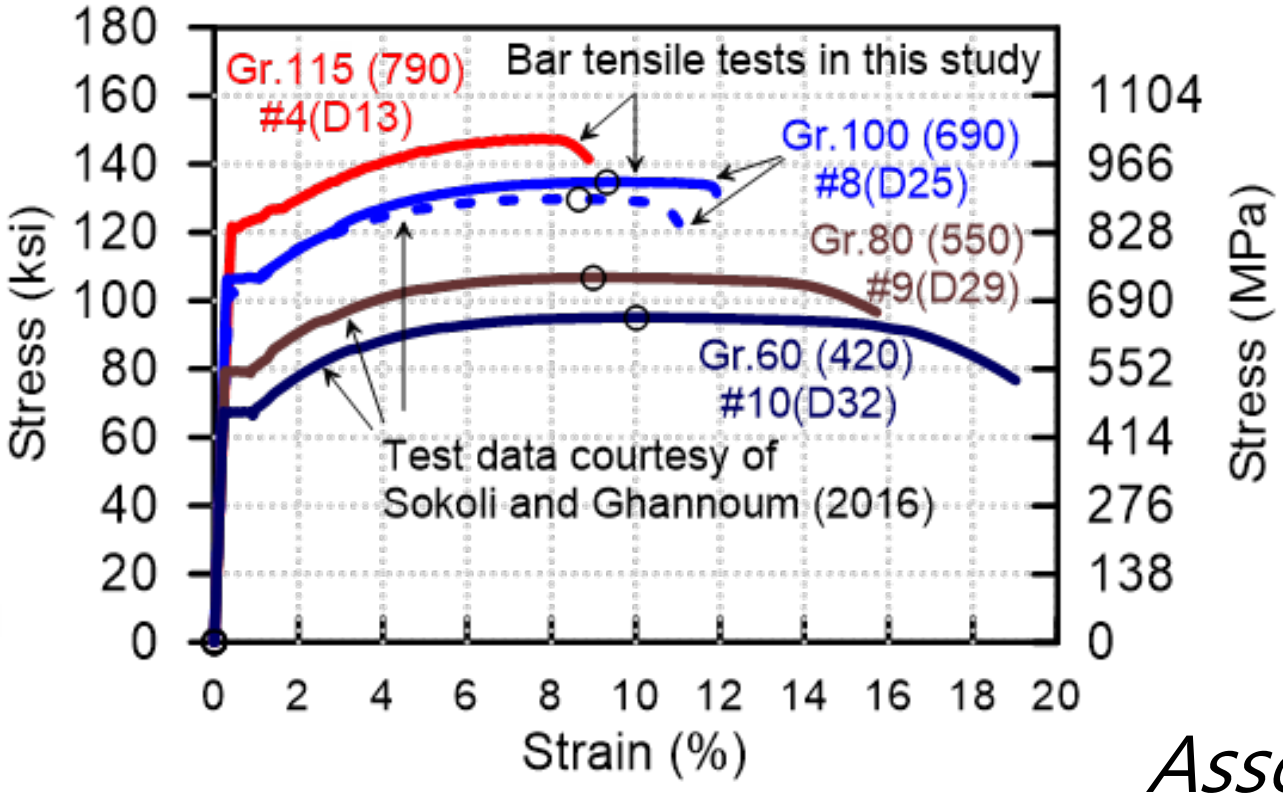
Updates for beam-column joints reinforced with high-strength reinforcement



Hung-Jen Lee

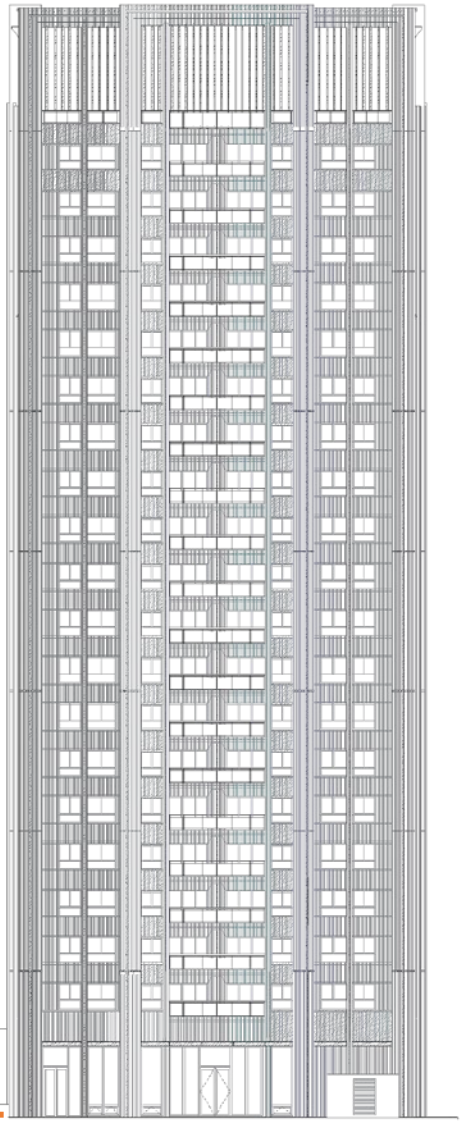
Associate Professor

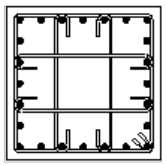
National Yunlin University of Science and Technology

YunTech 國立雲林科技大學 National Yunlin University of Science & Technology

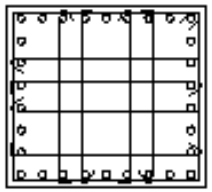
New RC ← RC

New RC	RC
f_c'= 28 MPa SD 420 bars	f_c'= 24 MPa SD 420 bars
f_c'= 42 MPa SD 490 bars	f_c'= 28 MPa SD 420 bars
f_c'= 70 MPa SD 690 bars	f_c'= 35 MPa SD 420 bars





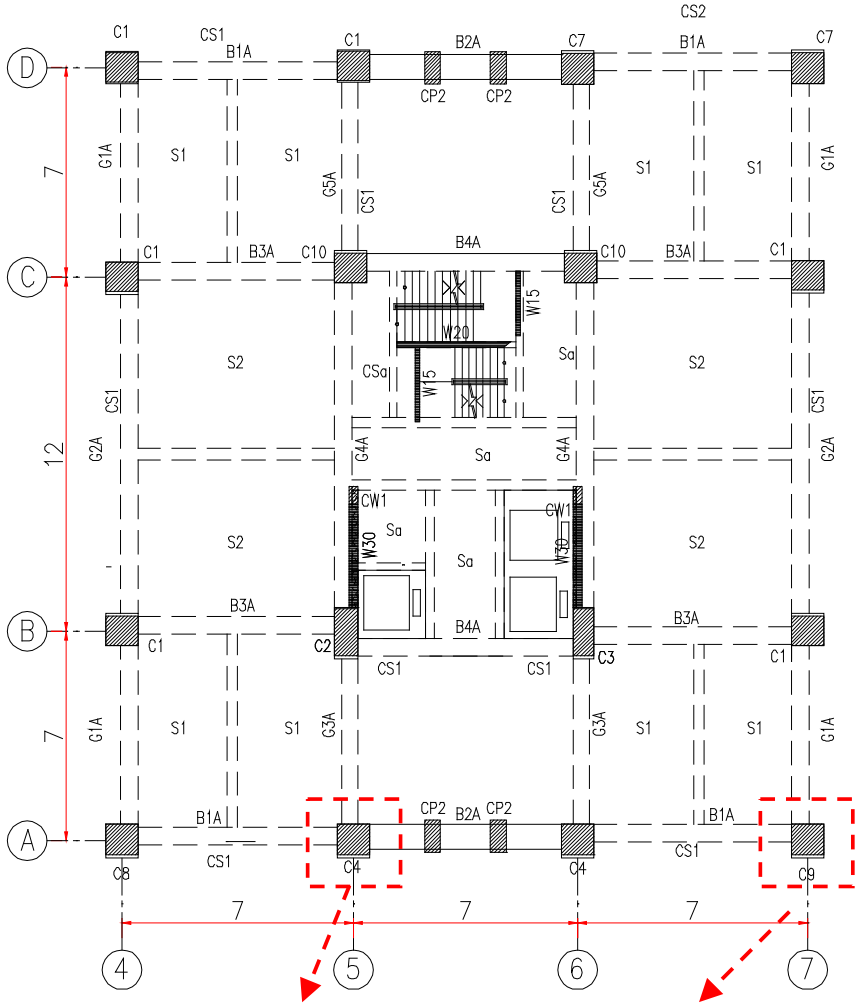
80x80 cm
24-#10

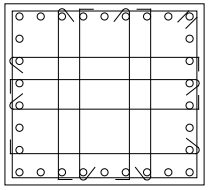


110x100 cm
30-#10

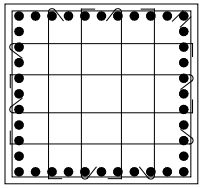
20-story case

Advantages



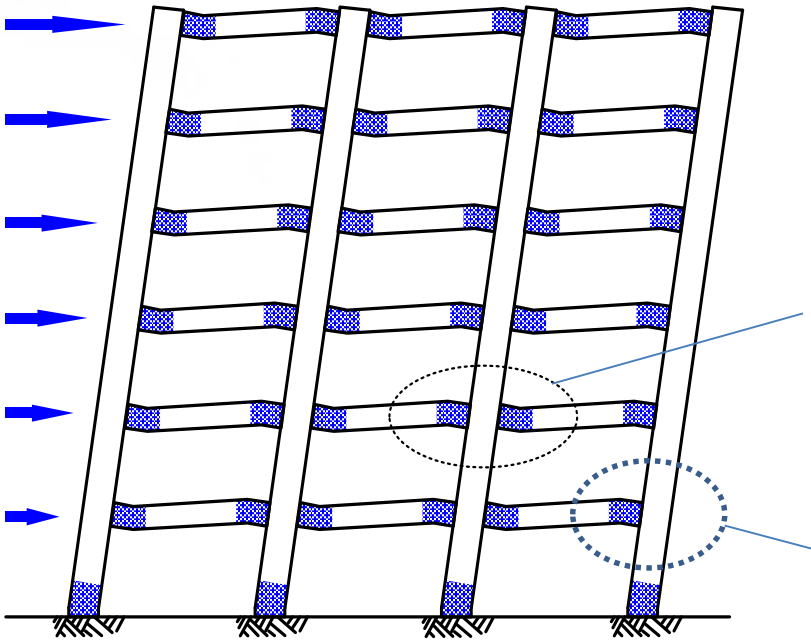


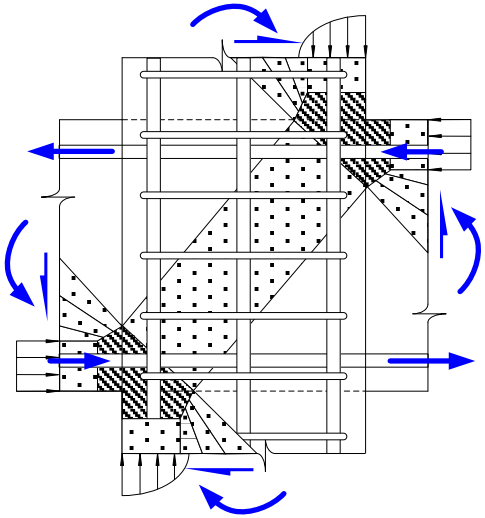
主筋 ○30-#10
圍束區 #4@10
非圍束區 #4@10
接頭區 #4@10
柱尺寸（110×100）



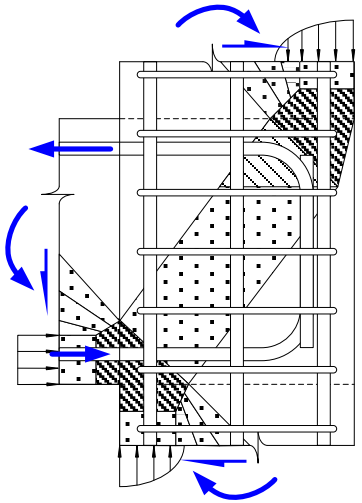
主筋 ●40-#8
圍束區 #4@10
非圍束區 #4@10
接頭區 #4@10
柱尺寸（110×105）

Moment-resisting frame joints





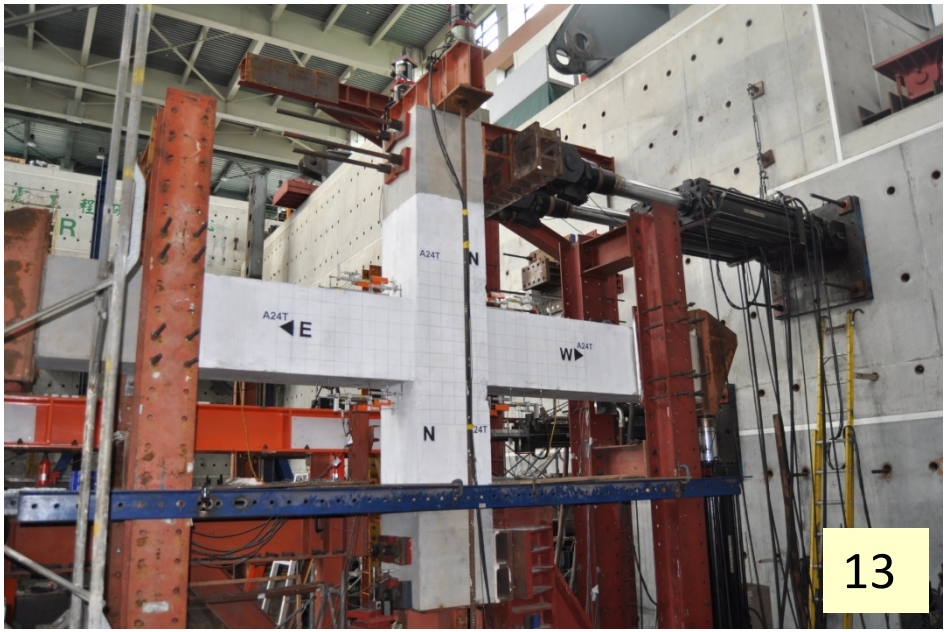
Interior joint



Exterior joint

- **Nominal joint shear strength**
- **Joint confinement**
- **Development and Anchorage**

Beam-column joint tests at NCREE



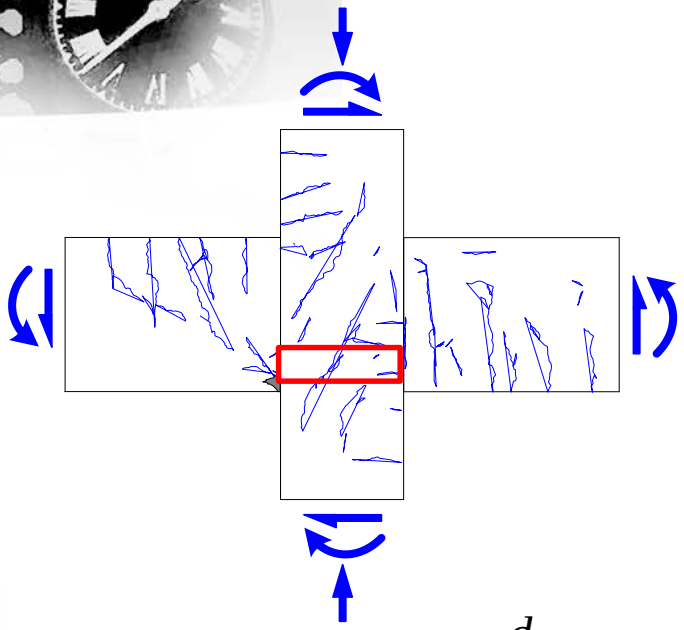
13

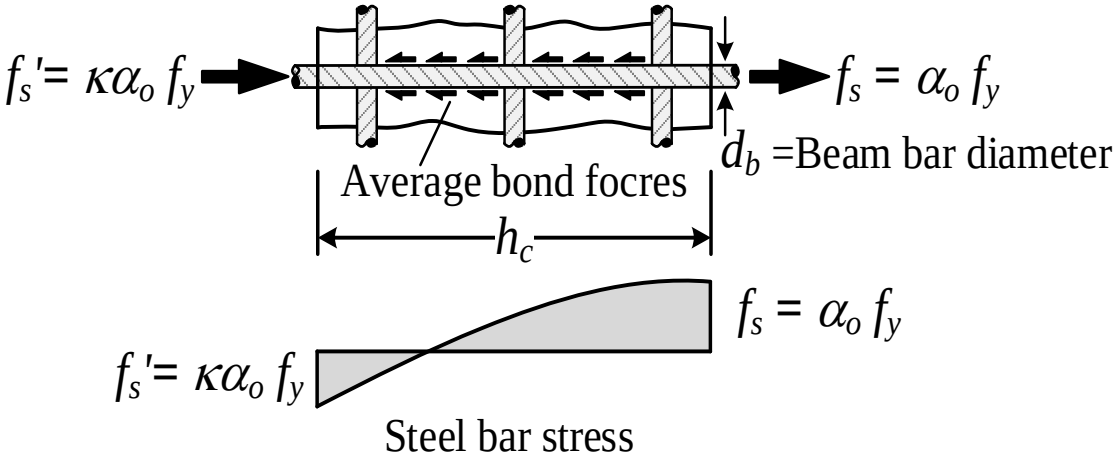
14

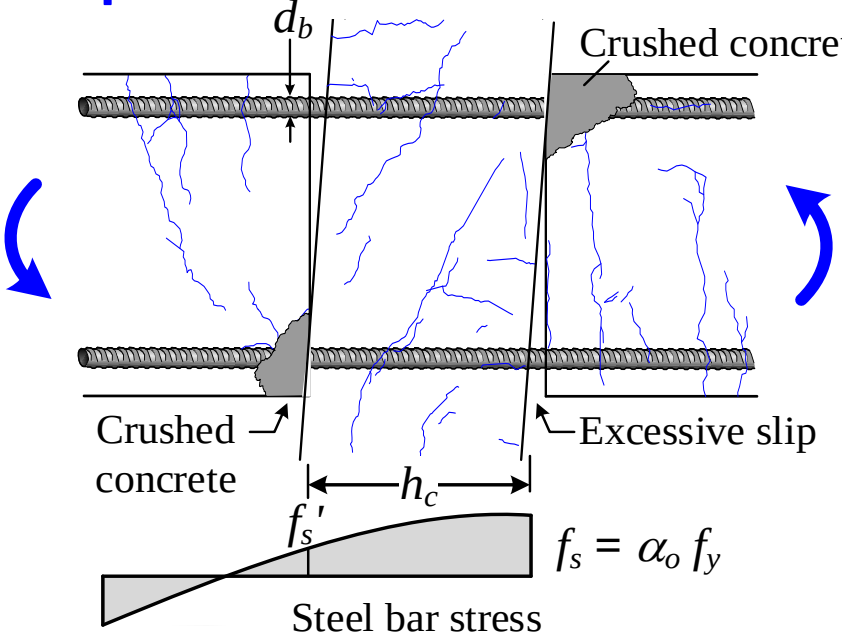
15

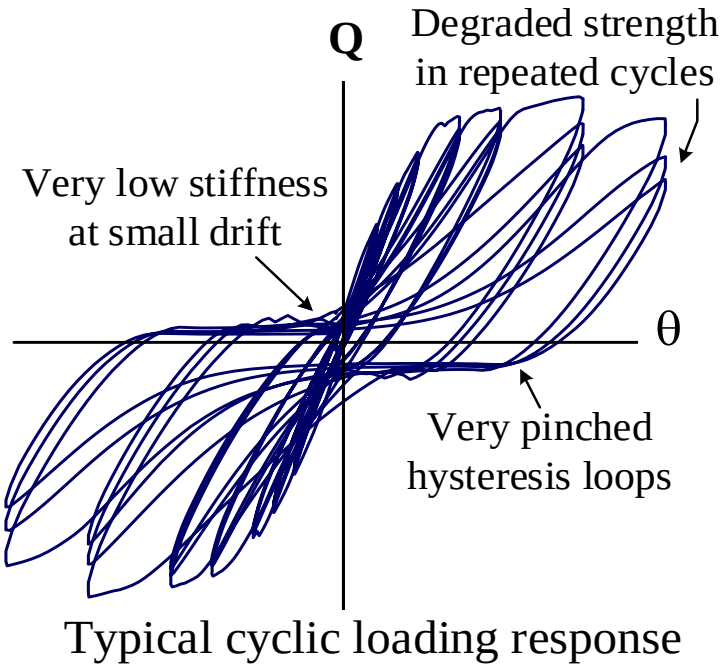

16

Can HSR be properly anchored in the joint ?







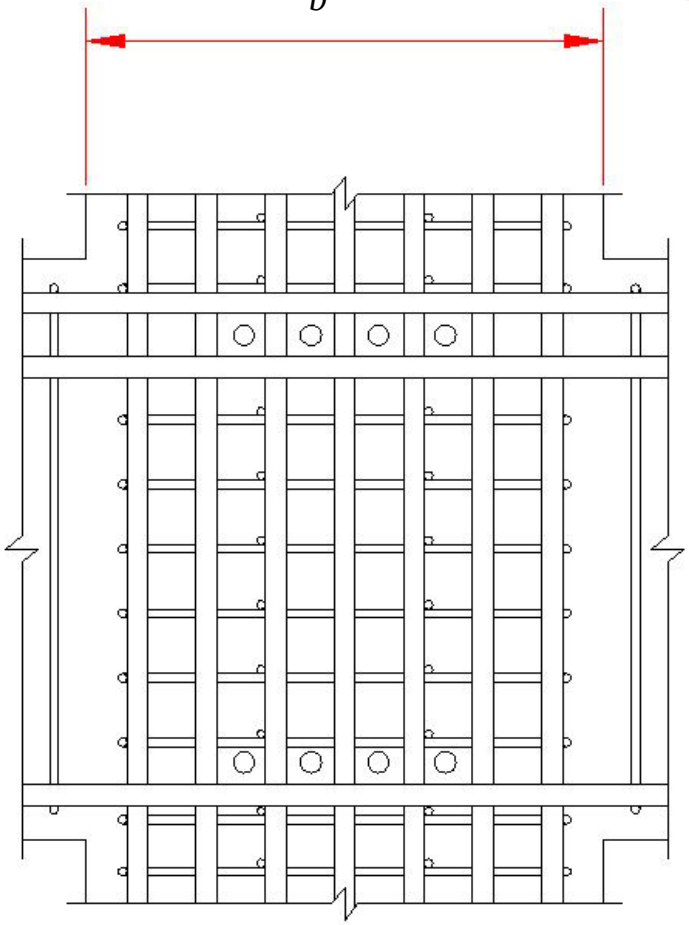


Typical cyclic loading response

Design Criteria for Minimum Joint Depth

ACI 318-14

$$\frac{h_c}{d_b} \geq 20$$



ACI 352-02

$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{f_y}{420\ \text{MPa}} \right)$$

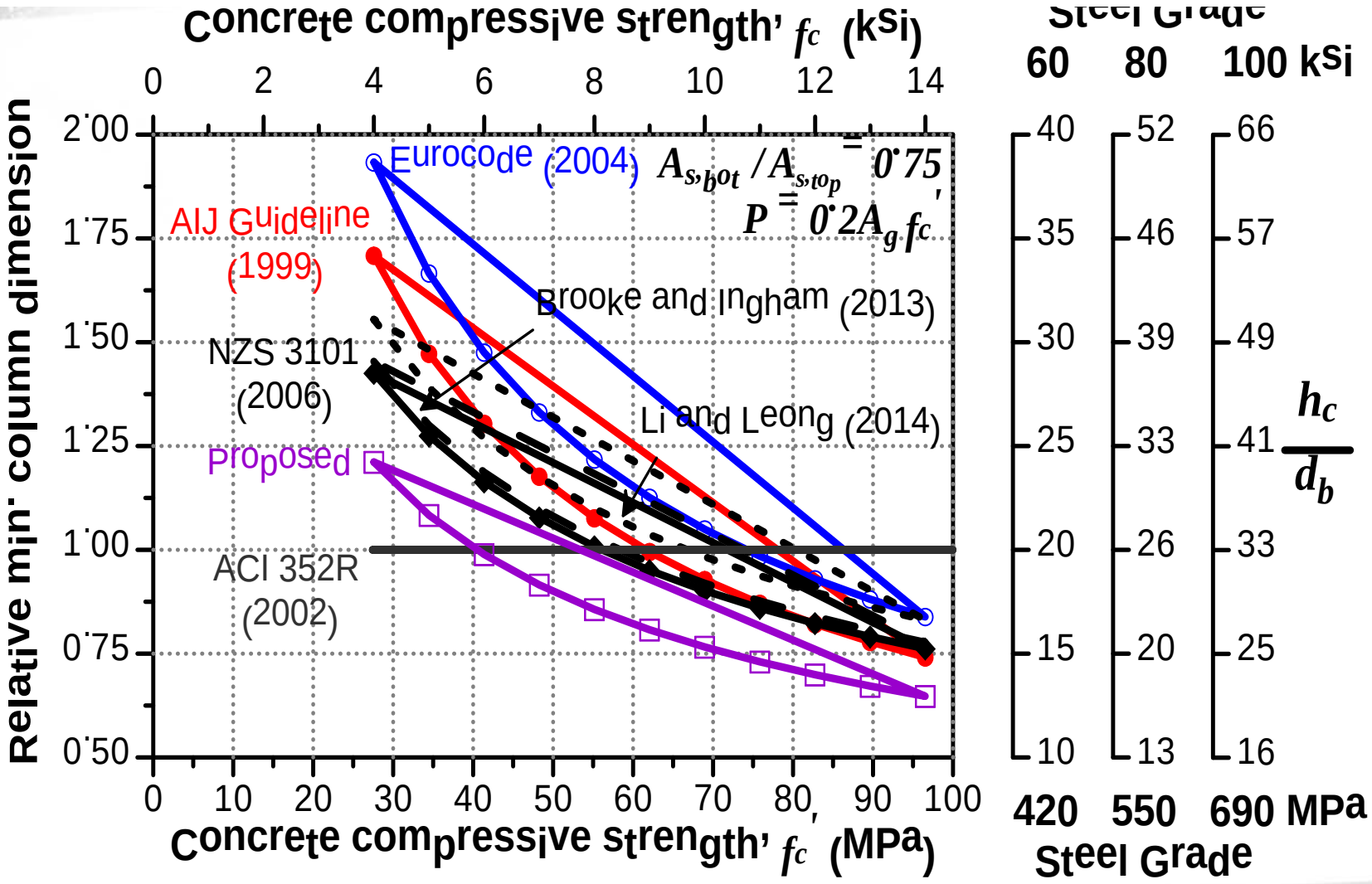
$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{550}{420} \right) = 26$$

$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{690}{420} \right) = 33$$

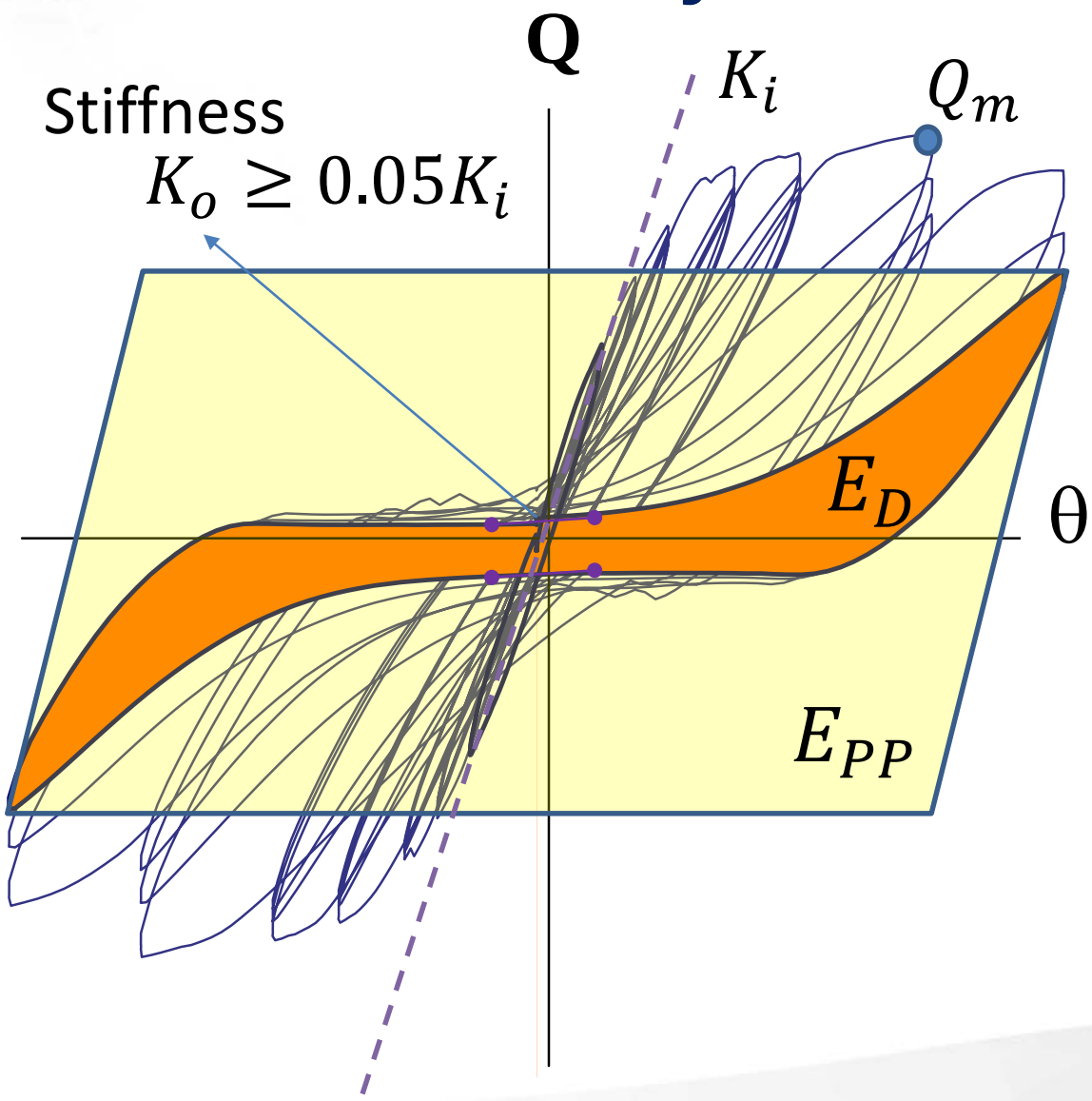
We proposed

$$\frac{h_c}{d_b} \geq \frac{f_y}{3.2\sqrt{f_c'}}\ (\text{MPa}) = \frac{f_y}{38.4\sqrt{f_c'}}\ (\text{psi})$$

Design Criteria for Minimum Joint Depth



Evaluation of hysteresis loop at the 2nd or 3rd cycle of 4% drift ratio



ACI 374.1-05

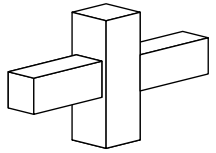
Strength

$Q \geq 0.75Q_m$

Energy dissipation

$E_D/E_{PP} \geq 0.125$

Beam-Column Joints with Grade 490 beam bars



26 data

$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{490}{420} \right) = 23$$

$$\frac{h_c}{d_b} \geq \frac{f_y}{3.2\sqrt{f_c'}}$$

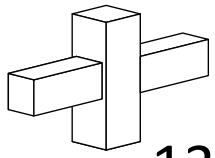
$\frac{h_c}{d_b}$

40
35
30
25
20
15
10

20 30 40 50 60 70 80 90 100 110 120

Concrete compressive strength, f_c' (MPa)

Beam-Column Joints with Grade 590 beam bars



13 data

$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{590}{420} \right) = 28$$

$$\frac{h_c}{d_b} \geq \frac{f_y}{3.2\sqrt{f_c'}}$$

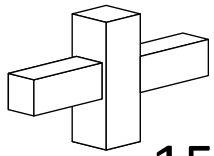
$\frac{h_c}{d_b}$

30
25
20
15
10

20 40 60 80 100 120 140 160

Concrete compressive strength, f_c' (MPa)

Beam-Column Joints with Grade 690 beam bars



15 data

$$\frac{h_c}{d_b} \geq 20 \cdot \left(\frac{690}{420} \right) = 33$$

$$\frac{h_c}{d_b} \geq \frac{f_y}{3.2\sqrt{f_c'}}$$

$\frac{h_c}{d_b}$

35
30
25
20
15
10

20 40 60 80 100 120 140 160 180 200

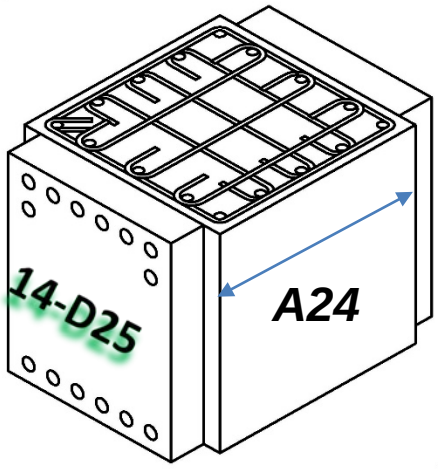
Concrete compressive strength, f_c' (MPa)

Seismic Testing for Interior Beam-Column Joints, Lee et al

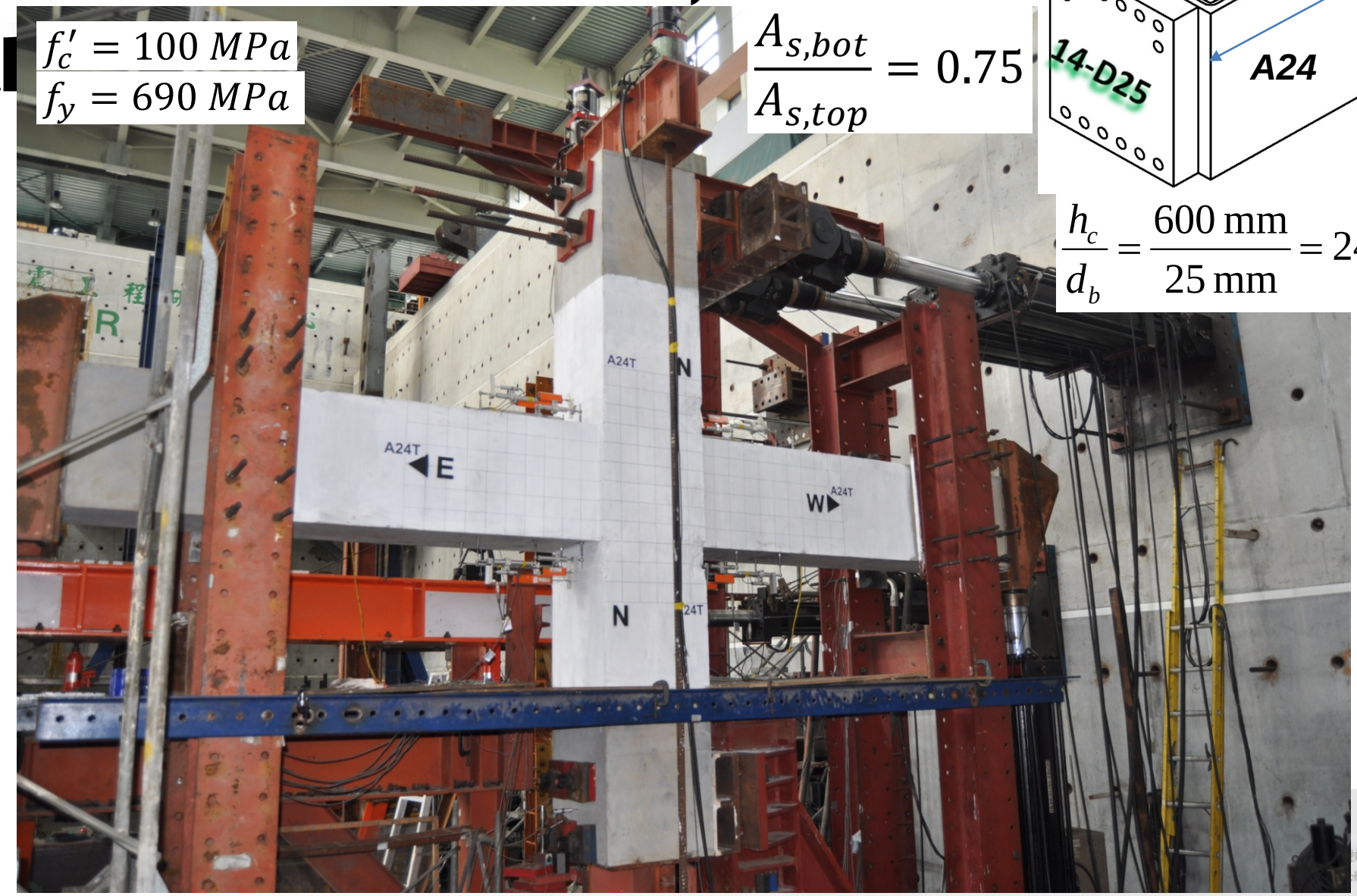
$f_c' = 100\ MPa$

$f_y = 690\ MPa$

$$\frac{A_{s,bot}}{A_{s,top}} = 0.75$$



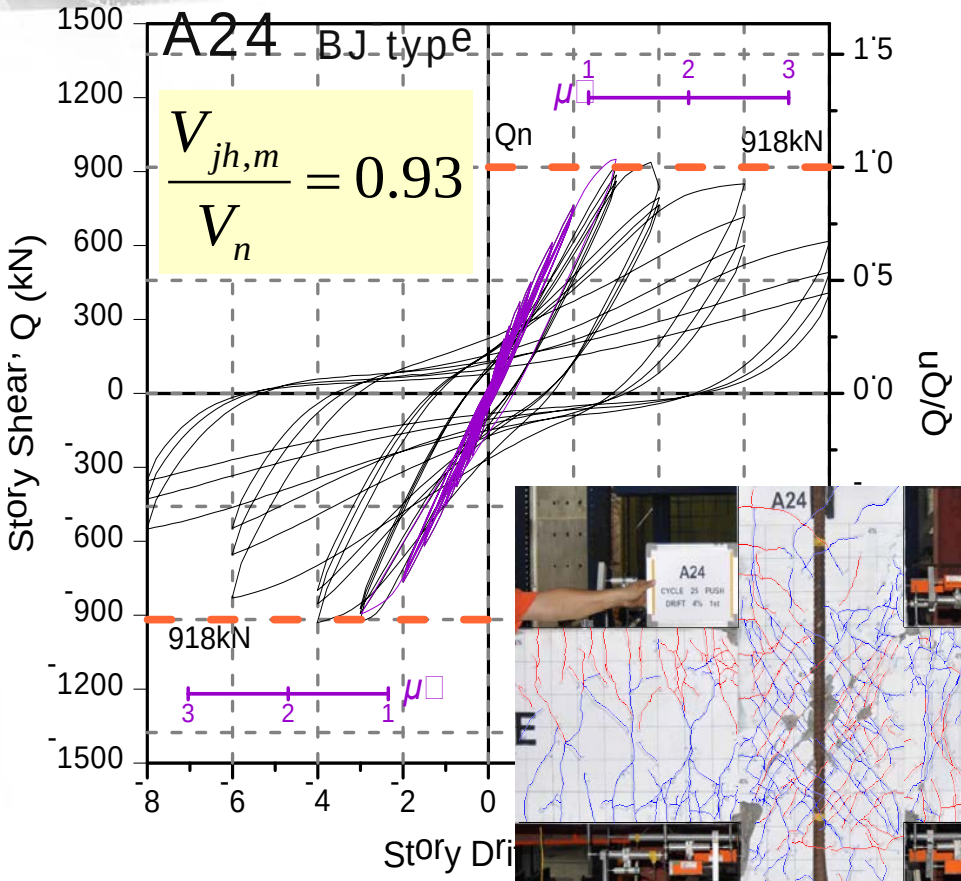
$$\frac{h_c}{d_b} = \frac{600\ \text{mm}}{25\ \text{mm}} = 24$$



Test results

$f_c' = 100(116)\ MPa$ $\quad P = 0.05A_g f_c'$

$f_y = 690(725)\ MPa$ $\quad \alpha_o = 1.15$



Simplified equation

$$\frac{h_c}{d_b} \geq \frac{690}{3.2\sqrt{100}} = 22$$

Provided

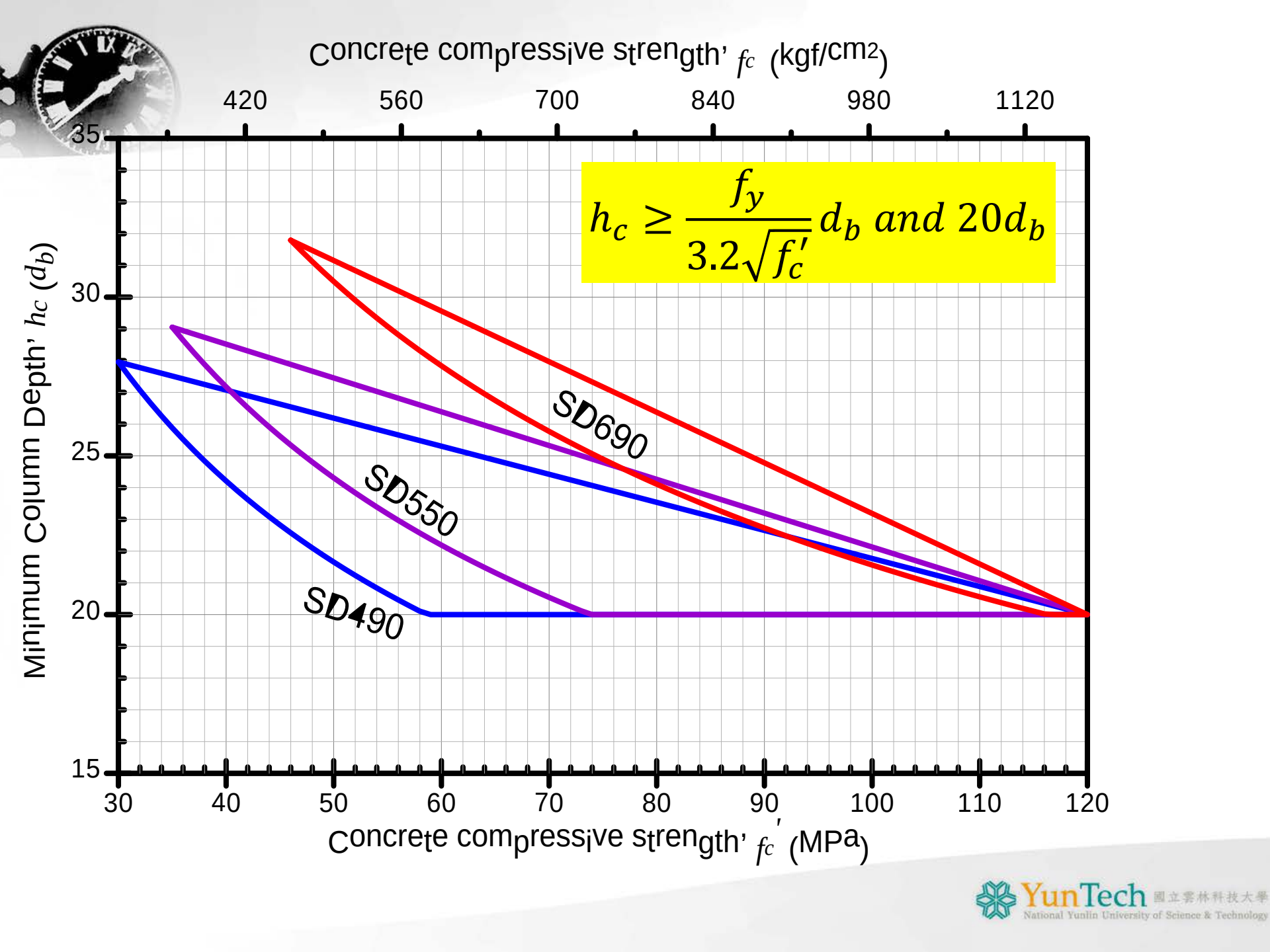
$$\frac{h_c}{d_b} = \frac{600\ \text{mm}}{25\ \text{mm}} = 24$$

4%-drift cycle

Performance Rating = 3

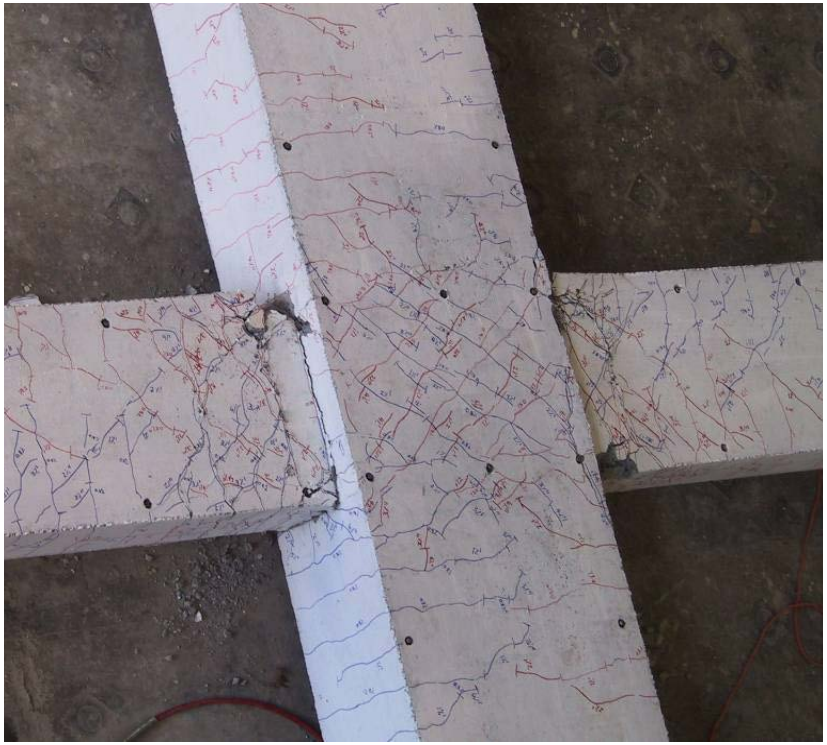
Acceptable

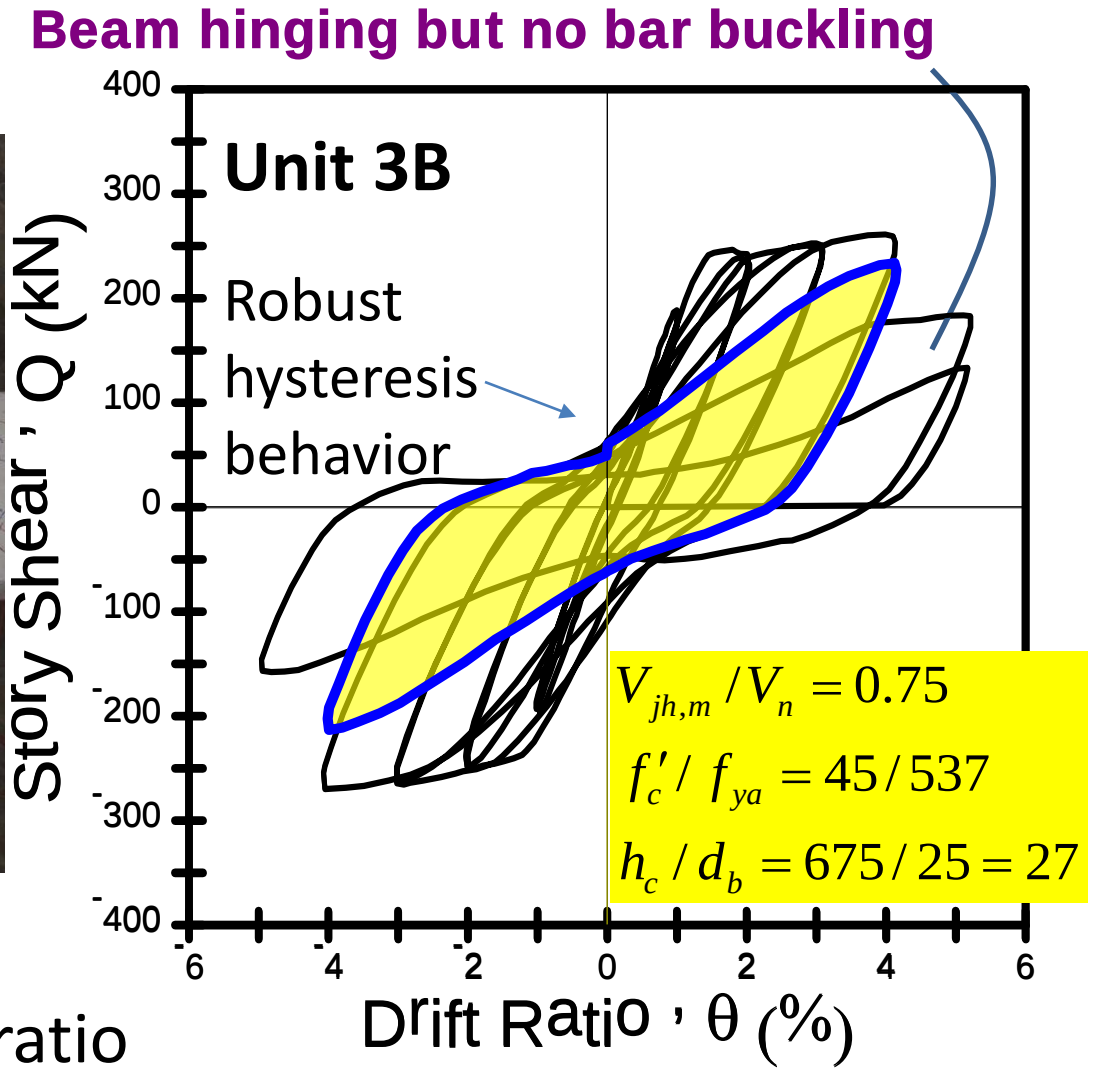
$$\frac{A_{s,bot}}{A_{s,top}} = 0.75$$



Thanks for your attention

Bond or anchorage failure (BJa failure)



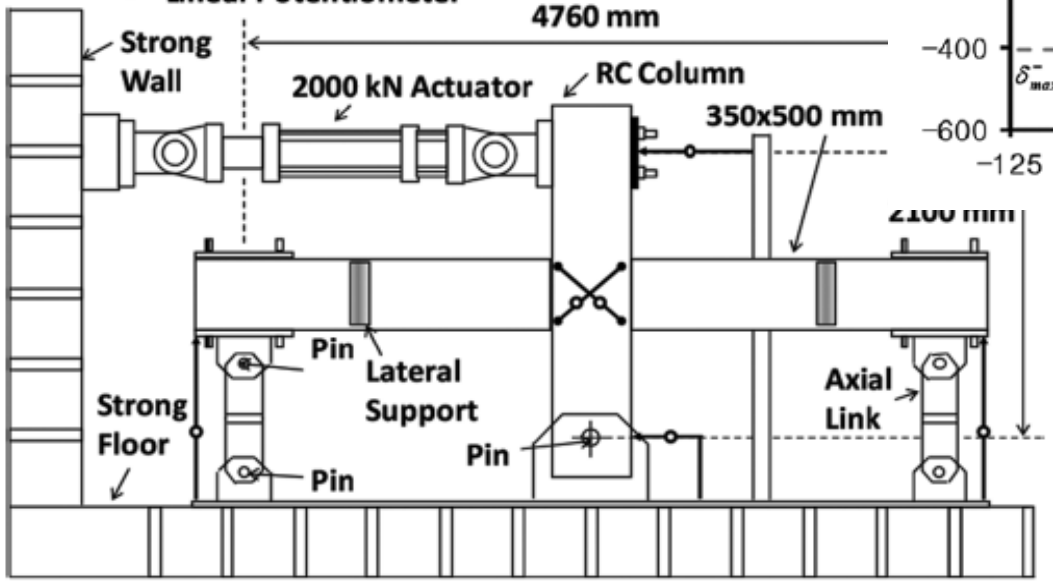


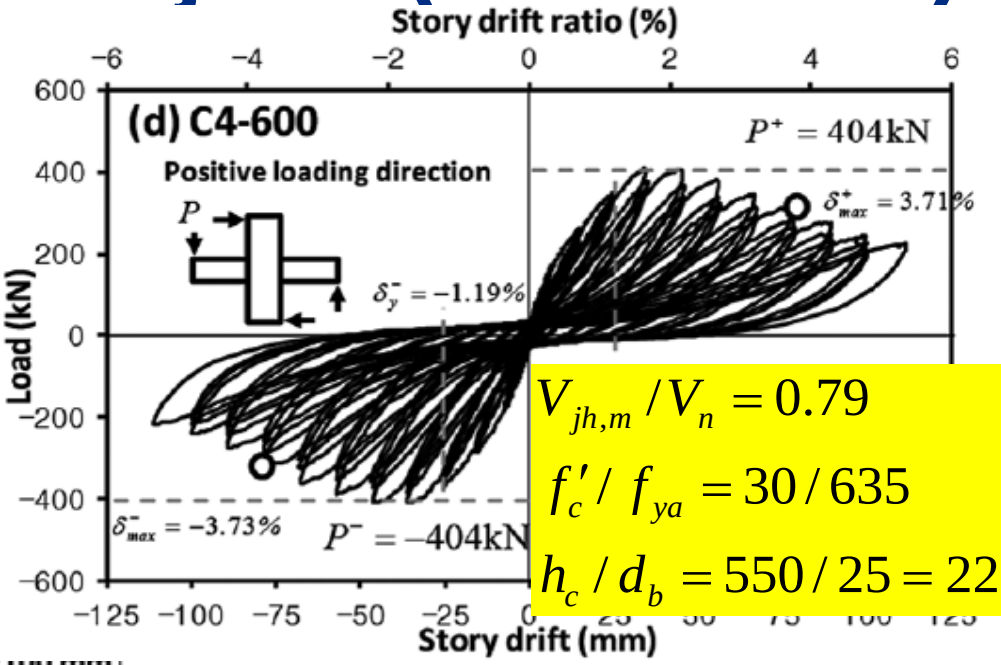
Bond failure at **4.4%** drift ratio

Brooke, N. J.; Megget, L. M.; and Ingham, J. M., (2006) "Bond Performance of Interior Beam-Column Joints with High-Strength Reinforcement," ACI Structural Journal, V. 103, No. 4, Jul-Aug,

Bond or anchorage failure along beam bars in the joint (BJa failure)

Concrete crushing at beam ends





$V_{jh,m} / V_n = 0.79$

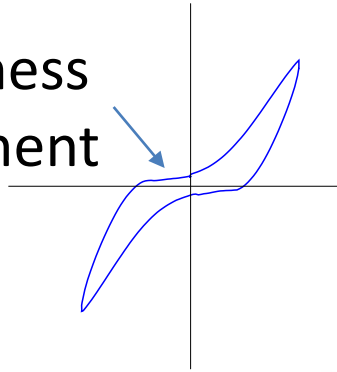
$f_c' / f_{ya} = 30 / 635$

$h_c / d_b = 550 / 25 = 22$

Low residual stiffness at small displacement

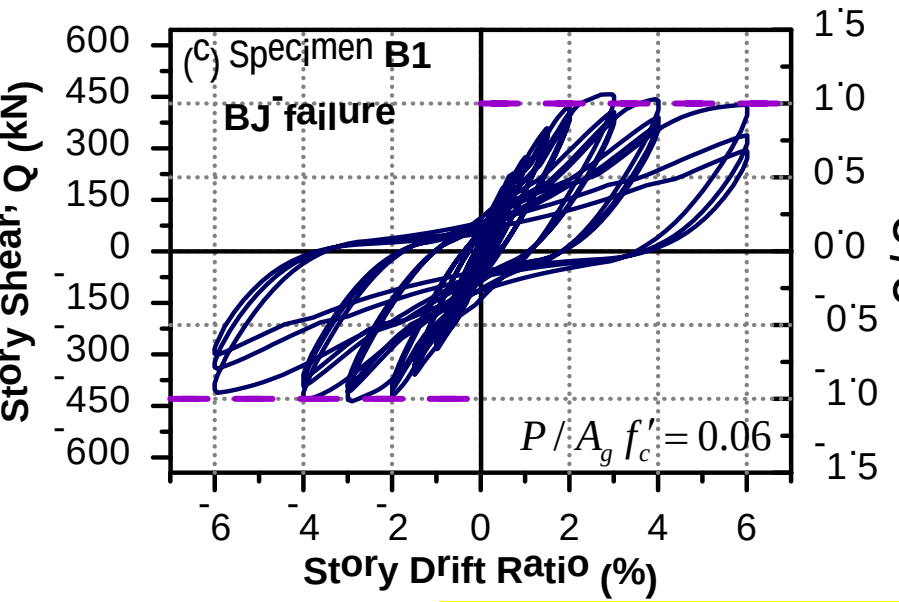
Pinching behavior

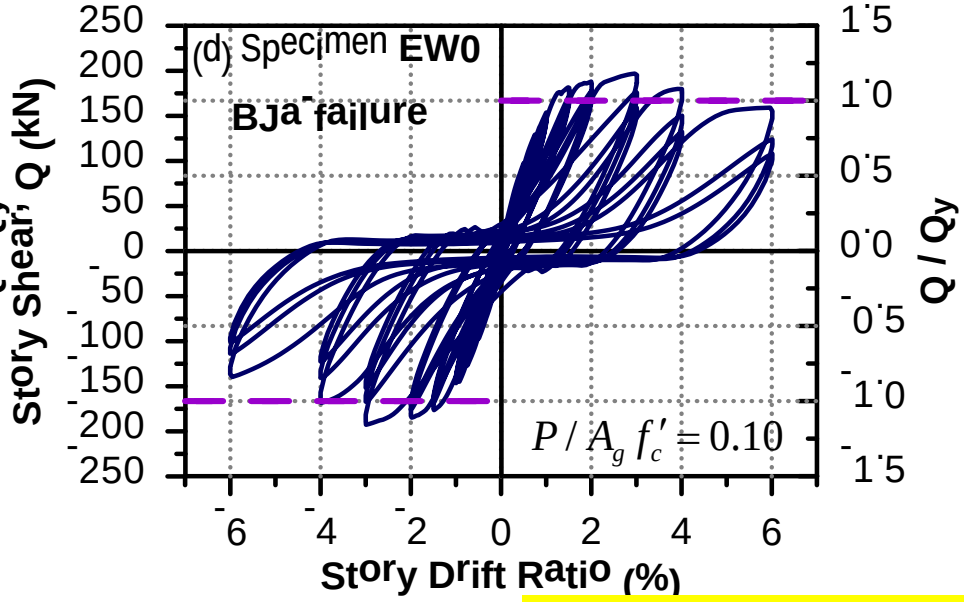
Unlikely to repair



Hwang H-J, Park H-G, Choi W-S, et al. (2014) Cyclic Loading Test for Beam-Column Connections with **600 MPa (87 ksi) Beam Flexural Reinforcing Bars**. *ACI Structural Journal* 111 (4)

“BJ” failure versus “BJa” failure



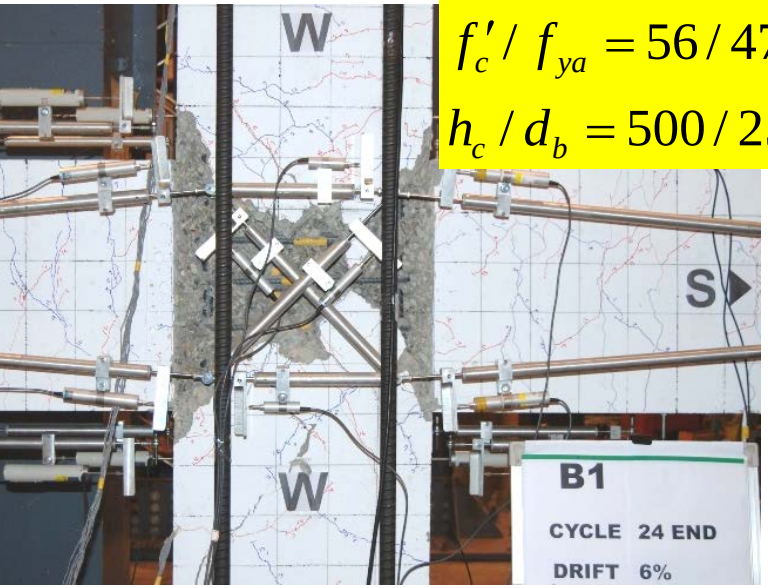


Lee et al. (2017)

$V_{jh,m} / V_n = 1.08$

$f_c' / f_{ya} = 56 / 470$

$h_c / d_b = 500 / 25 = 20$

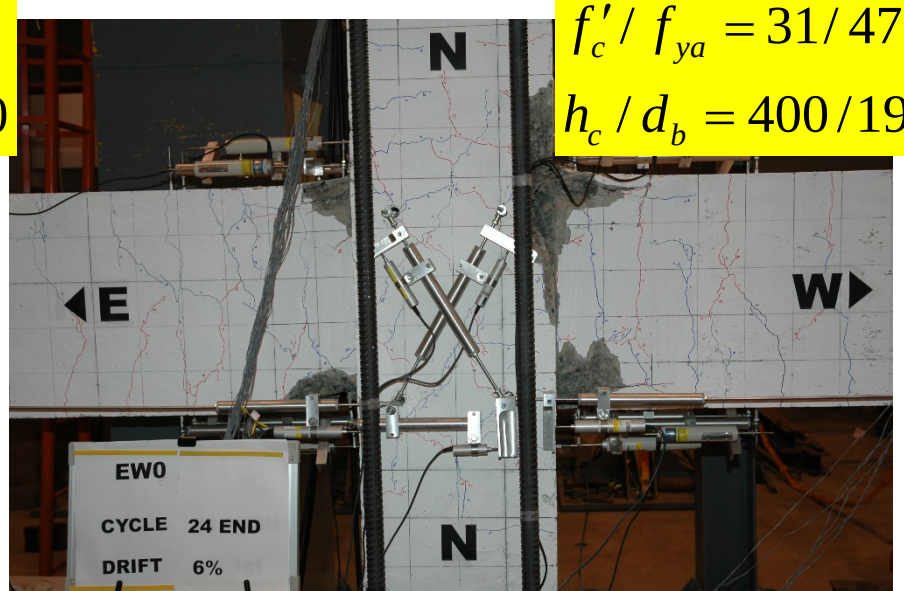


Lee et al. (2007)

$V_{jh,m} / V_n = 0.78$

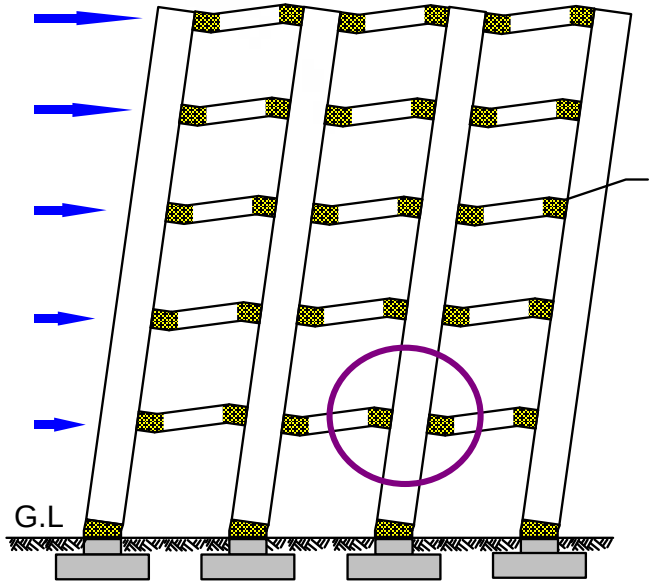
$f_c' / f_{ya} = 31 / 473$

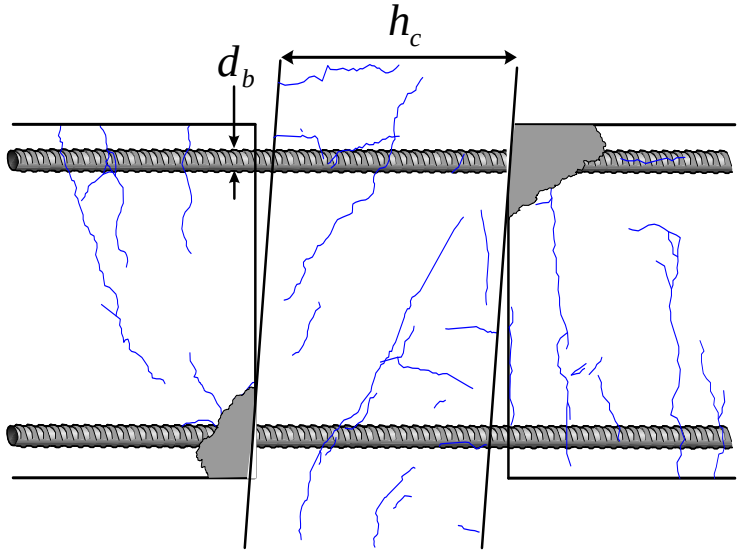
$h_c / d_b = 400 / 19 = 20$



Concluding remarks

Bond failure ⇒ Strength and stiffness degradation, poor hysteresis behavior

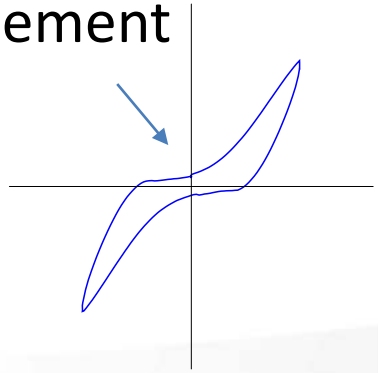




Unlikely to repair

Low residual stiffness at small displacement

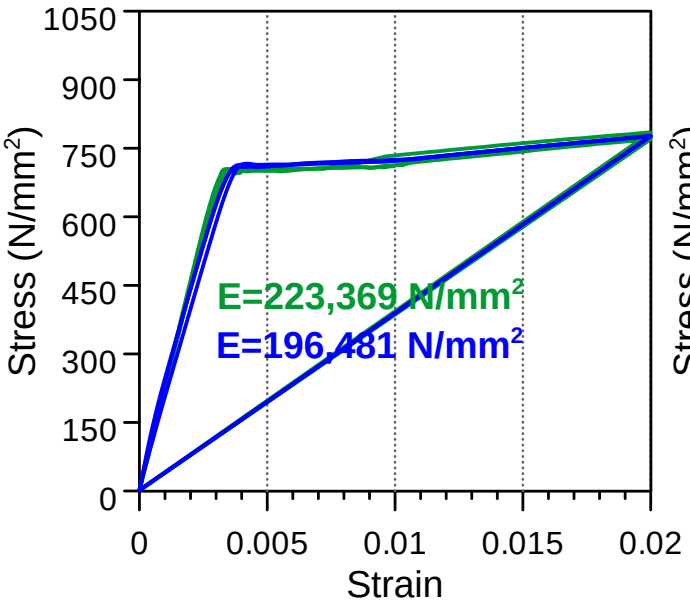
Pinching effect

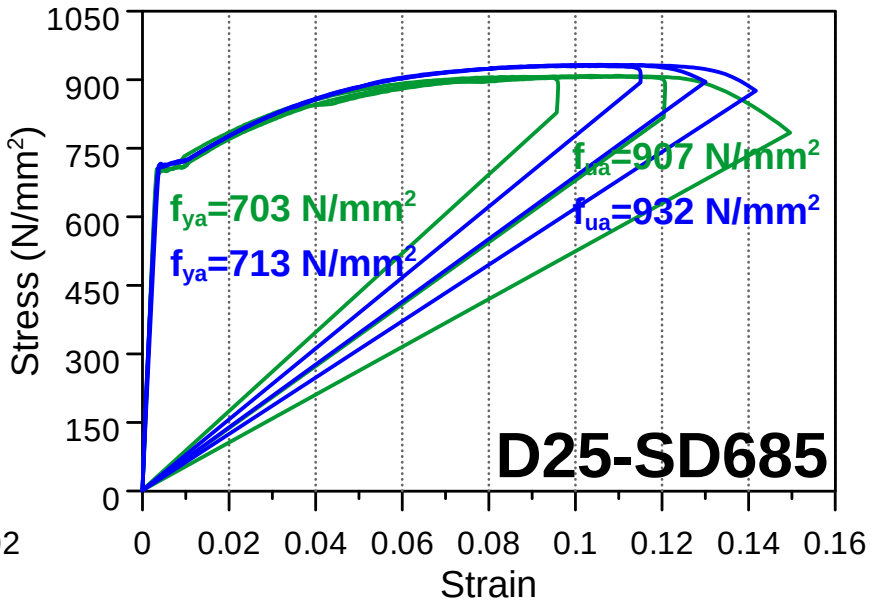


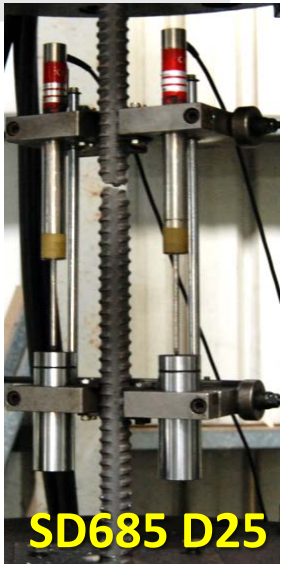
$$h_c \geq \frac{f_y}{3.2\sqrt{f_c'}} d_b \; and \; 20d_b$$

SD685-D25 Bar tensile tests

Grade, Size	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation (%)	TS/YS	Yield Pleatau
Criteria	685~785	≧860	≧10	≧1.25	≧0.014
SD685,D25	703	907	16	1.29	0.022
SD685,D25 (Retest)	713	932	15	1.31	0.0216

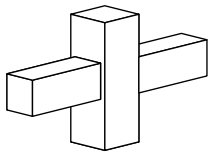






Tensile tests

Beam-Column Joints with Grade 420 beam bars



15 data

$\frac{h_c}{d_b}$

30
25
20
15
10

20 30 40 50 60 70

Concrete compressive strength, f_c' (MPa)

$$\frac{h_c}{d_b} \geq \frac{f_y}{3.2\sqrt{f_c'}}$$