



鋼斜撐補強設計

國家地震工程研究中心

蕭輔沛 博士

2016年5月13日

2016建築物耐震評估與補強技術講習會

www.narlabs.org.tw

簡報大綱

- ✓ 動機與目的
- ✓ 直接接合型鋼斜撐補強設計
- ✓ 間接接合型鋼斜撐補強設計

動機

- ✓ 鋼框架斜撐補強，可有效增加強度與韌性，且勁度適中
- ✓ 具有可工廠預鑄、組裝快速與施工環境清潔等優勢

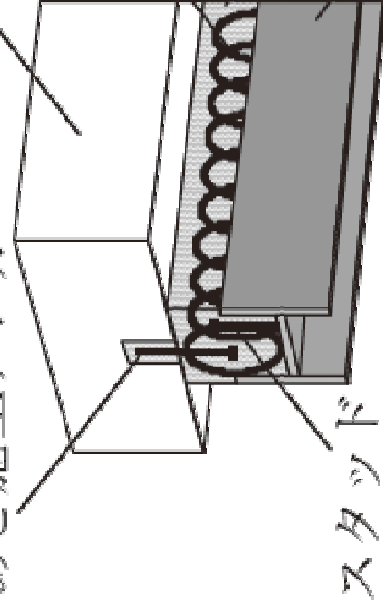
目的

- ✓ 框架斜撐與既有RC建物屬不同材質，要有良好接合才能有效地將力量傳遞
- ✓ 比較接口接合型式與受力行爲乃主要課題



あと施工アンカー

既存 RC 骨組



既存 RC 骨組

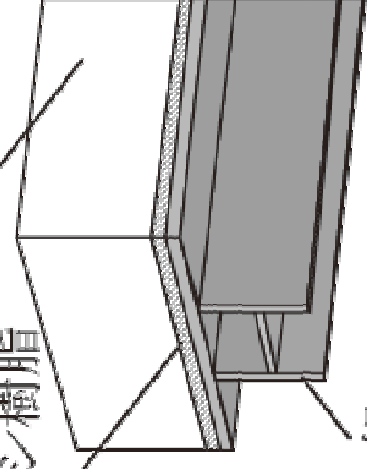
エポキシ樹脂

スパイラル筋

無収縮モルタル

鉄骨棒組

鉄骨棒組



- 褚有倫，「既有鋼筋混凝土結構應用直接接合型鋼框架斜撐補強工法之研究」，國立臺北科技大學碩士論文 (2014)。
- 林叡延，「補強用鋼框架斜撐與既有RC構架之接合研究」，國立臺灣大學碩士論文 (2013)。
- 楊季軒，「間接接合型鋼框架斜撐在鋼筋混凝土構架耐震補強之應用」，國立臺灣大學碩士論文 (2014)。
- 簡巧涵，「間接接合型鋼框架斜撐在RC構架之耐震補強研究」，國立臺灣大學碩士論文 (2015)。

直接接合型鋼斜撐補強設計

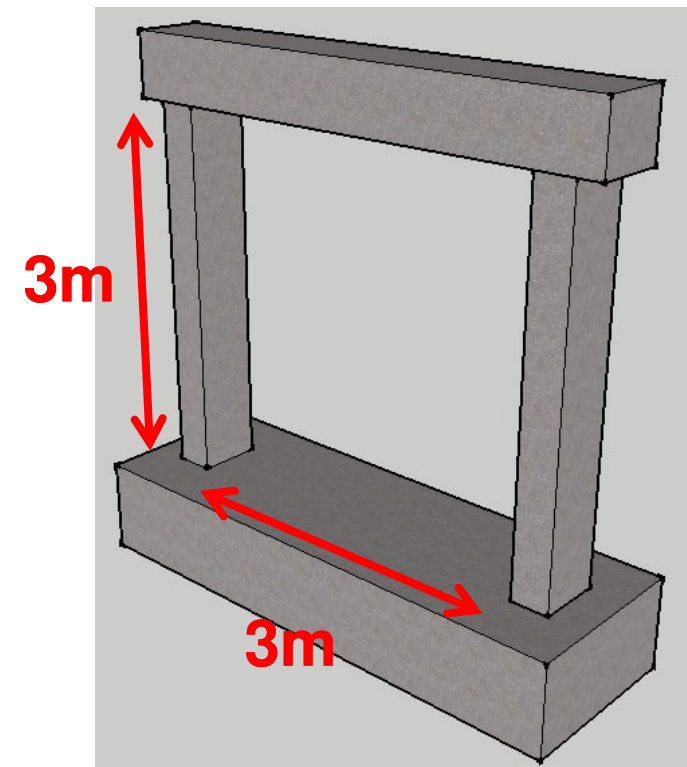
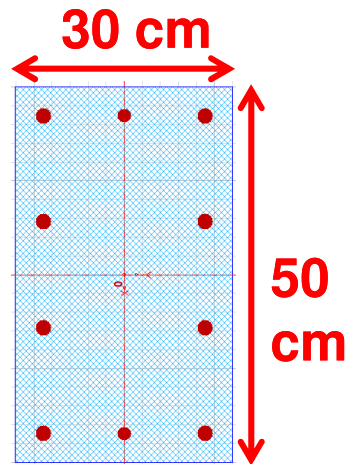
- ✓ 試驗規劃與試體設計
- ✓ 試驗結果與耐震行為之探討
- ✓ 試驗模擬與案例分析
- ✓ 結論

直接接合型鋼斜撐補強設計

✓ 試驗規劃與試體設計

純構架(Pure Frame)

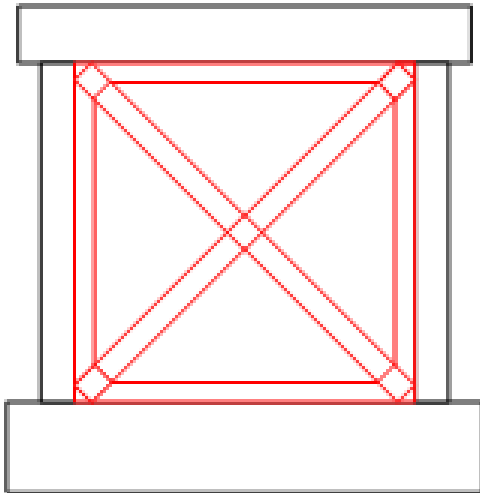
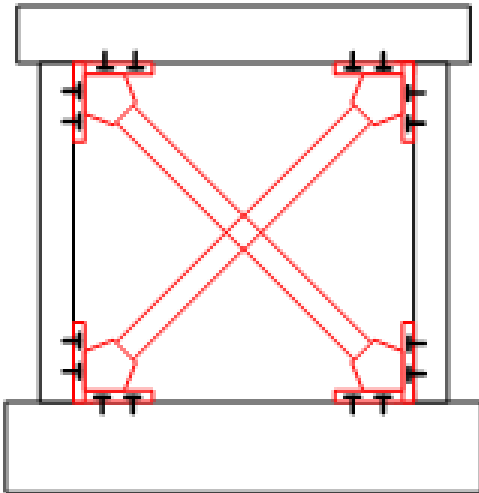
- 非韌性配筋構架
- 箍筋間距較大且未做135度彎鉤
- 柱配筋10-#8，主筋比(ρ_c)=3.38%



- 構架強度試驗結果約338 kN (設計強度約306 kN)

試驗規劃

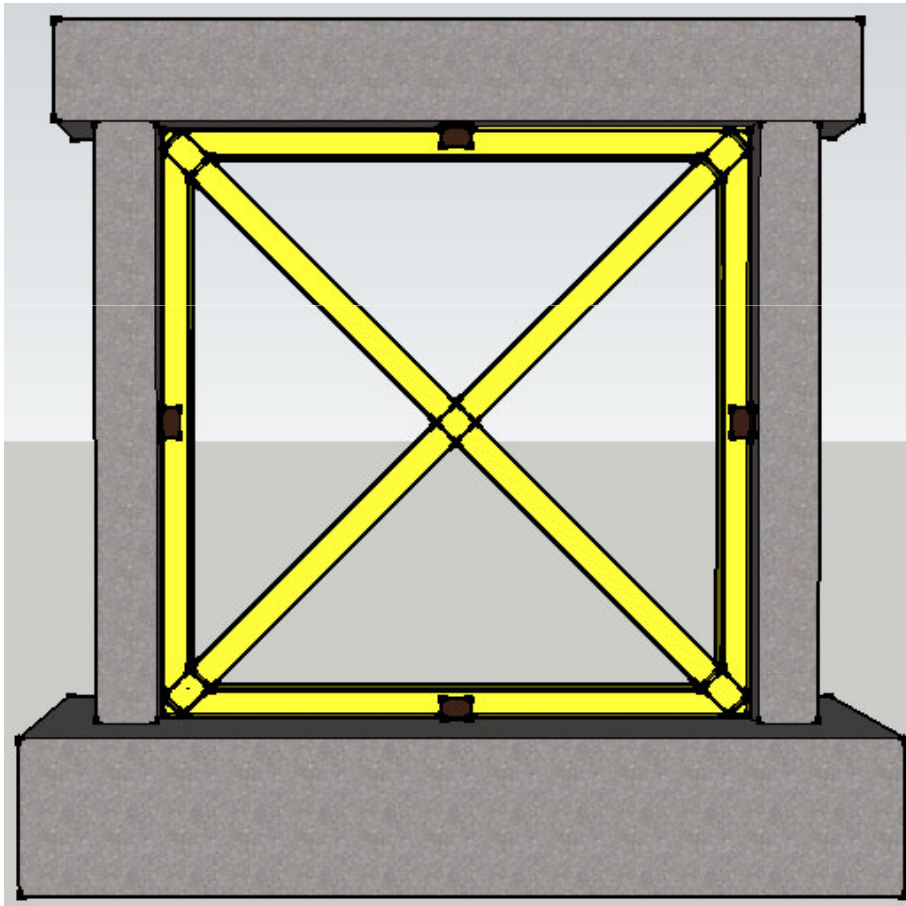
NAR Labs

試體	CPFX	DPFX
補強構件	鋼框架+X形鋼斜撐	X形鋼斜撐+L形基鈑
接合型式	介面填充環氧樹脂	化學錨栓接合
示意圖		

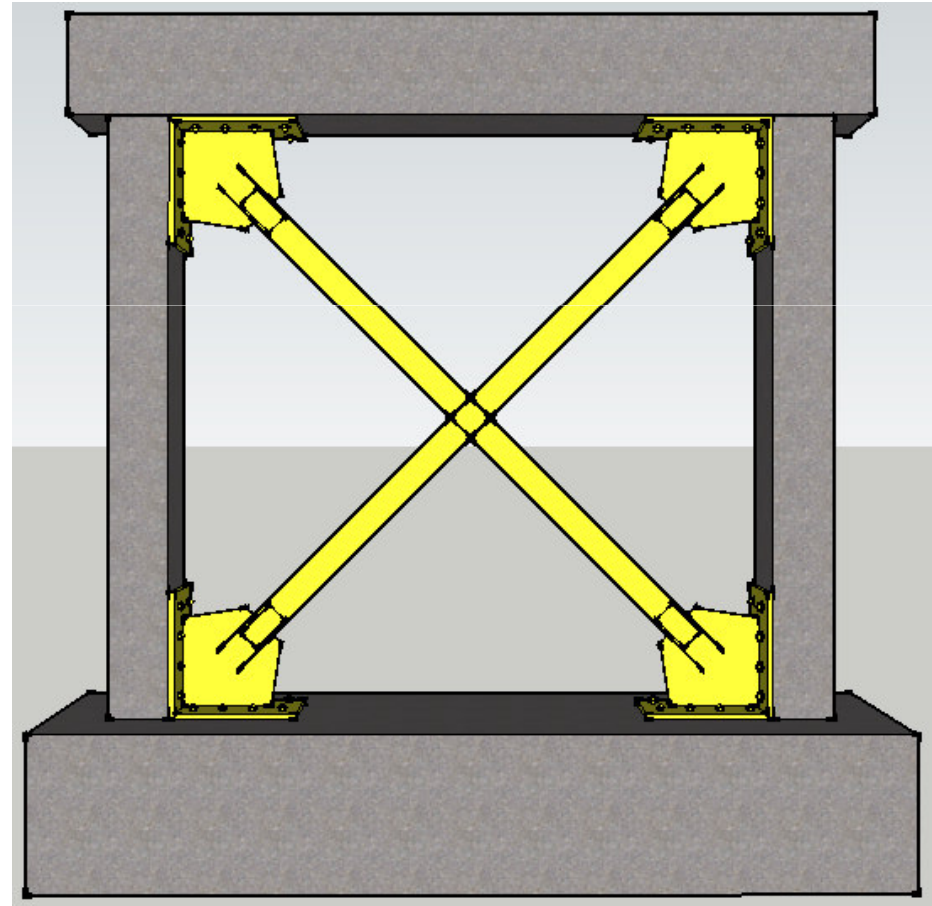
試體設計

NARLabs

CPFX



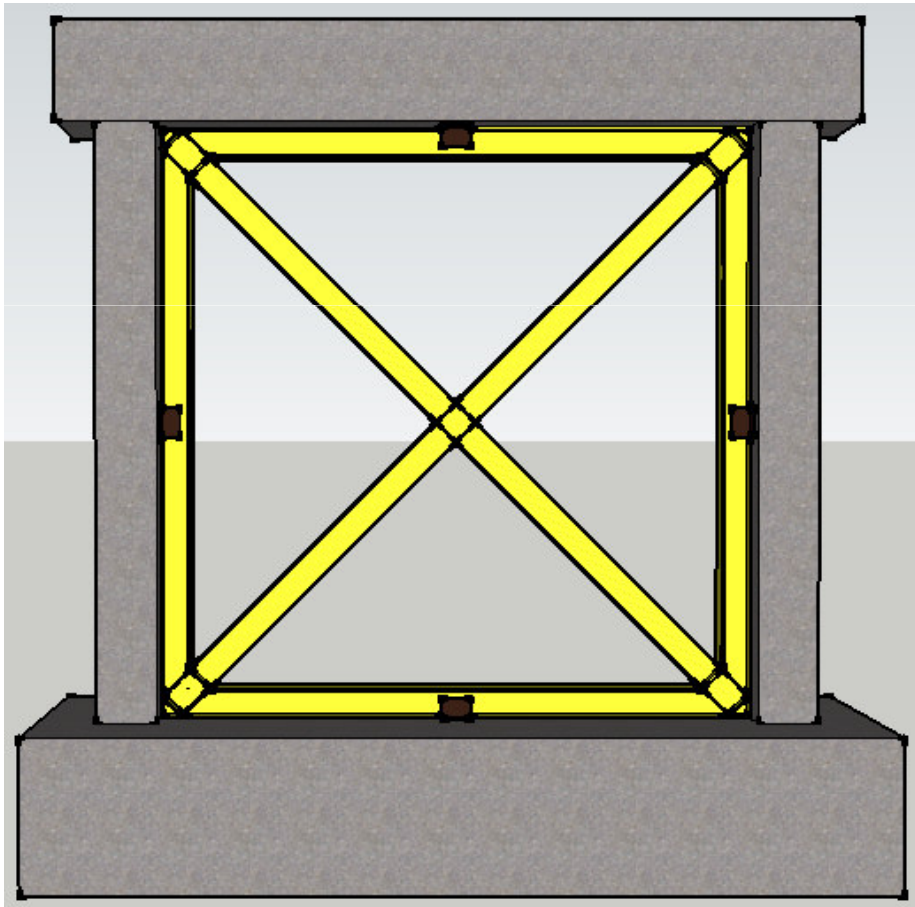
DPFX



試體設計

NARLabs

CPFX

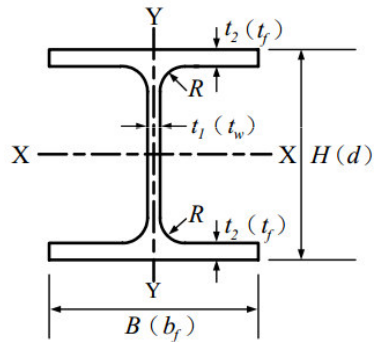


DPFX



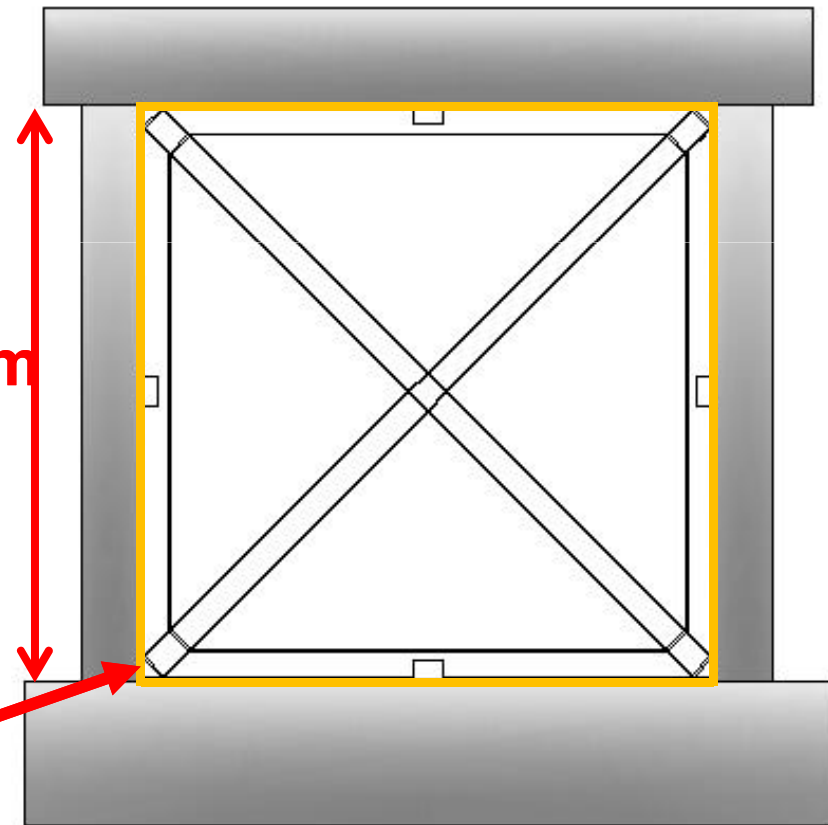
試體介紹

- 鋼框架+X形斜撐補強



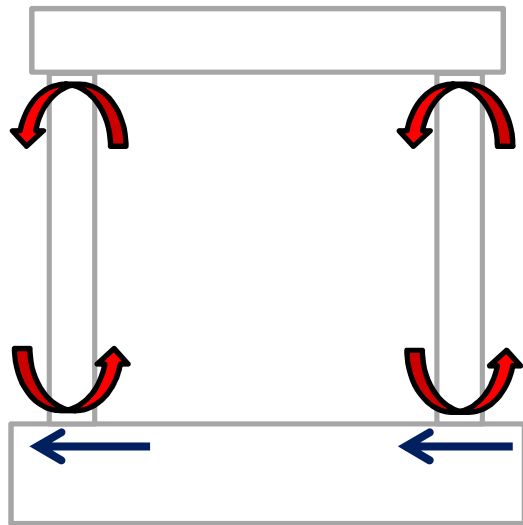
- RH 150x150x7x10
- A36 鋼材 ($F_y = 252 \text{ MPa}$)
- 四邊介面保留10mm間隙，填充環氧樹脂(EPOXY)

2980 mm



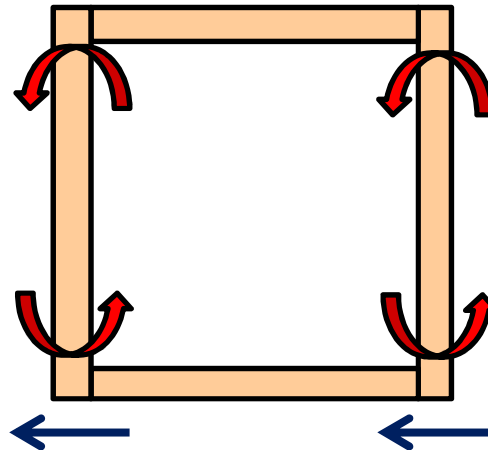
2980 mm

試體設計強度



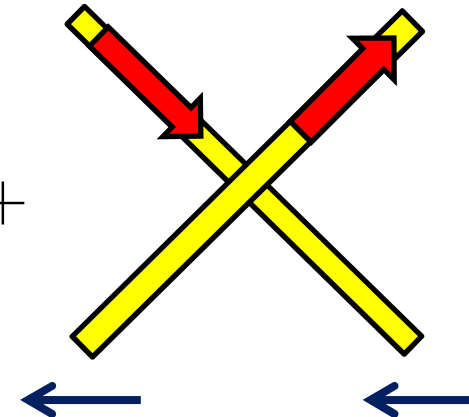
(I) RC Frame

+



(II) Steel Frame

+



(III) Steel Brace

$$V_u = V_{\text{RC Frame}} + V_{\text{Steel Frame}} + V_{\text{Brace}} = \underline{1687\text{kN}}$$

a. 鋼骨框架斜撐組立



b. 界面環氧樹脂灌注



c. 試體完成



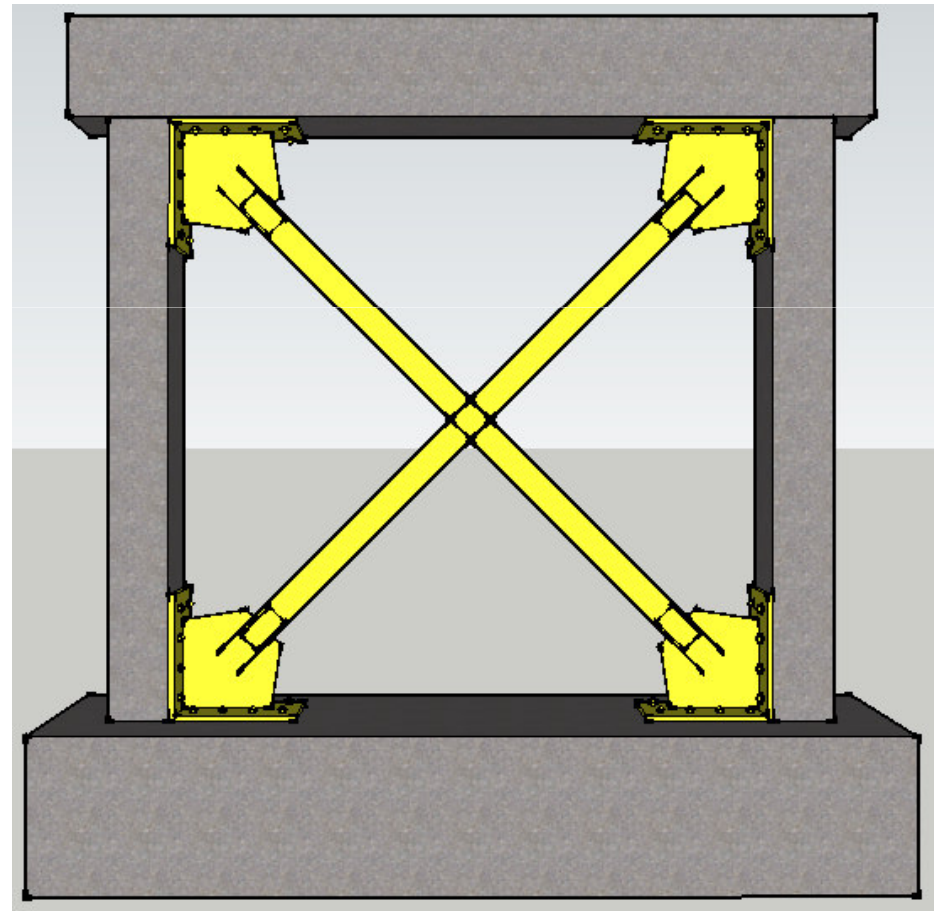
試體設計

NARLabs

CPFX

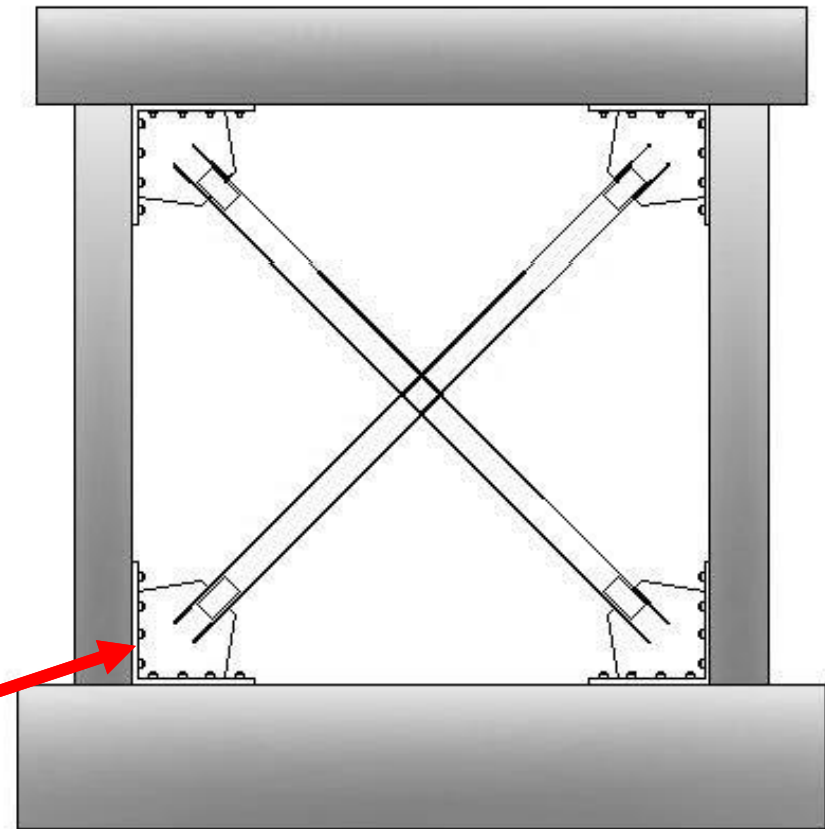


DPFX

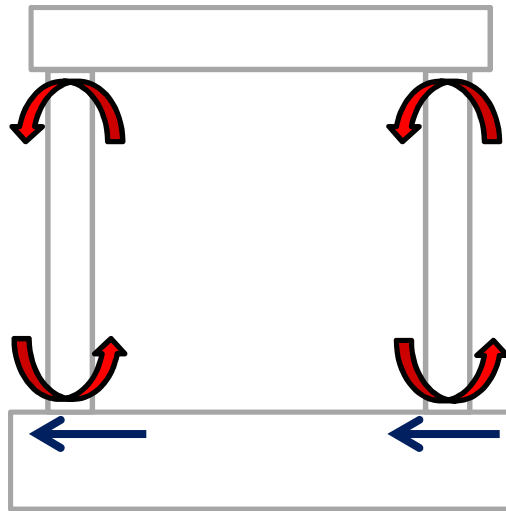


試體介紹

- X形鋼斜撐+L型基版補強
- RH 150x75x5x7
A36 鋼材 ($F_y = 252 \text{ Mpa}$)
- 槽接式隅鋸連接
A572 鋼材 ($F_y = 345 \text{ Mpa}$)
- 介面採用後置式化學錨栓接合

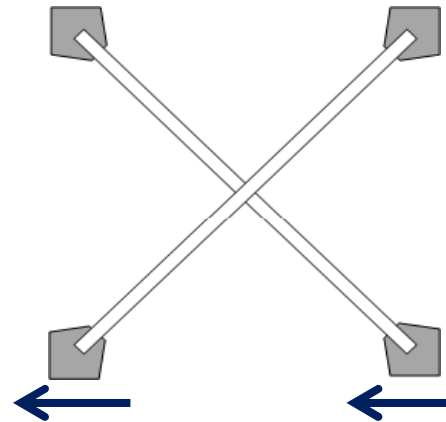


試體強度設計



(I) RC Frame

+



(II) Steel
Brace

$$V_u = V_{\text{RC Frame}} + V_{\text{Brace}} = \underline{\underline{989\text{kN}}}$$

a. 試體放樣鑽孔



b. 鋼骨斜撐組立與鉚鑄



c. 化學錨栓安裝



d. 界面環氧樹脂灌注



e. 試體完成

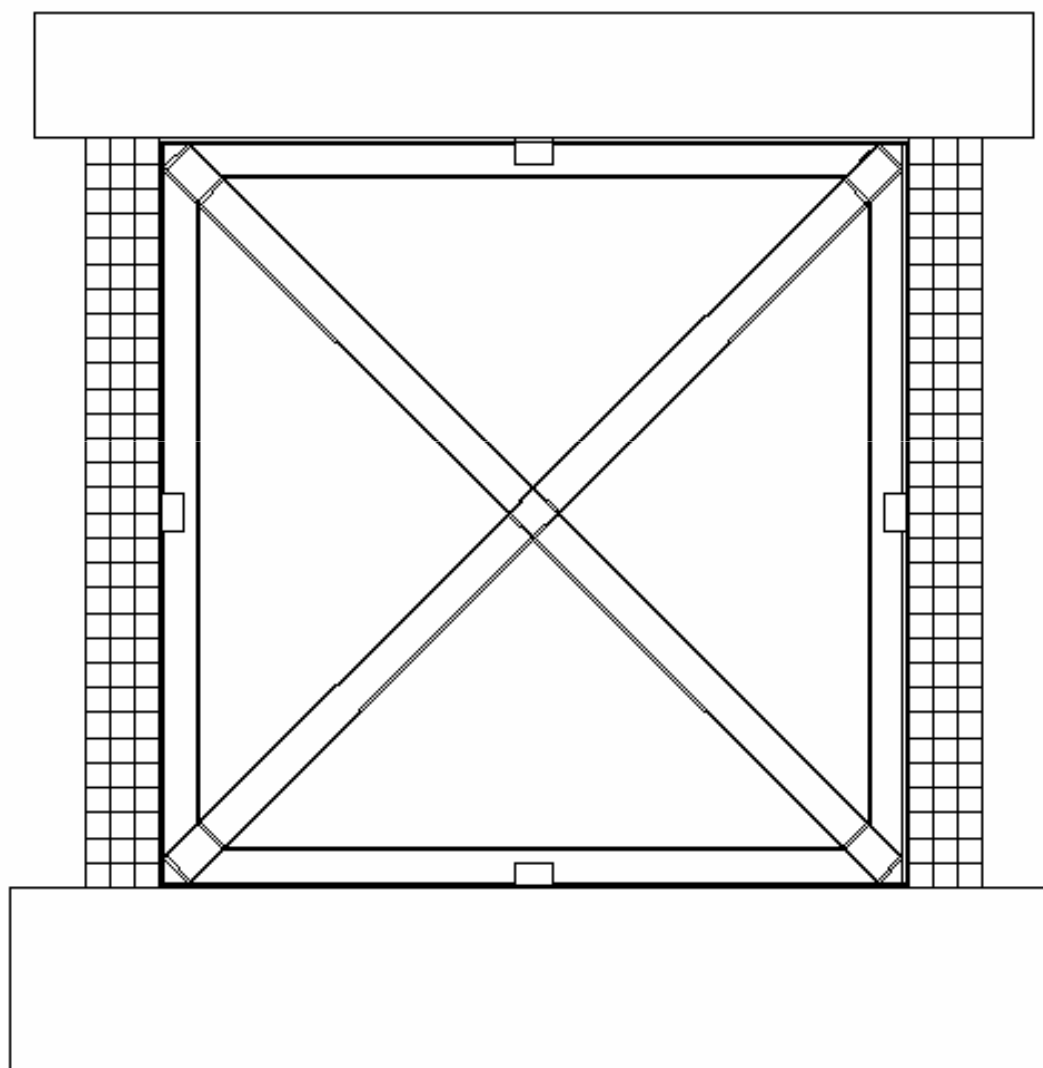


直接接合型鋼斜撐補強設計

- ✓ 試驗結果與耐震行為之探討

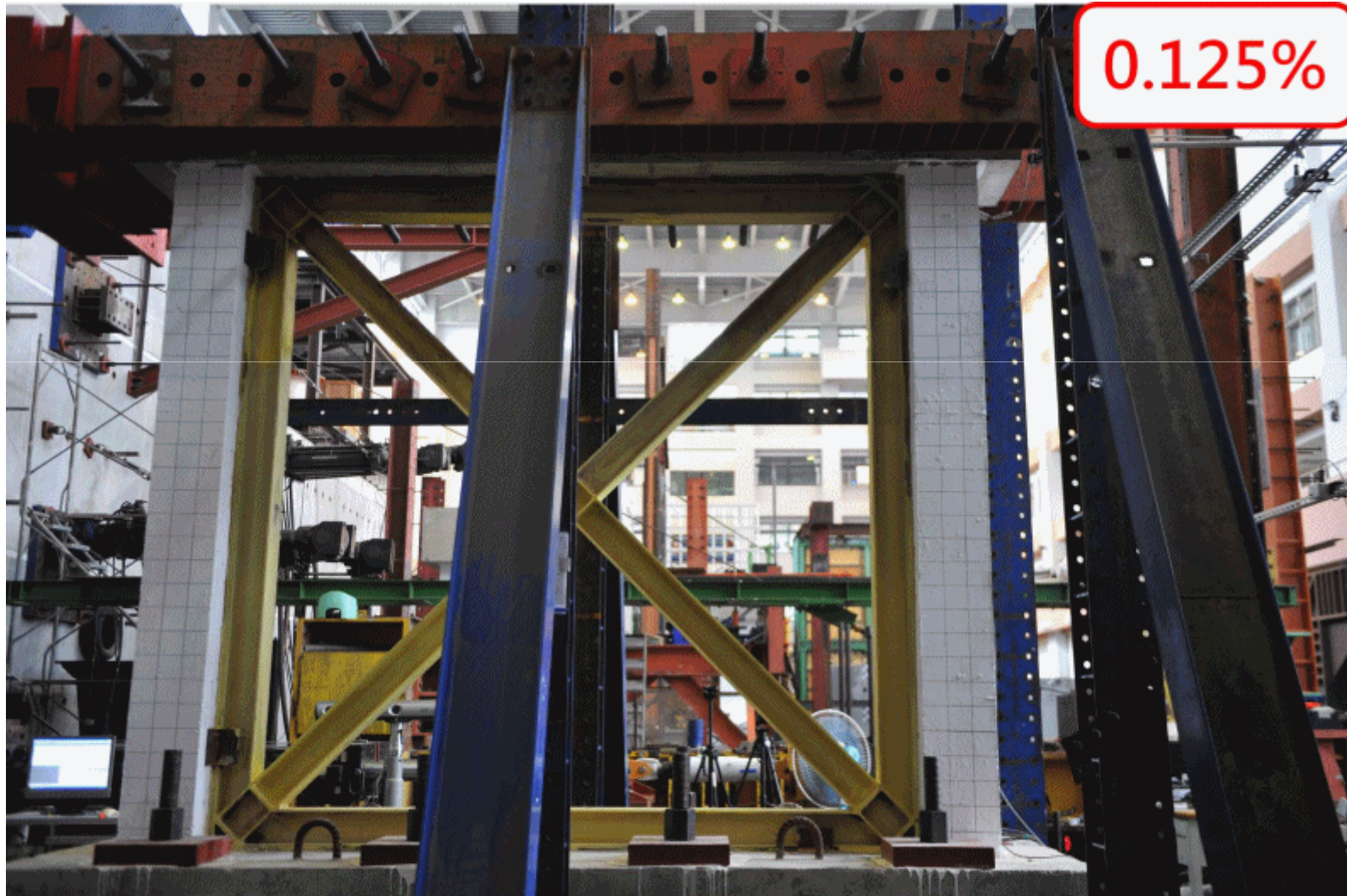
CPFX

NARLabs



CPFX

NARLabs



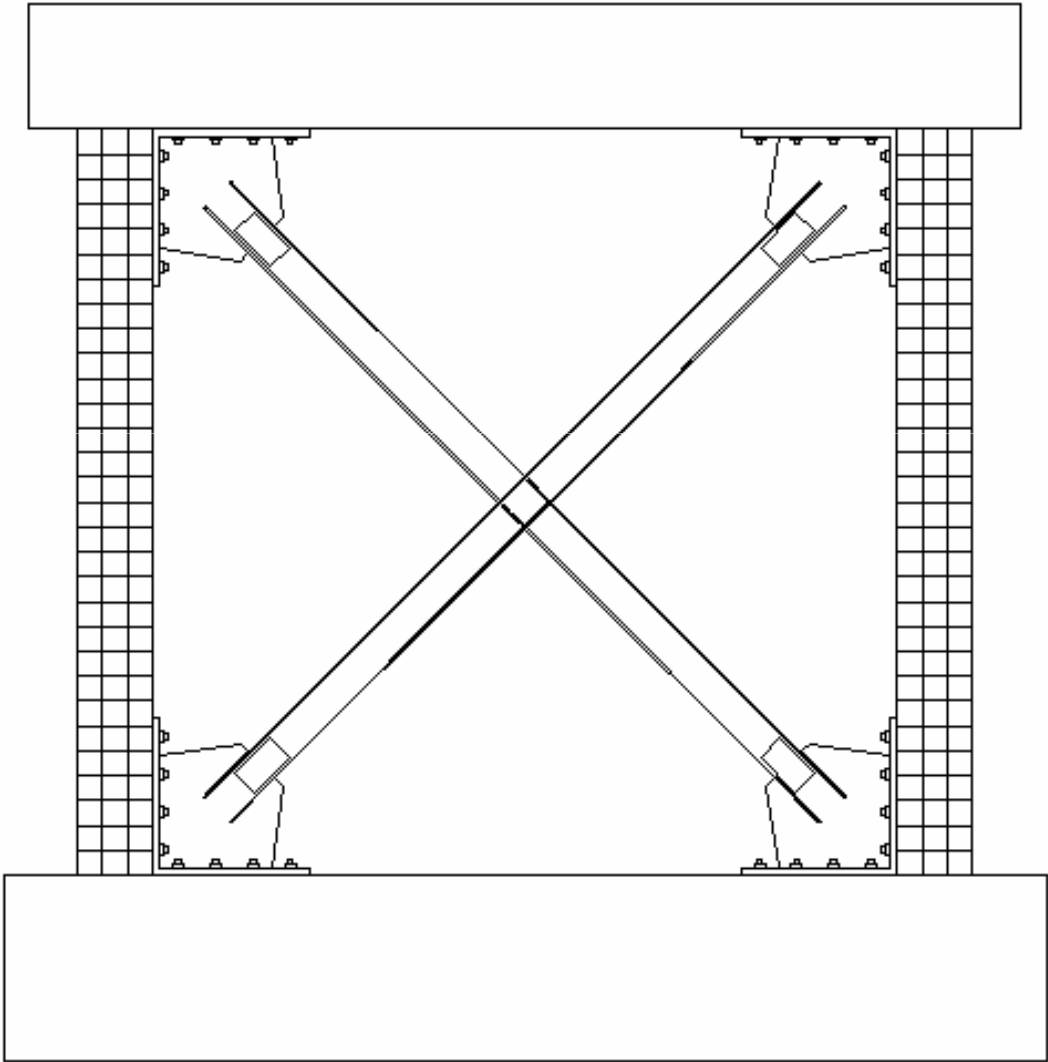
CPFX

NARLabs



DPFX

NAR*Labs*



DPFX

NARLabs

0.125%



DPFX

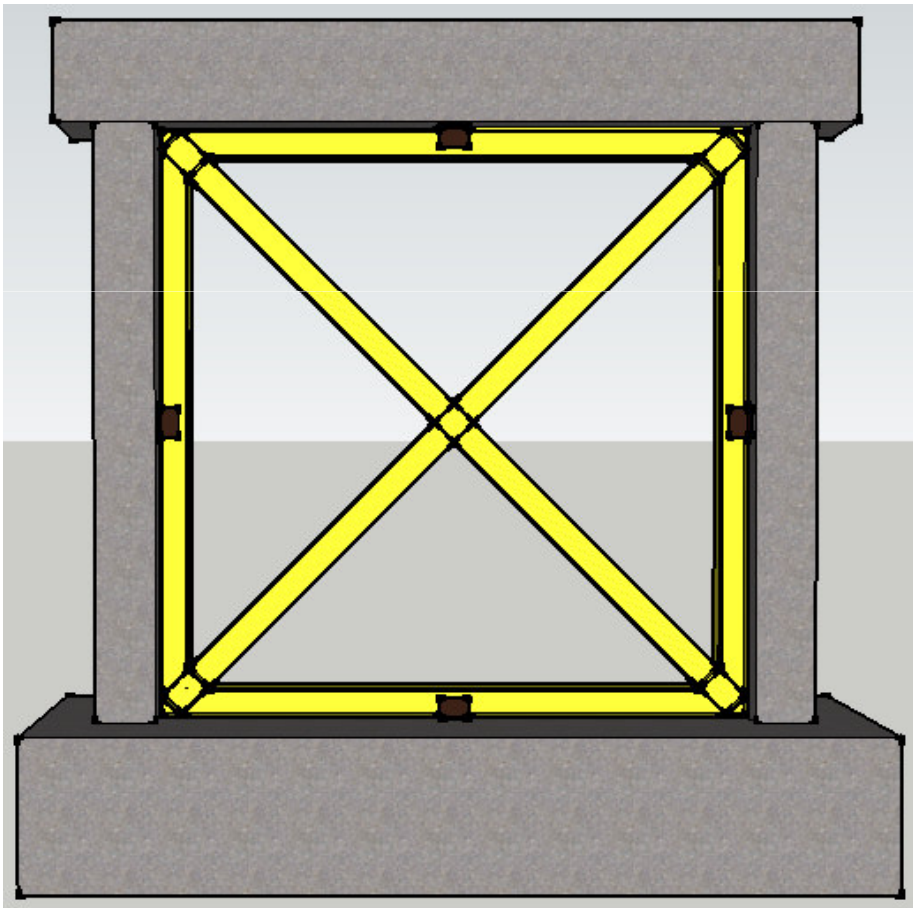
NARLabs



載重 - 位移曲線

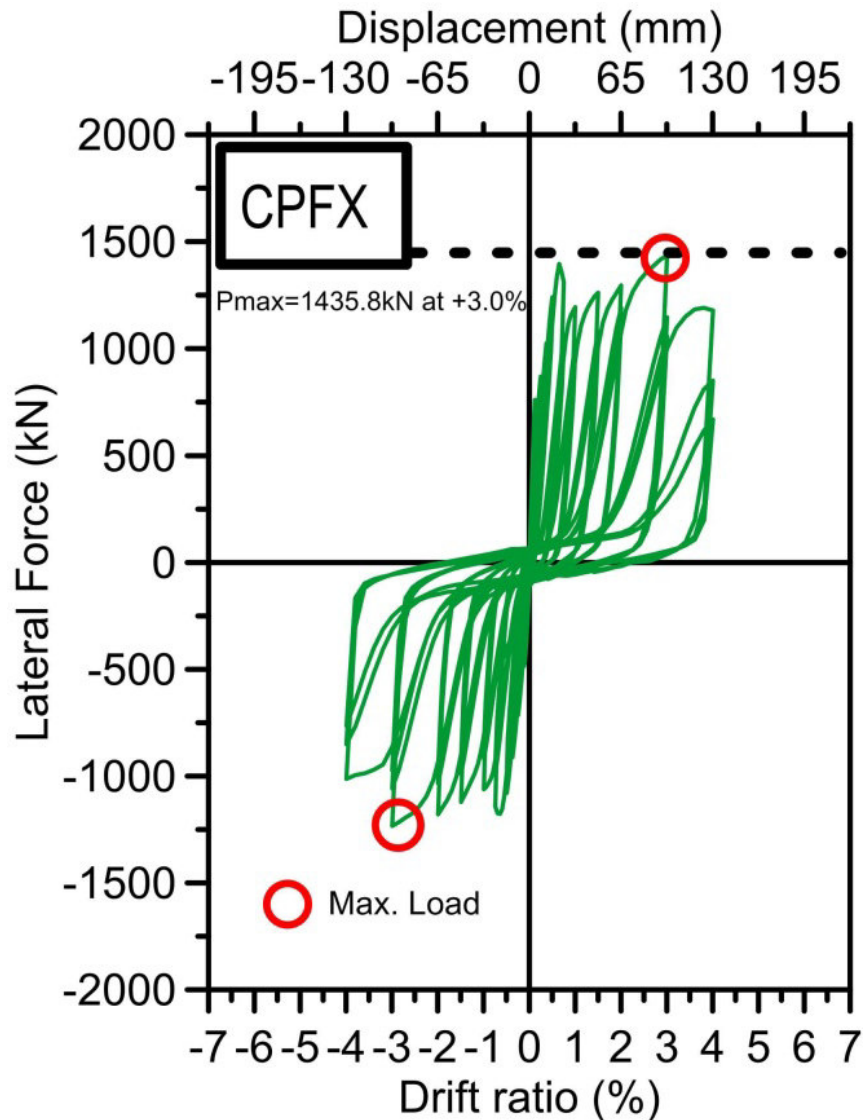
NARLabs

CPFX

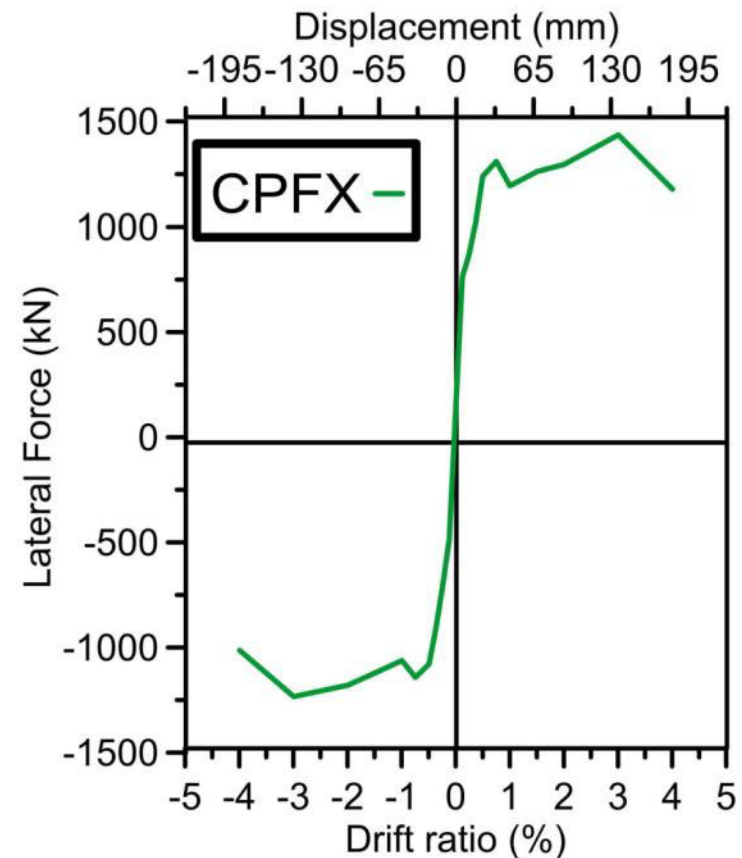


DPFX





$P_{max}=1435.8\text{ kN at }+3.0\%$



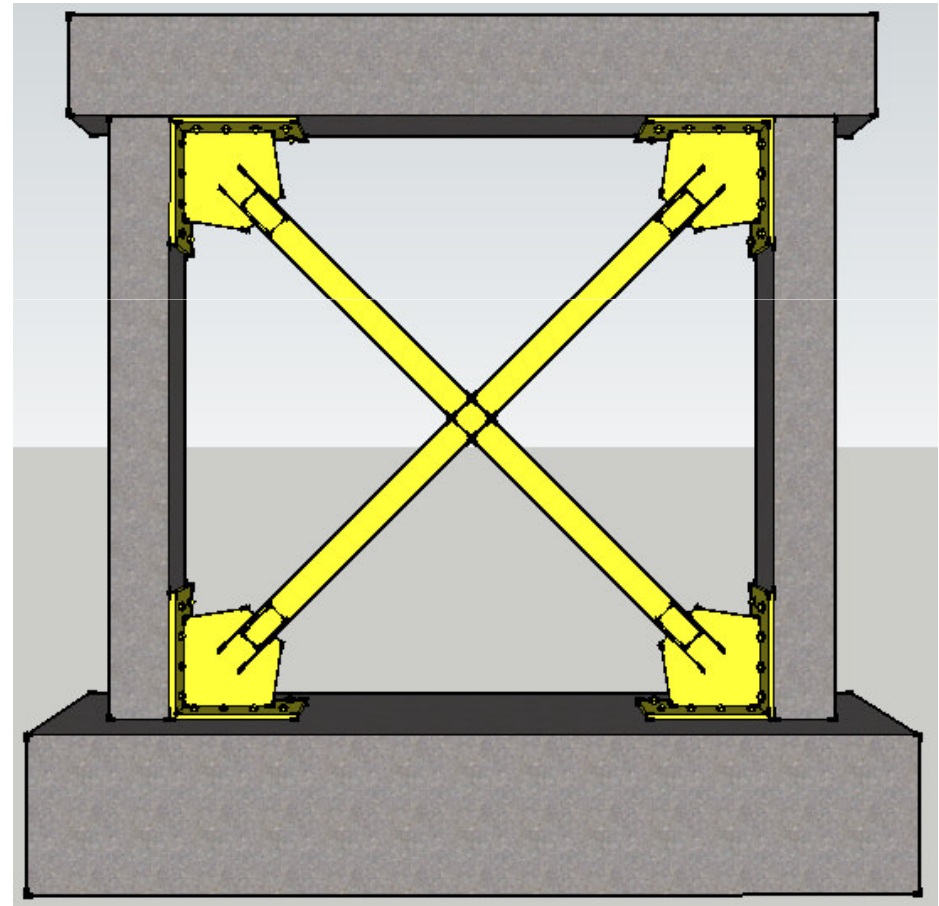
載重 - 位移曲線

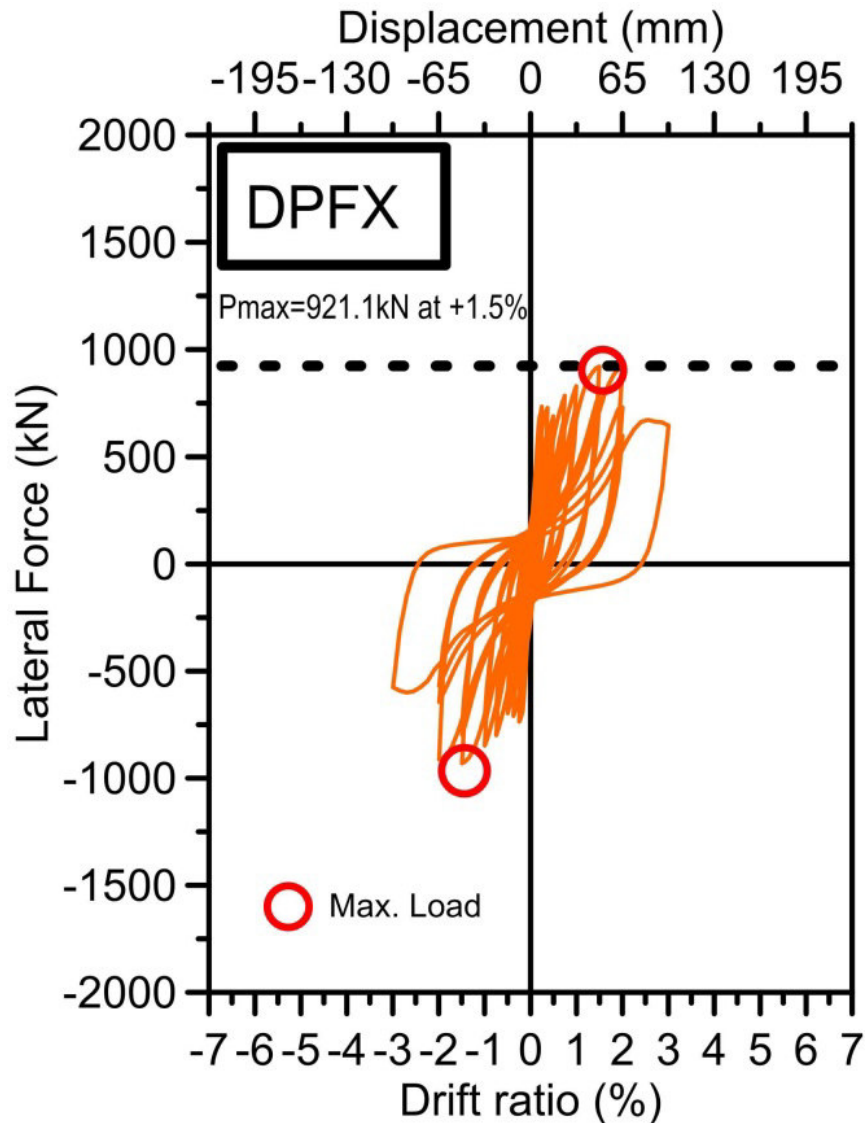
NARLabs

CPFX

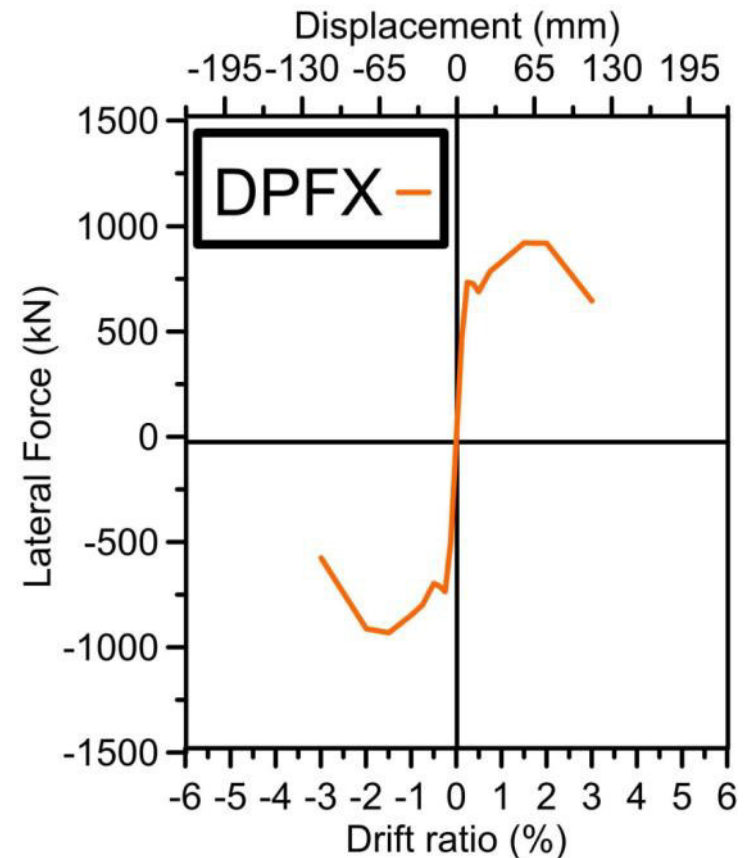


DPFX





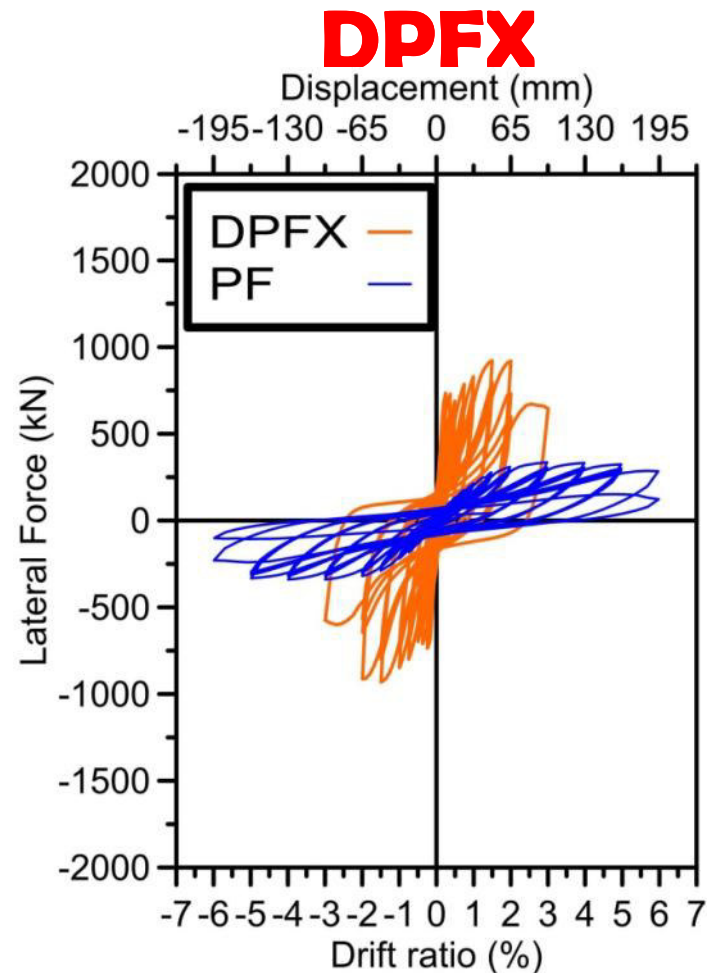
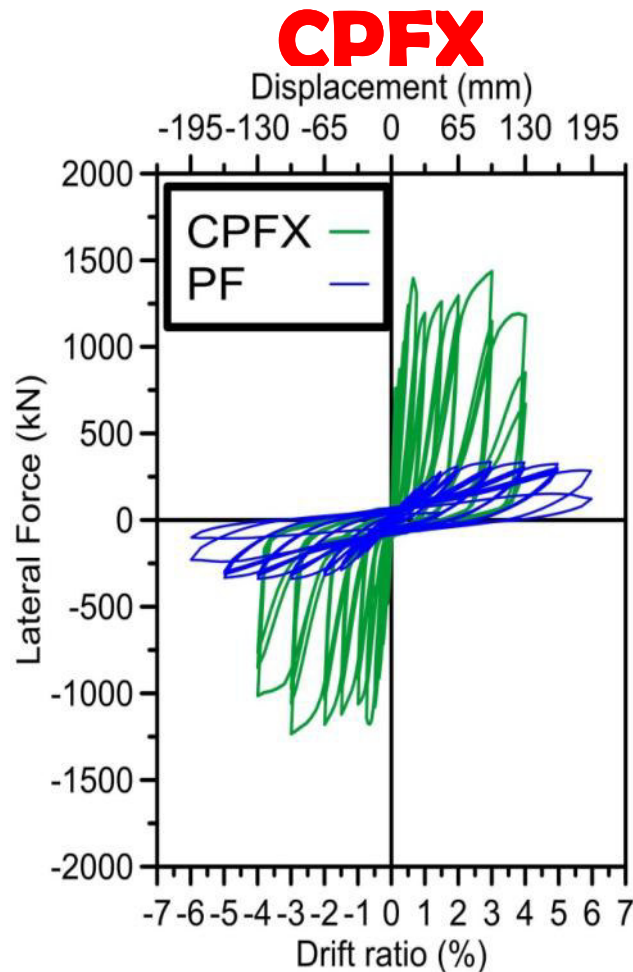
$$P_{max} = 921.1 \text{ kN at } +1.5\%$$



載重 - 位移曲線

NAR Labs

補強構架與純構架之載重-位移遲滯迴圈曲線比較



載重 - 位移曲線

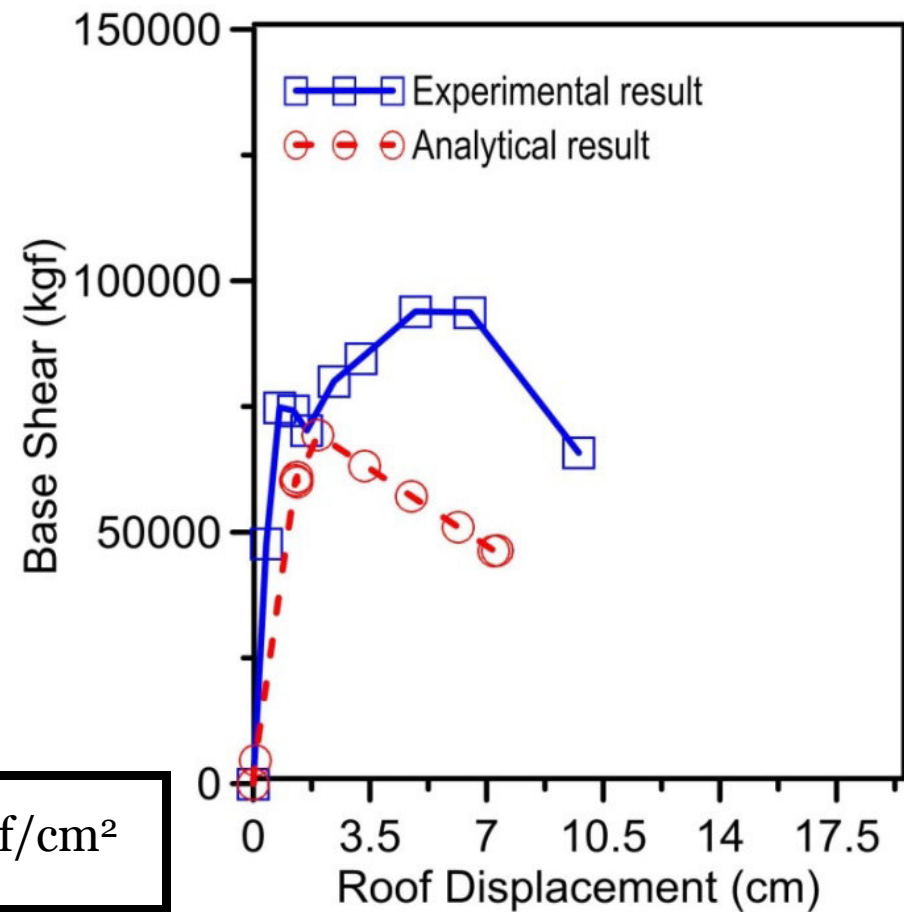
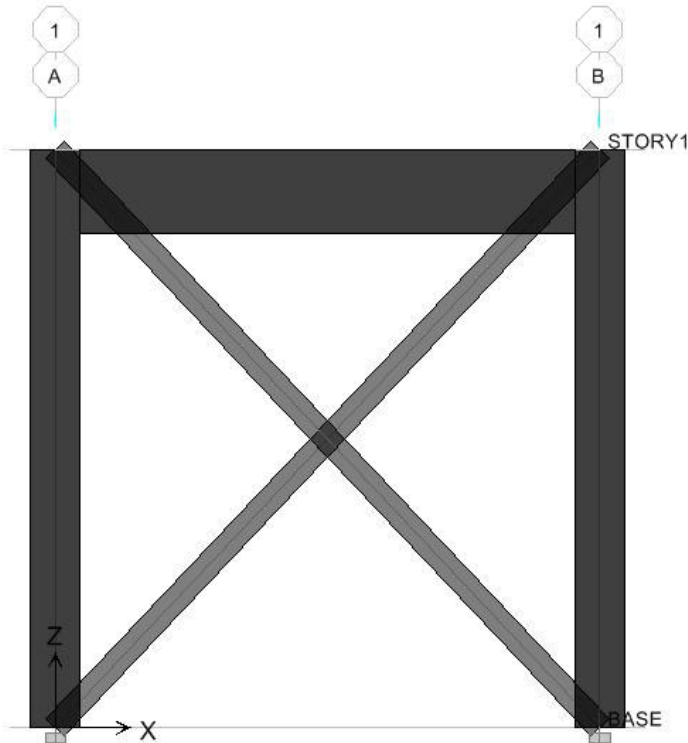
NAR Labs

補強構架之載重-位移遲滯迴圈曲線行為比較

	CPFX	DPFX
試體最大強度	強度較大	強度較小
試體韌性	韌性中等	韌性較差
遲滯迴圈 束縮效應	束縮效應 較明顯	束縮效應中等

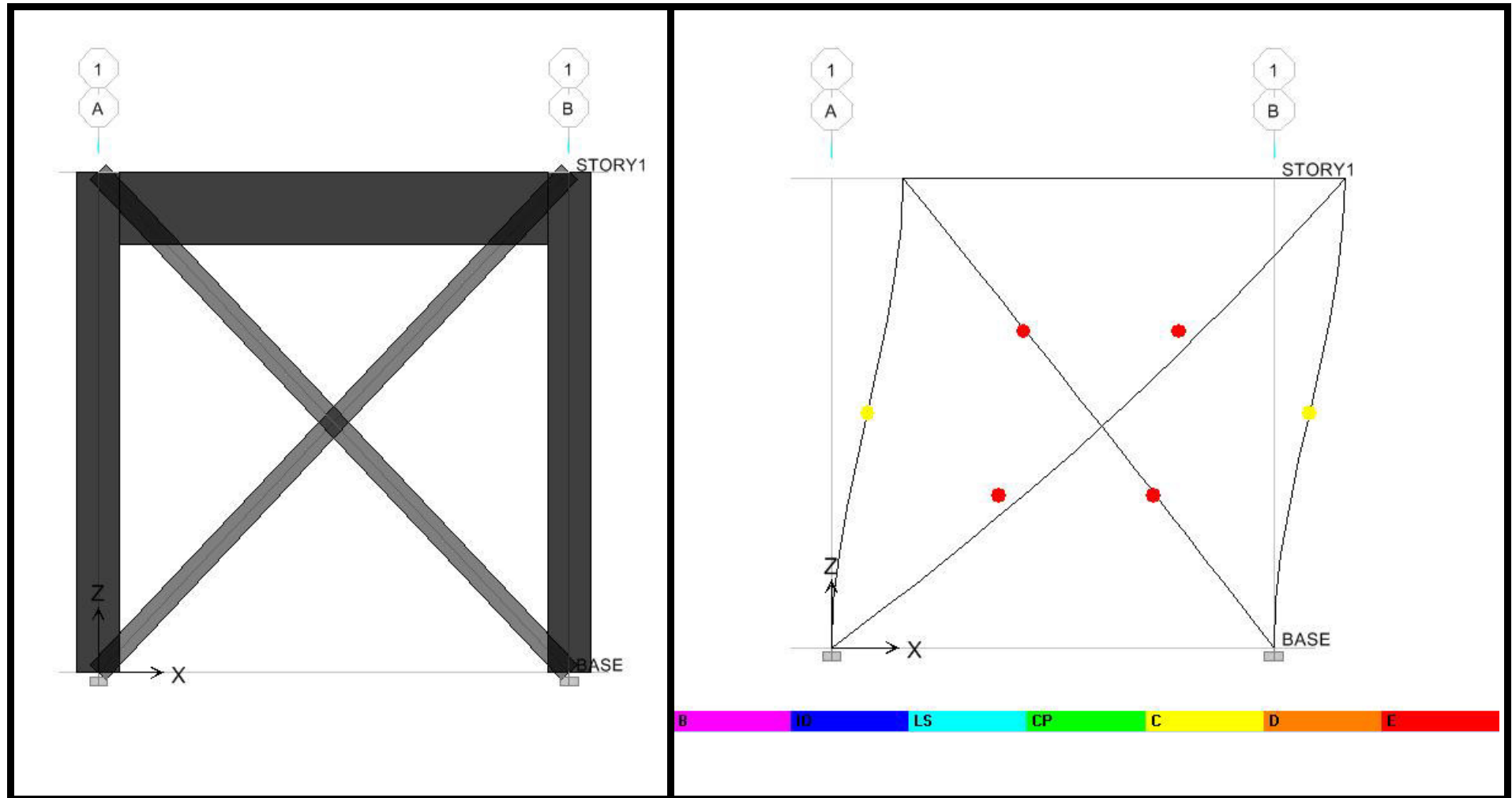
直接接合型鋼斜撐補強設計

✓ 試驗模擬與案例分析



實驗最大荷重kgf/cm ²	分析最大荷重kgf/cm ²
93896	69415

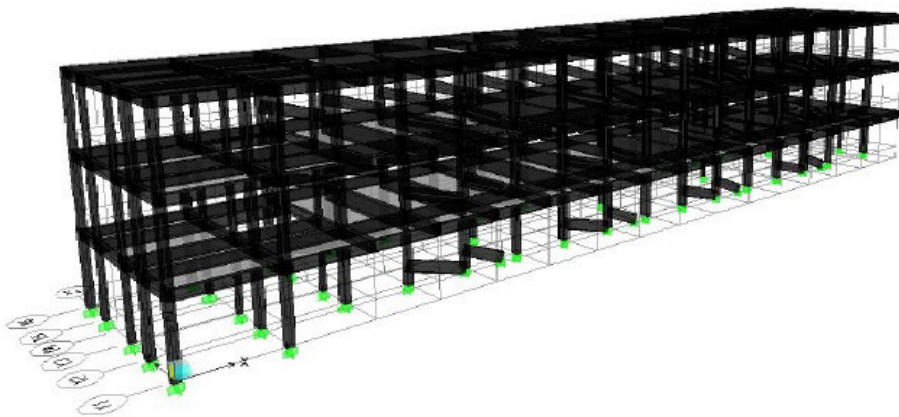
塑角發展



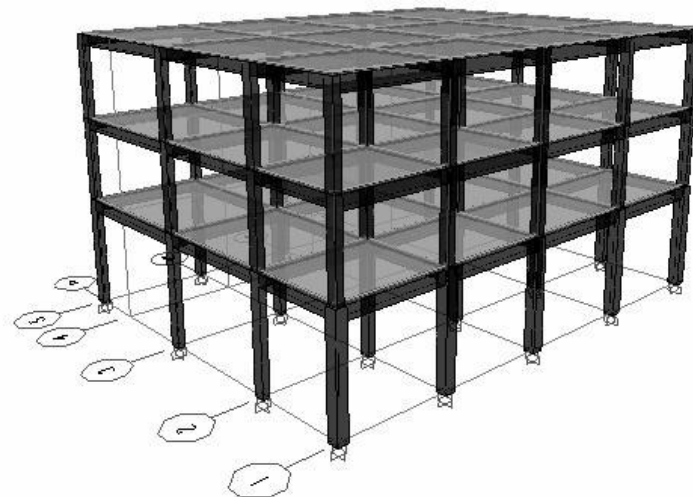
案例分析

NAR Labs

校舍結構物



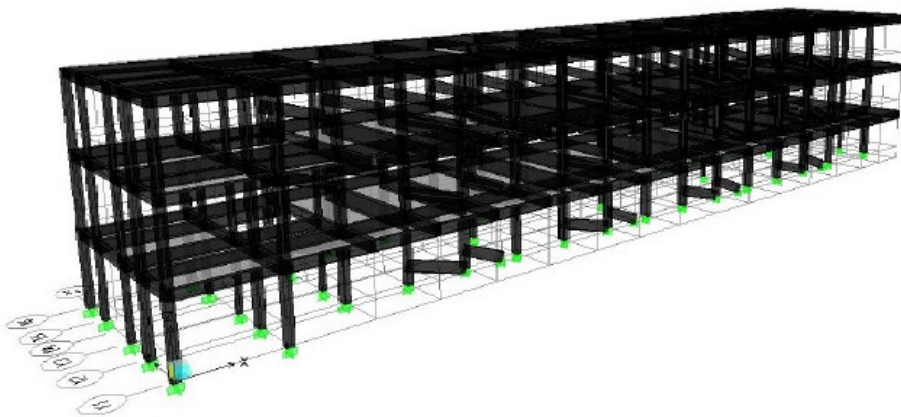
街屋結構物



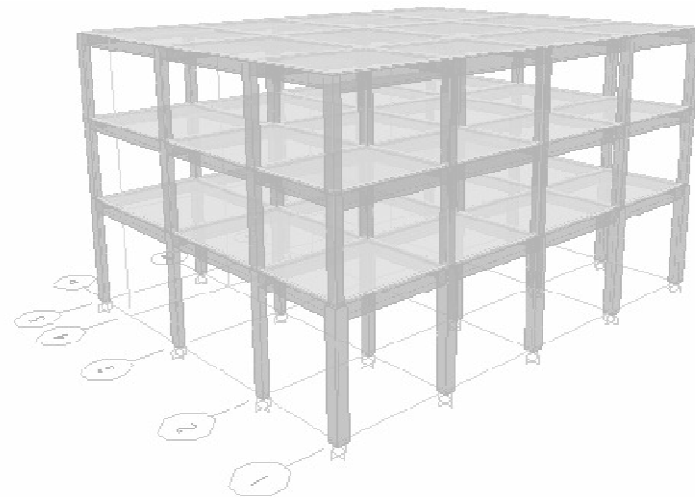
案例分析

NAR Labs

校舍結構物



街屋結構物



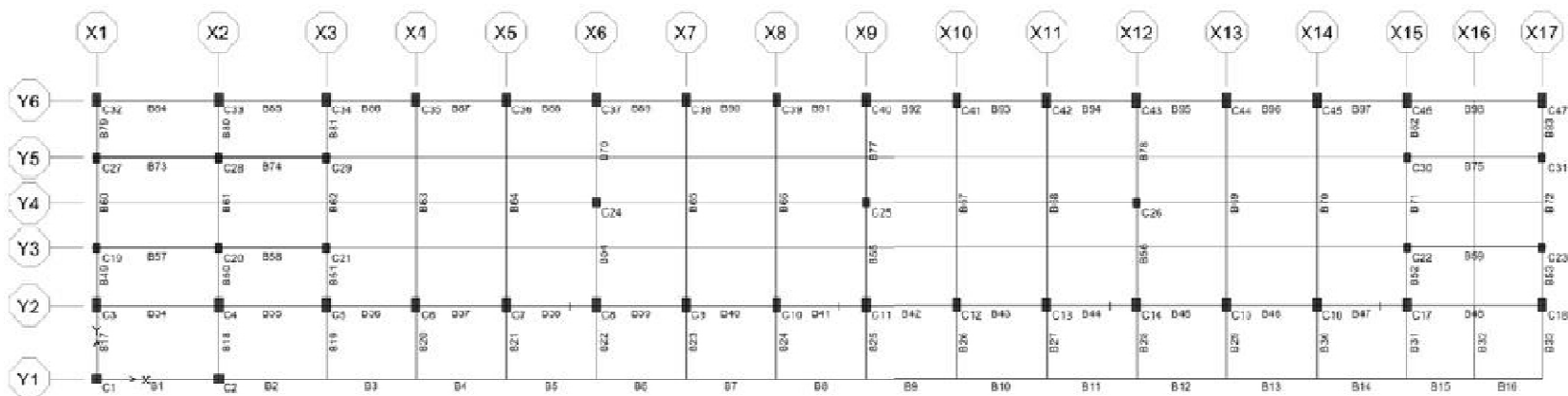
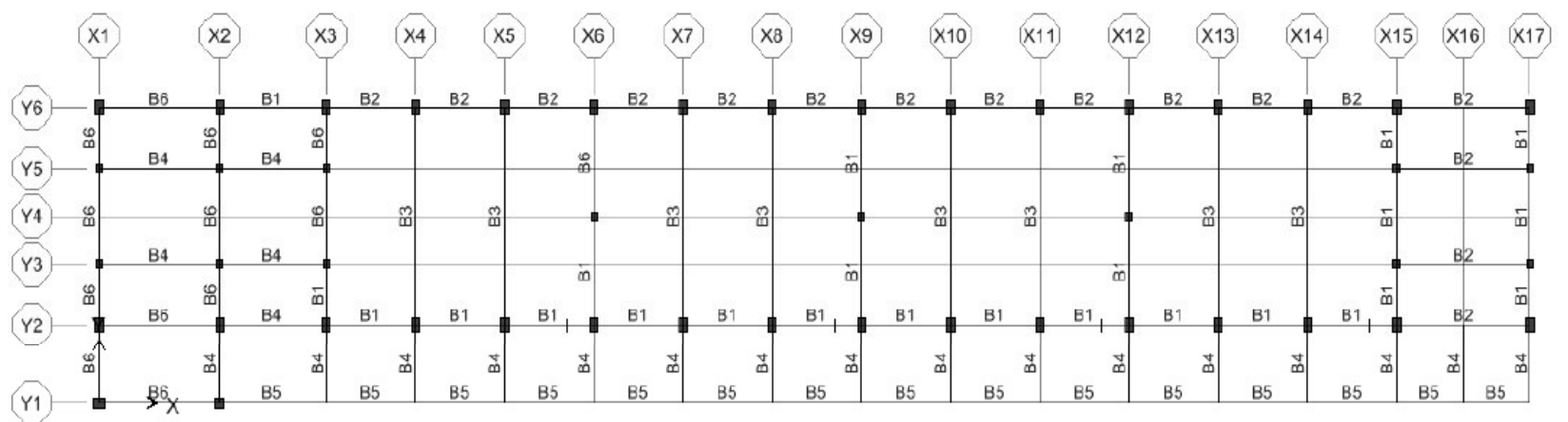
校舍結構物

NAR Labs

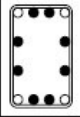
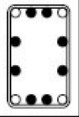
案例校舍為地上三層之鋼筋混凝土建築物，每層樓高3.6公尺，長向長度為53.5公尺、短向為10.2公尺。



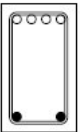
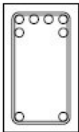
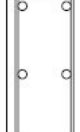
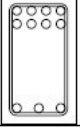
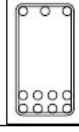
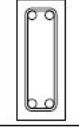
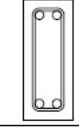
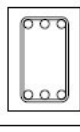
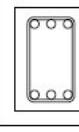
結構平面圖



梁柱配筋圖及材料參數

柱編號	C1L	C1S	C2	C3
斷面				
主筋	○ 4-D22 ● 8-D19	○ 4-D22 ● 8-D19	● 6-D16	○ 4-D19 ● 4-D16
箍筋	D9@25	D9@25	D9@25	D9@25
尺寸	30' 50	30' 50	24' 30	36' 36

材料參數	強度 kgf/cm ²
混凝土	160
鋼筋	2800
砂漿	100
磚	150

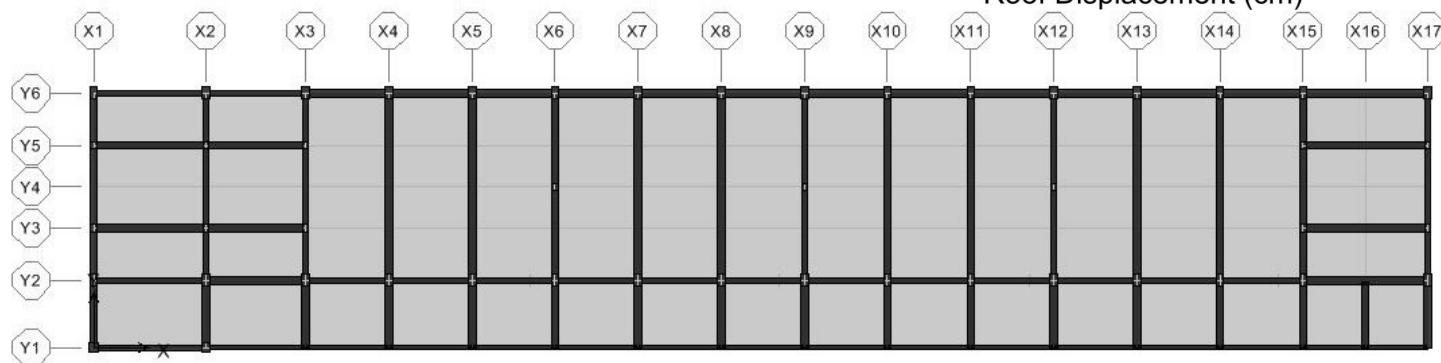
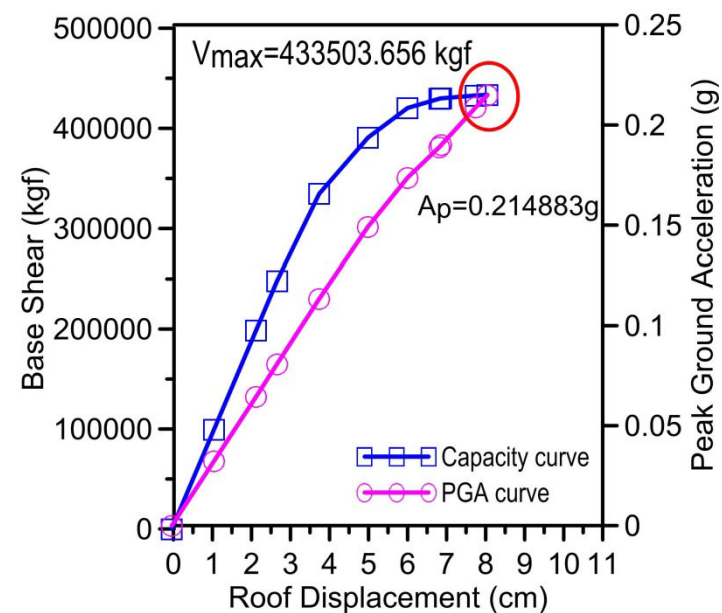
梁編號	B1		B2		B3	
	兩端	中央	兩端	中央	兩端	中央
斷面						
主筋	○ 4-D19 ● 2-D16		○ 8-D22		○ 10-D22	
箍筋	D9@25		D9@25		D9@25	
尺寸	24' 60		30' 60		30' 90	
梁編號	B4		B5		B6	
	兩端	中央	兩端	中央	兩端	中央
斷面						
主筋	○ 11-D22		○ 4-D13		○ 6-D16	
箍筋	D9@25		D9@25		D9@25	
尺寸	30' 55		15' 55		24' 45	

耐震能力評估

NAR Labs

最大側力強度分析值 $V_{\max} = 433.503 \text{ tf}$ ，性能目標地表加速度 $A_p = 0.214 \text{ g}$

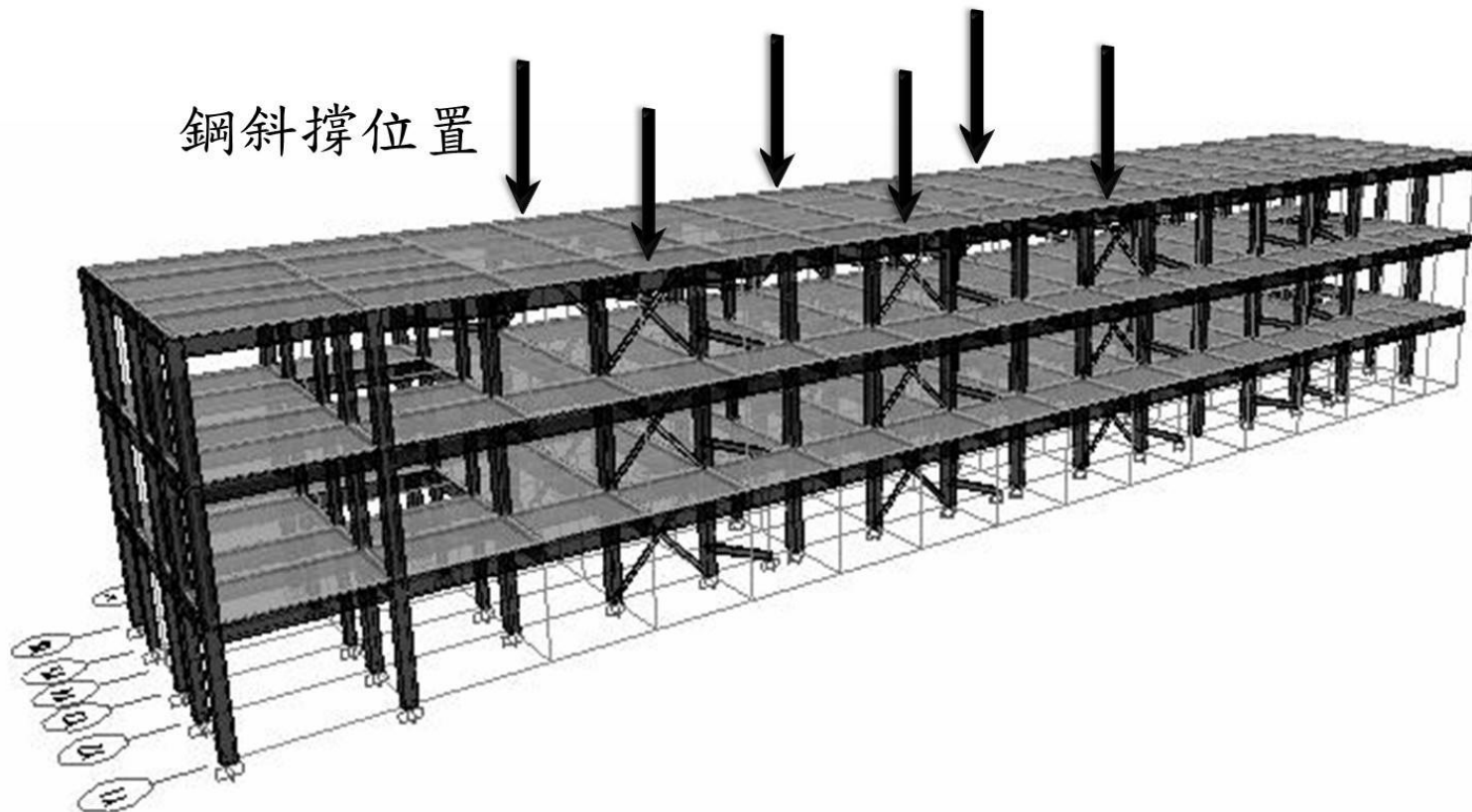
耐震能力需求 $A_T = 0.4S_{DS} = 0.28 \text{ g}$ ➡ 耐震能力不足

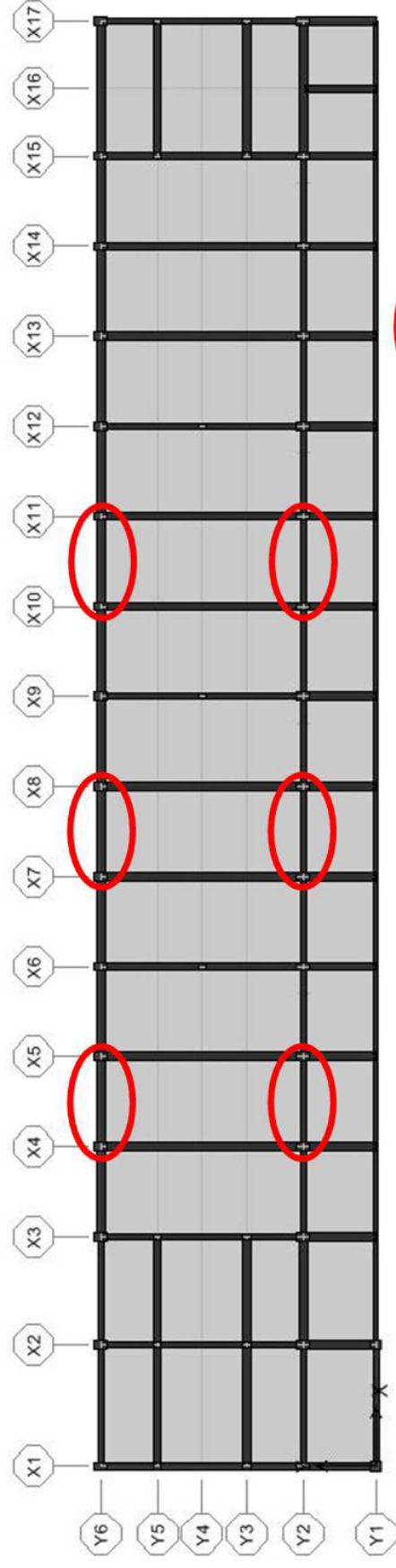


鋼斜撐補強

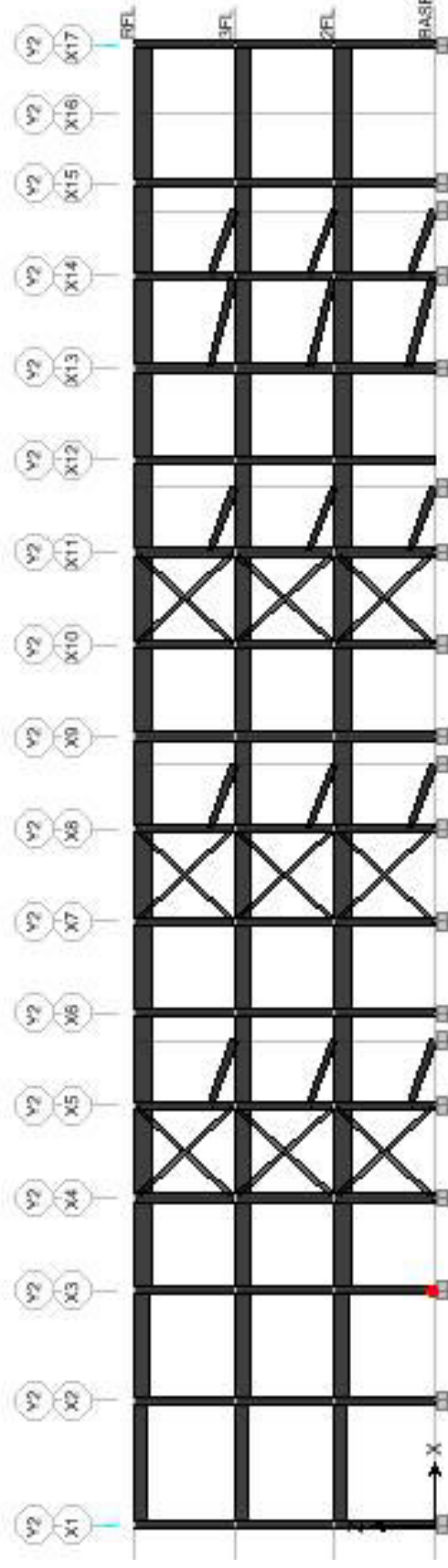
鋼斜撐補強工法，即本實驗之補強試體DPFX之應用

增設6處鋼斜撐補強





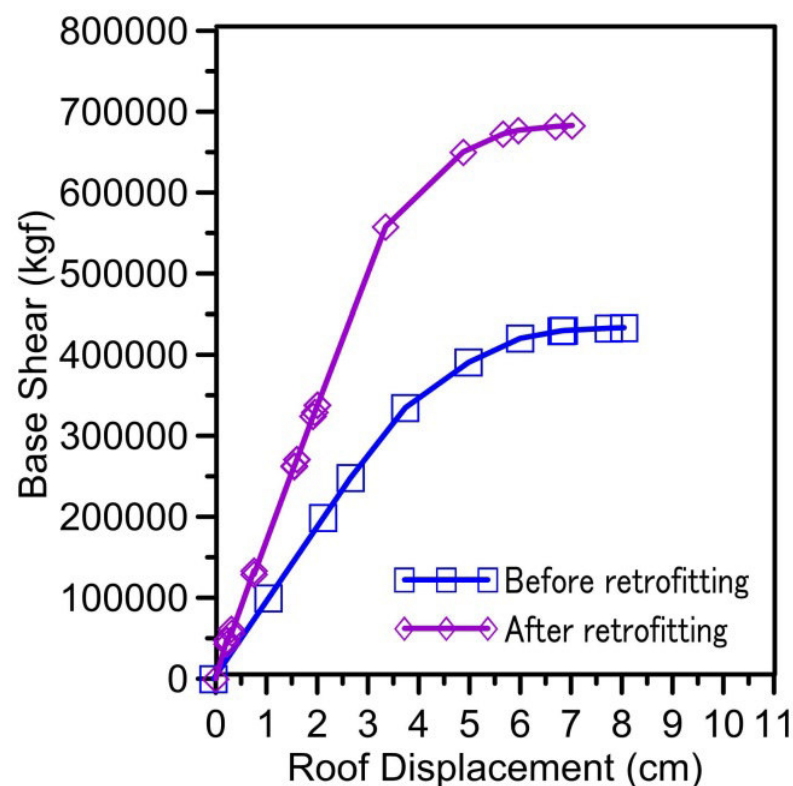
補強位置



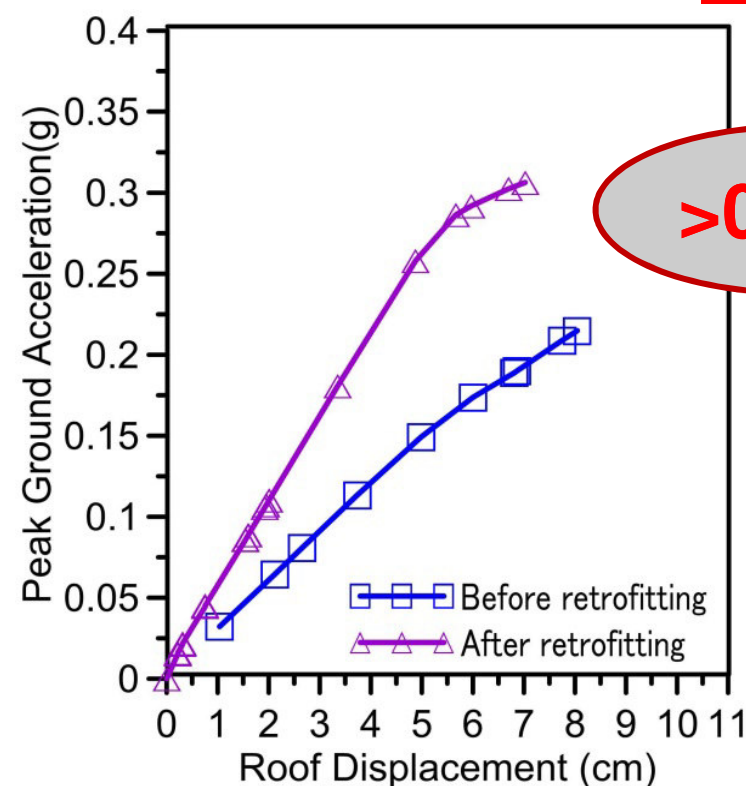
補強後耐震能力評估

AR Labs

容量曲線由433503 kgf提升至682956 kgf



耐震能力由0.214 g提升至0.306 g

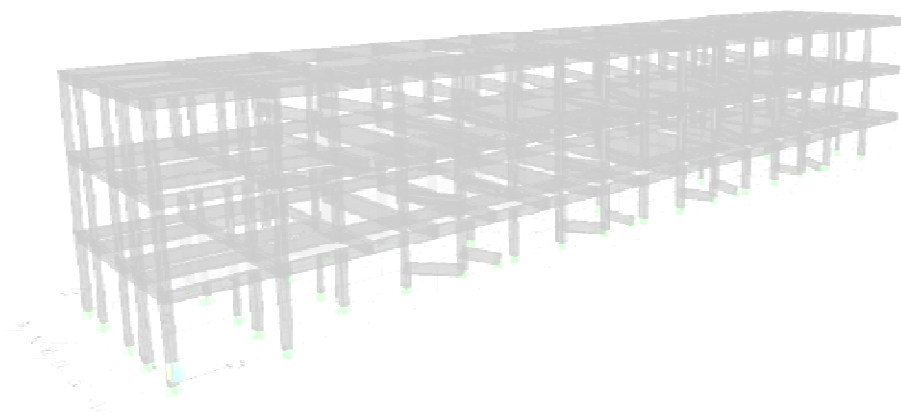


>0.28g

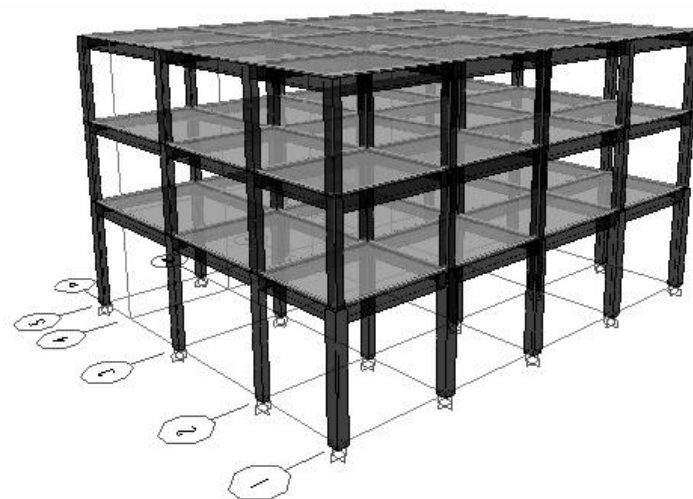
案例分析

NAR Labs

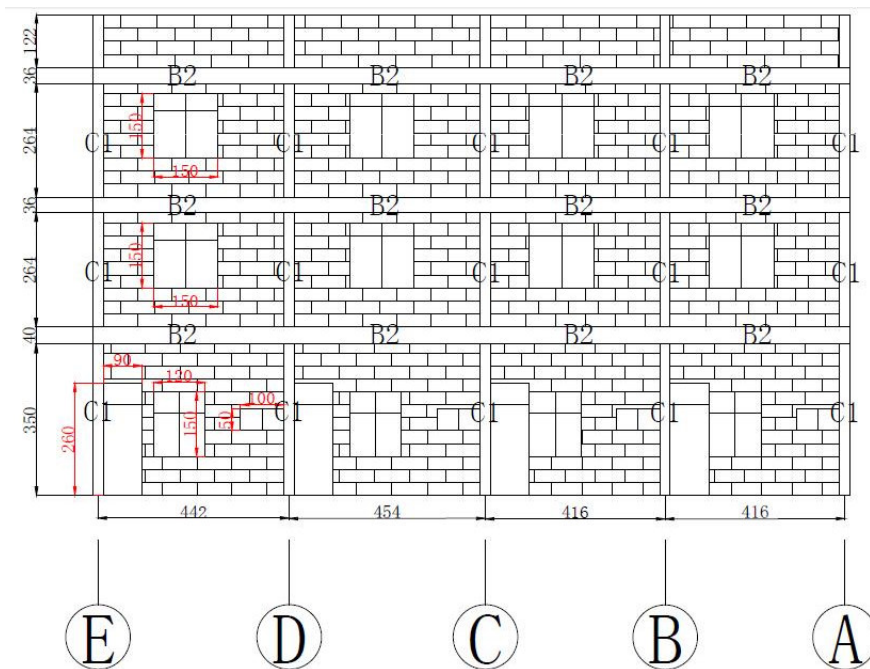
校舍結構物



街屋結構物

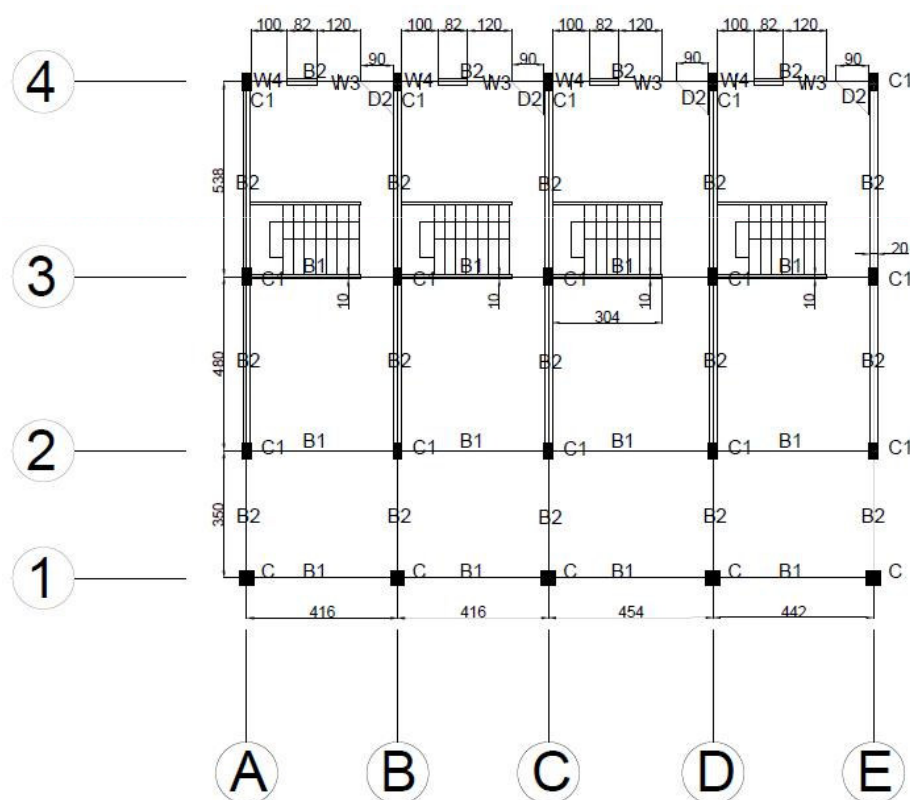


NARLabs

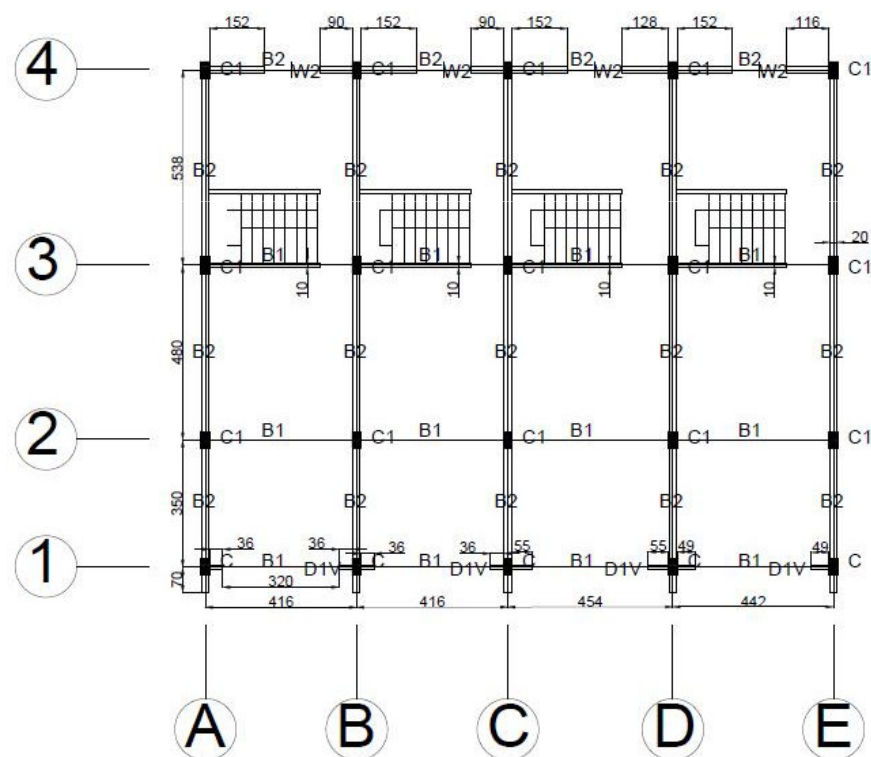


結構平面圖

一樓平面圖



二、三樓平面圖



梁柱配筋圖及材料參數

1F		2F		3F	
1C	1C1	2C	2C1	3C	3C1
40X40 8-#5	24X40 8-#5	24X36 6-#5	24X36 6-#5	24X36 6-#5	24X36 6-#5
hoop #3@25					

材料參數	強度 kgf/cm ²
混凝土	160
鋼筋	2800
砂漿	150
磚	150

1F		2F	
1B1	1B2	2B1	2B2
30X45 4-#5 2-#6	24X40 5-#5	30X45 6-#5	24X36 5-#5
hoop #3@20			

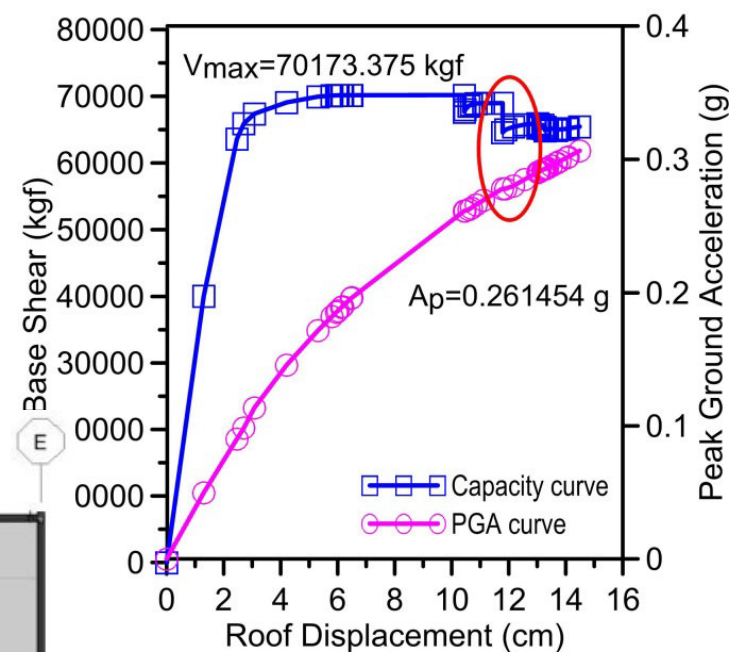
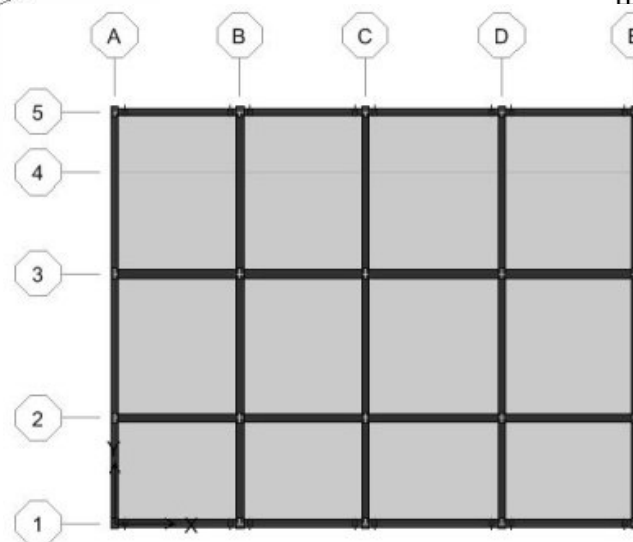
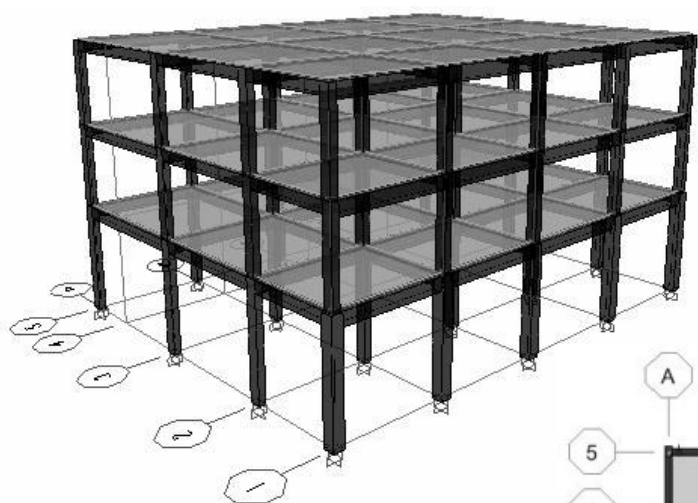
3F			
3B1	3B2	TB	
30X45 6-#5	24X36 5-#5	24X36 6-#5	
hoop #3@20			

耐震能力評估

NAR Labs

最大側力強度分析值 $V_{\max} = 70.173 \text{ tf}$ ，性能目標地表加速度 $A_p = 0.261 \text{ g}$

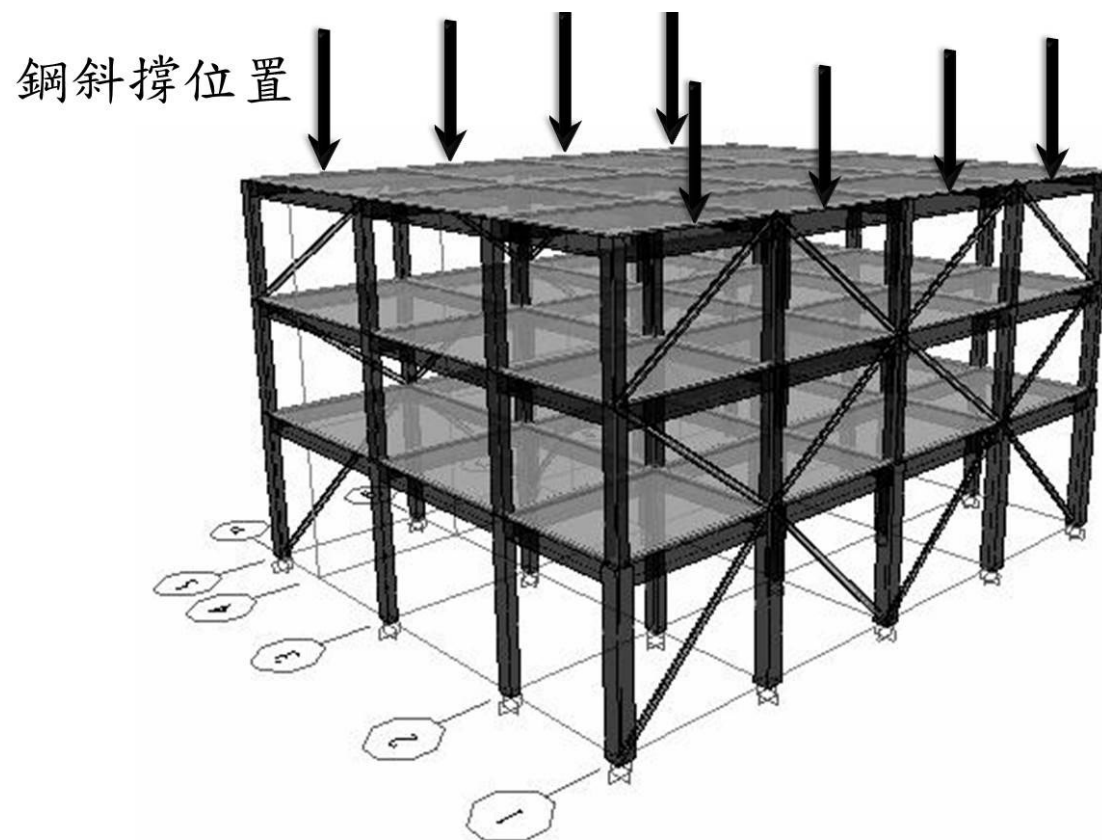
耐震能力需求 $A_T = 0.4 S_{DS} = 0.371 \text{ g}$ ➡ 耐震能力不足

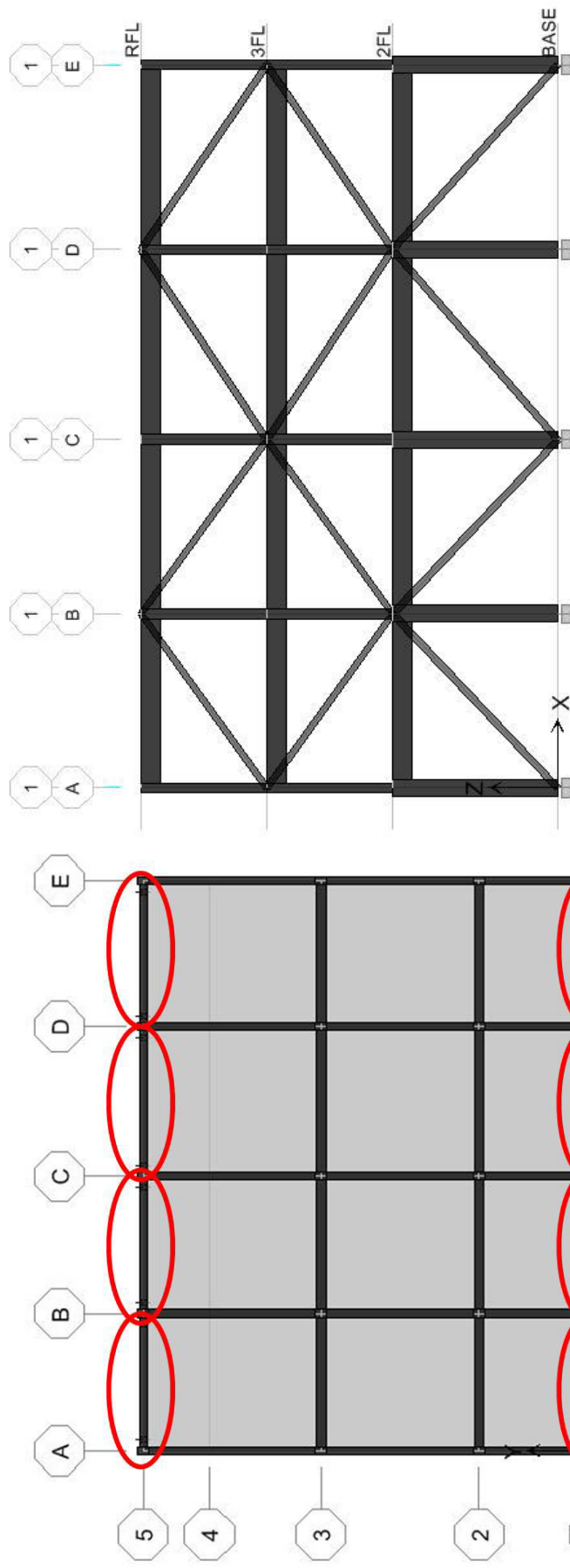


鋼斜撐補強

鋼斜撐補強工法，即本實驗之補強試體DPFX之應用

增設8處鋼斜撐補強



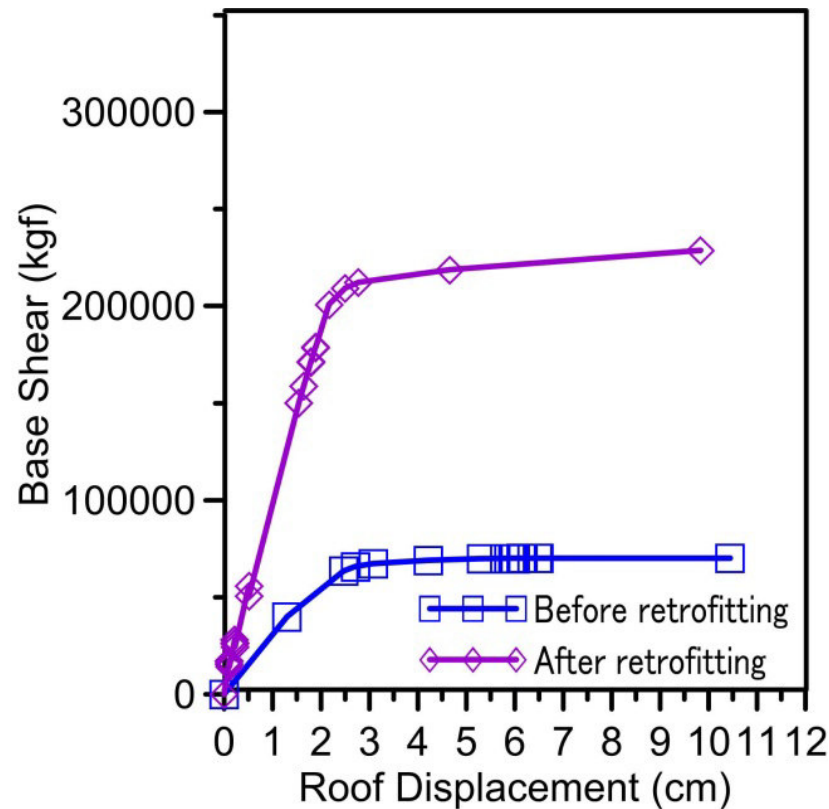


補強位置

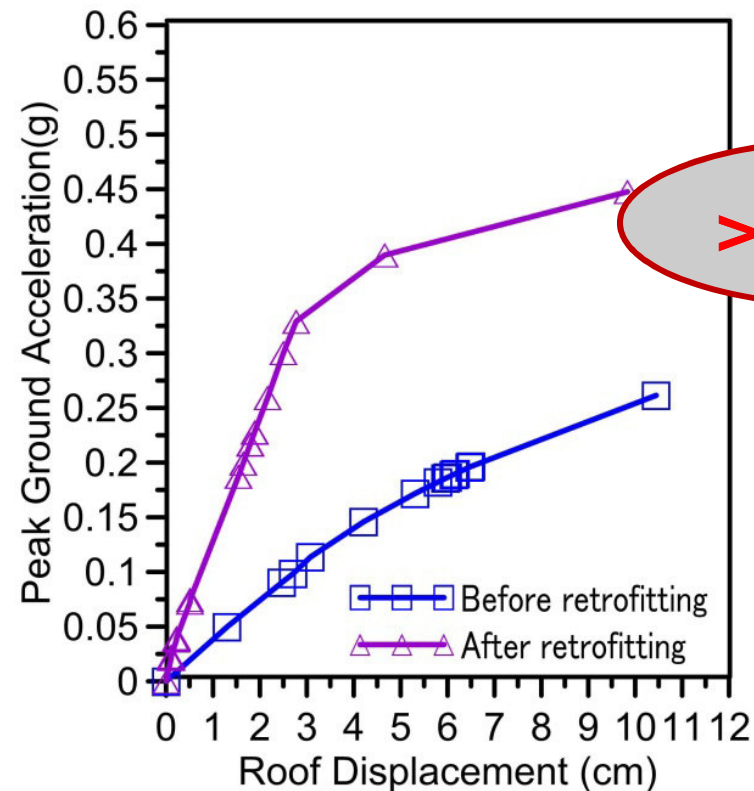


補強後耐震能力評估

容量曲線由70173 kgf提升至228682kgf



耐震能力由0.261 g提升至0.447 g



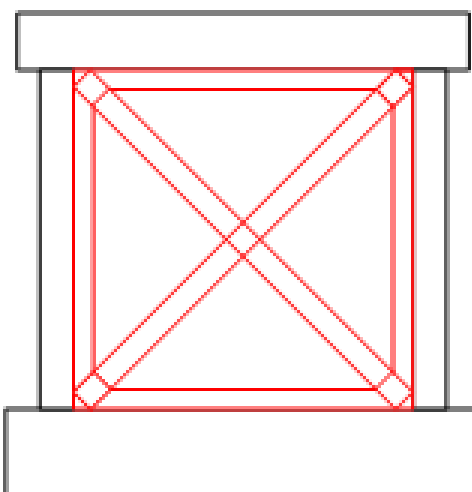
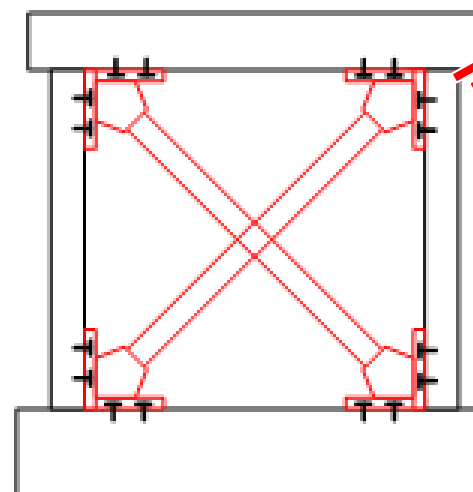
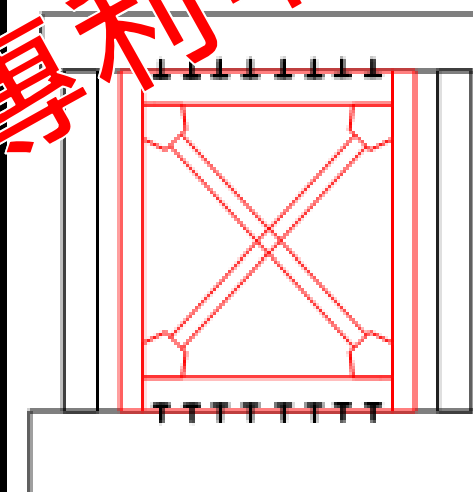
>0.371g

直接接合型鋼斜撐補強設計

✓ 結論

小 結

1. 綜合本試驗結果，利用鋼斜撐補強的非韌性RC構架，其最大側向力皆有明顯的提升，表示以鋼斜撐進行補強，能達到有效的補強效果。
2. 鋼斜撐與RC構架間之接合方式影響整體構架強度、勁度以及韌性甚巨，化學錨栓接合能有效以剪力摩擦形式傳遞力量，使得補強構件與RC構架間能有良好的黏合。
3. 整體而言，鋼斜撐補強能有效提升既有鋼筋混凝土建物最大基底剪力及性能目標地表加速度，達到耐震能力補強的目標。

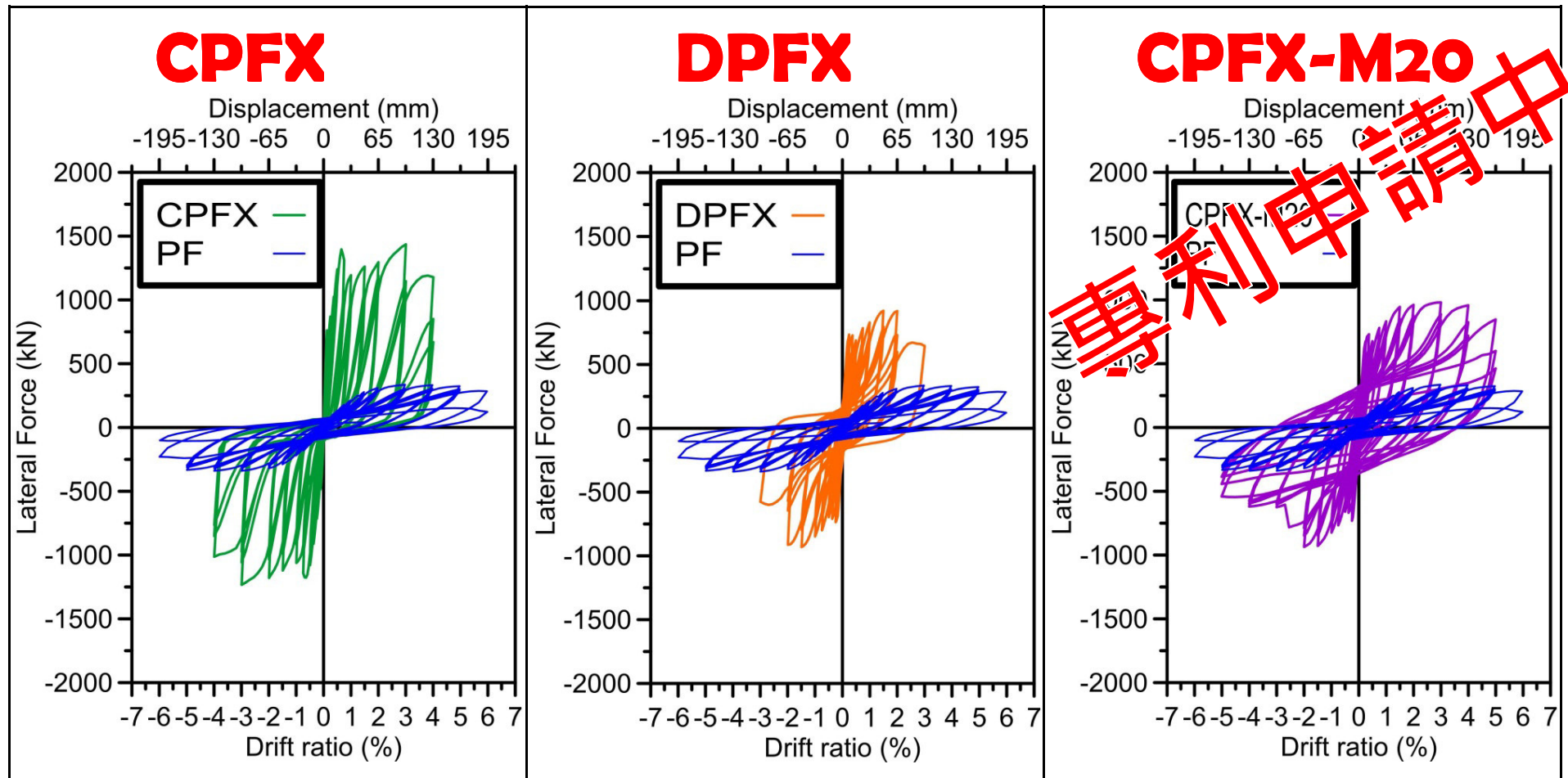
試體	CPFX	DPFX	CPFX-M20
補強構件	鋼框架+X形鋼斜撐	X形鋼斜撐+L形基鈑	鋼框架+X型鋼斜撐
接合型式	介面填充環氧樹脂	化學錨栓接合	化學錨栓接合
示意圖			

專利申請中

載重 - 位移曲線

NAR Labs

補強構架與純構架之載重-位移遲滯迴圈曲線比較



CPFX-M20

NARLabs



CPFX-M20

NARLabs



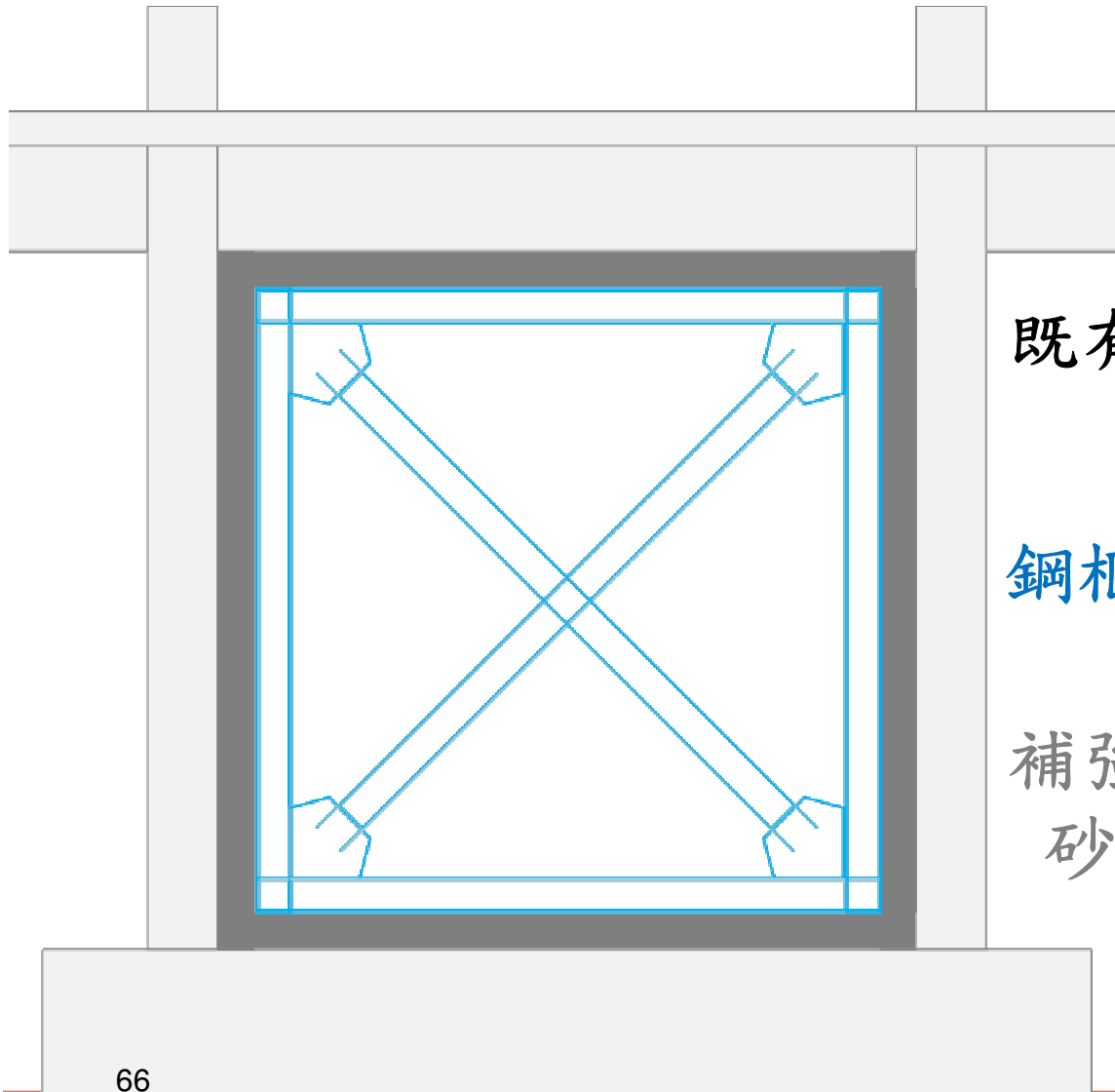
間接接合型鋼斜撐補強設計

- ✓ 簡介
- ✓ 補強設計目標
- ✓ 設計步驟
- ✓ 測試結果
- ✓ 結論

間接接合型鋼斜撐補強設計

✓ 簡介

間接接合型鋼框架斜撐補強

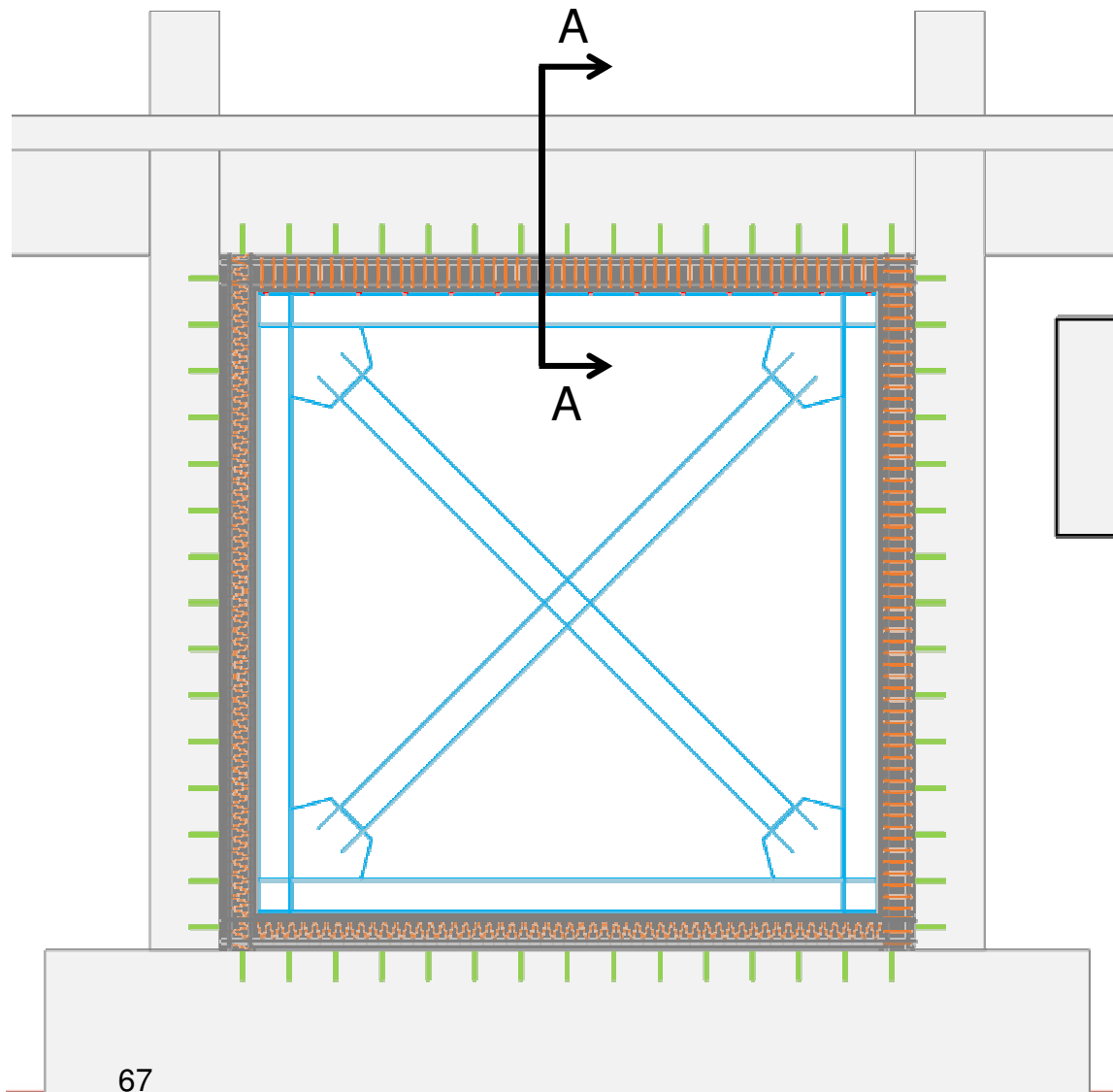


既有空構架 → 既有校舍

+
鋼框架斜撐 → 提升強度
垂直承載

+
補強接合部 → 傳遞斜撐力量
砂漿界面 16~25cm
吸收施工誤差

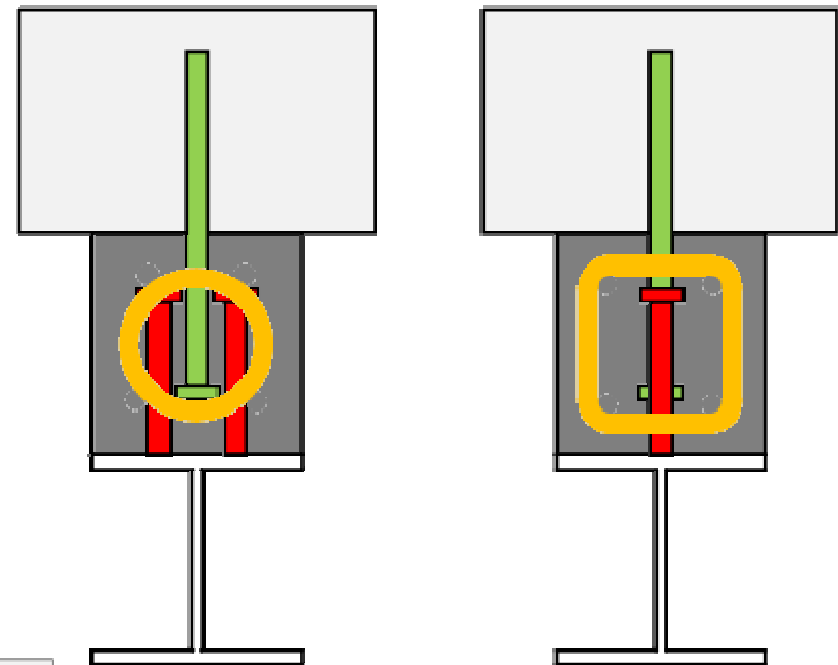
補強接合部細節



螺栓

剪力釘

箍筋、貫通鋼筋



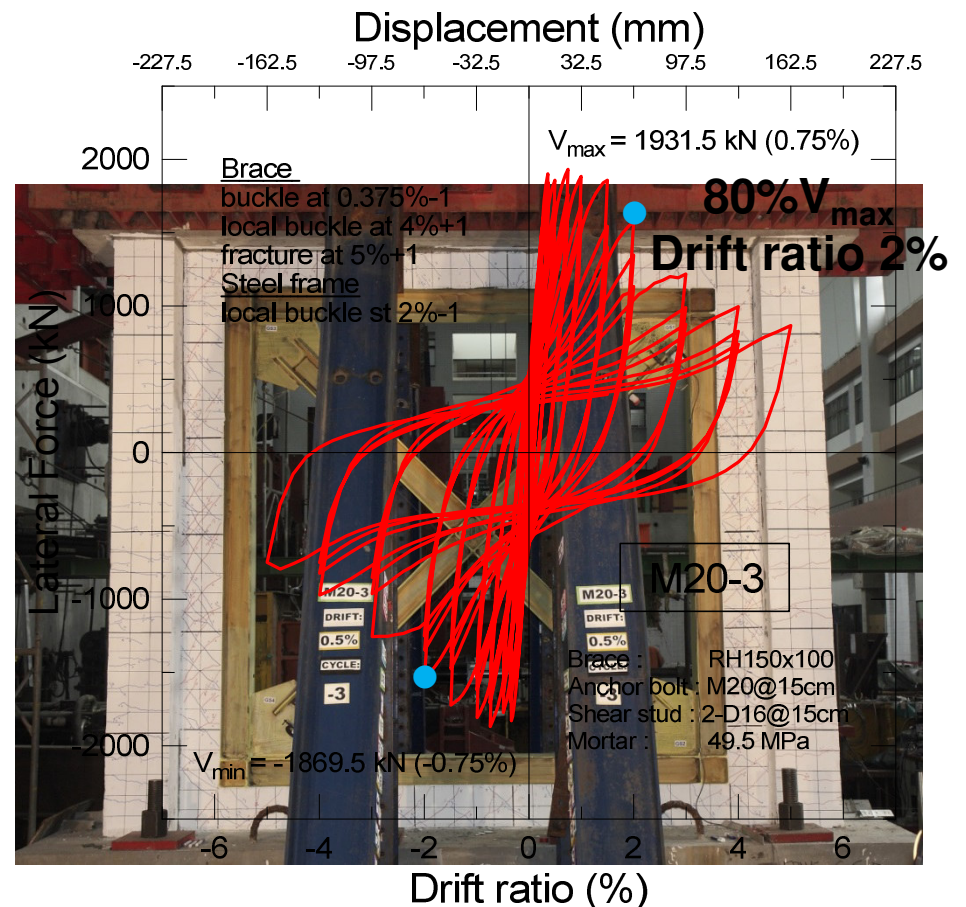
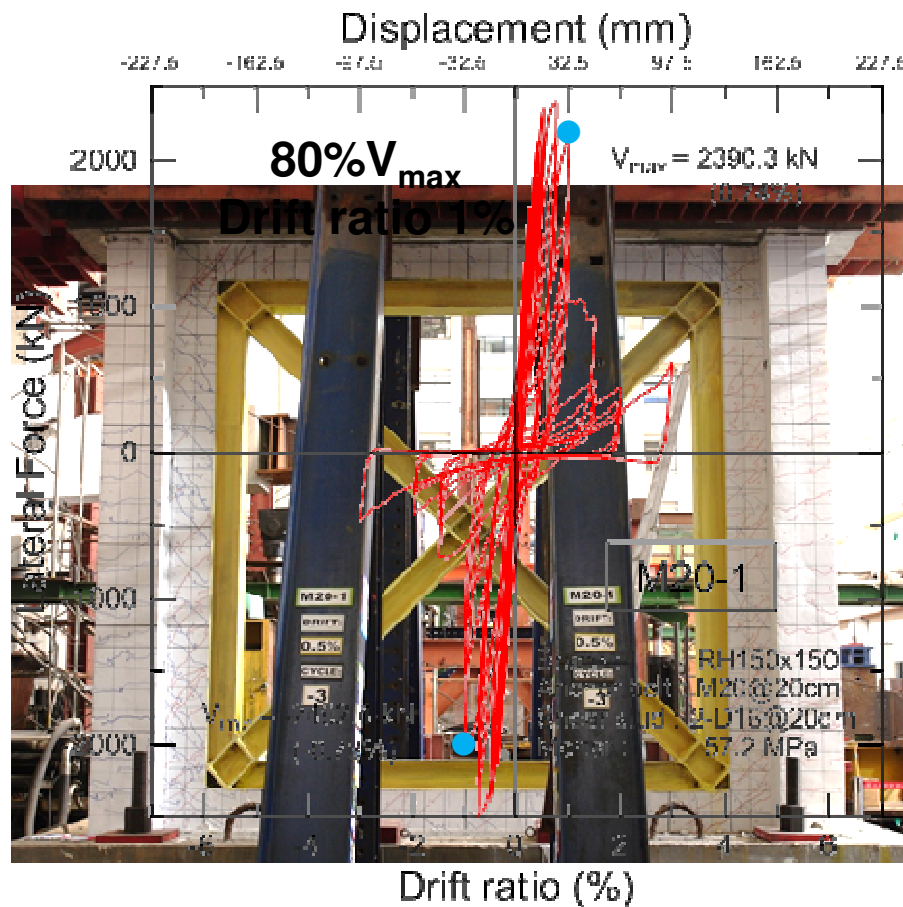
Section A-A

楊季軒試體

無隅板M20-1

vs.

有隅板M20-3

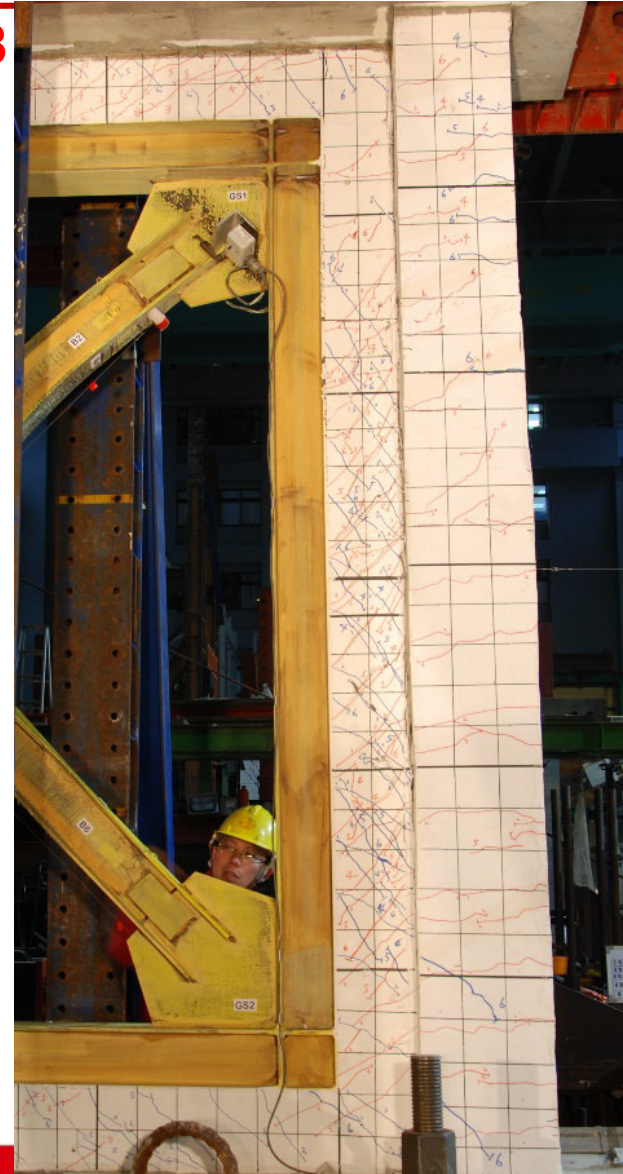


隅板的必要性

M20-1
1%-3



M20-3
1%-3

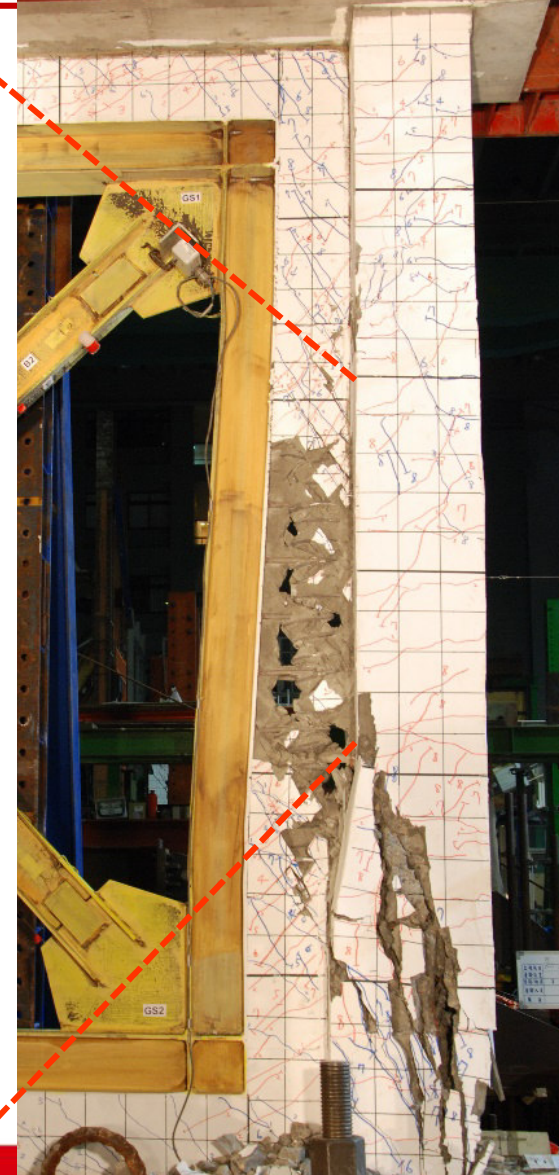


隅板的必要性

M20-1
1%-3

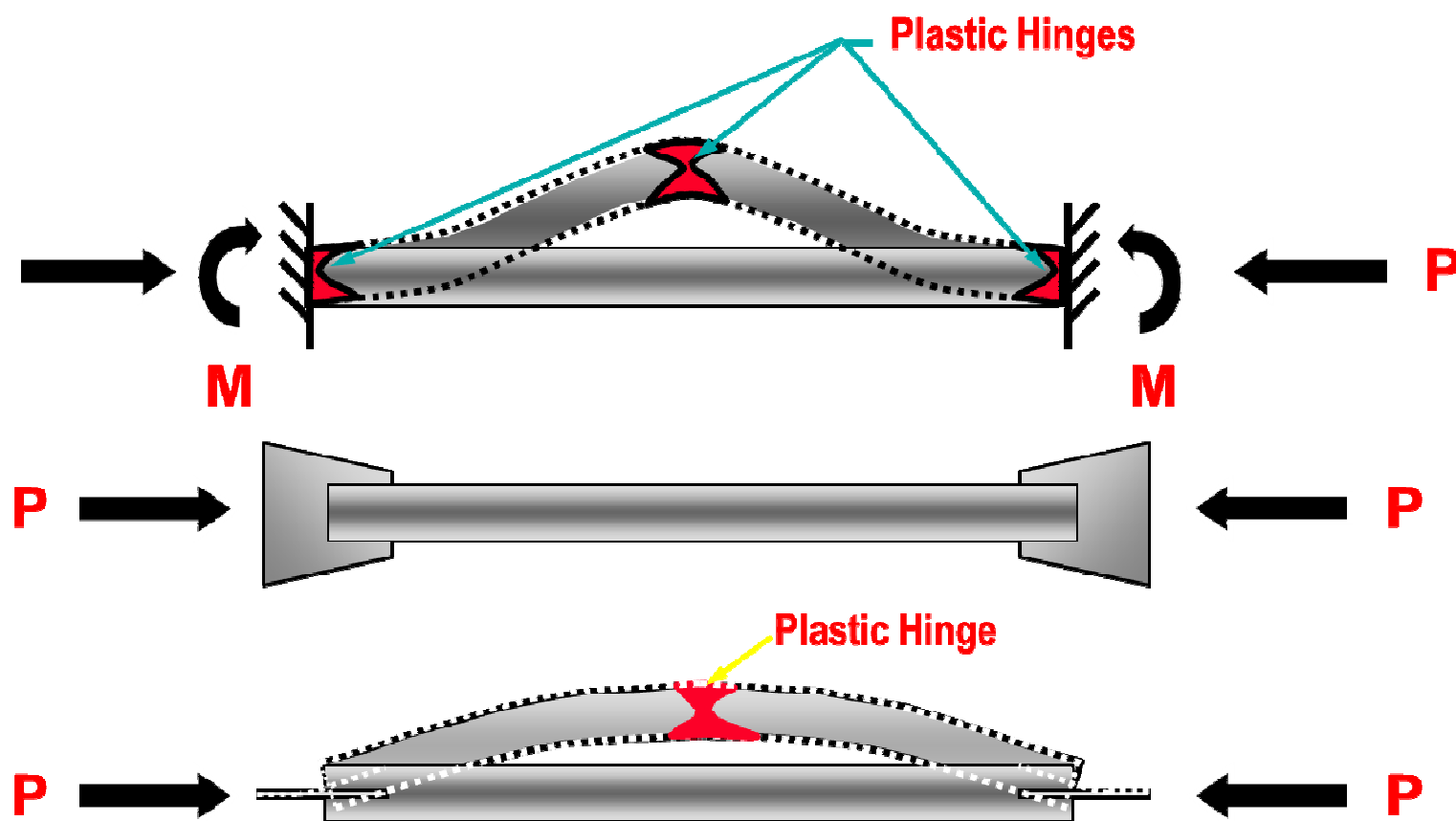


M20-3
3%+1



隅板的必要性

使斜撐產生塑性變形以消能、增加韌性

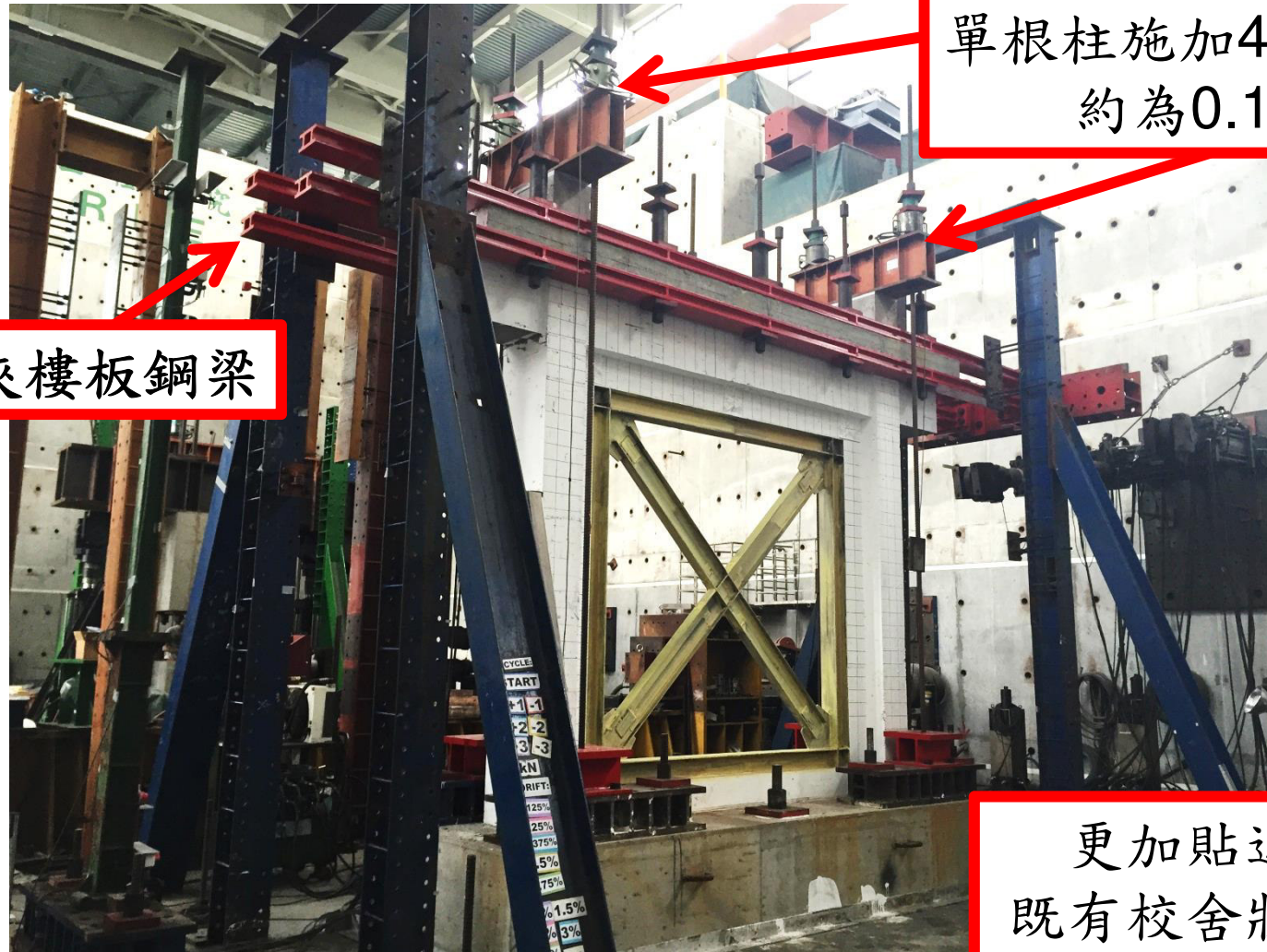


測試佈置改善



夾梁鋼梁
形成複合梁
且無法觀察梁與梁柱接頭破壞情形

測試佈置改善



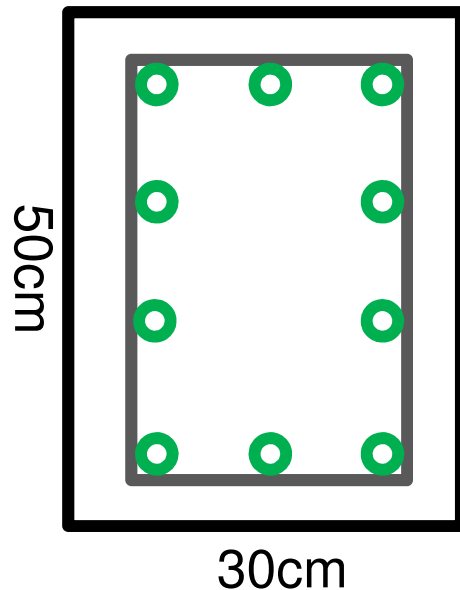
軸力系統
單根柱施加40噸軸力
約為 $0.13A_g f'_c$

夾樓板鋼梁

更加貼近
既有校舍狀況

邊界柱配筋改善

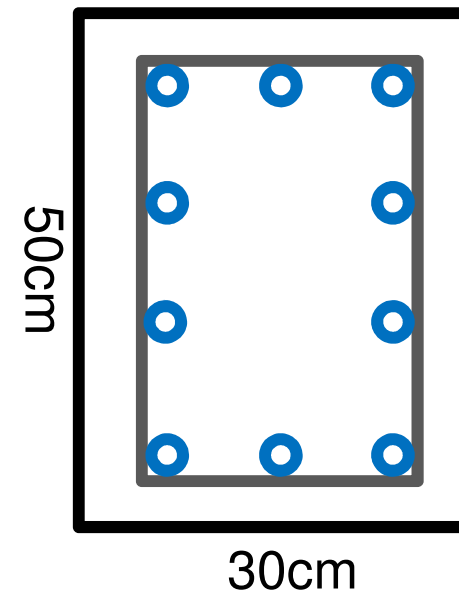
校舍教室柱 平均主筋比**1.8%**



10 - #8

$\rho=3.38\%$

Stirrup - #3@25cm

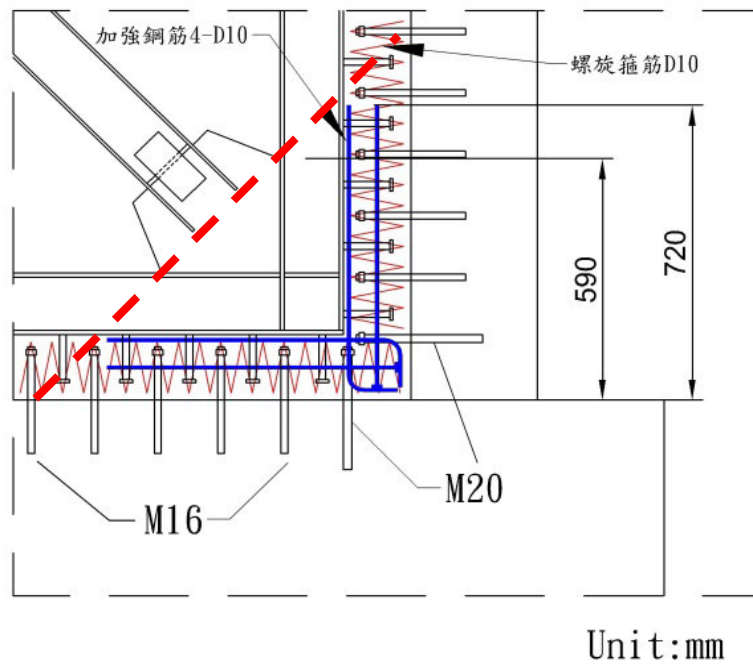


10 - #6

$\rho=1.89\%$

Stirrup - #3@25cm

原角隅鋼筋



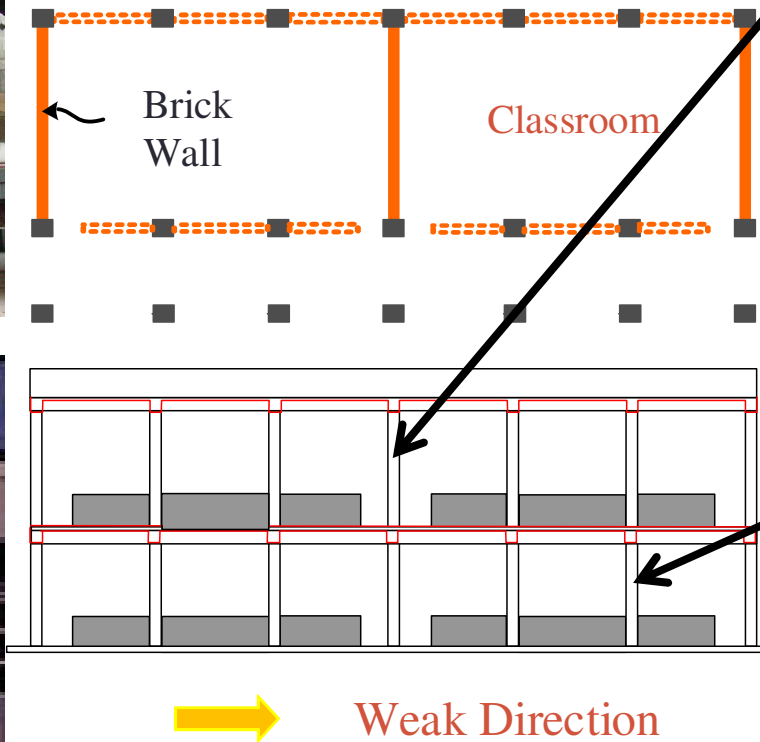
改為貫通鋼筋的配置



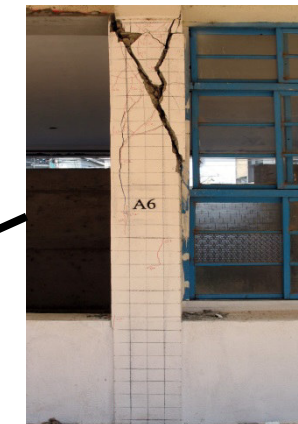
間接接合型鋼斜撐補強設計

✓ 補強設計目標

補強變形能力目標



一般柱
 V_{max} @2~3%

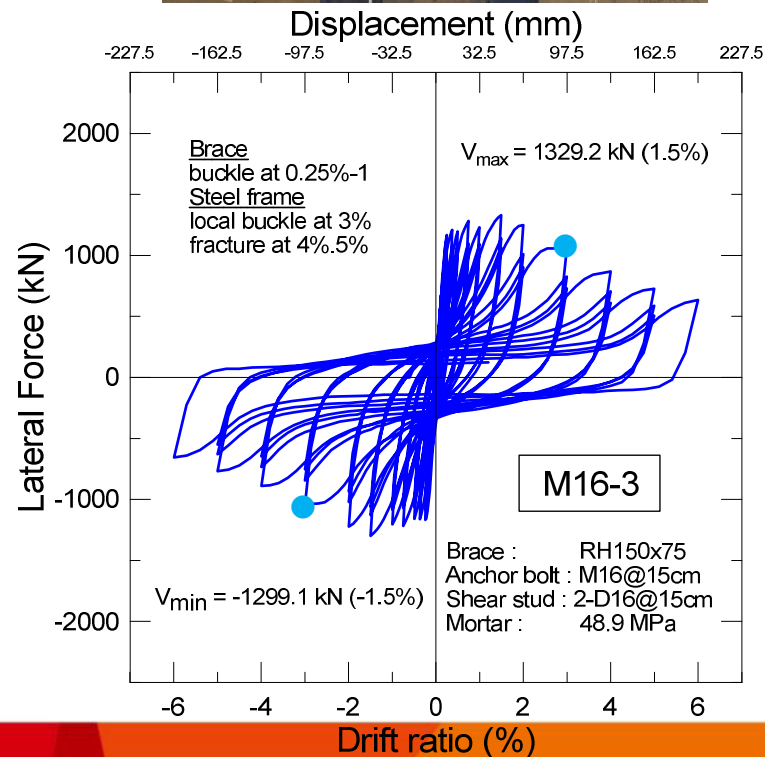
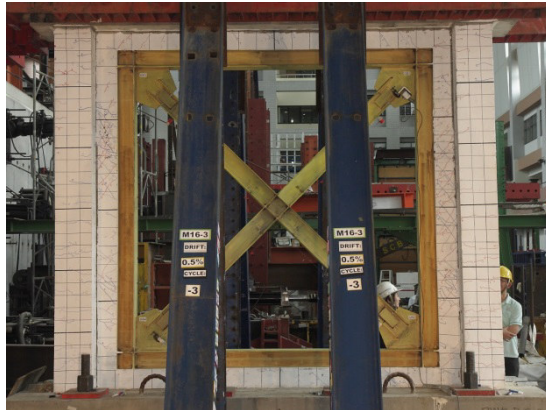


窗台柱
 V_{max} @1.5%

楊季軒試體

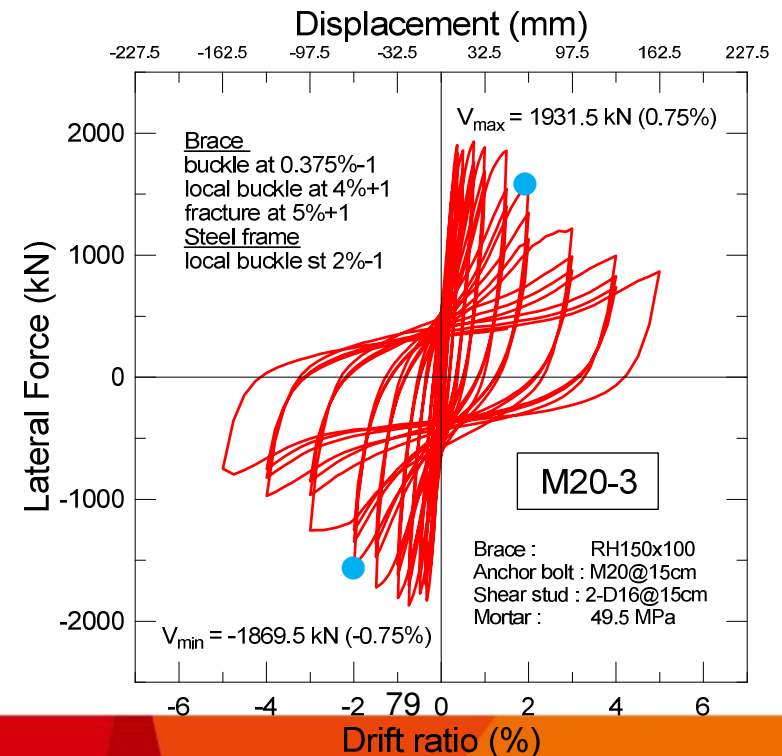
M16-3

**80% V_{max}
Drift ratio 3%**

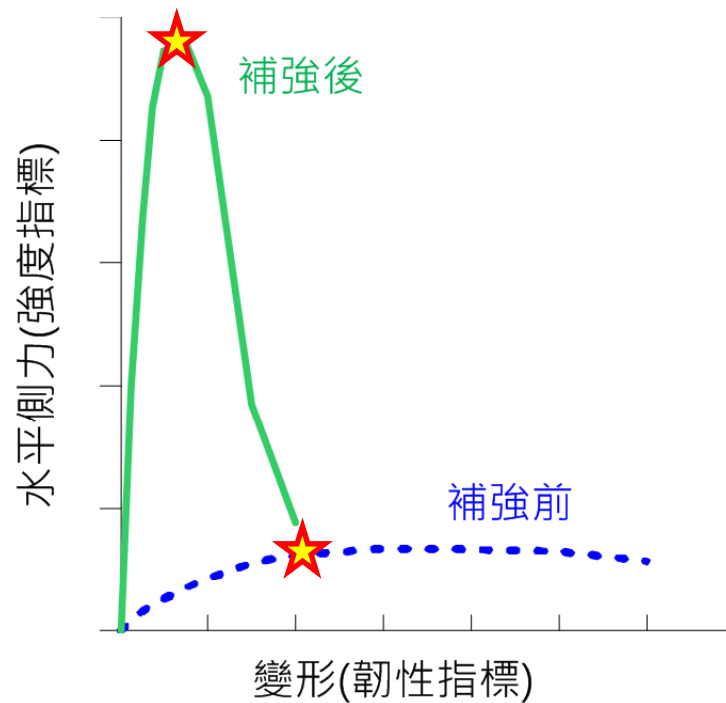


M20-3

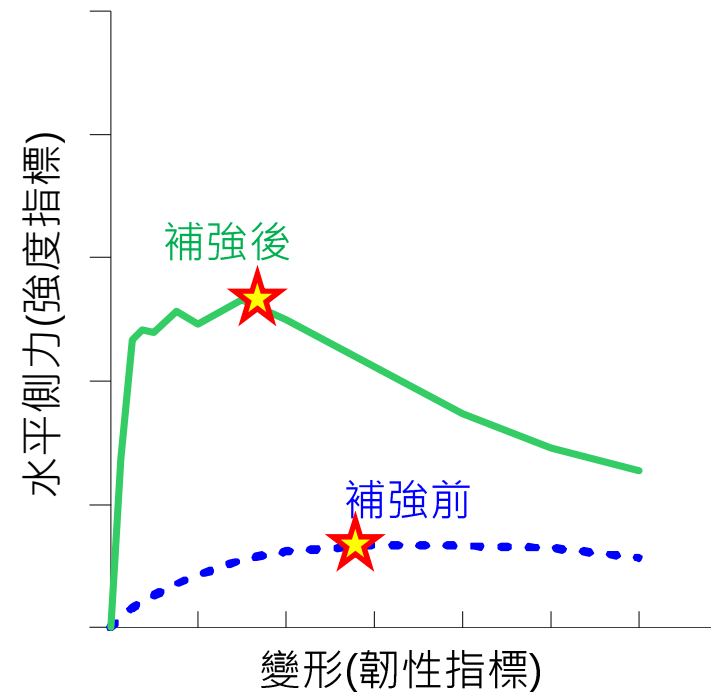
**80% V_{max}
Drift ratio 2%**



補強變形能力目標



強度抵抗型補強



強度韌性抵抗型補強

80%最大強度之位移能力達2%
鋼框斜撐強度+既有構架強度

間接接合型鋼斜撐補強設計

✓ 設計步驟

1. 設計補強接合部配置

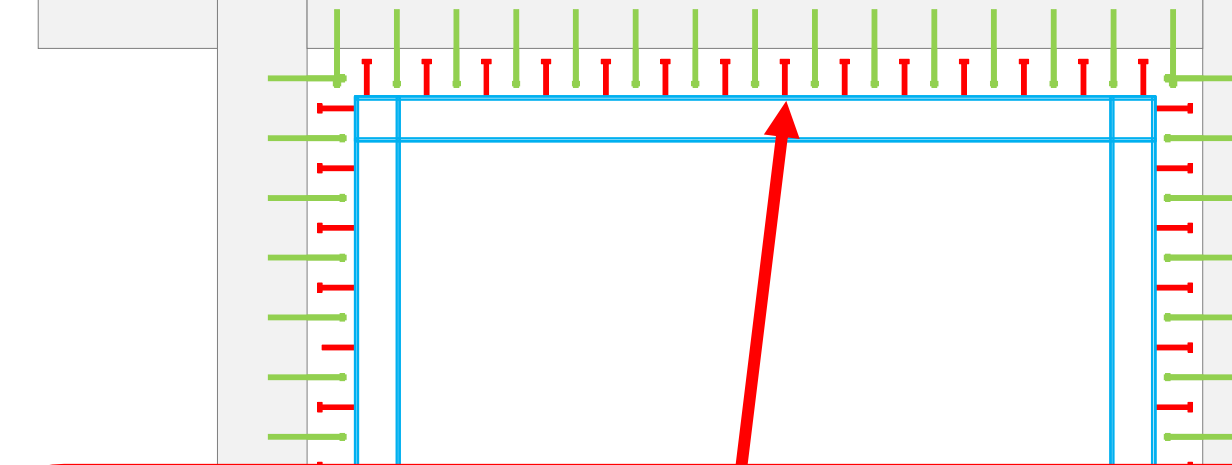
IAR Labs

化學錨栓

尺寸M16、M20
間距25公分以下

1. 設計補強接合部配置

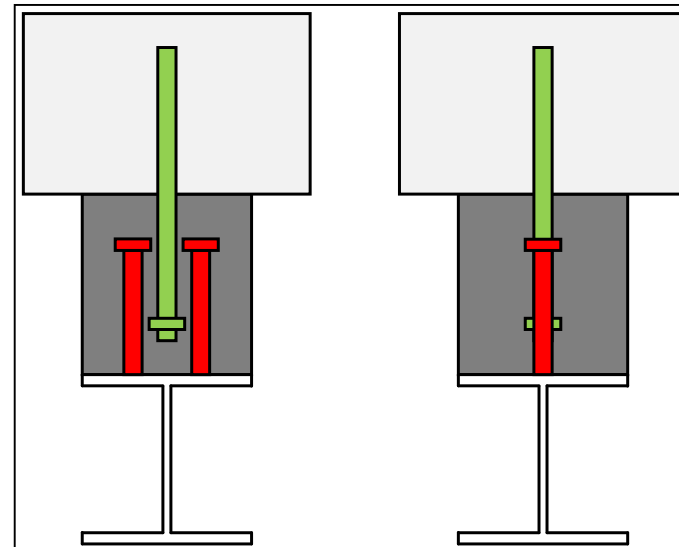
IAR Labs



剪力釘

尺寸D16以上

可單排或雙排配置
間距與化學錨栓相同
並交錯配置



1. 設計補強接合部配置

鋼框架

寬度至少15公分

螺旋箍筋

#2以上

@40~60mm

or $\frac{1}{3} \sim \frac{1}{6}$ 錨栓間距

矩形箍筋

#3以上

貫通鋼筋#4以上

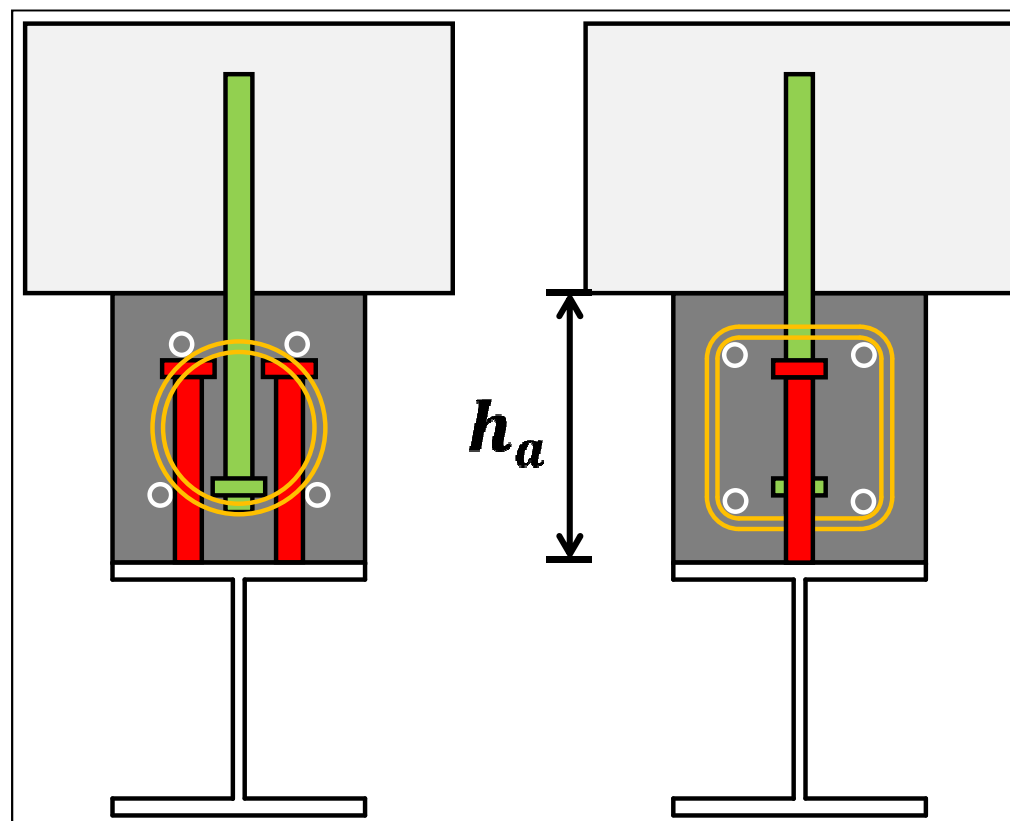
@ $\frac{1}{2} \sim \frac{1}{3}$ 錨栓間距

填充砂漿

使用M16→ $h_a=16$ 公分

使用M20→ $h_a=20$ 公分

無收縮水泥砂漿50MPa以上





www.narlabs.org.tw

埋深

$$l_n \geq 6d_a$$

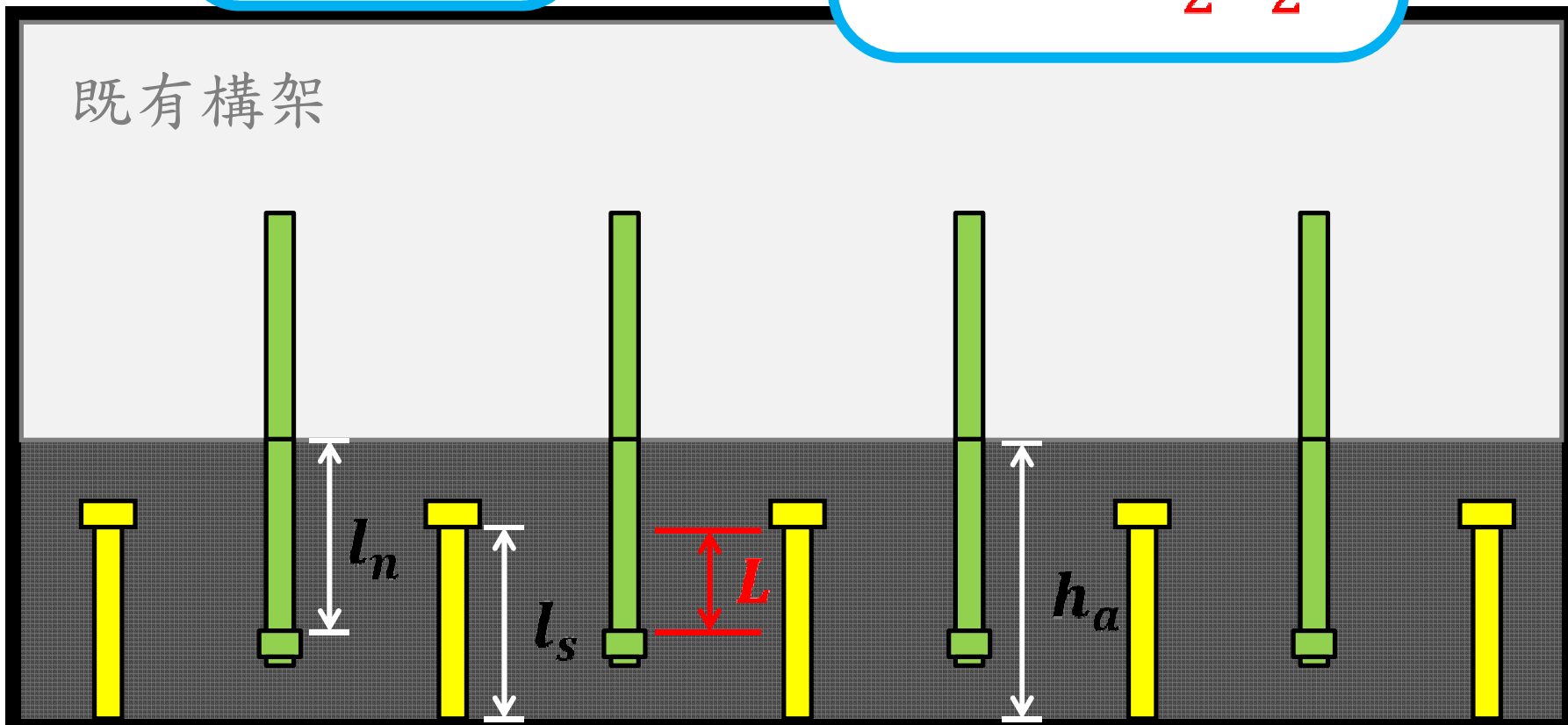
$$l_s \geq 6d_a$$

搭接長度

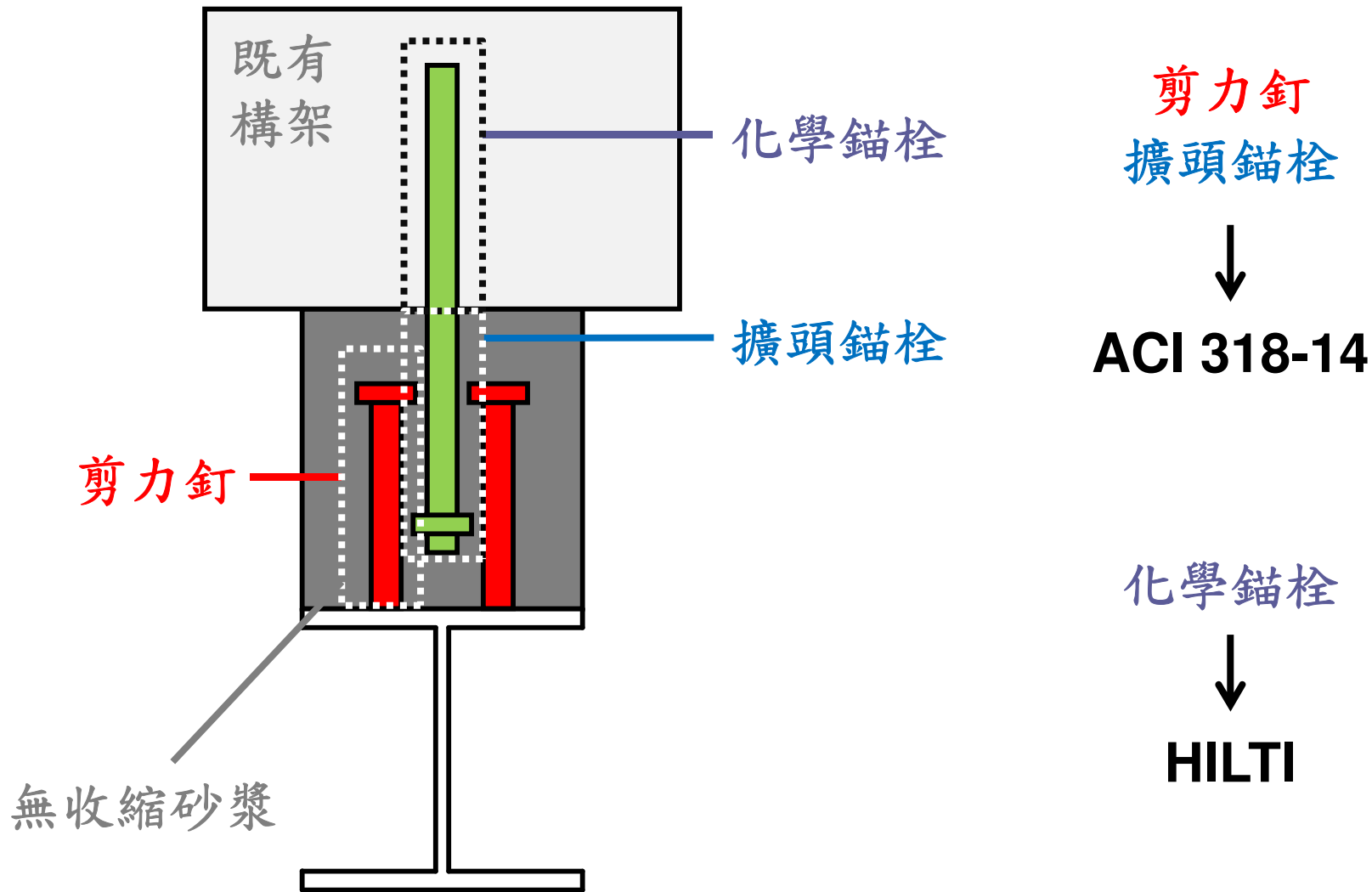
$$L = l_n + l_s - h_a$$

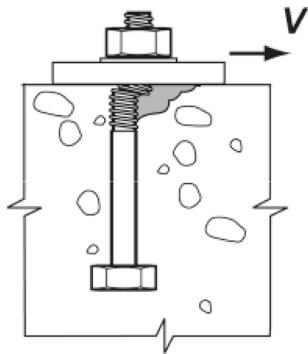
$$L \geq \max\left\{\frac{l_n}{2}, \frac{l_s}{2}\right\}$$

既有構架

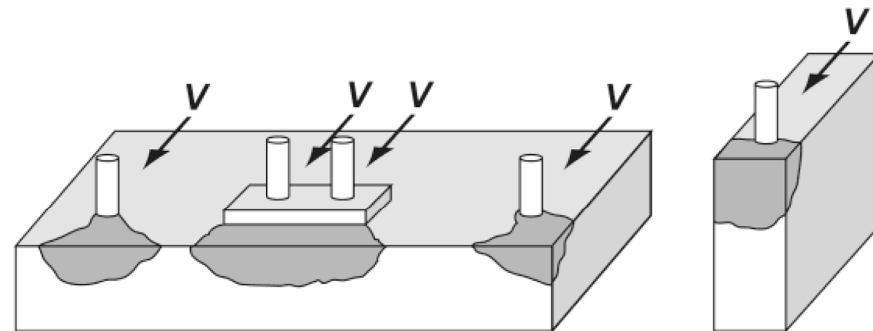
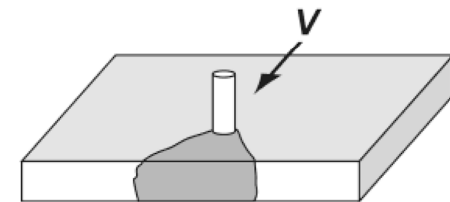
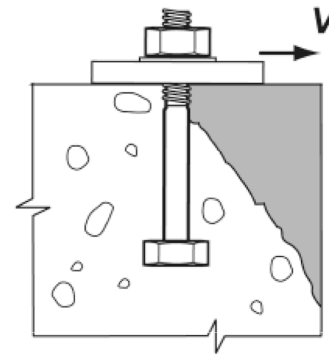


2. 計算接合部剪力強度





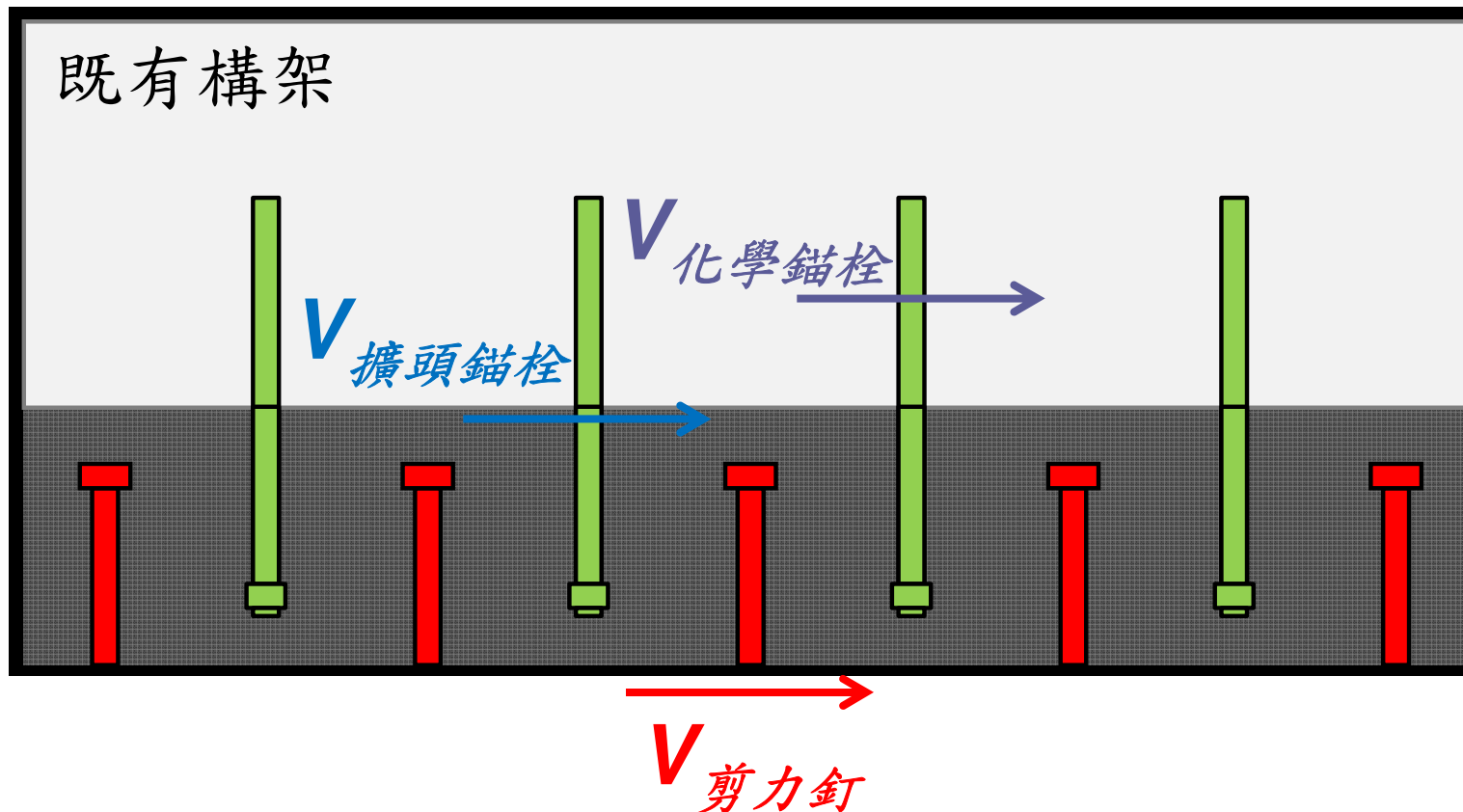
鋼材剪力強度



混凝土剪破強度

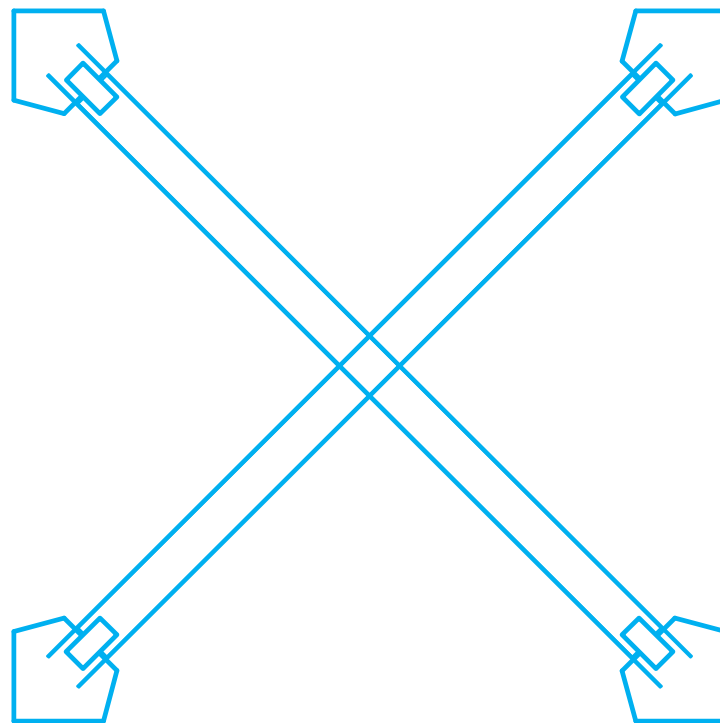
2. 計算接合部剪力強度

$$V_{anchor} = \min(V_{\text{化學錨栓}}, V_{\text{剪力釘}}, V_{\text{擴頭錨栓}})$$



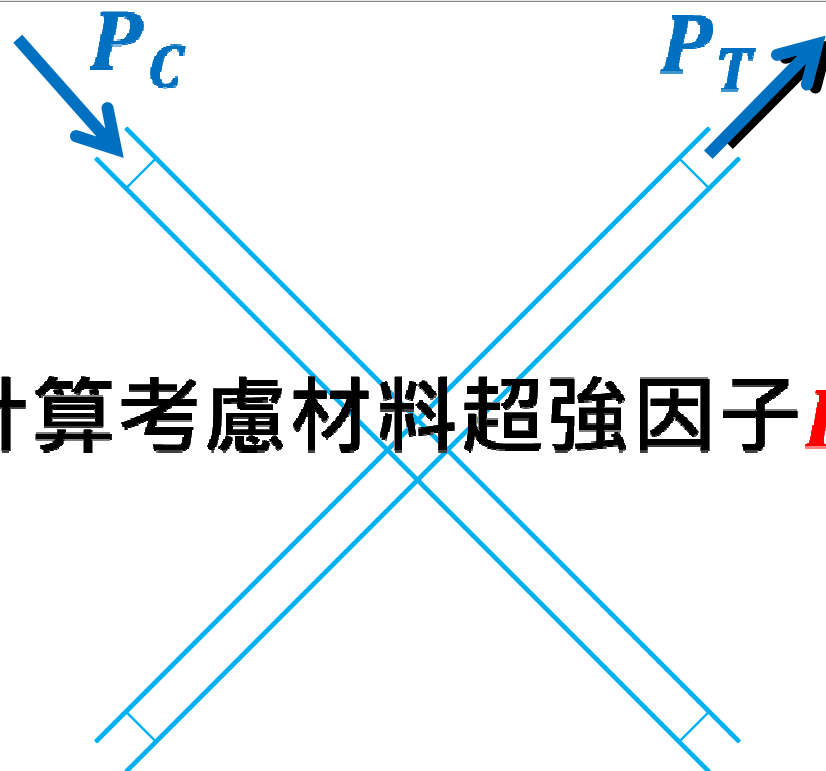
3.

板 **IAR Labs**



3.

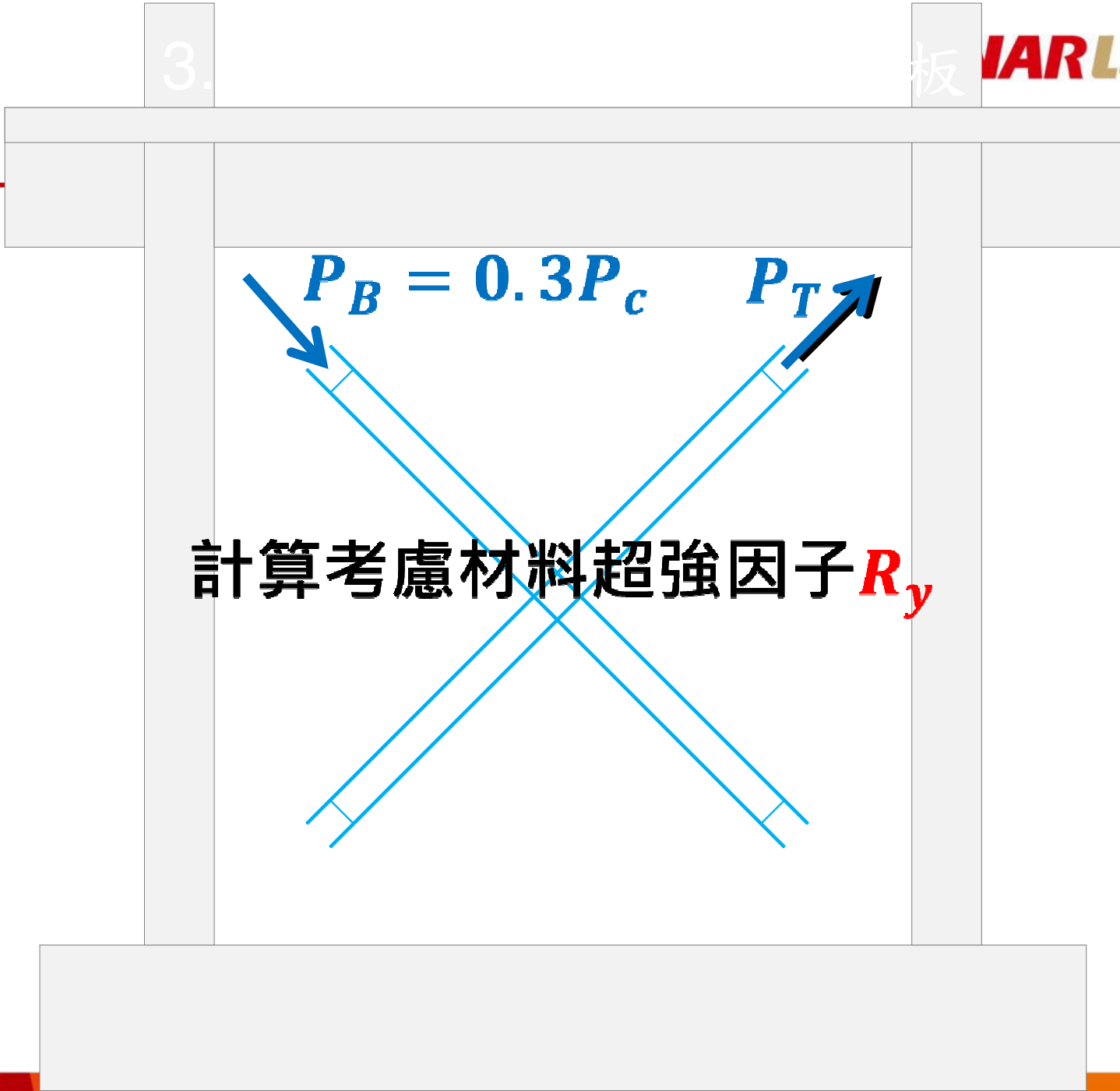
板 IAR Labs



計算考慮材料超強因子 R_y

3.

板 IAR Labs



$P_B = 0.3 P_c$ P_T

計算考慮材料超強因子 R_y

1. 銲道長度

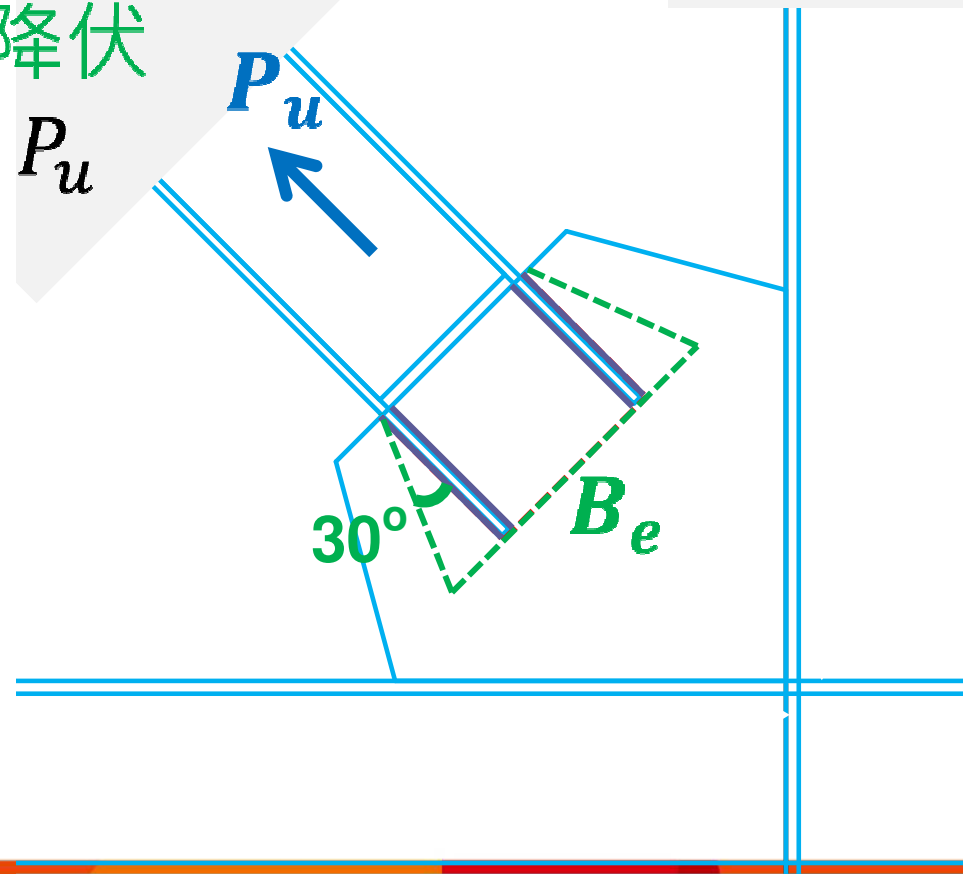
$$\phi(0.6F_{exx})(0.707T_w)(8L_w) \geq P_u$$

2. 塊狀剪力破壞

$$\phi P_n = \phi(0.6F_{y,g}A_{gv} + F_{u,g}A_{nt}) \geq P_u$$

3. 隅板拉力降伏

$$\phi F_{y,g}B_e t_g \geq P_u$$



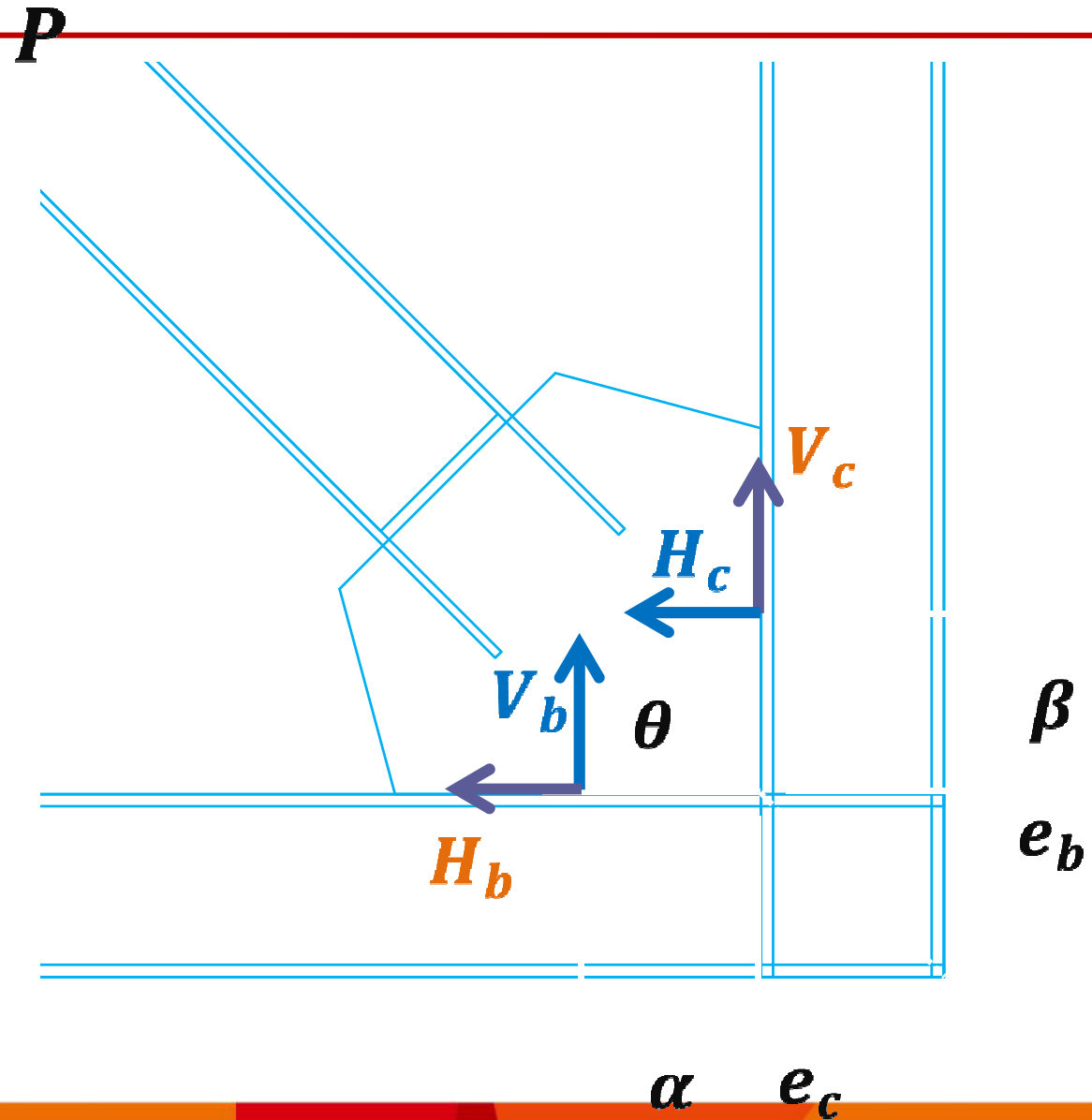
均力法

$$V_c = \frac{\beta}{\gamma} P$$

$$H_c = \frac{e_c}{\gamma} P$$

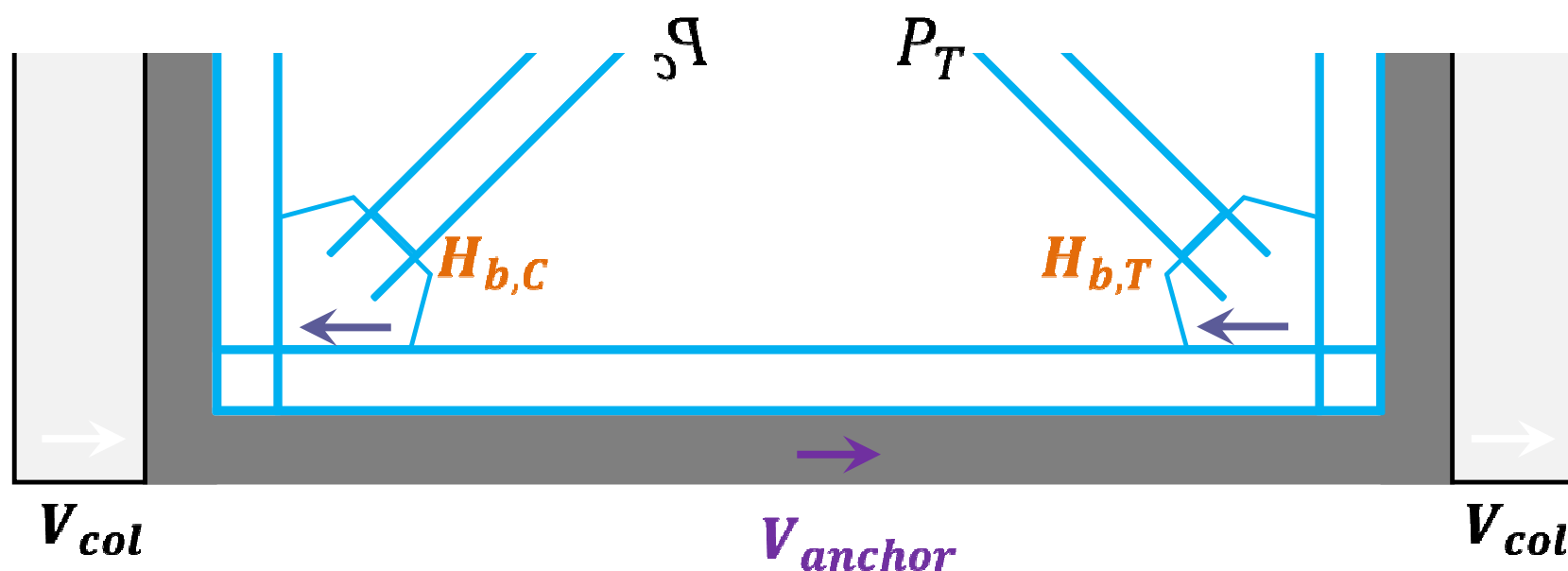
$$H_b = \frac{\alpha}{\gamma} P$$

$$V_b = \frac{e_b}{\gamma} P$$



■ 鋼斜撐發揮最大拉力及最大壓力時，藉由隅板分散的力量，不造成接合部及既有柱之破壞

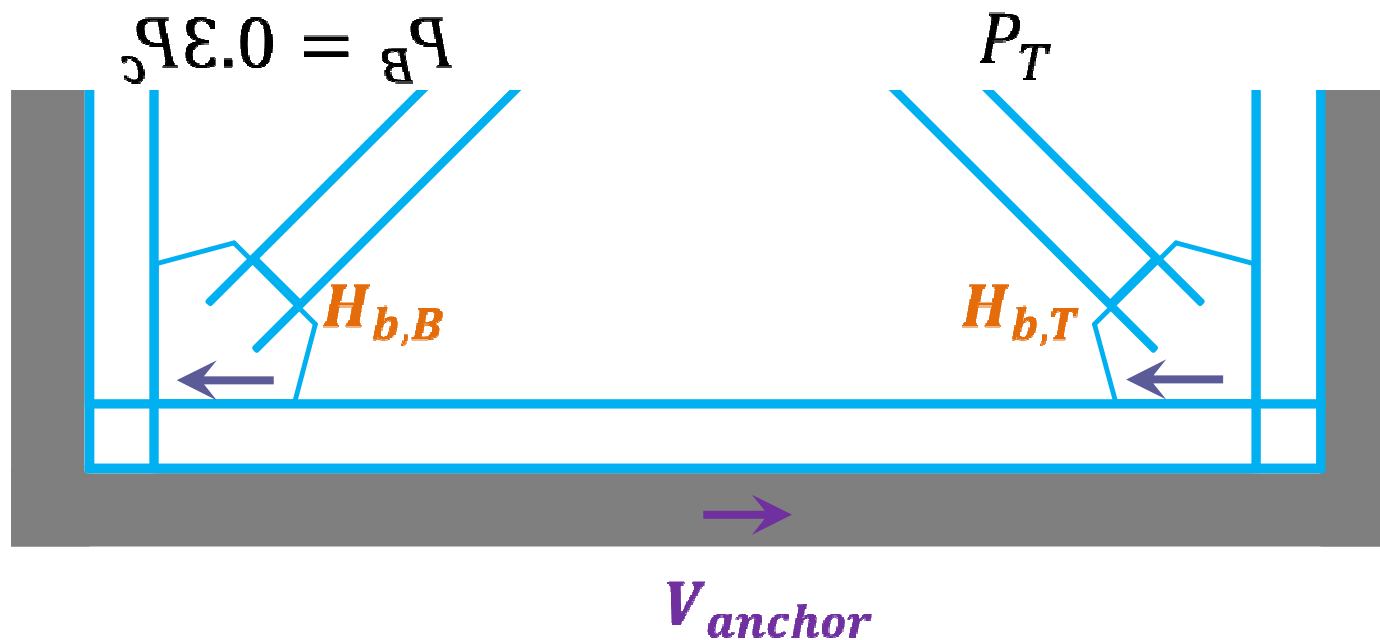
$$V_{anchor} + 2V_{col} > H_{b,C} + H_{b,T}$$



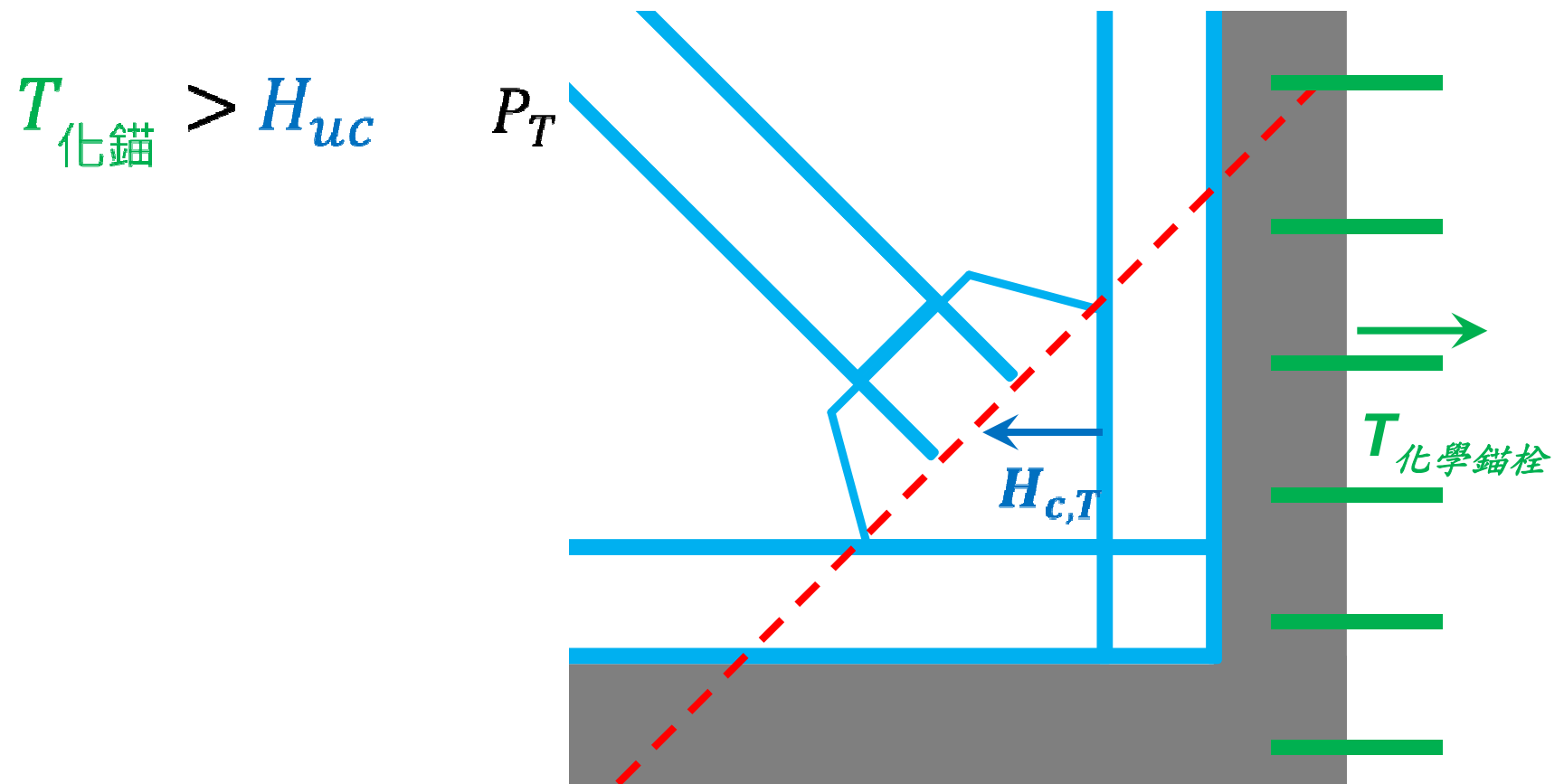
$$V_{col} = V_c + V_s$$

■ 當鋼斜撐挫曲後，已發展許多裂縫之補強接合部，
能抵抗鋼斜撐拉力及挫曲後之力量

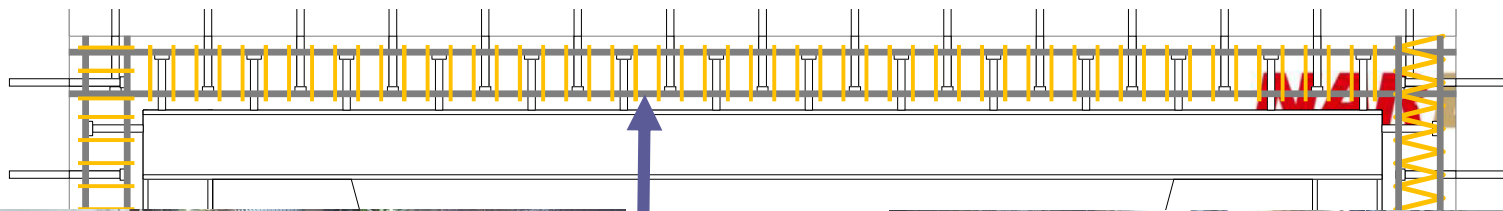
$$V_{anchor} > H_{b,B} + H_{b,T}$$



■ 鋼斜撐發揮至最大拉力時，隅板分力不造成力量分散區域之化學錨栓拔出破壞



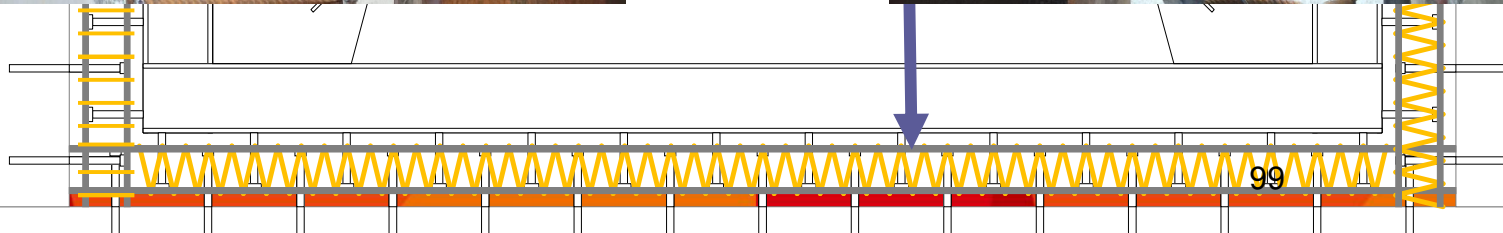
試體名稱	M16	M20
化學錨栓	M16@20cm	M20@20cm
剪力釘	D16@20cm單排	
鋼框架	RH150x150x7x10	
鋼斜撐	RH150x75x5x7	RH175x90x5x8
預估補強後側推力	1176 kN	1487 kN
預估補強倍率	5.5倍	7倍



箍筋
50mm
鋼筋#4



螺旋
#2@5
貫通

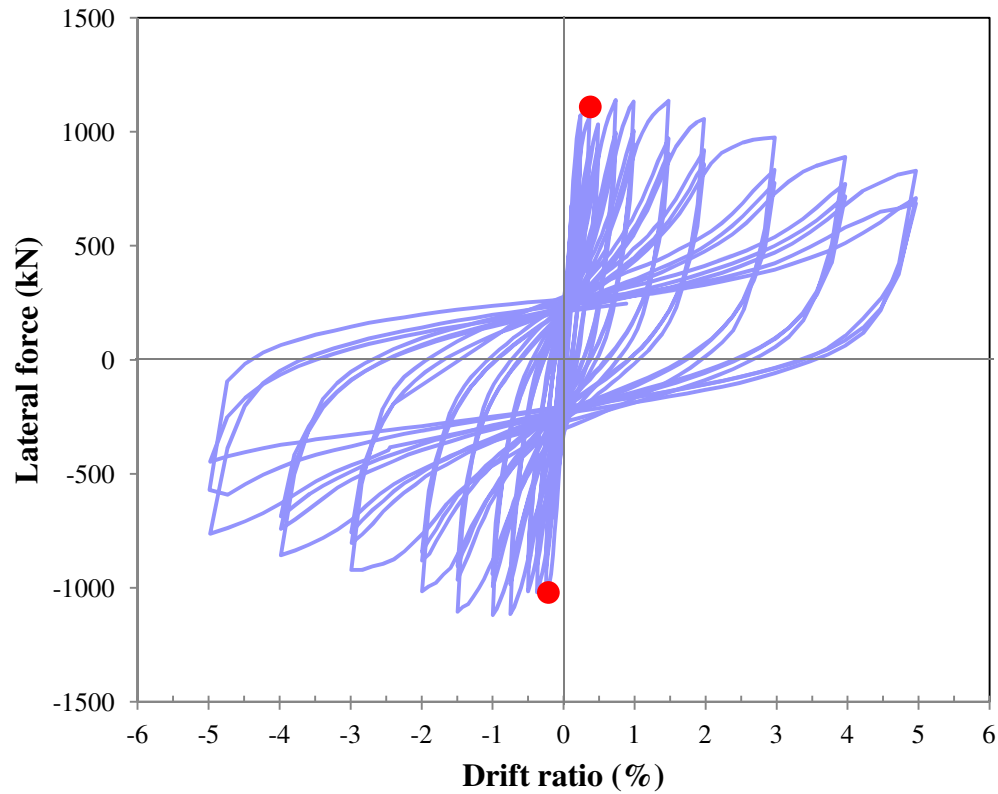


間接接合型鋼斜撐補強設計

✓ 測試結果

試體M16

強度發展階段0.25%



$$V(0.25\%+1) = 1072.8 \text{ kN}$$

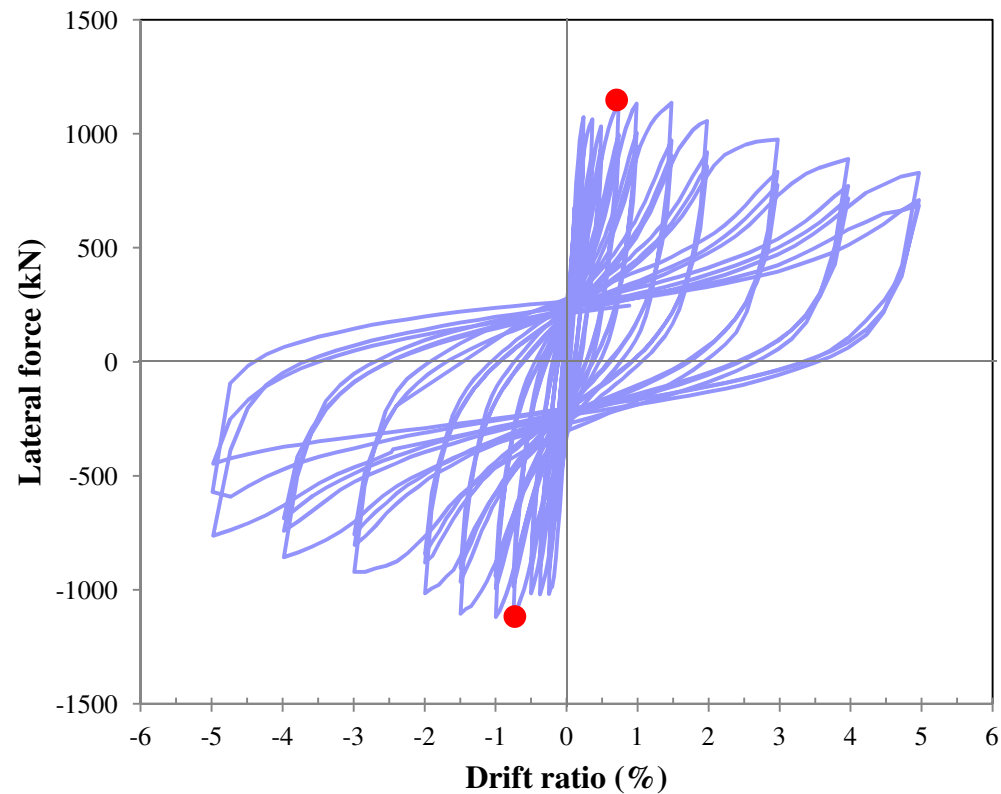
$$V(0.25\% -1) = -1018.5 \text{ kN}$$

斜撐產生些微挫屈



試體M16

強度持平階段0.75%-1%



$$V(0.75\%+1) = 1140.0 \text{ kN}$$

$$V(0.75\% -1) = -1114.8 \text{ kN}$$

東側砂漿與鋼框脫開

正向最大強度 0.75%+1 1140.0kN

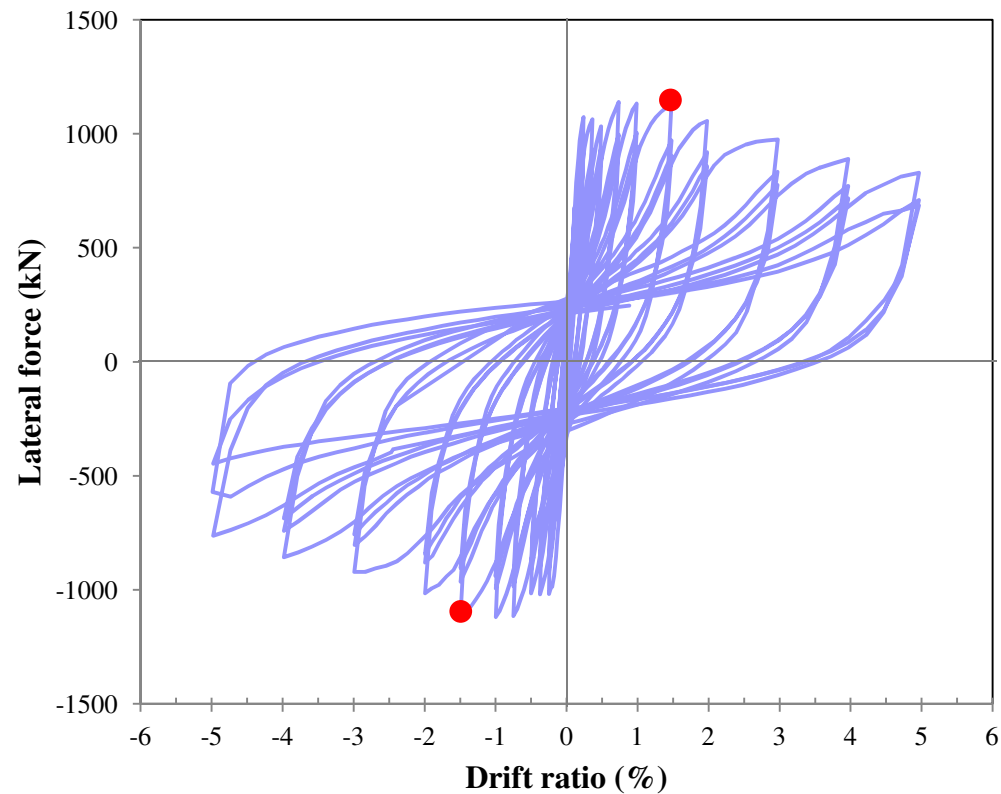
負向最大強度 1% -1 -1119.3kN

(預估1176kN)



試體M16

強度持平階段1.5%



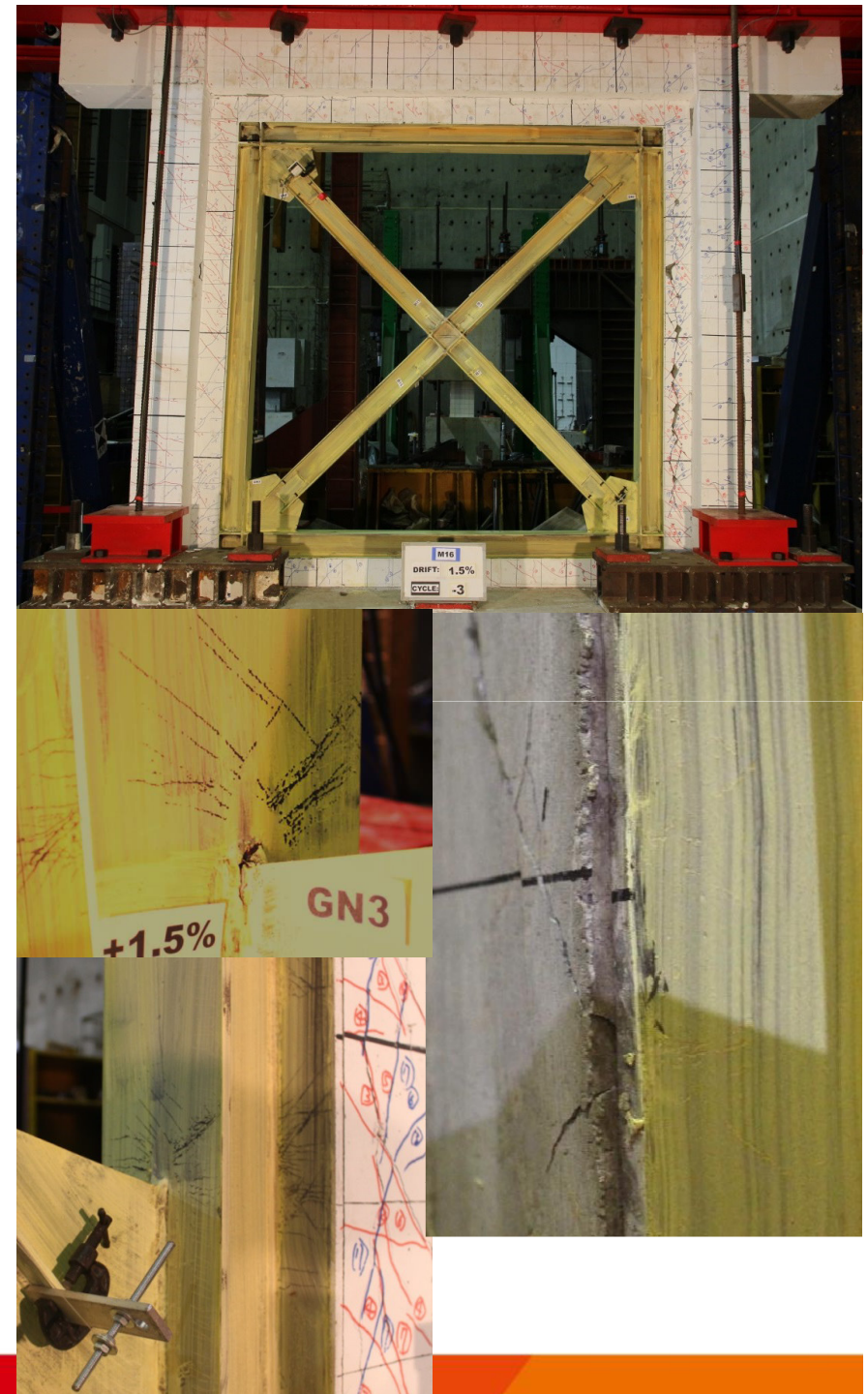
$$V(1.5\%+1) = 1136.4 \text{ kN}$$

$$V(1.5\%-1) = -1104.9 \text{ kN}$$

螺旋箍筋部分砂漿脫落嚴重

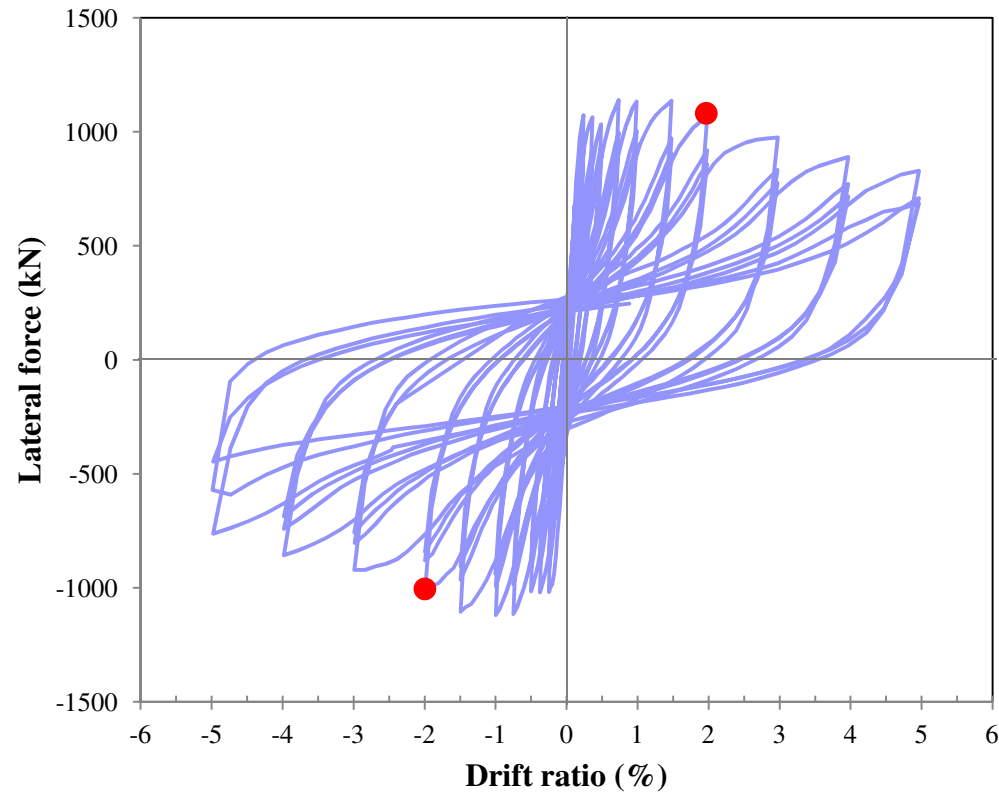
隅板出現銲道斷裂

鋼框發展降服線



試體M16

強度衰減階段2%



$V(2\%+1) = 1056.0 \text{ kN}$

$V(2\%-1) = -1015.2 \text{ kN}$

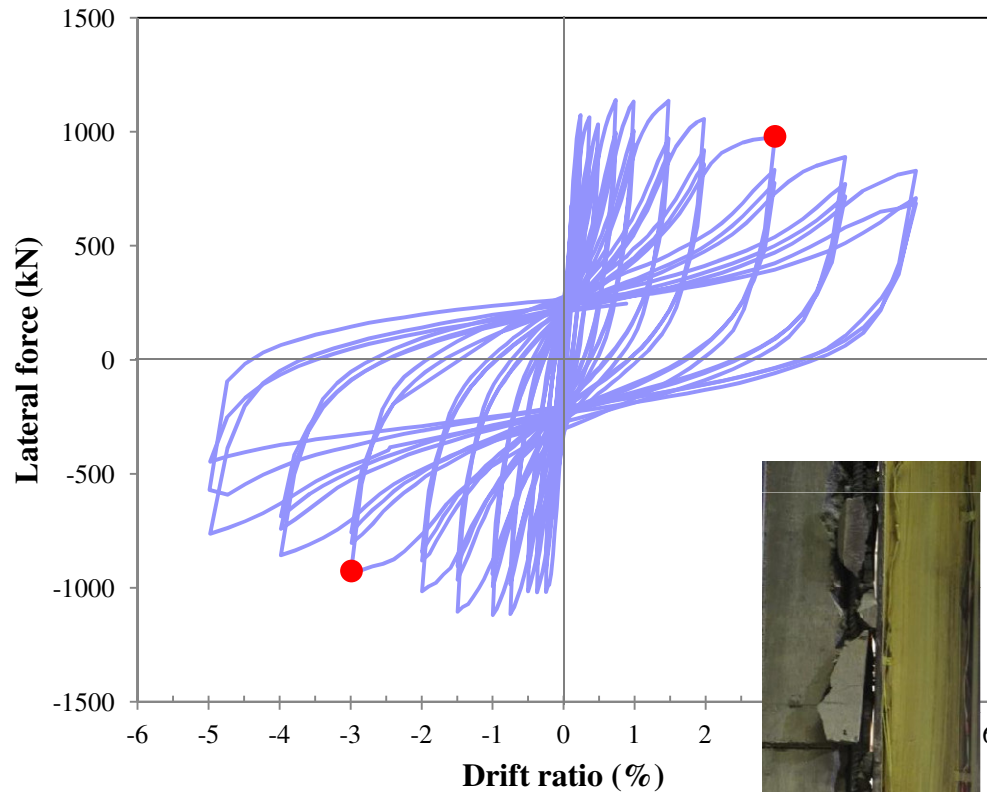
發現東側剪力釘斷裂

角落砂漿開始擠碎



試體M16

強度衰減階段3%



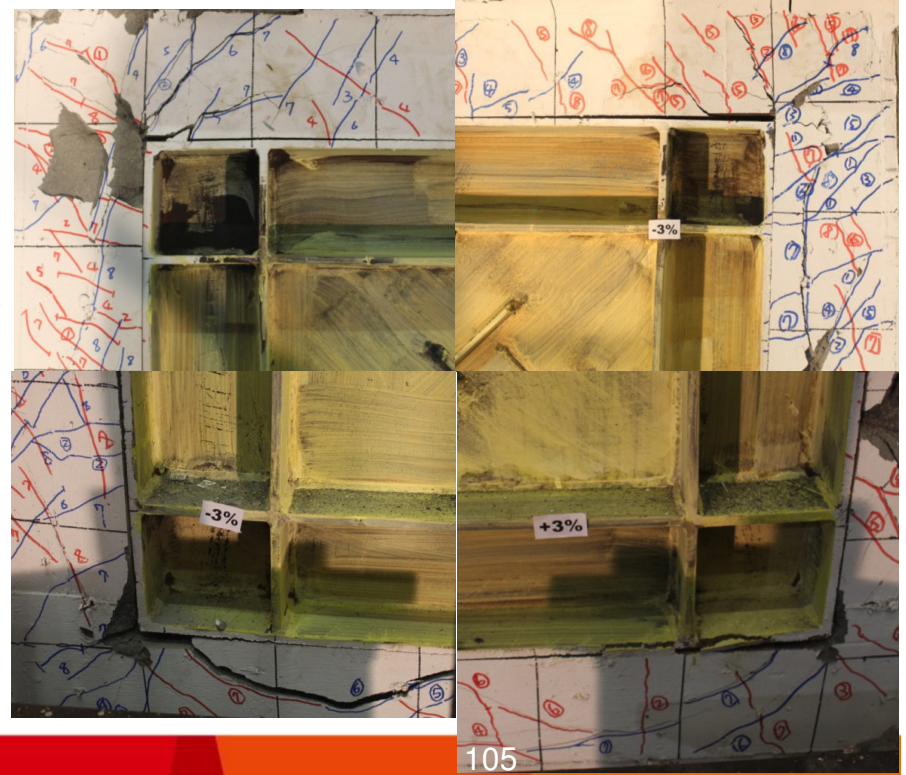
$V(3\%+1) = 975.8 \text{ kN}$

$V(3\% -1) = -921.7 \text{ kN}$

最大強度83%

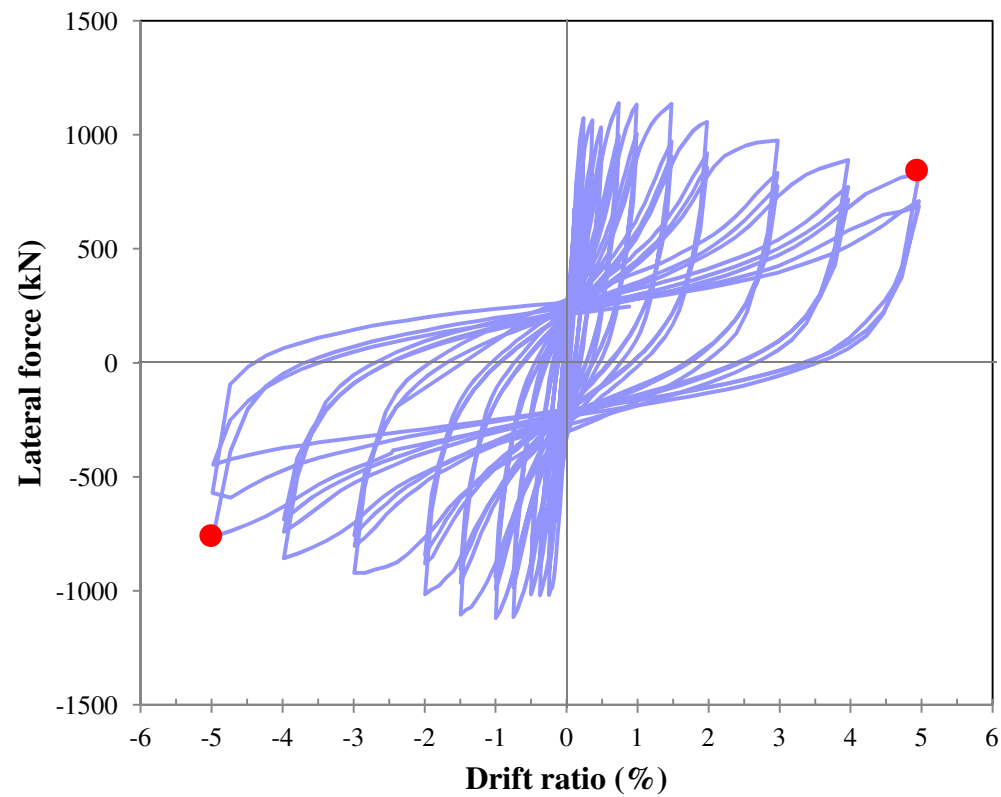
西側砂漿內鋼筋裸露

角落砂漿受拉分離鋼框



試體M16

最終破壞5%



$$V(5\%+1) = 828.8 \text{ kN}$$

$$V(5\% -1) = -763.2 \text{ kN}$$

最大強度70%

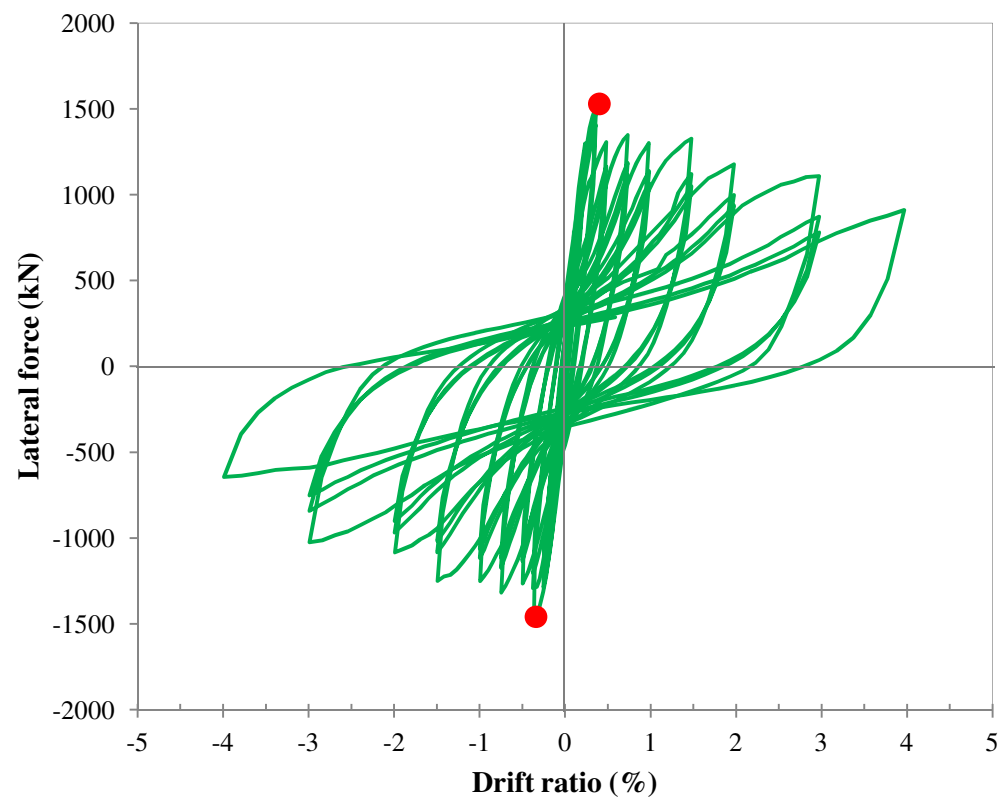


試體M16
最終破壞5%

NARLabs



試體M20 最大強度0.375%



$V(0.375\%+1) = 1504.5 \text{ kN}$

$V(0.375\% -1) = -1505.7 \text{ kN}$

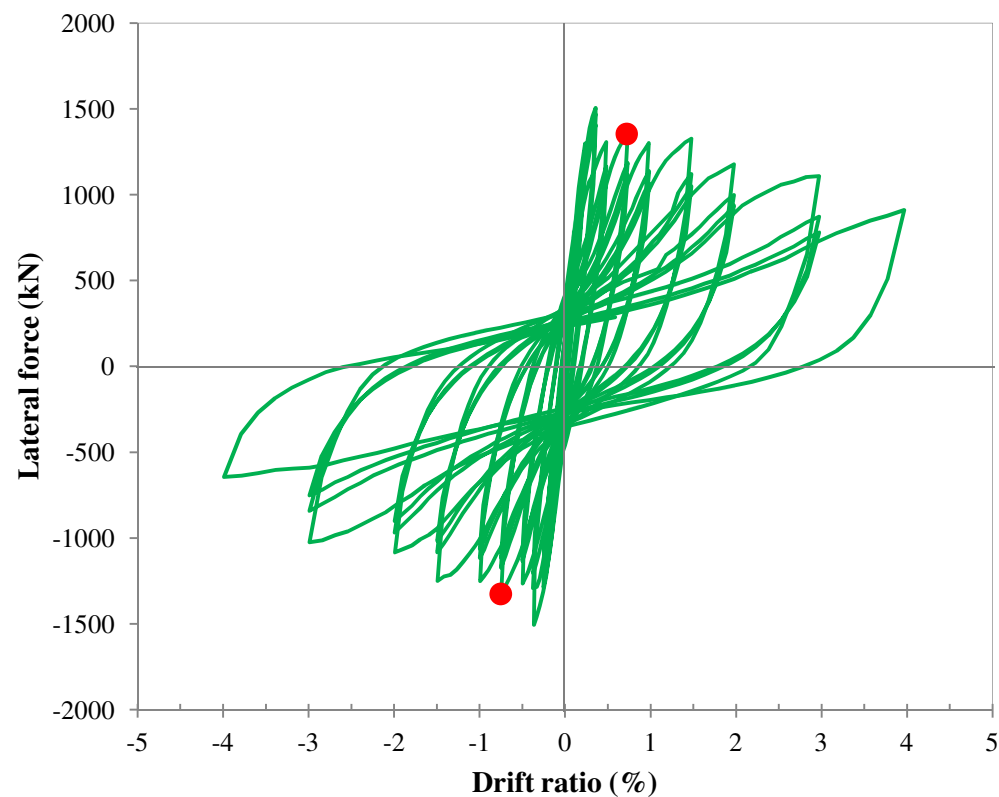
(預估1487.0kN)

斜撐開始些微挫屈



試體M20

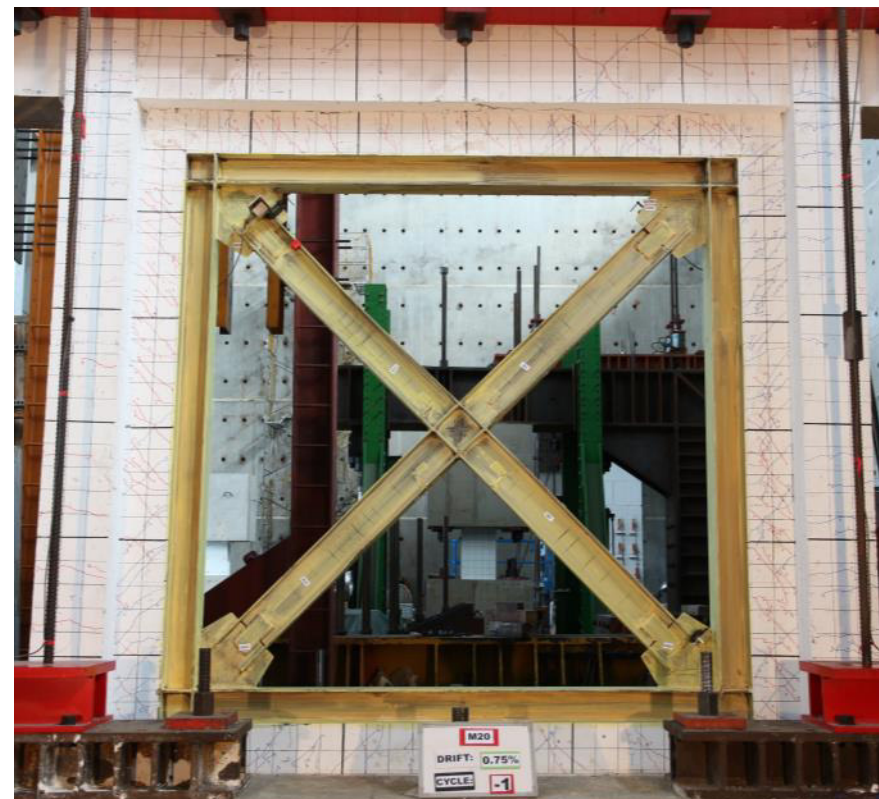
強度持平階段0.75%



$$V(0.75\%+1) = 1347.0 \text{ kN}$$

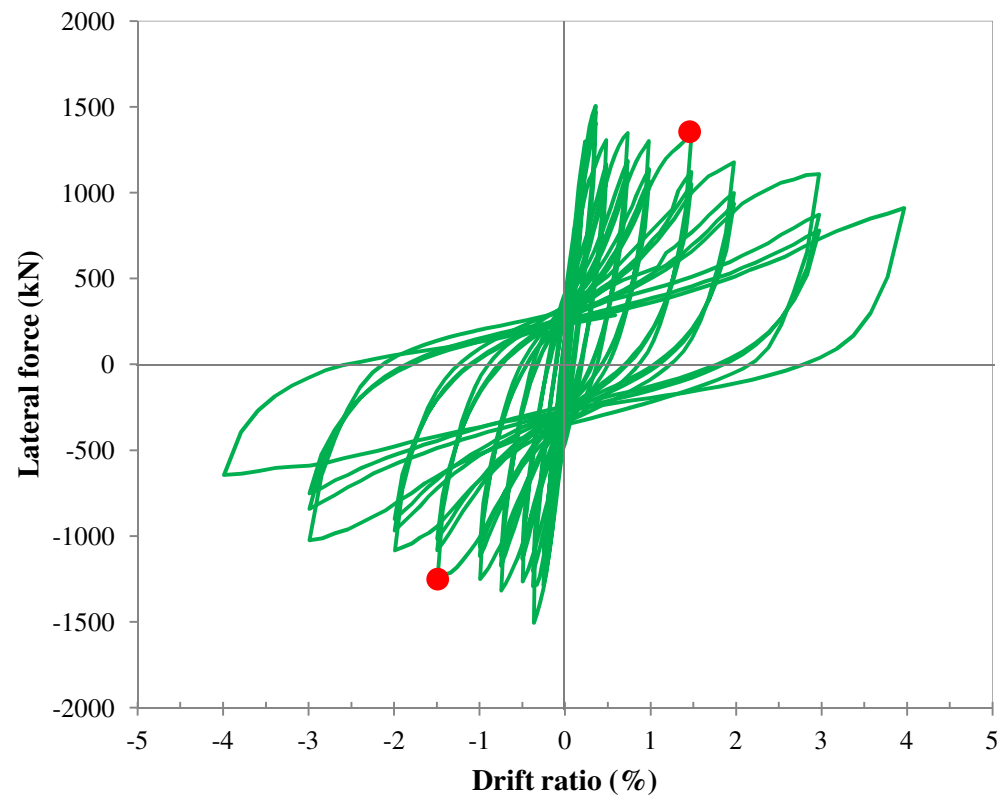
$$V(0.75\% -1) = -1317.0 \text{ kN}$$

受拉斜撐持續發展降伏線



試體M20

強度持平階段1.5%

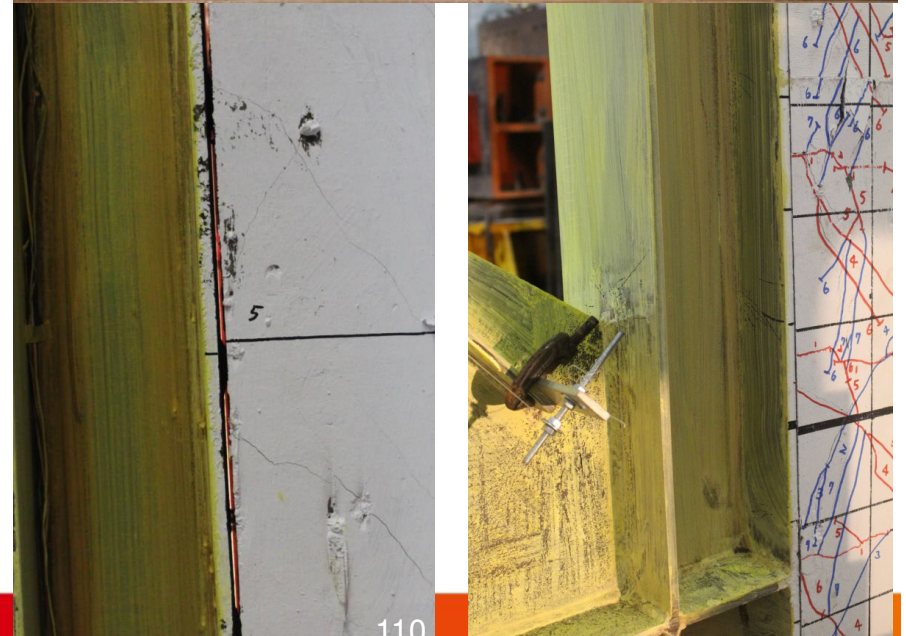


$$V(1.5\%+1) = 1325.4 \text{ kN}$$

$$V(1.5\%-1) = -1250.7 \text{ kN}$$

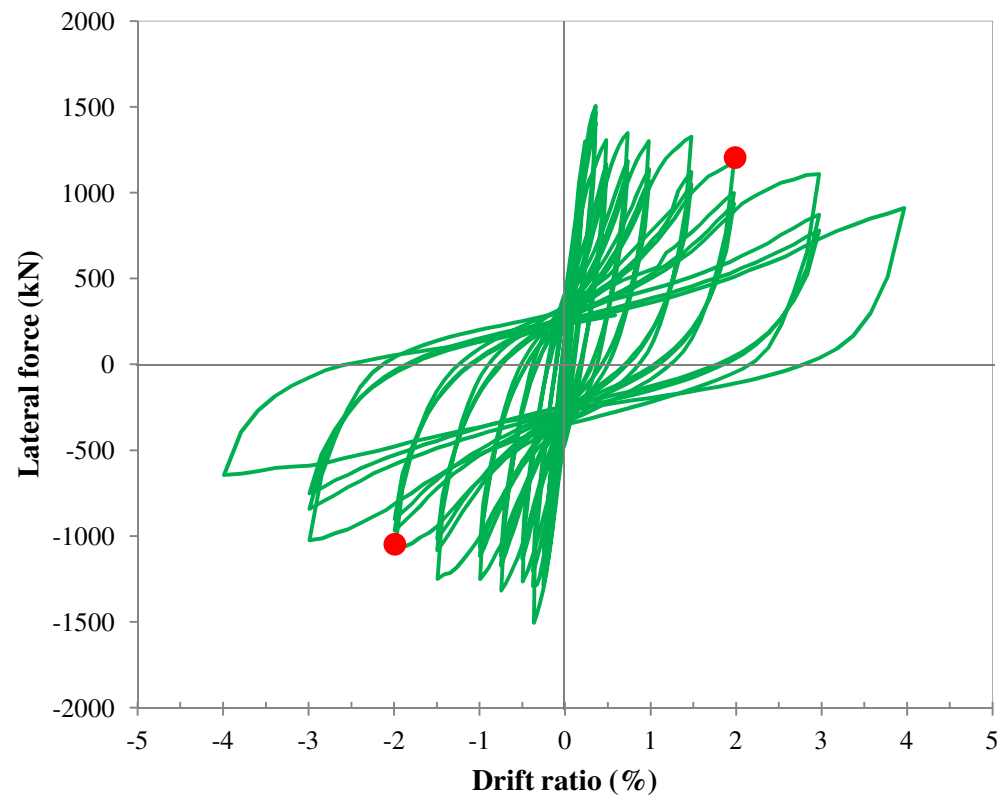
東側砂漿脫開

西側滑移



試體M20

強度衰減階段2%



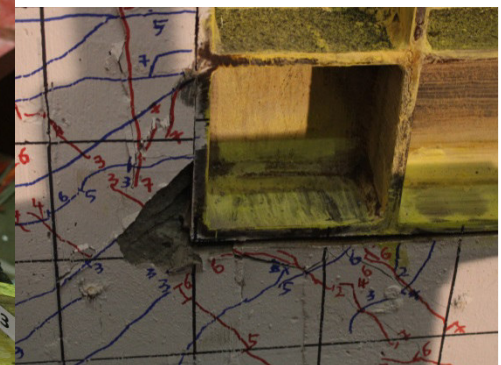
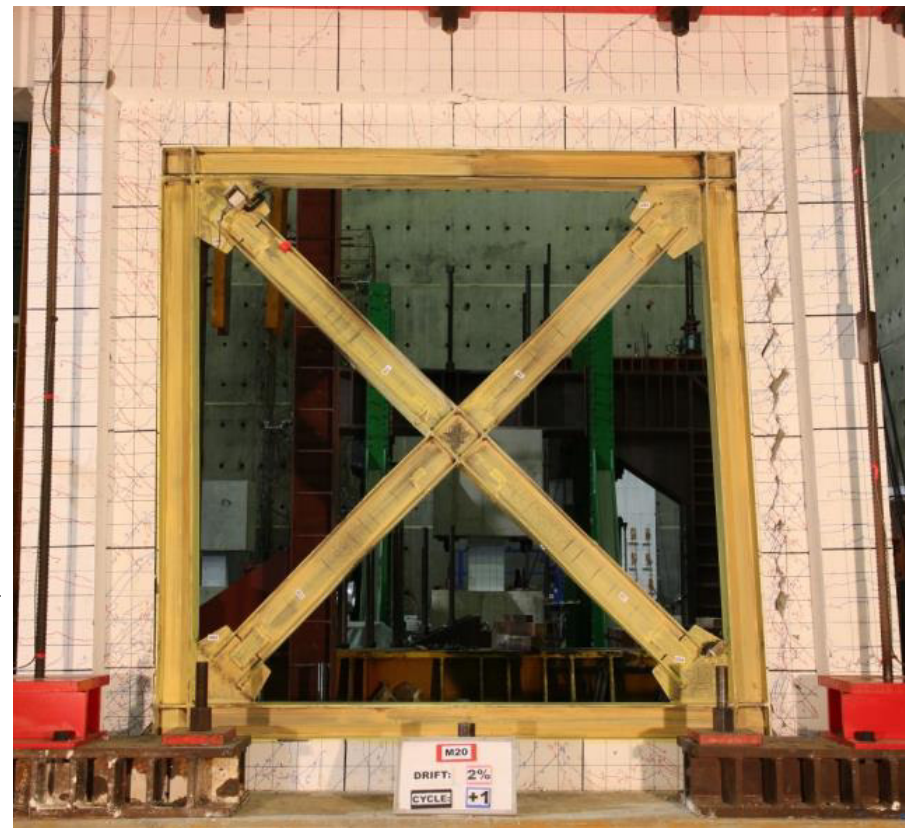
$V(2\%+1) = 1176.6 \text{ kN}$

$V(2\%-1) = -1084.8 \text{ kN}$

最大強度78%

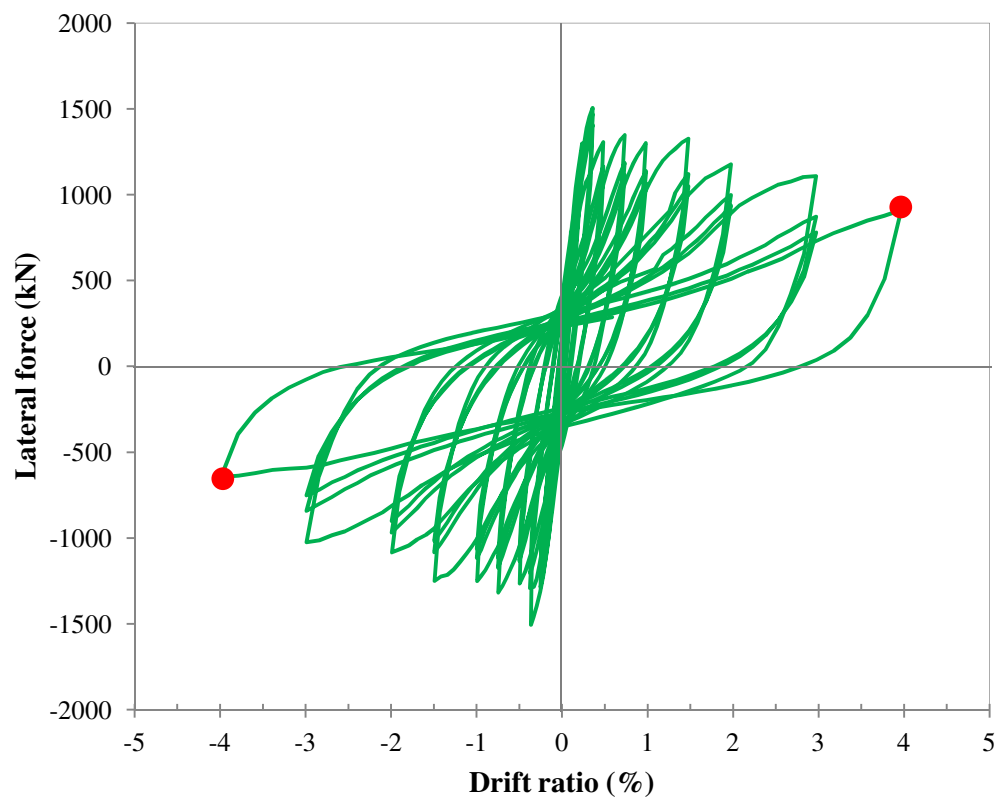
西側砂漿剝落

角落砂漿擠碎



試體M20

強度衰減階段4%

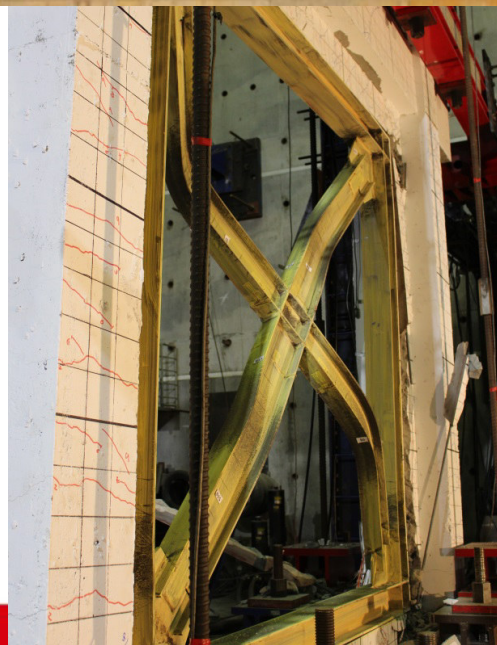
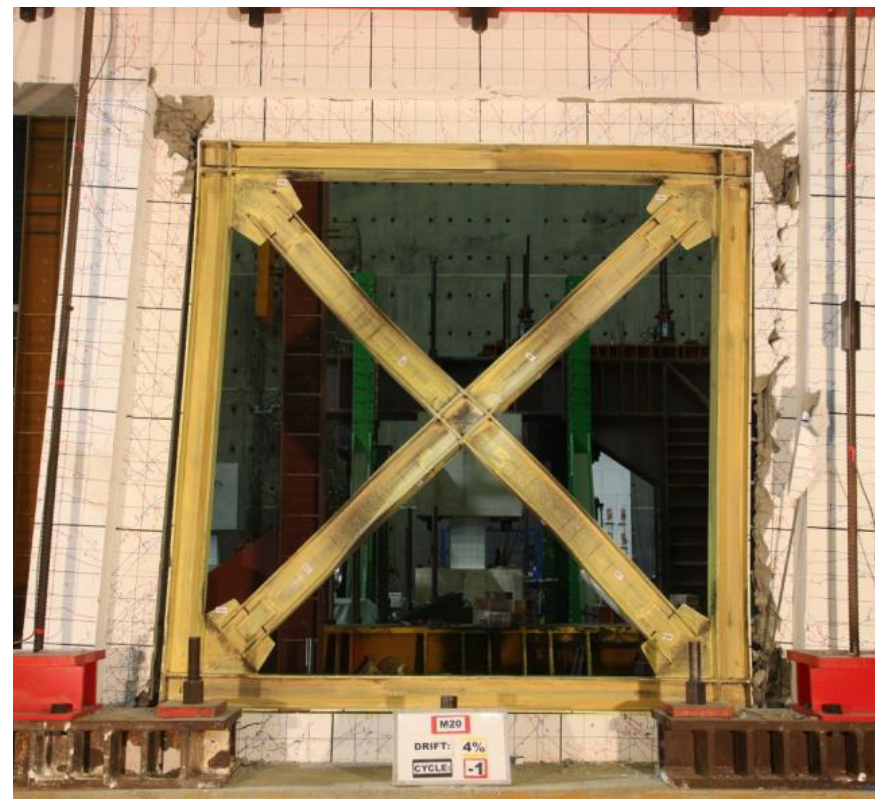


$V(4\%+1) = 910.3 \text{ kN}$ (最大強度60%)

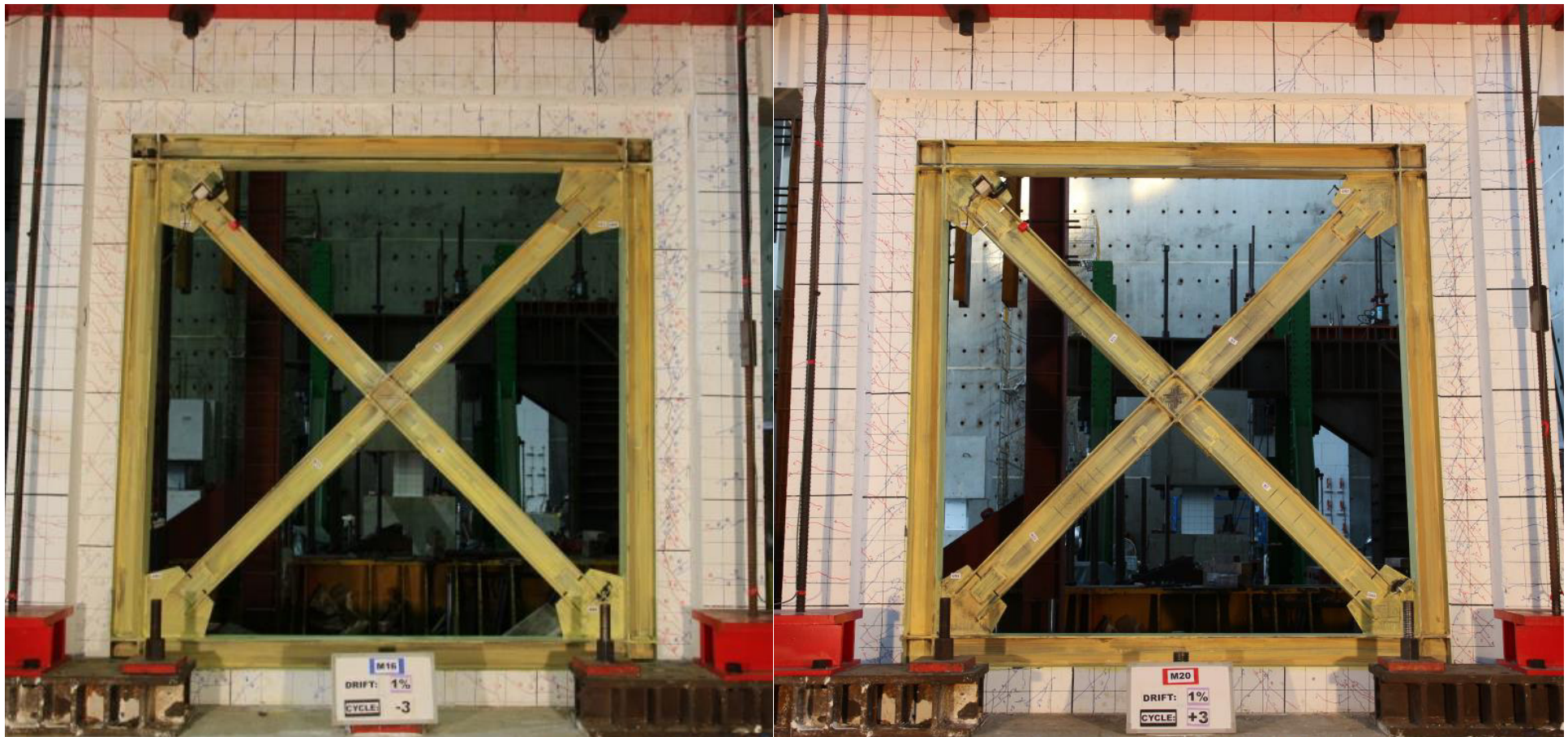
$V(4\%-1) = -644.2 \text{ kN}$ (最大強度42%)

西側貫通鋼筋脫落

東側砂漿與鋼框明顯分離



矩形箍筋VS.螺旋箍筋



試體M16-1%

試體M20-1%

貫通鋼筋差異

M20(2015)
3%+1



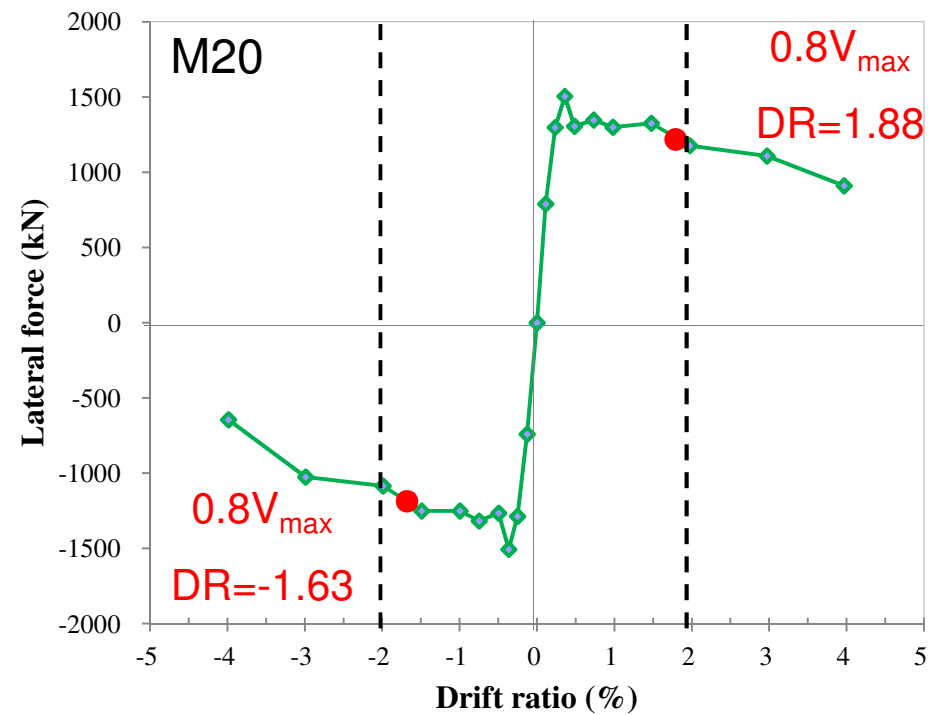
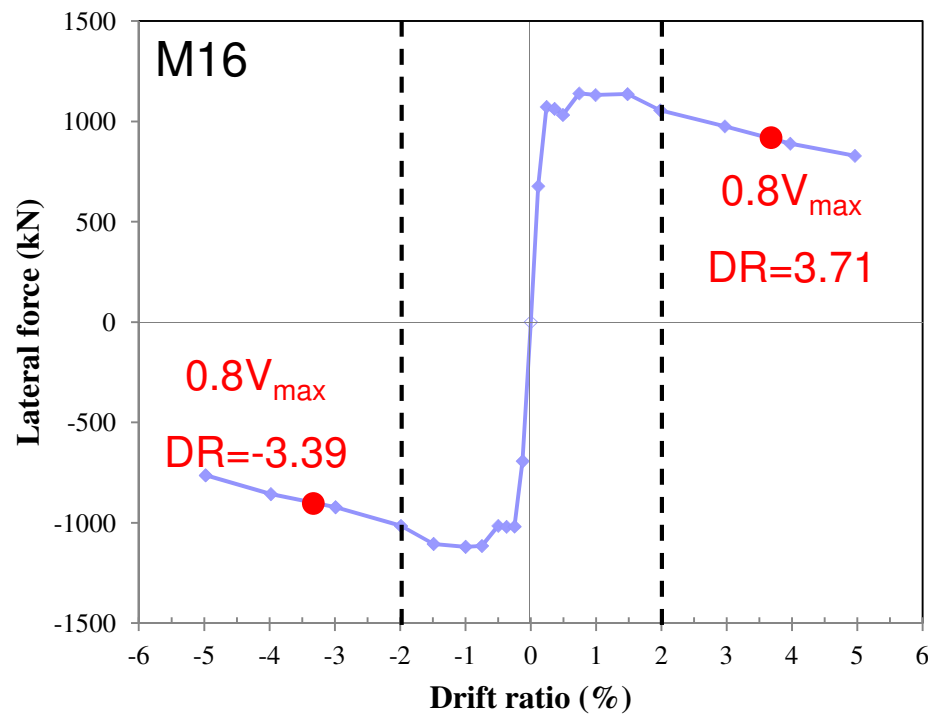
M20-3(2014)
3%+1



間接接合型鋼斜撐補強設計

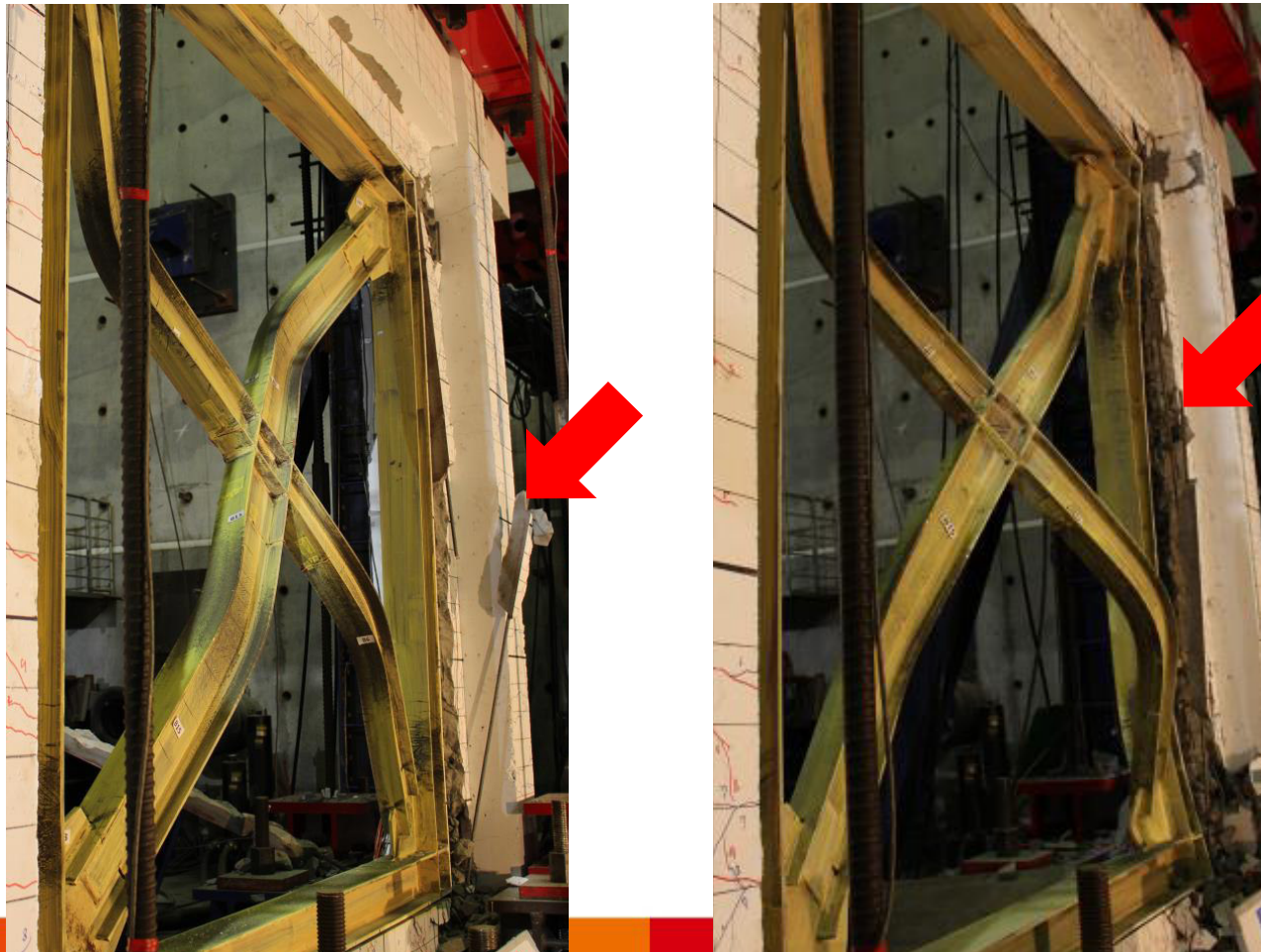
✓ 結論

1. 建議設計流程之可行性



2. 貫通鋼筋配置

無論使用矩形或螺旋箍筋，
貫通鋼筋都應配置在箍筋內



3. 非預期剪力釘斷裂

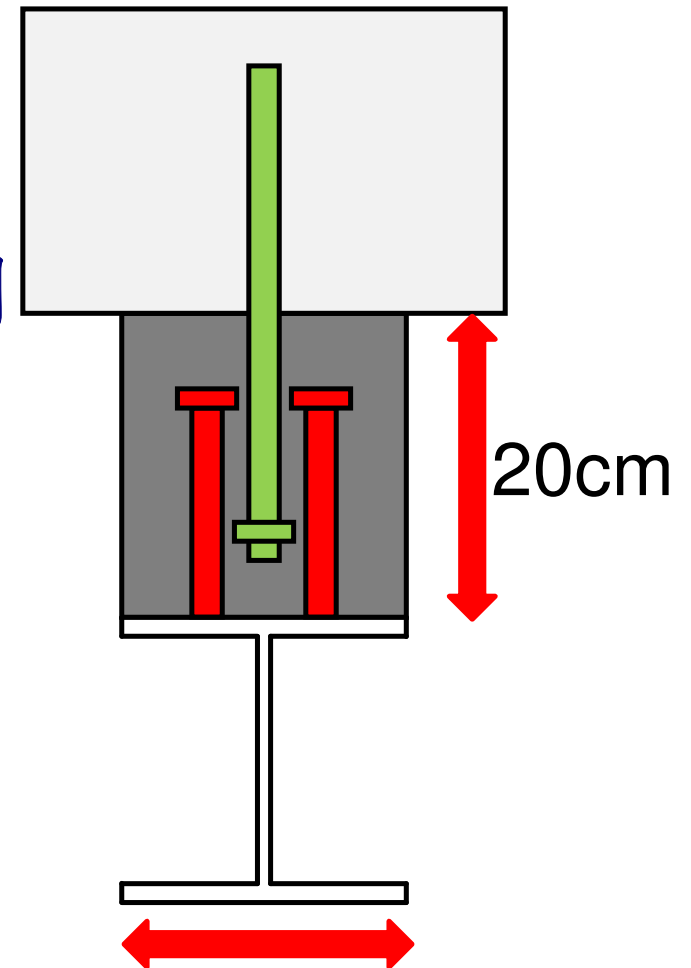
1. 控管剪力釘施工品質
2. 使用較大號數剪力釘
3. 雙排配置，增加安全係數



4. 增加補強接合部寬度及厚度

1. 雙排剪力釘，配合貫通鋼筋放置於箍筋內
2. 一般工程使用#3鋼筋製作閉合箍筋及組裝

→ 增加鋼框翼板寬度與砂漿深度，減低施工困難度



**Thank you for your
attention !**