高強度鋼筋混凝土(New RC)結構設計手冊研討會
NCREE,12/11, 2015

高強度鋼筋及錨定頭於高強度鋼筋混凝土之應用與握裹設計

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December 11, 2015

Outlines

- Background
- Properties of Reinforcement
- Development Length of Reinforcement
- Development of Standard Hooks
- Development of Headed Bars

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- **Background**
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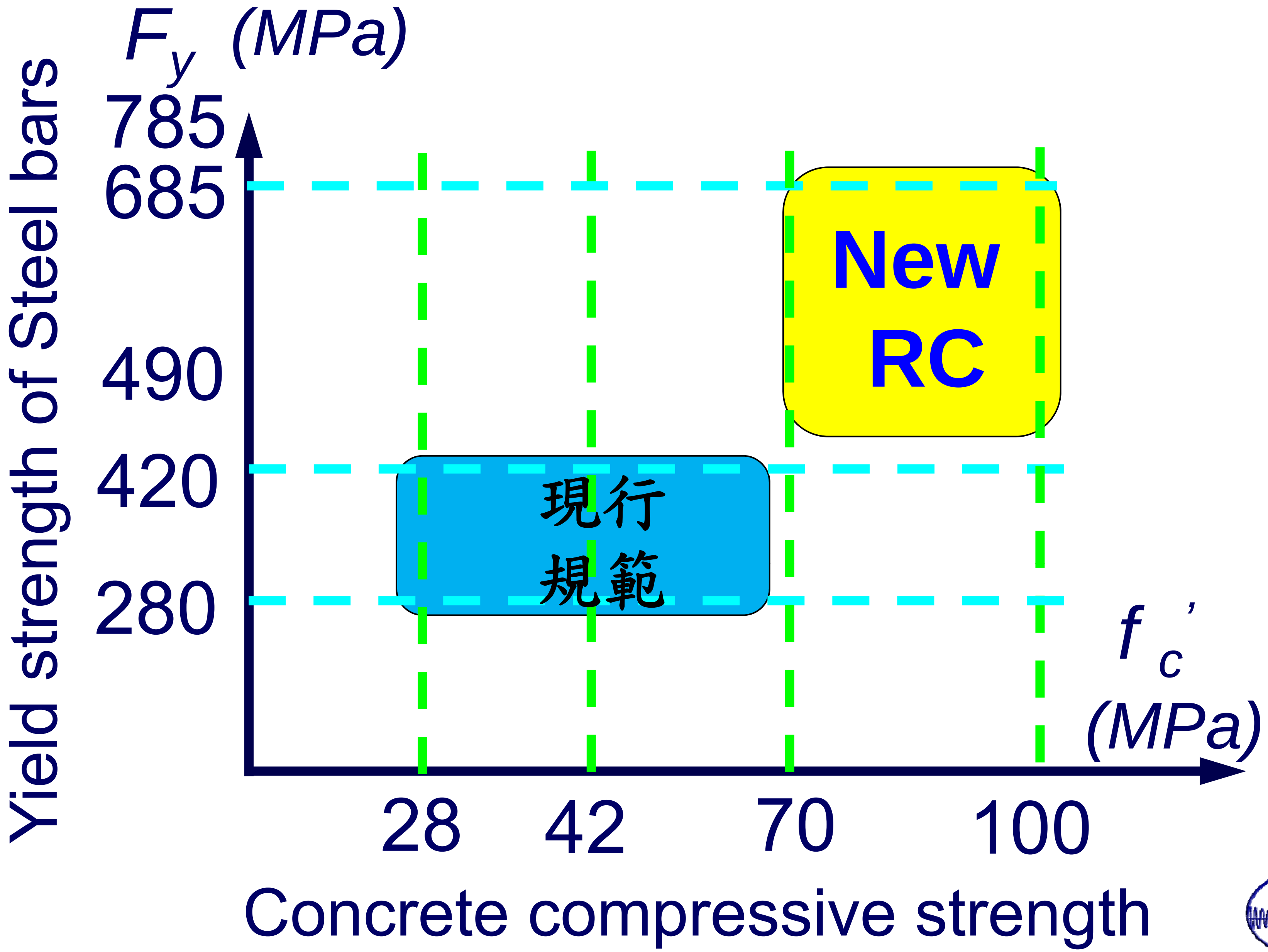
New RC 材料強度應用範圍



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Taiwan New RC Group 2008~

技術推動

產業界

潤弘、亞利
東鋼、TTK

材料規格制定與推廣

組織社團

TCI

NCREE
TW New RC
Project / Group
台灣新型高強度鋼筋
混凝土結構系統

台大土木系
台大材料系
台科大營建系
中央大學土木系
雲科大營建系
成功大學土木系

學術界

科技部整合研究

SD685、SD785
fc’ ≧ 70 MPa

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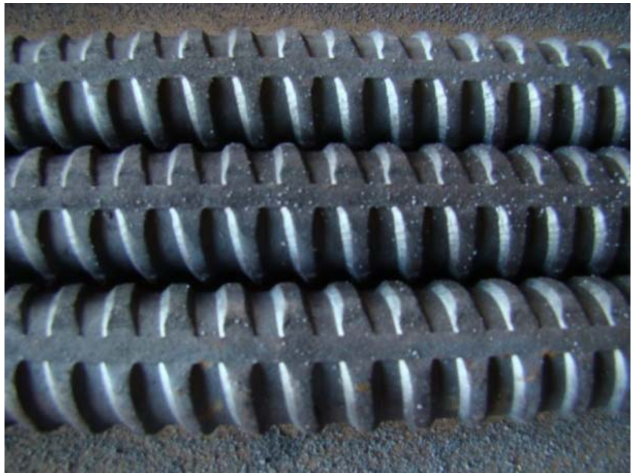
研究單位

構件行為研究
與設計指針建立

Background

- Non-Welded, Non-Bend for High Strength Rebar

- Threaded Rebar
- Precast



- Coupling Sleeve for Mortar
- Anchor for Mortar

Different Types of Rebars

Thread Rebar
Hot roll

Deformed Rebar
X & Diamond

Thread Rebar
Milled

Deformed Rebar
Rectangular

Plain Rebar

Deformed Rebar
Parallelogram

Outlines

- Background
- **Properties of Reinforcement**
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Mechanical Properties of Reinforcement

符號	f_y N/mm²	f_u N/mm²	$\frac{f_{ua}}{f_{ya}}$	達降伏強度上限之應變	試片	伸長率	彎曲角度	彎曲直徑
SD490	490~625	620 以上	-	-	2號 14A號	12以上 13以上	90°	D25以下，5d_b D25以上，6d_b
SD490W	490~625	620 以上	1.25 以上	0.014以上	2號 14A號	12以上	90°	5d_b
SD550W	550~675	690 以上	1.25 以上	0.014以上	2號 14A號	12以上	90°	4d_b
SD685	685~785	860 以上	1.25 以上	0.014以上	2號 14A號	10以上	90°	4d_b
SD785	785以上	930 以上	—	—	母材 2號 14A號	8以上	180°	3d_b
					銲接處 2號 14A號	5以上	—	—

- **SD490W**：增加實際抗拉強度與實際降伏強度比值需大於1.25之限制，並將彎曲直徑採用5倍鋼筋直徑，不隨鋼筋直徑而變化。

Chemical Composition of Reinforcement

材質	化學成分%					
	C	M_n	P	S	S_i	C.E.
SD490	0.32 以下	1.80 以下	0.050 以下	0.050 以下	0.5 以下	0.57 以下
SD490W	0.32 以下	1.80 以下	0.050 以下	0.050 以下	0.5 以下	0.55 以下
SD550W	0.30 以下	1.50 以下	0.040 以下	0.040 以下	0.50 以下	0.55 以下
SD685	0.50 以下	1.80 以下	0.030 以下	0.030 以下	1.50 以下	--
SD785	0.50 以下	1.80 以下	0.030 以下	0.030 以下	1.50 以下	--

- **SD490W、SD550W**：為符合銲接性之要求，依據美國銲接學會AWS D1.4 (AWS, 2011)規定，**碳當量不應超過0.55**。
- C.E. 為碳當量(%) 。

$$\left[C+\frac{M_n}{6}+\frac{C_u}{40}+\frac{N_i}{20}+\frac{C_r}{10}-\frac{M_o}{50}-\frac{V}{10}\right]\%$$

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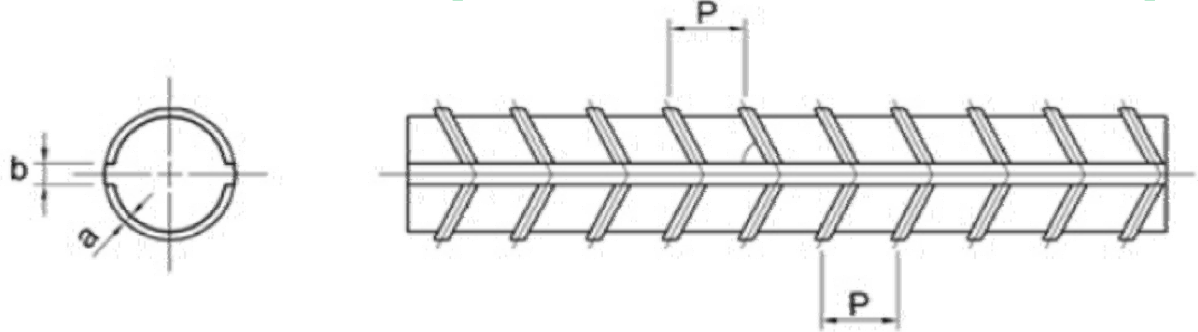
Applications of Longitudinal Reinforcement

符號	續接形式		錨定形式		
	銲接	搭接	彎鉤	銲接錨定裝置	套筒式錨定裝置
SD490	X	▲	O	X	O
SD490W	O	▲	O	O	O
SD550W	O	▲	O	O	O
SD685	X	X	X	X	O

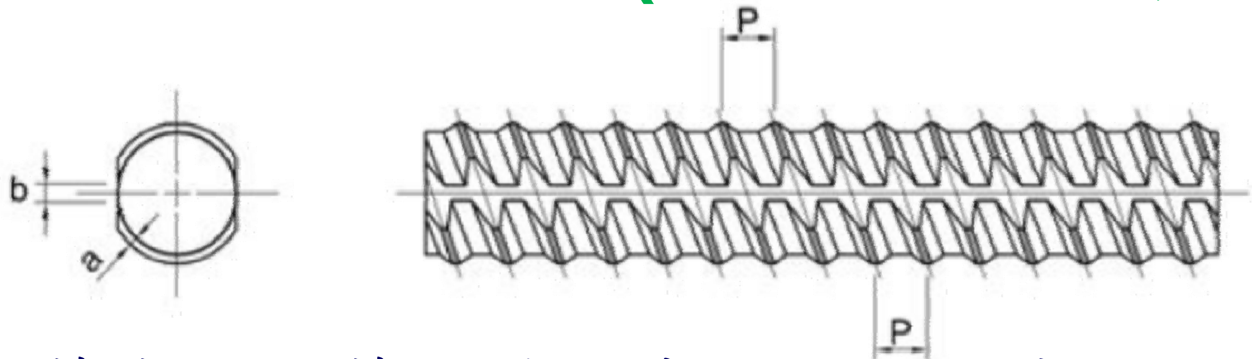
- **SD685**：不得採用銲接或搭接續接，且鋼筋端部不得以彎鉤或銲接錨定裝置作為錨定之用。
- **SD785**：僅適用於橫向鋼筋，不得作為梁、柱構件之縱向主筋。

Surface Geometry of Reinforcement

- 竹節鋼筋：鋼筋表面節之平均節高與平均節距比值，分別不得小於0.1。(採用ACI 408-03建議)



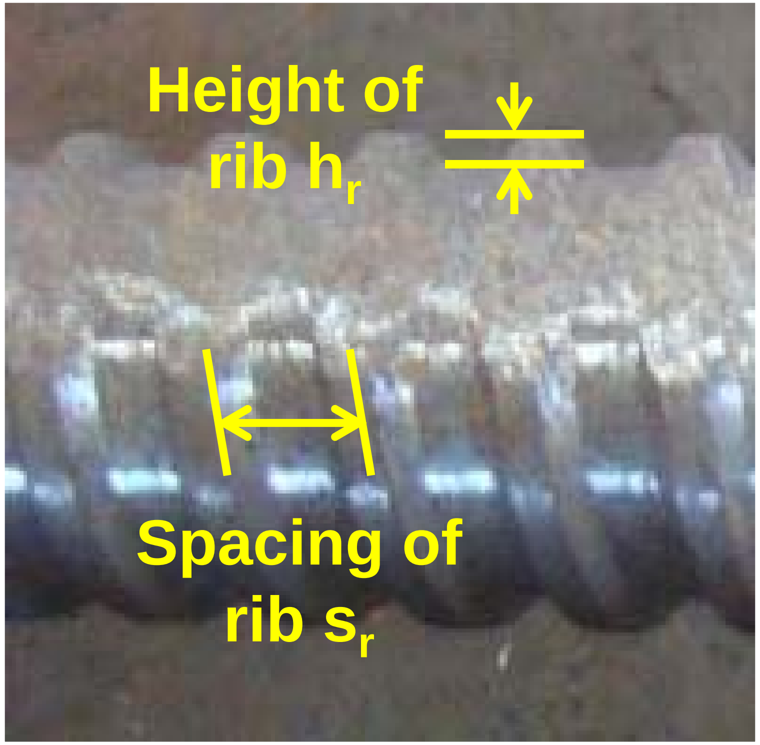
- 螺紋節鋼筋：鋼筋表面節之平均節高與平均節距比值，分別不得小於0.17。(採用國震中心研究成果)

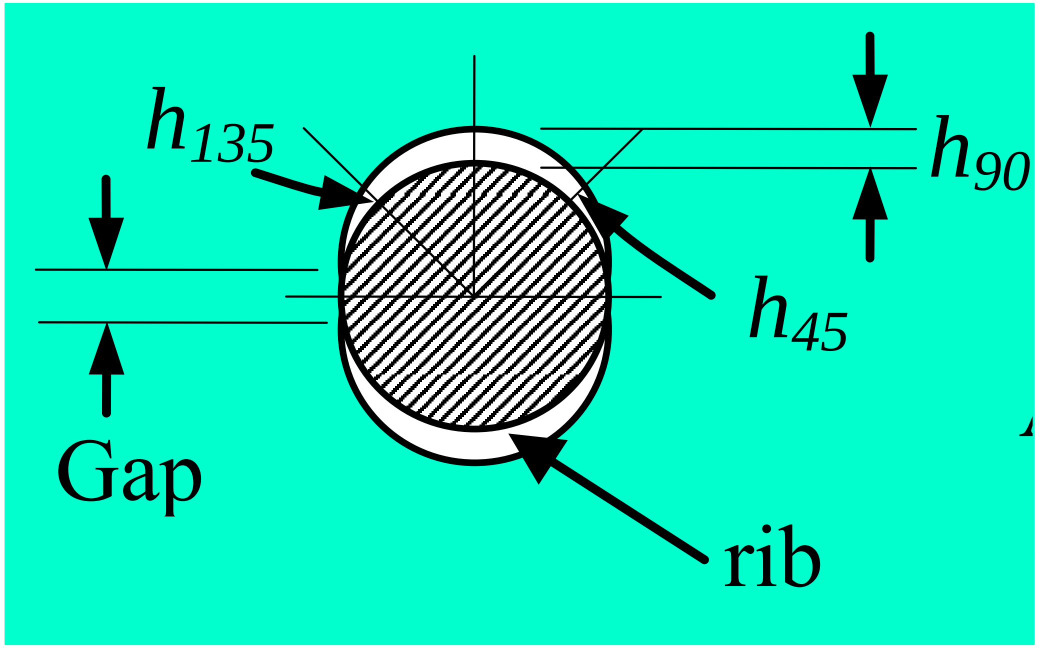


- 一般竹節與螺紋節鋼筋之表面形狀尺度分別詳設計手冊中之表C3-2與表C3-3。

Parameter of Threaded Rebar

Relative Rib Area R_r





$$R_r = \frac{\text{bearing area}}{\text{shear area}} \approx \frac{h_r}{s_r}$$

Max. $h_r = h_{90}$

Avg. $h_r = (h_{90}+h_{45}+h_{135})/3$

$$\boxed{R_{r,ave} = \frac{h_{r,ave}}{s_r} \geq 0.17}$$

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Standard Specification for Reinforcement

社團法人 台灣混凝土學會

Taiwan Concrete Institute

鋼筋混凝土用鋼筋

Steel bars for Concrete Reinforcement

—SD550W、SD685、SD785

新高強度鋼筋混凝土技術委員會報告

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蔡江洋 蔡益超

研 究 助 理： 陳智軒 (按姓氏筆畫順序)

2014 年 09 月審定版

4. 形狀、尺度、質量及許可差

4.5 鋼筋之節，其高度最小值及最大值依表2之規定。為確保鋼筋在混凝土之握裹強度，**竹節鋼筋稱號D22以上**，其節之高度平均值不得小於其節距平均值之**10%**；**螺紋節鋼筋稱號D22以上**，其節之高度平均值不得小於其節距平均值之**18%** **(17%)**。

表 4　螺紋節鋼筋之標示代號、單位質量、標稱尺度及節之尺度

鋼筋稱號	標示代號	單位質量 (W) kg/m	標稱直徑 (d) mm	標稱剖面積 (S) mm^2	標稱周長 (ℓ) mm	節之尺度			
						節距平均值最大值 (P) mm	節之高度(a)		單一間隙寬度最大值 (b) mm
							最小值 (h) mm	最大值 (H) mm	
D13	4	0.994	12.7	126.7	40	6.4	0.8	1.3	5.0
D16	5	1.56	15.9	198.6	50	8.0	1.0	1.7	6.2
D19	6	2.25	19.1	286.5	60	9.6	1.2	2.0	7.5
D22	7	3.04	22.2	387.1	70	11.1	1.3	2.2	8.7
D25	8	3.98	25.4	506.7	80	12.7	1.6	2.6	10.0
D29	9	5.08	28.7	646.9	90	14.4	1.7	2.8	11.3
D32	10	6.39	32.2	814.3	101	16.1	1.9	3.2	12.6
D36	11	7.90	35.8	1007	113	17.9	2.2	3.6	14.1
D39	12	9.57	39.4	1219	124	19.7	2.4	4.0	15.5
D43	14	11.4	43.0	1452	135	21.5	2.5	4.2	16.9
D50	16	15.5	50.2	1979	158	25.1	3.0	5.0	19.7
D57	18	20.2	57.3	2579	180	28.7	3.5	5.8	22.5

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Objectives

ACI 318-11, 14 and Taiwan (2011) Codes

Straight Development length in tension (unit : SI)

$$l_d = \frac{A_b \cdot f_s}{\pi \cdot u \cdot d_b} \Rightarrow l_d = 0.9 \frac{f_y}{\sqrt{f_c'}} \frac{1}{\left(\frac{c_b + k_{tr}}{d_b}\right)} d_b$$

Limitations for Equation

- $f_y \leqq 420$ MPa
- $f_{yt} \leqq 420$ MPa
- $f_c' \leqq 70$ MPa

$$1.0 \leq \left(\frac{c_b + K_{tr}}{d_b}\right) \leq 2.5$$

$$K_{tr} = \frac{40 A_{tr}}{sn} \quad \text{(ACI 318-11)}$$

$$K_{tr} = \frac{A_{tr} f_{yt}}{10.3 sn} \quad \text{(Taiwan, 2011)}$$

25.4.1.4 The values of $\sqrt{f_c'}$ used to calculate development length shall not exceed 100 psi.

From 1989

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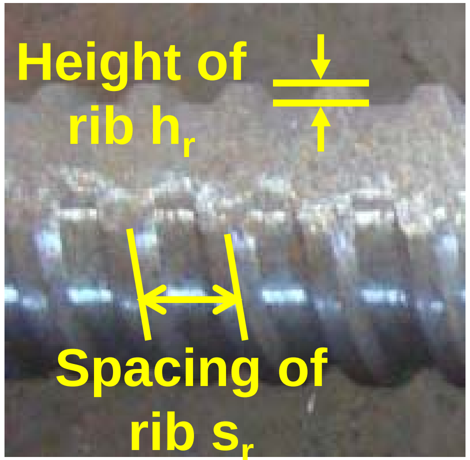
Development Length of Bars

Section 8.1.2

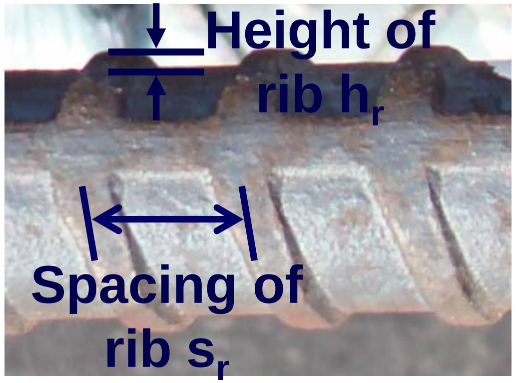
(本設計手冊建議)

Development length in tension following ACI 318 code (unit : SI)

$$l_d = 0.9\frac{f_y}{\sqrt{f_c'}}\frac{\psi_t\psi_e\psi_s\lambda}{\left(\frac{c_b+k_{tr}}{d_b}\right)}d_b$$



$$R_{r,ave} = \frac{h_r}{s_r} \geq 0.17$$



$$R_{r,ave} = \frac{h_r}{s_r} \geq 0.10$$

Limitations for Bond Equation

- $f_y \leqq$ 685 MPa
- $f_{yt} \leqq$ 420 MPa
- $f_c' \leqq$ 100 MPa

$$1.0 \leq \left(\frac{c_b+K_{tr}}{d_b}\right) \leq 2.5$$

$$K_{tr} = \frac{A_{tr}f_{yt}}{10.3sn}$$

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Development Length of Bars

Section 8.1.2

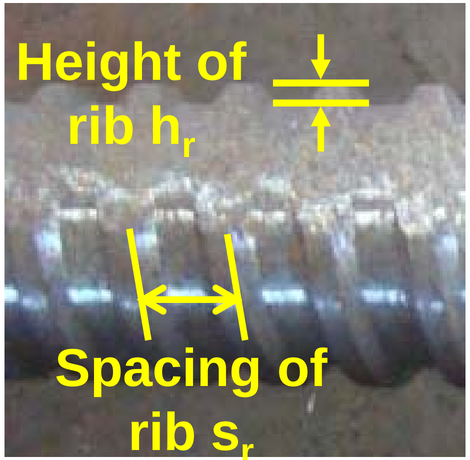
(本設計手冊建議)

Development length in compression following ACI 318 code (unit : SI)

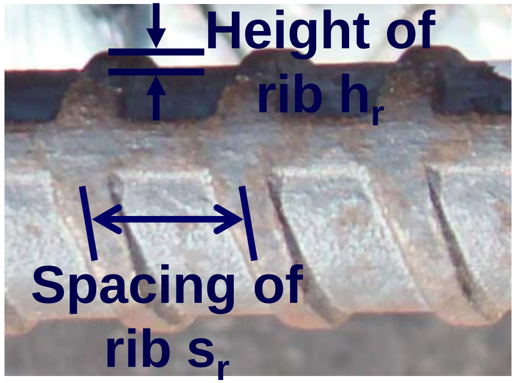
$$l_d = 0.24 \frac{f_y}{\sqrt{f_c'}} d_b \geq 0.043 f_y d_b$$

Limitations for Bond Equation

- $f_y \leqq 685$ MPa
- $f_{yt} \leqq 420$ MPa
- $f_c' \leqq 100$ MPa



$$R_{r,ave} = \frac{h_r}{s_r} \geq 0.17$$



$$R_{r,ave} = \frac{h_r}{s_r} \geq 0.10$$

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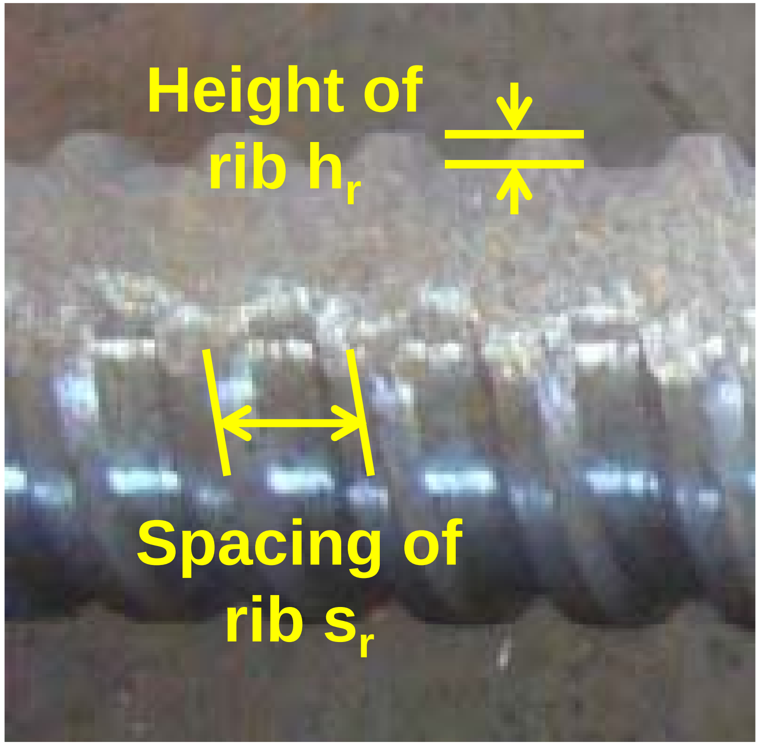
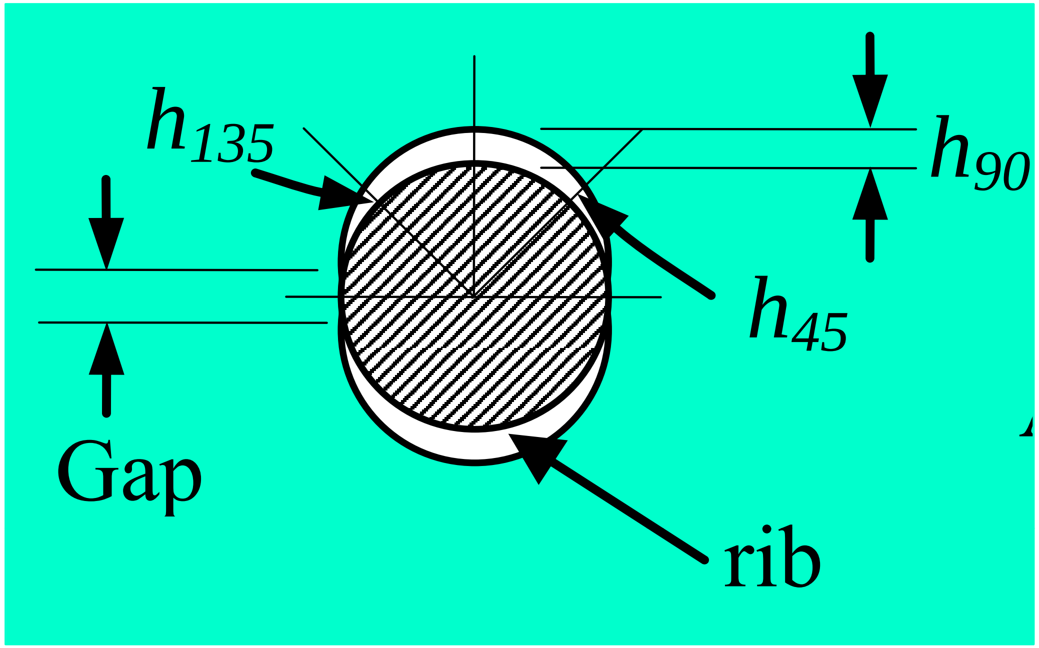
Parameter of Threaded Rebar

Relative Rib Area R_r





$$R_r = \frac{\text{bearing area}}{\text{shear area}} \approx \frac{h_r}{s_r}$$

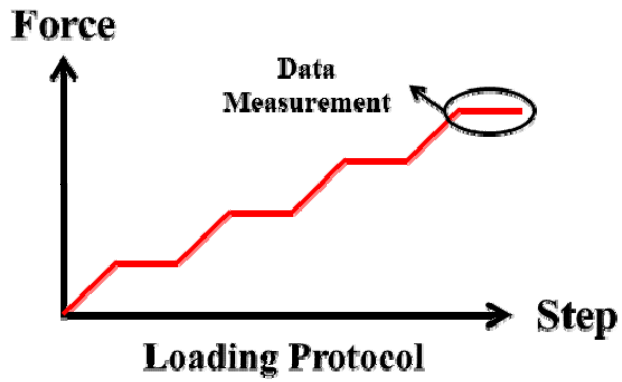
Max. $h_r = h_{90}$

Avg. $h_r = (h_{90}+h_{45}+h_{135})/3$

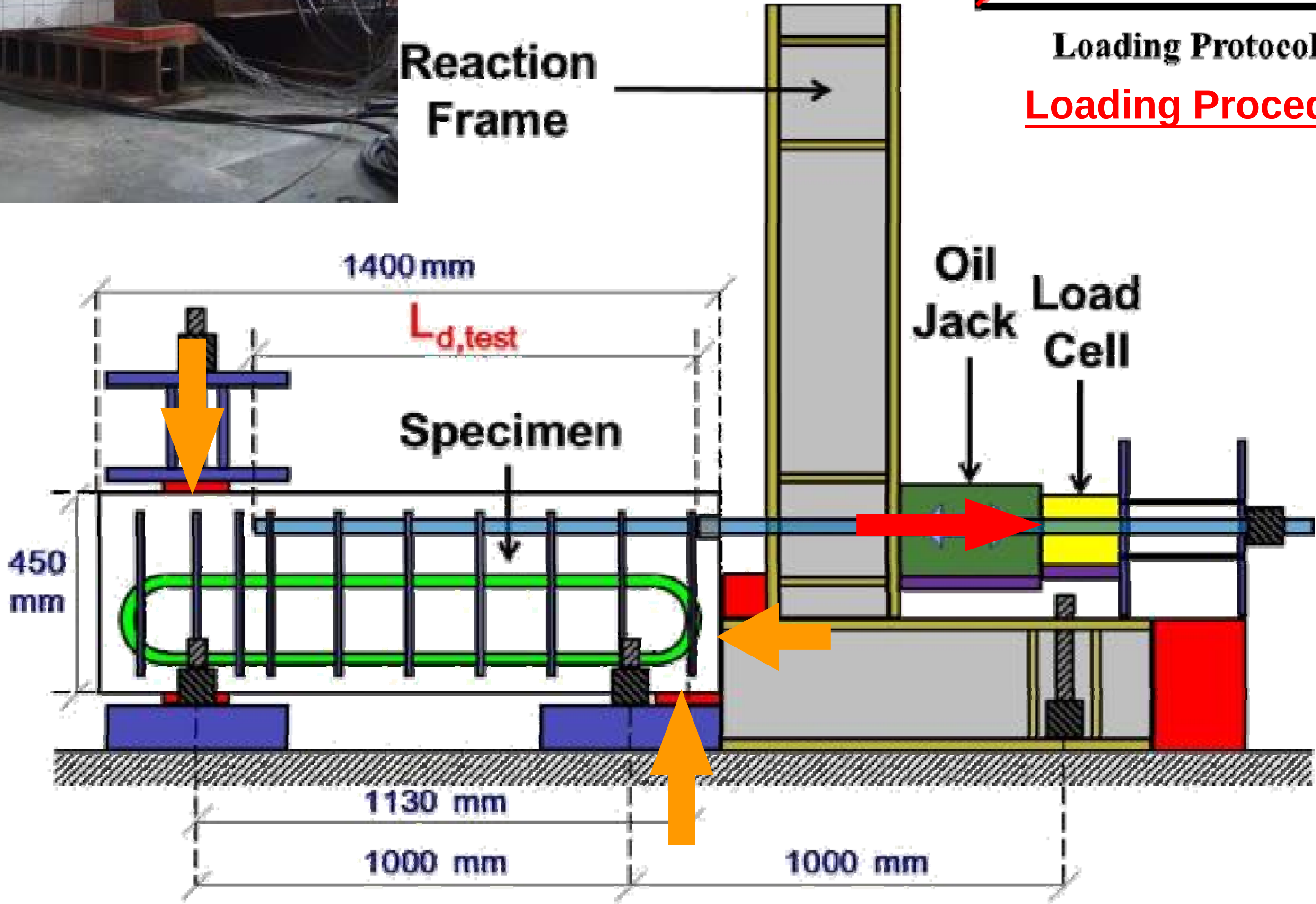
Experimental Program

Stopping Criteria

1. Concrete Failure
2. Bar Fracture
3. Bar Pullout

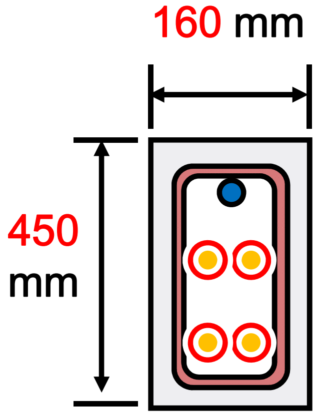


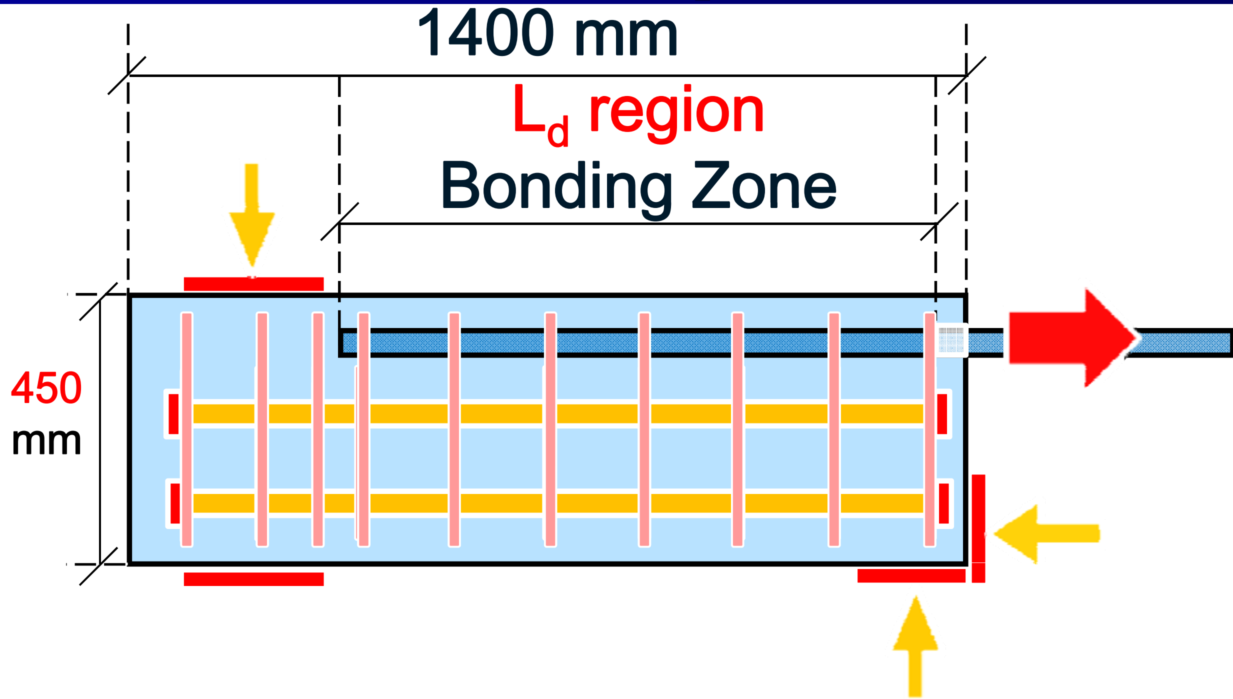
Loading Procedure



Design Variables of All Specimens

紀凱甯-2012~2014





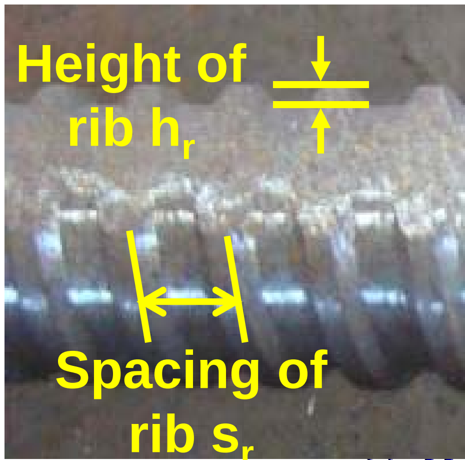
Batches : 3

Specimens : 42

Design variables

1. **Bar size : D25, D32, D35, D38, D41**
2. **Geometry : Plain, Thread (R_r = 0.12 – 0.19)**
3. **f_c' : 56, 70, 80, 100 MPa**
4. $\frac{c_{b,t} + K_{tr}}{d_b} = 2.5 - 4.2$

$$R_{r,ave} = \frac{h_r}{s_r}$$



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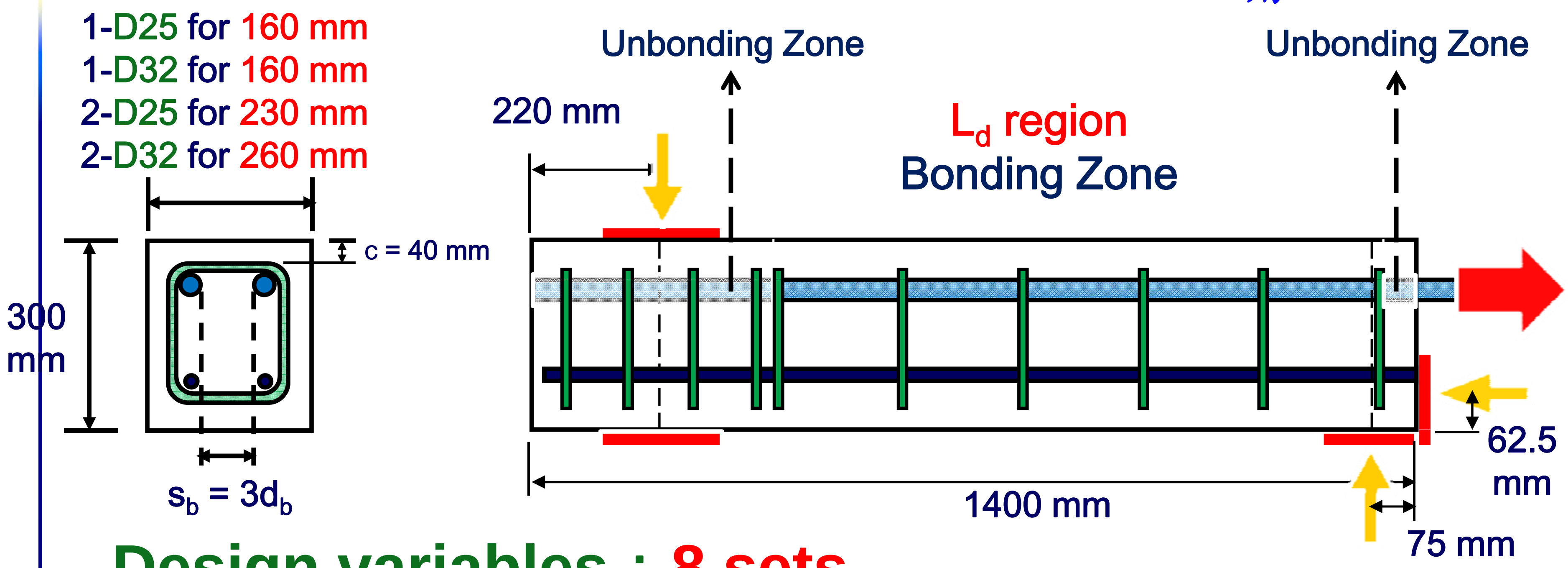
Design Variables of Specimens (I)

紀凱甯-2012



Design variables : 8 sets

1. Bar size : D25, D32
2. Number of bars : 1, 2-($3d_b$)
3. $L_{d,test}$ / $L_{d,dem}$: 0.6, 0.8, 1.0
4. h_r / s_r : 0.126, 0.143
5. f_c' : 70 MPa

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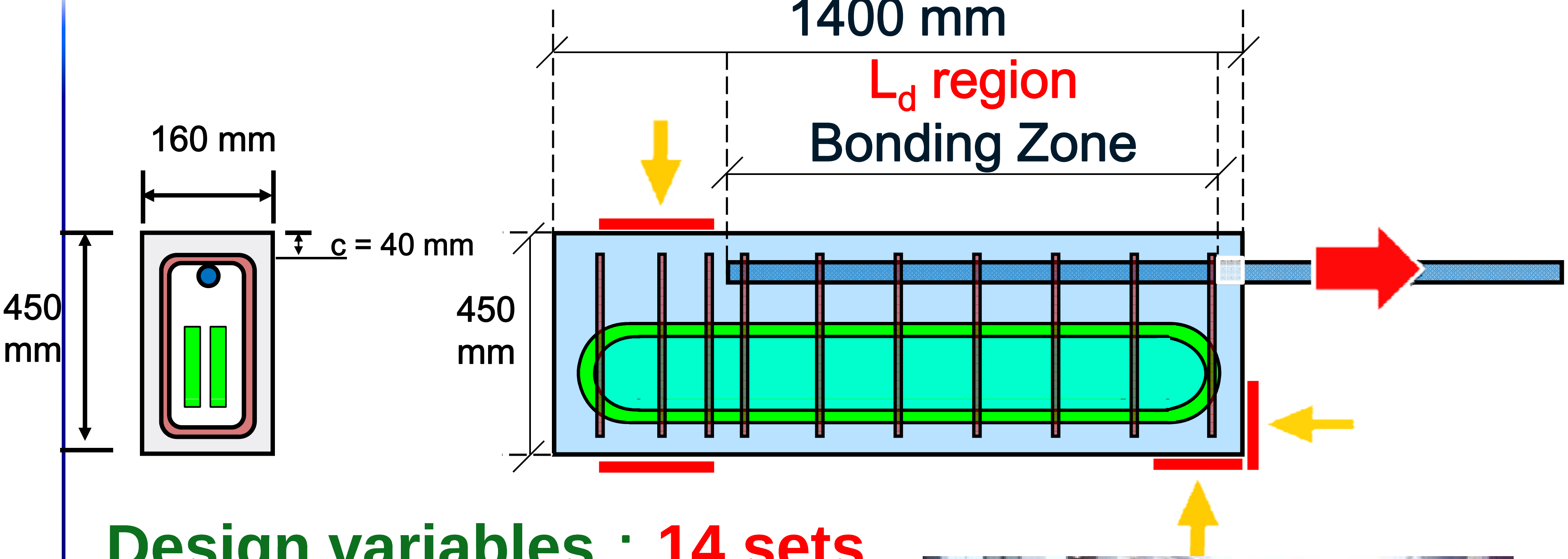
Design Variables of Specimens (II)

紀凱甯-2013

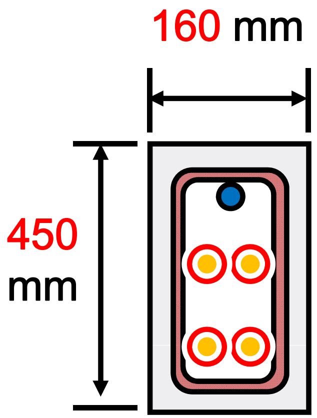


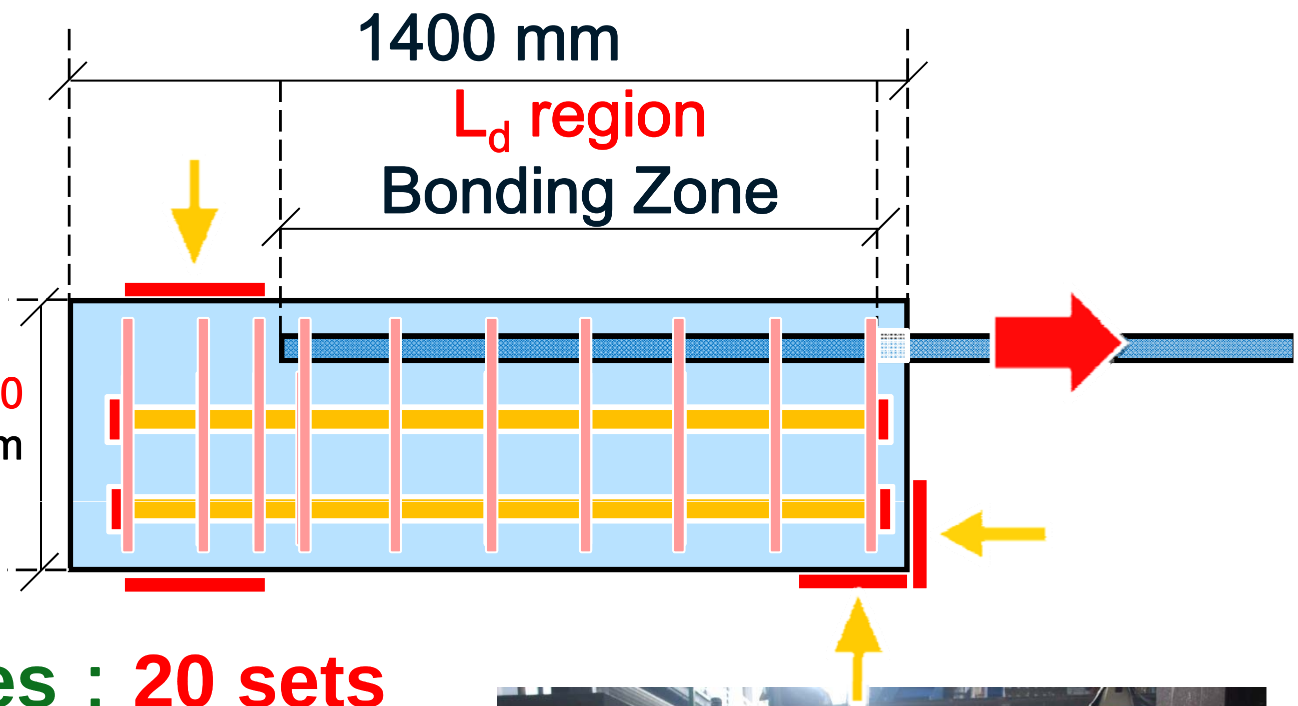
Design variables：14 sets

1. Bar size：D32, D39
2. Geometry：Thread, Plain
3. f_c' : 70, 100 MPa
4. f_{yt} : 280, 420, 785 MPa
5. $R_r = h_r / s_r$: 0, 0.13, 0.16, 0.18

Design Variables of Specimens (III)

紀凱甯-2014





Design variables：20 sets

1. Bar size：D25, D32, D35, D38, D41
2. Geometry：Thread
3. f_c'：56, 80, 100 MPa
4. $$\frac{c_{b,t}+K_{tr}}{d_b}=2.5-4.2$$

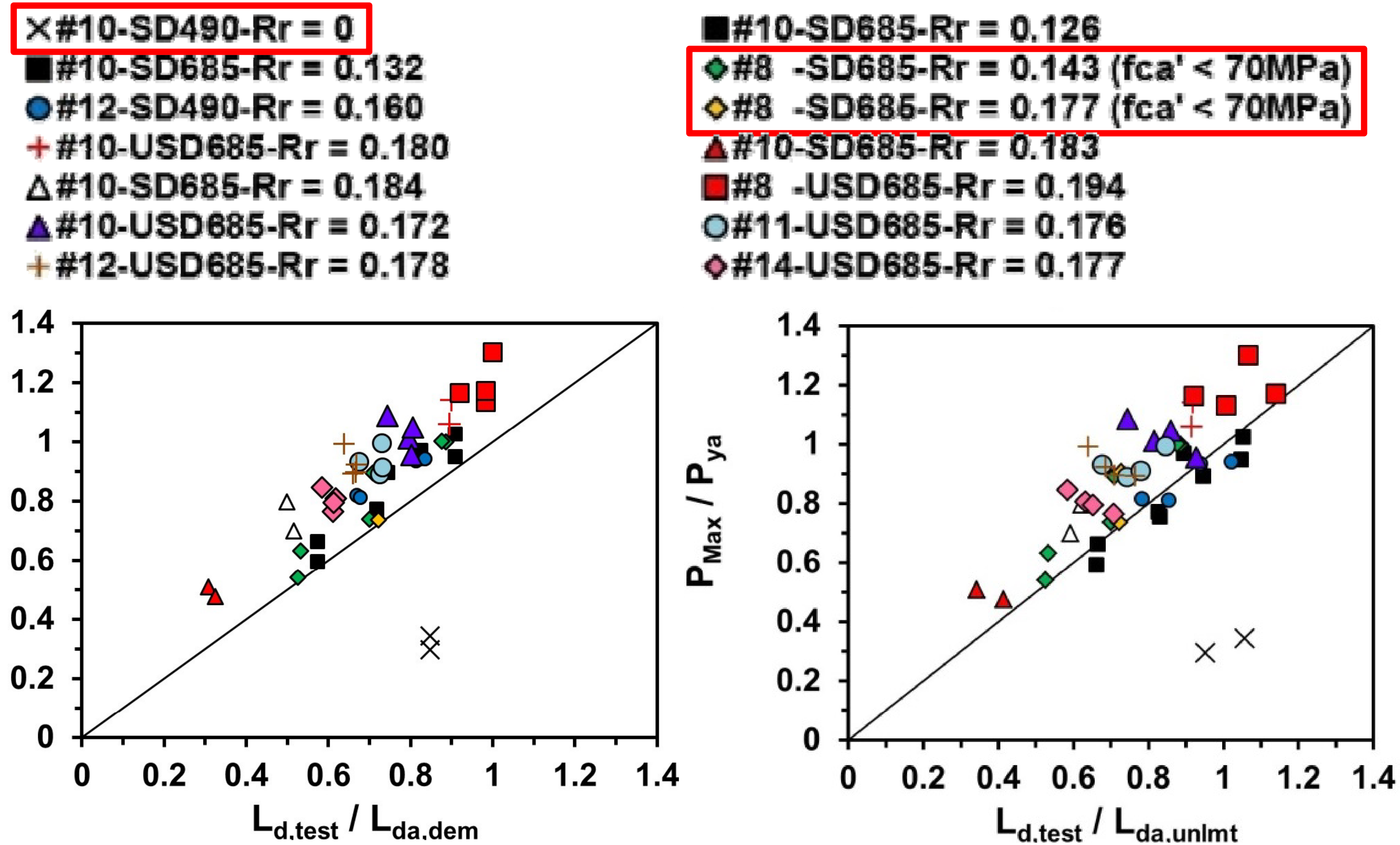
Actual Concrete Strength

Specimen	f_c', Testing Day (MPa)	Specimen	f_c', Testing Day (MPa)	Specimen	f_c', Testing Day (MPa)
BE1~BE3	64.3	SP10	106.4	D35C4F56	61.2
BE4	62.7	SP11	91.4	D35C4F8-V	72.0
BE7~BE9	90.9	SP12	102.3	D35C5F10	92.0
BE10	91.8	TD1	71.8	D35C7F8	78.0
SP1	80.4	TD2	71.8	D38C4F56	61.2
SP2	110.6	D25C4F56	61.2	D38C4F8-V	72.0
SP3	84.8	D25C4F8-V	72.0	D38C5F10	92.0
SP4	110.7	D25C5F10	92.0	D38C7F8	78.0
SP5	90.7	D25C7F8	78.0	D41C4F56	61.2
SP6	106.2	D32C4F56	61.2	D41C4F8-V	72.0
SP7	93.8	D32C4F8-V	72.0	D41C5F10	92.0
SP8	109.0	D32C5F10	92.0	D41C7F8	78.0
SP9	86.6	D32C7F8	78.0		

Actual Reinforcement Strength

Group	Spec. Name	Bar Size	Type	h_r (mm)	s_r (mm)	Relative of Area, R_r	Yield f_{ya}(MPa)	Ult. f_{ua} (MPa)
Series (I)	BE1-BE4	D25	SD685 Hot Roll	1.44	10.00	0.143	738	932
	BE7-BE10	D32	SD685 Hot Roll	1.50	11.90	0.126	742	966
Series (II)	SP1-SP2	D32	SD685 Hot Roll	1.56	11.88	0.131	710	924
	SP3-SP4			2.21	12.06	0.183	716	933
	SP5-SP6		SD685 Milled	2.21	12.01	0.184	777	971
	SP9-SP10		SD490 Plain	X	X	X	503	698
	SP7-SP8 SP11-SP12	D39	SD490 Hot Roll	2.37	14.80	0.160	534	701
	TD1-TD2	D32	USD685 Hot Roll	2.22	12.34	0.180	693	925
Series (III)	D25 Type	D25	USD685 Hot Roll	2.03	10.44	0.194	694.4	x
	D32 Type	D32		2.28	13.27	0.172	671.8	x
	D35 Type	D35		2.46	14.00	0.176	676.9	x
	D38 Type	D38		2.72	15.24	0.178	679.3	x
	D41 Type	D41		2.83	15.96	0.177	693.2	x

Test Results - Strength



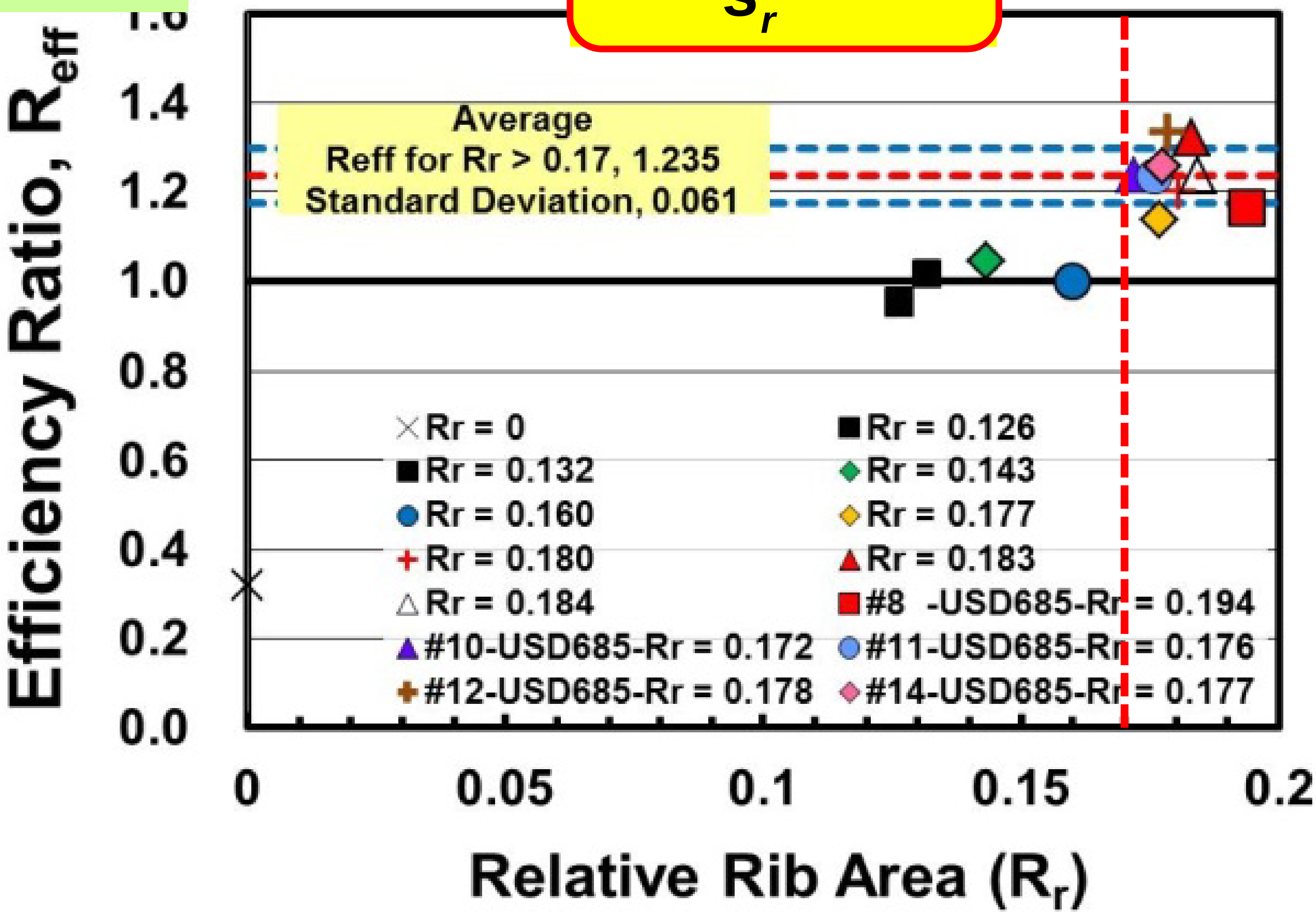
Limit for $f_c' \leqq 70$ MPa

No Limit for $f_c' \leqq 70$ MPa

Test Results - Strength

$$R_{eff} = \frac{R_P}{R_L}$$

$$R_r = \frac{h_r}{s_r} \geq 0.17$$



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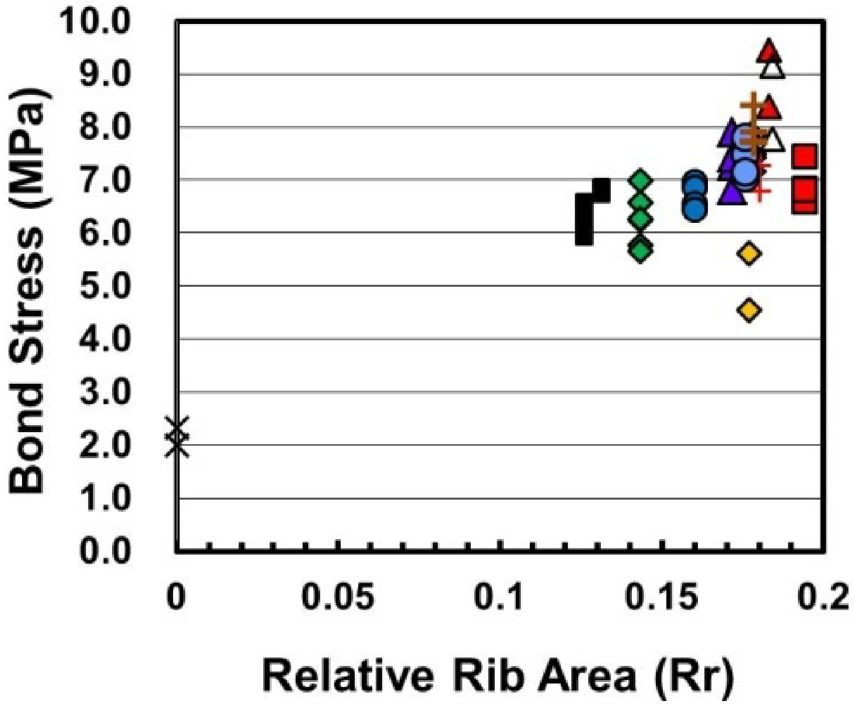
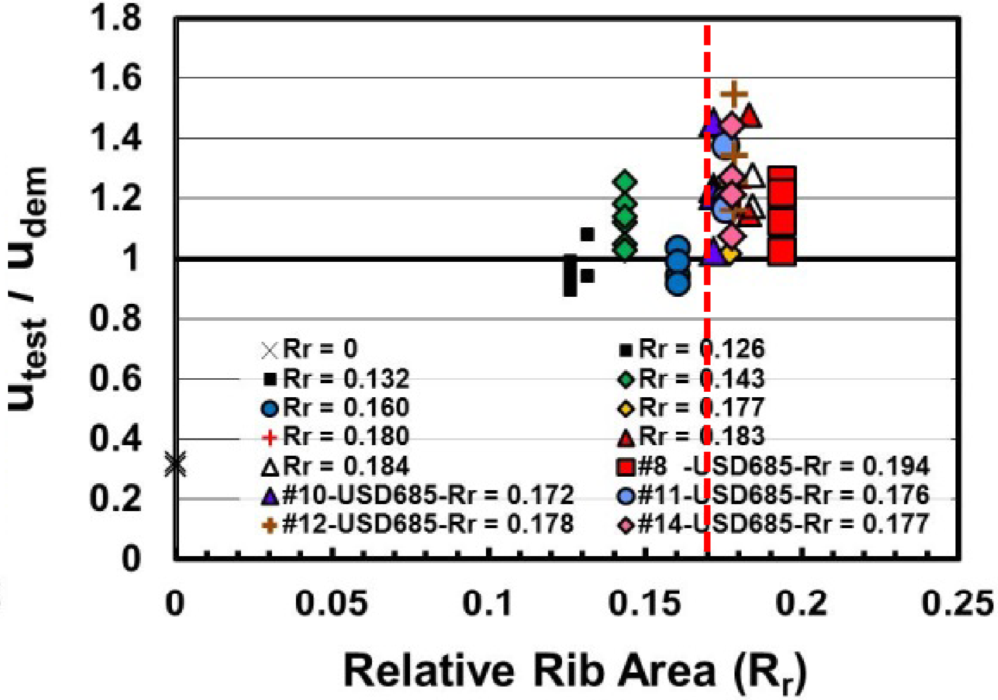
Bond Stress

u_{test}

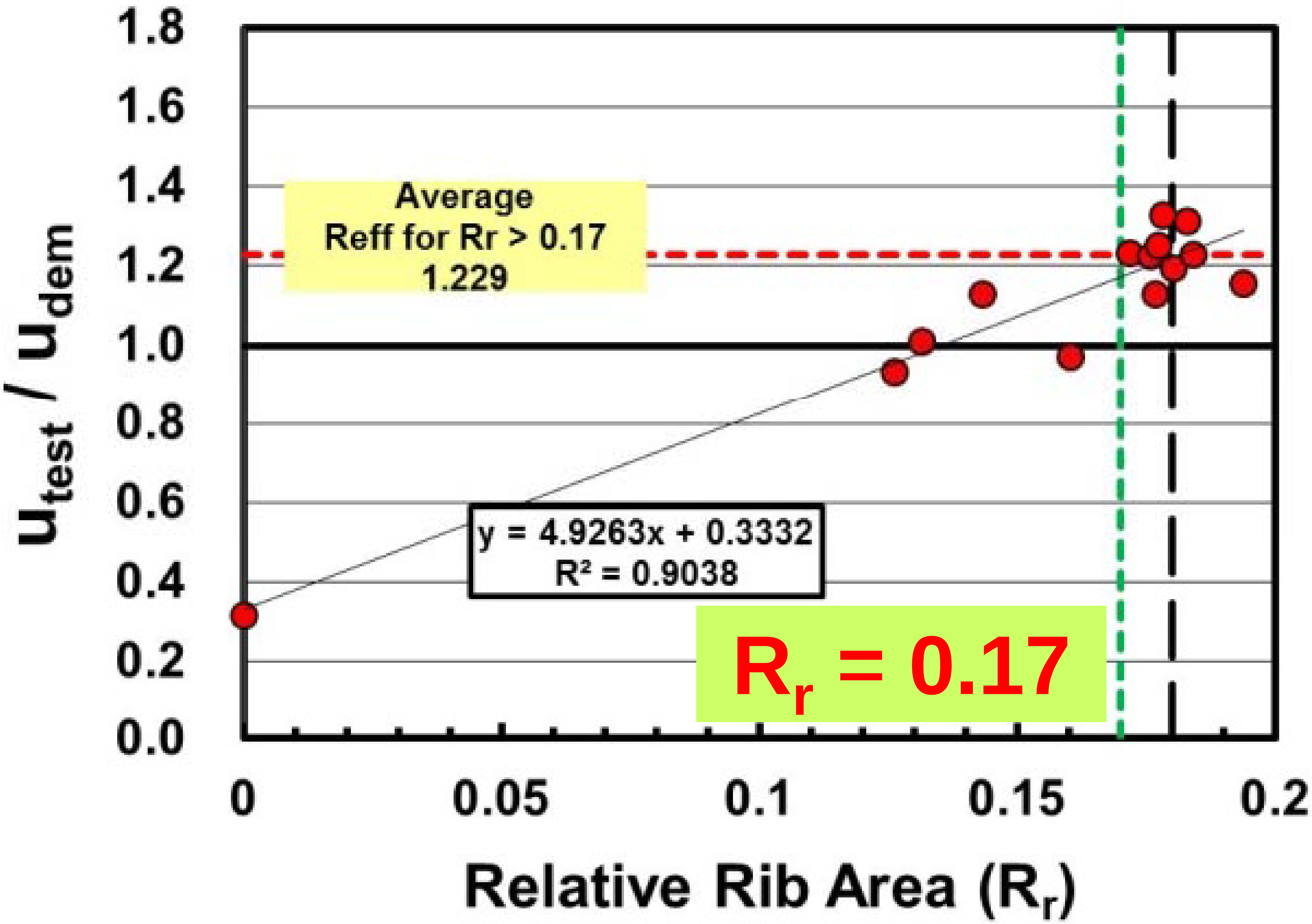


u_{test}/u_{dem}



$$u_{dem} = \frac{A_b \times f_s}{\pi \times d_b \times \ell_d} = \frac{\frac{\pi d_b^{\,2}}{4} \times f_s}{\pi \times d_b \times \frac{0.9 f_s \times d_b}{\sqrt{f_{ca}^{'}}\left(\frac{c_b + K_{tr}}{d_b}\right)}} = \frac{\sqrt{f_{ca}^{'}}\left(\frac{c_b + K_{tr}}{d_b}\right)}{3.6} = \frac{(1 \sim 2.5)\sqrt{f_{ca}^{'}}}{3.6}$$

Bond Stress



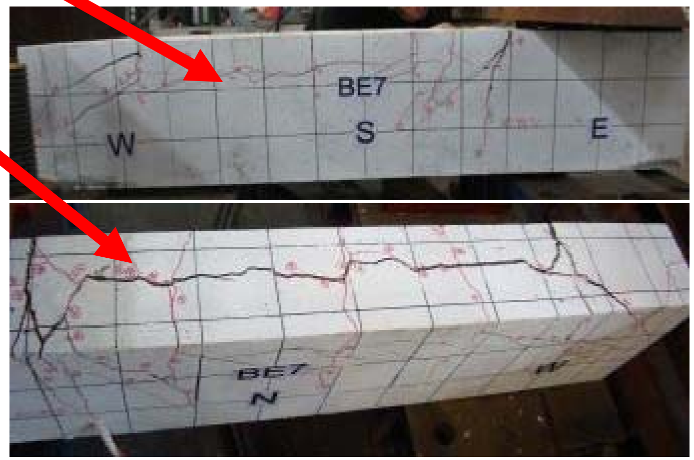
NCREE

Test Results – Splitting (I)

Specimen (n_b = 1)		$\frac{c_b + K_{tr}}{d_b}$ Top cover	$\frac{c_b + K_{tr}}{d_b}$ Side cover	Splitting Top cover	Splitting Side cover
R_r = 0.143	BE1 – BE3	3.64	4.22	■	—
R_r = 0.126	BE7 – BE9	2.94	3.29	■	■

BE1 – BE3

BE7 – BE9



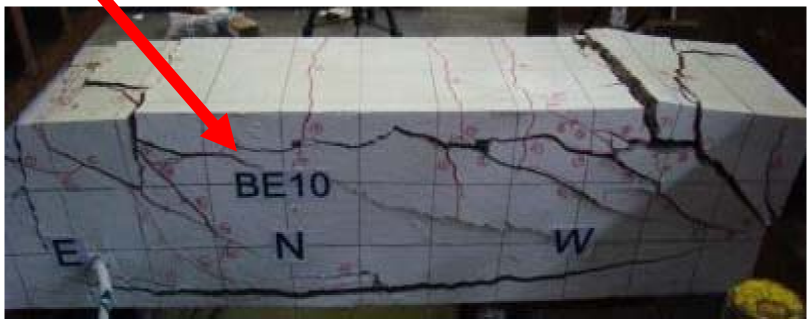
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 3.65$$ is a upper bound for splitting

Test Results – Splitting (I)

	Specimen (n_b = 2)	$\frac{c_b + K_{tr}}{d_b}$			Splitting	
		Top cover	Side cover	Bar spacing	Top	Side
R_r = 0.143	**BE4**	4.64	4.63	4.03	—	—
R_r = 0.126	**BE10**	3.73	3.65	3.58	—	■

BE4

BE10

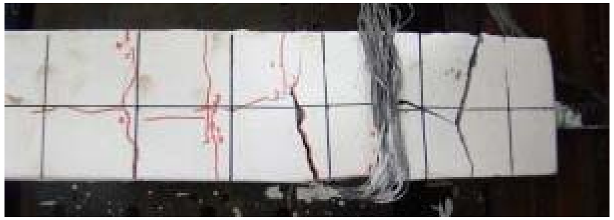


$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 3.65$$ is a upper bound for splitting

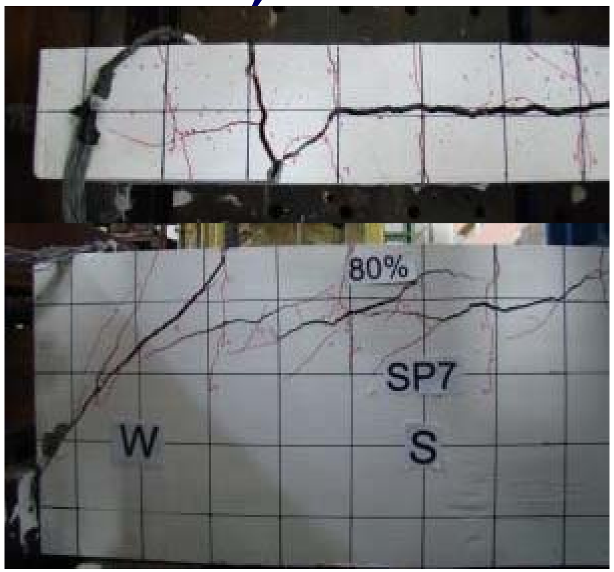
Test Results – Splitting (II)

	Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
		Top cover	Side cover	Top cover	Side cover
R_r = 0.13, 0.18	SP1 – SP6	3.36	3.43	■	■
R_r = 0.16	SP7 – SP8 SP11 – SP12	2.72	2.78	■	■

SP1-SP6



SP7-SP8, SP11-SP12



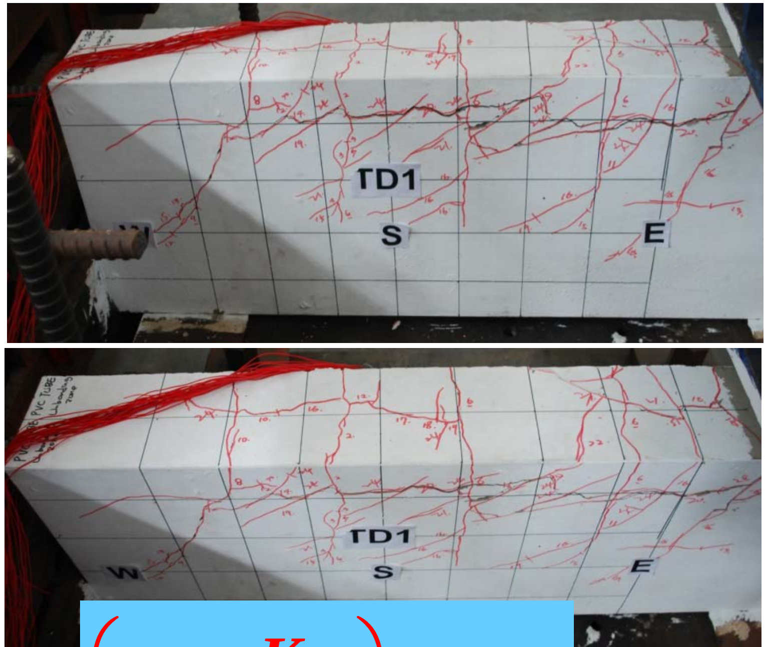
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 3.65$$

is a upper bound for splitting

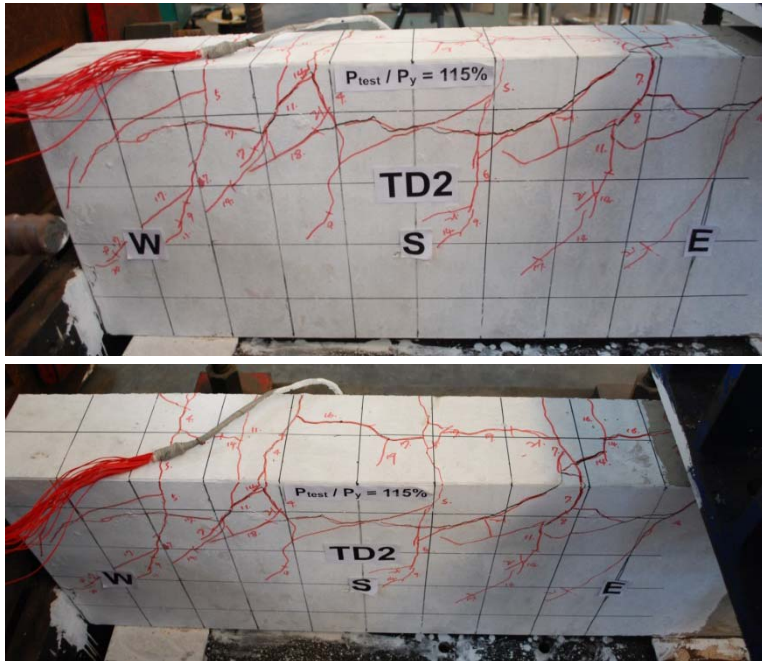
Test Results – Splitting (II)

Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
	Top cover	Side cover	Top cover	Side cover
R_r = 0.18 TD1 – TD2	3.34	3.41	■	■

TD1



TD2



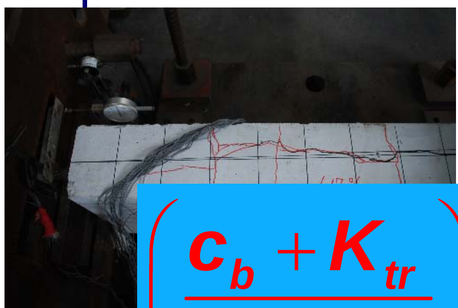
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 3.65$$ is a upper bound for splitting

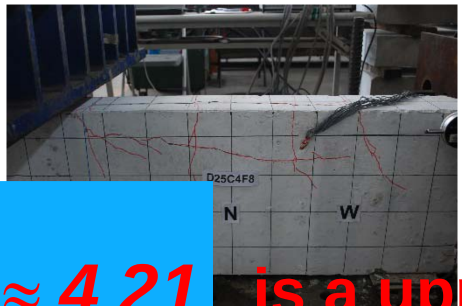
Test Results – Splitting (III)

R_r = 0.194

Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
	Top cover	Side cover	Top cover	Side cover
D25C4F56	3.84	4.21	■	■
D25C4F8	3.84	4.21	■	
D25C4F10	3.84	4.21	■	■
D25C7F8	5.04	4.21		■

D25C4F8





D25C7F8

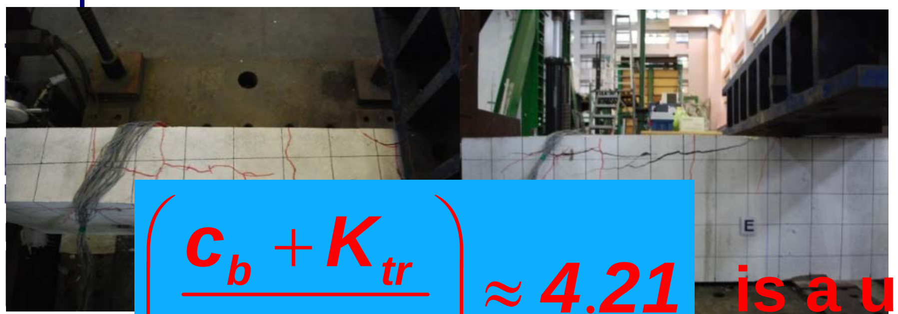
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 4.21$$ is a upper bound to occur splitting

Test Results – Splitting (III)

Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
	Top cover	Side cover	Top cover	Side cover
D32C4F56	3.11	3.29	■	■
D32C4F8	3.11	3.29	■	■
D32C4F10	3.11	3.29		■
D32C7F8	4.05	3.29		■

$R_r = 0.172$

D32C4F10



D32C7F8

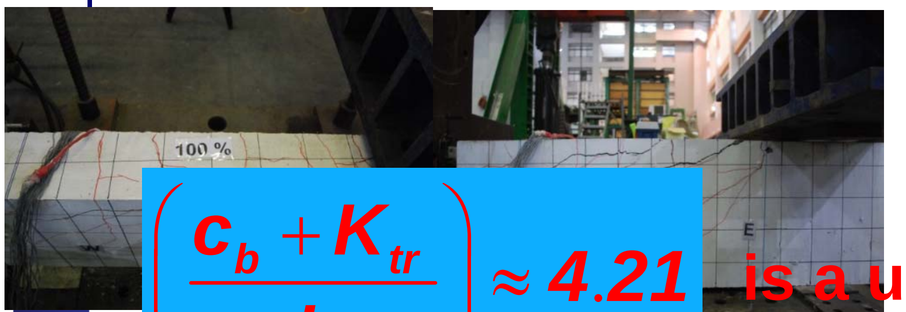
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 4.21$$ is a upper bound to occur splitting

Test Results – Splitting (III)

Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
	Top cover	Side cover	Top cover	Side cover
D35C4F56	2.89	3.01	■	■
D35C4F8	2.89	3.01	■	■
D35C4F10	2.89	3.01		■
D35C7F8	3.74	3.01		■

R_r = 0.176

D35C4F10



D35C7F8

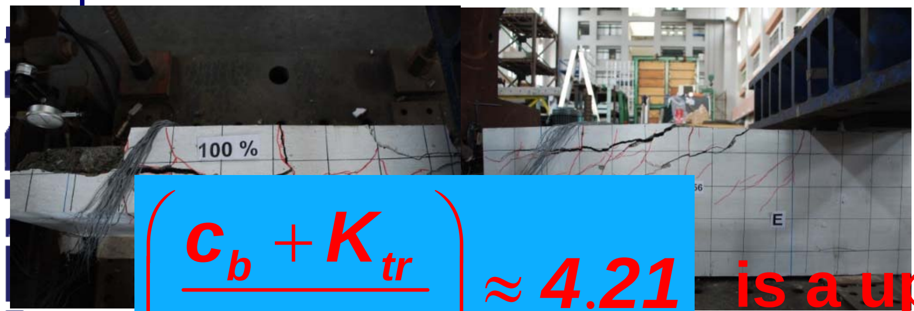
$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 4.21$$ is a upper bound to occur splitting

Test Results – Splitting (III)

Specimen	$\frac{c_b + K_{tr}}{d_b}$		Splitting	
	Top cover	Side cover	Top cover	Side cover
D38C4F56	2.70	2.77	■	■
D38C4F8	2.70	2.77	■	■
D38C4F10	2.70	2.77	■	■
D38C7F8	3.49	2.77		■

$R_r = 0.178$

D38C4F56



D38C7F8

$$\left(\frac{c_b + K_{tr}}{d_b}\right) \approx 4.21$$ is a upper bound to occur splitting

Summary

Development length in tension following ACI 318 code (unit : SI)

$$l_d = 0.9 \frac{f_y}{\sqrt{f_c'}} \frac{1}{\left(\frac{c_b + k_{tr}}{d_b}\right)} d_b$$

- $f_y \leqq 685$ MPa
- $f_{yt} \leqq 420$ MPa
- $f_c' \leqq 100$ MPa

$$R_{r,ave} = \frac{h_r}{s_r} \geq 0.17$$

Limitations for Bond Equation

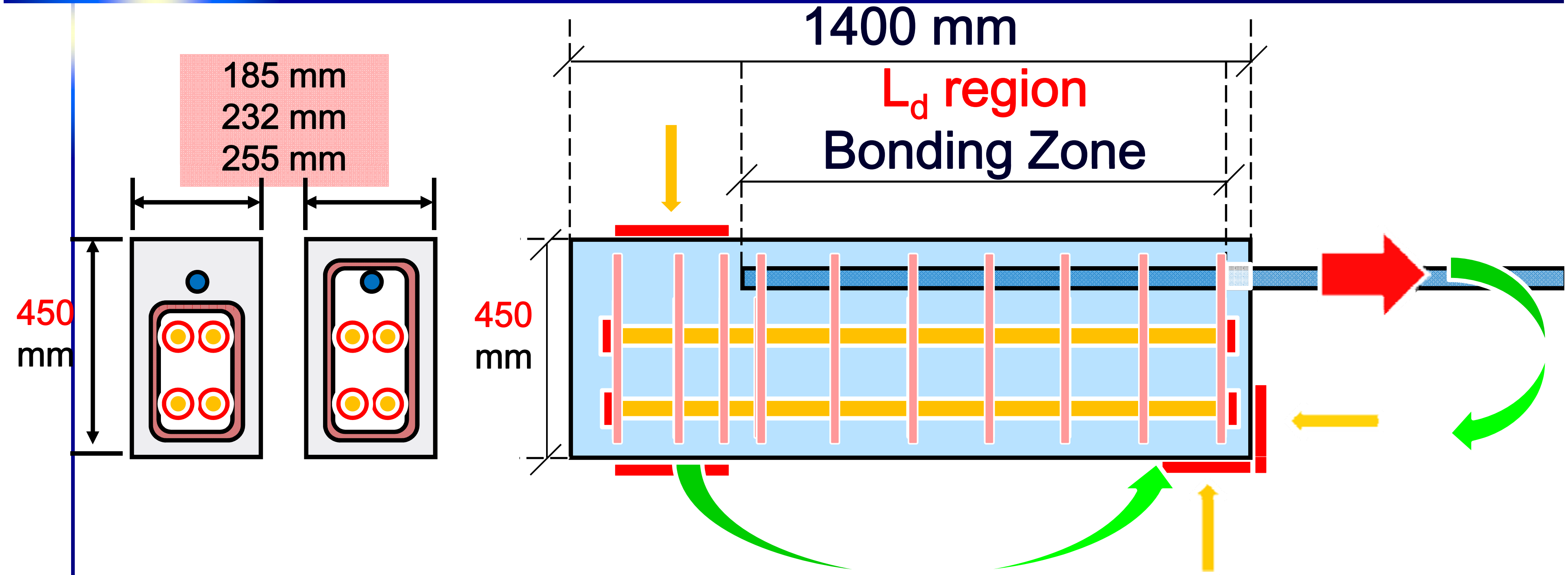
$$1.0 \leq \left(\frac{c_b + K_{tr}}{d_b}\right) \leq 2.5 \uparrow$$

?

$$l_d = 0.9 \frac{f_y}{\sqrt{f_c'}} \frac{1}{\left(\frac{c_b + k_{tr}}{d_b}\right)} d_b$$

NCREE

Design Variables of Specimens-2016



Design variables：24 sets

1. Bar size：D25, D32, D35
2. Geometry：Thread, Plain
3. f_c'：80 MPa
4. c_b / d_b : 2.5, 3.65, 4.0
5. s_s : 0, 200 mm, 100 mm

$$\frac{c_{b,t}+K_{tr}}{d_b}=2.5, 3.65, 4.0, 4.5$$

$$\frac{c_{b,s}+K_{tr}}{d_b}=3.65, 4.0, 4.5, 5.0, 5.5$$

NCREE

Design of Specimens-2016

Spec.	Bar Type	$d_{b,b}$ (mm)	$C_{b,side}$ (mm)	$C_{b,side} / d_b$	$C_{b,top}$ (mm)	$C_{b,top} / d_b$	S_s (mm)	K_{tr} / d_b	$C_{b,side} + K_{tr} / d_b$	$C_{b,top} + K_{tr} / d_b$
D25C5F8-U	Thread	25	80	3.70	50	2.50	0	0	3.70	2.50
D25C8F8-U			80	3.70	80	3.70	0	0	3.70	3.70
D25C9F8-U			80	3.70	90	4.10	0	0	3.70	4.10
D25C5F8-S20			80	3.70	50	2.50	200	2.53	4.71	3.51
D25C8F8-S20			80	3.70	80	3.70	200	2.53	4.71	4.71
D25C5F8-S10			80	3.70	50	2.50	100	5.07	5.73	4.53
D32C6.5F8-U		32	100	3.63	65	2.53	0	0	3.63	2.53
D32C10F8-U			100	3.63	100	3.63	0	0	3.63	3.63
D32C11F8-U			100	3.63	110	3.94	0	0	3.63	3.94
D32C6.5F8-S20			100	3.63	65	2.53	200	2.53	4.42	3.32
D32C10F8-S20			100	3.63	100	3.63	200	2.53	4.42	4.42
D32C6.5F8-S10			100	3.63	65	2.53	100	5.07	5.21	4.11
D35C7F8-U		35	110	3.64	70	2.50	0	0	3.64	2.50
D35C11F8-U			110	3.64	110	3.64	0	0	3.64	3.64
D35C12F8-U			110	3.64	120	3.93	0	0	3.64	3.93
D35C7F8-S20			110	3.64	70	2.50	200	2.53	4.37	3.22
D35C11F8-S20			110	3.64	110	3.64	200	2.53	4.37	4.37
D35C12F8-S10			110	3.64	120	2.50	100	5.07	5.09	3.95
D25C5F8-UP	Plain	25	80	3.70	50	2.50	0	0	3.70	2.50
D25C5F8-S20P			80	3.70	50	2.50	100	0	3.70	2.50
D32C6.5F8-UP		32	100	3.63	65	2.53	0	0	3.63	2.53
D32C6.5F8-S20P			100	3.63	65	2.53	100	0	3.63	2.53
D35C7F8-UP		35	110	3.64	70	2.50	0	0	3.64	2.50
D35C7F8-S20P			110	3.64	70	2.50	100	0	3.64	2.50

Outlines

- Background
- Properties of Reinforcement
- Development Length of Reinforcement
- **Development of Standard Hooks**
- Development of Headed Bars

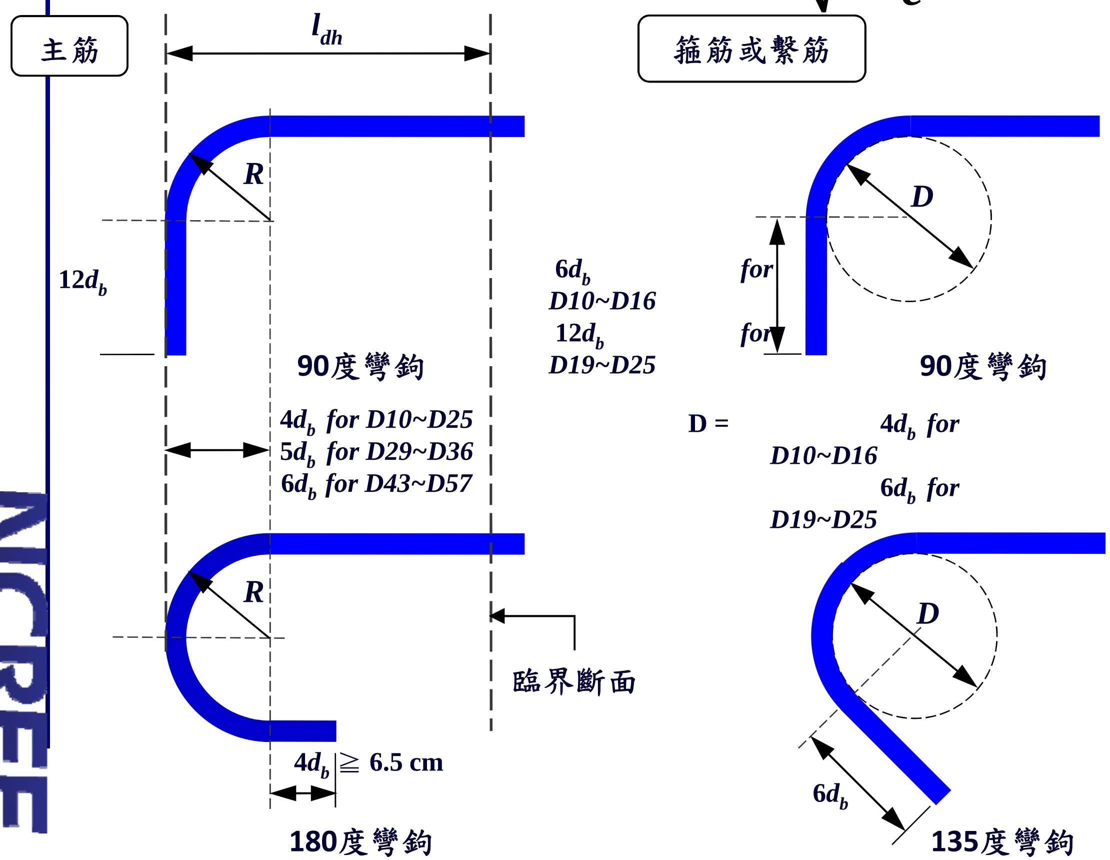
NCREE

Development of Standard Hooks

Section 8.1.3

Development length in tension following ACI 318 code (unit : SI)

$$l_{dh} = 0.24\frac{f_y \psi_e \lambda}{\sqrt{f_c'}} d_b \geq 0.043 f_y d_b$$



Limitations for Bond Equation

- f_y ≦ 685 MPa
- f_{yt} ≦ 420 MPa
- f_c' ≦ 100 MPa
- 彎鉤不計受壓

修正因子詳設計手冊之表8-3

Outlines

- Background
- Properties of Reinforcement
- Development Length of Reinforcement
- Development of Standard Hooks
- **Development of Headed Bars**

NCREE

Introduction of T-Head Bars

銲接式錨定頭鋼筋

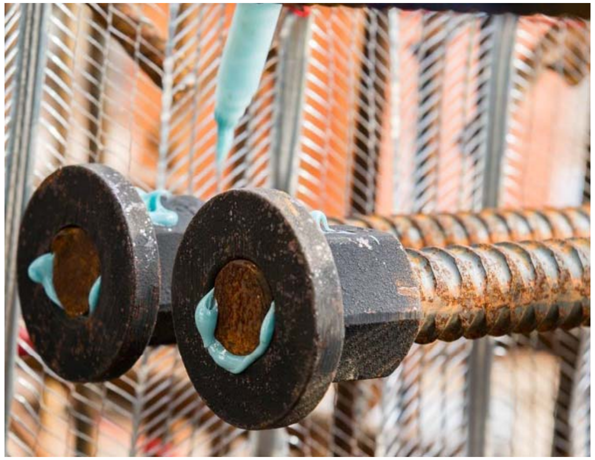
(東和鋼鐵)

銲接螺紋式錨定頭鋼筋

熱軋擴頭式錨定頭鋼筋

(日本DHF)

灌漿式套筒錨定頭鋼筋



(日本TTK)

NCREE

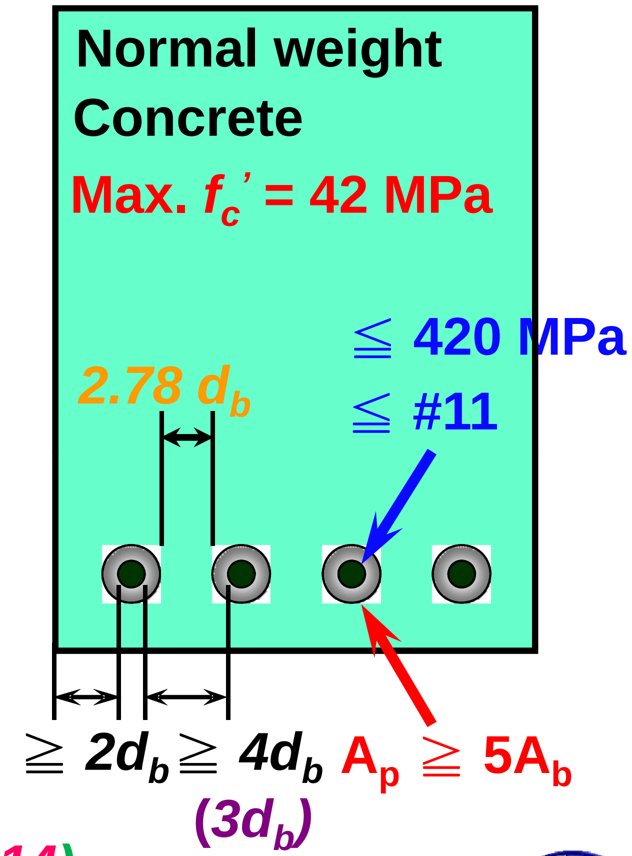
Related Provisions for Headed Bars

ACI 318-14 (2011, 2014)

25.4.4 Development of headed deformed bars in tension

25.4.4.1

(a) Bar shall conform to ASTM Rebar;
(b) Bar f_y shall not exceed 60,000 psi;
(c) Bar size shall not exceed No. 11;
(d) Concrete shall be normal weight;
(e) Net bearing area of head A_{brg} shall not be less than $4A_b$;
(f) Clear cover for bar shall not be less than $2d_b$;
(g) Clear spacing between bars shall not be less than $4d_b$.



18.8.5.2 (Earthquake-Resistant Structures, 2014)
clear spacing between bars shall be permitted to be at least $3d_b$ or greater.

Related Provisions for Headed Bars

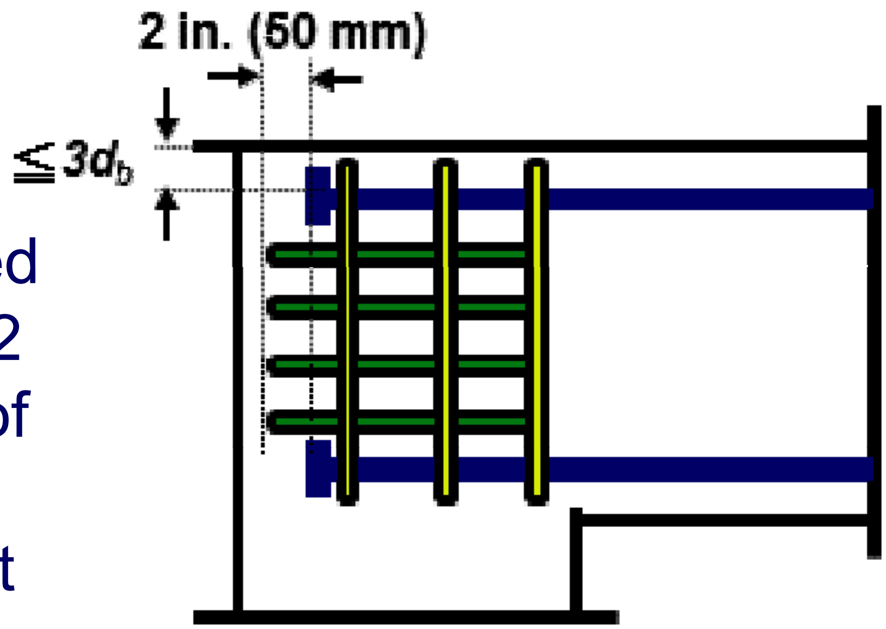
ACI 352-02 (2002)

4.5.3 Headed bars terminating in the connection

(a) Net bearing area of head A_{brg} shall not be less than $9A_b$ (ASTM A970-97).

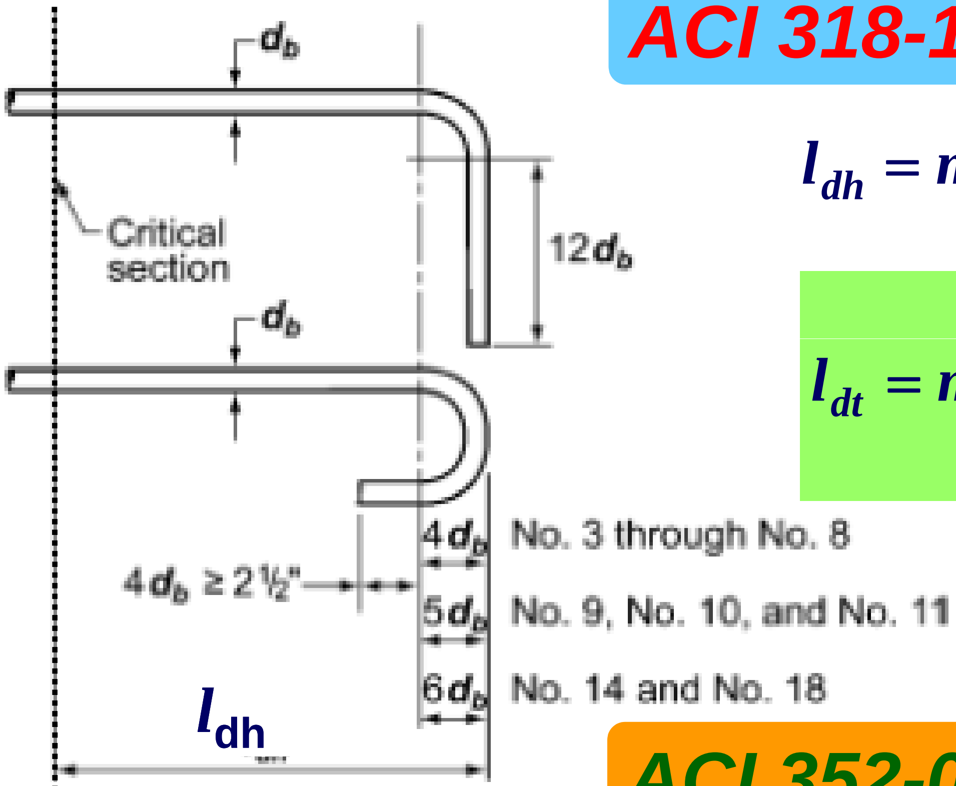
(b) Bar heads should be located in the confined core within 2 in. (50 mm) from the back of the confined core.

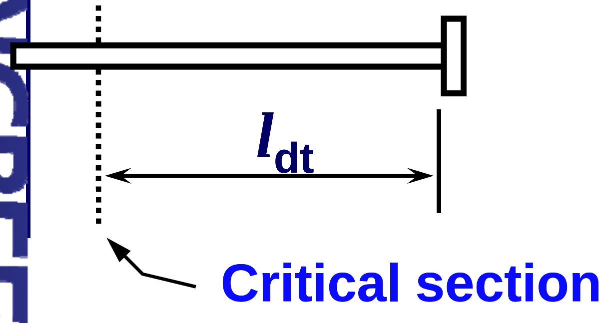
(c) Clear cover for bar shall not be less than $3d_b$, otherwise transversely restrained stirrup or hoop leg is needed.



NCREE

Development Length of L_{dh} and L_{dt}





ACI 318-14

$$l_{dh} = max\left\{0.24\frac{f_y}{\sqrt{f_c'}}d_b\ ,8d_b\ ,150mm\right\}$$

$$l_{dt} = max\left\{0.19\frac{f_y}{\sqrt{f_c'}}d_b\ ,8d_b\ ,150mm\right\}$$

$$L_{dt} = 0.8\ L_{dh} \quad (\,ACI\ 318-14\,)$$

$$L_{dt} = 0.75\ L_{dh} \quad (\,ACI\ 352-02\,)$$

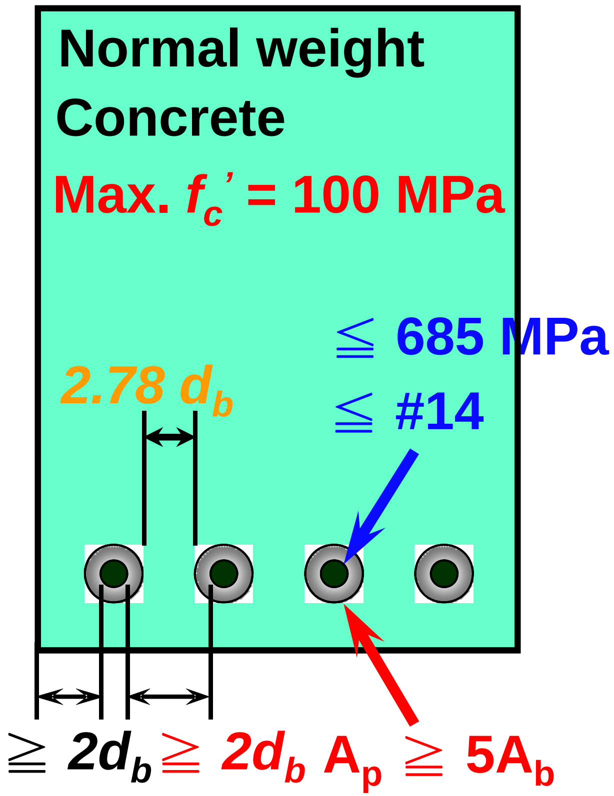
ACI 352-02

$$l_{dh} = max\left\{0.16\frac{f_y}{\sqrt{f_c'}}d_b\ ,8d_b\ ,150mm\right\}$$

$$l_{dt} = max\left\{0.12\frac{f_y}{\sqrt{f_c'}}d_b\ ,8d_b\ ,150mm\right\}$$

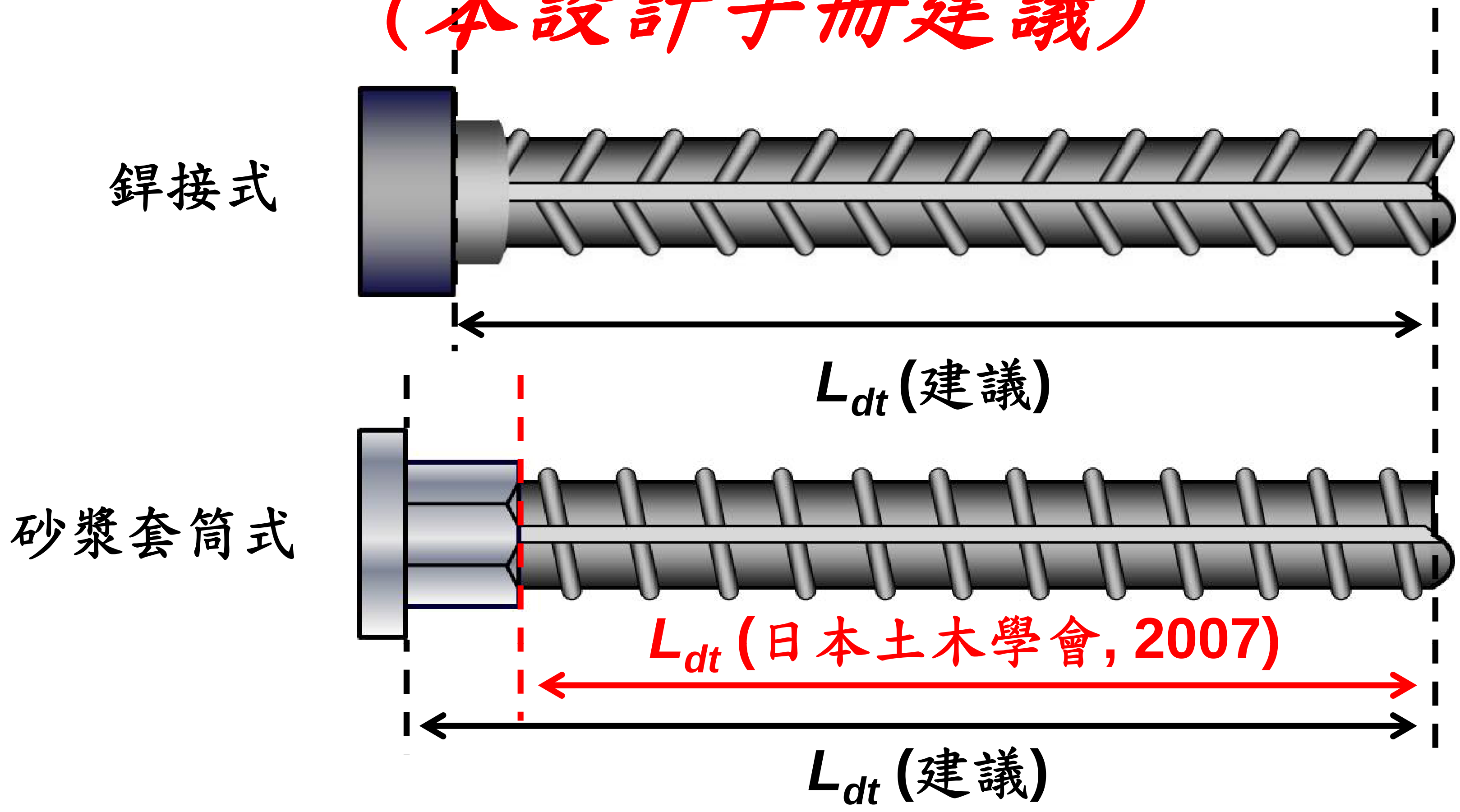
Development of Headed Bars in Tension (本設計手冊建議)

(a) f_y shall not exceed 6850 kgf/cm^2;
(b) Bar size shall not exceed No. 14;
(c) Net bearing area of head A_{brg} shall not be less than $4A_b$;
(d) Clear cover for bar shall not be less than $2d_b$;
(e) Clear spacing between bars shall not be less than $2d_b$;
(f) Concrete shall be normal weight;
(g) f_c' shall not exceed 1000 kgf/cm^2;



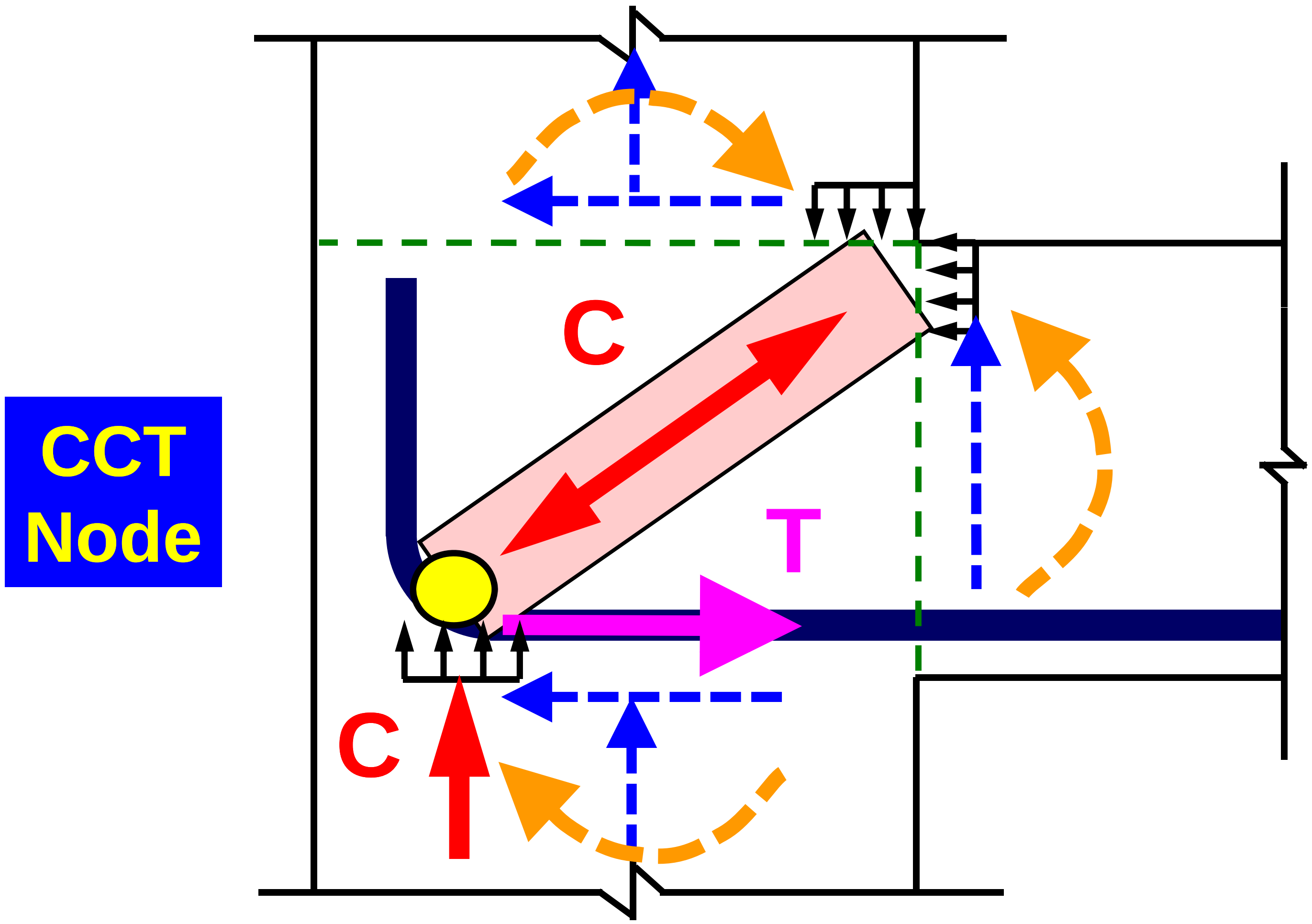
Development Length of L_{dt}

（本設計手冊建議）



$$L_{dt} = max\left\{0.19\frac{f_y}{\sqrt{f_c'}}d_b\ ,\ 8d_b\ ,\ 150mm\right\}$$

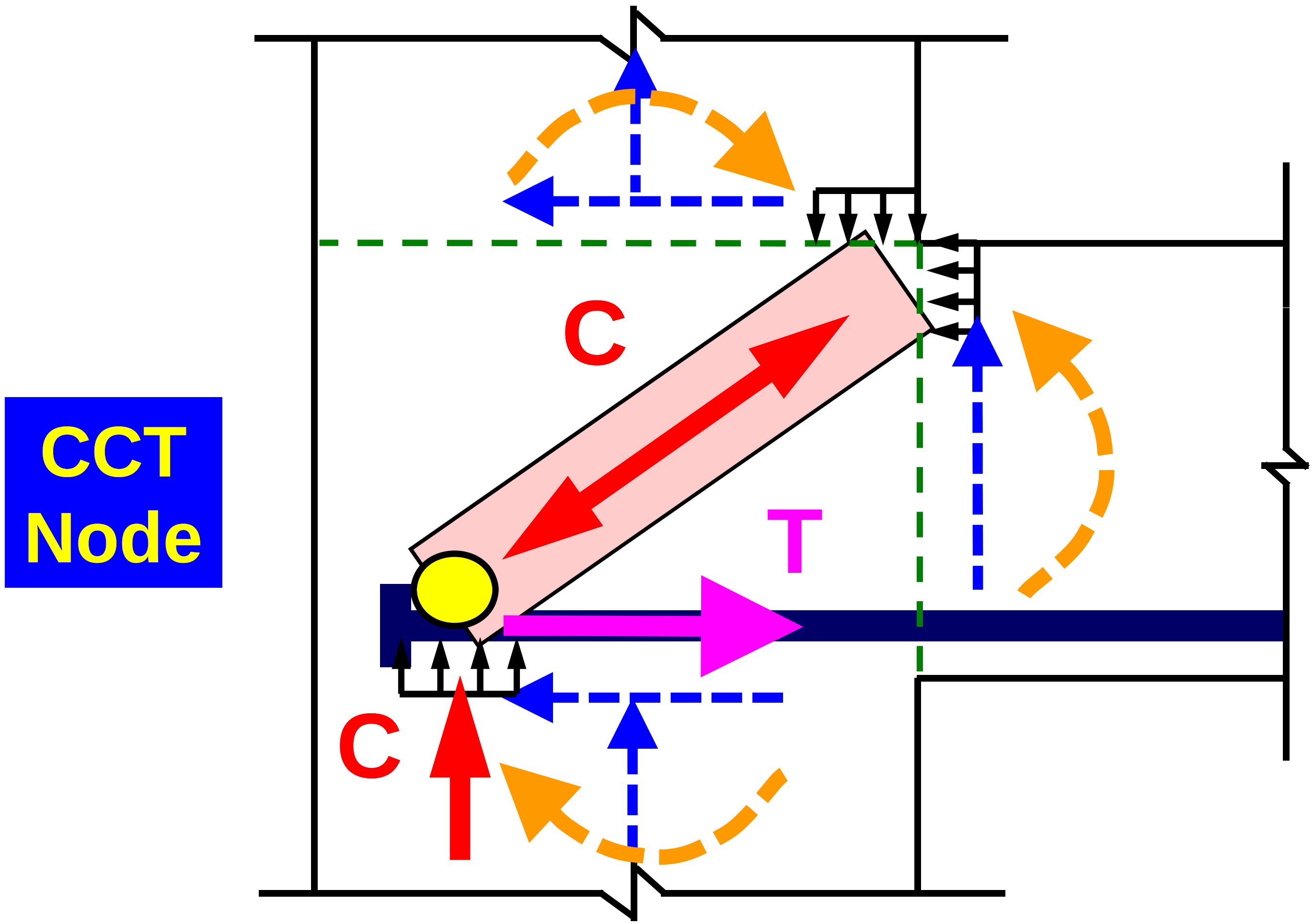
Force Mechanism of Hook



C：Compression

T：Tension

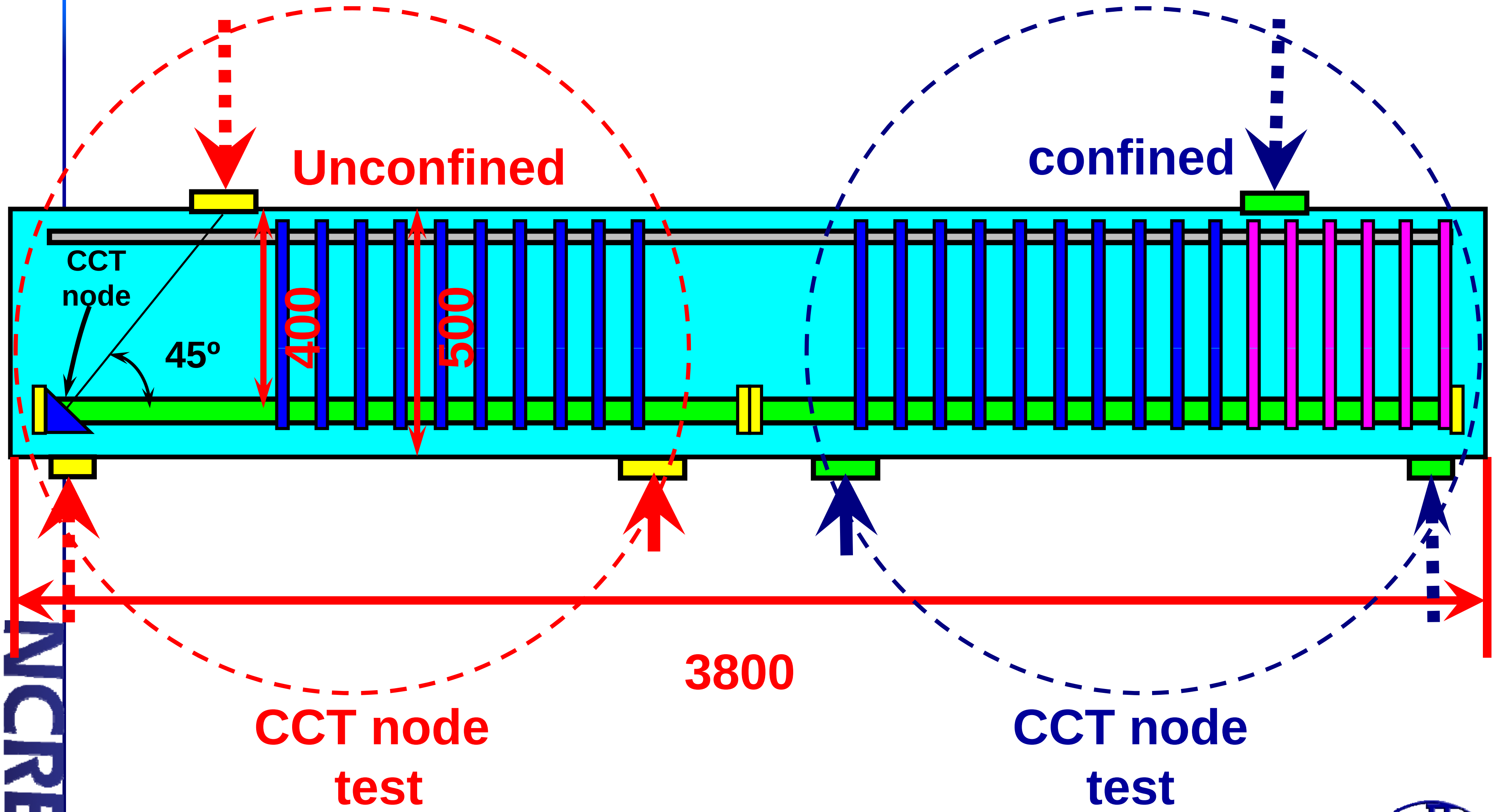
Force Mechanism of T-Head



C：Compression

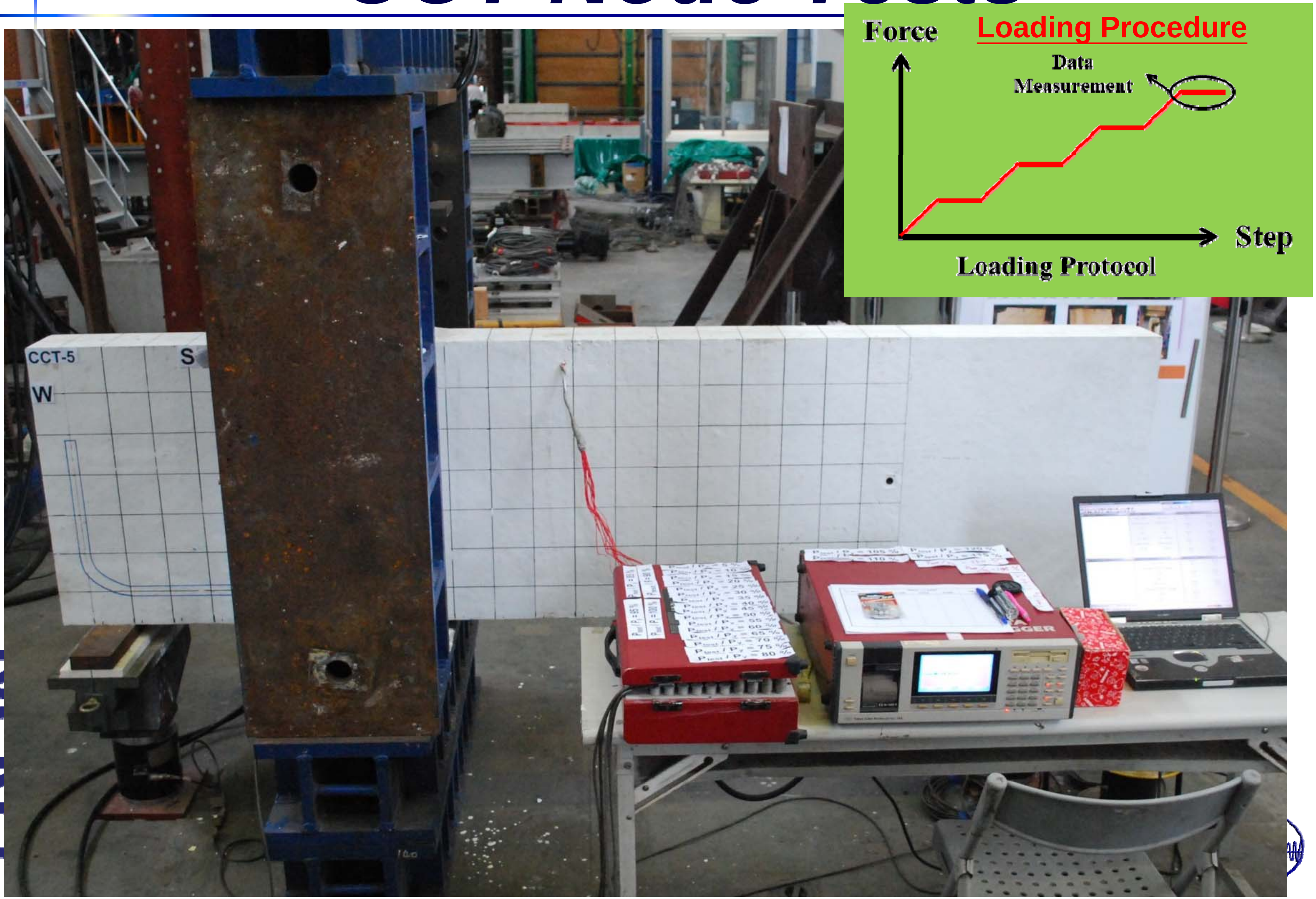
T：Tension

Experimental Program (CCT Node)



Units : mm

CCT Node Tests



Design Variables of Specimens (I)

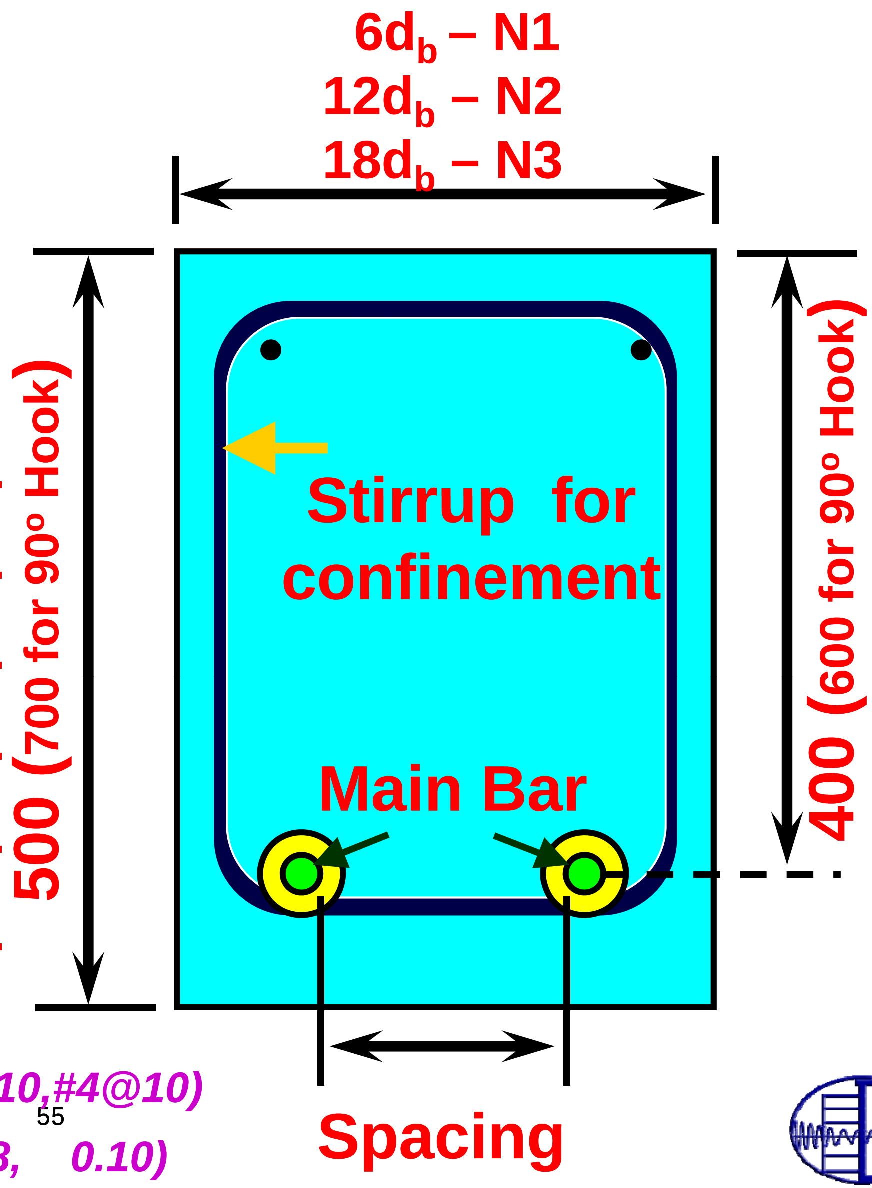
紀凱甯 - 2010

Number of Specimens:

- *43*

Variables:

Type	*Hook*(90°,180°) *Head*(no, yes)
Main bar	*#8,#10,#11*
A_p/A_b	*1,3,5,7*
No.of bar	*1,2,3*
Spacing	*1.5d_b,4d_b*
f_c'(MPa)	*42,56,70*
Confine	*no* *yes*(#3@20,#3@10,#4@10) (0.04, 0.08, 0.10)



Units : mm

Design Variables of Specimens (II)

紀凱甯 - 2014

CCT Node for Hooked

Unconfined

Confined

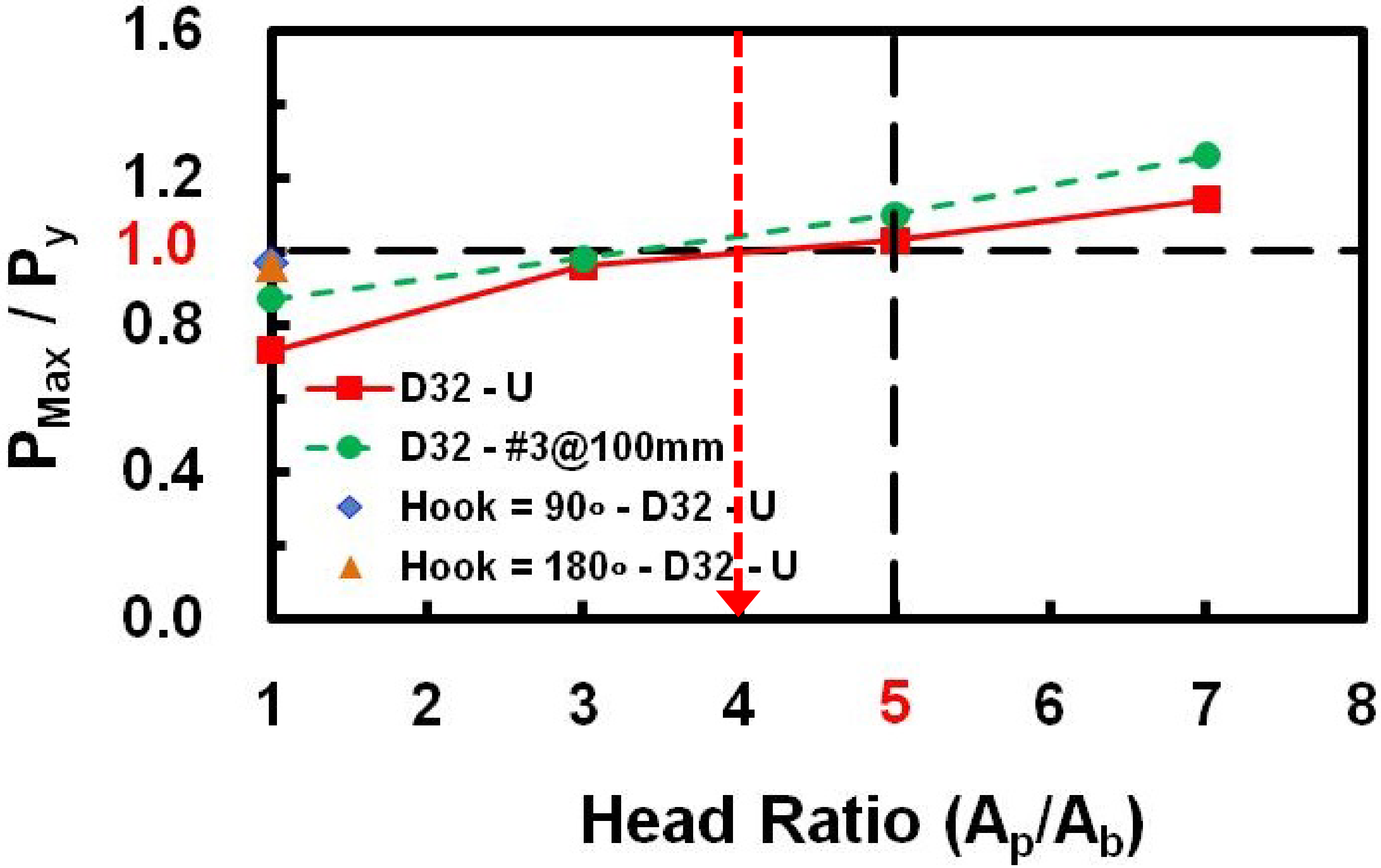
CCT Node for Headed

Unconfined

Confined

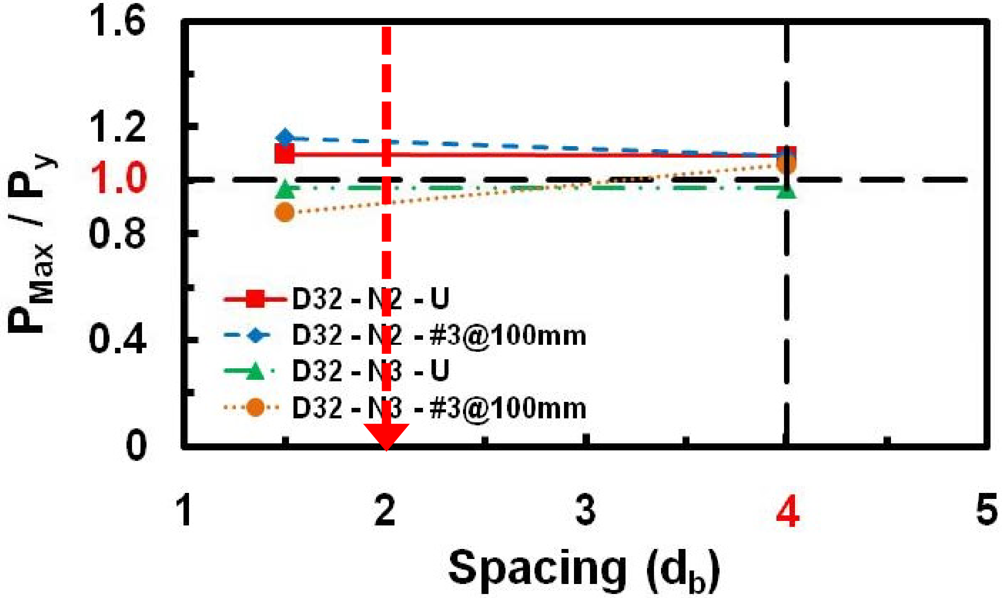
Spec.	Width B (mm)	Depth D (mm)	Bar d_b (mm)	Anchorage Type	f_y (MPa)	f_{yt} (MPa)	f_c' (MPa)	Confine (mm)
CCT-1	150	700	25	90º Hook	685	785	70	X
CCT-2	150	700	25	90º Hook	685	785	70	D10@100
CCT-3	150	700	25	Plate Nut	685	785	70	X
CCT-4	150	700	25	Plate Nut	685	785	70	D10@100
CCT-5	160	700	32	90º Hook	685	785	70	X
CCT-6	160	700	32	90º Hook	685	785	70	D10@100
CCT-7	160	700	32	Plate Nut	685	785	70	X
CCT-8	160	700	32	Plate Nut	685	785	70	D10@100

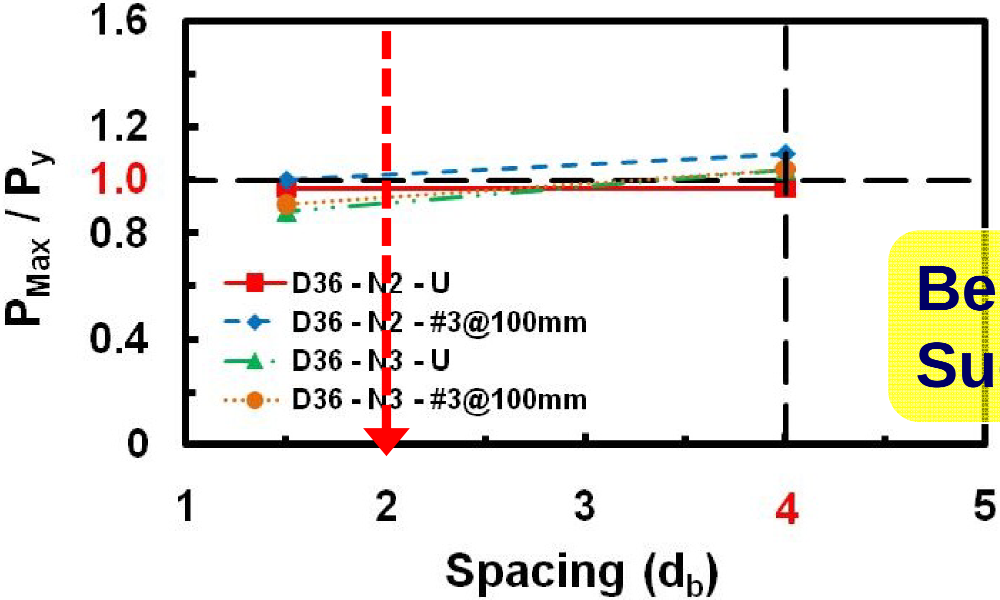
Anchorage Strength – Head Ratio (I)



Benefit：Hook → T head
Suggestion：T head ratio = 4

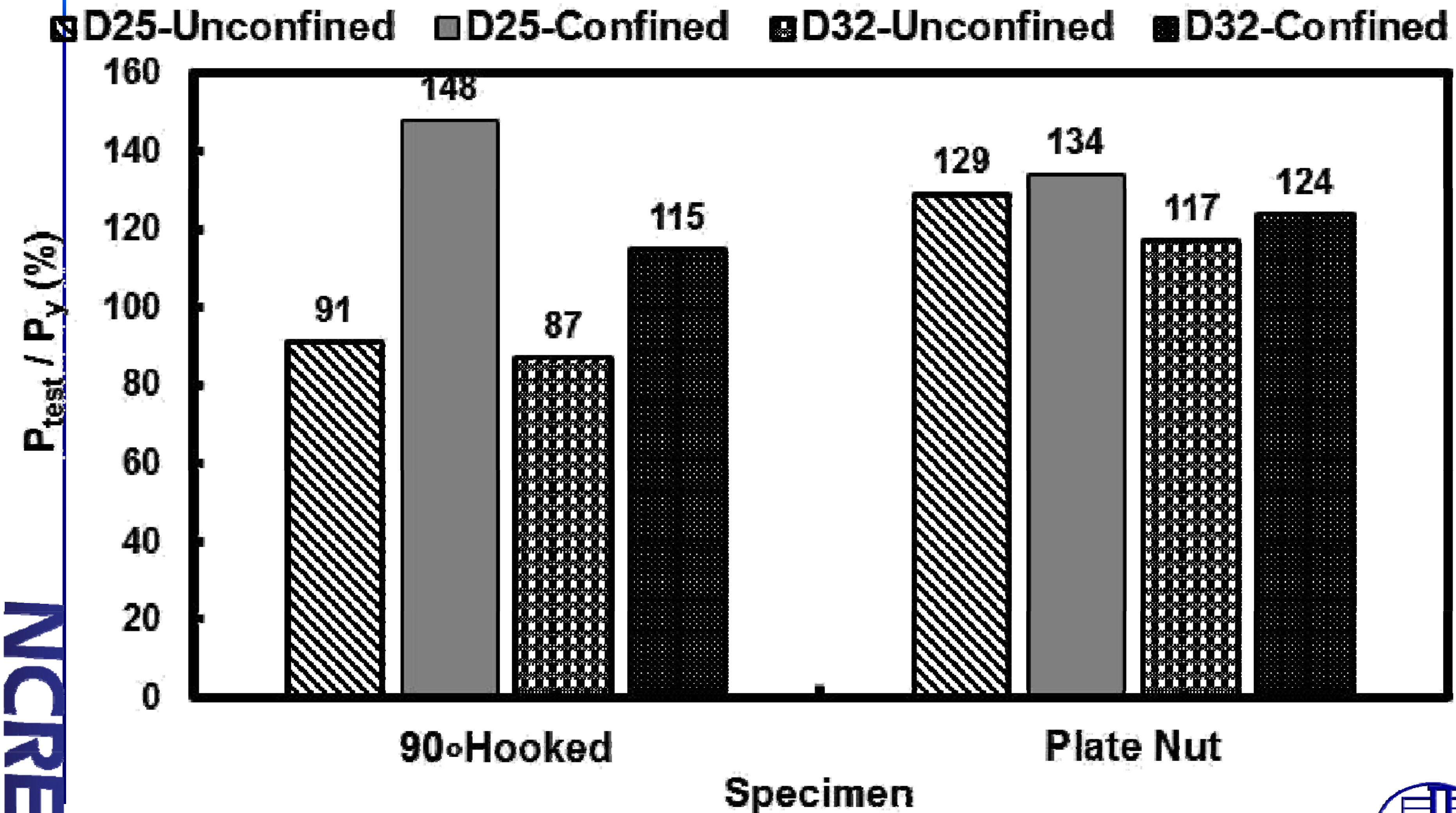
Anchorage Strength – Spacing of bars (I)





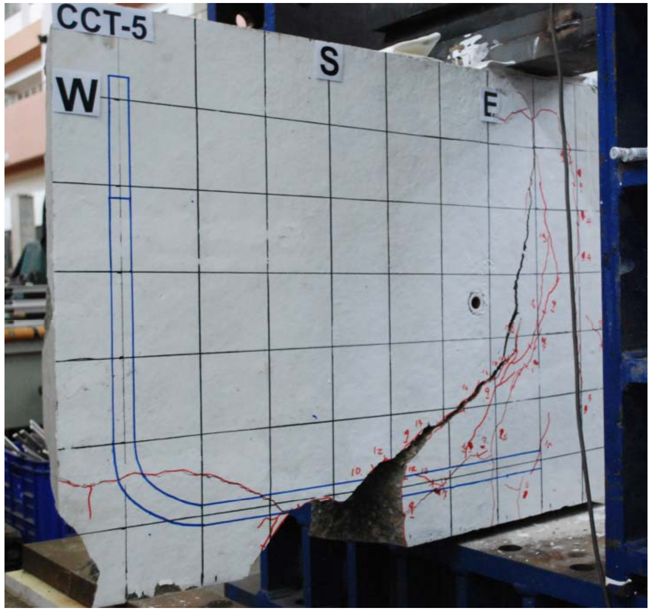
Benefit： break $4d_b$ limit
Suggestion：Spacing ≒ $2d_b$

Anchorage Strength (II)



Failure Modes

D32 – Unconfined



Hooked

Strut Failure

$P_{test} / P_y = 87\ \%$

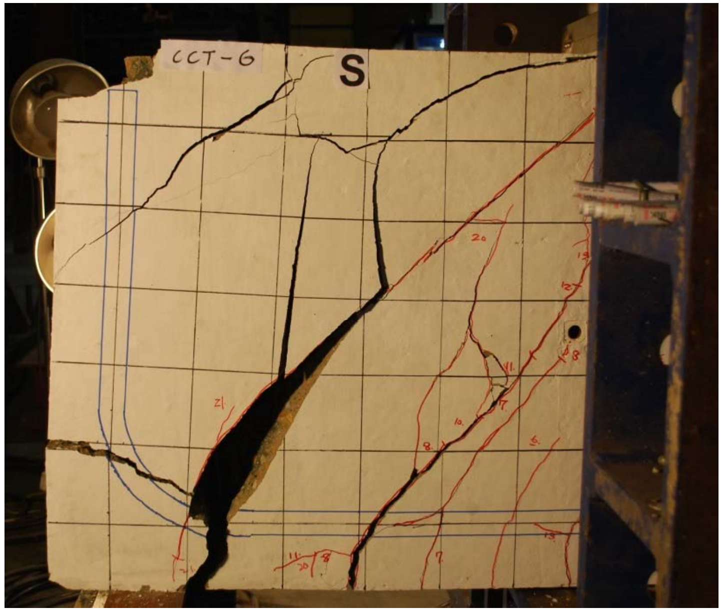
Headed

Flexural Failure

$P_{test} / P_y = 117\ \%$

Failure Modes

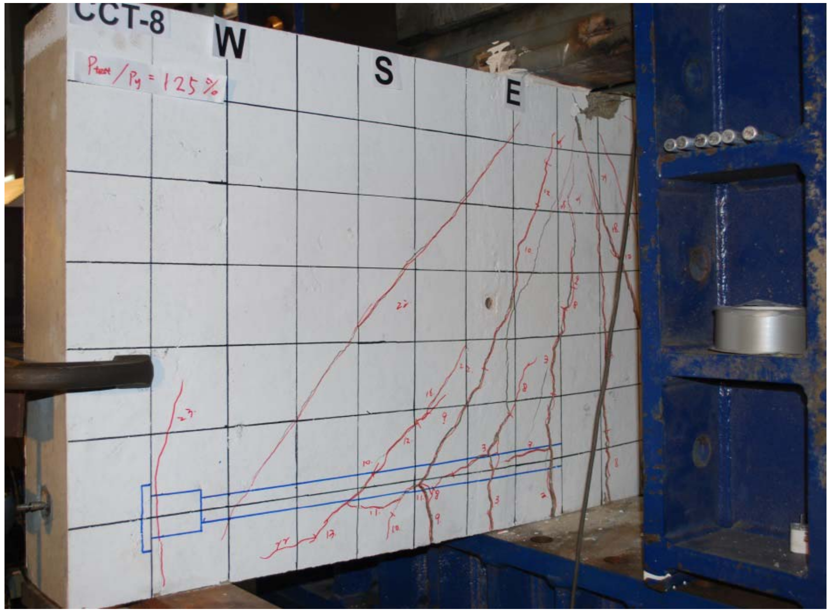
D32 – Confined



Hooked

Strut Failure

$P_{test} / P_y = 115\ \%$



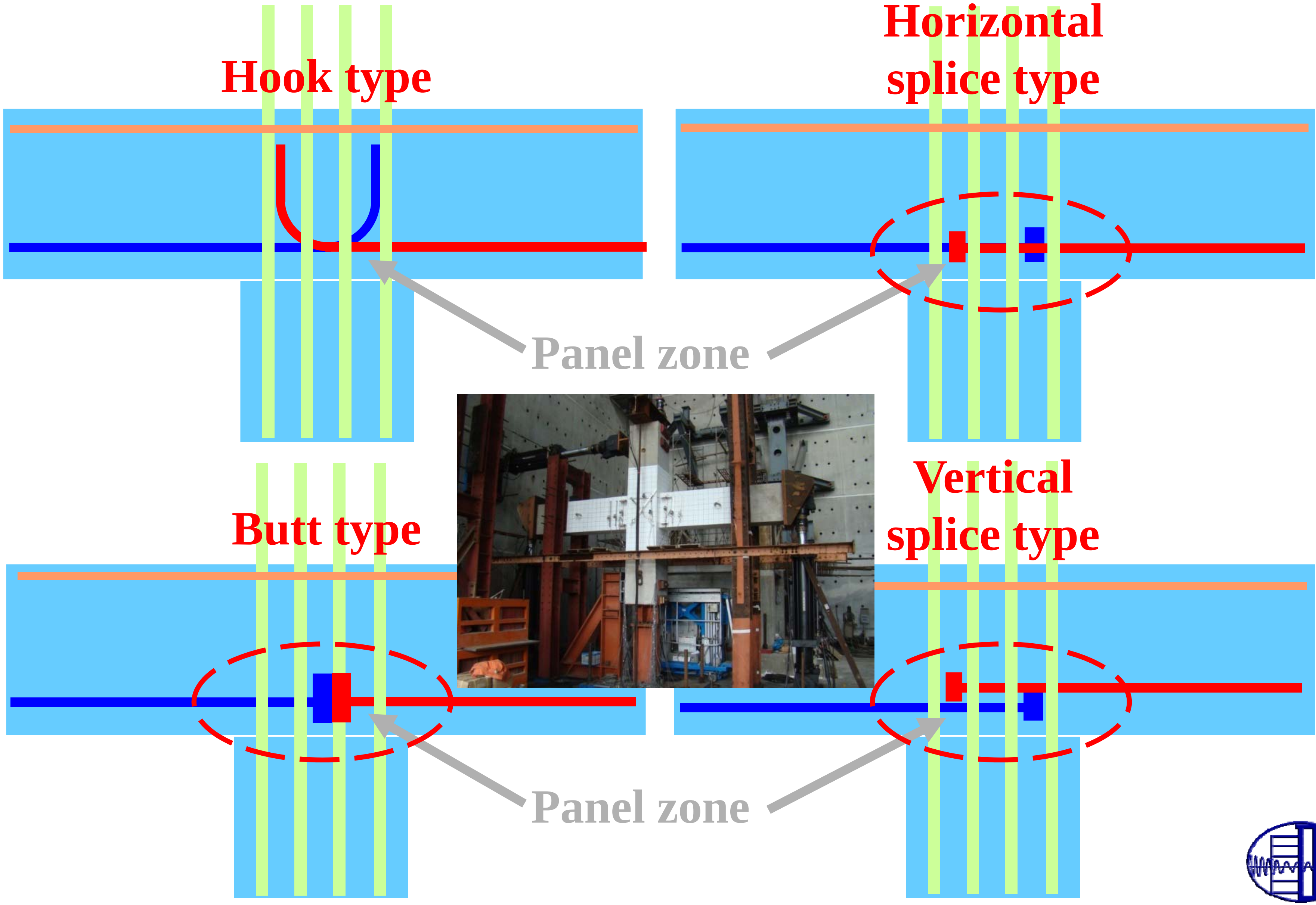
Headed

Flexural Failure

$P_{test} / P_y = 124\ \%$

NCREE

Precast Beam-Column Joints

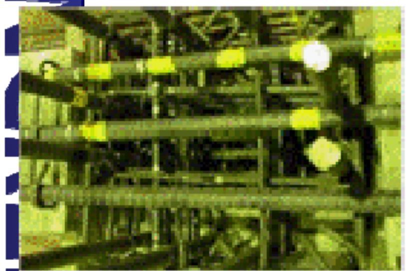


NCREE

Interior Beam-Column Joints

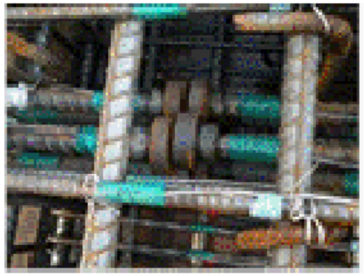
陳政宇、高文良 - 2010 、2012

Specimen Name	Seat	Beam Bar			Connection Type	Spacing of Rebar (d_b)	Materials				Member Strength		Development Length	
							Design		Actual				Design	
		Num	d_b (mm)	ρ (%)			f_c' (MPa)	f_y (MPa)	f_{ca}' (MPa)	f_{ya} (MPa)	ΣM_{nc} / ΣM_{nb}	$V_{jh,u}$ / V_n	**L_{dt} (mm)**	**L_{dt} / d_b**
JX5_4D_II_M	Top.	5	25	1.2	I	4.0	41.2	412	43.2	469	1.47	0.87	**650**	**25.6**
	Bot.				II								**528**	**20.8**
JX5_4D_III_M	Top.	5	25	1.2	I	4.0			42.3	469	1.47	0.87	**650**	**25.6**
	Bot.				III								**309**	**12.2**
JX6_2D_II_H	Top.	6	25	1.5	I	2.2			40.5	469	1.24	1.08	**650**	**25.6**
	Bot.				II								**528**	**20.8**
JX6_2D_III_H	Top.	6	25	1.5	I	2.2			46.3	469	1.26	1.01	**650**	**25.6**
	Bot.				III								**309**	**12.2**
JX4_2D_II_L	Top.	4	25	1.0	I	2.2			44.8	489	1.83	0.51	**650**	**25.6**
	Bot.				II								**528**	**20.8**
JX4_2D_III_L	Top.	4	25	1.0	I	2.2			44.4	489	1.83	0.64	**650**	**25.6**
	Bot.				III								**309**	**12.2**
JX8_2D_III_Uni	Top.	8	25	2.0	III	2.2			54.4	465	1.26	X	**309**	**12.2**
	Bot.	4		1.0	III								**309**	**12.2**



Type I

Type II



Type III

Exterior Beam-Column Joints

陳政宇、高文良 - 2010 、2012

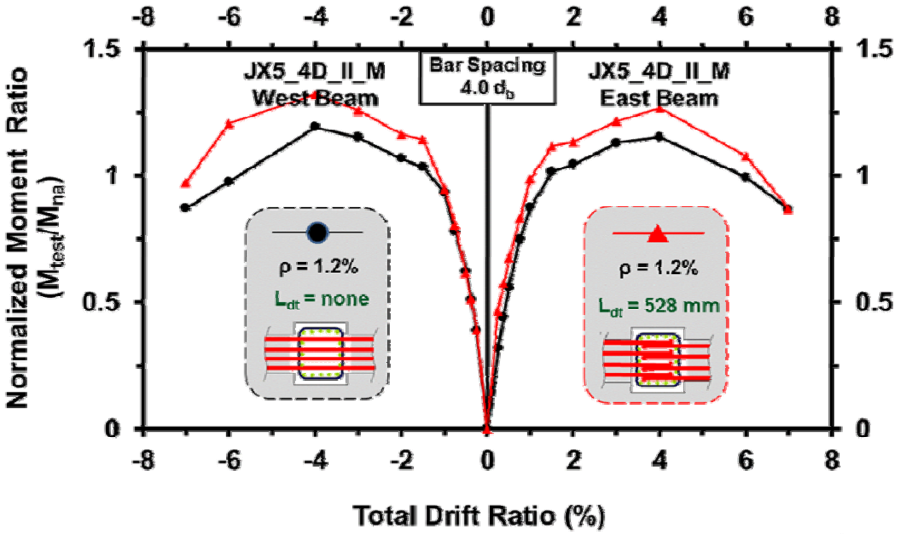
Specimen Name	Seat	Beam Bar			Connection Type	Spacing of Rebar (d_b)	Materials				Member Strength		Development Length	
							Design		Actual				Design	
		Num	d_b (mm)	ρ (%)			f_c' (MPa)	f_y (MPa)	f_{ca}' (MPa)	f_{ya} (MPa)	ΣM_{nc} / ΣM_{nb}	$V_{jh,u}$ / V_n	**L_{dt} (mm)**	**L_{dt} / d_b**
JT6_TB528_IV	Top.	6	25	1.5	IV	2.2			46.8	445	2.64	0.59	**528**	**20.8**
	Bot.				IV								**528**	**20.8**
JT6_TB528_V	Top.	6	25	1.5	V	2.2			49.4	445	2.66	0.58	**528**	**20.8**
	Bot.				V								**528**	**20.8**
JT6_T309B216_IV	Top.	6	25	1.5	IV	2.2	41.2	412	50.2	465	2.51	0.61	**309**	**12.2**
	Bot.				IV								**216**	**8.5**
JT6_T450B380_IV	Top.	6	25	1.5	IV	2.2			53.8	465	2.51	0.61	**450**	**17.7**
	Bot.				IV								**380**	**15.0**
JT6_TB309_IV	Top.	6	25	1.5	IV	2.2			50.0	465	2.51	0.61	**309**	**12.2**
	Bot.				IV								**309**	**12.2**

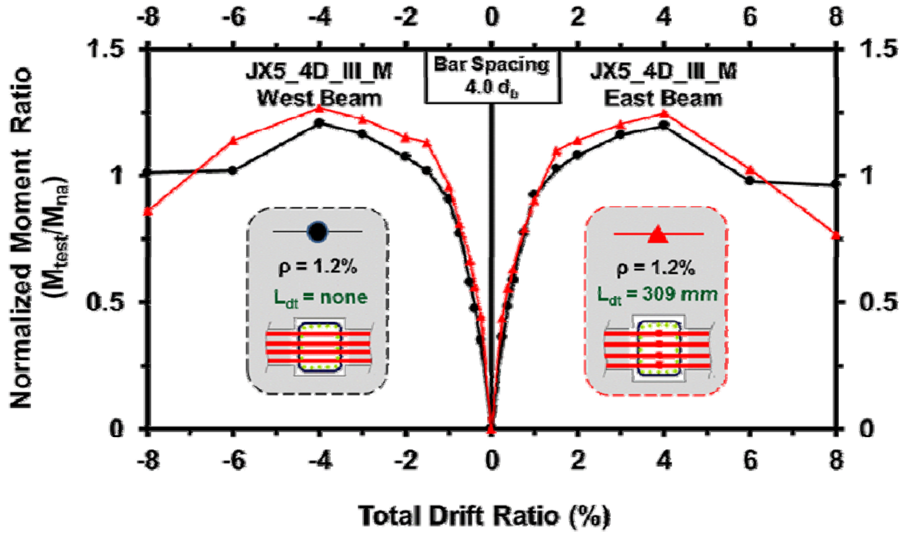
Type IV

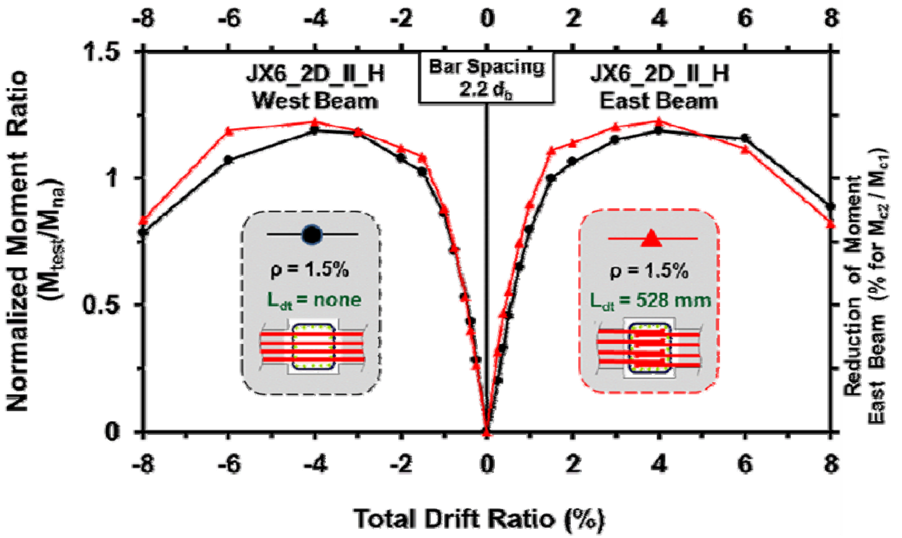
Type V

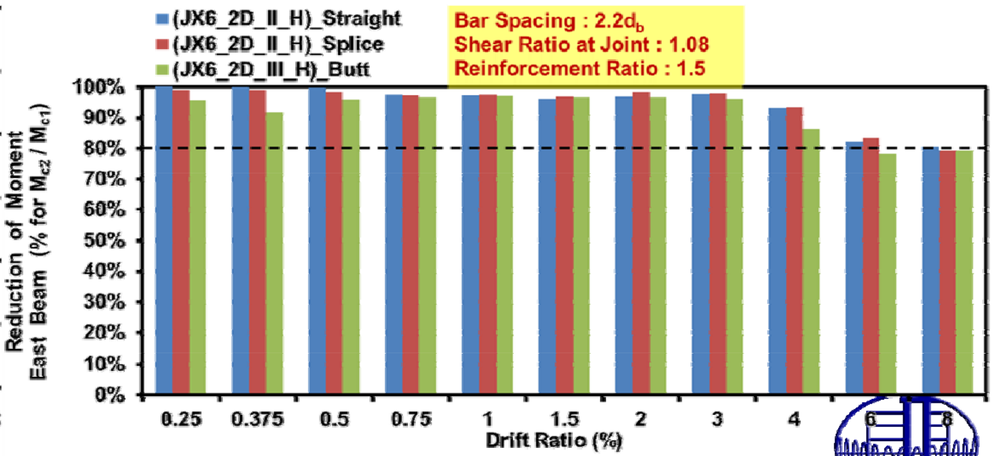
NCREE

Results for BC Joints Tests

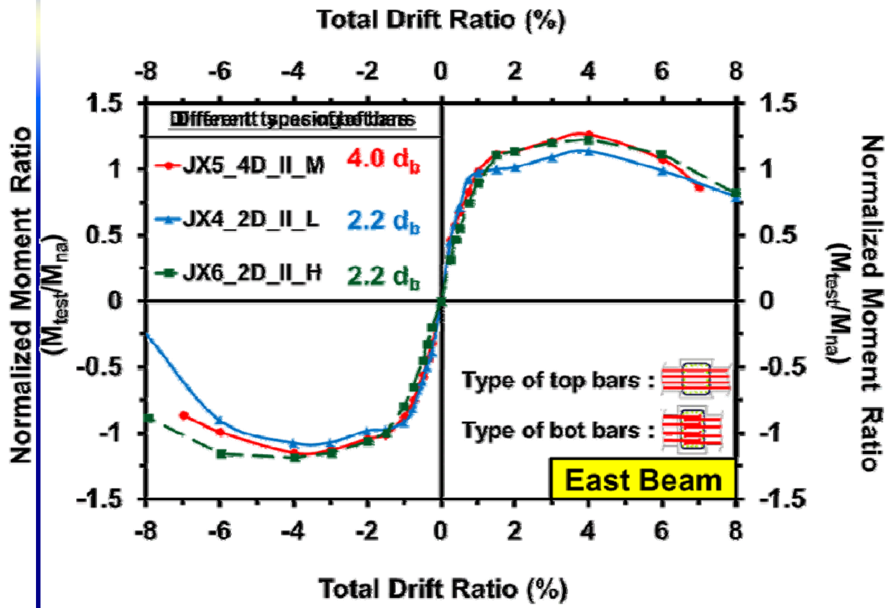


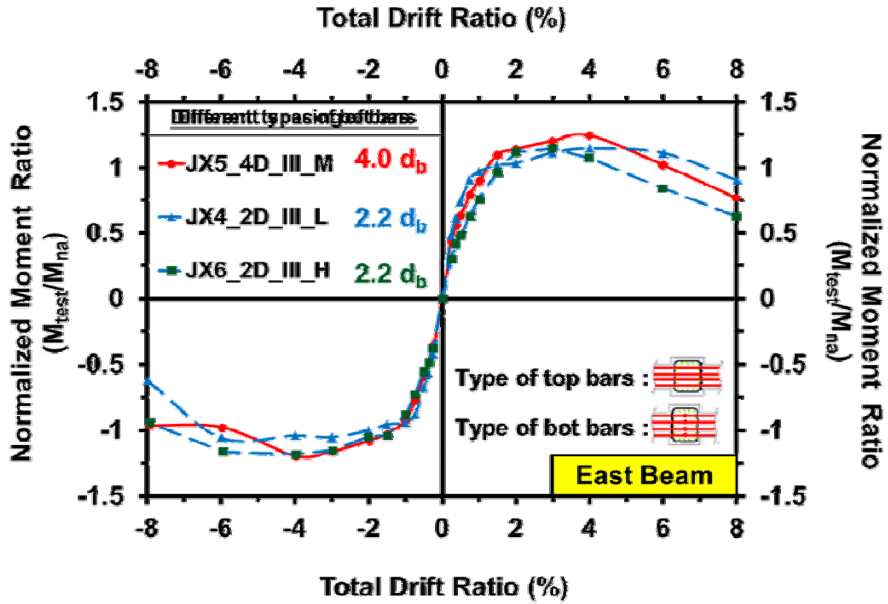


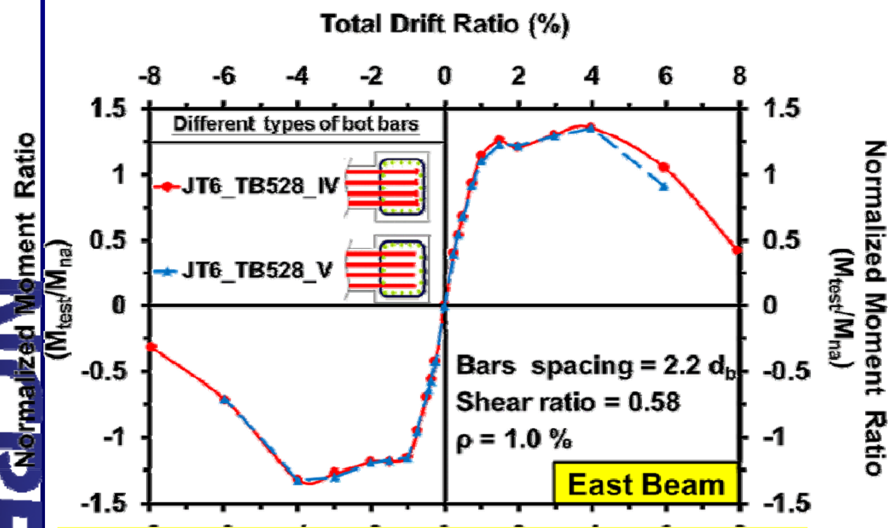


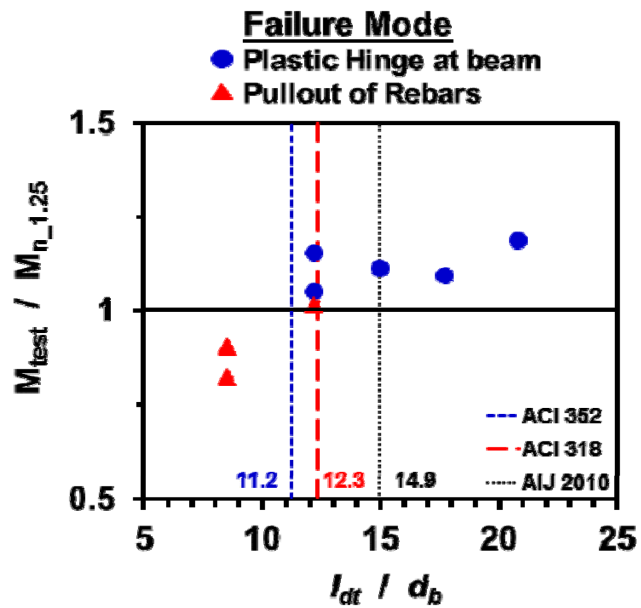


Results for BC Joints Tests







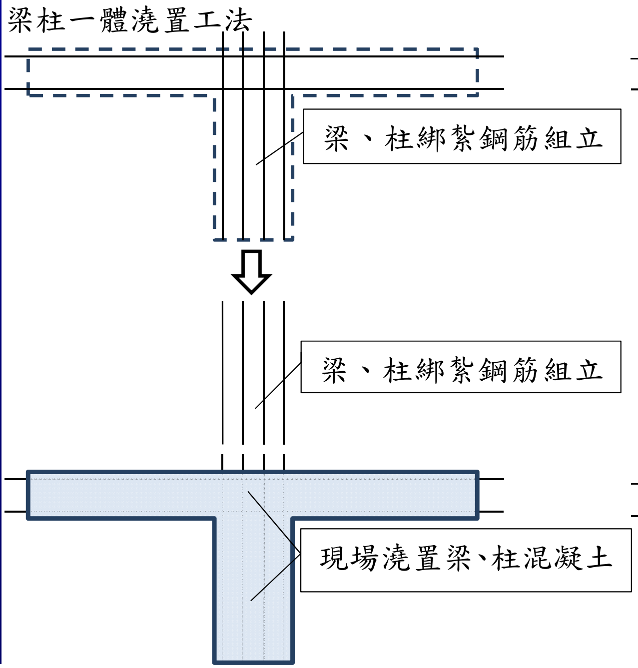


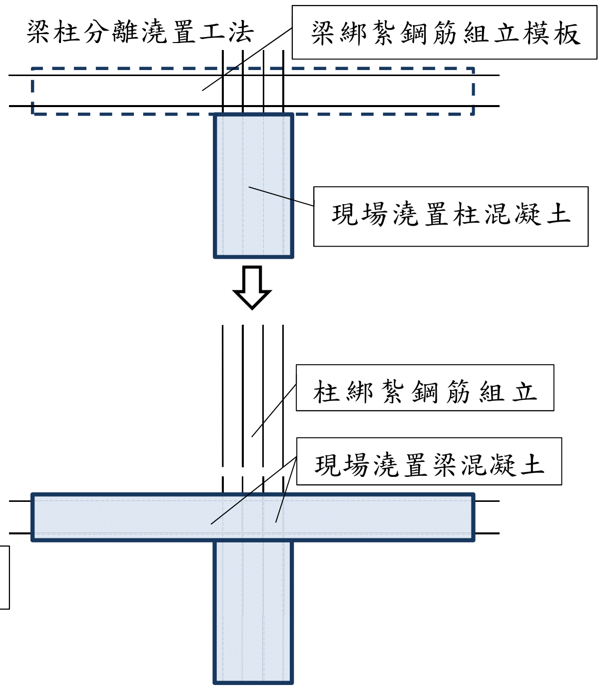
$L_{dt} = L_{dh} = 528$ mm

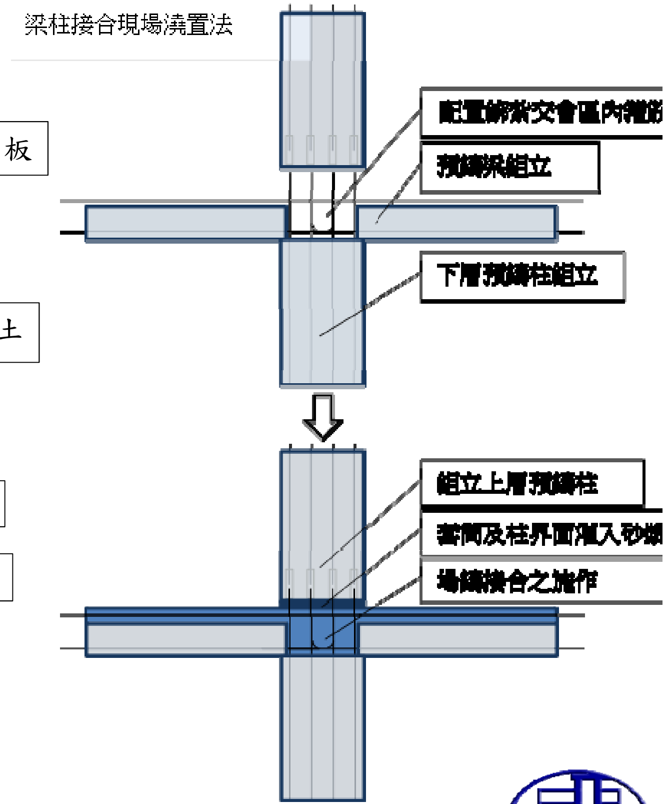
Interior Beam-Column Joints

(*陳肇宸*– 2015)

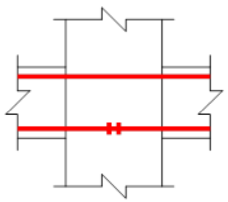
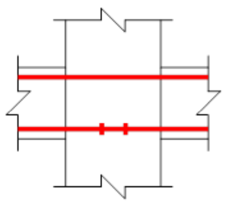
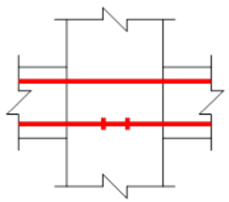
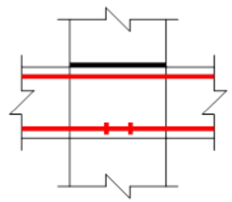
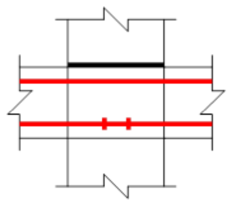
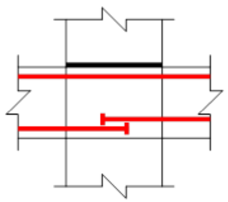
梁柱一體澆置工法	梁柱分離澆置工法	梁柱接合現場澆置工法



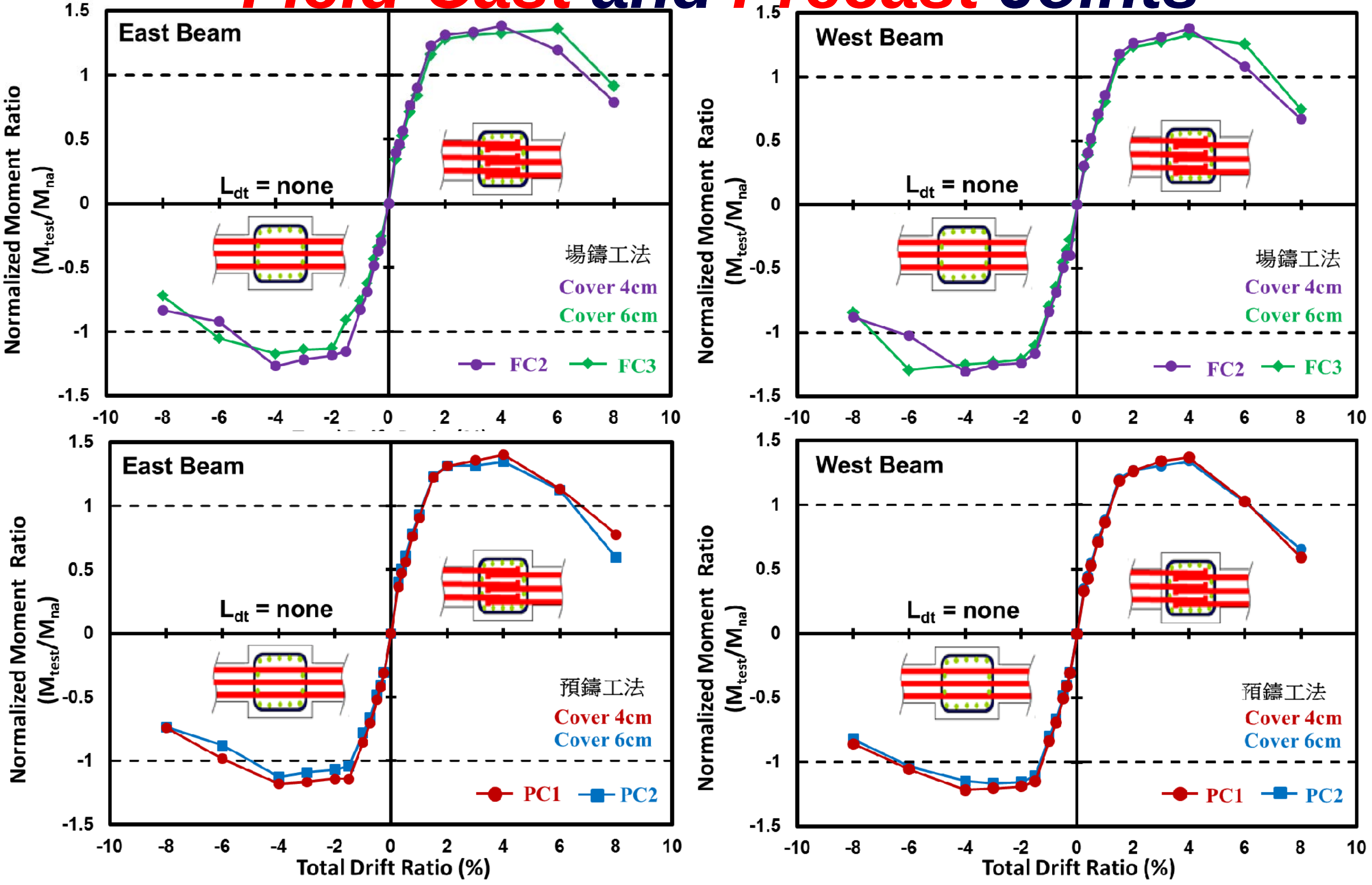




Interior Beam-Column Joints

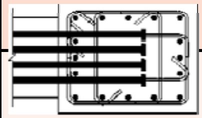
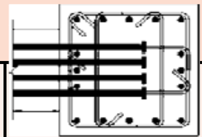
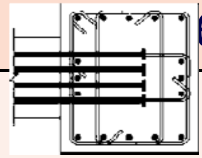
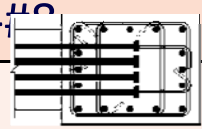
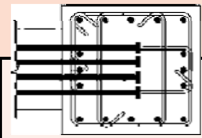
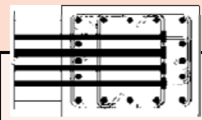
Specimen		Field cast			Pre-cast		
		FC1	FC2	FC3	PC1	PC2	PC3
Beam	b x h (mm)	500 x 600			500 x 600		
	Top Bar	4-#10	3-#12		3-#12		
	Bottom Bar	4-#10	3-#12		3-#12		
	Strrups	#4 @ 150 mm			#4 @ 150 mm		
	Cover (mm)	40	40	**60**	40	**60**	40
Column	b x h (mm)	800 x 800			800 x 800		
	Main Bar	12-#10	12-#12		12-#12		
Connection Type							
L_{dt}	(mm)	458.2	560.6	560.6	560.6	560.6	560.6
	d_b	14.23	14.23	14.23	14.23	14.23	14.23
Steel Spacing		2.752	3.598	3.081	3.598	3.081	3.598
ρ		0.0123	0.0139	0.0144	0.0139	0.0144	0.0139
$R_m = \frac{\Sigma(M_n)_c}{\Sigma(M_n)_b}$		2.15	2.56	2.68	2.56	2.68	2.56 3.01
$V_{jh,u} / V_n$		0.817	0.921	0.928	0.921	0.928	0.921 0.945

Results for Field-Cast and Precast Joints

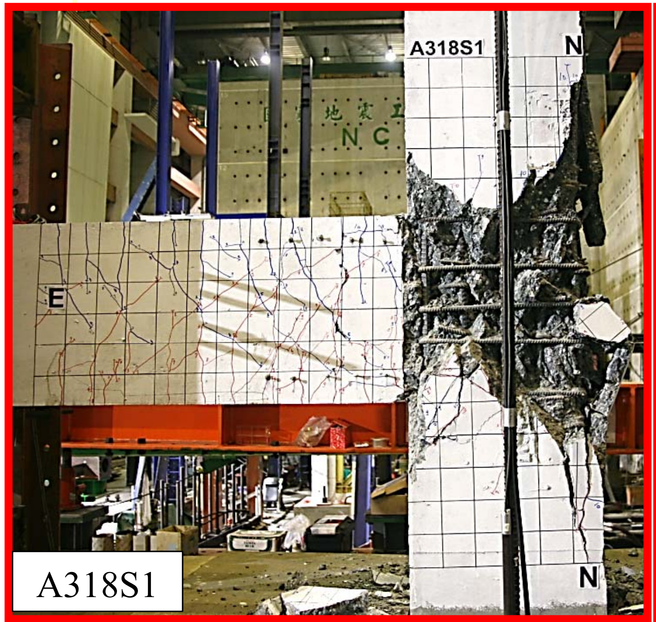


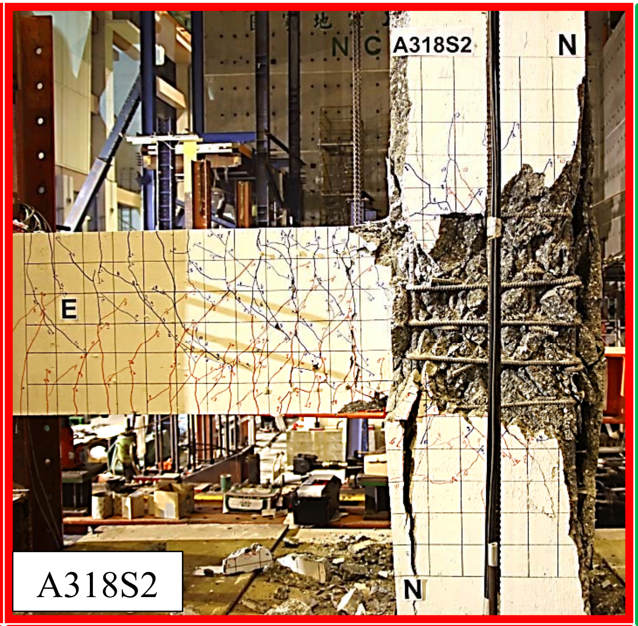
Exterior Beam-Column Joints

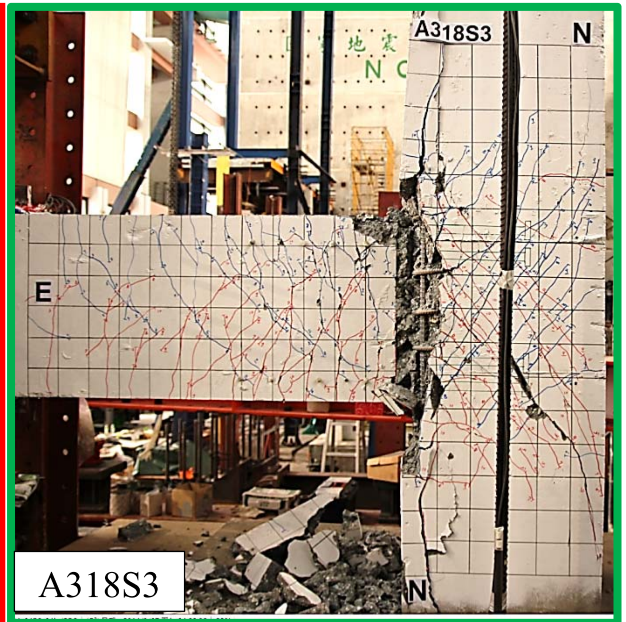
(許書豪– 2015)

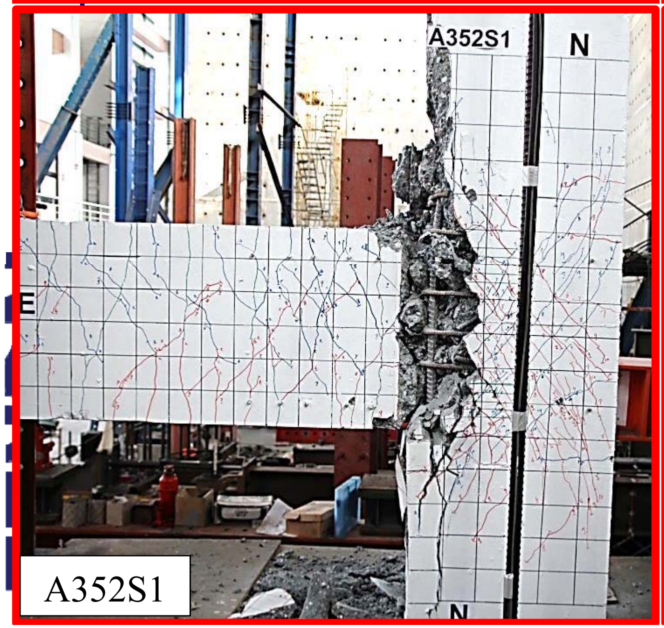
Specimen		A318S1	A318S2	A318S3	A352S1	A352S2	AAIJS1
Beam	b x h (mm)	400 x 600					
	Top Bar	4+4-#8					
	Bottom Bar	4+4-#8					
	Stirrups	#4 @ 100 mm					
	Cover (mm)	40					
Column	b x h (mm)	550 x 600	650 x 600	750 x 600	550 x 600	650 x 600	550 x 600
	Main Bar	6-#8					
Connection Type							
L_{dt}	(mm)	358	358	358	323	323	440
	d_b	14.108	14.108	14.108	12.713	12.713	17.321
Steel Net Spacing		2.0	2.0	2.0	2.0	2.0	2.0
ρ		0.0204					
		2.28	2.44	2.59	2.28	2.44	2.28

Failure Modes for Joints

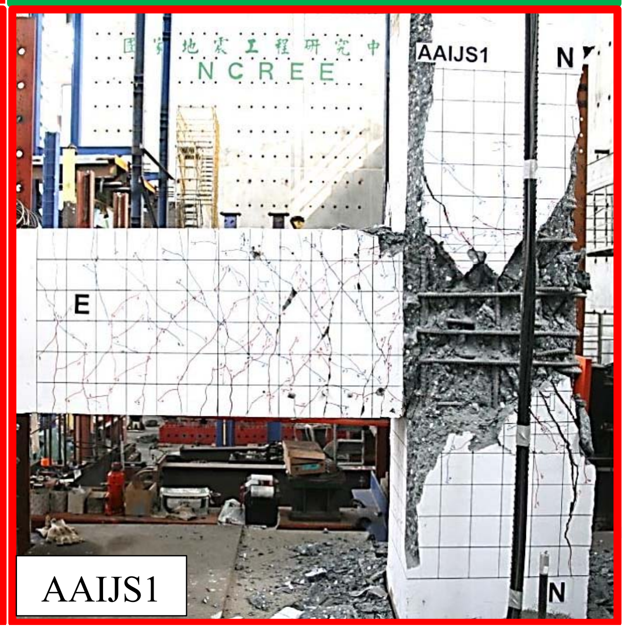

A318S1


A318S2

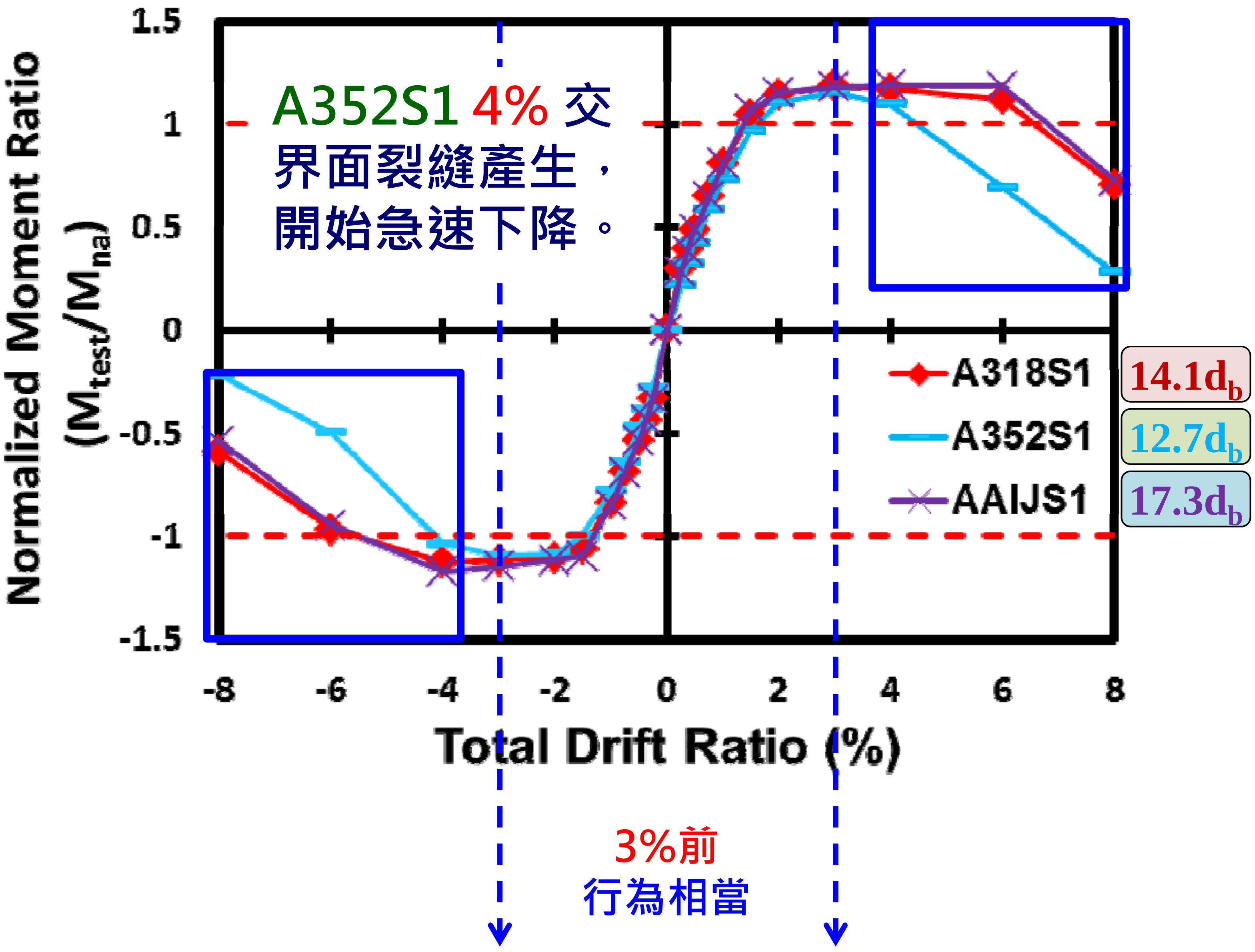

A318S3


A352S1


A352S2

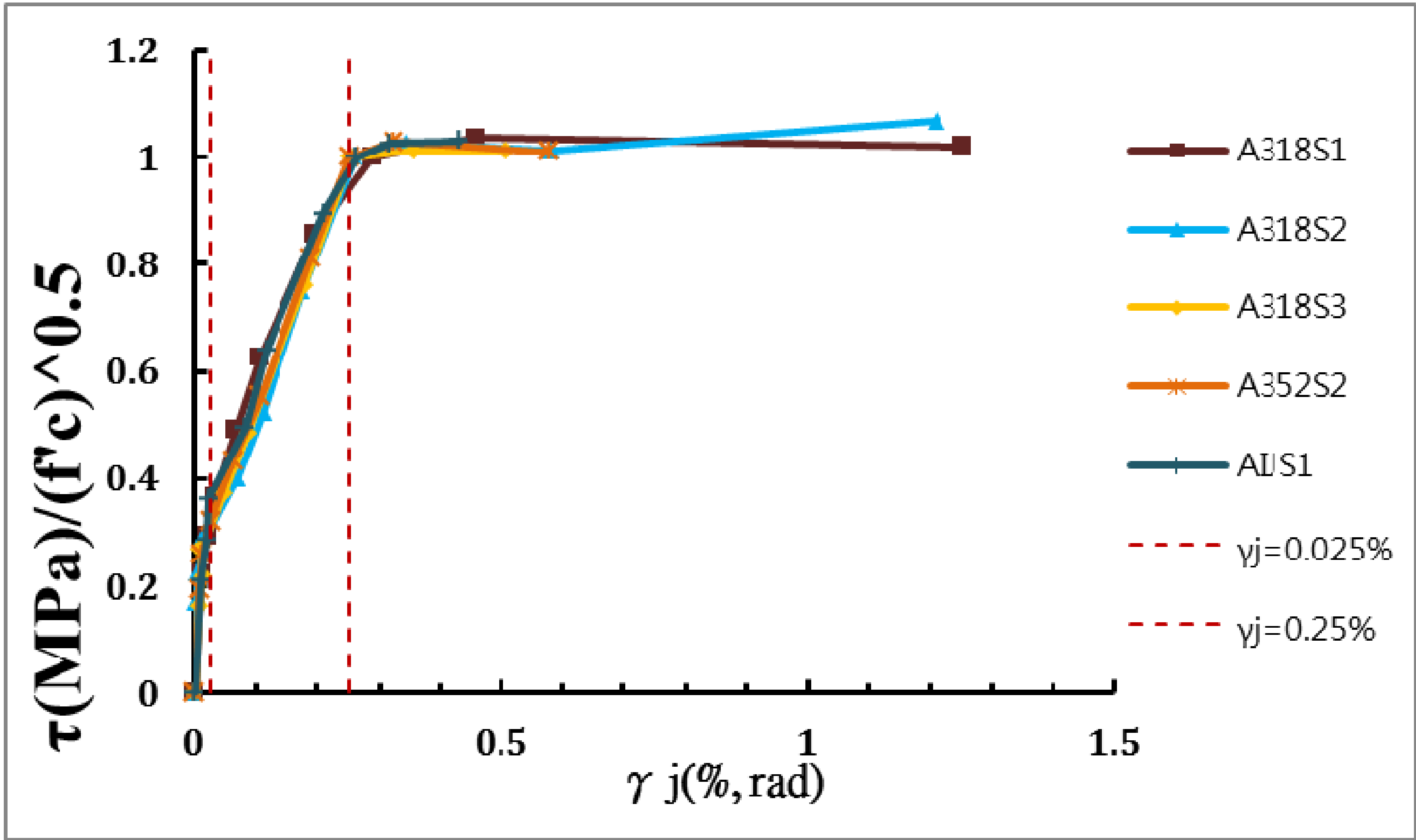

AAIJS1

Results for L_{dt}



PZ Relationship between

Shear Stress and Strain



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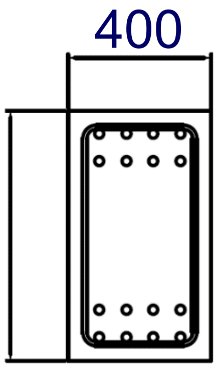
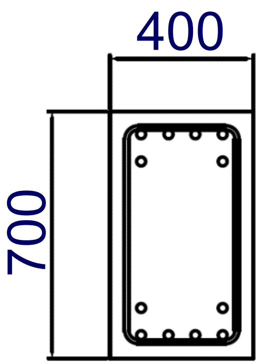
Exterior Beam-Column Joints

P-δ effect (趙偉帆 – 2015)

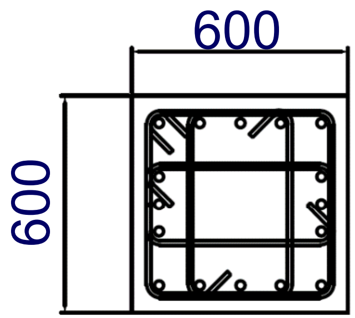
Variables	LAHV (11/2)	LAMV (11/5)	HAHV (11/19)	HAMV (11/24)
F_c' (MPa)	93.8	81.2	89.8	84.1
F_y (MPa)	710			
V_{jh} / V_n	**0.907**	0.729	**0.928**	0.716
L_{dt} (mm)	**390 (ACI 318-14 Code)**			
$P / A_g f_c'$	**0.10**	**0.10**	**0.45**	**0.44**



LAHV、HAHV
主筋16-#8
箍筋#4@100
繫筋#4@100

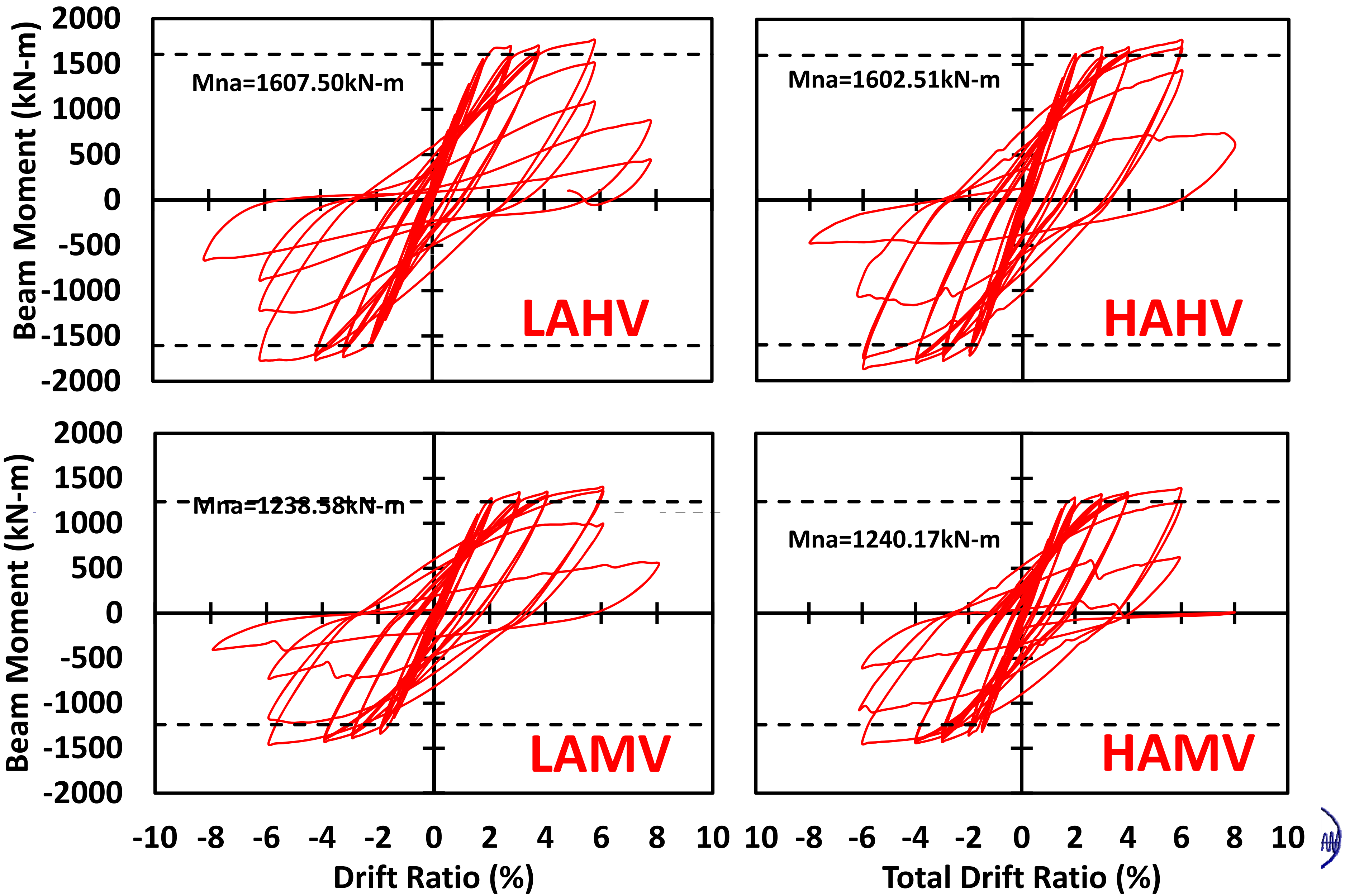


LAMV、HAMV
主筋12-#8
箍筋#4@100
繫筋#4@100

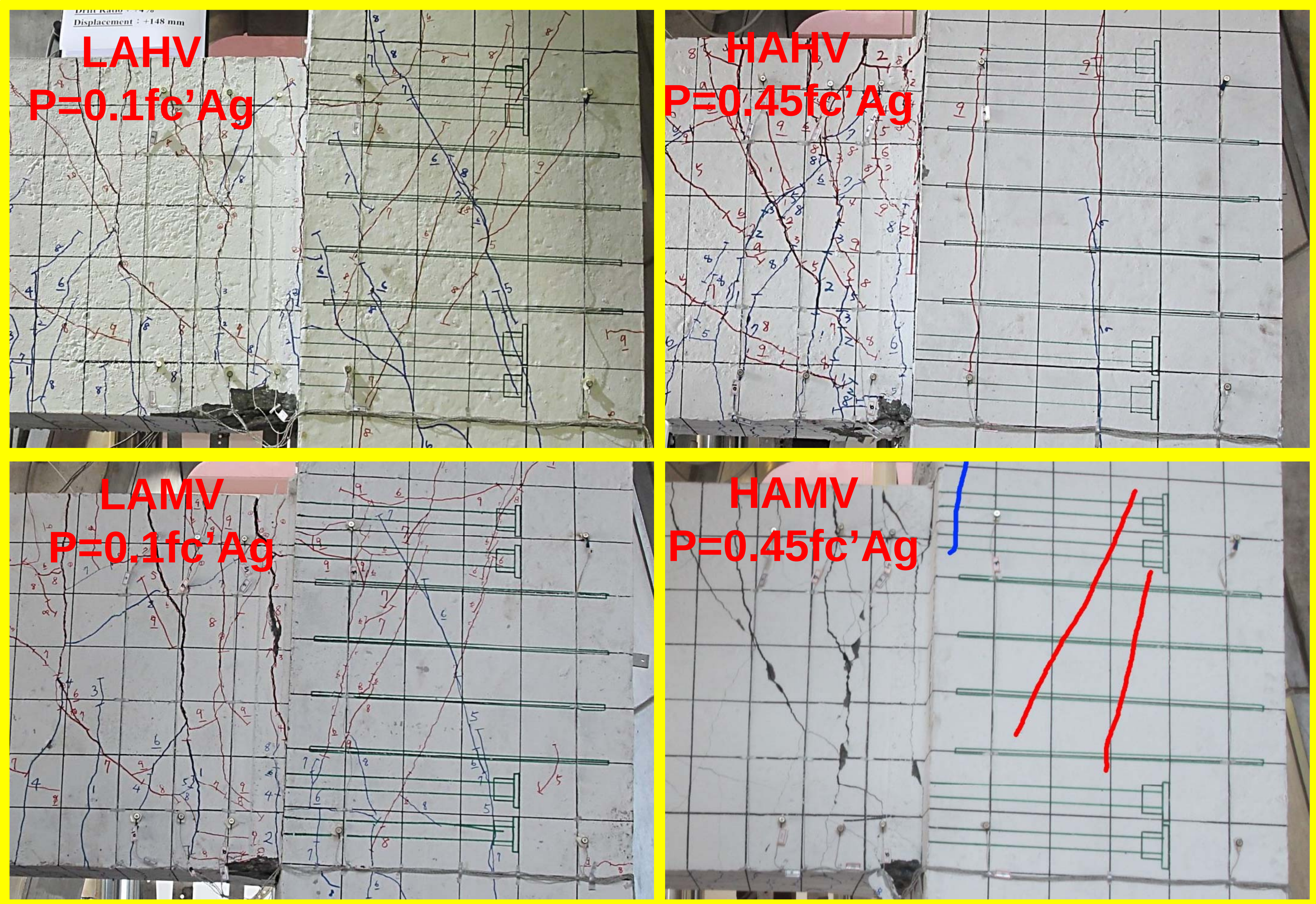


主筋16-#8
箍筋#4@100

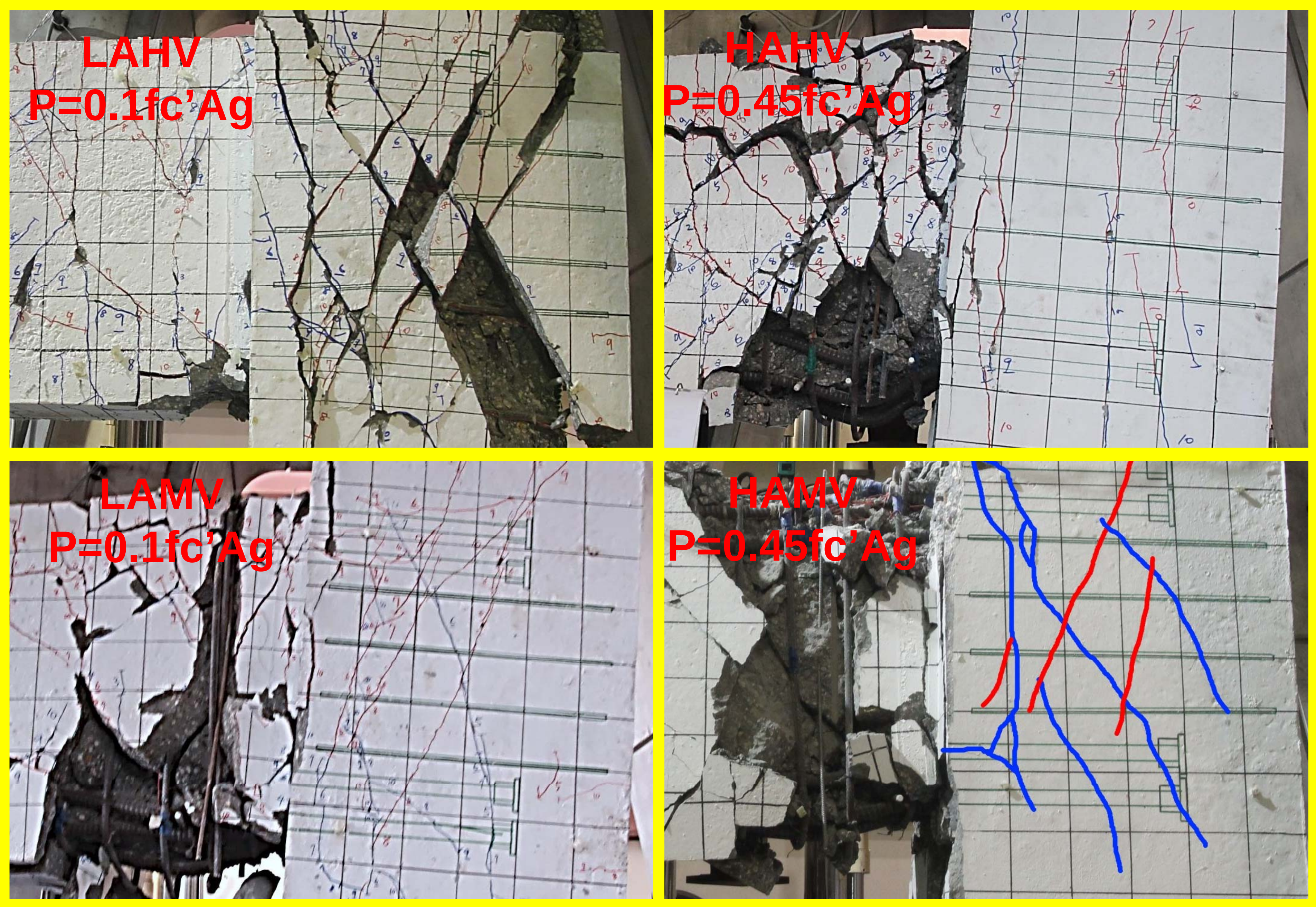
Tests Results for P-δ effect of BC Joints



Crack at 4%



Failure at 8%



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東和鋼鐵企業股份有限公司

日本東京鐵鋼(TTK)

潤弘精密工程股份有限公司

亞利預鑄工業股份有限公司

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NCREE

Thank you for your attentions

NARL 國家實驗研究院 National Applied Research Laboratories

國家地震工程研究中心 National Center for Research on Earthquake Engineerin