含挫屈束制支撐之新建RC構架耐震設計與試驗

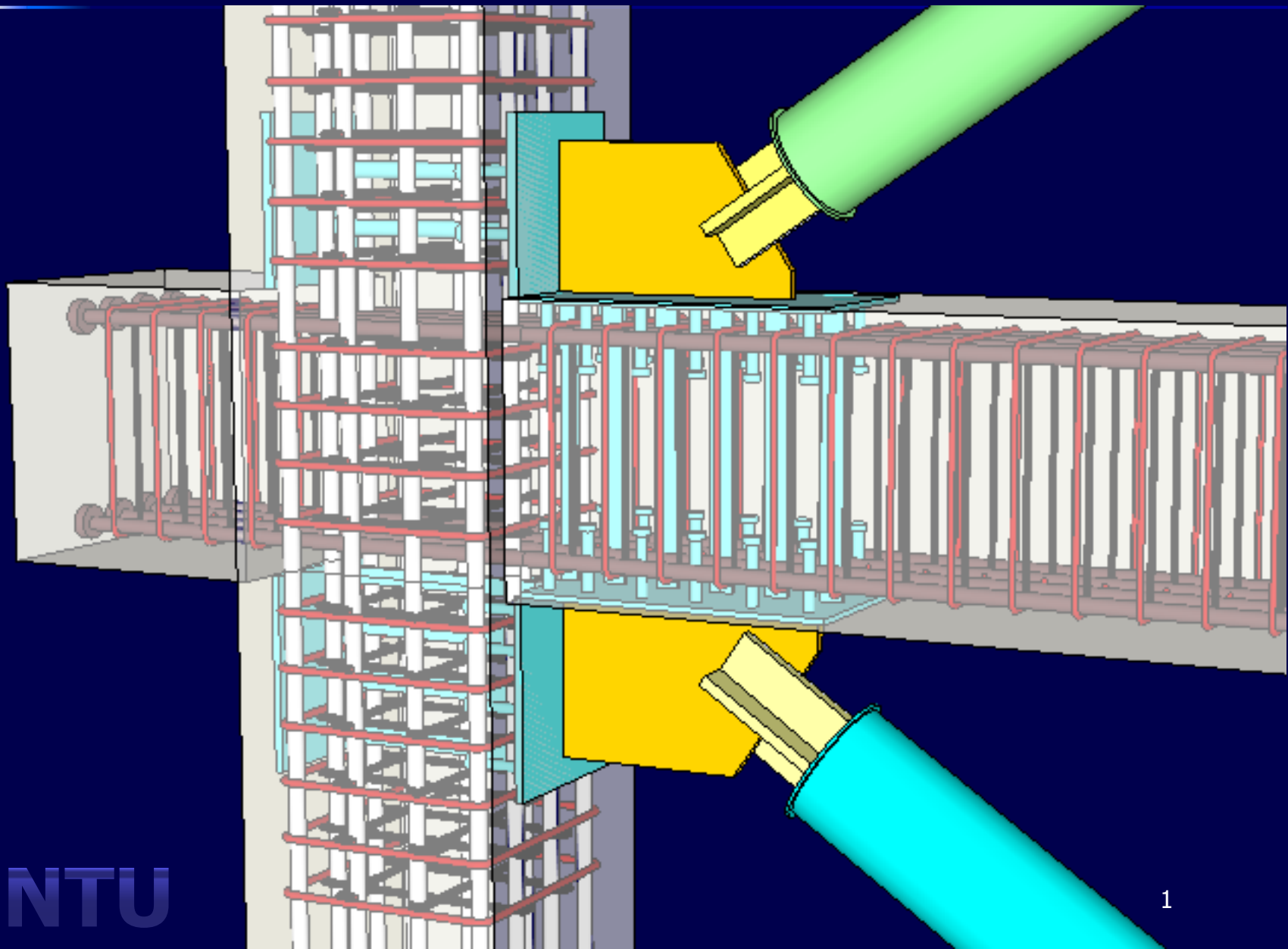
楊巽閎/黃潔倫/吳安傑
蔡青宜/李昭賢/王孔君/蔡克銓

國家地震工程研究中心 (NCREE)
國立台灣大學土木工程系 (NTU)

NCREE

含挫屈束制支撐之RC構架
耐震設計、試驗與應用研討會 2015/11/13

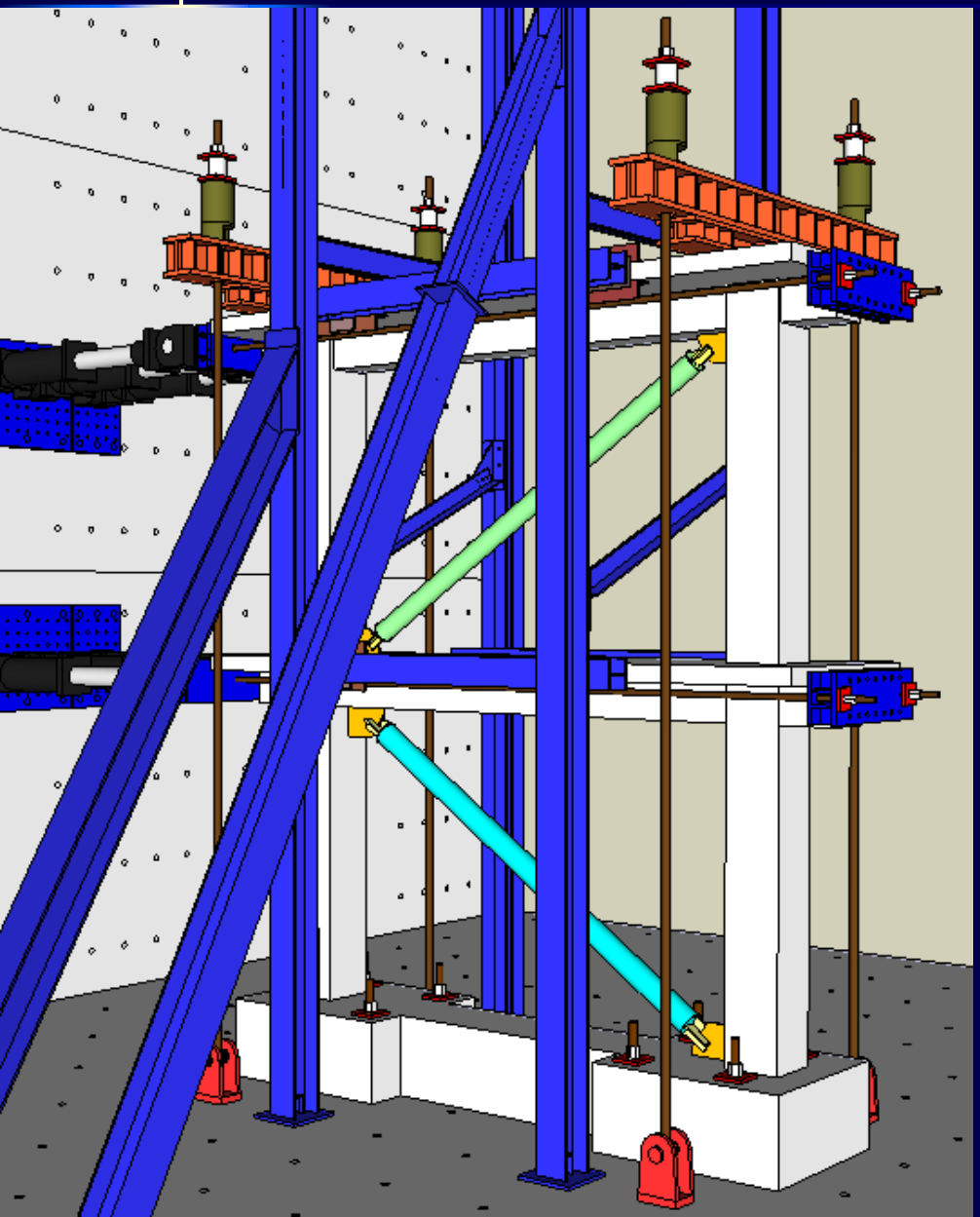
預埋鐵件-RC與BRB連接介面



NCREE

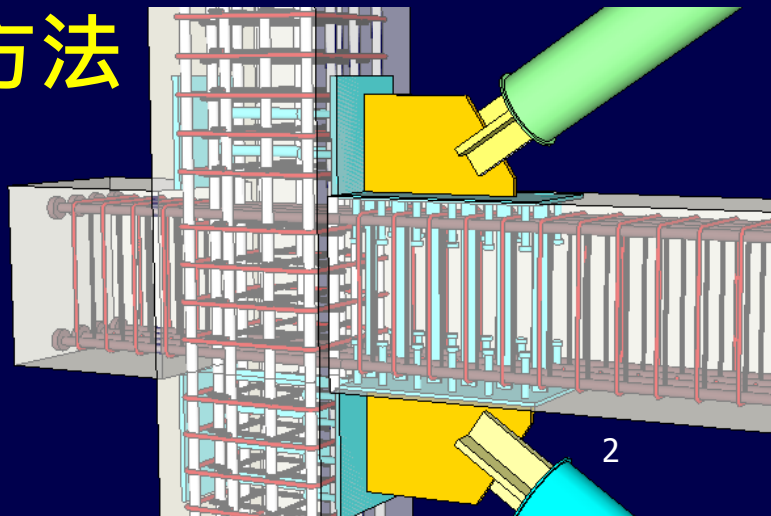
NTU

含BRB之實尺寸RC構架耐震試驗研究



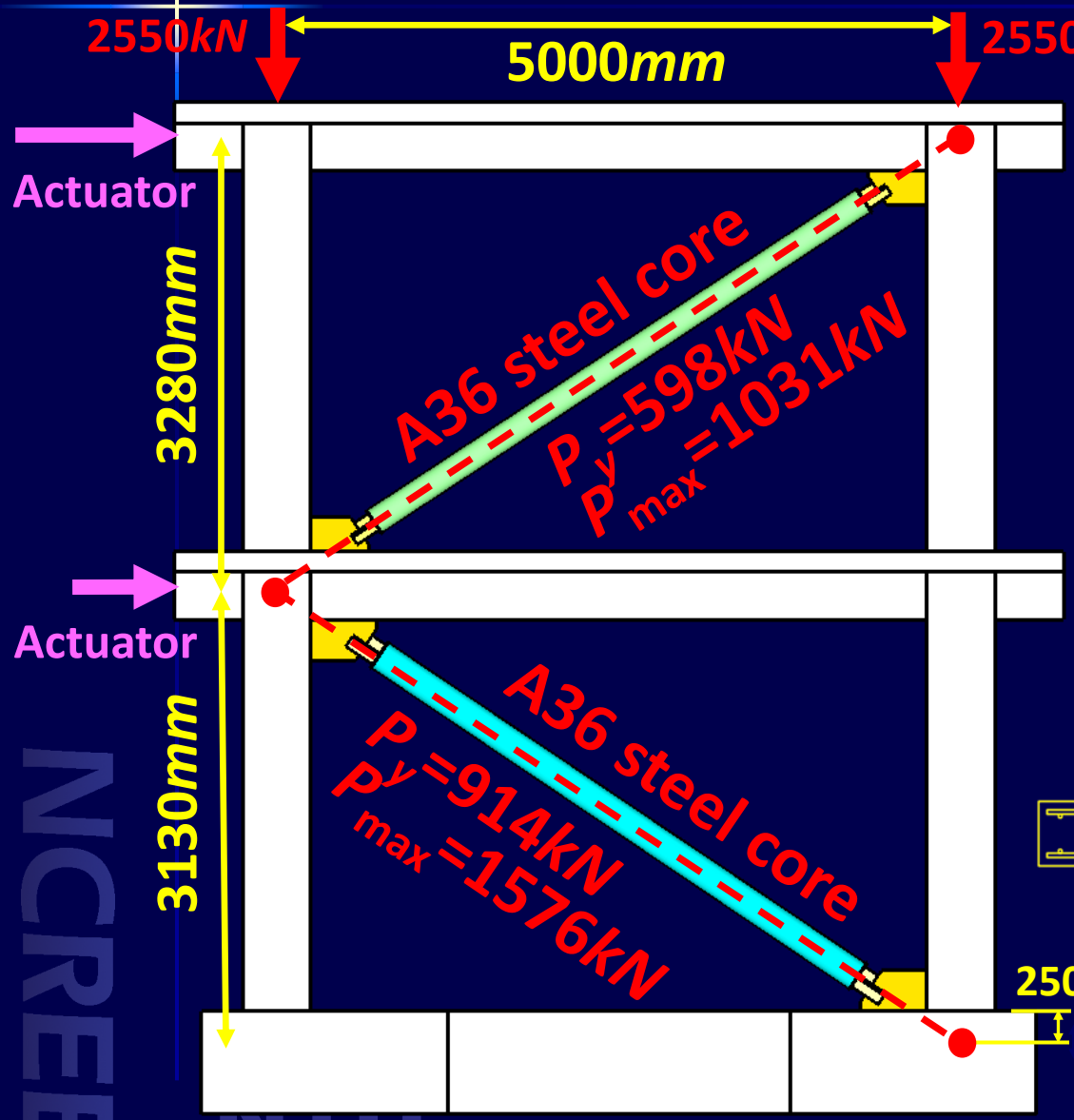
研究項目：

- 結構系統耐震設計與分析方法
- BRB與接合設計方法
- RC構件D-region設計方法
- 預埋鐵件設計與施工方法



BRB-RCF構架試體設計

Vertical force Applied: 2550kN
$=0.3f_c'A_g$

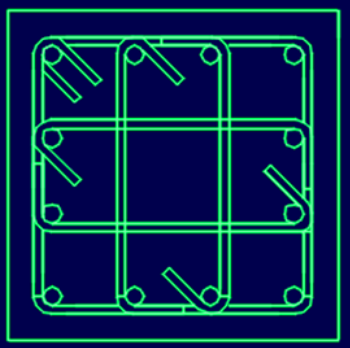


Column: 500x500, 12-#7

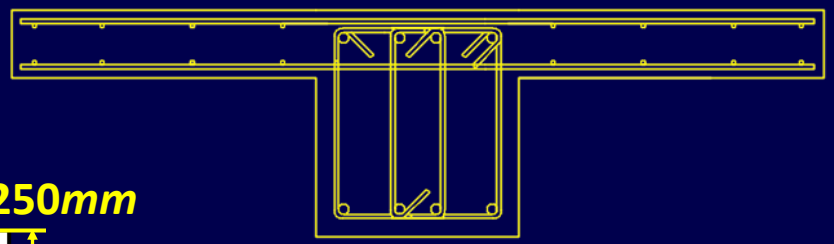
Top Beam: 400x500, 8-#5

Mid Beam: 450x500, 8-#7

f_y=420MPa, f_c'=35MPa



Column steel ratio=1.86%

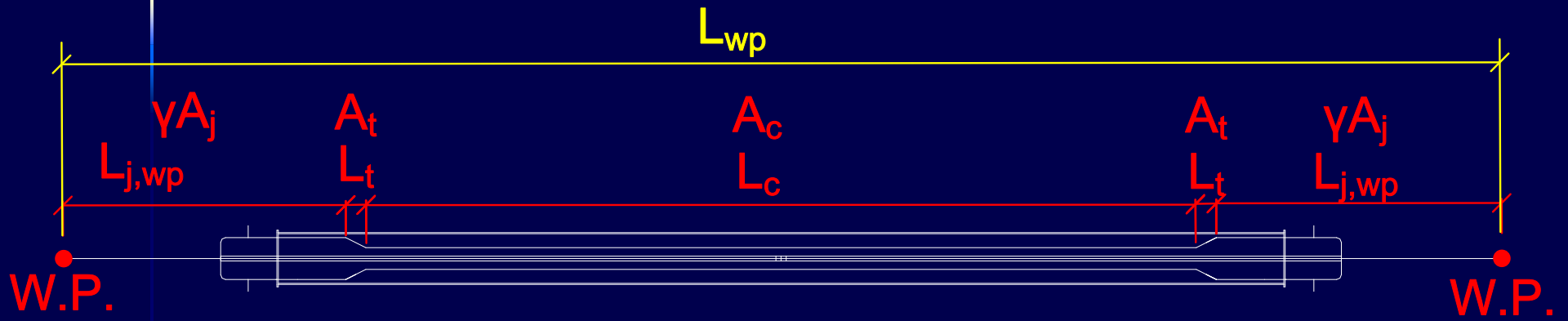


Beam steel ratio
Top Beam=0.5%
Mid Beam=0.78%

簡報大綱

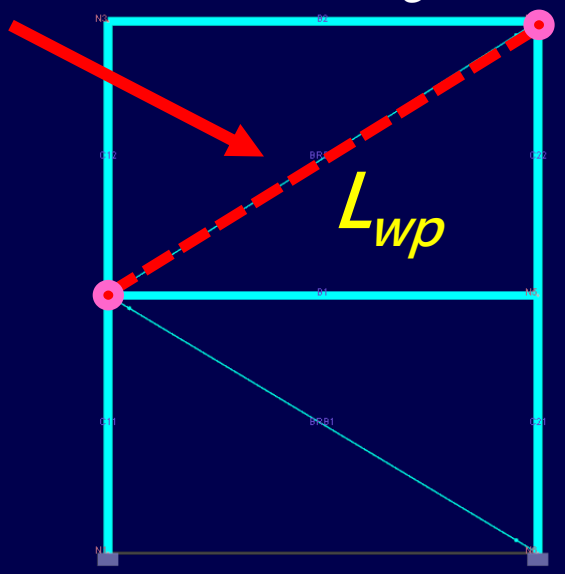
- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- 試體製作與施工
- 試驗配置
- 試驗結果與討論

BRB軸向等效彈性勁度

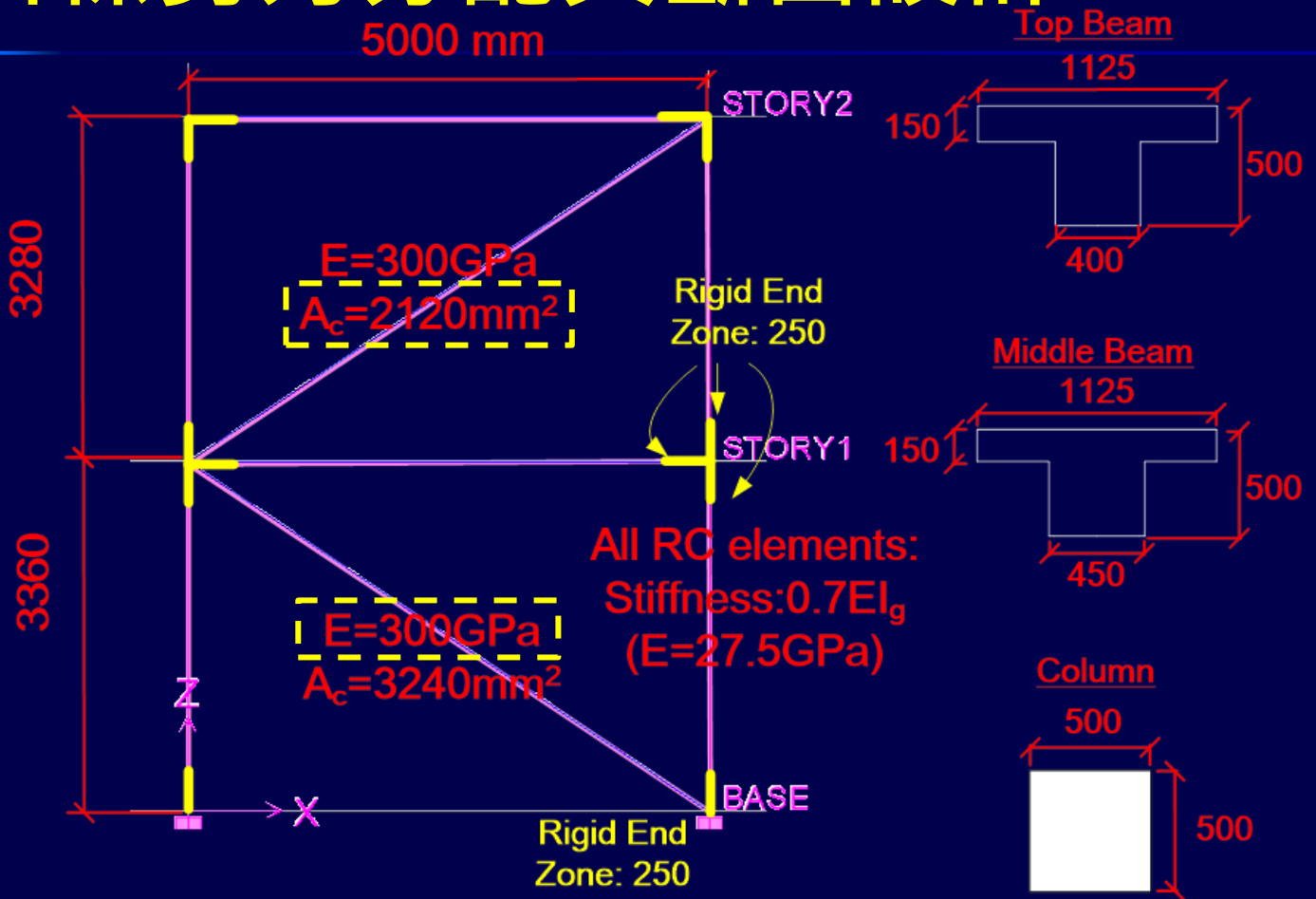


$$K_{eff} = \frac{E}{\frac{L_c}{A_c} + \frac{2L_t}{A_t} + \frac{2L_{j,wp}}{\gamma A_j}} = \frac{QEA_c}{L_{wp}}$$

K_{eff}：BRB等效勁度
Q：等效勁度因子
L_{wp}：節點長度
A_c：核心消能段斷面積



目標剪力分配與斷面設計



目標水平剪力分配比例：

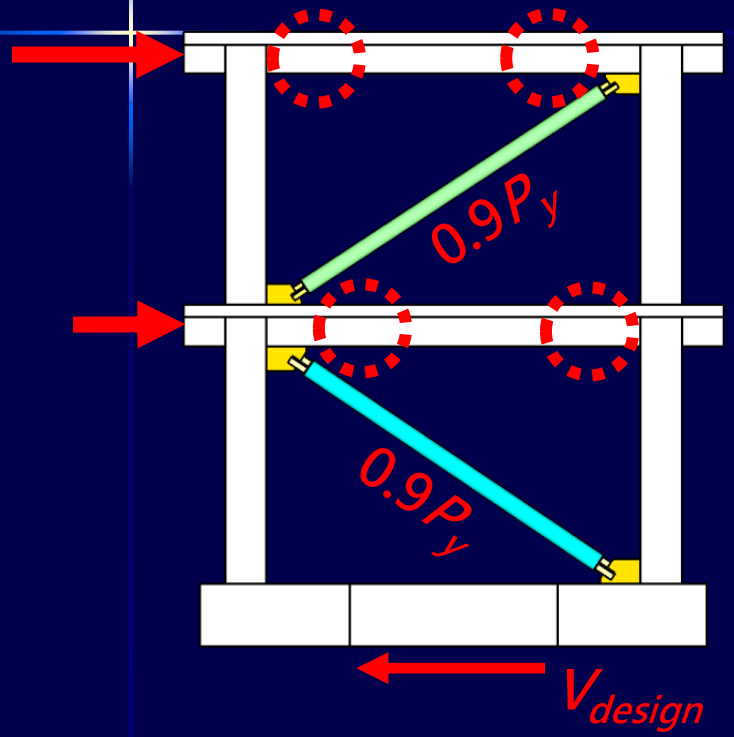
- RC frame 30%
- BRB 70%

ETABS模型構件勁度：

- RC構件勁度=0.7E_cI_g
- BRB Q=1.5

→設計RC構件斷面→設計BRB斷面

主筋配筋與RC梁設計檢核



BRB	1F	2F
Q	1.35	1.39

設計基底剪力：

BRB軸力達$0.9P_y$時

$P_{BRB}=0.9P_y$ (AISC 341-10)

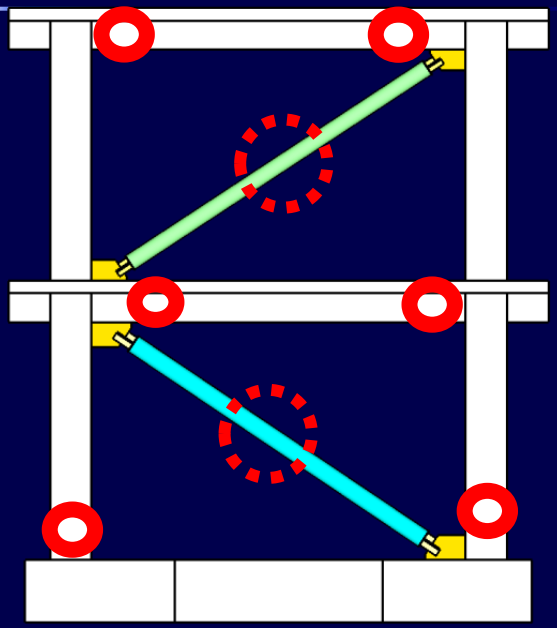
$\rightarrow V_{design}$

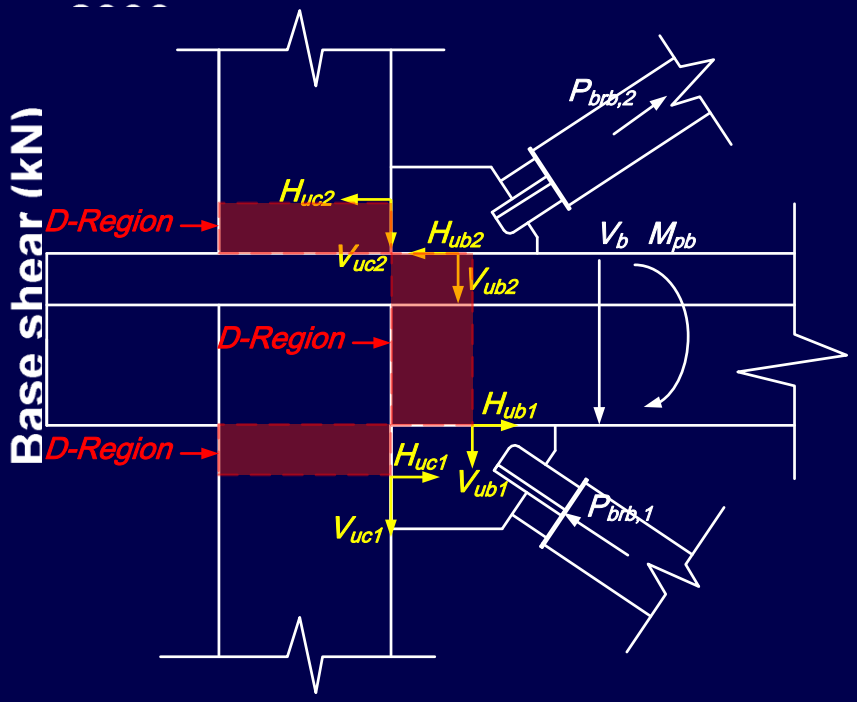
V_{design} → ETABS → M_u

$M_u \leqq \phi M_n$, $\phi=0.9$

	M_u (kN-mm)	ϕM_n (kN-mm)	DCR
Top Beam	120212	126227	0.96
Mid. Beam	203503	238329	0.86

容量設計-極限狀態 (P_{BRB}= P_{max})





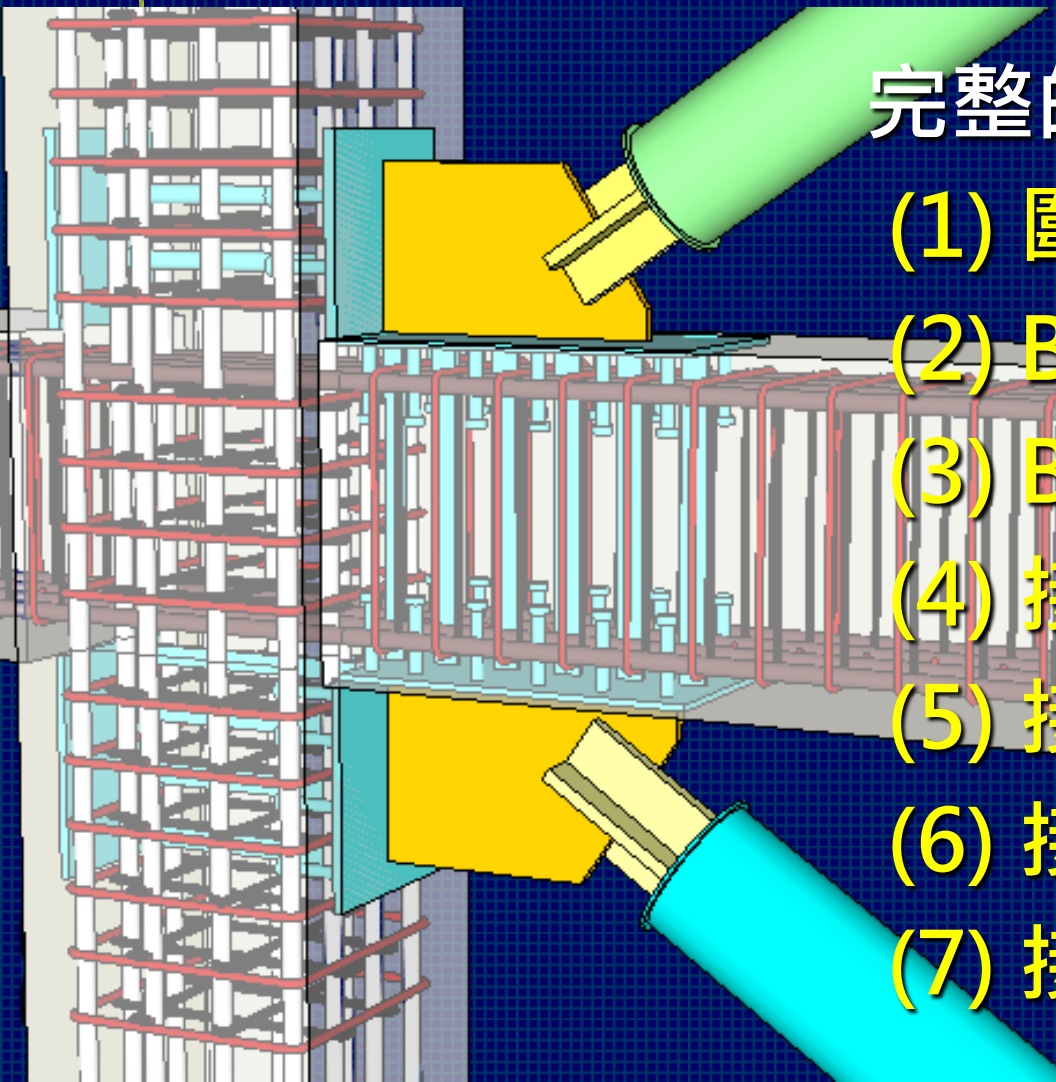
- 強柱弱梁檢核：
- 梁柱交會區檢核：
  ACI 318-14
  軟化壓拉桿模型簡算法
- BRB與接合板設計檢核
- 預埋鐵件設計檢核

RC構件D-region設計檢核：

- ACI 318-14 深梁設計
- ACI 318-14 托架設計
- 軟化壓拉桿模型簡算法

WES-BRB及接合設計檢核

http://BOD.ncree.org.tw



完整的破壞檢核：

(1) 圍束鋼管撓曲挫屈

(2) BRB接合段降伏

(3) BRB接合段挫屈

(4) 接合板塊狀剪力破壞

(5) 接合板降伏

(6) 接合板挫屈

(7) 接合板與梁柱接面強度

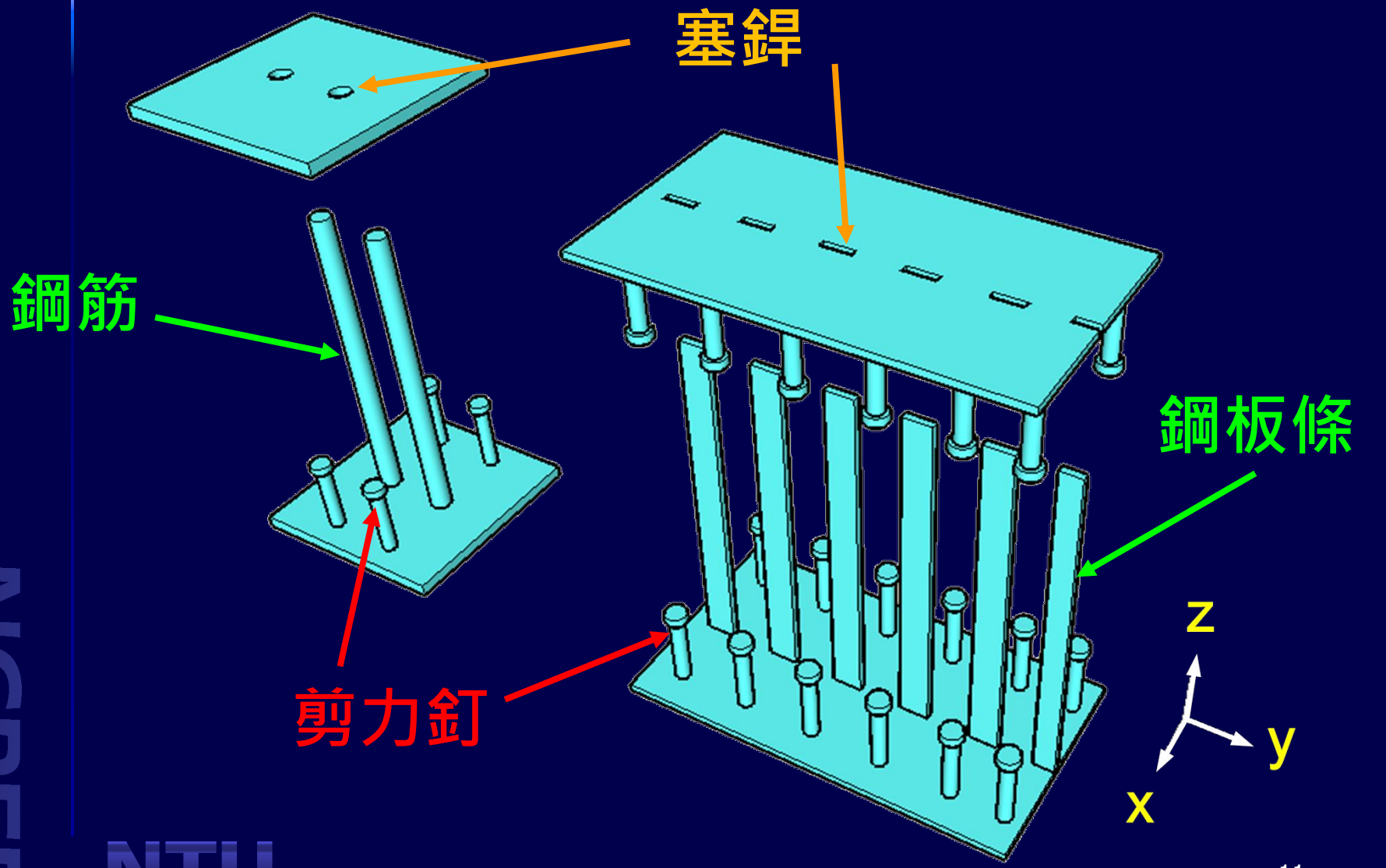
簡報大綱

- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- 試體製作與施工
- 試驗配置
- 試驗結果與討論

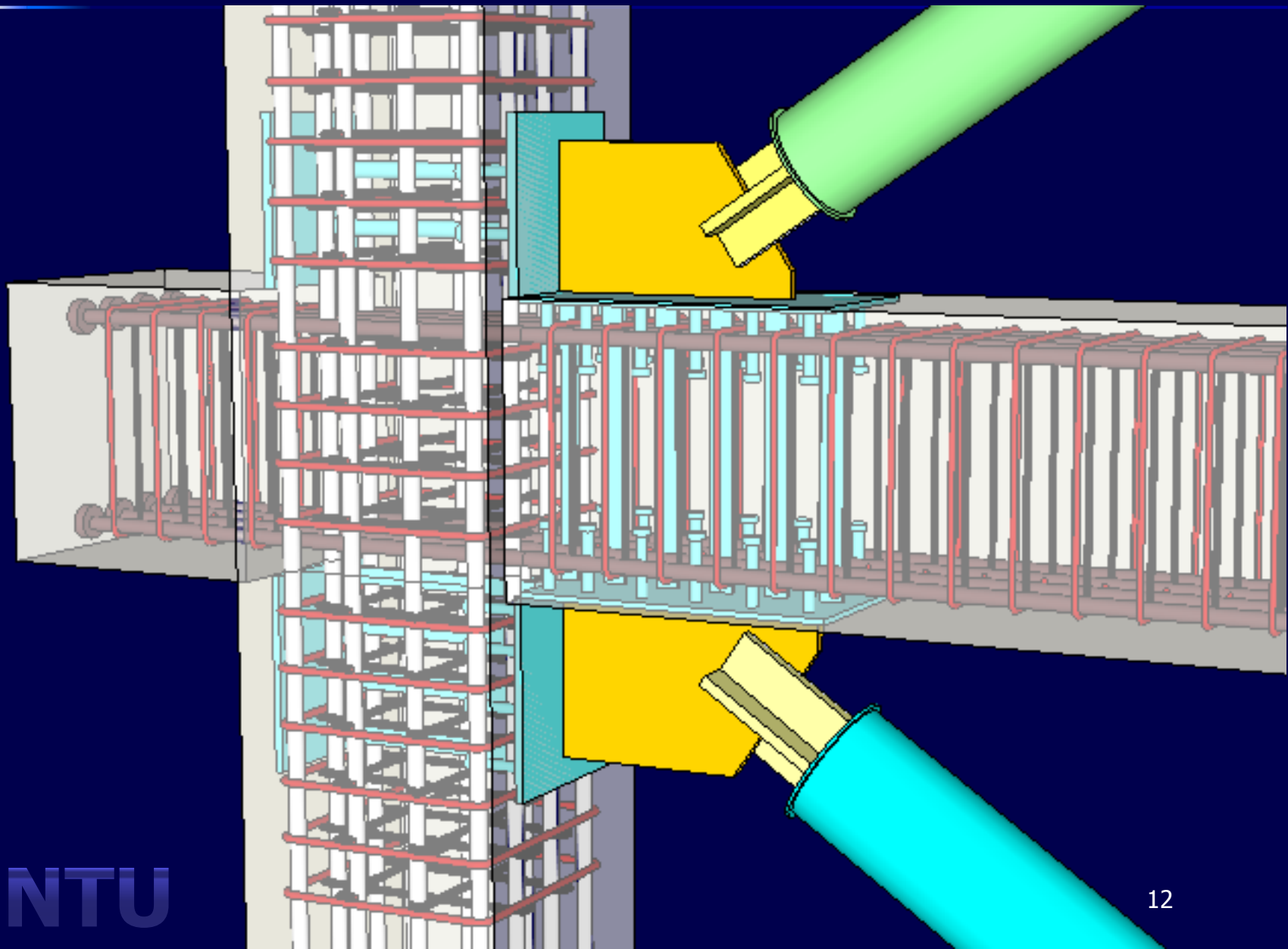
NCREE

NTU

預埋鐵件



預埋鐵件於RC構件之配置

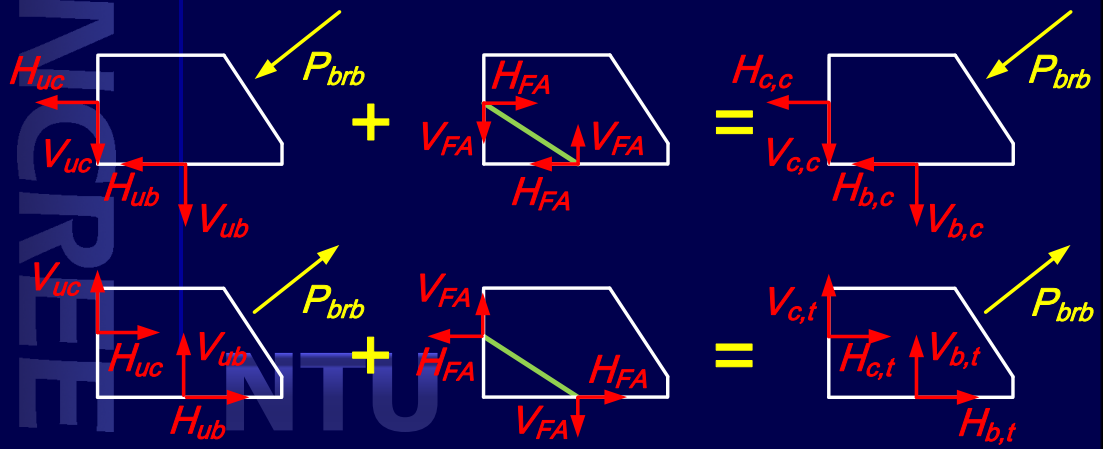


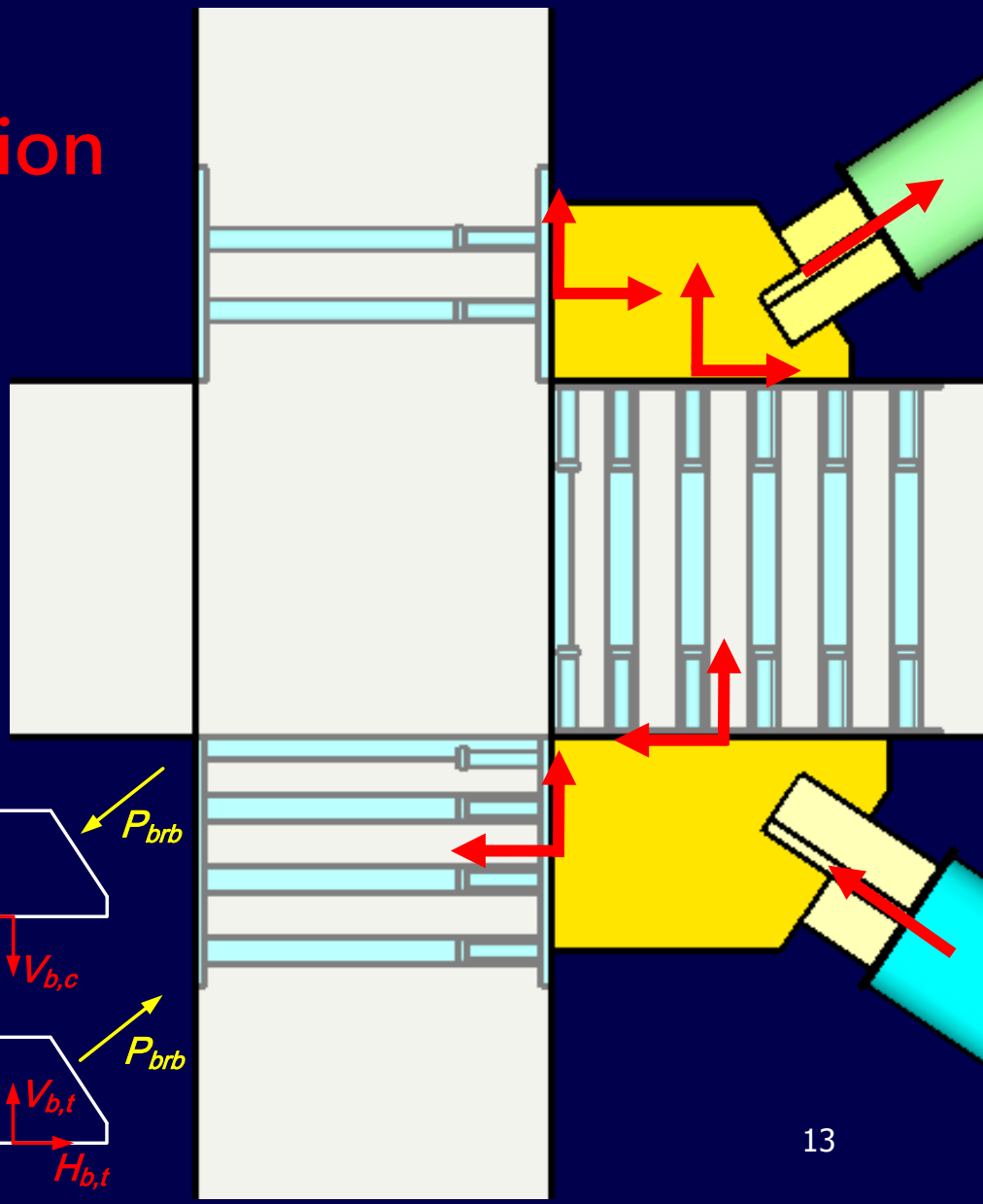
NCREE

NTU

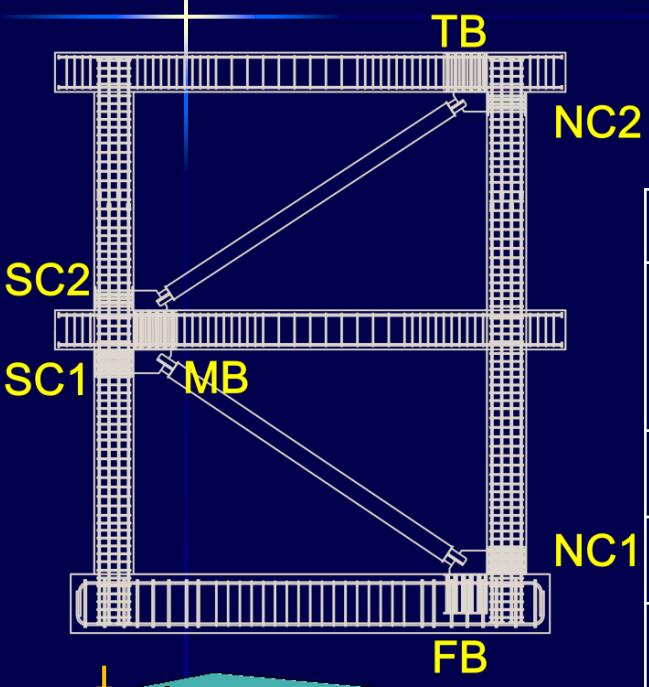
預埋鐵件受力分析

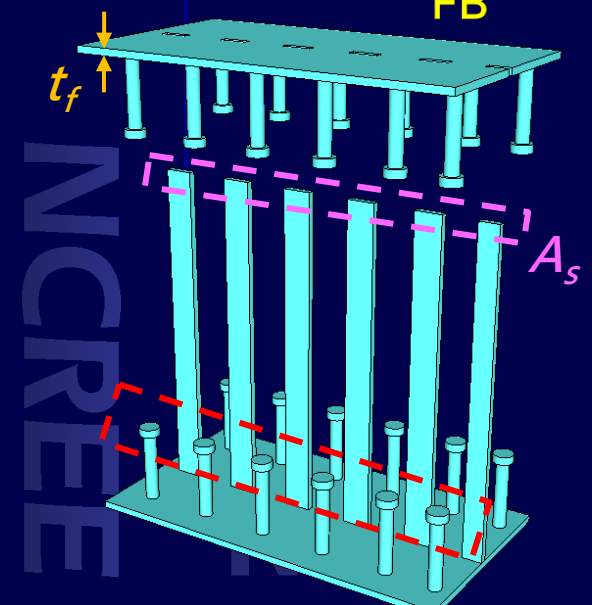
- 剪力需求：
  UFM + Frame Action
- 拉力需求：
  UFM only (保守)
- 剪力釘：
  承受全部水平剪力
- 連接單元：
  承受全部拉力





預埋鐵件設計檢核





	NC1	FB	SC1	MB	SC2	NC2	TB
No. of shear stud (19ϕ, $115mm$)	4	12	4	12	4	4	12
A_s (mm^2)	1800	2300	1800	2300	647	647	1800
t_f (mm)	14	10	14	10	18	18	10
t_{pw} (mm)	8	7	8	7	12	12	7
DCR_{shear}	1.53	0.83	1.28	0.72	0.81	0.81	0.50
$DCR_{tension}$	0.85	0.67	0.85	0.67	0.68	0.68	0.59
DCR_{pw}	0.73	0.57	0.73	0.57	0.70	0.70	0.50
DCR_{fw}	0.84	0.72	0.84	0.72	0.79	0.79	0.61

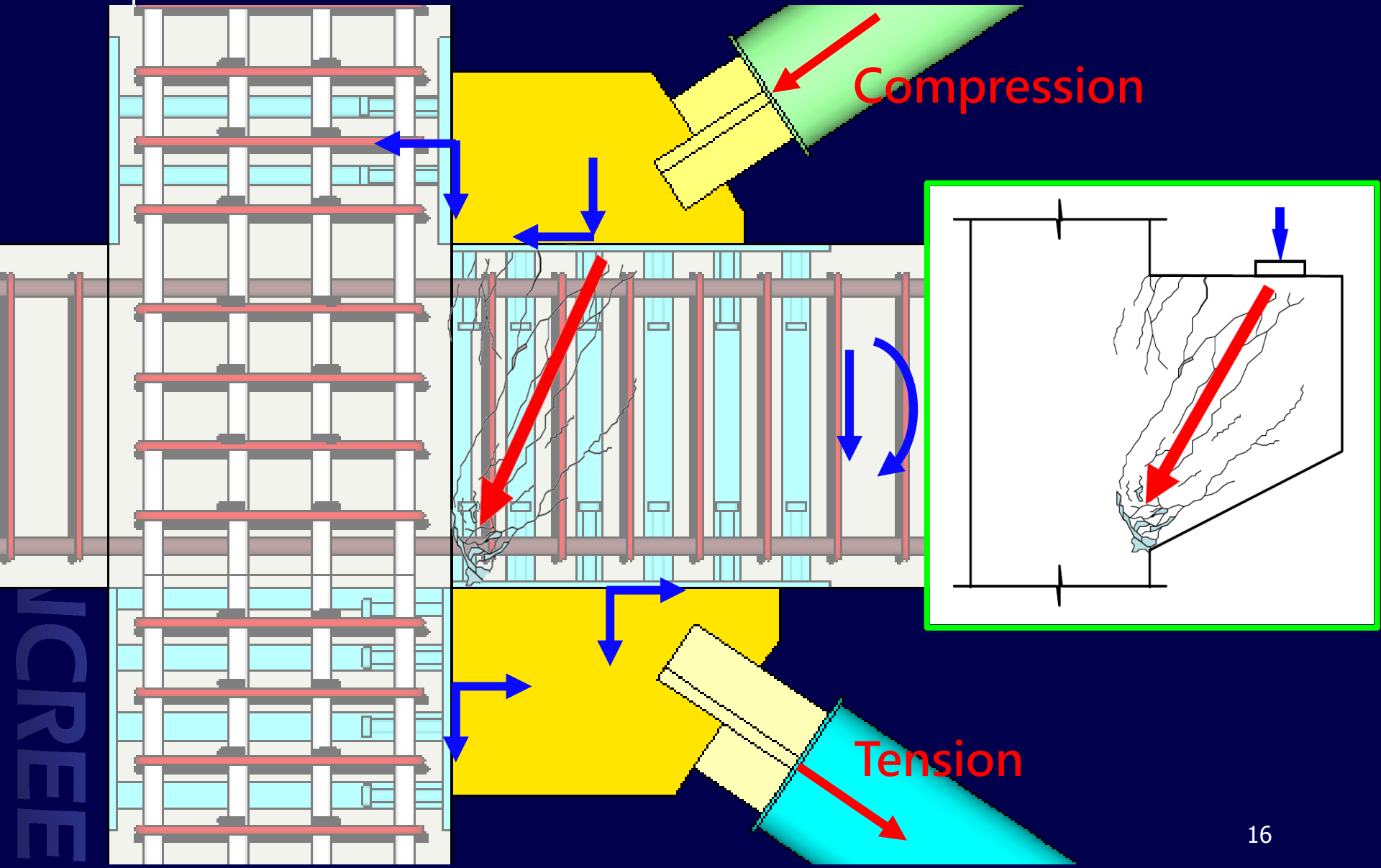
簡報大綱

- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- 試體製作與施工
- 試驗配置
- 試驗結果與討論

NCREE

NTU

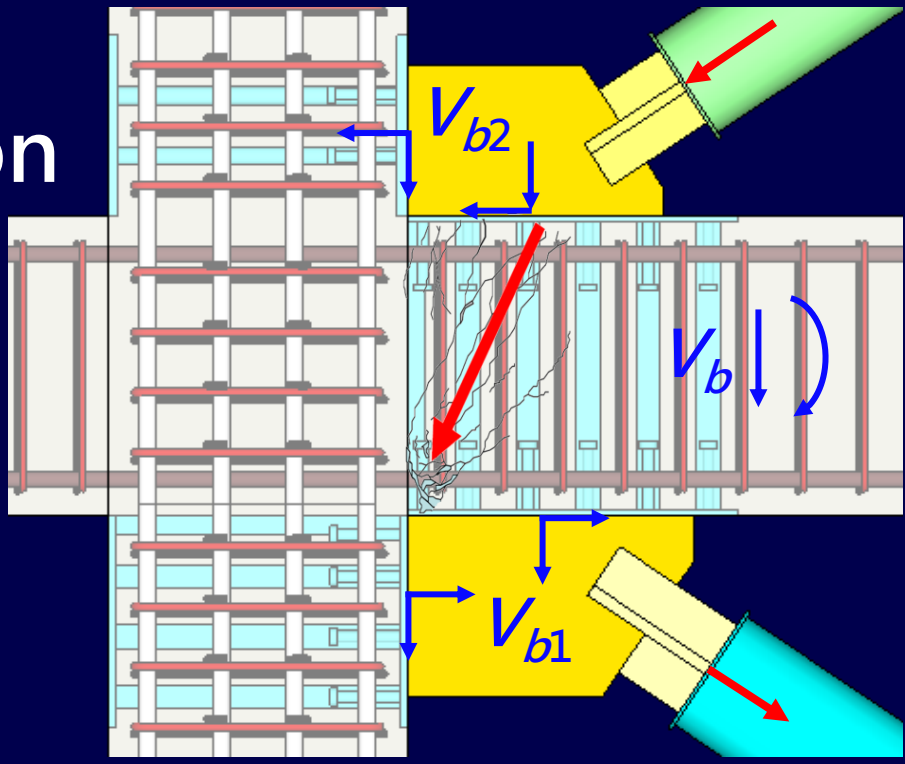
D-region設計檢核



D-region設計檢核

- 設計需求：
  UFM + Frame action
  + Beam shear

$$V_u = V_{b2} + V_{b1} + V_b$$



- 設計容量：

1. ACI 318-14 深梁

$$V_n = 0.85\sqrt{f_c'}\,b_w d$$

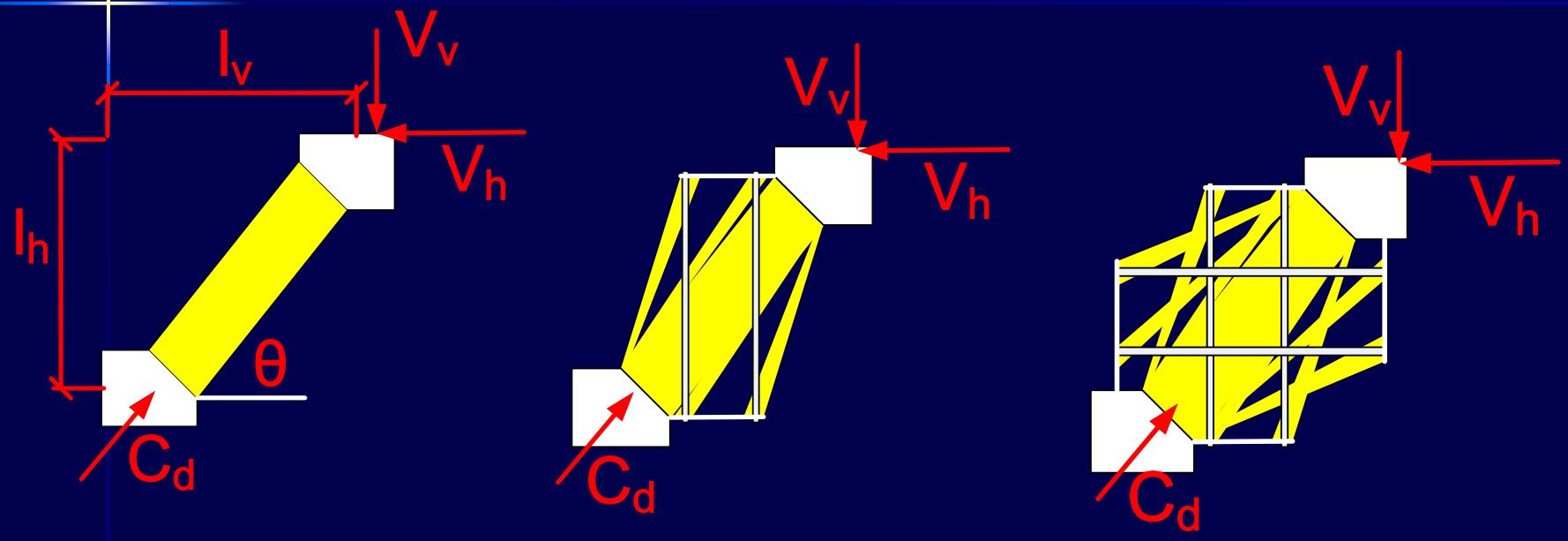
2. ACI 318-14 托架

$$V_n = A_{vf}\, f_y \mu \le (0.2 f_c' A_c, 5.5 A_c)$$

3. 軟化壓拉桿簡算法

$$V_n = K\zeta f_c' A_{str} \sin\theta$$

軟化壓拉桿模型 [黃世建、李宏仁, 2002]



$$C_d = (K_v + K_h - 1)\zeta f_c' A_{str} = K\zeta f_c' A_{str}$$

C_d : 抗對角壓力強度

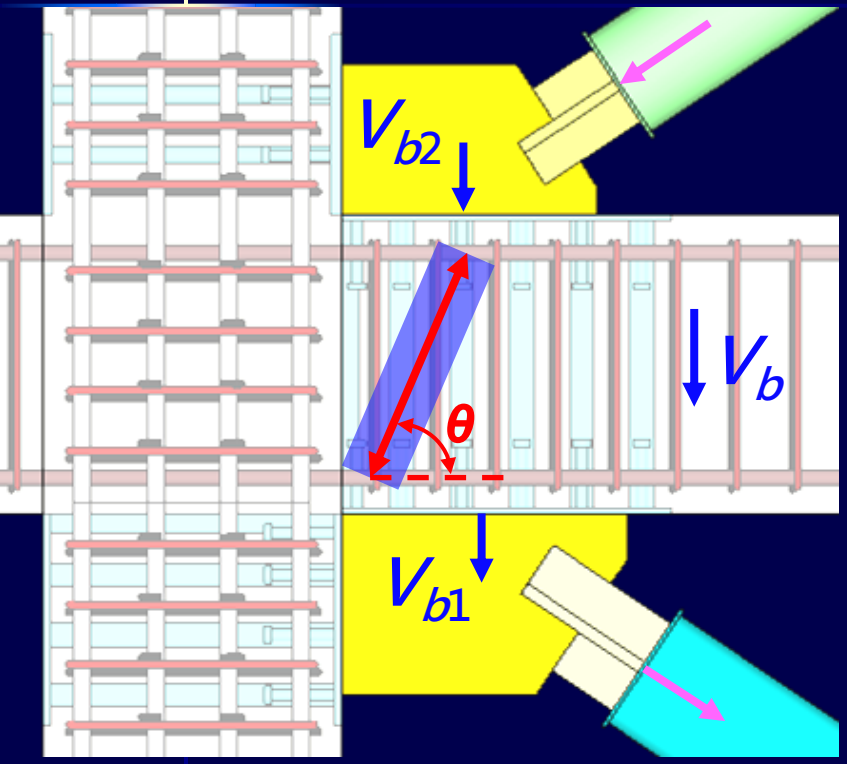
K : 壓拉桿指標

ζ : 混凝土軟化係數 $= 3.35 / \sqrt{f_c'(MPa)} \leq 0.52$

A_{str} : 壓桿有效斷面積

軟化壓拉桿模型簡算法

[黃世建、李宏仁，2002]



應變諧和條件

$$0 \le \gamma_h = \frac{2\tan\theta - 1}{3} \le 1$$

$$0 \le \gamma_v = \frac{2\cot\theta - 1}{3} \le 1$$

$$\overline{K_h} = \frac{1}{1 - 0.2(\gamma_h + \gamma_h^{\,2})}$$

$$\overline{K_v} = \frac{1}{1 - 0.2(\gamma_v + \gamma_v^{\,2})}$$

實際拉桿指標

$$\overline{F_h} = \gamma_h(\overline{K_h}\zeta f_c' A_{str})\cos\theta$$

$$\overline{F_v} = \gamma_v(\overline{K_v}\zeta f_c' A_{str})\sin\theta$$

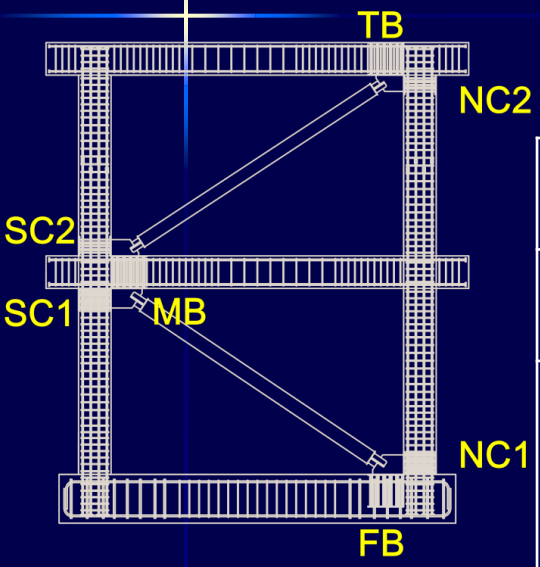
$$K_h = 1 + (\overline{K_h} - 1)\frac{A_{th} f_{yh}}{\overline{F_h}} \le \overline{K_h}$$

$$K_v = 1 + (\overline{K_v} - 1)\frac{A_{tv} f_{yv}}{\overline{F_v}} \le \overline{K_v}$$

$$C_d = (K_v + K_h - 1)\zeta f_c' A_{str} = K\zeta f_c' A_{str}$$

$$V_n = C_d \sin\theta$$

D-region設計檢核DCR



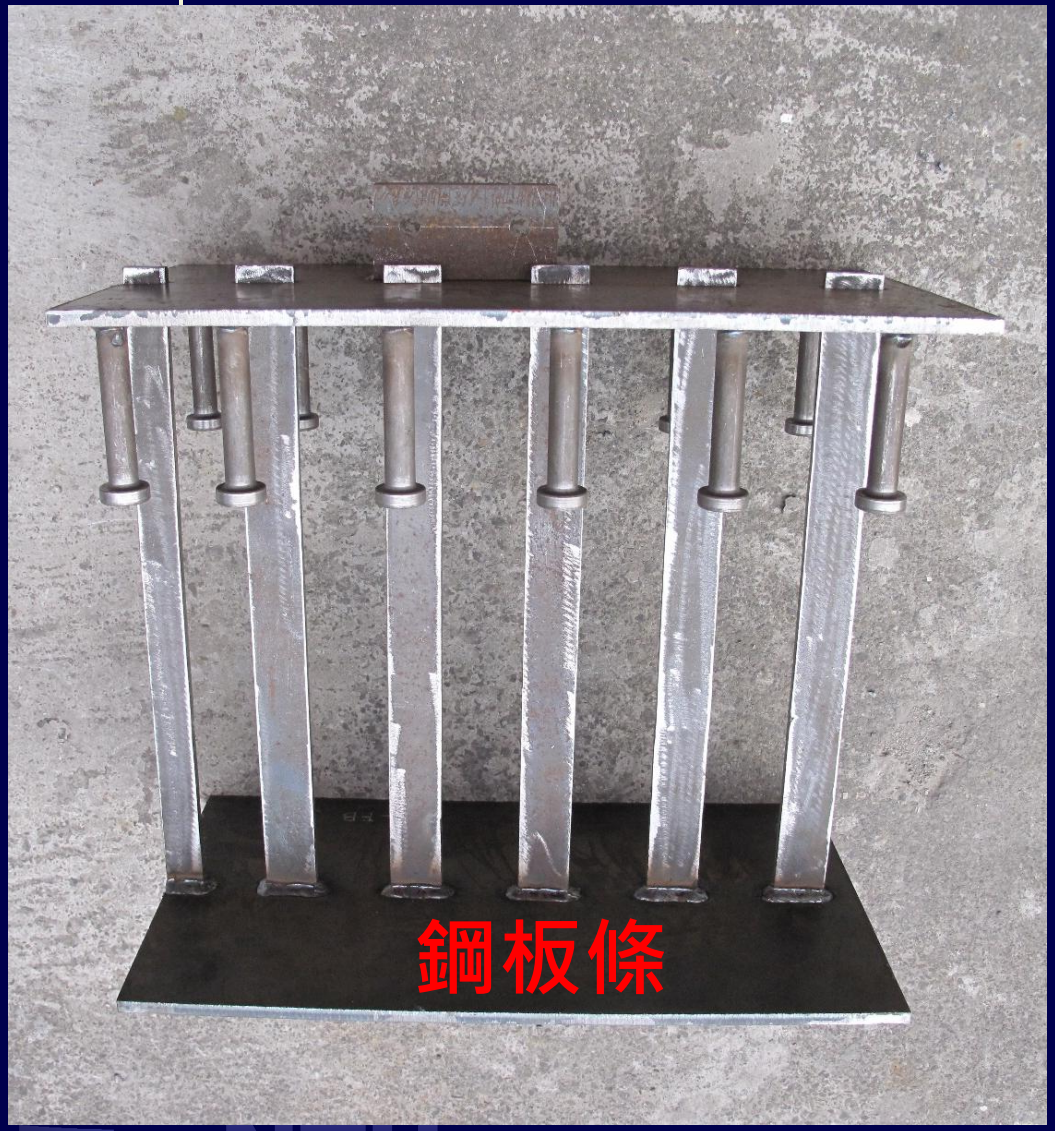
Location		NC1	FB	SC1	MB	SC2	NC2	TB
V_u		421	146	423	789	302	285	400
ACI 318 Deep beam	V_n (kN)	1057	4361	1057	958	1057	1057	858
	DCR	0.35	0.09	0.35	0.73	0.25	0.24	0.46
ACI 318 Corbel	V_n (kN)	1198	1648	1198	1086	1198	1198	863
	DCR	0.40	0.03	0.40	0.82	0.29	0.27	0.47
Simplified SST	V_n (kN)	1193	4052	1193	846	1255	1255	549
	DCR	0.35	0.04	0.35	0.93	0.24	0.23	0.73

NCREE NTU

簡報大綱

- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- **試體製作與施工**
- 試驗配置
- 試驗結果與討論

不同連接單元型式之預埋鐵件



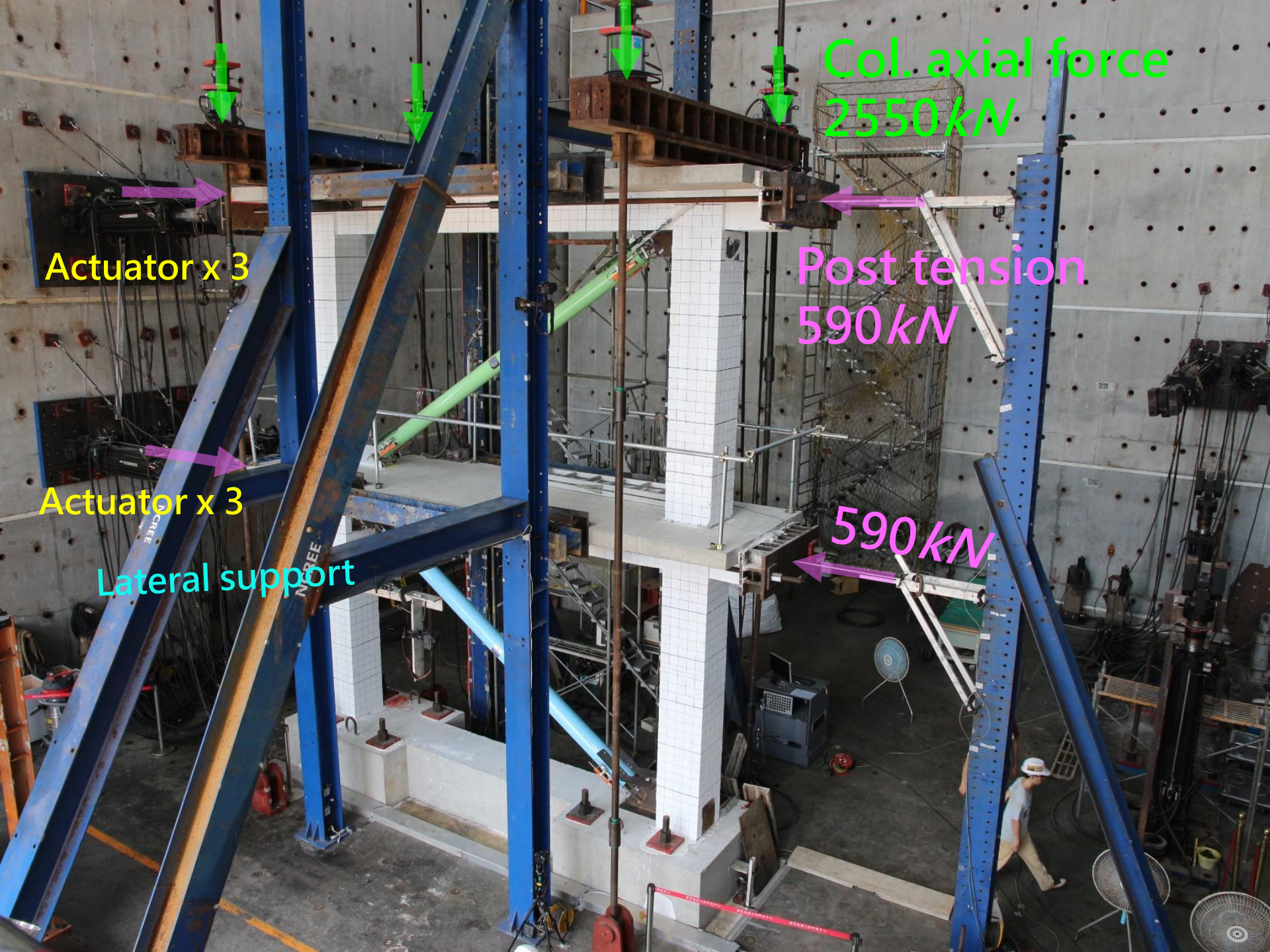
BRB-RCF試體完工

NCREE

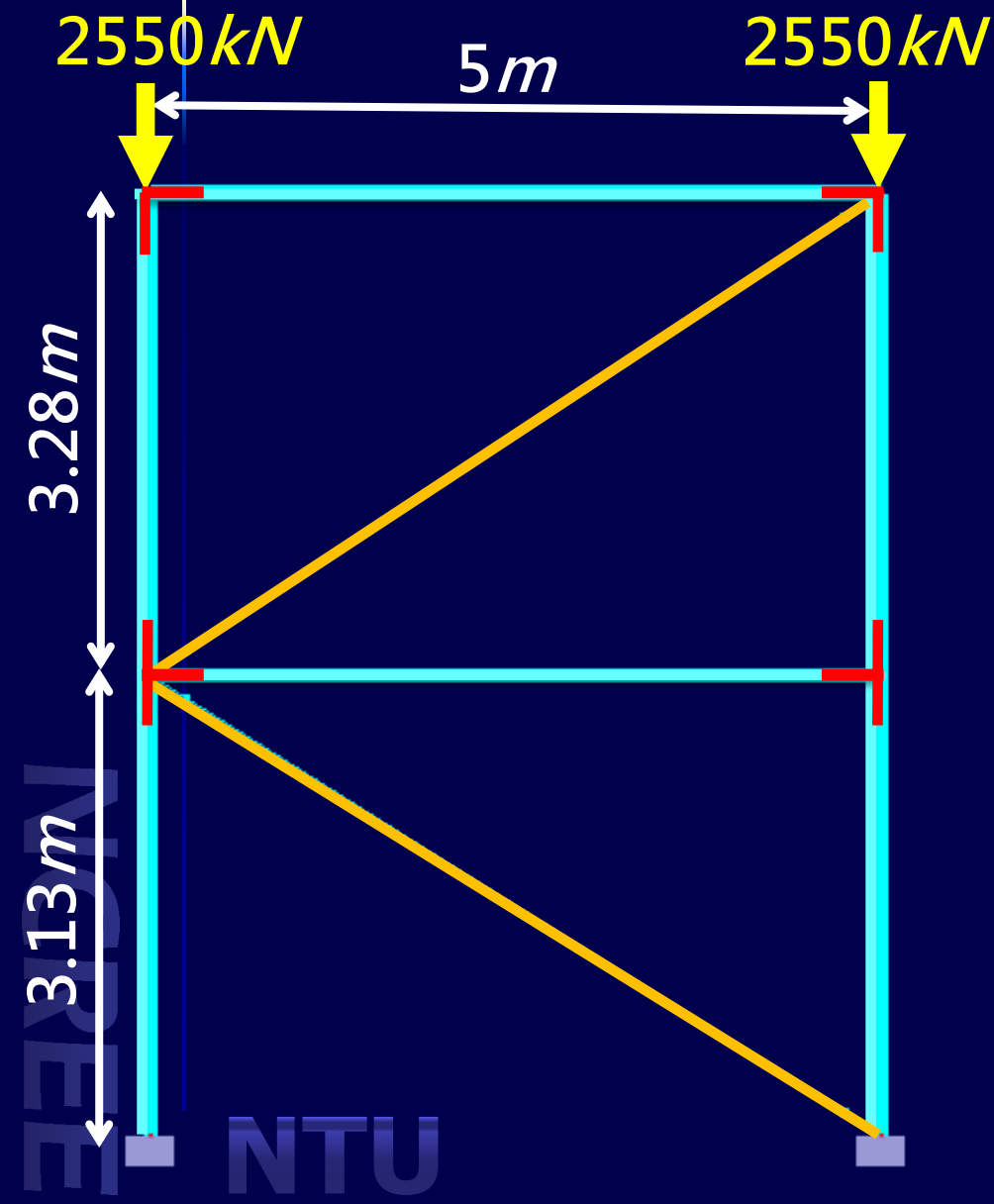
NTU

簡報大綱

- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- 試體製作與施工
- **試驗配置**
- 試驗結果與討論


Col. axial force
2550kN
Actuator x 3
Post tension
590kN
Actuator x 3
590kN
Lateral support

PISA3D非線性動力分析模型



考慮構件端部剛域

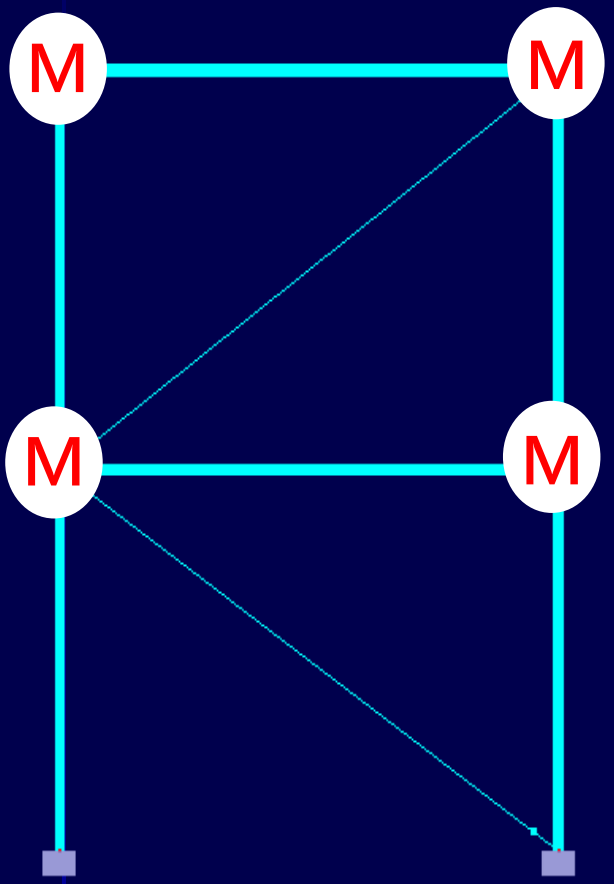
柱及T型梁斷面:

- 纖維梁柱元素 (Fiber element)
- 混凝土材料: Opensees Con04
- 鋼筋材料: Degrading

BRB:

- 走動與等向硬化材料 (Hardening material)
- 桁架元素 (Truss element)

選定質量與阻尼



選定質量
使第一振態週期
$T_1 \approx 0.4sec$

假設上下層
質量相同

$Mass = 0.113 kN \cdot s^2/mm$

$\xi_1 = \xi_2 = 2\%$

$T_1 = 0.38sec$
$T_2 = 0.13sec$

試驗程序-擬動態試驗階段

Free vibration test 1

50/50 hybrid test

Free vibration test 2

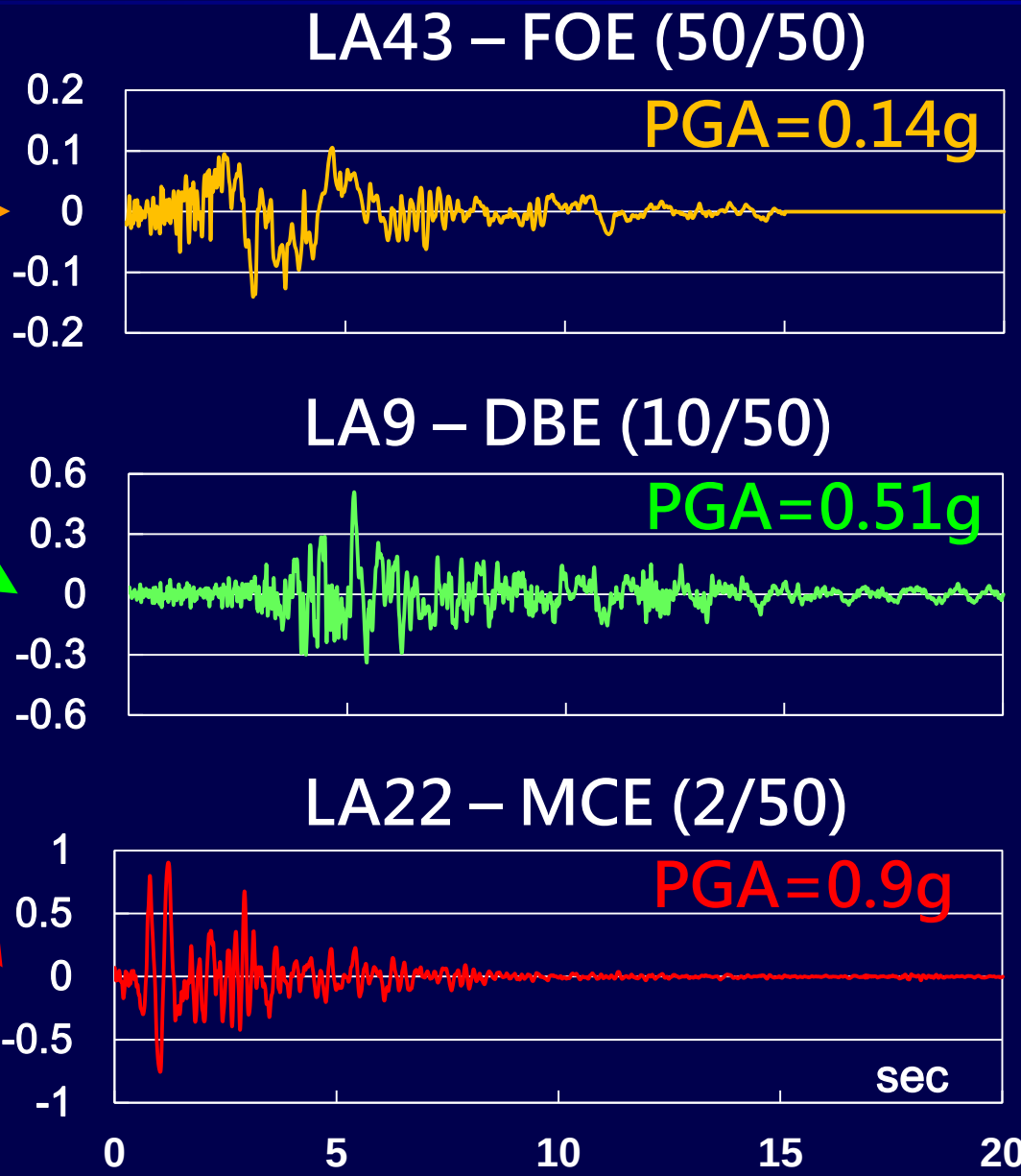
10/50 hybrid test

Free vibration test 3

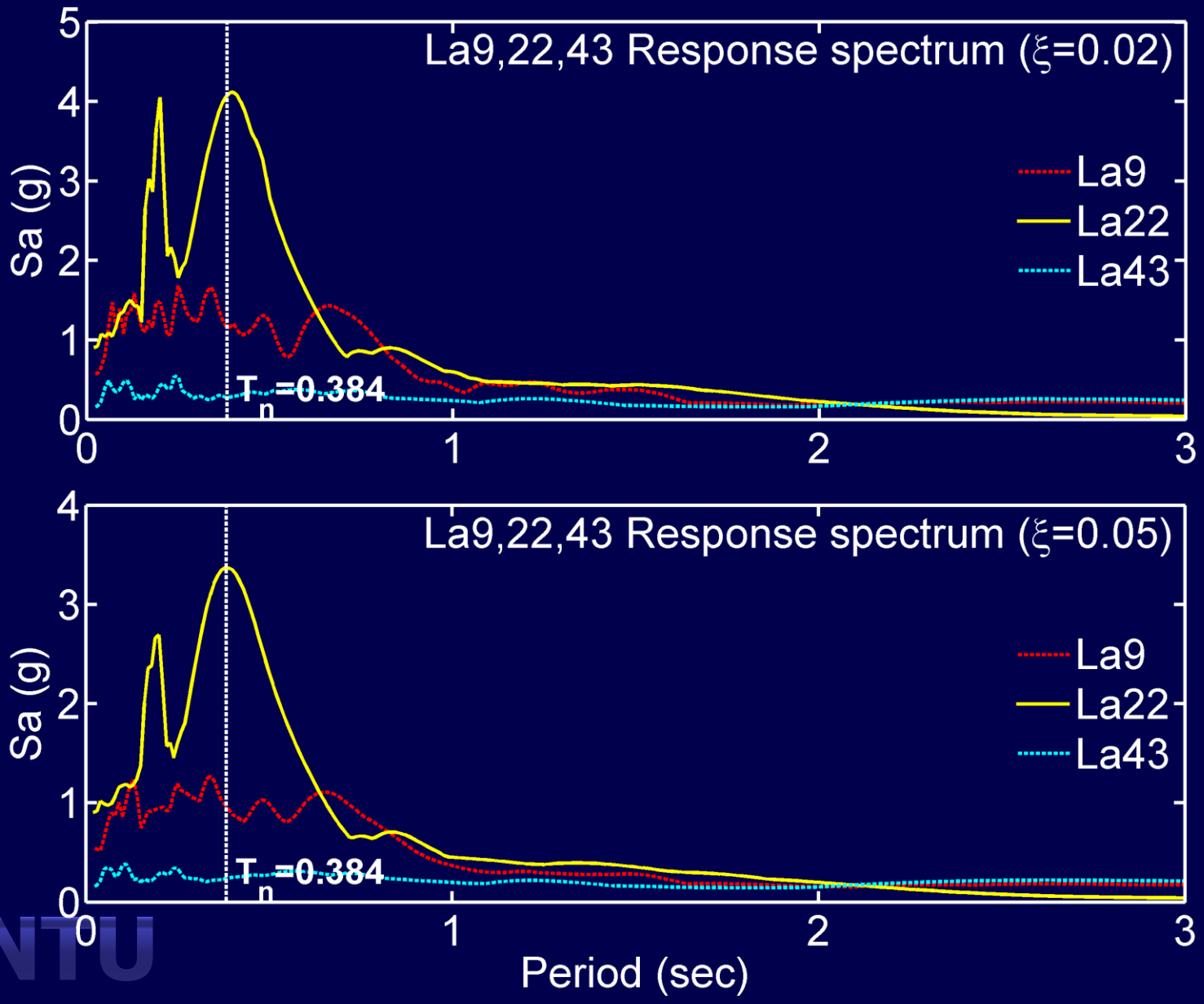
2/50-1 hybrid test

Free vibration test 4

2/50-2 hybrid test



加速度反應譜 (2%與5%阻尼)



試驗程序-反覆載重試驗階段

Free vibration test 1

50/50 hybrid test

Free vibration test 2

10/50 hybrid test

Free vibration test 3

2/50-1 hybrid test

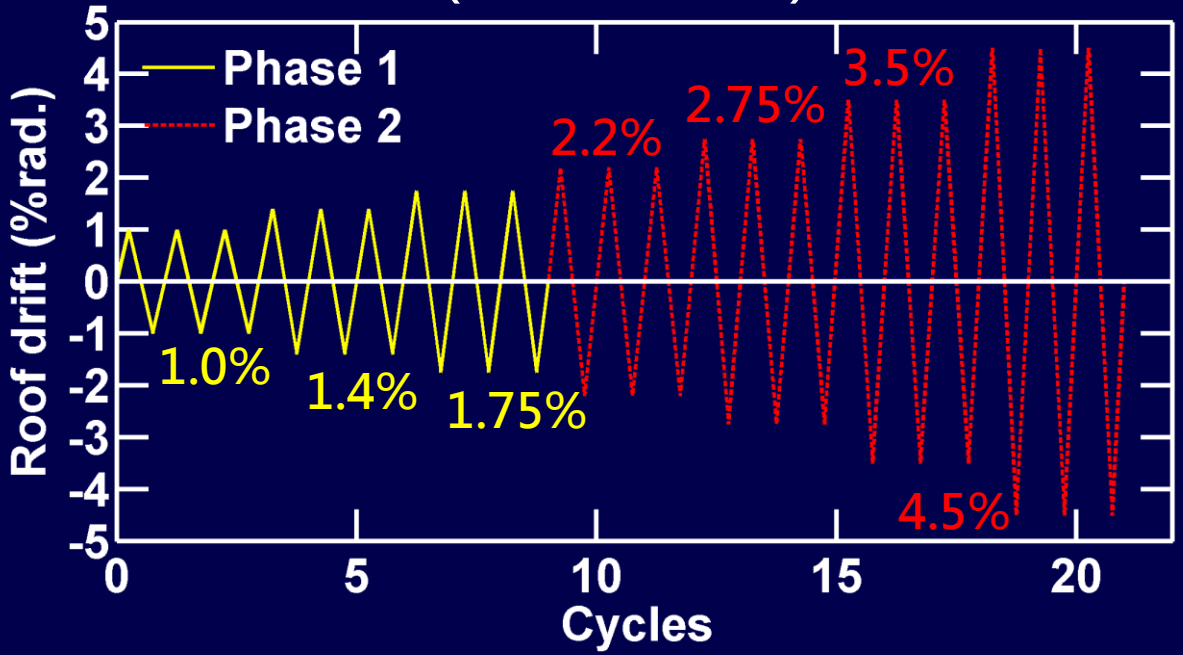
Free vibration test 4

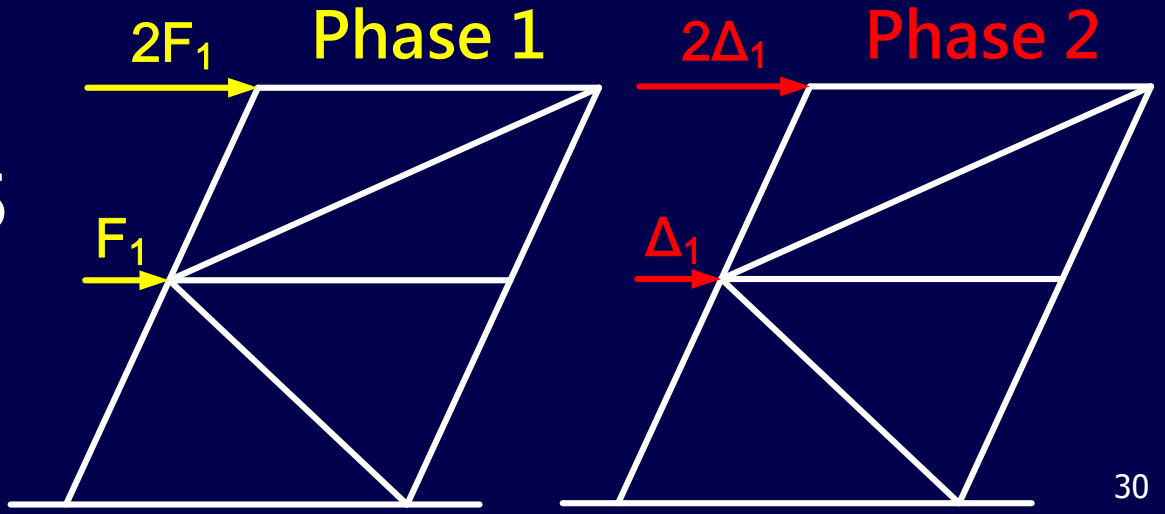
2/50-2 hybrid test

Free vibration test 5

Cyclic loading test

(ACI 374.1-05)





簡報大綱

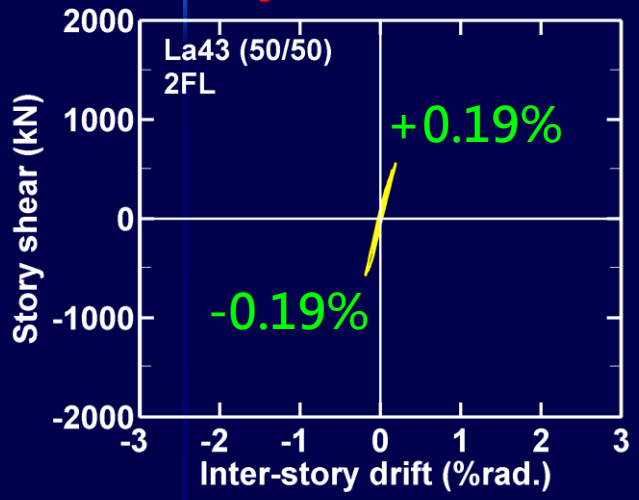
- BRB-RCF設計步驟
- 預埋鐵件設計
- RC構件D-region設計檢核
- 試體製作與施工
- 試驗配置
- 試驗結果與討論

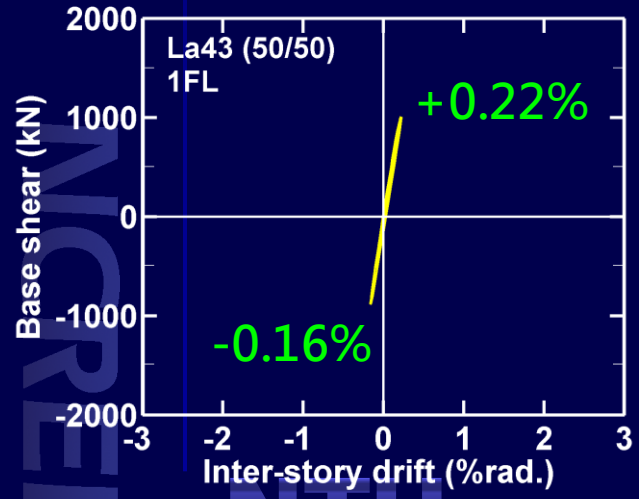
NCREE

NTU

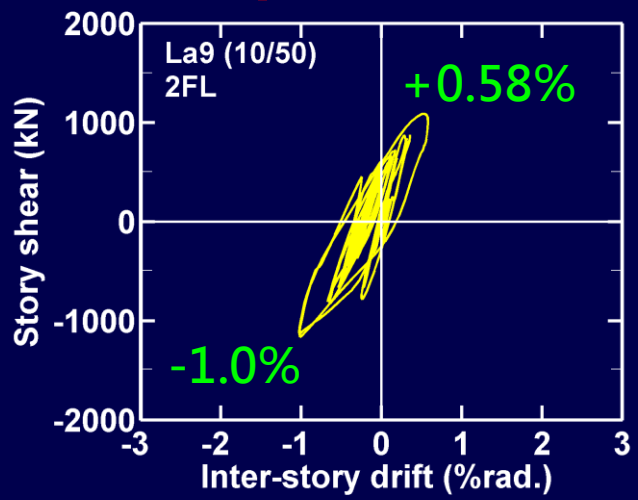
樓層剪力-層間側位移角

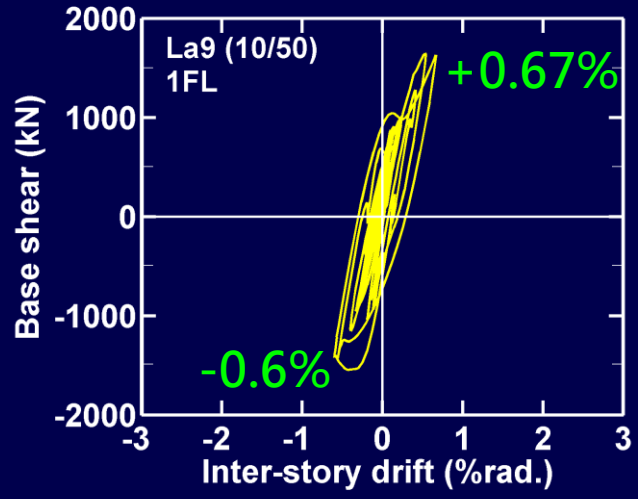
50/50-FOE



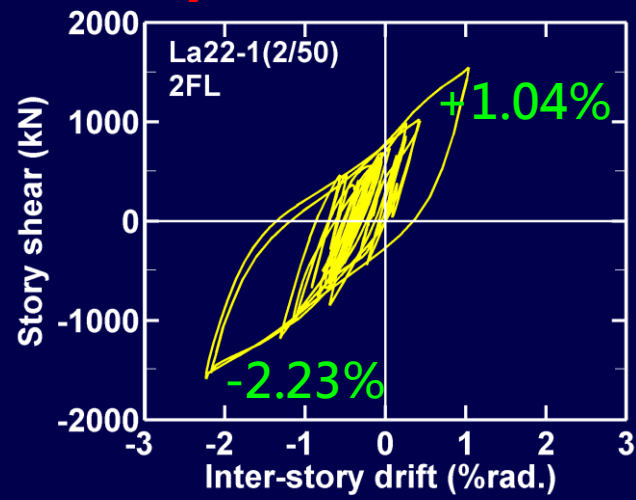


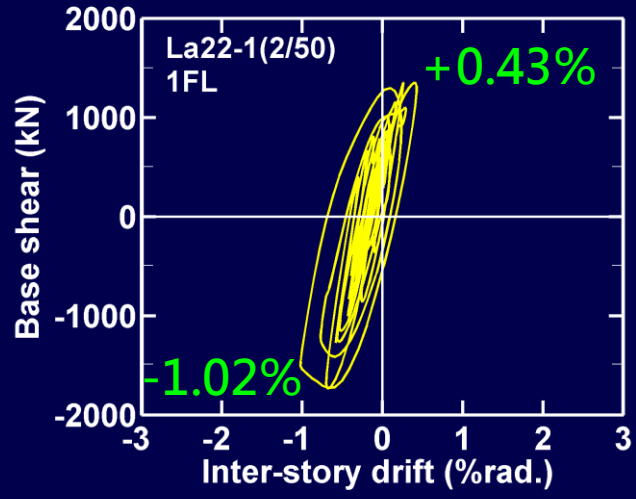
10/50-DBE





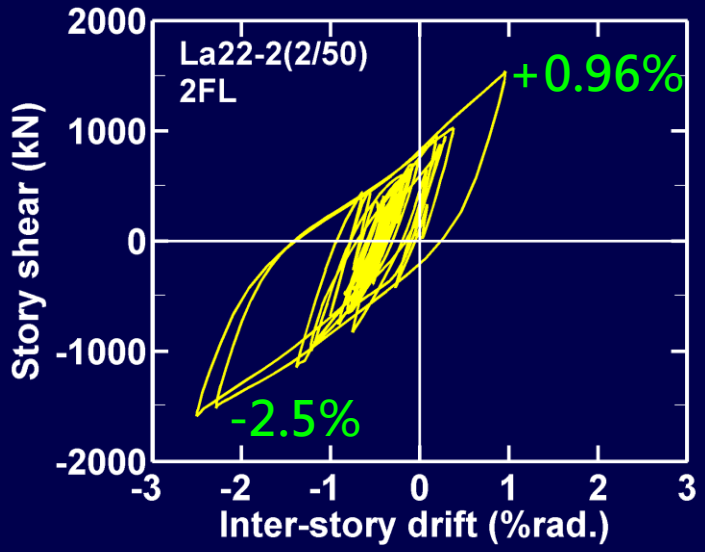
2/50-MCE 1

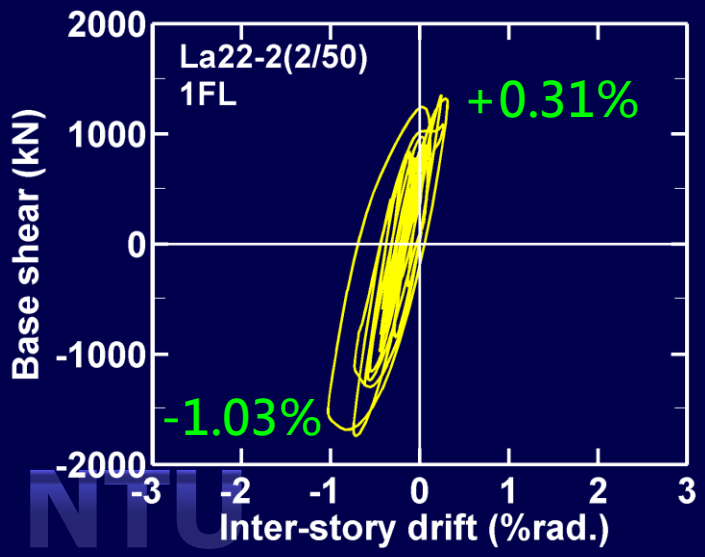




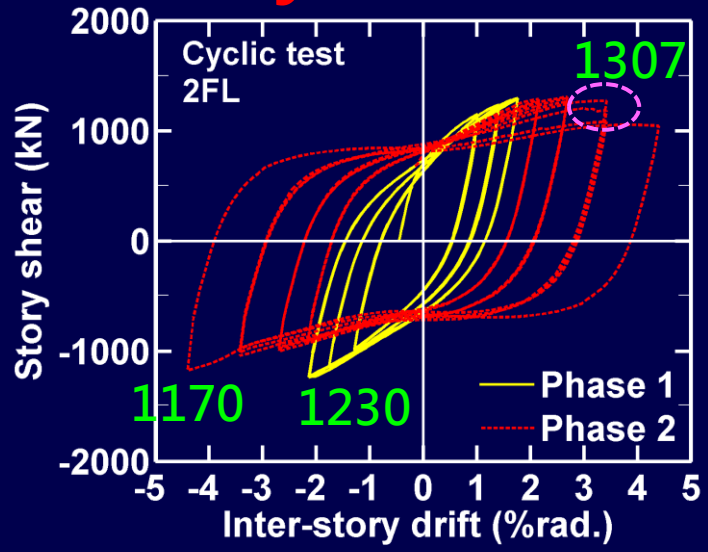
樓層剪力-層間側位移角

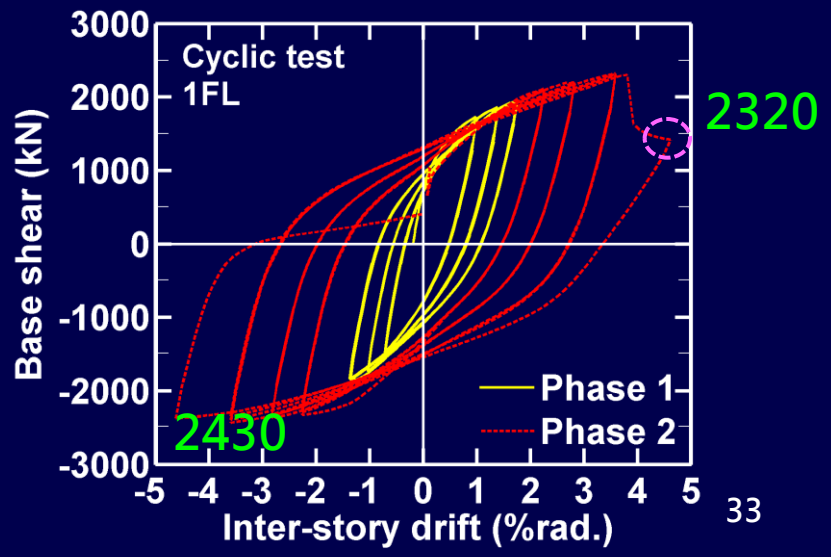
2/50-MCE 2





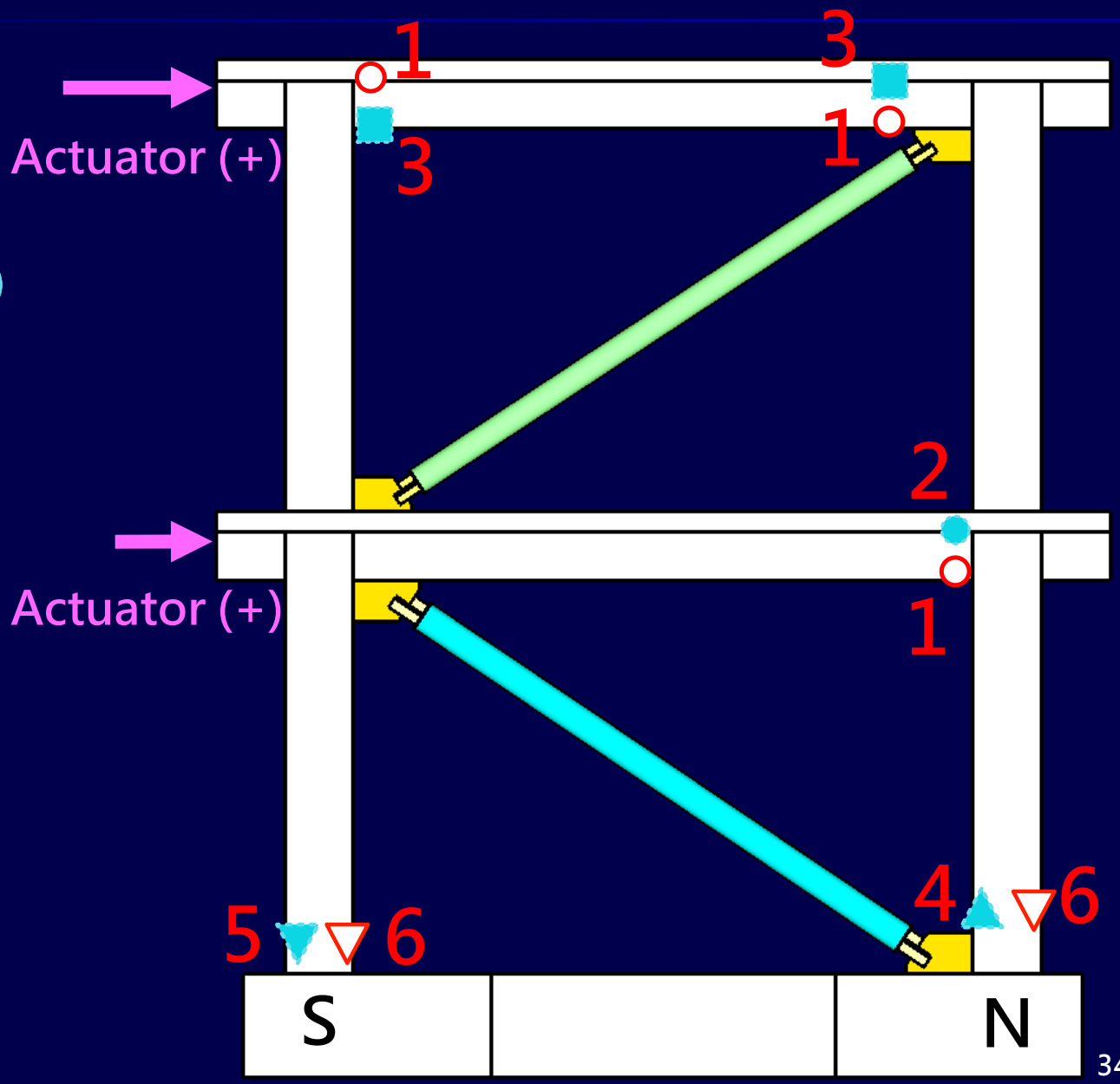
Cyclic test





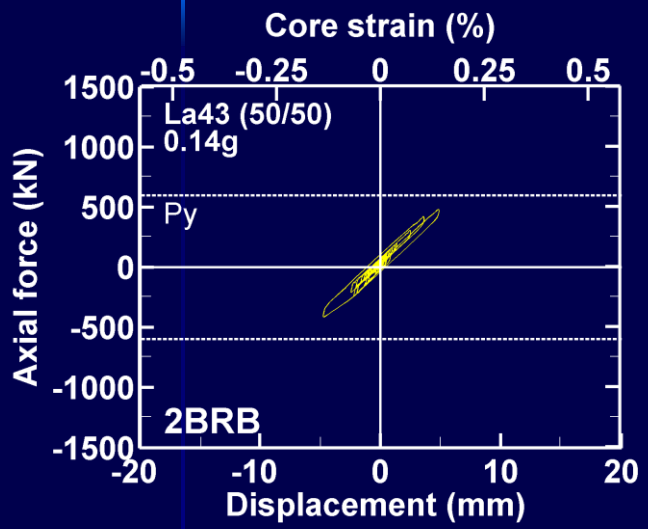
主筋降伏時機與順序

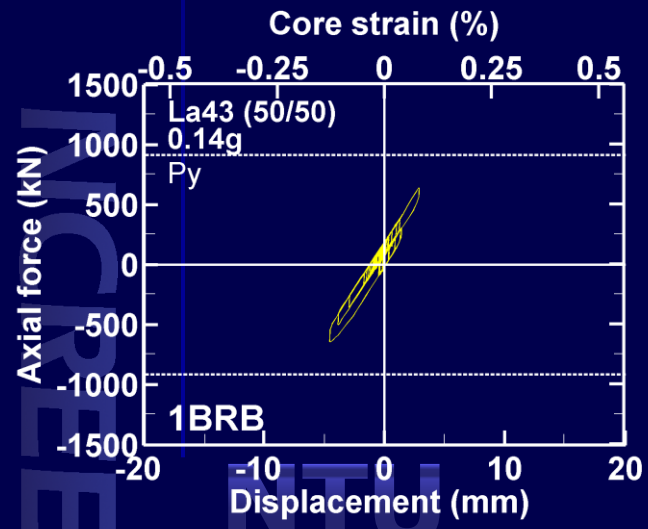
1: 10/50 5.35s (-)
2: 10/50 5.66s (+)
3: 2/50 1.23s (+)
4: CYC +1.0%
5: CYC +1.4%
6: CYC - 1.4%



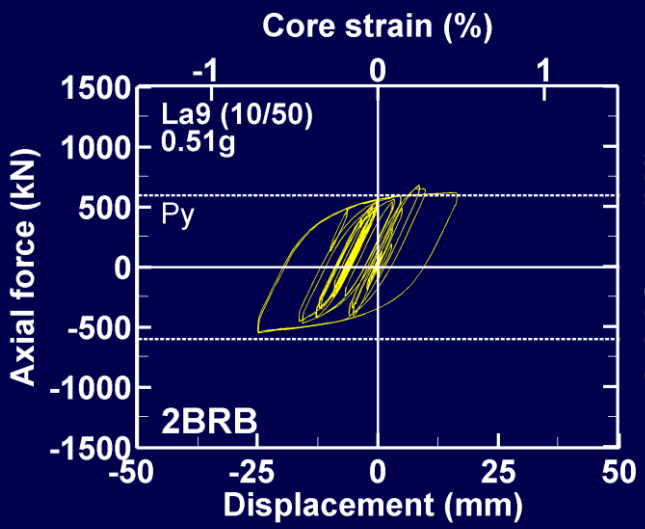
BRB軸力-軸向變形

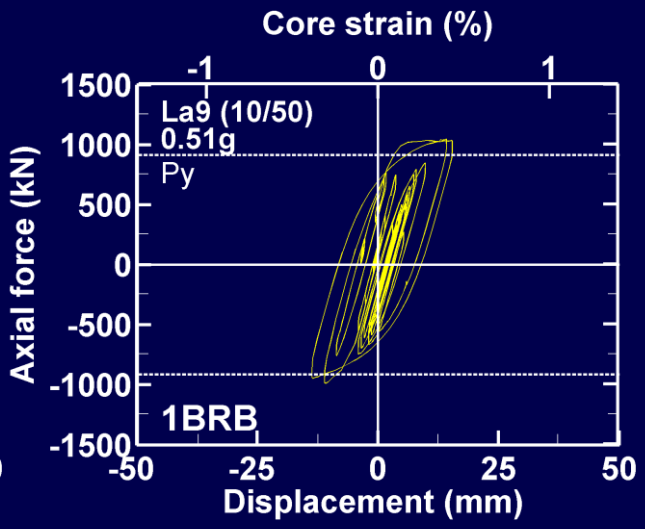
50/50-FOE



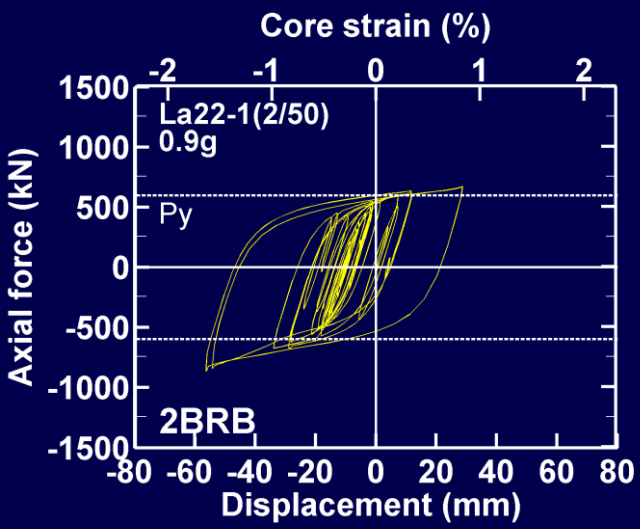


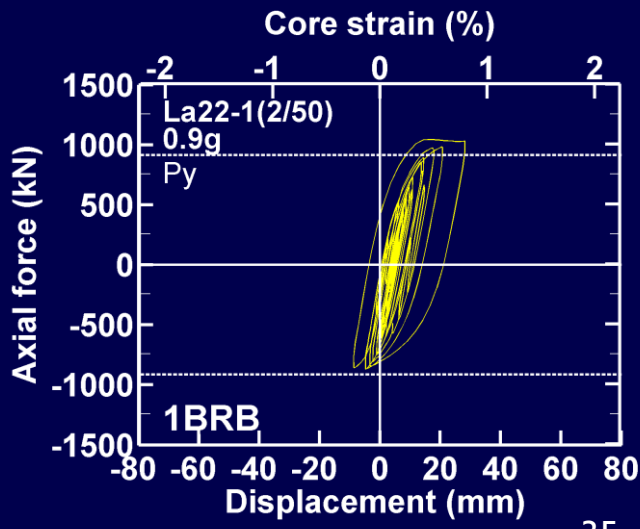
10/50-DBE





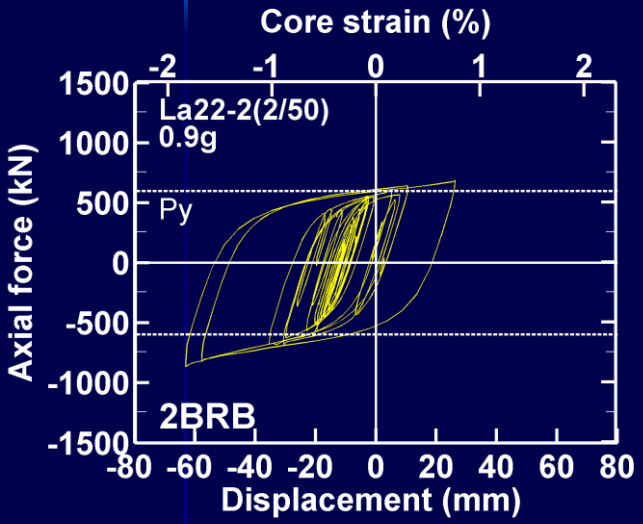
2/50-MCE 1



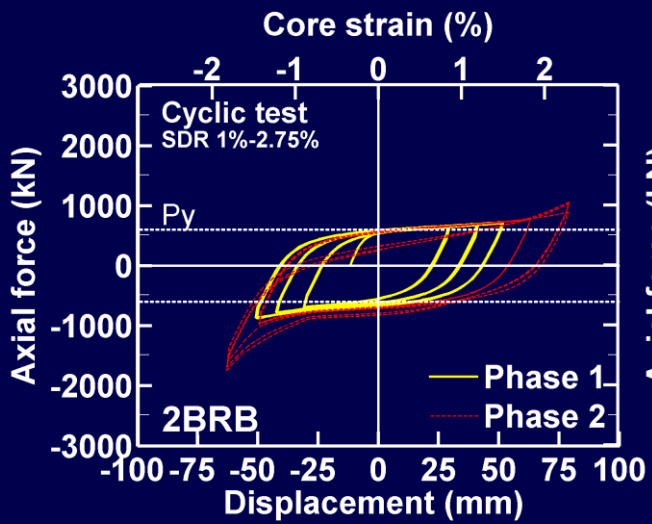


BRB軸力-軸向變形

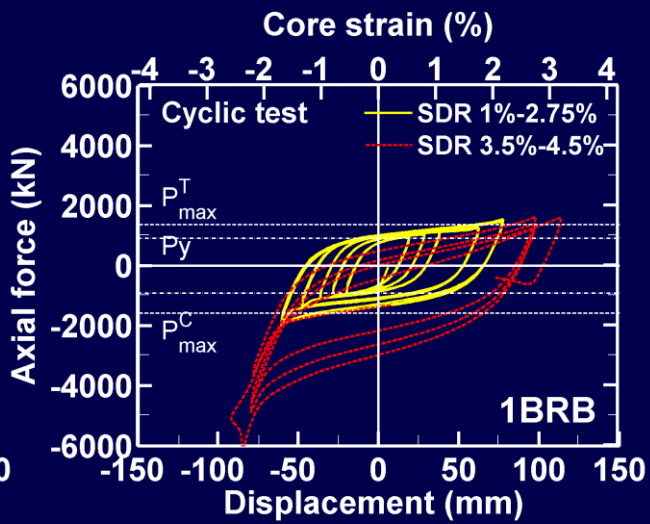
2/50-MCE 2

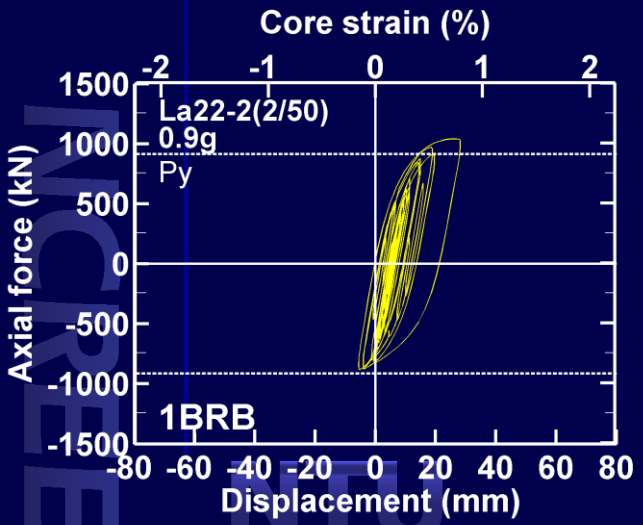


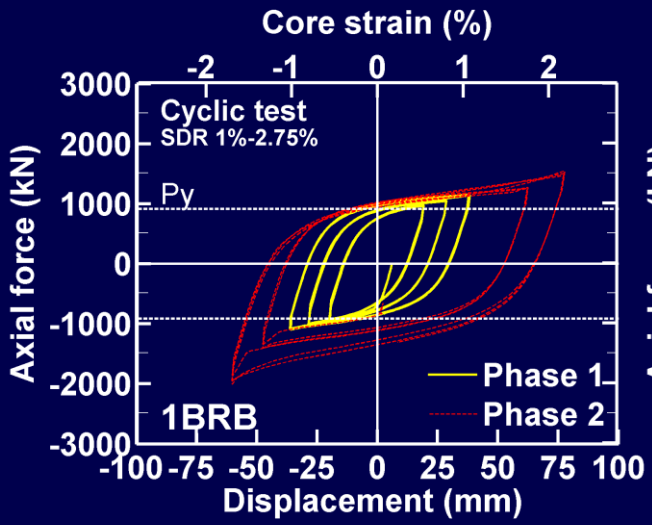
Cyclic test

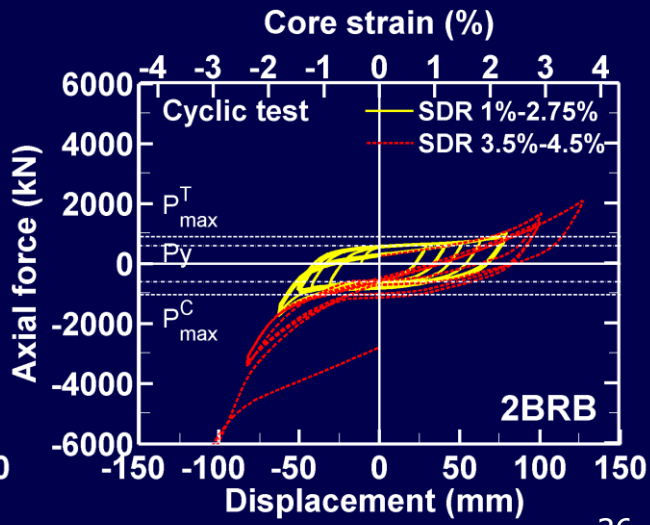


Cyclic test



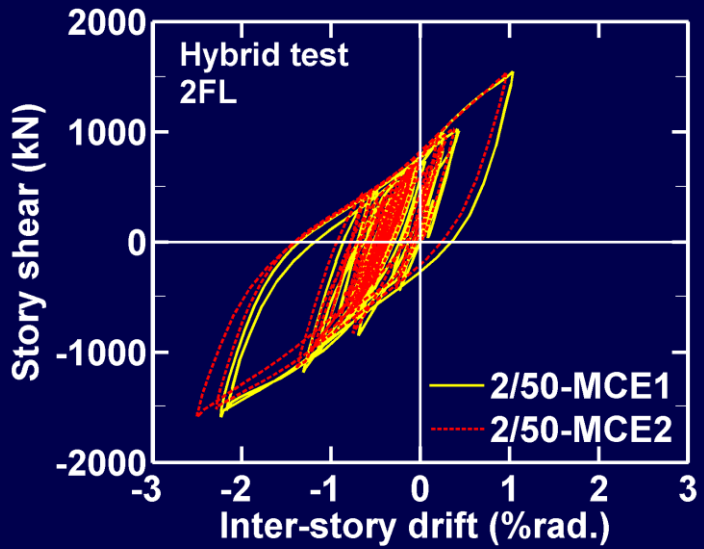


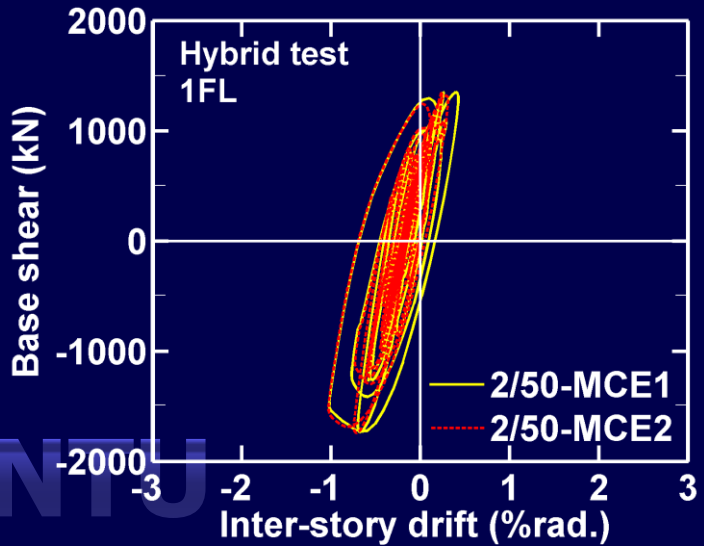




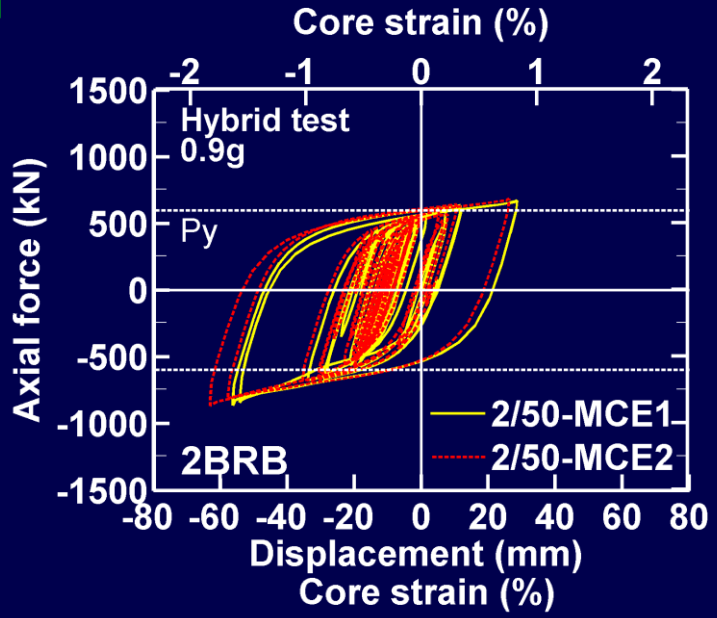
MCE 1 vs MCE 2

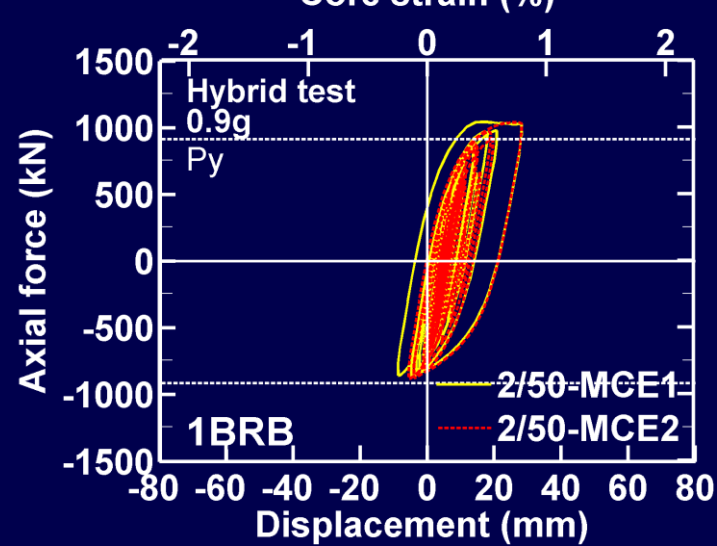
層剪力-樓層側位移角





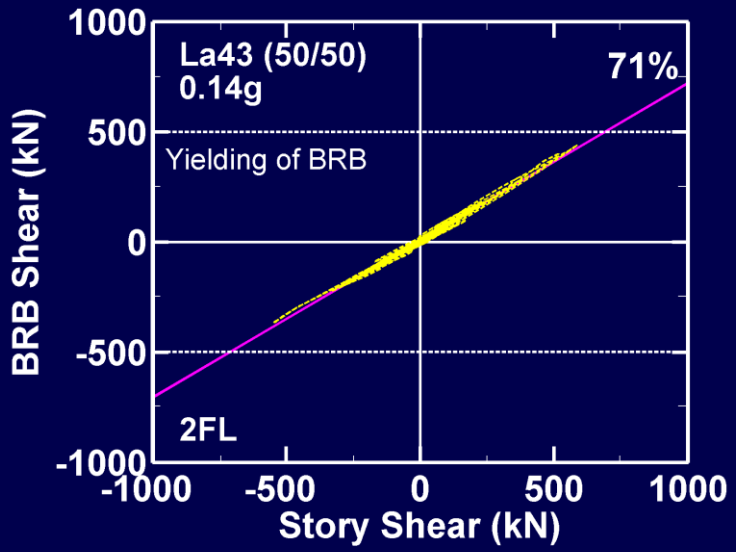
BRB受力變形

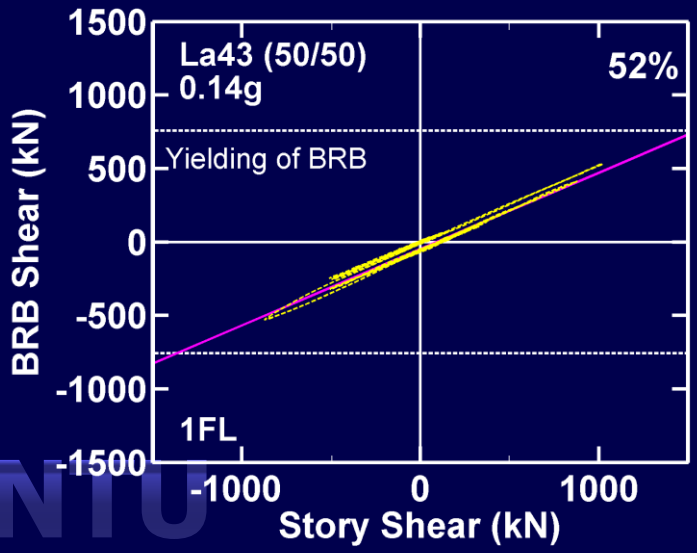




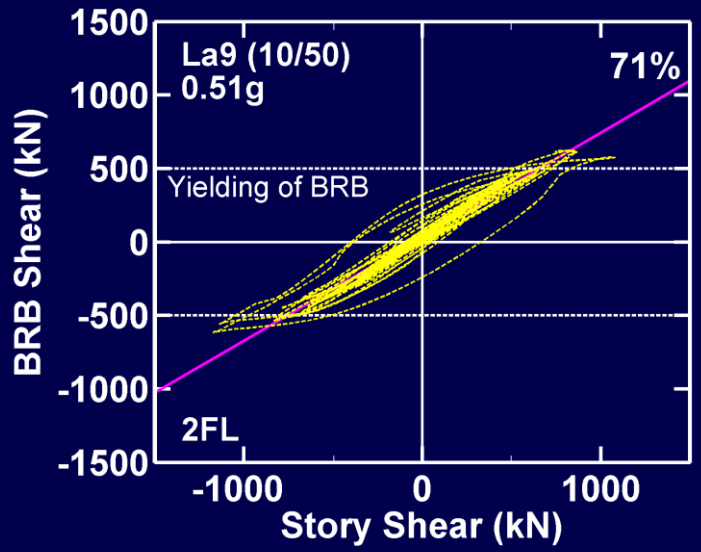
BRB水平剪力-樓層剪力

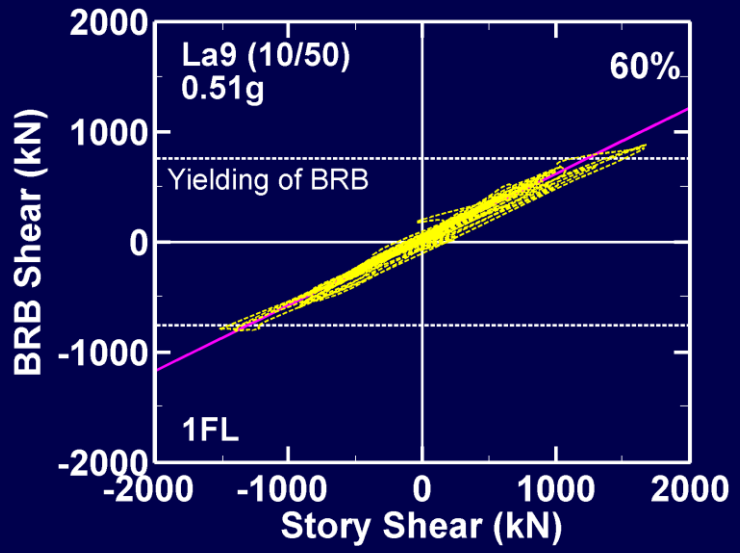
50/50-FOE





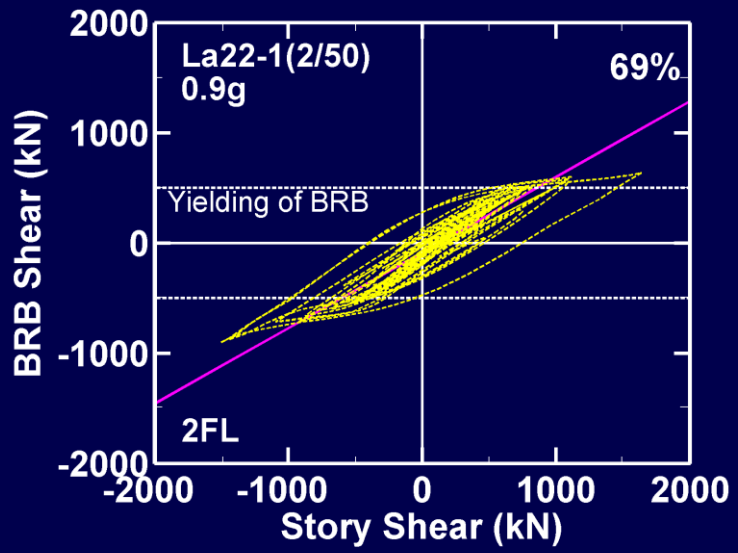
10/50-DBE



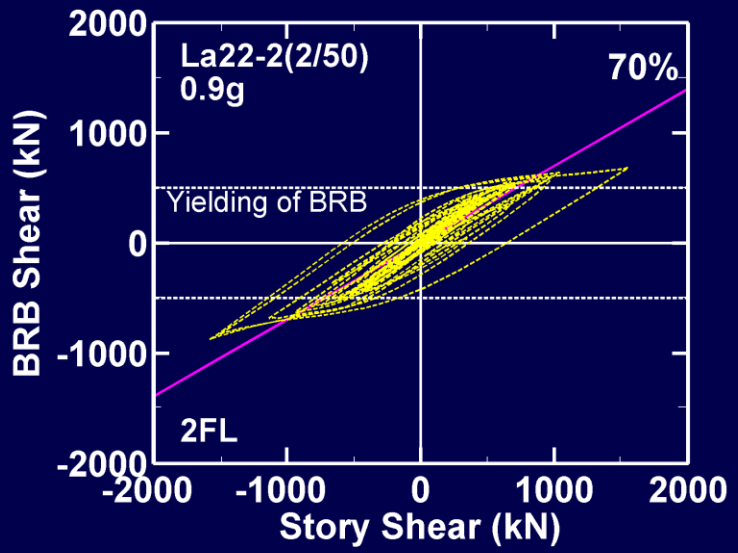


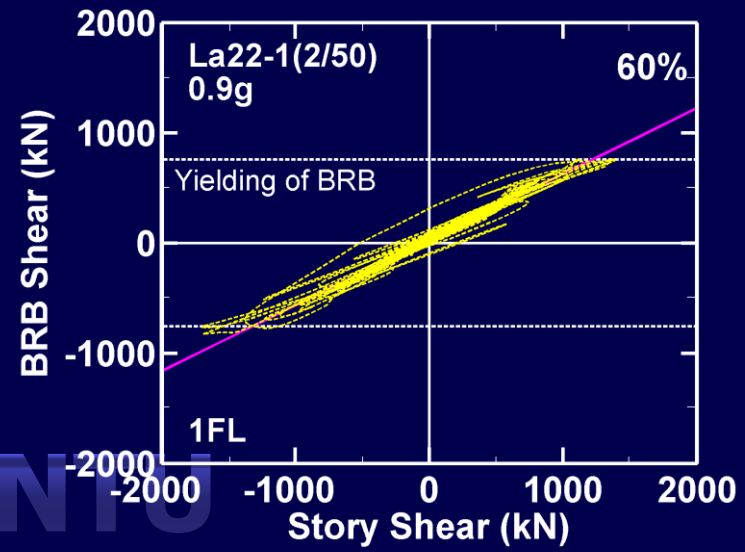
BRB水平剪力-樓層剪力

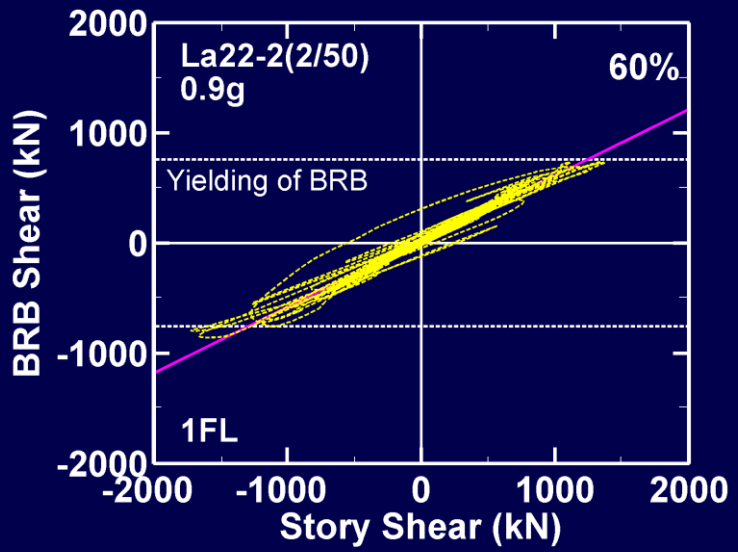
2/50-MCE 1



2/50-MCE 2







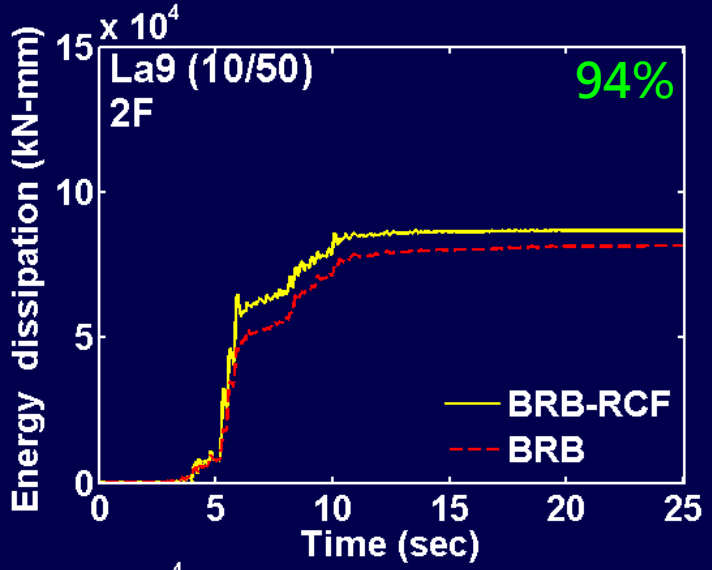
BRB累積非線性變形量(CPD)

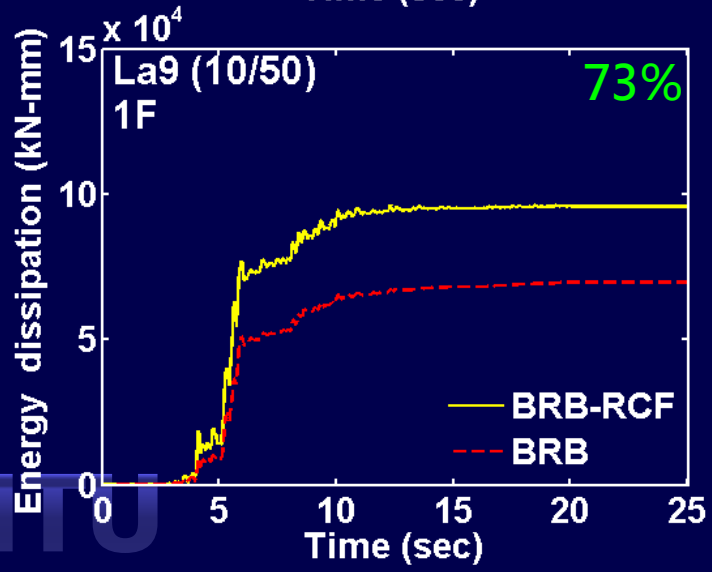
BRB	1F		2F	
Test	CPD	Cum. CPD	CPD	Cum. CPD
50/50	1	1	0	0
10/50	14	15	28	28
2/50-1	20	35	79	107
2/50-2	19	54	83	190
Cyclic test (to 2.75%)	422	476	490	679

>200 (AISC 341-10)

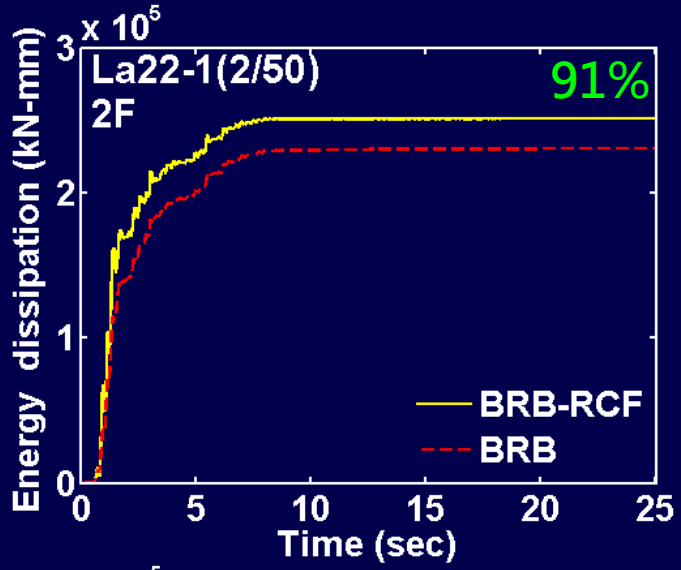
累積能量消散比例

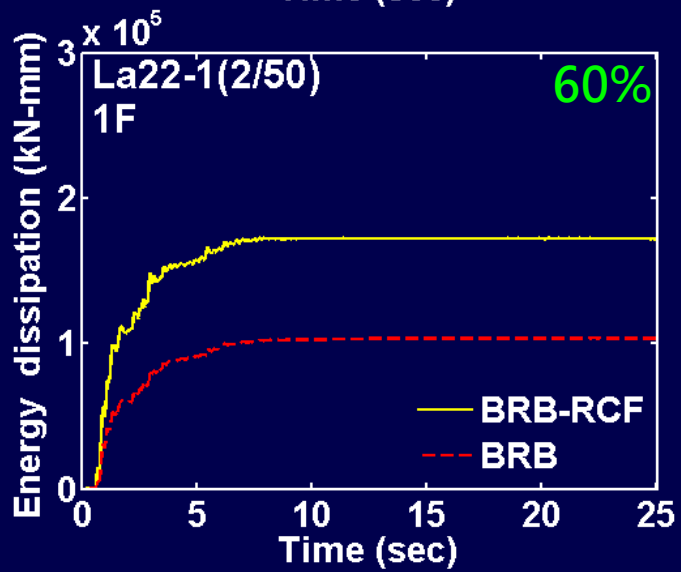
10/50-DBE





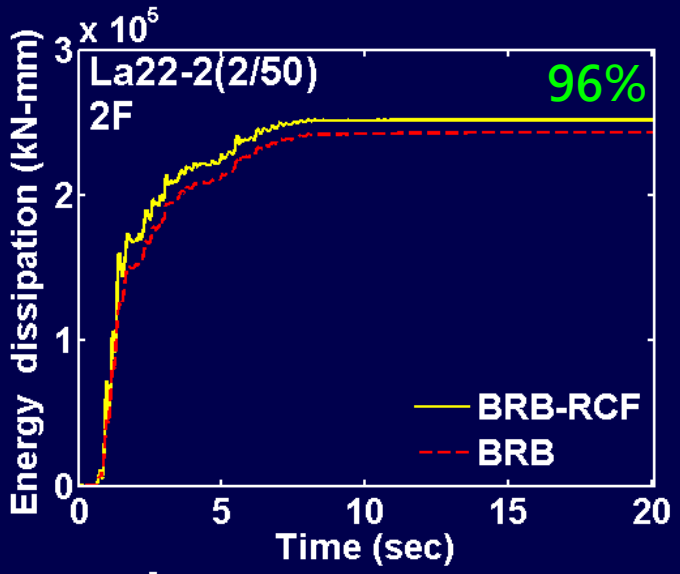
2/50-MCE 1

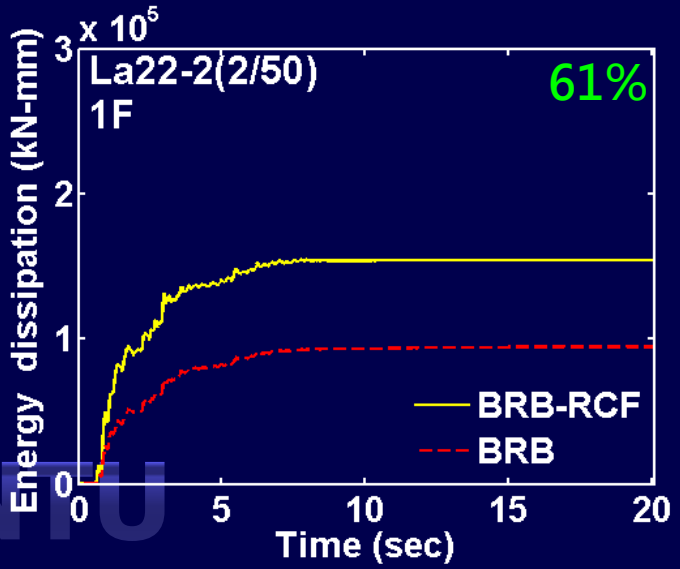




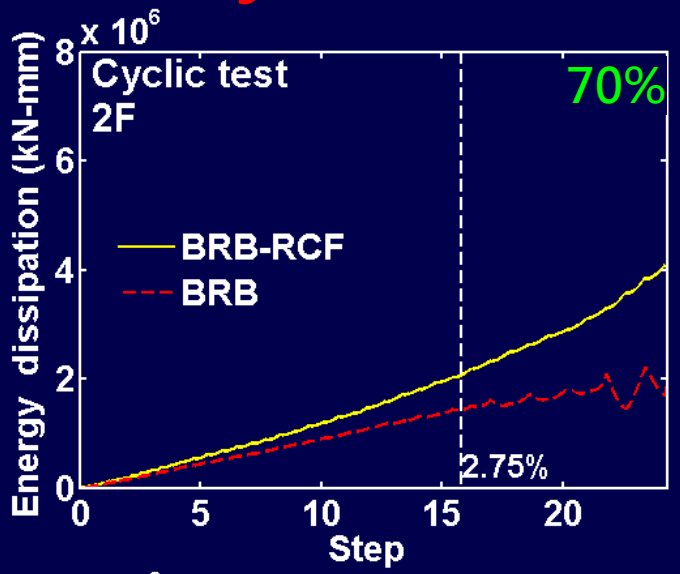
累積能量消散比例

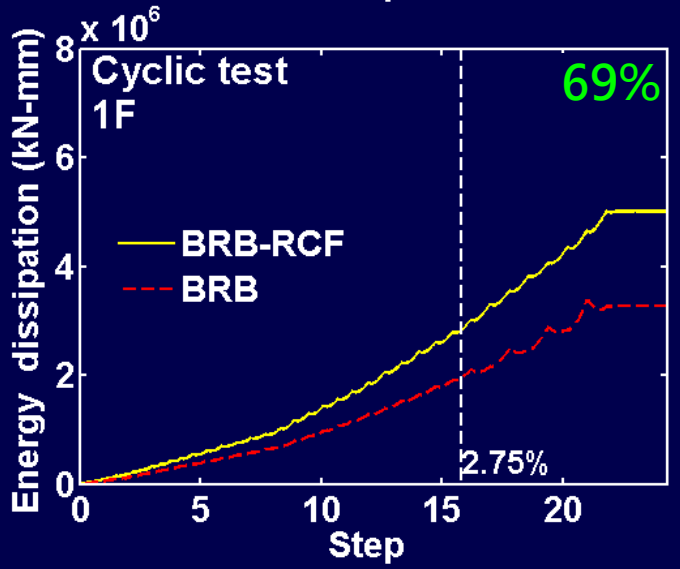
2/50-MCE 2





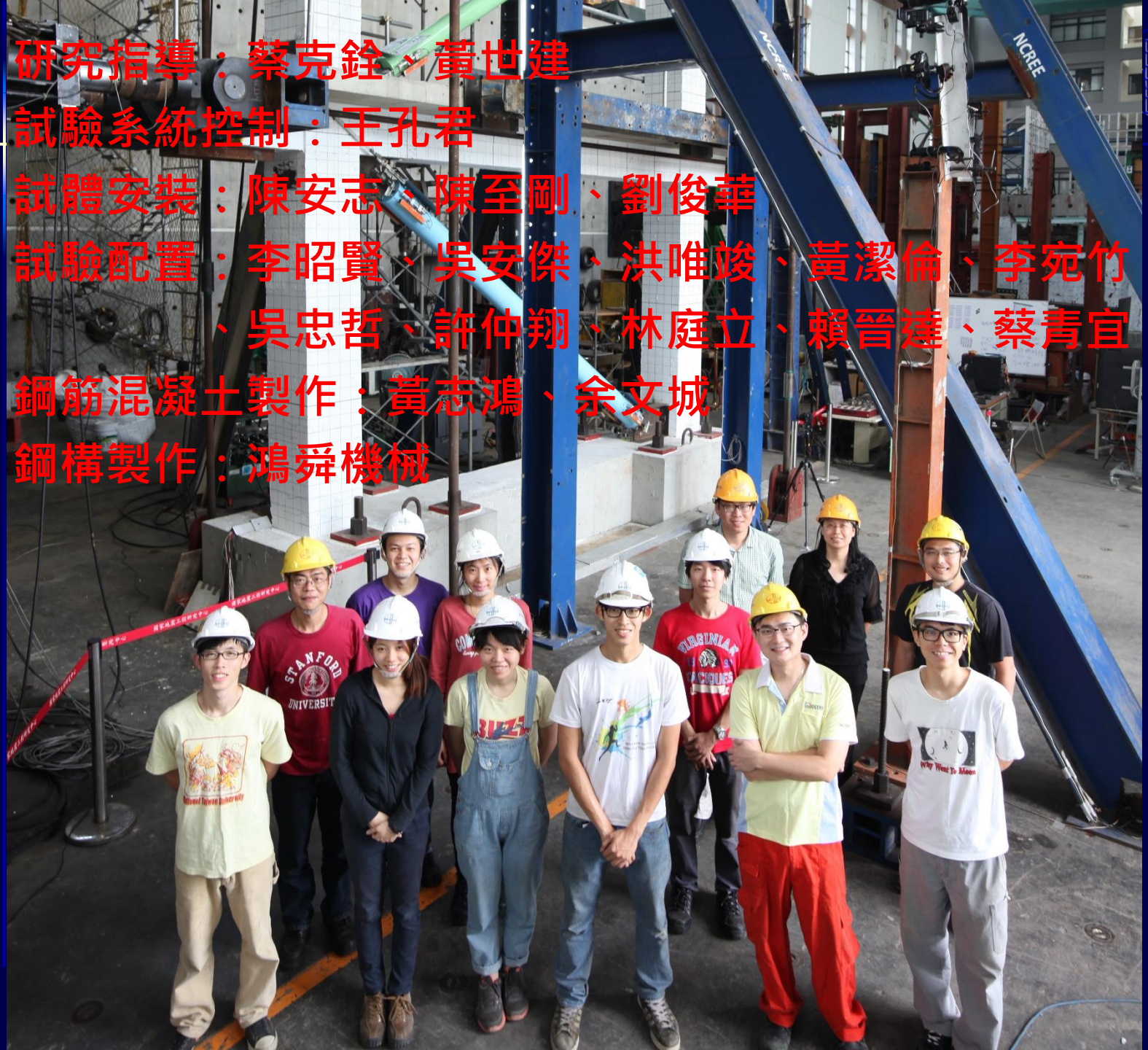
Cyclic test





結論

1. 預埋鐵件施工方法可行，梁柱鋼筋可順利綁紮
2. 鐵件設計步驟可確保BRB與RC構件之抗震性能試驗過程中沒有任何鐵件產生破壞
3. 預埋鐵件連接單元始終保持彈性，連接單元主要承受拉應力，無壓力符合預期
4. BRB降伏與梁柱塑鉸發生順序與預測相符
5. BRB水平剪力占樓層剪力約52%~71%
6. BRB可消散大部分的能量，能量消散比例介於60%~96%


研究指導：蔡克銓、黃世建
試驗系統控制：王孔君
試體安裝：陳安志、陳至剛、劉俊華
試驗配置：李昭賢、吳安傑、洪唯竣、黃潔倫、李宛竹
、吳忠哲、許仲翔、林庭立、賴晉達、蔡青宜
鋼筋混凝土製作：黃志鴻、余文城
鋼構製作：鴻舜機械
NCREE