2016建築結構創新研發及評估補強技術研討會

鋼筋混凝土建築結構耐震補強技術

鄭元良　廖文義　李台光　黃國倫　周楷峻
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現況檢視與調查項目、規劃與結構設計

- 對主要梁柱與非結構牆作實地調查及審閱原始設計圖
  - 確認建物之結構特性，減少不確定性
- RC梁柱檢測
  - 混凝土強度、鋼筋強度與量
  - 既有缺陷之影響(鋼筋銹蝕、震害缺陷、不均勻沉陷影響…)
- RC 結構施工規定
- 補強設計策略
- 補強材料規定

構材補強

擴柱補強

一般原則

規劃

設計程序

施作方式與結構細節

施工步驟說明與施工照片

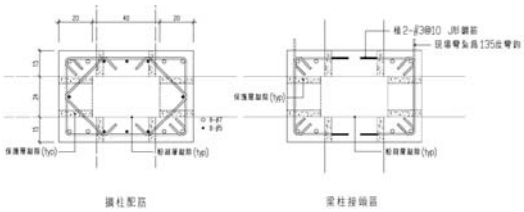
增設翼牆補強

RC包覆韌性補強

柱包覆鋼板補強

碳纖維(CFRP)包覆補強

加強磚造結構之補強



系統補強

鋼筋混凝土剪力牆

一般原則

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施工步驟說明與施工照片

RC開口剪力牆補強

設計概要說明

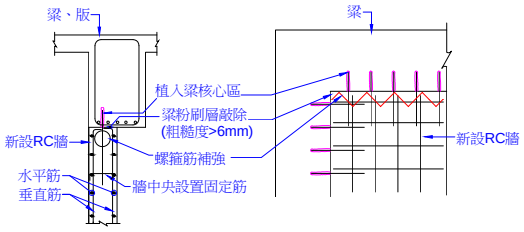
開口牆施工概要說明

鋼造斜撐或鋼板剪力牆

挫屈束制支撐

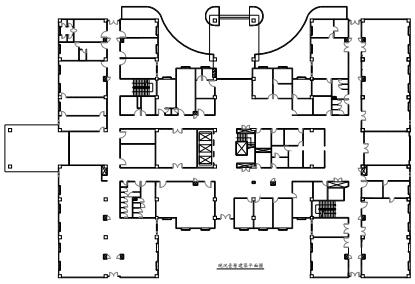
消能補強

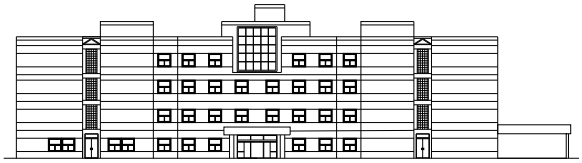
其他補強技術



設計範例(一): 概述

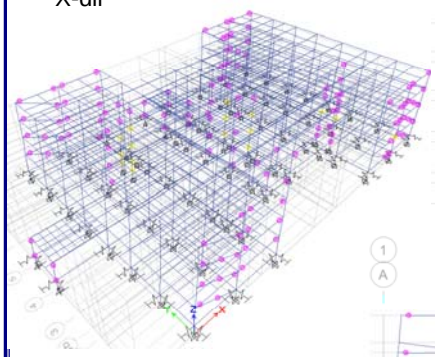
- 中部某醫院
  - 地上四層、無地下室之RC構架，12公分之RC牆為外牆及1B磚隔間牆
  - 提供4種補強工法

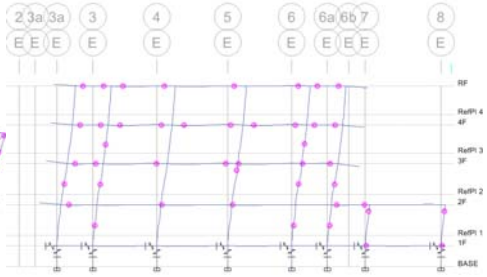




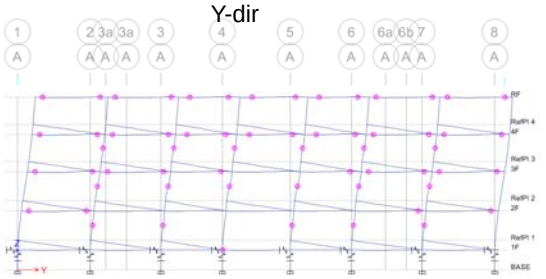
設計範例(一): 現況破壞機制

X-dir



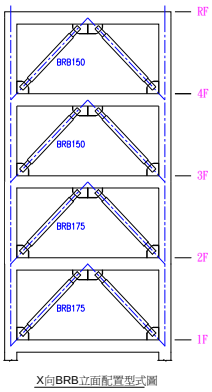


Y-dir

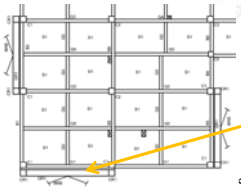


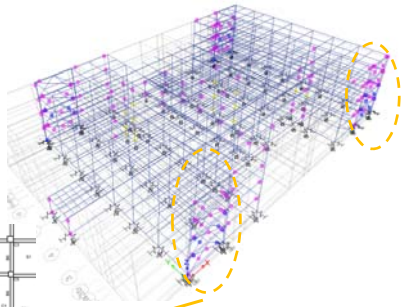
設計範例(一):外部構架與位移型消能斜撐

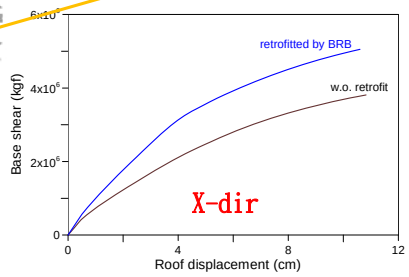
- 系統補強配置
- 補強後結構整體阻尼修正係數
- 角隅板之錨錠設計
- 基礎補強



X向BRB立面配置型式圖

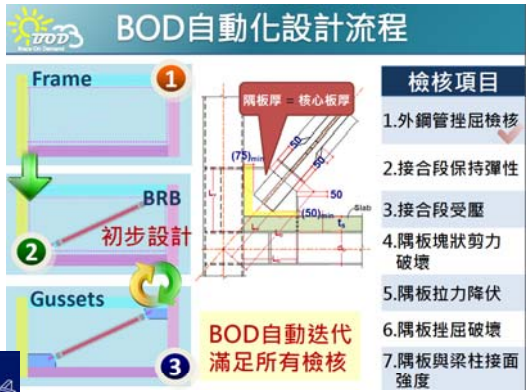


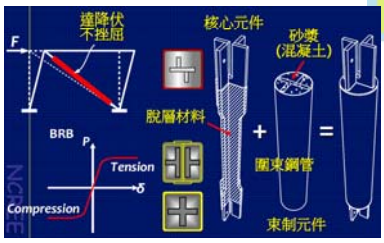




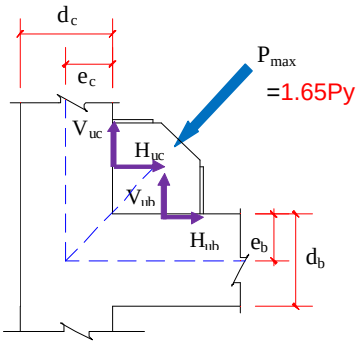
設計範例(一):BRB設計(蔡克銓教授, BOD)

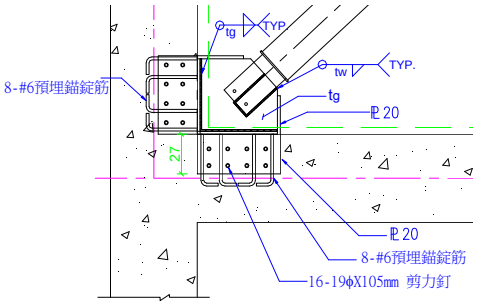

鋼斜撐面內挫屈破壞





設計範例(一):下角隅板之錨錠設計





$$H_{uc}=\frac{P_{max}e_c\sin\varphi}{e_b+0.5L_v}$$

$$V_{ub}=P_{max}\left[\frac{e_b\left[(e_b+0.5L_v)\cos\phi-e_c\sin\varphi\right]}{0.5L_h(e_b+0.5L_v)}\right]$$

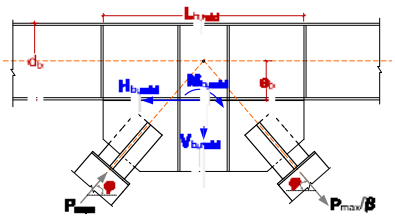
$$H_{ub}=P_{max}\cos\varphi-H_{uc}\qquad H_{ub}=P_{max}\sin\varphi-V_{ub}$$

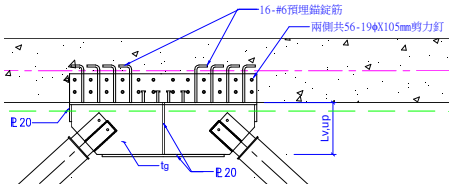
H_{uc}=90.9 tf、V_{uc}=72.2 tf、H_{ub}=89.4 tf、V_{ub}=95.6 tf。假設V_{ub}完全由錨錠鋼筋承擔、H_{ub}完全由連接板剪力釘承擔。

$$A_s=\frac{V_{ub}}{f_y}=\frac{95.6}{4.2}=22.76\ \text{cm}^2$$

使用D=19 mm, L=105 mm剪力釘，每支釘提供之水平力=6.05 tf，需Hub/6.05= 15支

設計範例(一):梁跨中央隅板之錨錠設計





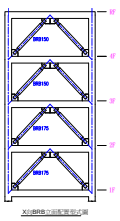
$$V_{b,mid}=P_{max}\left(1-\frac{1}{\beta}\right)\sin\varphi$$

$$H_{b,mid}=P_{max}\left(1+\frac{1}{\beta}\right)\cos\varphi$$

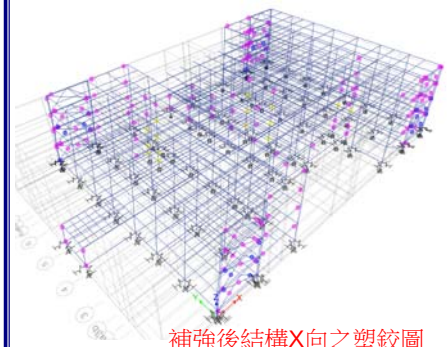
$$M_{b,mid}=P_{max}e_b\left(1+\frac{1}{\beta}\right)\cos\varphi$$

$V_{b,mid}$ =22 tf、$H_{b,mid}$ =337 tf、$M_{b,mid}$ =100.2 tf-m。梁跨中央隅板之寬度為143 cm，取105 cm 為力臂，則中心線每側需求鋼筋面積:

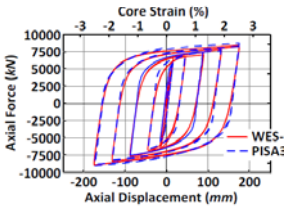
$$A_s=\frac{M_{b,mid}}{1.05\times f_y}=\frac{100.2}{1.05\times4.2}=22.7\,\text{cm}^2$$



設計範例(一)：補強後耐震能力



補強後結構X向之塑鉸圖



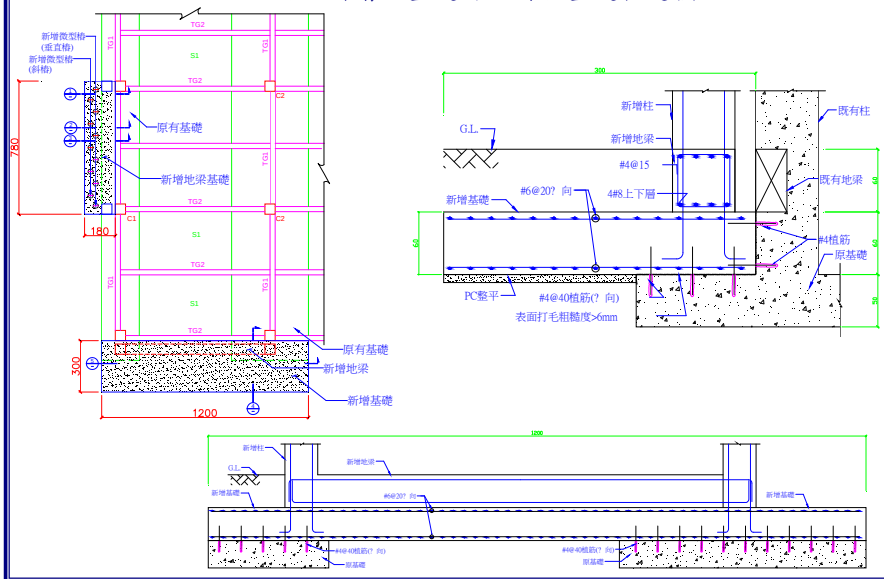
補強後基底剪=5049 tf，
原結構基底剪力=3812 tf
差值=1237 tf

增加之基底剪力來自於外部增設RC構架及BRB；因新增構架及BRB有較飽滿之遲滯迴圈，阻尼修正係數k取為0.67，以基底剪力為加權，計算補強後阻尼修正係數k:

$$\kappa = \frac{1237 \times 0.67 + 3812 \times 0.33}{5049} = 0.41$$

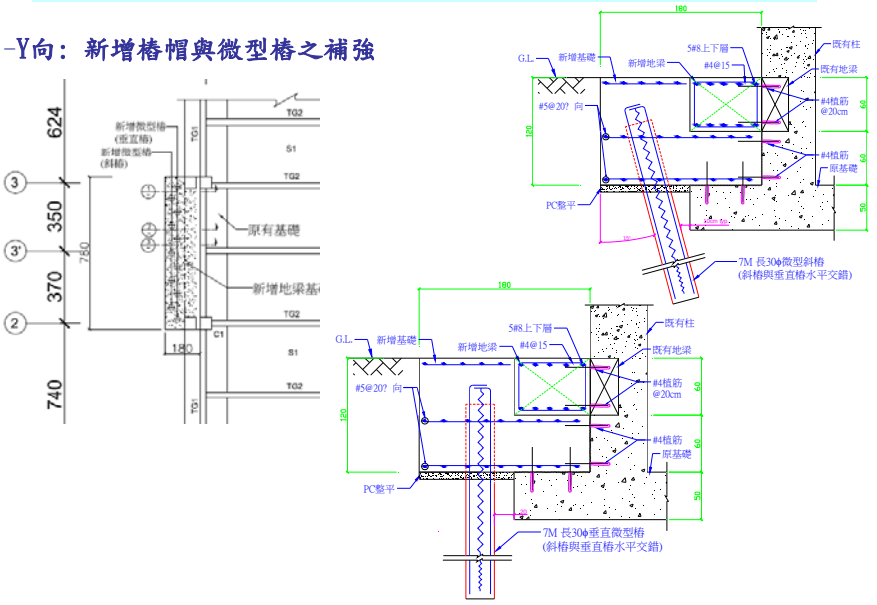
設計範例(一)：基礎補強

– X向：新增一基礎將兩聯合基礎相連接



設計範例(一)：基礎補強

-Y向：新增樁帽與微型樁之補強



設計範例(一)：補強後外觀

① 病房大樓東南向補強立面圖(BRB)

病房大樓東北向補強立面圖(BRB)

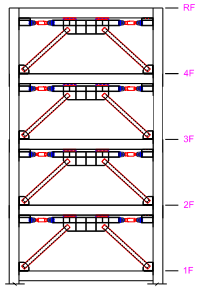
設計範例(一)：外部構架與速度型消能元件(2)

- 系統補強配置
- 側推分析之等效阻尼計算
- 角隅板之錨錠設計

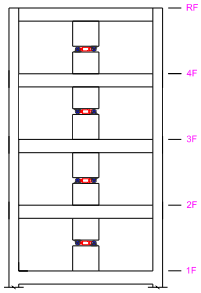
阻尼器之遲滯能 $\sum W_{Vj} = \left(\frac{2\pi}{T_S}\right)^{\alpha} \sum \lambda C_j \left|\Delta_{rj} \cos\theta_j\right|^{1+\alpha}$

有效阻尼比 $\xi_{eff} = \eta \frac{\sum W_{Vj}}{4\pi W_K}$

$\eta = 1 - \left(\frac{K_a'}{K_b}\right)^{1-\alpha}$



X向阻尼器立面配置型式圖



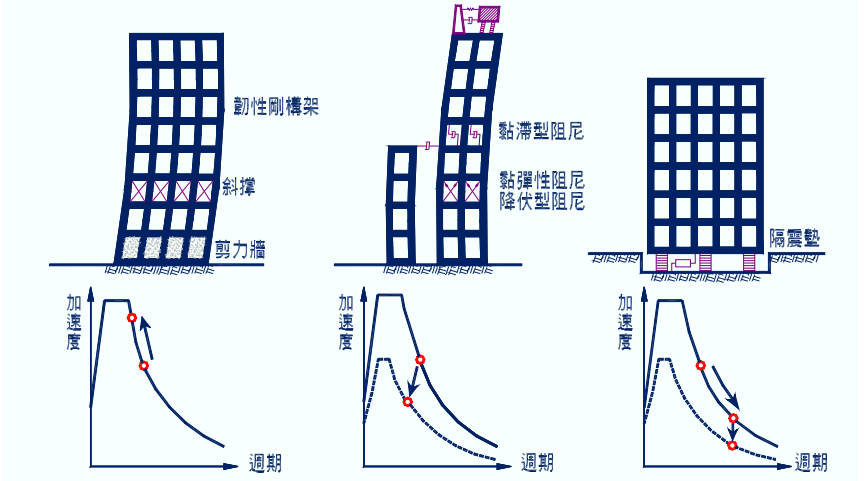
Y向阻尼器立面配置型式圖

story	Displ. (cm)	H(cm)	Drift/PF_1	damping coefficient, C	no. of damper	damping work, Wj
RF	10.644	380	1.170	24.90	8	1806.8
4F	9.099	380	1.768	24.90	8	3153.4
3F	6.765	400	2.886	24.90	8	6110.8
2F	2.955	400	2.238	24.90	8	4336.1
					Σ=	15407.1
					η=	0.912
					ξ_{eff}=	5.23%

使用阻尼器之減震結構設計

耐震設計方式

（1）韌性需求設計　（2）減震設計　（3）隔震設計



取自聯邦工程顧問資料

被　動　消　能　元　件　種　類

位移型：

（1）摩擦式

（2）金屬降伏式

速度型：

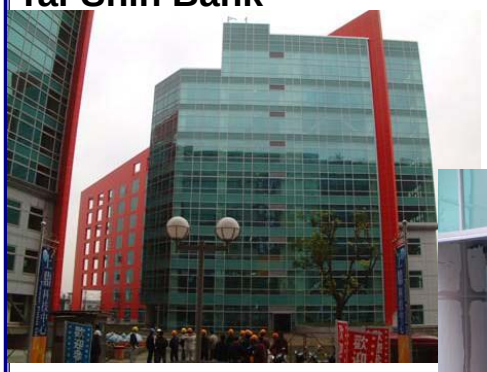
（3）黏彈式

（4）黏滯式（Viscous）

Viscous Dampers

Viscous Dampers

Tai-Shin Bank



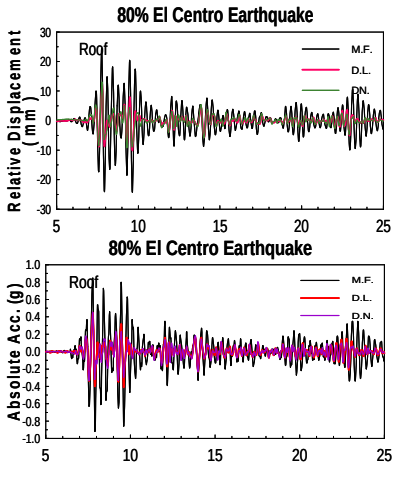
Experimental Validation

2000~2003
三層樓之兩跨乘兩跨空間鋼構架

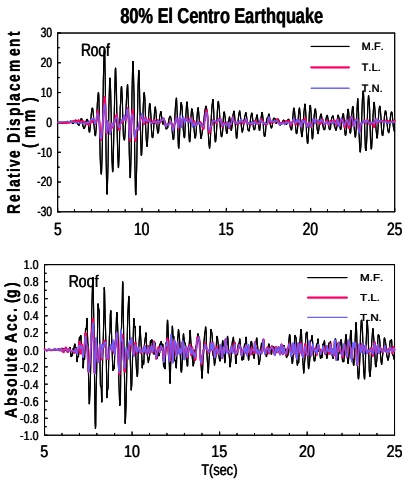
2004~2005
三層樓之兩跨乘兩跨空間鋼筋混凝土構架

Response History

Diagonal-Damper-Brace



Toggle-Brace-Damper

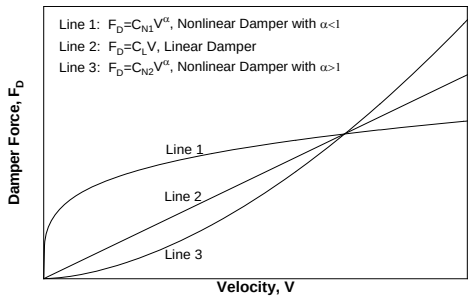


Force-Velocity Relationship of Viscous Dampers

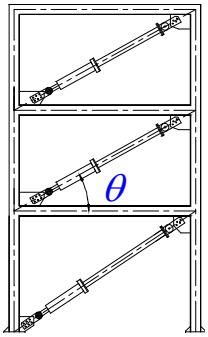
$$F_D = C\left|\dot{u}\right|^{\alpha}\operatorname{sgn}\left(\dot{u}\right)$$

$\alpha = 1$ → **Linear Viscous Dampers**

$0 < \alpha < 1$ → **Nonlinear Viscous Dampers**



MDOF System with Linear Viscous Dampers



SDOF $\xi_d = \dfrac{W_D}{2\pi W_s}$

$\xi_{eff} = \xi_0 + \xi_d$

MDOF $\xi_d = \dfrac{\sum_{all\ dampers} W_D}{2\pi W_S}$

MDOF System with Linear Viscous Dampers

黏性阻尼器之設計 — Elastic Response

$$\xi_d = \frac{T\sum_j C_j \phi_{rj}^2 \cos^2\theta_j}{4\pi \sum_i m_i \phi_i^2}$$ ⇐ Linear Damper

$$\xi_d = \frac{T^{2-\alpha}\sum_j \lambda C_j \phi_{rj}^{1+\alpha} \cos^{1+\alpha}\theta_j}{(2\pi)^{3-\alpha} D^{1-\alpha} \sum_i m_i \phi_i^2}$$ ⇐ Nonlinear Damper

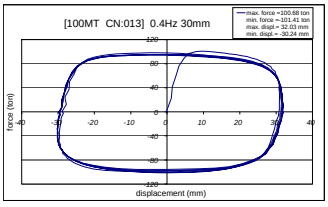
位移設計法

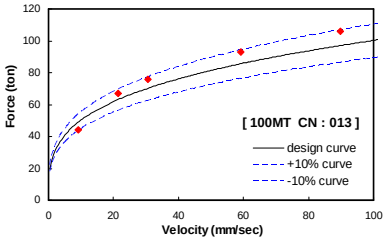
$$S_d = \frac{g}{4\pi^2}\frac{S_{aD} I T_1^2}{(1.4\alpha_y F_u)B} \qquad D = \Gamma_1 S_d$$

加裝Viscous Damper 動力歷時反應分析

Viscous Damper 測試

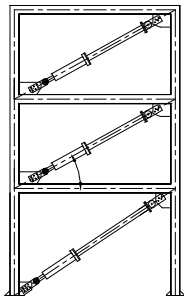
試驗要求: 阻尼器的速度-出力曲線中，在各種不同速度情況下，出力之試驗值與設計值差異不得超過±15%。

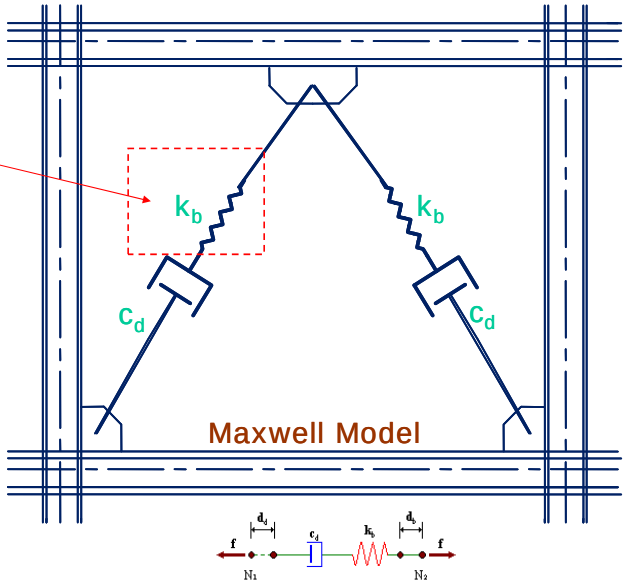




FVD 模擬模式

斜撐勁度
- 影響反應甚大
- 需準確模擬





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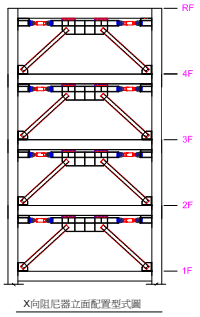
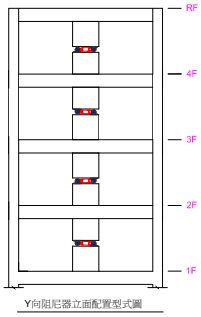
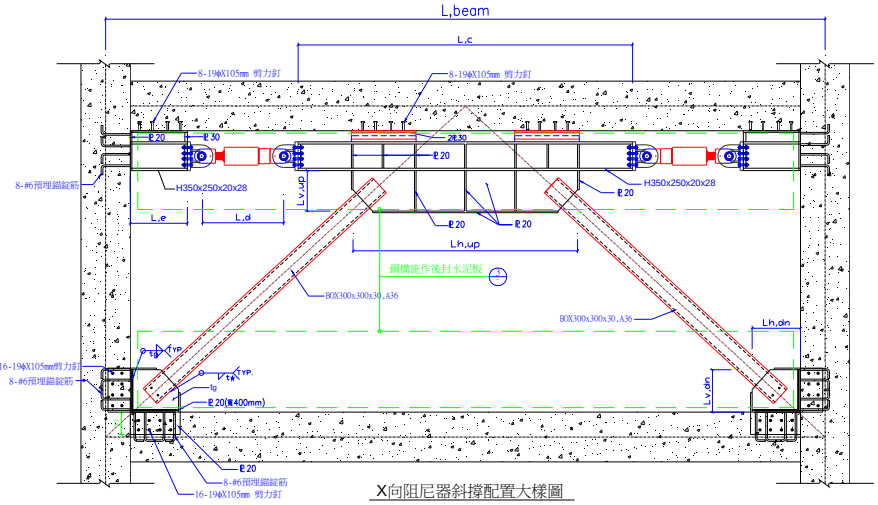
$$\eta = 1 - \left(\frac{K_a'}{K_b}\right)^{1-\alpha}$$





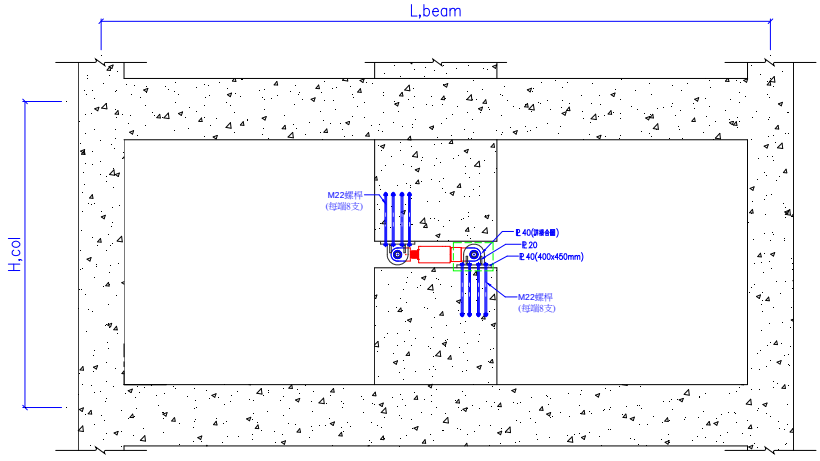
story	Displ. (cm)	H(cm)	Drift/PF$_1$	damping coefficient, C	no. of damper	damping work, Wj
RF	10.644	380	1.170	24.90	8	1806.8
4F	9.099	380	1.768	24.90	8	3153.4
3F	6.765	400	2.886	24.90	8	6110.8
2F	2.955	400	2.238	24.90	8	4336.1
					Σ=	15407.1
					η=	0.912
					ξ_{eff}=	5.23%

設計範例(一): X向阻尼器配置大樣圖



X向阻尼器斜撐配置大樣圖

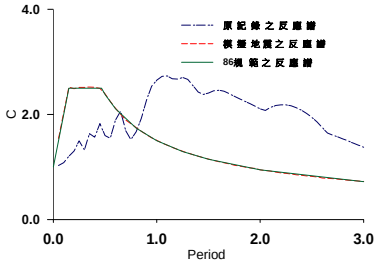
設計範例(一): Y向阻尼器配置大樣圖



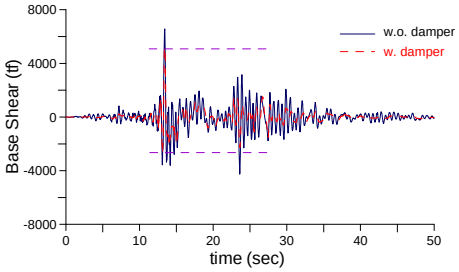
Y向阻尼器斜撐配置大樣圖

設計範例(一):歷時分析

歷時分析驗證補強功效: 採用921地震中部地區之地震記錄TCU052、TCU060及TCU104為輸入地震，依耐震設計規範規定驗證

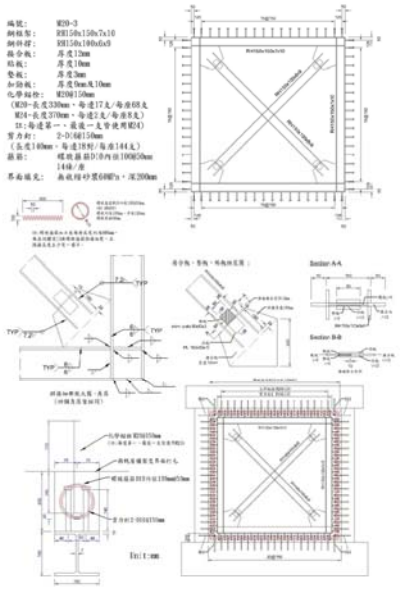


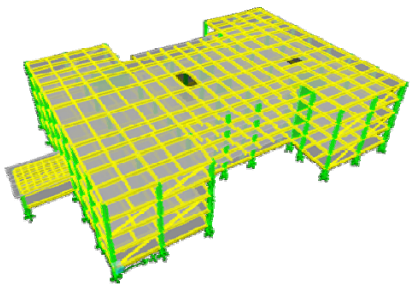
TCU052之調整前後正規化反應譜圖



基底剪力比較圖

設計範例(一): 增設鋼斜撐補強(3)

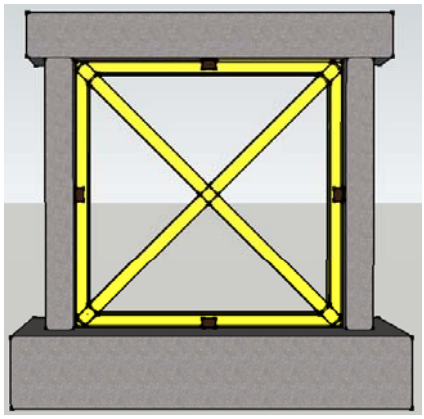




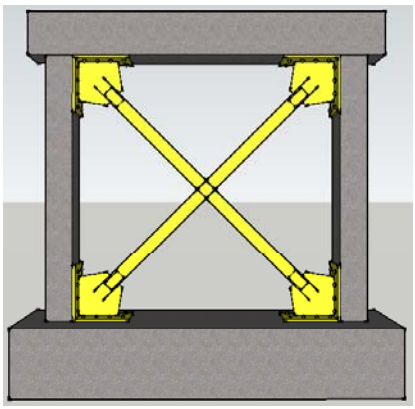
- ✓ 直接接合型鋼斜撐補強設計
- ✓ 間接接合型鋼斜撐補強設計

試體設計

CPFX



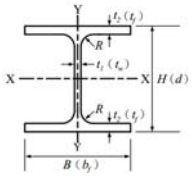
DPFX



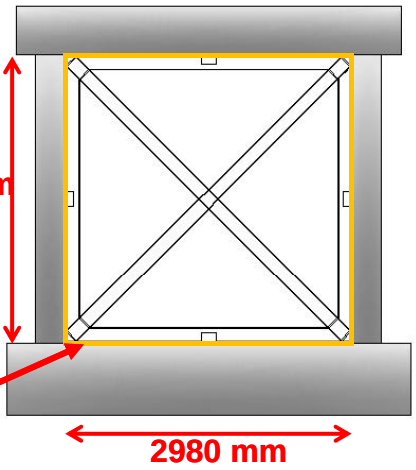
CPFX

試體介紹

- 鋼框架+X形斜撐補強

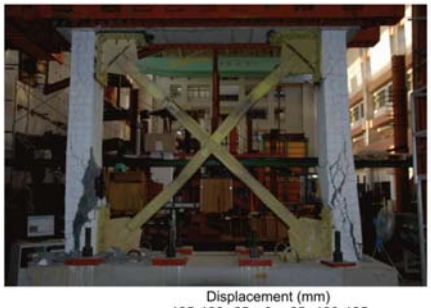


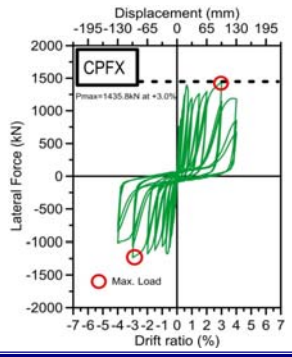
- RH 150x150x7x10
- A36 鋼材 (F_y= 252 MPa)
- 四邊介面保留10mm間隙，填充環氧樹脂(EPOXY)

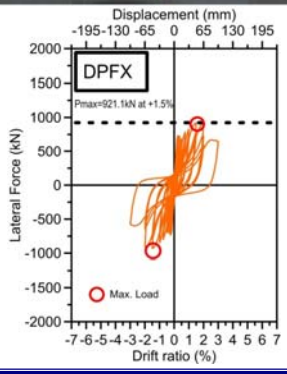


界面環氧樹脂灌注

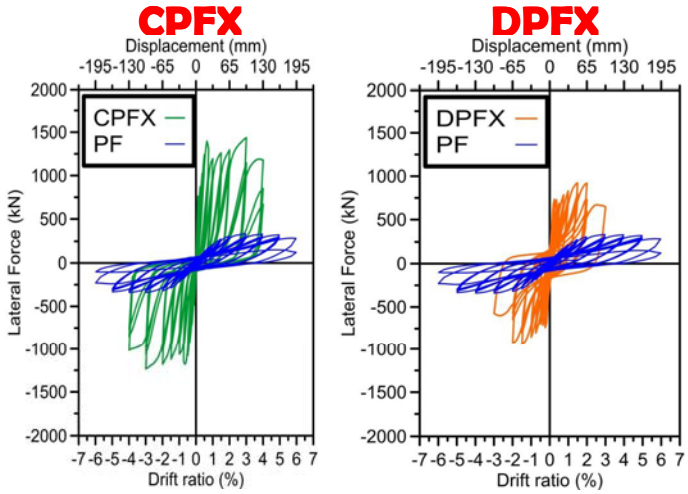
DPFX 試體完成



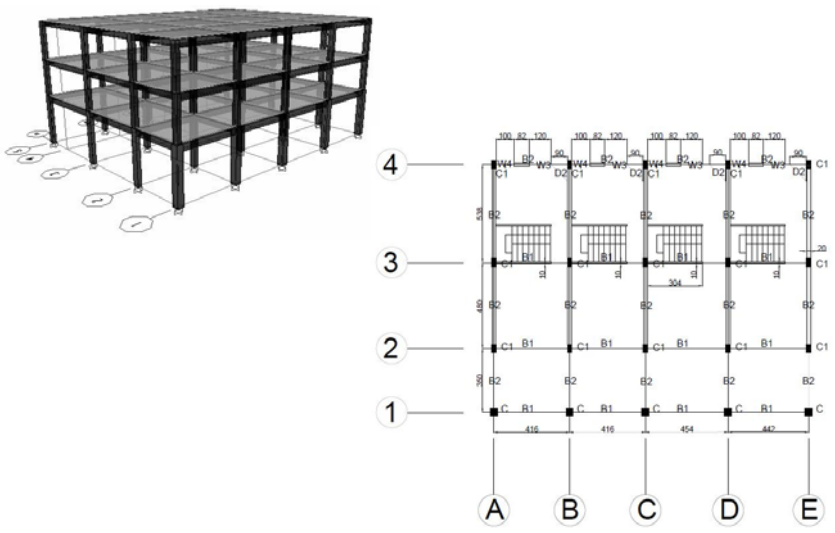

Displacement (mm)
-195 -130 -65 0 65 130 195
CPFX
Pmax=1435.8kN at +3.0%
Lateral Force (kN)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Max. Load
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Drift ratio (%)


Displacement (mm)
-195 -130 -65 0 65 130 195
DPFX
Pmax=921.1kN at +1.5%
Lateral Force (kN)
2000
1500
1000
500
0
-500
-1000
-1500
-2000
Max. Load
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7
Drift ratio (%)

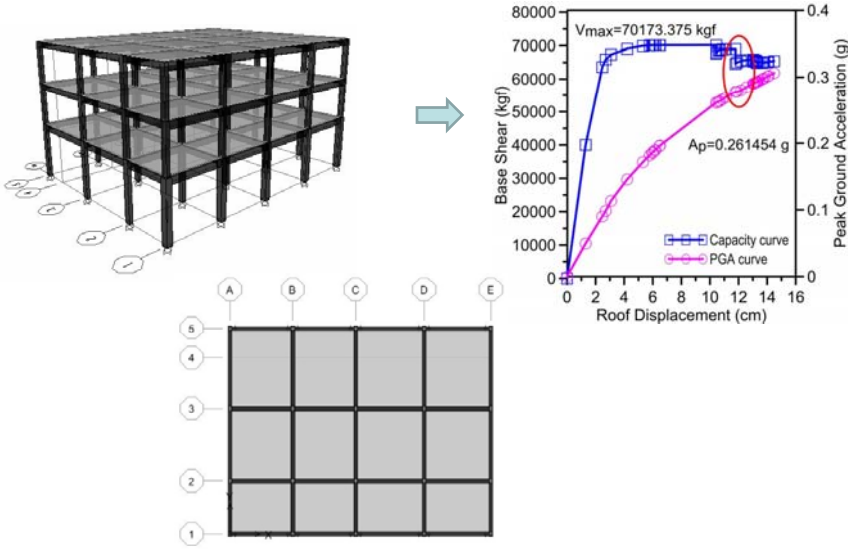
補強構架與純構架之載重-位移遲滯迴圈曲線比較



街屋結構物

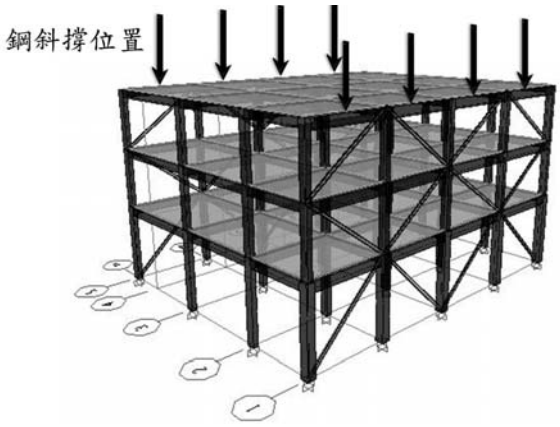


耐震能力評估

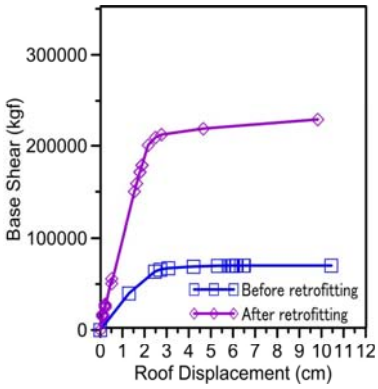


鋼斜撐補強工法，即本實驗之補強試體DPFX之應用

增設8處鋼斜撐補強

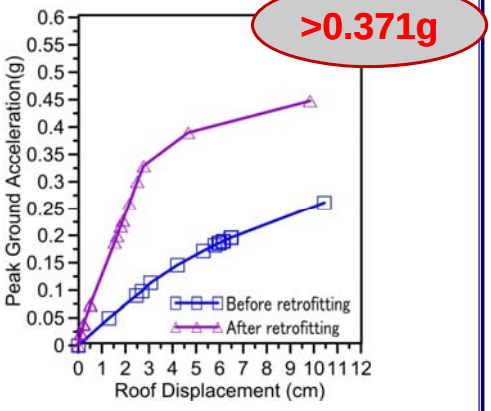


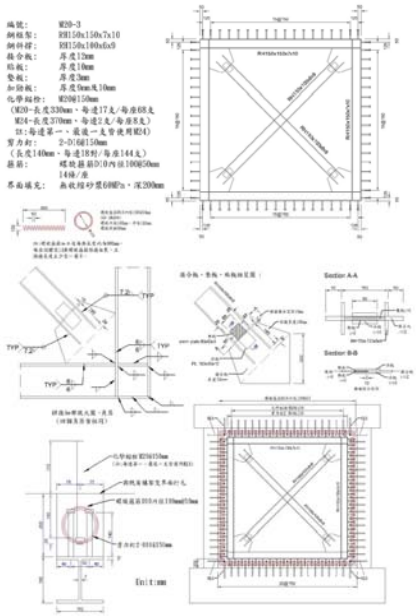
容量曲線由70173 kgf提升至**228682kgf**



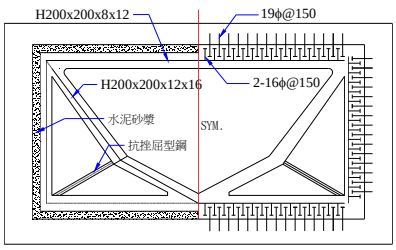
耐震能力由0.261 g提升至**0.447 g**

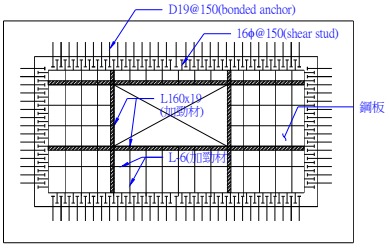
>0.371g

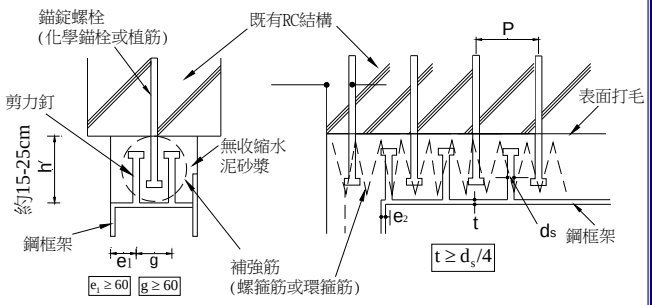




鋼構架與既存RC構架間之接合







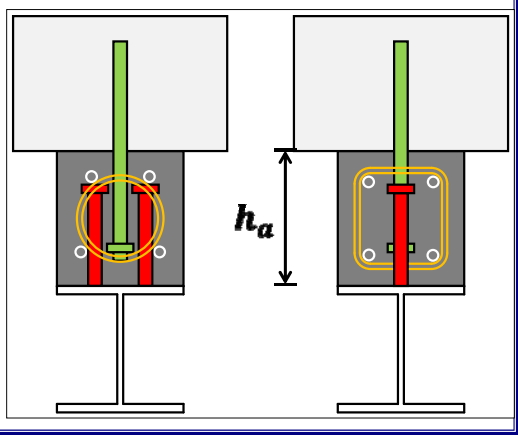
1. 設計補強接合部配置

鋼框架
寬度至少15公分

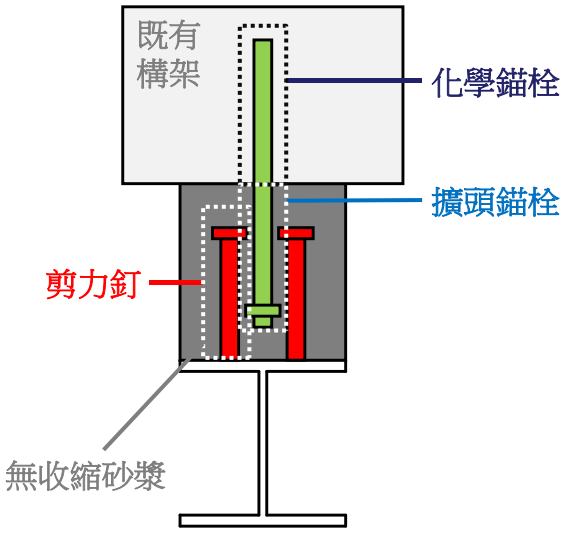
螺旋箍筋
#2以上
@40~60mm
or $\frac{1}{3}\sim\frac{1}{6}$錨栓間距

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

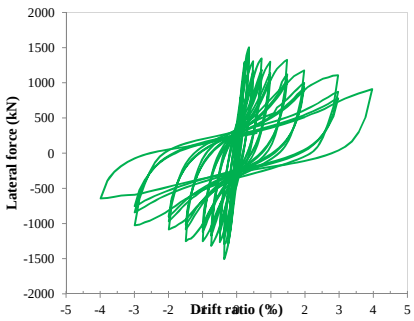


2. 計算接合部剪力強度



剪力釘
擴頭錨栓
↓
化學錨栓
↓
HILTI

參考文獻
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)。



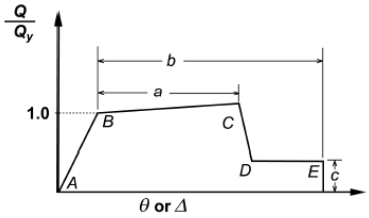
乾式補強工法與模擬研究

補強構材行為模擬

- 提供耐震能力分析模擬參考

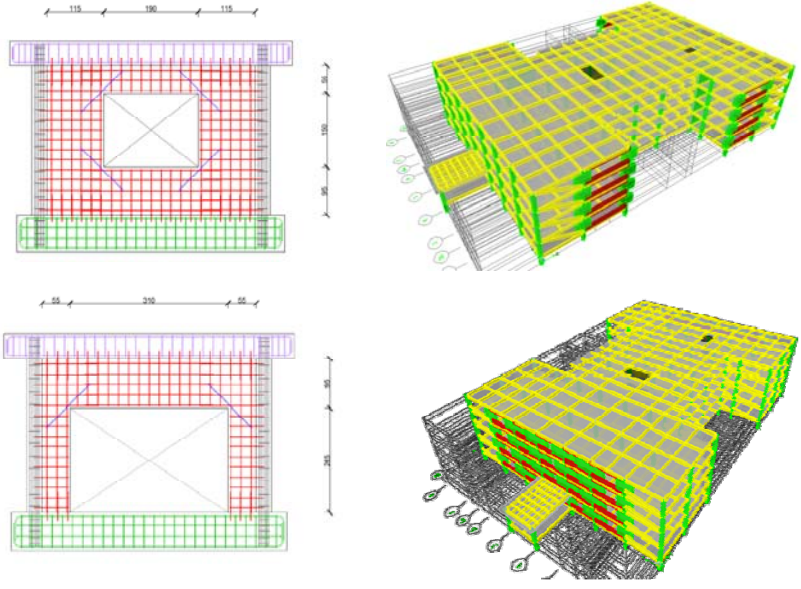
斜撐有效強度

$$P_n = A_g F_{cr}$$



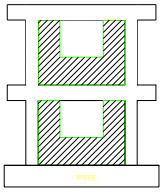
桿件 / 荷載	模擬參數		
	塑性變形		殘餘強度比
	a	b	c
受 壓 斜 撐			
a. 雙角鋼面內外挫屈	$0.5\Delta_C$	$8\Delta_C$	0.2
b. W 或 I 型	$0.5\Delta_C$	$8\Delta_C$	0.2
c. 雙槽型鋼面內外挫屈	$0.5\Delta_C$	$8\Delta_C$	0.2
d. 鋼管混凝土	$0.5\Delta_C$	$7\Delta_C$	0.2

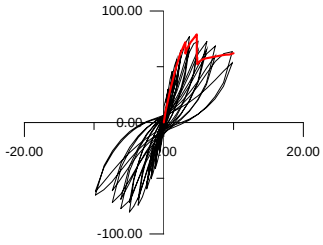
設計範例(一):增設開口RC牆(4)



開口RC牆設計模擬原則

- 開口 RC牆體與磚牆耐震行為研究





- 蒐集試驗資料所含蓋情況
- 探討不同型式(開窗、開門、翼牆) 牆體行為
- 建立可靠且簡易之設計公式

開孔強度折減(寬度不超過60%)　$\eta = 1 - \frac{\sum L_i}{L_w}$

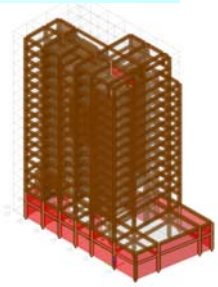
開孔強度折減(寬度超過60%) => 以翼牆方式計算

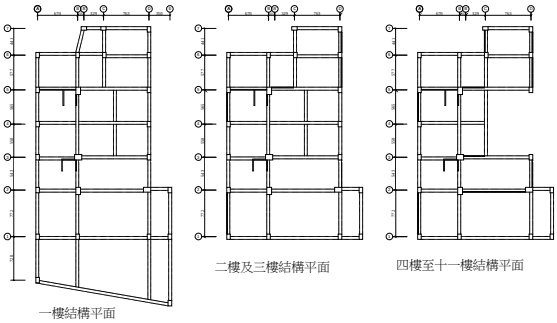
設計範例(二): 概述

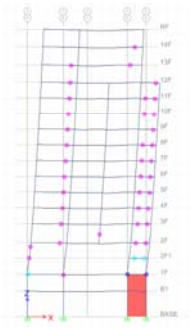
- 住商混合大樓

-地下2層、地上14層RC構造，一、二樓有夾層，挑高設計，筏式基礎，平面呈不規則冂字型之住商混合大樓

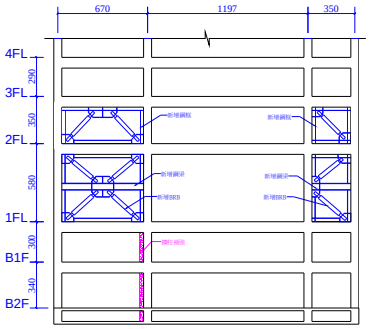
- 提供2種補強工法(RC牆與消能斜撐)



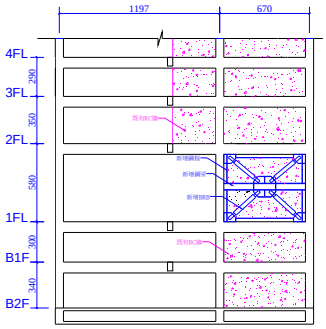




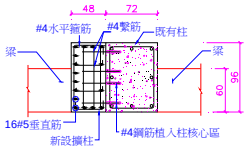
設計範例(二):增設位移型消能斜撐(1)



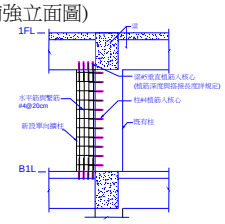
SEC. A-A' (Line-1 構架補強立面圖)



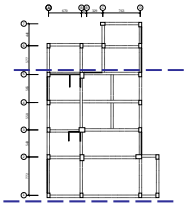
SEC. B-B' (Line-5 構架補強立面圖)



新增單向擴柱平剖面詳圖(柱區域)

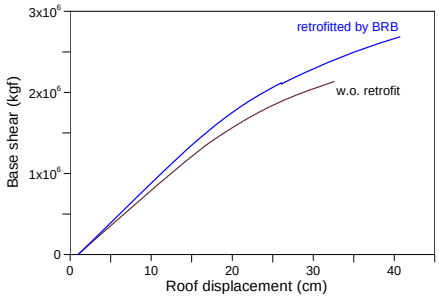


新增擴柱補強立面圖

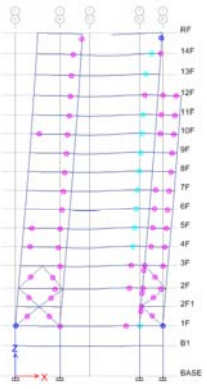


設計範例(二): 容量曲線比較

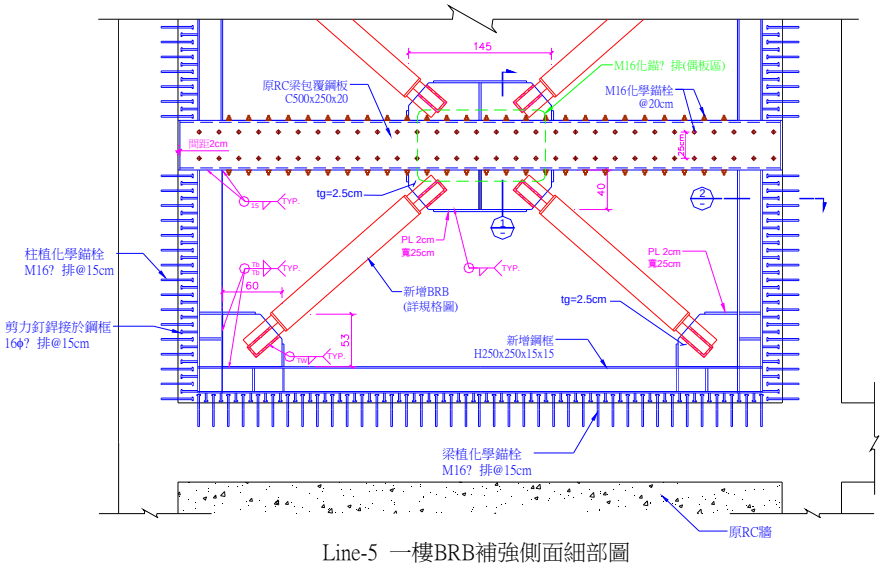
補強後結構性能點下最大層間變位角為**1.13%**小於補強前，但整體之屋頂位移高於補強前，主要補強功效來自於不規則處之改善，使變形較均勻之平面與立面分配而不如原結構之集中變形於底層側邊。



補強前後結構X向之容量曲線

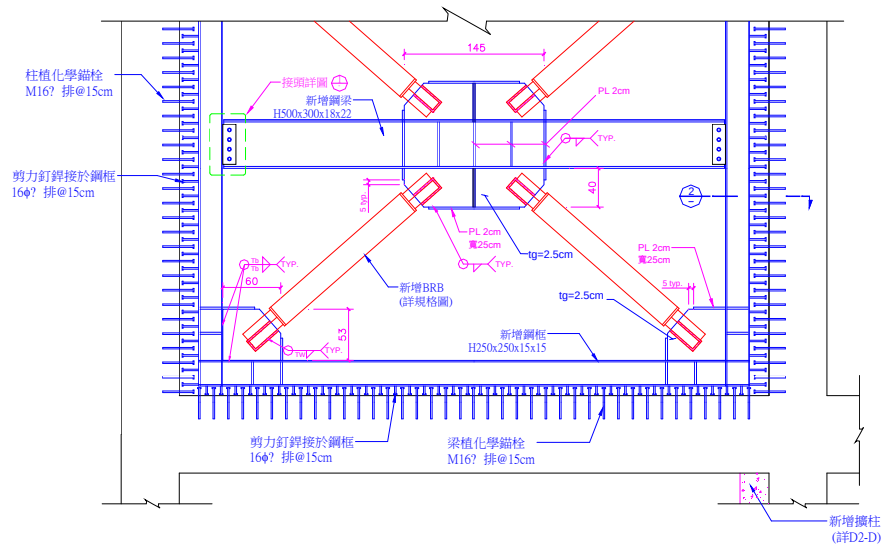


設計範例(二)：細部圖(a)



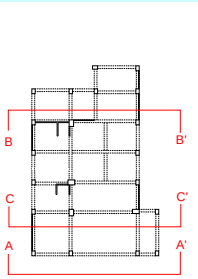
Line-5 一樓BRB補強側面細部圖

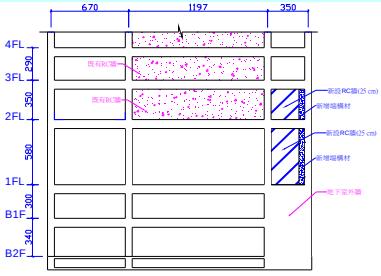
設計範例(二)：細部圖(b)



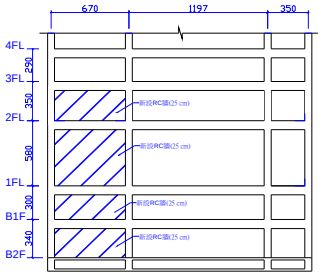
Line-1 一樓BRB補強側面細部圖

設計範例(二): 增設RC牆(1)

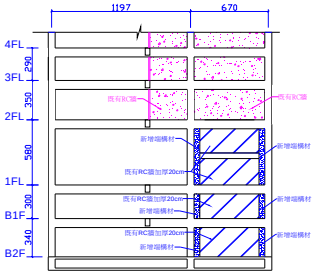




SEC. C-C' (Line-2 構架補強立面圖)

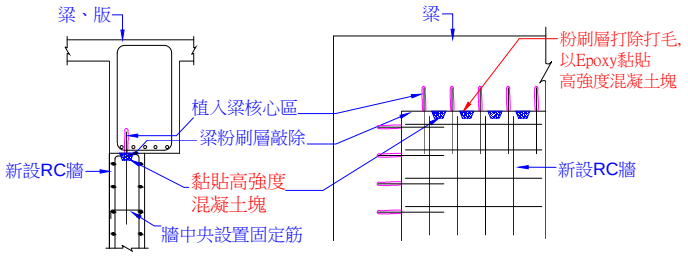


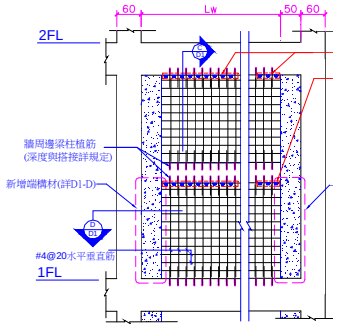
SEC. A-A' (Line-1 構架補強立面圖)



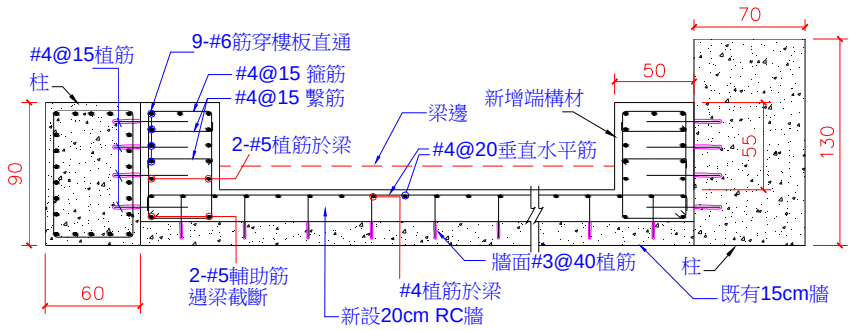
SEC. B-B' (Line-5 構架補強立面圖)

設計範例(二): RC牆細部



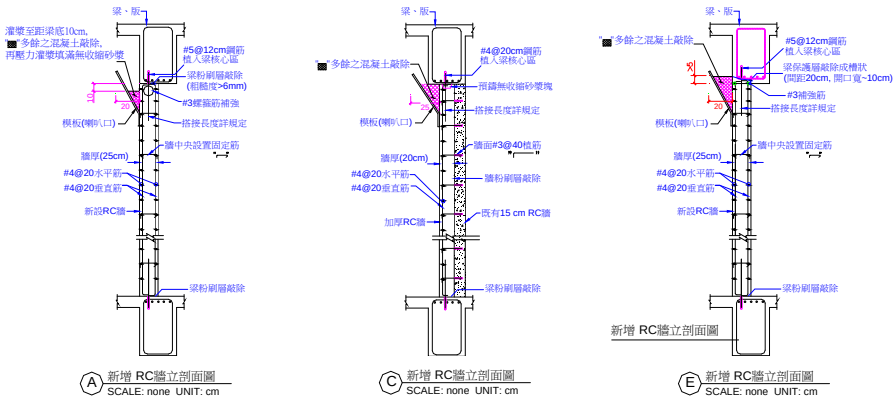


設計範例(二): RC牆加厚細部



D 新增 RC牆平剖面圖
SCALE: none UNIT: cm

設計範例(二): 增設RC牆細部



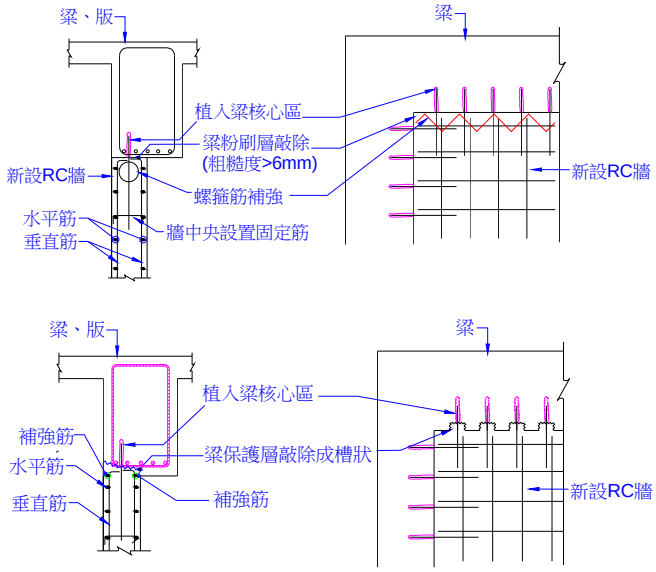
A 新增 RC牆立剖面圖
SCALE: none UNIT: cm

C 新增 RC牆立剖面圖
SCALE: none UNIT: cm

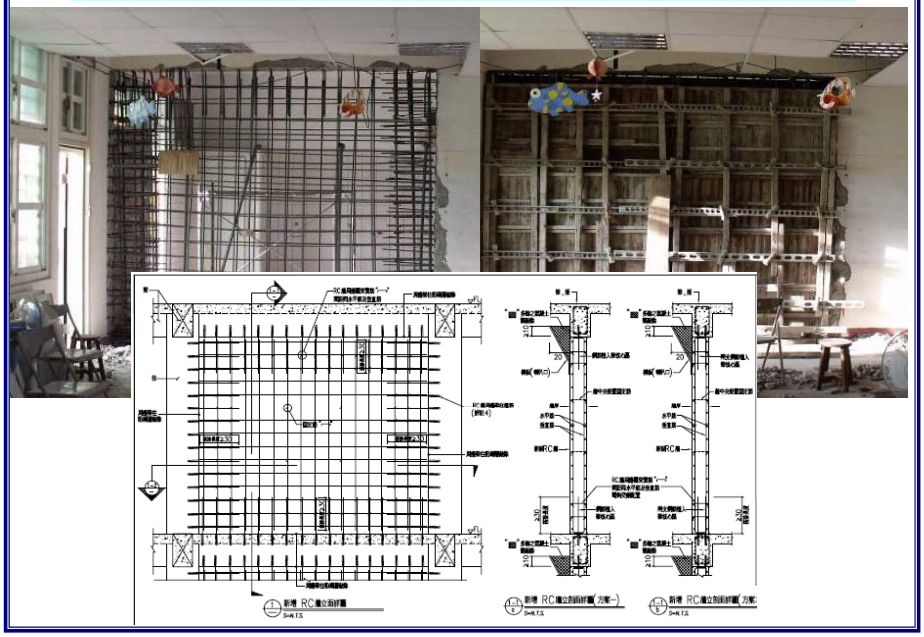
E 新增 RC牆立剖面圖
SCALE: none UNIT: cm

螺旋筋補強　　砂漿塊補強　　梁敲成槽狀補強

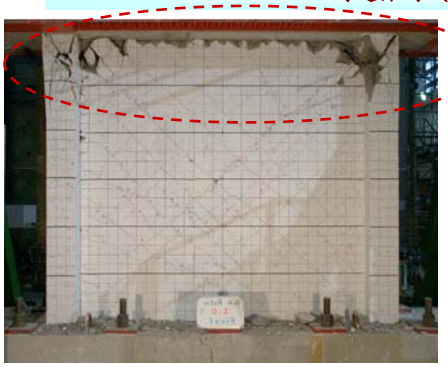
設計範例(二)：增設RC牆細部



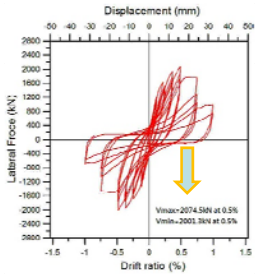
問題探討 (RC wall)

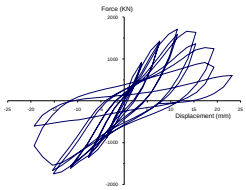


問題探討（RC wall）



- 摩擦剪力不足產生滑動
- 力量集中牆頂角落而壓碎





- 純RC牆體之drift達1.0%

問題探討（RC wall）

安和國小921後補強之剪力牆 =>於311地震中損壞照片

補強設計手冊

- 鋼筋混凝土建築結構耐震補強設計手冊
  - 基本資料調查與相關圖說
  - 構材補強與相關圖說
  - 系統補強與相關圖說
  - 基礎補強
  - 補強設計示範例
  - 其他補強設計細節

補強設計手冊

報告完畢！謝謝