建築物耐震能力評估及補強講習

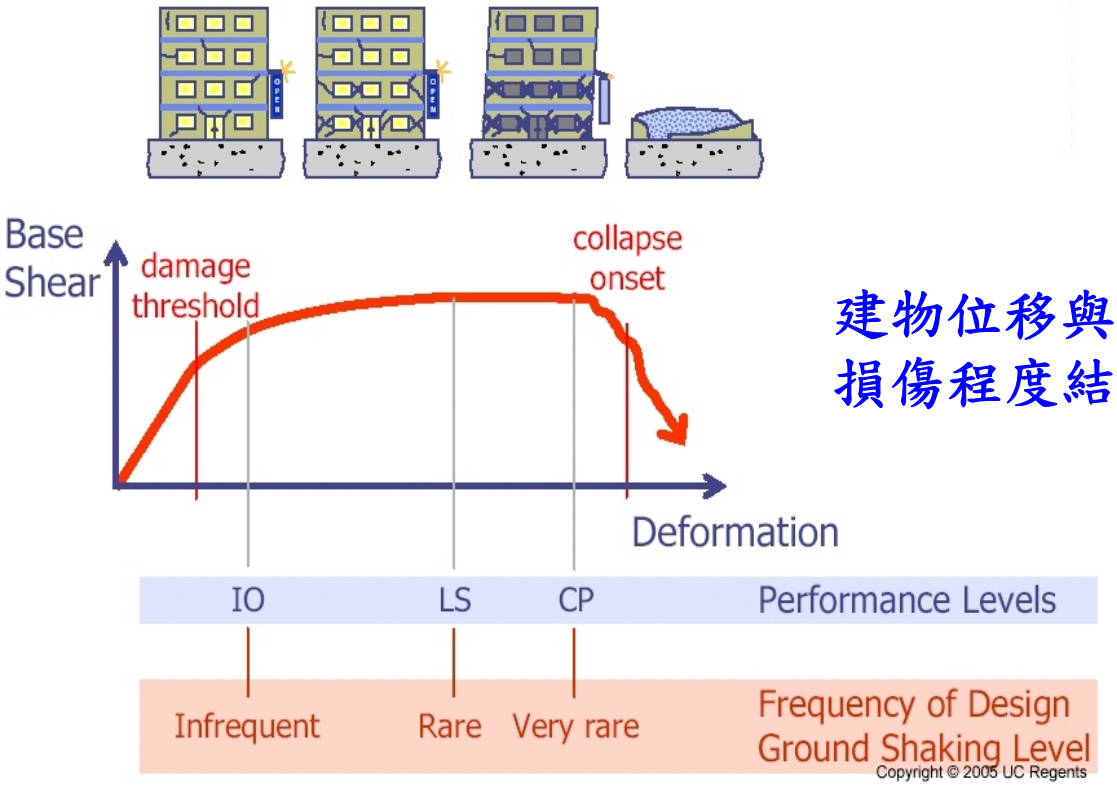
主辦：中華民國全國建築師公會

耐震能力詳細評估
(TEASPA介紹)
(Taiwan Earthquake Assessment for Structures by Pushover Analysis)

主講人：楊耀昇

非線性靜力側推分析

容量曲線：建物地震反應之包絡線



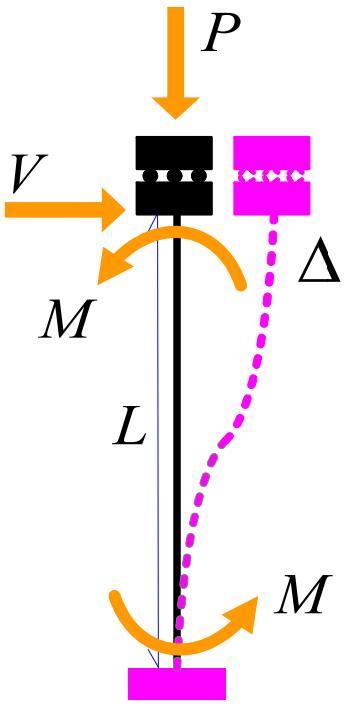
建物位移與損傷程度結合

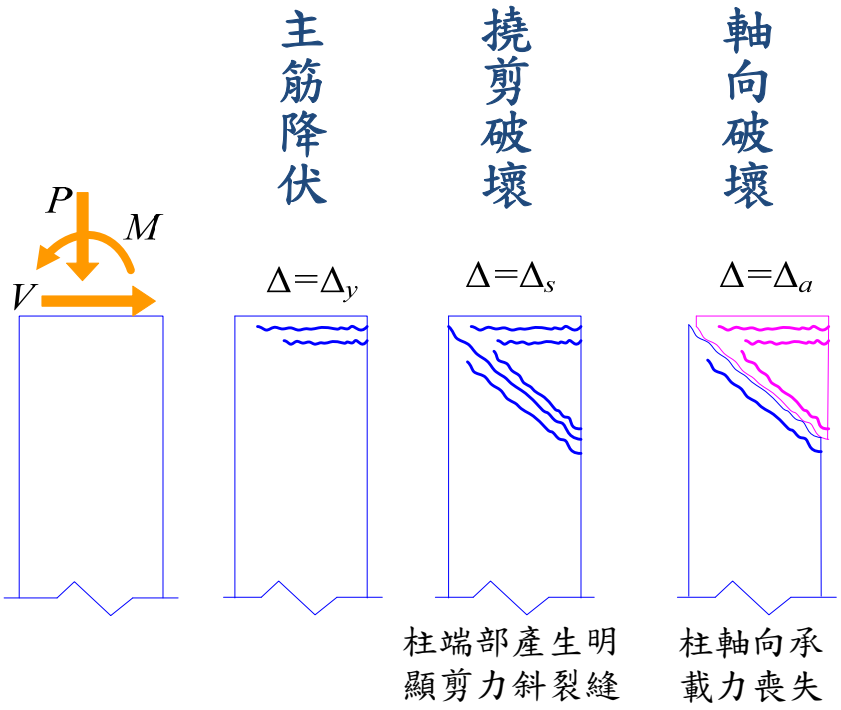
RC柱構件之模擬

柱之破壞模式

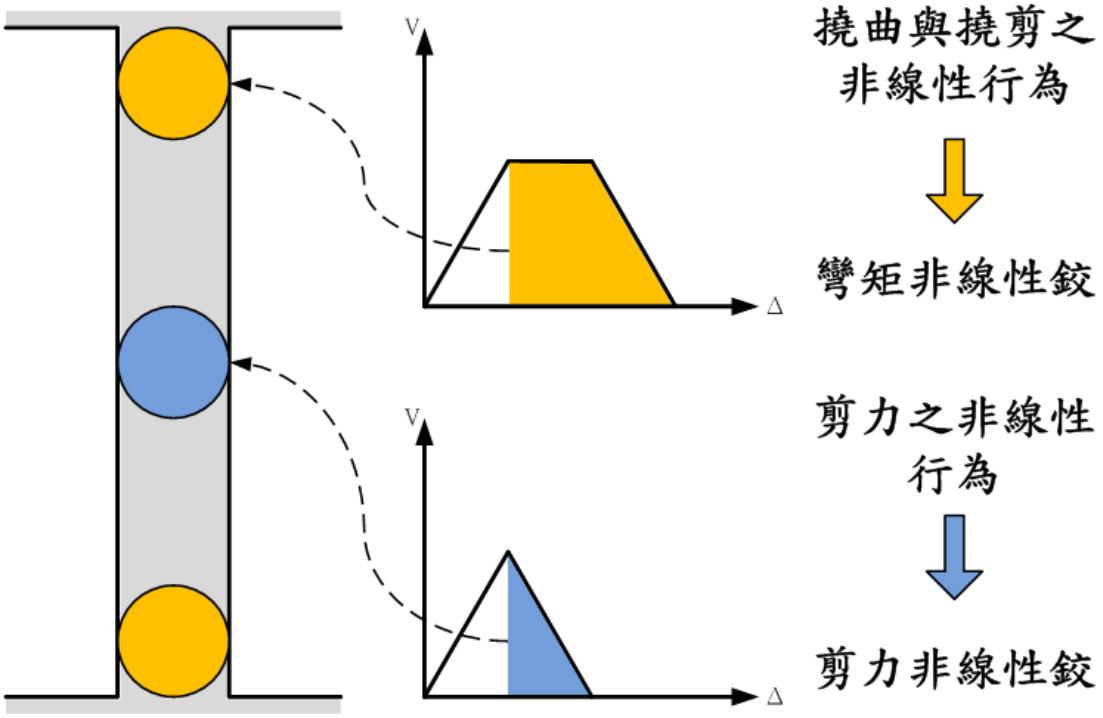
撓曲、撓剪與剪力破壞

雙曲率柱側變位之發展歷程





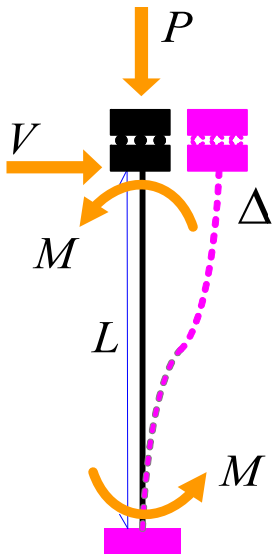
柱非線性行為模擬



柱子撓曲之側向強度

假設柱為雙曲率，反曲點位於柱高之中央，則撓曲之側向強度 (kgf) 為：

$$V_m = \frac{2M_n}{H_c}$$



M_n：斷面之彎矩計算強度 (kgf-cm)

H_c：柱子之淨高度 (cm)

柱子剪力之側向強度

柱子斷面之剪力計算強度 V_n (kgf)

$$V_n = V_c + V_s$$

土木401-96節4.2式4-2

$$V_c = 0.53\left(1+\frac{N_u}{140A_g}\right)\sqrt{f_c'}b_w d$$

土木401-96節4.4式4-4

$$V_s = \frac{A_v f_{yt} d}{s}\cot\alpha$$

土木401-96節4.6式4-15

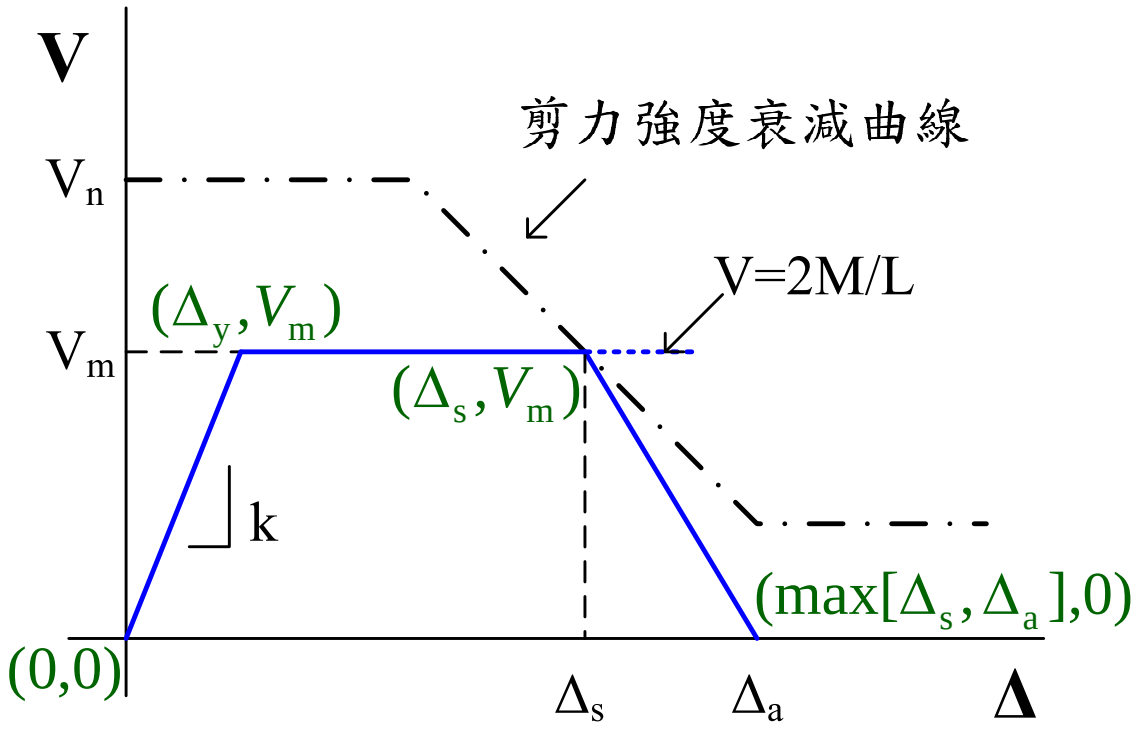
$$V_s = \frac{A_v f_{yt} d}{s}$$

$$\alpha = \frac{\pi}{4} - \frac{1}{2}\tan^{-1}\left(\frac{\sigma}{2f_t\sqrt{1+\sigma/f_t}}\right)$$

$$\sigma = \frac{N_u}{A_g}$$

$$f_t = 1.06\sqrt{f_c'}$$

柱子撓剪破壞之側力與側位移關係



柱子撓剪破壞之側力與側位移關係

若柱子撓曲之側向強度低於其剪力之側向強度，即 $V_m < V_n$，則為撓剪或撓曲破壞。

柱子撓曲破壞之側力 V 與側位移 Δ 關係，以四點表示之。

第一點 $\Delta = 0, \quad V = 0$

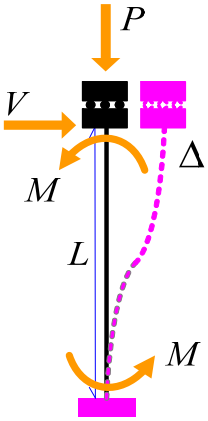
第二點 $\Delta = \Delta_y, \quad V = V_m$

第三點 $\Delta = \Delta_s, \quad V = V_m$

第四點 $\Delta = \max(\Delta_s, \Delta_a), \quad V = 0$

柱子撓剪破壞之側力與側位移關係

第二點 $\Delta = \Delta_y = \dfrac{V_m}{k_c}, \quad V = V_m = \dfrac{2M_n}{H_c}$



柱子之撓曲勁度 (kgf/cm) $k_c = \dfrac{12(EI)_c}{H_c^3}$

柱子之開裂撓曲剛度 (kgf-cm²) $(EI)_c = 0.35 E_c I_g$

混凝土之彈性模數 (kgf/cm²) $E_c = 15000\sqrt{f'_c}$

柱子總斷面對其中心軸之慣性矩 (cm⁴) I_g

柱子撓剪破壞之側力與側位移關係

第三點 $\Delta = \Delta_s, \quad V = V_m = \dfrac{2M_n}{H_c}$

由撓曲裂縫轉為剪力裂縫之側位移 Δ_s (cm)

$$\frac{\Delta_s}{H_c} = \frac{3}{100} + 4\rho'' - \frac{v_m}{133\sqrt{f_c'}} - \frac{N_u}{40A_g f_c'} \geq \frac{1}{100}$$

剪力箍筋體積比 $\rho'' = \dfrac{A_v}{bs}$ 柱寬 (cm) b

間距 s 內之箍筋斷面積 (cm^2) A_v 柱深 (cm) h

剪應力 (kgf/cm^2) $v_m = \dfrac{V_m}{bd}$ 有效柱深 (cm) $d = 0.8h$

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柱子撓剪破壞之側力與側位移關係

第四點 $\Delta = \max(\Delta_s, \Delta_a), \quad V = 0$

軸向破壞時之側位移 Δ_a (cm)

$$\frac{\Delta_a}{H_c} = \frac{4}{100} \frac{1 + \tan^2\theta}{\tan\theta + N_u s / (\phi_s A_v f_{yt} d_c \tan\theta)}$$

剪力裂縫與水平之夾角 $\theta = \min(65^\circ, \tan^{-1}\dfrac{H_c}{h})$

90度彎鉤對於箍筋剪力強度之折減係數

$$\phi_s = \begin{cases} 1, & 0 \leq \mu < 2 \\ 1.15 - 0.075\mu, & 2 \leq \mu < 6 \\ 0.7, & 6 \leq \mu \end{cases}$$

柱子核心混凝土之深度 (cm) d_c 韌性比 $\mu = \Delta_s / \Delta_y$

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柱子剪力破壞之側力與側位移關係

若柱子剪力之側向強度低於其撓曲之側向強度，即 $V_n < V_m$，則為剪力破壞。

柱子剪力破壞之側力 V 與側位移 Δ 關係，以三點表示之。

第一點 $\Delta = 0, \quad V = 0$

第二點 $\Delta = \Delta_s, \quad V = V_n$

第三點 $\Delta = \max[\Delta_s, \min(\Delta_a, 0.04H_c)], \quad V = 0$

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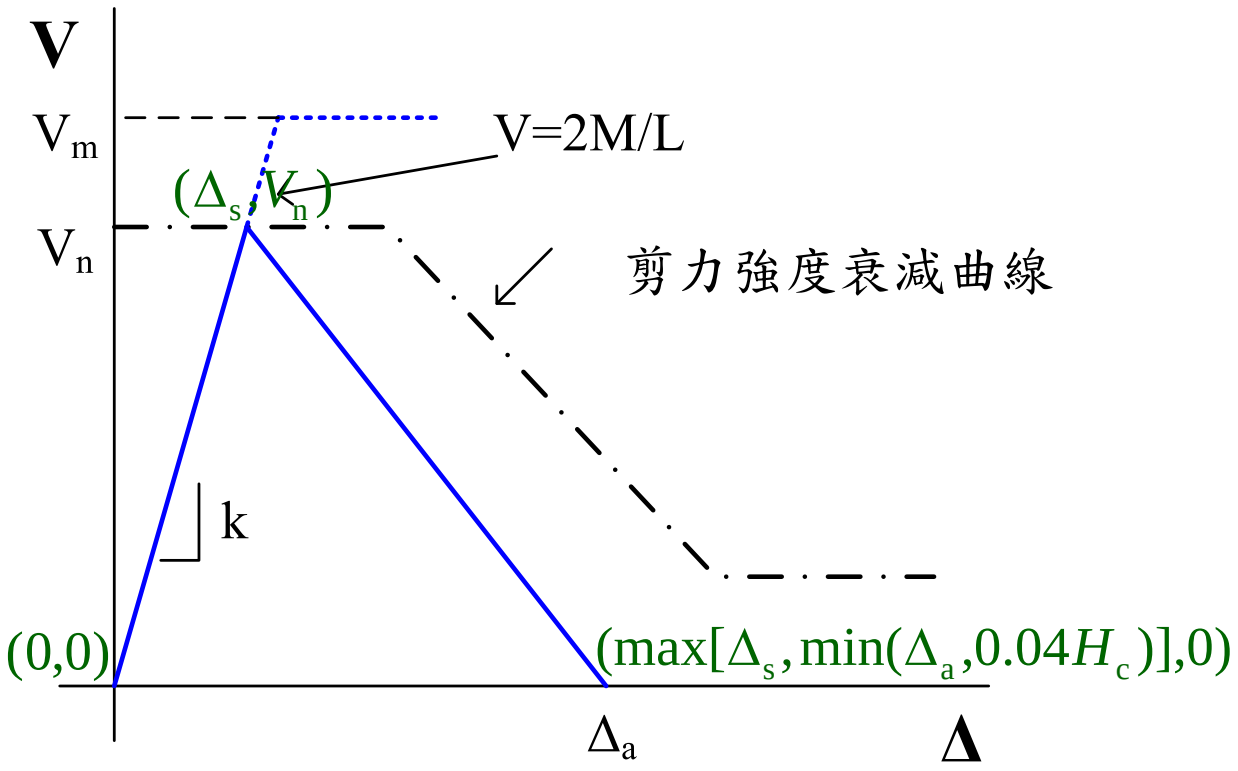
柱子剪力破壞之側力與側位移關係



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柱子剪力破壞之側力與側位移關係

第二點 $\Delta = \Delta_s = \dfrac{V_n}{k_c}, \quad V = V_n = V_c + V_s$

$$k_c = \frac{12(EI)_c}{H_c^3}$$

第三點 $\Delta = \max[\Delta_s, \min(\Delta_a, 0.04H_c)], \quad V = 0$

$$\frac{\Delta_a}{H_c} = \frac{4}{100} \frac{1+\tan^2\theta}{\tan\theta + N_u s/(\phi_s A_{st} f_{yt} d_c \tan\theta)}$$

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RC柱之非線性鉸參數

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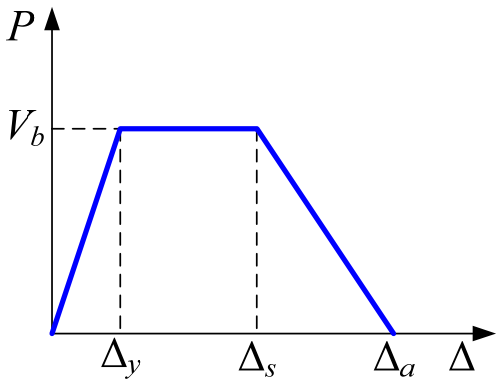
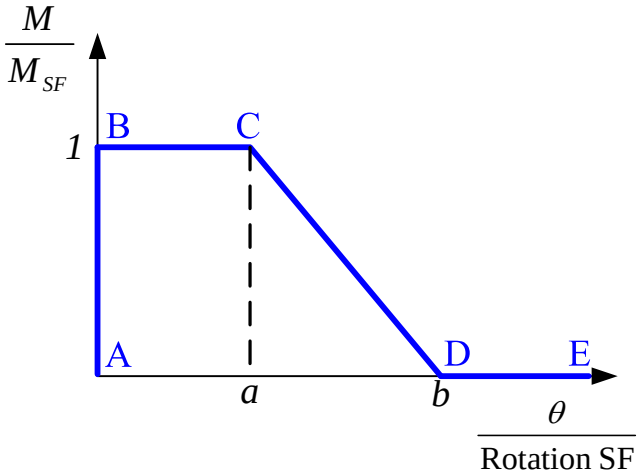
撓剪破壞非線性鉸參數





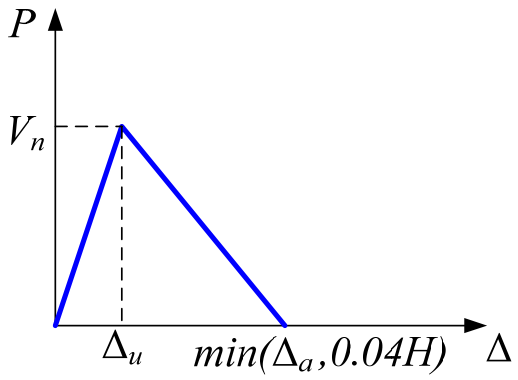
Point	Moment / SF	Rotation / SF
A	0	0
B	1	0
C	1	a
D	0	b
E	0	10b

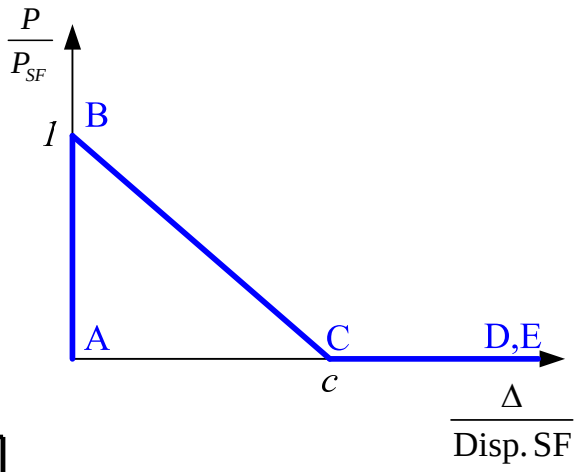
$$a = \frac{\Delta_s}{H} - \frac{\Delta_y}{H} \qquad b = \max\left(\frac{\Delta_a}{H}, \frac{\Delta_s}{H}\right)$$

$$\Delta_y = \frac{V_b}{k} = \frac{V_b H^3}{12(EI)_c}$$

Moment SF	M_n
Rotation SF	1

剪力破壞非線性鉸參數





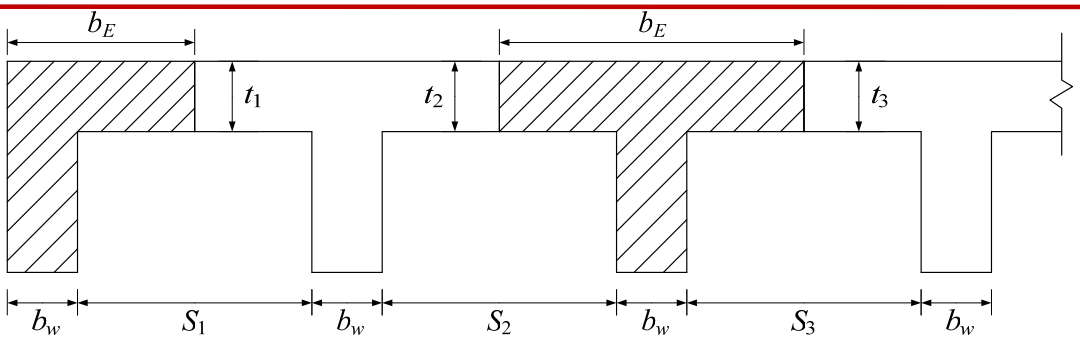
Point	Force / SF	Disp / SF
A	0	0
B	1	0
C	0	c
D	0	10c
E	0	10c

$$c = \min\left(\frac{\Delta_a}{H}, 0.04\right)$$

Force SF	V_n
Disp SF	H

RC梁之非線性鉸參數與設定

T型梁有效翼緣寬度



1. T型梁翼緣之有效版寬不得超過該梁跨度之1/4；梁腹每側懸出之有效翼緣寬度不得超過翼緣厚(版厚)之8倍或該梁與鄰梁間淨距之1/2。

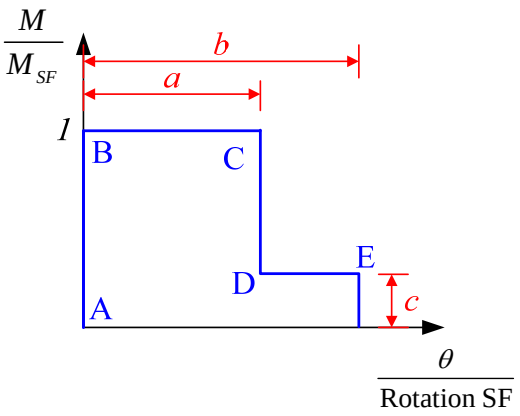
$$b_E = \min(L/4, b_w + \min(8t_2, \frac{S_2}{2}) + \min(8t_3, \frac{S_3}{2}))$$

2. 梁僅一側有翼緣者，其有效懸出翼緣寬度不得超過該梁跨度之1/12、翼緣厚(版厚)之6倍或該梁與鄰梁間淨距之1/2。

$$b_E = \min(b_w + \frac{L}{12}, b_w + 6t_1, b_w + \frac{S_1}{2})$$

梁彎矩非線性鉸參數(ASCE 41-06)

$\frac{\rho-\rho'}{\rho_{bal}}$	箍筋	$\frac{0.27V}{b_w d\sqrt{f'_c}}$	a	b	c
≦0.0	有圍束	≦3	0.025	0.05	0.2
≦0.0	有圍束	≧6	0.02	0.04	0.2
≧0.5	有圍束	≦3	0.02	0.03	0.2
≧0.5	有圍束	≧6	0.015	0.02	0.2
≦0.0	無圍束	≦3	0.02	0.03	0.2
≦0.0	無圍束	≧6	0.01	0.015	0.2
≧0.5	無圍束	≦3	0.01	0.015	0.2
≧0.5	無圍束	≧6	0.005	0.01	0.2



彎矩非線性鉸

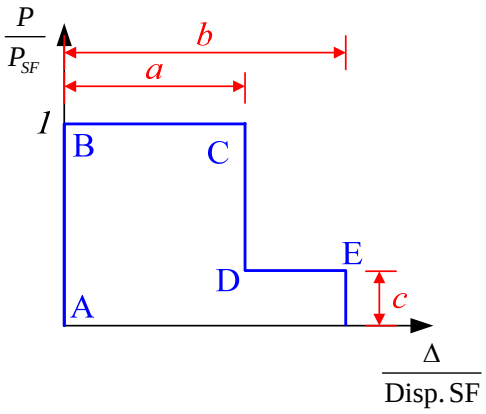
Points	Moment/SF	Rotation/SF
A	0	0
B	1	0
C	1	a
D	c	a
E	c	b

ρ ：梁斷面受拉鋼筋比

ρ' ：梁斷面受壓鋼筋比

ρ_{bal}：梁斷面產生平衡應變狀態之鋼筋比

梁剪力非線性鉸參數(ASCE 41-06)



箍筋間距	a	b	c
箍筋間距≦(d/2)	0.003	0.02	0.2
箍筋間距>(d/2)	0.003	0.01	0.2

剪力非線性鉸

Points	Force/SF	Disp/SF
A	0	0
B	1	0
C	1	a
D	c	a
E	c	b

d：有效深度 (構材最外受壓纖維至受拉鋼筋斷面重心之距離)

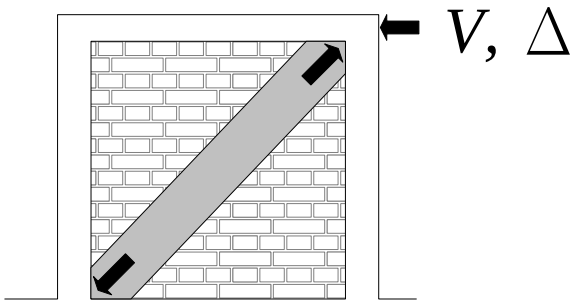
磚牆之非線性鉸

✓等值斜模型

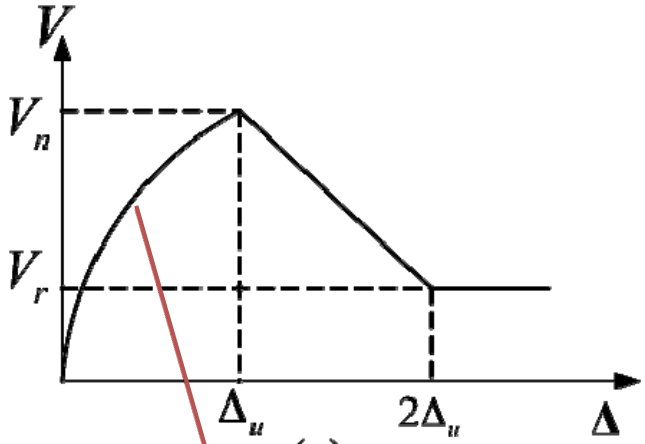
磚牆構件之非線性鉸計算

1. 磚牆行為之模擬
   - 成大許茂雄教授進行一系列磚牆研究，建議磚牆可採等值受壓斜撐模擬，該斜撐必須與磚牆具有相等之勁度與強度，端點與構架鉸接。
   - 以斜撐上之軸力非線性鉸表現磚牆破壞行為。

2. 磚牆壓力非線性鉸計算依據
   - 建築物磚構造設計及施工規範 (2008)

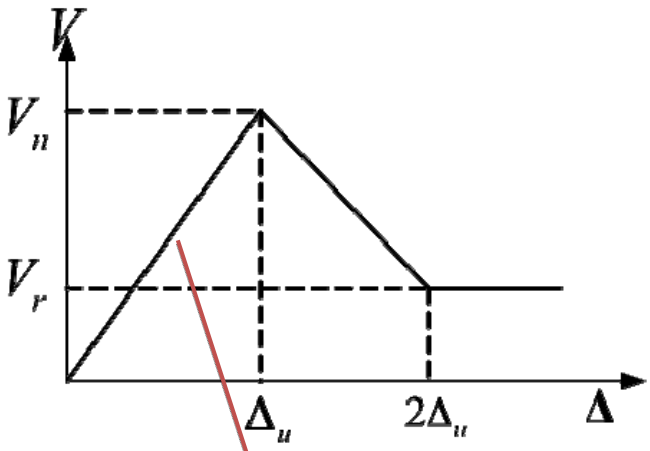


磚牆等值斜撐模型



(a)

建築物磚構造設計及施工規範
側向載重位移曲線



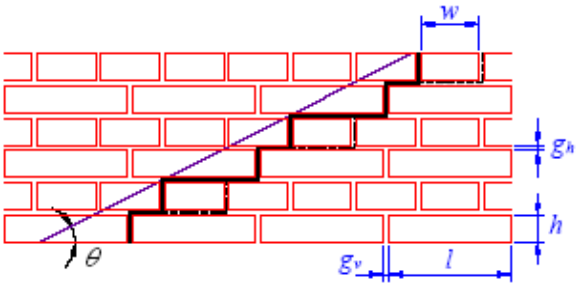
(b)

NCREE: 建議曲線

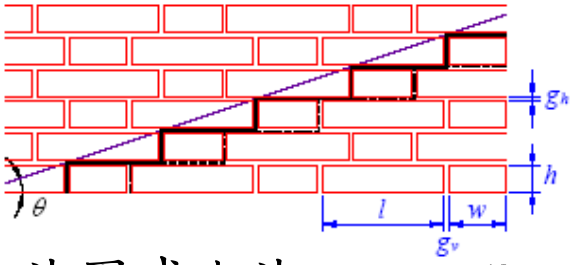
$$\frac{V}{V_u} = a_1\left(\frac{\Delta}{\Delta_u}\right) + a_2\left(\frac{\Delta}{\Delta_u}\right)^2 + a_3\left(\frac{\Delta}{\Delta_u}\right)^3$$

$$E_u = 61.29\eta_1\eta_2 f_{bc}^{0.7} f_{mc}^{0.3}$$

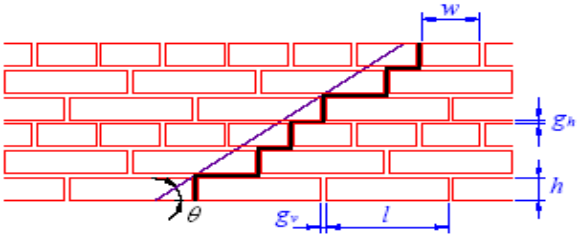
磚牆臨界破裂角



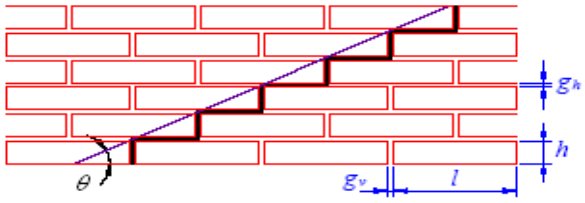
1. 英國式砌法 $\tan\theta = \dfrac{h+g_h}{w+g_v}$



2. 法國式砌法 $\tan\theta = \dfrac{2(h+g_h)}{w+l+2g_v}$



3. 二順一丁 $\tan\theta = \dfrac{3(h+g_h)}{2(w+g_v)}$



4. 順砌法 $\tan\theta = \dfrac{2(h+g_h)}{l+g_v}$

磚牆之側向載重位移曲線

依照其臨界破壞角、破壞路徑及經驗公式

四邊圍束：

$\tan\theta \geq (H_b/W_b)$:

$$V_n = T_b \times (W_b \times \tau_f + H_b \times \alpha\ f_{mbt})$$

$\tan\theta < (H_b/W_b)$:

$$V_n = T_b \times \left[W_b \times \tau_f + H_1 \times \alpha\ f_{mbt} + (H_b^{'} - H_1) \times (\alpha\ f_{mbt} + \beta\ f_{bt})/2\right]$$

三邊圍束：

$$V_n = T_b \times (W_b \times \tau_f + H_2 \times \alpha\ \ f_{mbt})$$

台度磚牆：

$$V_n = T_b \times (W_b \times 0.7\tau_f + H_2 \times \alpha\ \ f_{mbt})$$

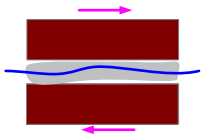
磚牆殘餘強度點之強度與位移

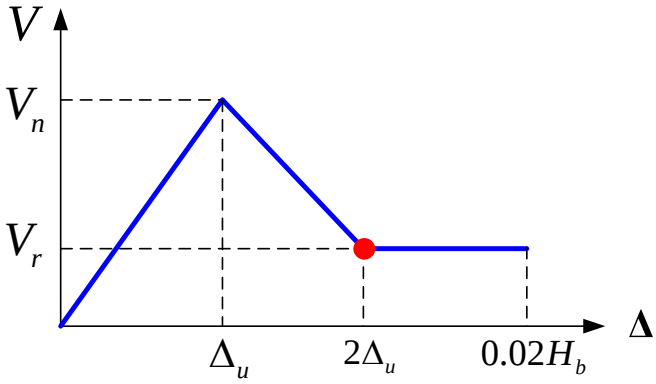
（A）非窗台磚牆之殘餘強度為：

$$V_r = \tau_f \times T_b \times W_b \leq\ \ 0.6\,V_n$$

（B）窗台磚牆之殘餘強度為：

$$V_r = 0.7 \times \tau_f \times T_b \times W_b \leq\ \ 0.6\,V_n$$

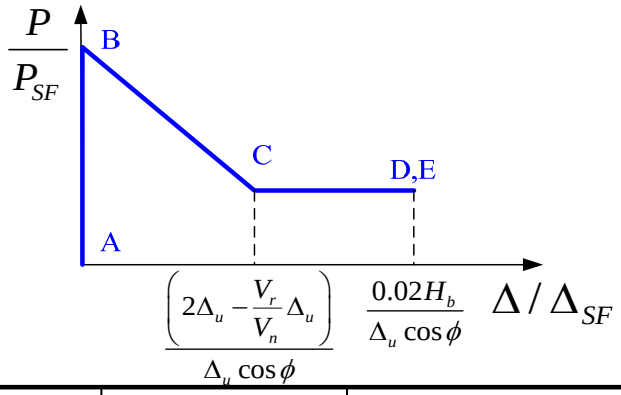


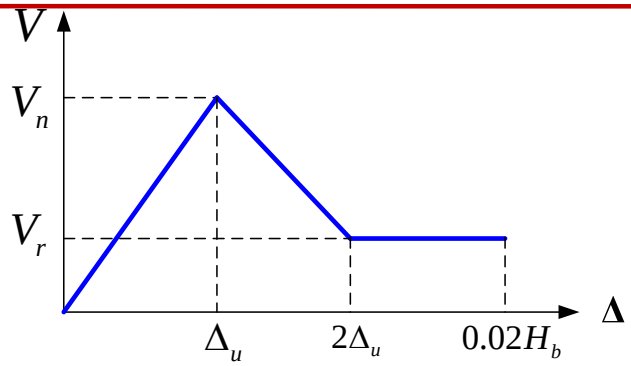


根據試驗之觀察，磚牆約在達到約兩倍水平極限位移時，磚牆強度會衰減至水平殘餘強度，

磚牆之最大水平位移可參考試驗結果並保守考慮取牆高之2.0% 為限制

軸力破壞非線性鉸參數



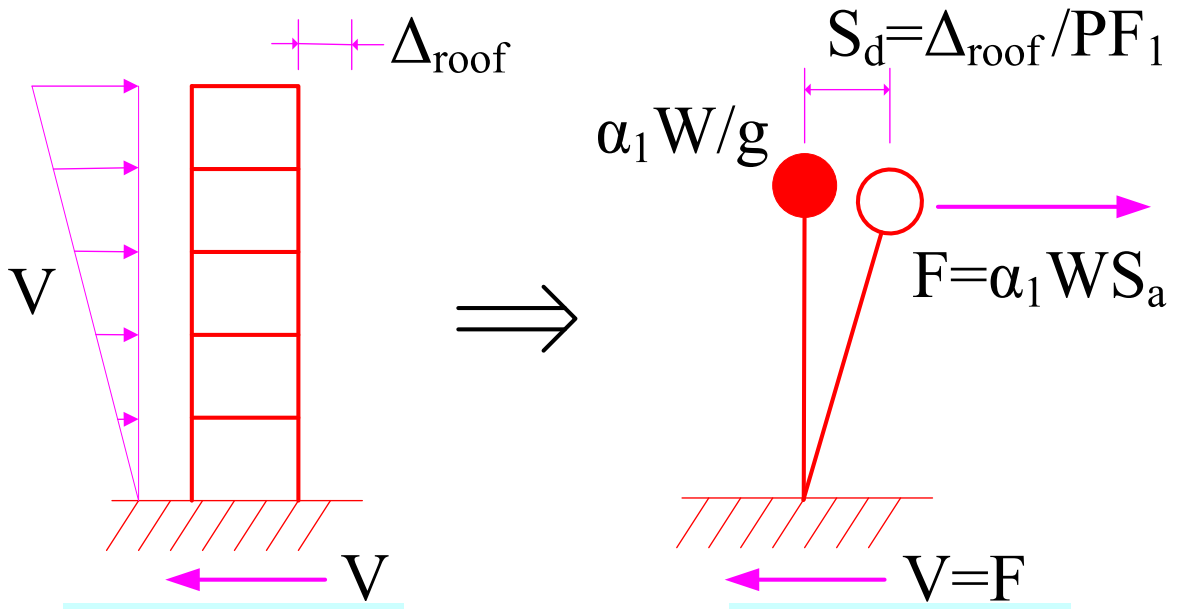


Points	Force / SF	Disp / SF
A	0	0
B	1	0
C	V_r / V_n	$\left(2\Delta_u - \frac{V_r}{V_n}\Delta_u\right) \Big/ \Delta_u \cos\phi$
D	V_r / V_n	$(0.02H_b)/(\Delta_u \cos\phi)$
E	V_r / V_n	$(0.02H_b)/(\Delta_u \cos\phi)$

Force SF	$V_n / \cos\phi$
Disp. SF	$\Delta_u \cos\phi$

容量震譜法之介紹

多自由度系統轉換為單自由度系統



容量曲線

V vs Δ_{roof}

容量震譜

S_a vs S_d

容量震譜法之等效單自由度系統

容量曲線 (ETABS)

V versus Δ_{roof}

$$PF_1 = \sum_i w_i \phi_i \Big/ \sum_i w_i \phi_i^2$$ (modal participation factor)

$$\alpha_1 = \left[\sum_i w_i \phi_i \Big/ W \right] PF_1$$ (modal mass coefficient)

容量震譜

S_a versus S_d

ϕ_i 為建物側推方向之主控模態於樓層 i 振幅在側推方向的分量(空間構架)

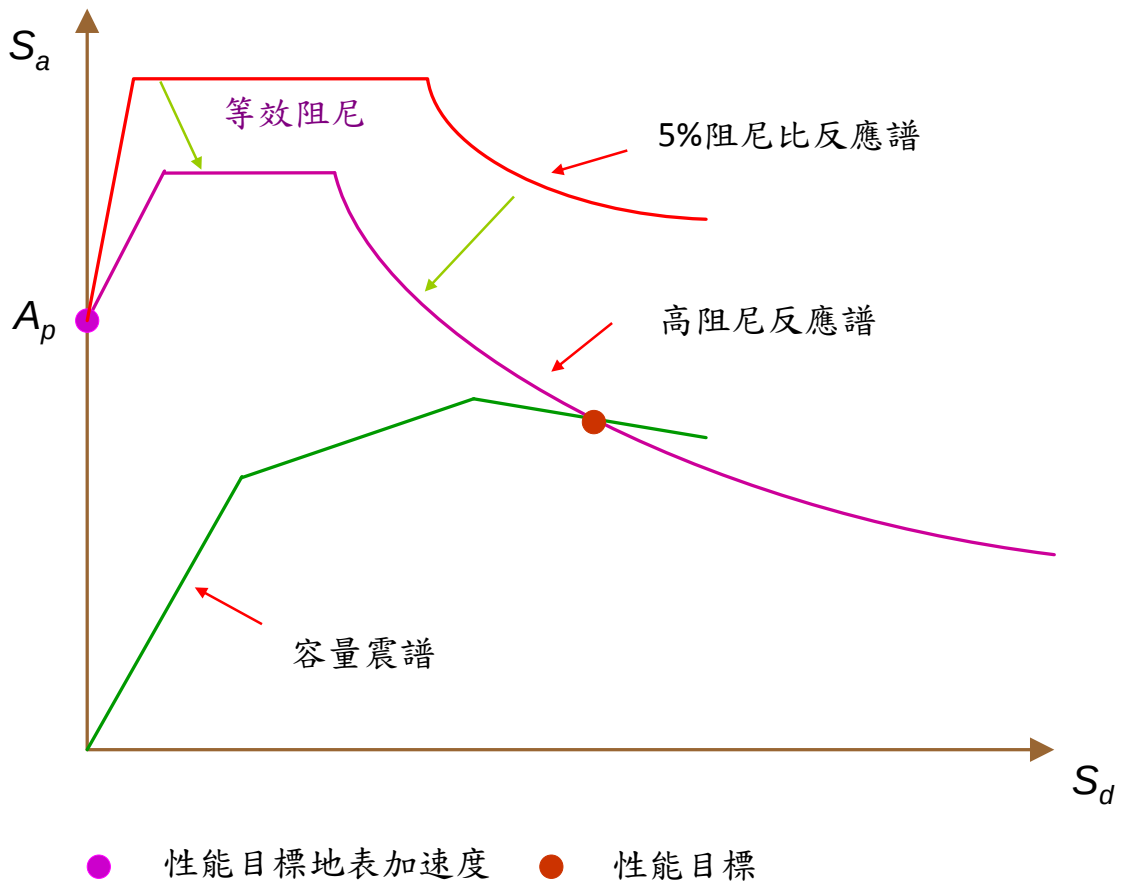
or 為倒三角形分量(空間構架、平面構架)

or 為建物第一模態於樓層 i 振幅(平面構架-ATC40)

or 為建物側推過程樓層 i 之位移(平面構架-ATC40，ETABS默認方式)

$$\phi_{roof} = 1$$

性能目標地表加速度之決定



性能曲線之建立(等效單自由度系統)

容量震譜 S_a versus S_d

性能點$(S_{d,p}, S_{a,p})$

等效基本週期 T_{eq}

等效阻尼比 β_{eq}

阻尼比修正係數 B_s、B_1

$$A_p = \begin{cases} S_{a,p} \Big/ \left[1+\left(\dfrac{2.5}{B_s}-1\right)\dfrac{T_{eq}}{0.2T_0}\right] & for\ T_{eq} \le 0.2T_0 \\ \dfrac{B_s}{2.5} S_{a,p} & for\ 0.2T_0 < T_{eq} \le T_0 \\ \dfrac{B_s T_{eq}}{2.5T_0} S_{a,p} & for\ T_0 < T_{eq} \end{cases}$$

性能曲線 A_p versus Δ_{roof}

耐震能力詳細評估
(TEASPA)

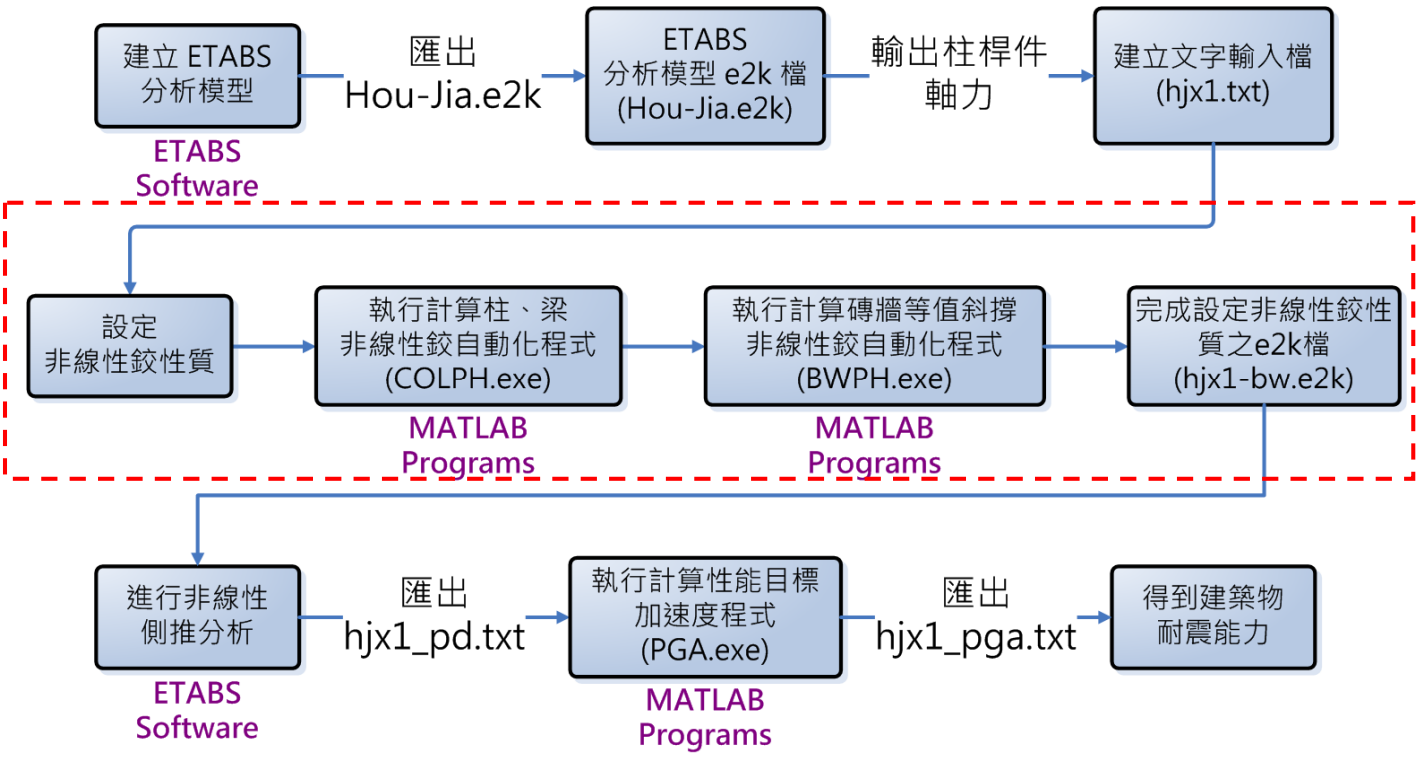
耐震能力詳細評估

- 資料蒐集、材料試驗
- 建立分析模型(計算軸力)
- 輔助分析程式(TEASPA)—柱、梁、牆
- 非線性鉸參數—柱、梁、牆
- 側推分析設定
- 側推分析與容量曲線
- 容量震譜與性能曲線

文字輸入檔

Colph.exe
Bwph.exe
Swph.exe
Pga.exe

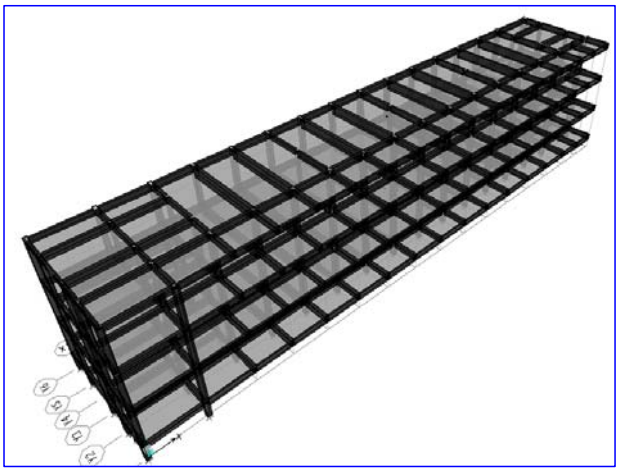
TEASPA (原NCREE)
側推分析流程-以ETABS為例

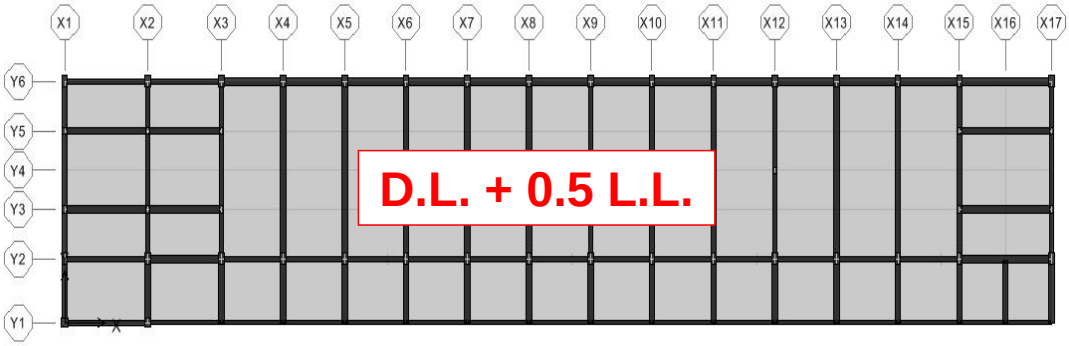


標的物基本資料

- 三層樓之鋼筋混凝土建築物，每層樓高 3.6 公尺
- 教室外單側有走廊，廊外無柱
- 長向長度為 53.5 公尺、短向為 10.2 公尺
- 長向有 90 公分高之窗台，教室間設置 1B 隔間磚牆
- 材料強度：混凝土抗壓強度 $f'_c = 160\ \mathrm{kgf/cm^2}$
  主筋與箍筋降伏強度均為 $f_y = 2800\ \mathrm{kgf/cm^2}$

建立分析模型





輔助分析程式—文字輸入檔

輔助程式文字輸入檔

- 建築物性質模組
- 工址震譜參數模組
- 磚牆性質模組
- 柱性質模組
- 梁性質模組
- 柱資料模組
- 梁資料模組
- 軸力資料模組
- 柱、梁斷面性質模組

提供柱、梁斷面材料參數

計算柱、梁斷面非線性鉸之部份參數

提供計算柱、梁彎矩強度所需之斷面配筋狀況

輔助程式共用輸入檔

x - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

```
$ Junior high school HJ (x) (Unit: kgf-cm)

$ BUILDING PROPERTIES
$Weight Height
479000    0.0151
479000    0.0270
413400    0.0333

$ SITE SPECTRUM PARAMETER
$S_s    S_1
0.7     0.52

$ BRICK WALL PROPERTIES
$Name  width  height  thick  f_mc  f_bc  P  Bond  Confinement
BW1    218    90      24     150   150   0  3     2
BW2    303    90      24     150   150   0  3     2
```

建築物性質模組

工址震譜參數模組

磚牆性質模組

輔助分析程式—文字輸入檔

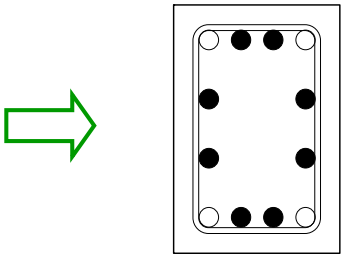
X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

柱性質模組

$ COLUMN PROPERTIES

$Name	f_cp	f_yl	f_yt	cover	hoop	spacing	num_hoop	TR		
C1L	160	2800	2800	4	3	25			2	0
C1S	160	2800	2800	4	3	25			2	0
C2	160	2800	2800	4	3	25			2	0
C3	160	2800	2800	4	3	25			2	0



側力方向所切過之箍筋及繫筋根數

TR=1 良好圍束
TR=0 不良好圍束

輔助分析程式—文字輸入檔

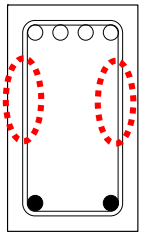
X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

梁性質模組

$ BEAM PROPERTIES

$Name	L	f_cp	f_yl	f_yt	cover	hoop	spacing	num_hoop	TR		
B1D_303	303	160	2800	2800	4	3	25			2	0
B1S_370	370	160	2800	2800	4	3	25			2	0
B2S_303	303	160	2800	2800	4	3	25			2	0
B2S_470	470	160	2800	2800	4	3	25			2	0
B2D_470	470	160	2800	2800	4	3	25			2	0



側力方向所切過之箍筋及繫筋根數

TR=1 良好圍束
TR=0 不良好圍束

輔助分析程式—文字輸入檔

X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

柱資料模組

```
$ COLUMN DATA
$Name  story  properties  section  H    L    fromBtm
C1     2FL    C3         C3       360  315  0
C1     3FL    C3         C3       360  315  0
C1     RFL    C3         C3       360  315  0
C2     2FL    C3         C3       360  305  0
C2     3FL    C3         C3       360  305  0
C2     RFL    C3         C3       360  305  0
C3     2FL    C1L        C1L      360  315  0
C3     3FL    C1L        C1L      360  315  0
C3     RFL    C1L        C1L      360  315  0
C4     2FL    C1L        C1L      360  305  0
C4     3FL    C1L        C1L      360  305  0
C4     RFL    C1L        C1L      360  305  0
C5     2FL    C1L        C1L      360  300  0
C5     3FL    C1L        C1L      360  300  0
```


柱資料模組

柱有效淨長=

(樓層高度) - (相連梁之最大深度) - (窗台高度)

- 長柱設定

$ Name	story	section	shape	Height	L	fromBtm
C1	2FL	C3	C3	360	315	0

(L=360-45-0=315)

(必須與ETABS上相同)

- 窗台柱設定

$ Name	story	section	shape	Height	L	fromBtm
C6	2FL	C1S	C1S	360	225	90

(L=360-45-90=225)

(必須與ETABS上相同)

輔助分析程式—文字輸入檔

X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

梁資料模組

(必須與ETABS上相同)

```
$ BEAM DATA
$Name   story   section
B1      2FL     B6S_414
B1      3FL     B6S_414
B1      RFL     B6S_414
B2      2FL     B5S_367
B2      3FL     B5S_367
B2      RFL     B5S_367
B3      2FL     B5S_303
B3      3FL     B5S_303
B3      RFL     B5S_303
B4      2FL     B5S_303
B4      3FL     B5S_303
B4      RFL     B5S_303
B5      2FL     B5S_303
B5      3FL     B5S_303
```


輔助分析程式—文字輸入檔

X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

軸力資料模組

```
$ AXIAL LOAD
$Story  Column  Loc     P
RFL     C1      0       -3951.01
RFL     C1      157.5   -3460.51
RFL     C1      315     -2970.01
3FL     C1      0       -8683.67
3FL     C1      157.5   -8193.17
3FL     C1      315     -7702.67
2FL     C1      0       -13202.93
2FL     C1      157.5   -12712.43
2FL     C1      315     -12221.93
GFL     C1      0       -17276.86
GFL     C1      52.5    -17113.36
GFL     C1      105     -16949.86
RFL     C2      0       -7922.73
RFL     C2      152.5   -7447.8
```

輔助分析程式—文字輸入檔

X - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

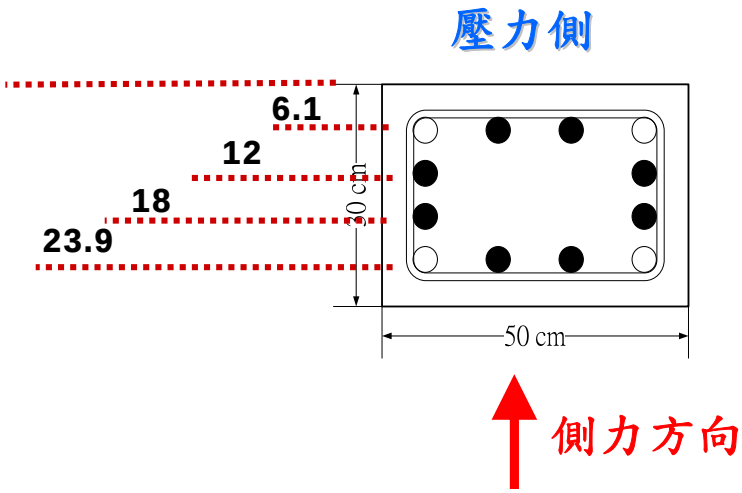
柱、梁斷面性質模組

```
$ COLUMN SECTION PROPERTIES
C1L
30      50
6.1     2800    7  6  6  7
12      2800    6       6
18      2800    6       6
23.9    2800    7  6  6  7

C1S
30      50
6.1     2800    7  6  6  7
12      2800    6       6
18      2800    6       6
23.9    2800    7  6  6  7

C2
```


柱、柱斷面性質模組

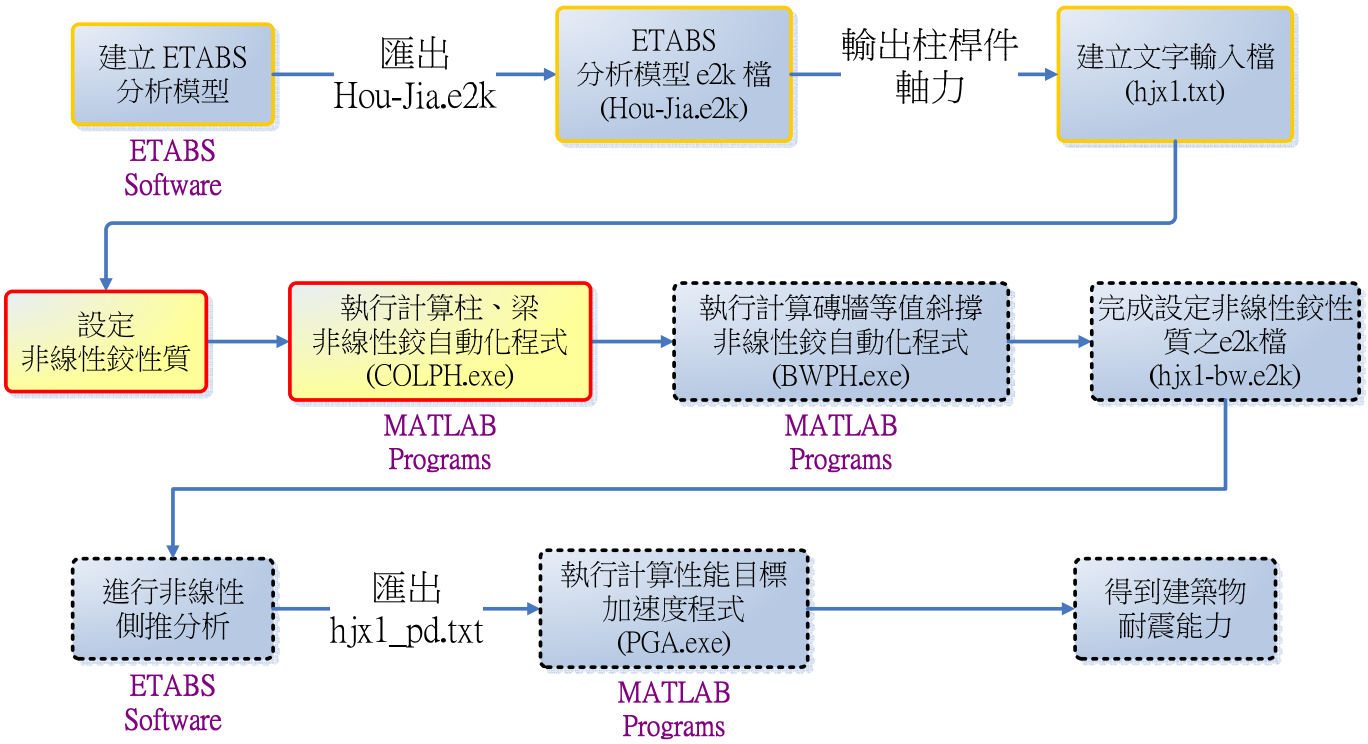
```
C1S
30      50          ← 斷面深度、斷面寬度
6.1     2800    7  6  6  7
12      2800    6       6
18      2800    6       6
23.9    2800    7  6  6  7
```

單位：kgf-cm

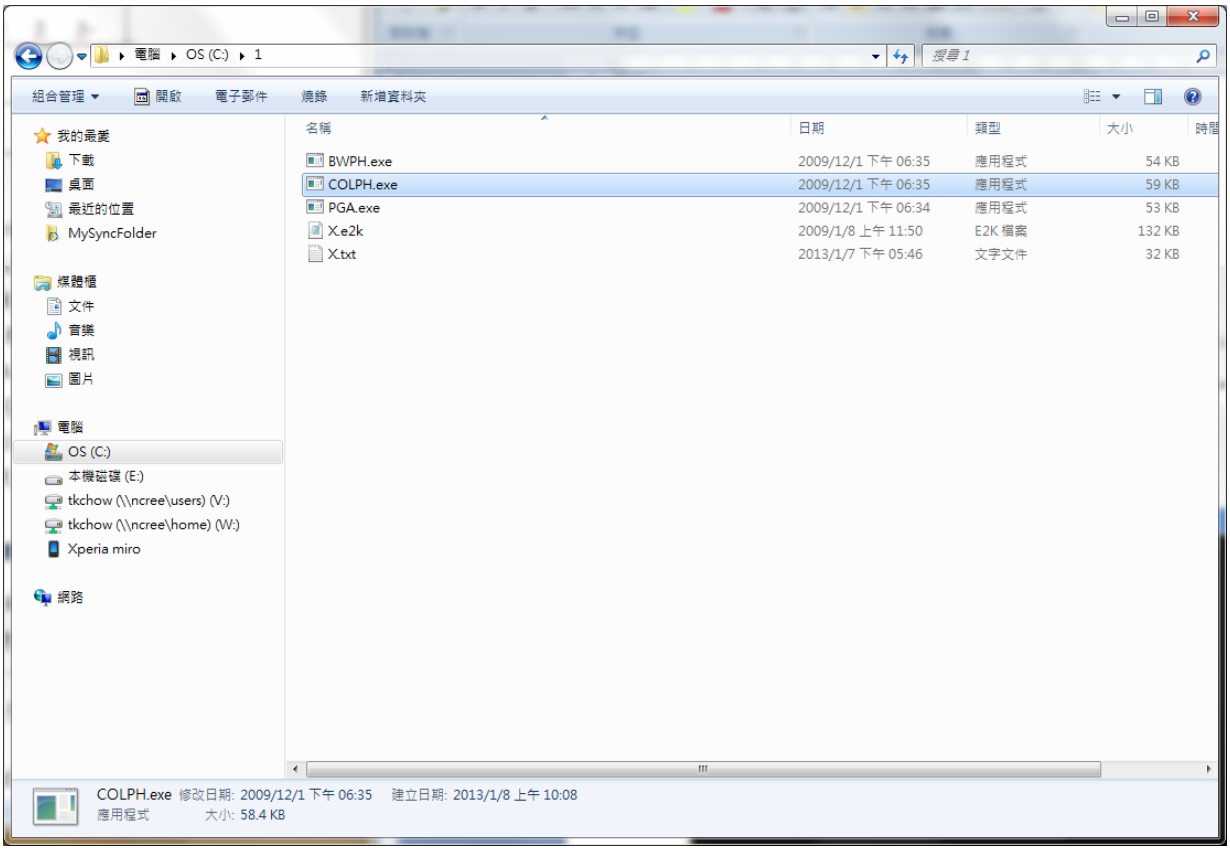


輔助分析程式—非線性鉸參數

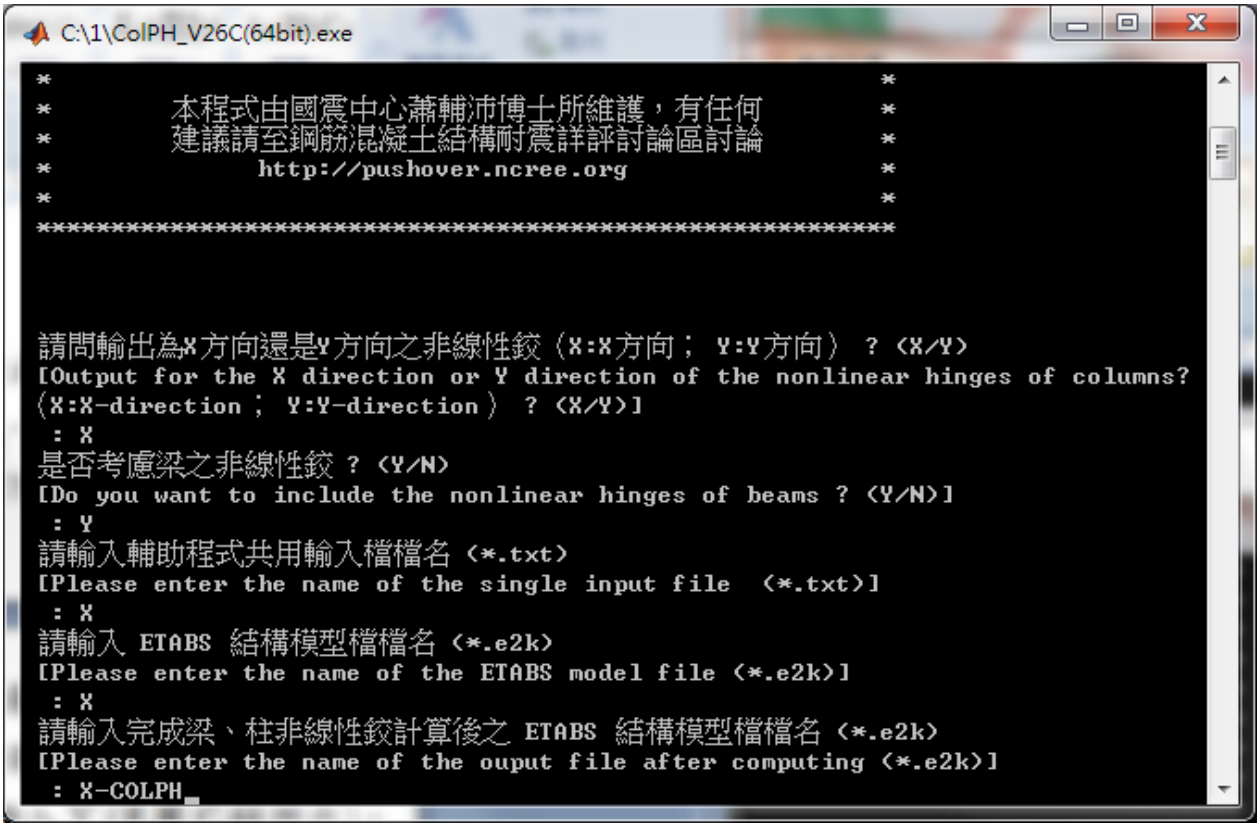
計算柱、梁非線性鉸參數



實際操作 (COLPH.exe)



實際操作 (COLPH.exe)



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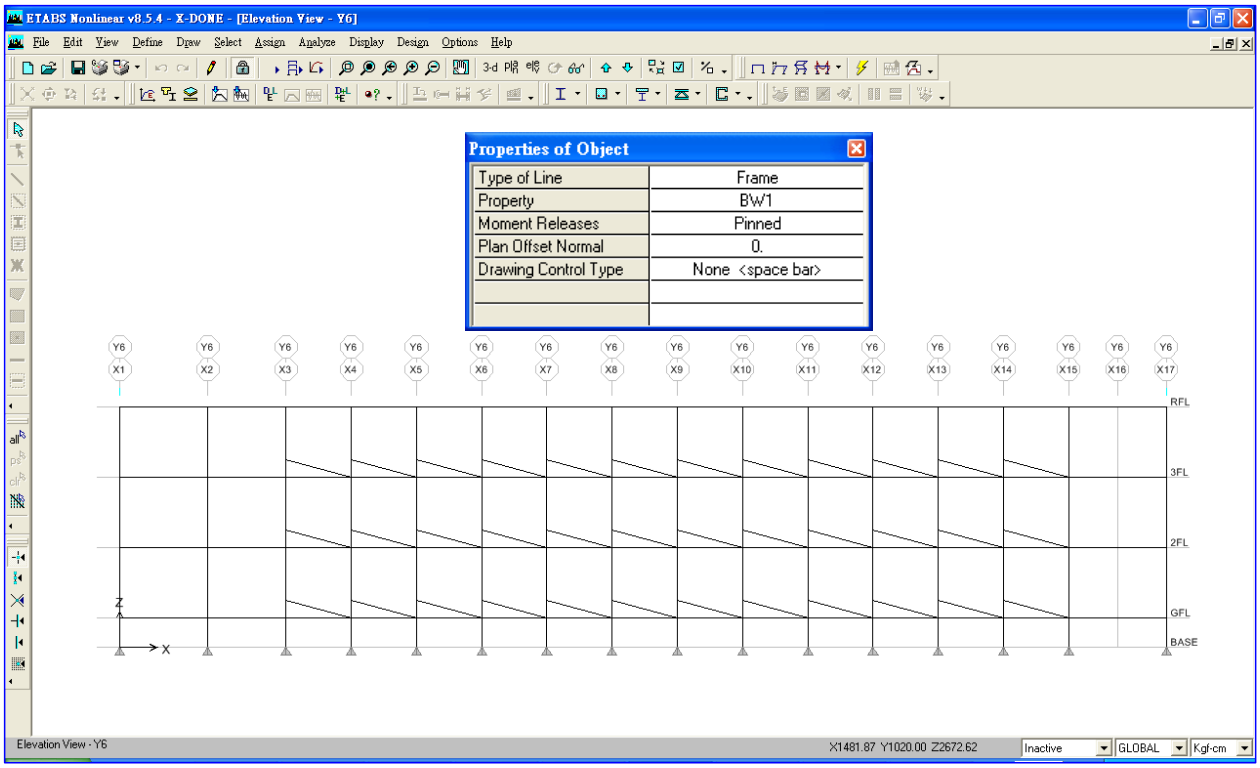
實際操作 (BWPH.exe)

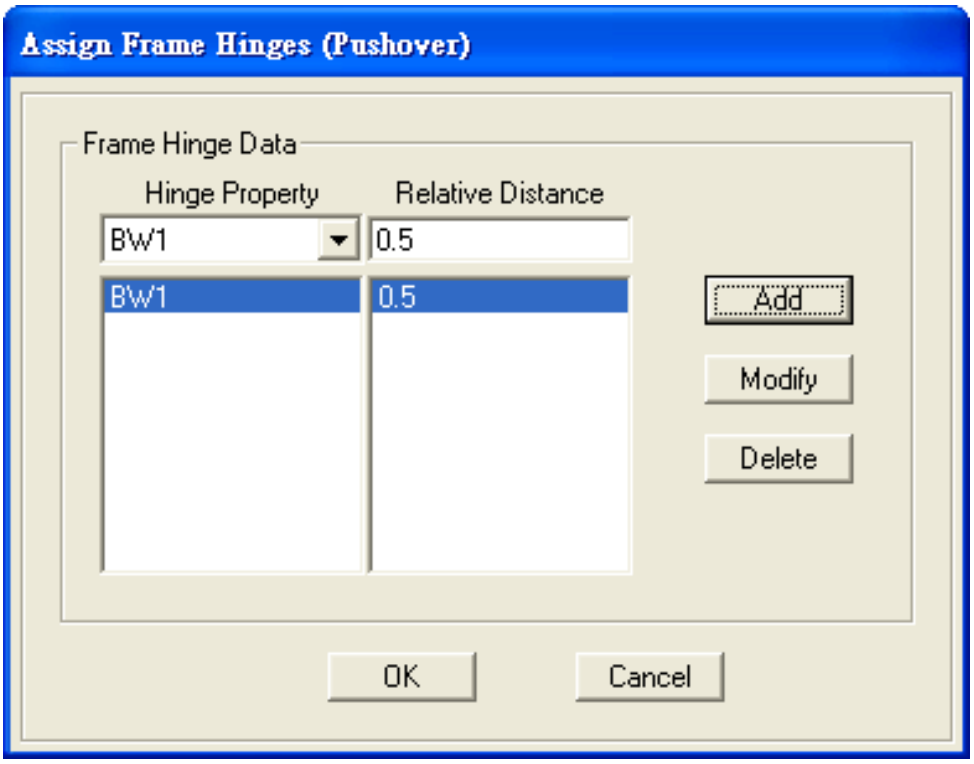
匯入ETABS之e2k檔

- 繪製磚牆等值斜撐



等值斜撐之軸力非線性鉸設定

- 選取斜撐桿件(例：BW1)，並將斜撐之軸力非線性鉸相對位置(Relative Distance)輸入0.5



執行側推分析

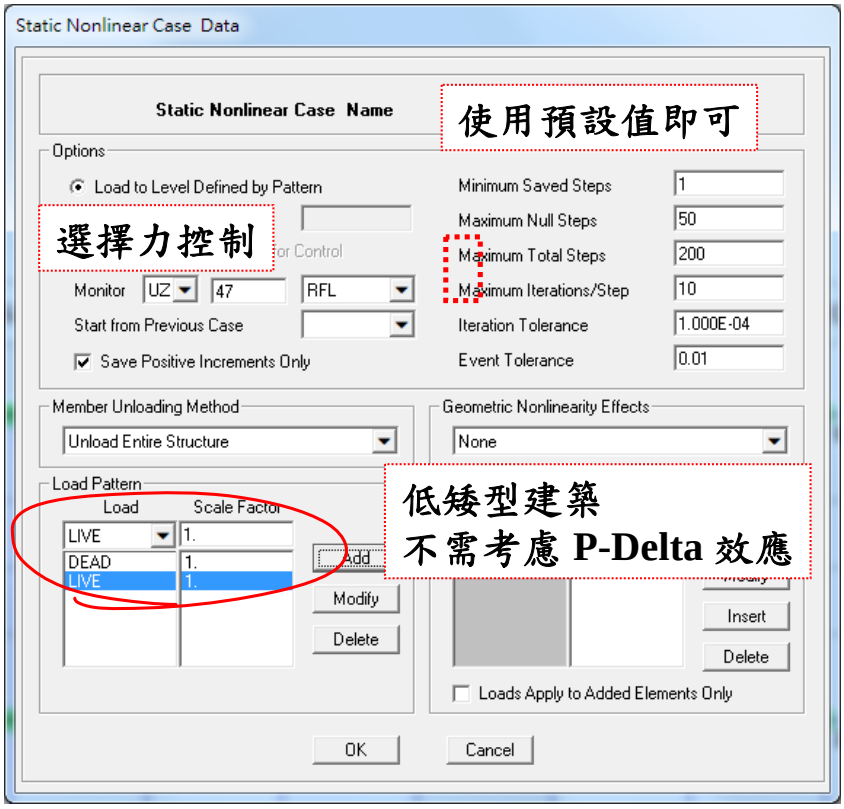
定義 PUSH1

依分析方向選擇 UZ

只儲存分析結果為正之步驟

建議選用「Unload Entire Structure」可得較可信的結果

除建築物本身靜載重外
另有設計靜載重 (Live Load)



定義 PUSHX

- 側推方向為 X 方向

質心點位編號

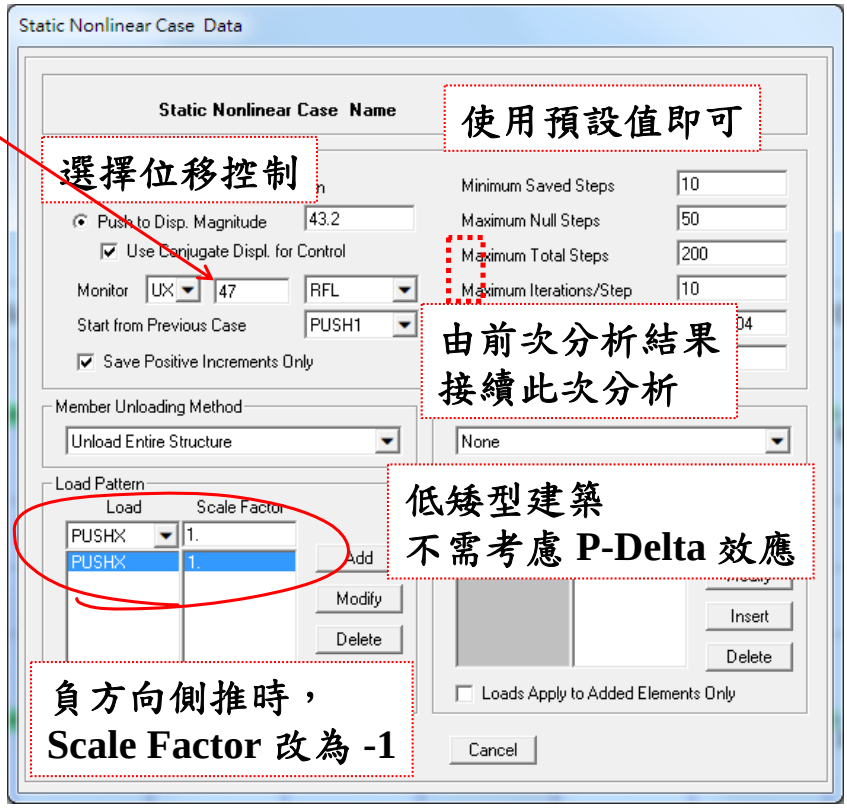
預設目標位移量為 0.04*總樓高

依分析方向選擇 UX

只儲存分析結果為正之步驟

建議選用「Unload Entire Structure」可得較可信的結果

Static Load Cases 新增之
地震力側向分佈 PUSHX



檢視容量曲線文字檔

hjxp_pd.txt

ETABS v8.5.4 File:X-DONE Units:Kgf-cm June 20, 2013 18:43 PAGE 1

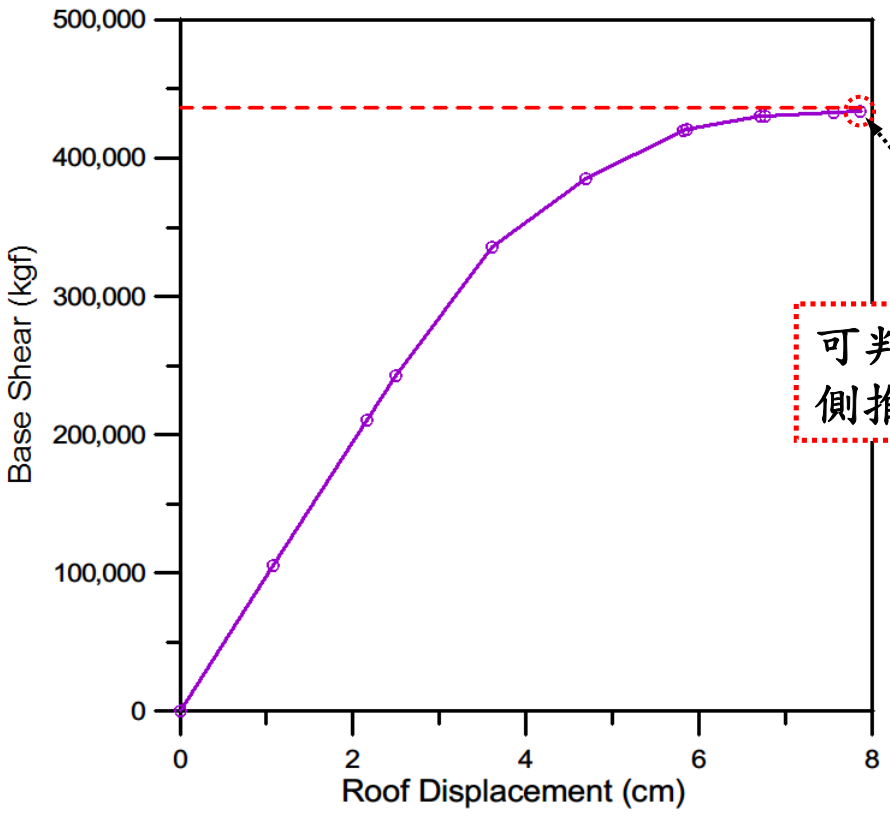
P U S H O V E R C U R V E

Pushover Case PUSHX

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0033	0.0000	848	13	0	0	0	0	0	0	861
1	1.0833	105387.7734	848	13	0	0	0	0	0	0	861
2	2.1633	210775.5469	847	14	0	0	0	0	0	0	861
3	2.4890	242557.0781	783	78	0	0	0	0	0	0	861
4	3.6015	335524.5313	728	113	0	0	0	20	0	0	861
5	4.6871	385255.0313	692	120	0	0	0	49	0	0	861
6	5.8165	419666.8750	685	126	0	0	0	50	0	0	861
7	5.8658	420679.5313	677	96	0	0	0	88	0	0	861
8	6.7100	430116.5625	677	88	0	0	0	96	0	0	861
9	6.7562	430414.2500	674	80	0	0	0	107	0	0	861
10	7.5619	433073.1250	672	82	0	0	0	104	3	0	861
11	7.8653	433697.0000	672	82	0	0	0	104	1	2	861

屋頂位移 基底剪力

容量曲線之檢核



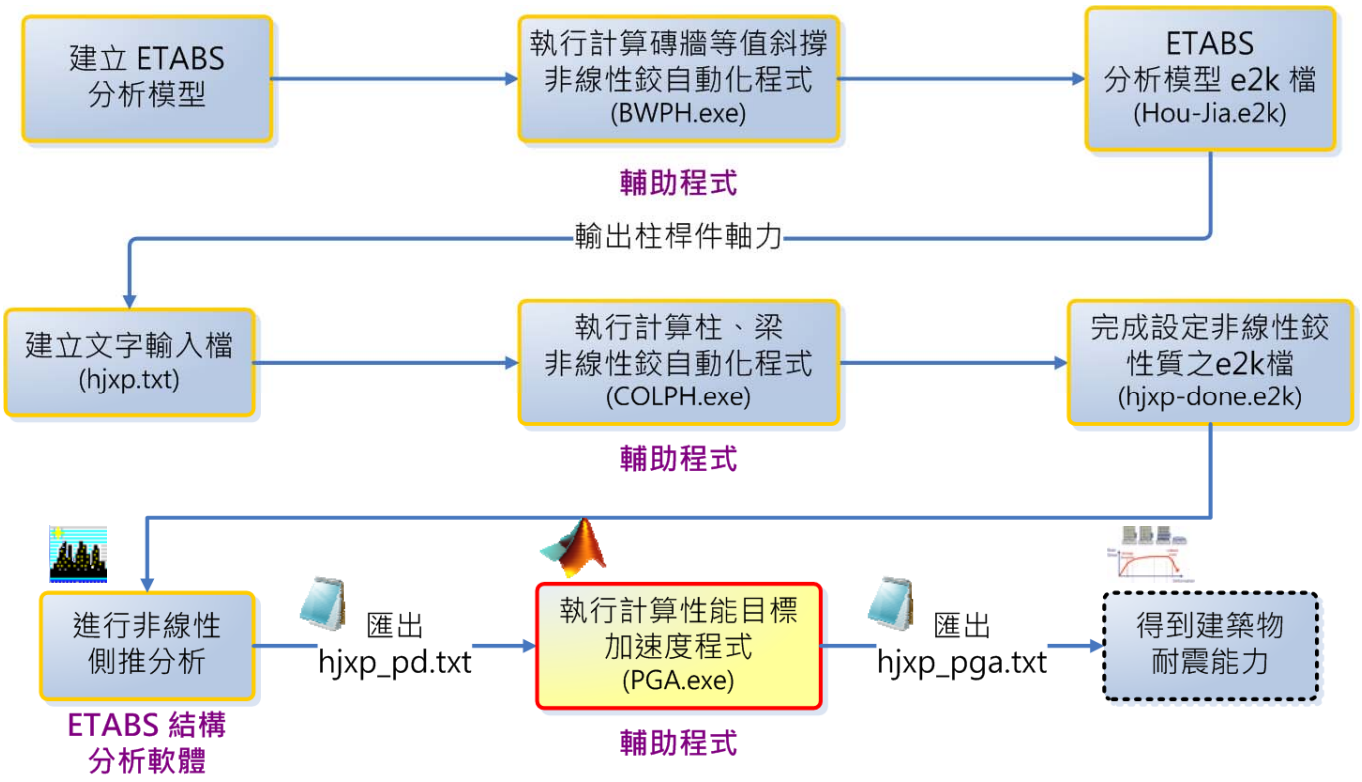
上限值：436401.8 kgf

分析值：433697 kgf

可判定已得最大基底剪力，側推分析結果應屬合理

性能曲線之分析

側推分析流程



自動計算性能目標地表加速度程式 (PGA.exe)

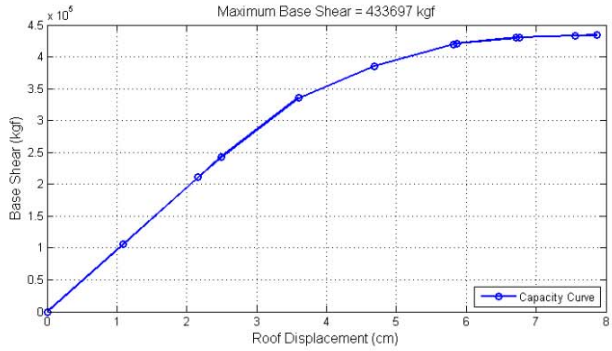
- 請輸入阻尼修正係數 (既有校舍建築 k 可設為 0.33)：**0.33 or 1/3**
- 請輸入輔助程式共用輸入檔檔名 (*.txt)：**hjxp**
- 請選擇要使用 [1]自行定義 或 [2]ETABS 定義 或 [3]MIDAS 定義之 P-D 曲線檔：**2**
- 請輸入 ETABS 定義之 P-D 曲線檔檔名 (*.txt)：**hjxp_pd**
- 請輸入完成性能目標地表加速度計算之文字檔檔名 (*.txt)：**hjxp_pga**

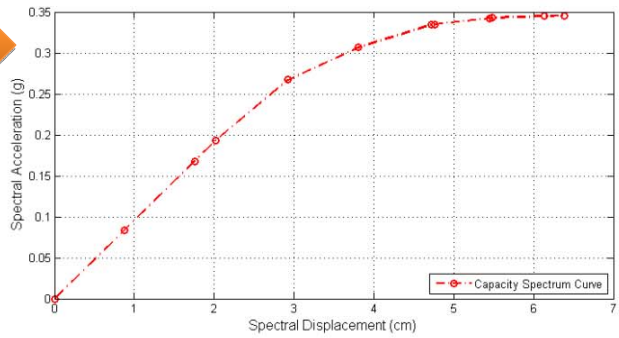
容量曲線轉換為性能曲線

容量曲線

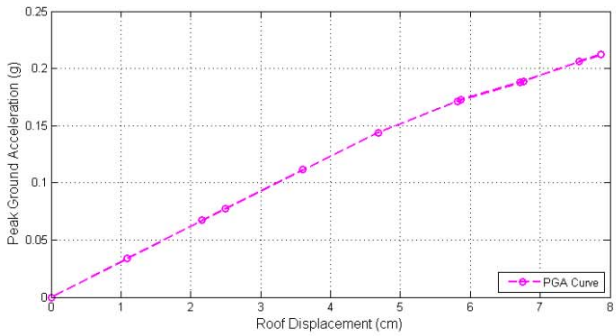
$$S_a = \frac{V}{\alpha_1 W} \quad S_d = \frac{\Delta_{roof}}{PF_1}$$

容量震譜

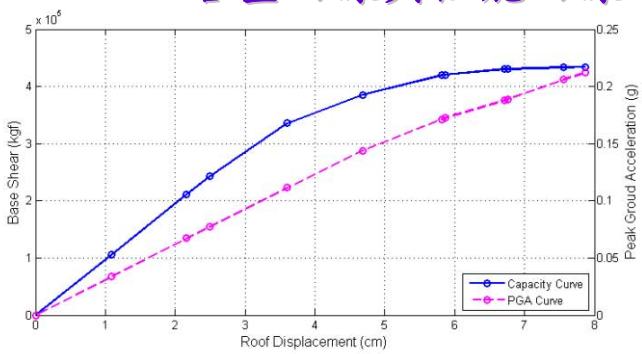




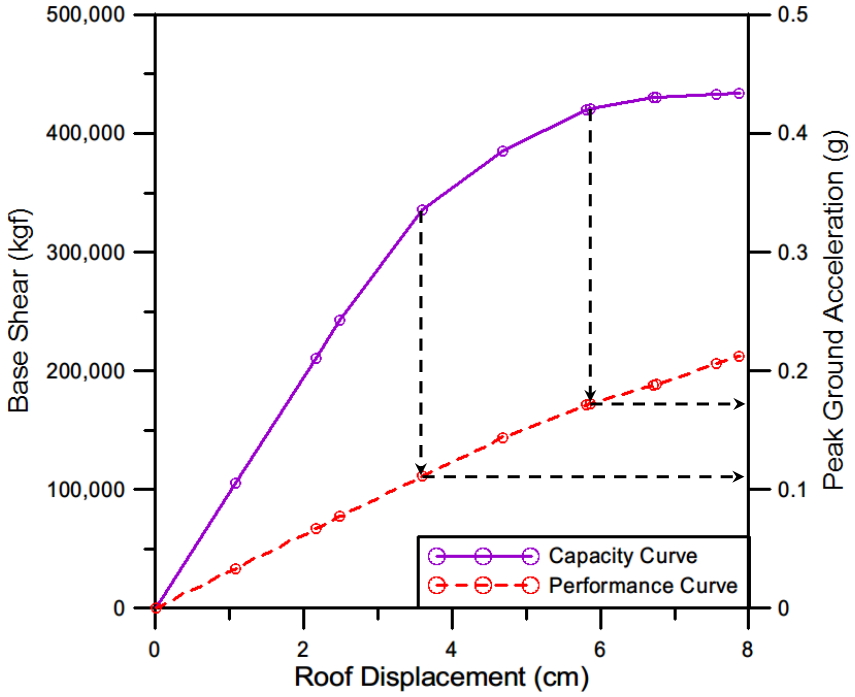
性能曲線



容量曲線與性能曲線



容量曲線與性能曲線



- 容量曲線上每一點均可為性能點
- 由使用需求 (一般用途或緊急避難用途) 決定性能點
- 不同性能點對應不同地表加速度

性能目標地表加速度之判定

性能目標判定準則

	強度準則	位移準則	軸力破壞準則
一般用途校舍	V_{max}	2.0% *Inter Story Drift*	任一豎向構材發生軸力破壞
緊急避難用途校舍	$0.8V_{max}$	1.0% *Inter Story Drift*	任一豎向構材發生軸力破壞

性能目標判定準則：強度準則

hjxp_pd.txt

ETABS v8.5.4 File:X-DONE Units:Kgf-cm June 20, 2013 18:43 PAG

P U S H O V E R C U R V E

Pushover Case PUSHX

Step	Displacement	Base Force	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	TOTAL
0	0.0033	0.0000	848	13	0	0	0	0	0	0	861
1	1.0833	105387.7734	848	13	0	0	0	0	0	0	861
2	2.1633	210775.5469	847	14	0	0	0	0	0	0	861
3	2.4890	242557.0781	783	78	0	0	0	0	0	0	861
4	3.6015	335524.5313	728	113	0	0	0	20	0	0	861
5	4.6871	385255.0313	692	120	0	0	0	49	0	0	861
6	5.8165	419666.8750	685	126	0	0	0	50	0	0	861
7	5.8658	420679.5313	677	96	0	0	0	88	0	0	861
8	6.7100	430116.5625	677	88	0	0	0	96	0	0	861
9	6.7562	430414.2500	674	80	0	0	0	107	0	0	861
10	7.5619	433073.1250	672	82	0	0	0	104	3	0	861
11	7.8653	433697.0000	672	82	0	0	0	104	1	2	861

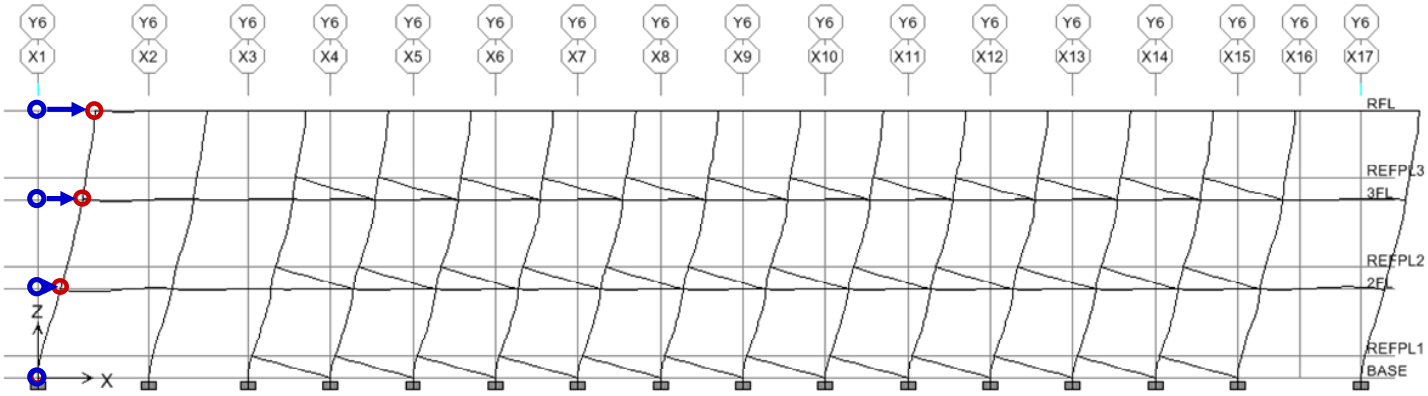
檢查最大基底剪力
發生於側推過程第幾步

發生於側推過程之第 11 步

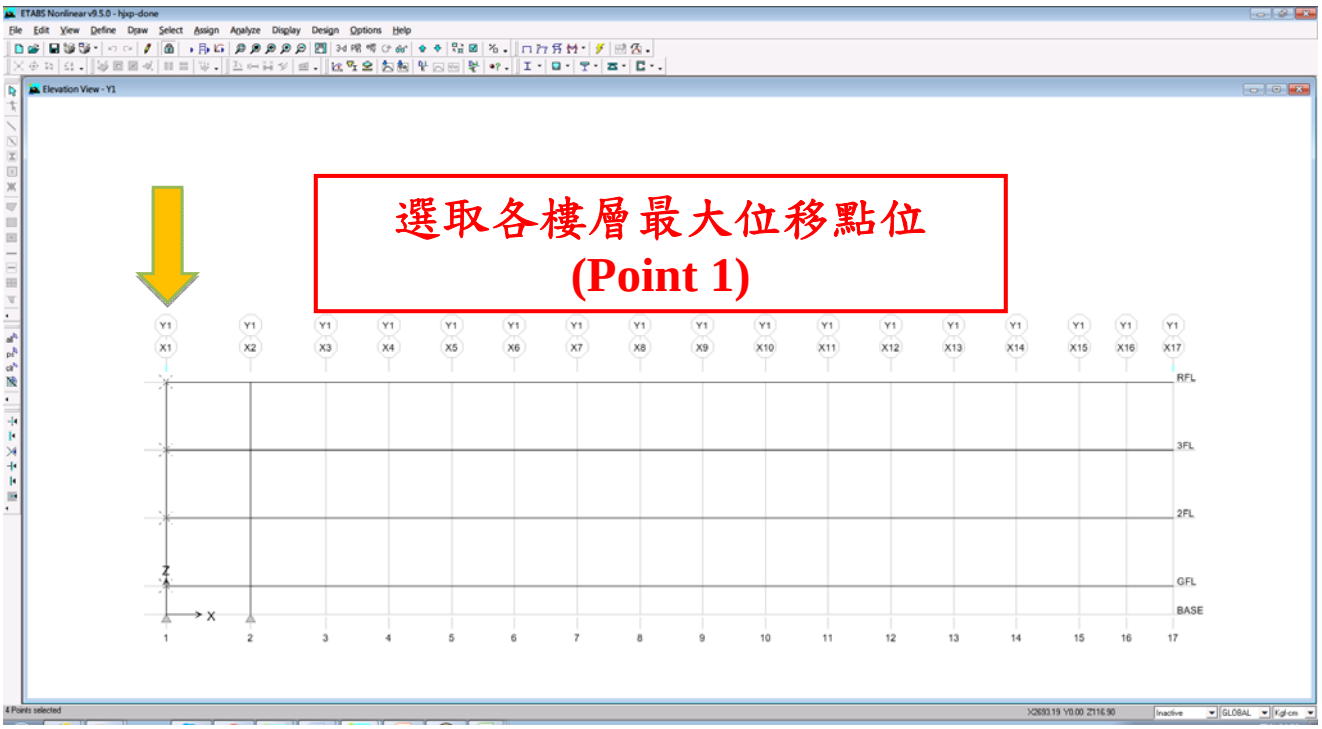
性能目標判定準則：位移準則

- 依不同使用需求限制層間位移比 (1% or 2% or ...)
- 計算每根柱之層間位移比 → 最大位移點位？

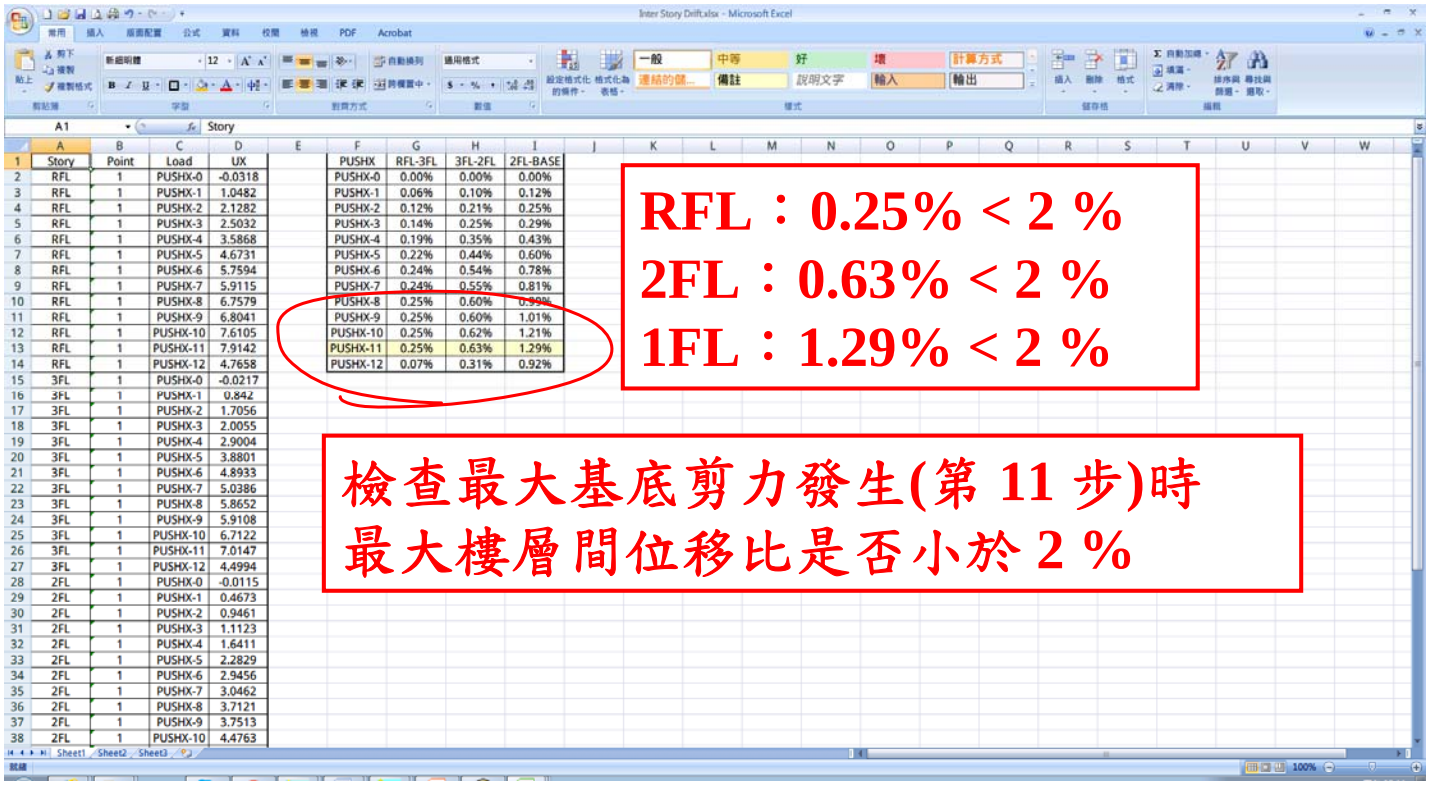
計算層間位移比



性能目標判定準則：位移準則



性能目標判定準則：位移準則



Story	Point	Load	UX
RFL	1	PUSHX-0	-0.0318
RFL	1	PUSHX-1	1.0482
RFL	1	PUSHX-2	2.1282
RFL	1	PUSHX-3	2.5032
RFL	1	PUSHX-4	3.5868
RFL	1	PUSHX-5	4.6731
RFL	1	PUSHX-6	5.7594
RFL	1	PUSHX-7	5.9115
RFL	1	PUSHX-8	6.7579
RFL	1	PUSHX-9	6.8041
RFL	1	PUSHX-10	7.6105
RFL	1	PUSHX-11	7.9142
RFL	1	PUSHX-12	4.7658
3FL	1	PUSHX-0	-0.0217
3FL	1	PUSHX-1	0.842
3FL	1	PUSHX-2	1.7056
3FL	1	PUSHX-3	2.0055
3FL	1	PUSHX-4	2.9004
3FL	1	PUSHX-5	3.8801
3FL	1	PUSHX-6	4.8933
3FL	1	PUSHX-7	5.0386
3FL	1	PUSHX-8	5.8652
3FL	1	PUSHX-9	5.9108
3FL	1	PUSHX-10	6.7122
3FL	1	PUSHX-11	7.0147
3FL	1	PUSHX-12	4.4994
2FL	1	PUSHX-0	-0.0115
2FL	1	PUSHX-1	0.4673
2FL	1	PUSHX-2	0.9461
2FL	1	PUSHX-3	1.1123
2FL	1	PUSHX-4	1.6411
2FL	1	PUSHX-5	2.2829
2FL	1	PUSHX-6	2.9456
2FL	1	PUSHX-7	3.0462
2FL	1	PUSHX-8	3.7121
2FL	1	PUSHX-9	3.7513
2FL	1	PUSHX-10	4.4763

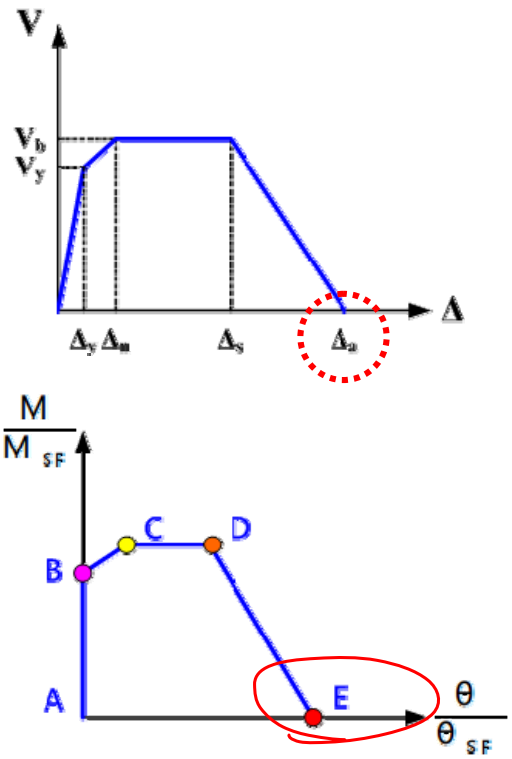
PUSHX	RFL-3FL	3FL-2FL	2FL-BASE
PUSHX-0	0.00%	0.00%	0.00%
PUSHX-1	0.06%	0.10%	0.12%
PUSHX-2	0.12%	0.21%	0.25%
PUSHX-3	0.14%	0.25%	0.29%
PUSHX-4	0.19%	0.35%	0.43%
PUSHX-5	0.22%	0.44%	0.60%
PUSHX-6	0.24%	0.54%	0.78%
PUSHX-7	0.24%	0.55%	0.81%
PUSHX-8	0.25%	0.60%	0.99%
PUSHX-9	0.25%	0.60%	1.01%
PUSHX-10	0.25%	0.62%	1.21%
PUSHX-11	0.25%	0.63%	1.29%
PUSHX-12	0.07%	0.31%	0.92%

RFL：0.25% < 2 %
2FL：0.63% < 2 %
1FL：1.29% < 2 %

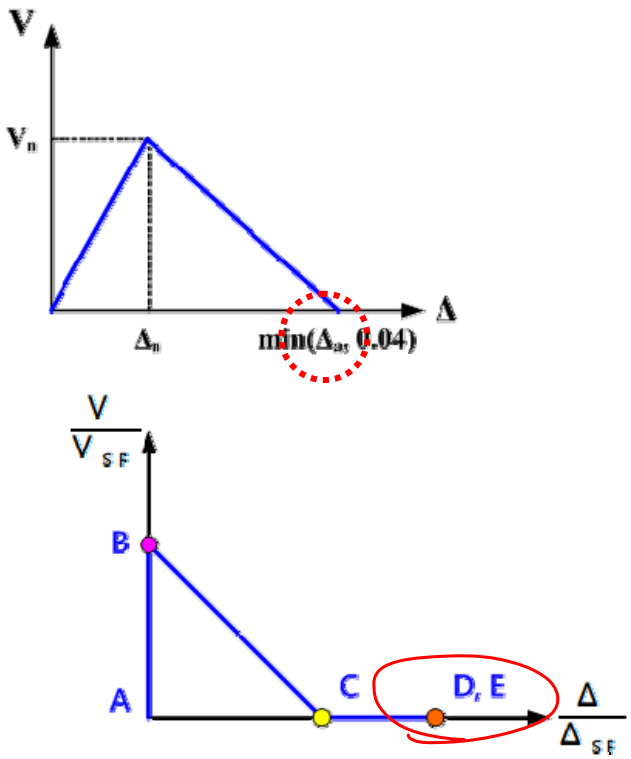
檢查最大基底剪力發生(第 11 步)時
最大樓層間位移比是否小於 2 %

性能目標判定準則：軸力破壞準則

彎矩非線性鉸

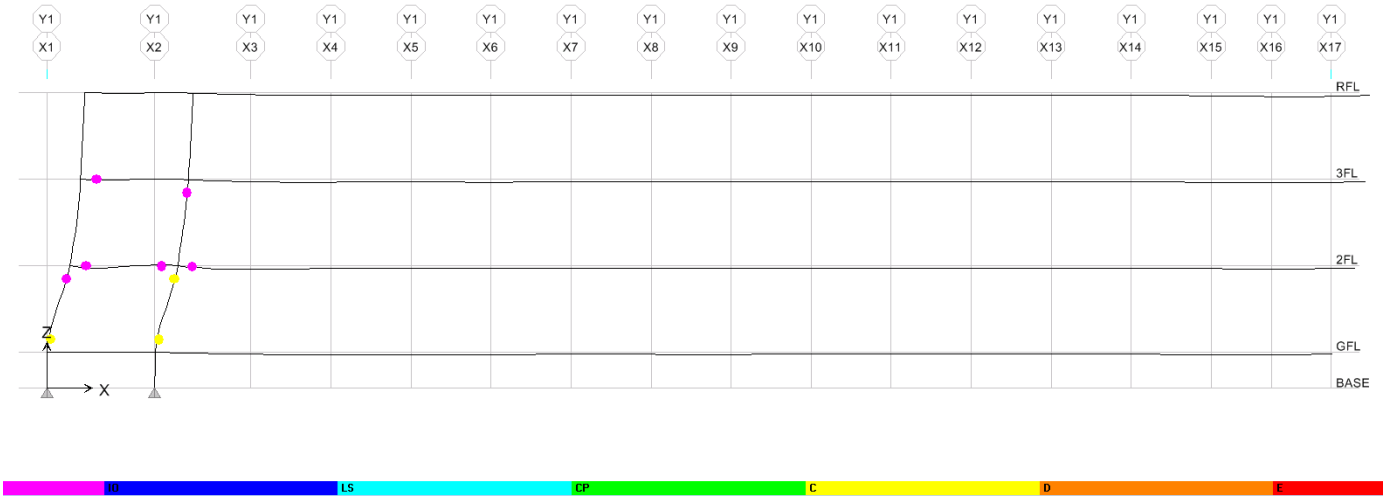


剪力非線性鉸



性能目標判定準則：軸力破壞準則

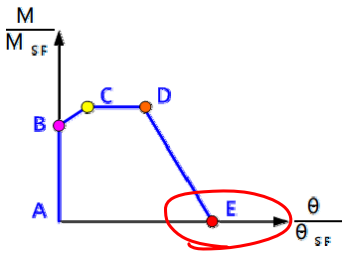
- **Y1-Frame (第 11 步)**



性能目標判定準則：軸力破壞準則

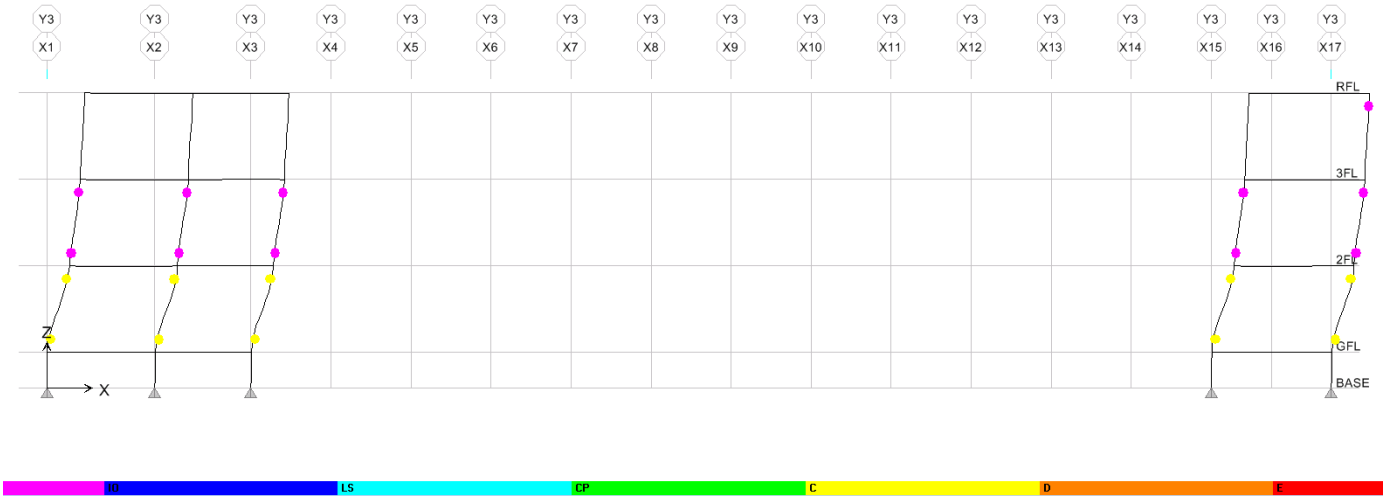
- **Y2-Frame (第 11 步)**

彎矩非線性鉸破壞模式未發展至 E 點 (紅色)



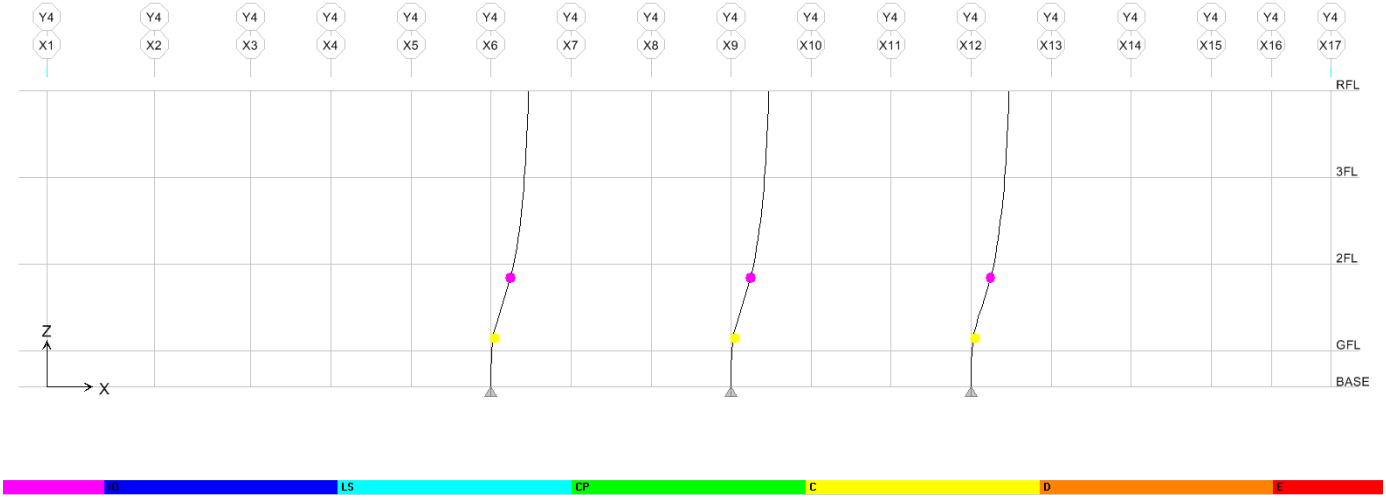
性能目標判定準則：軸力破壞準則

- **Y3-Frame (第 11 步)**



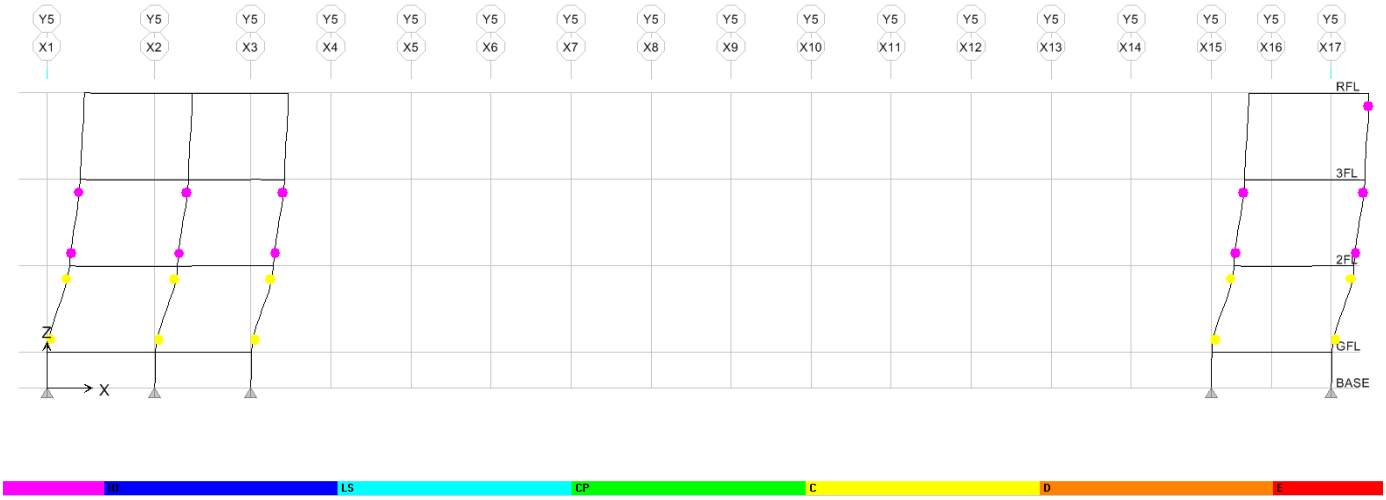
性能目標判定準則：軸力破壞準則

- **Y4-Frame (第 11 步)**



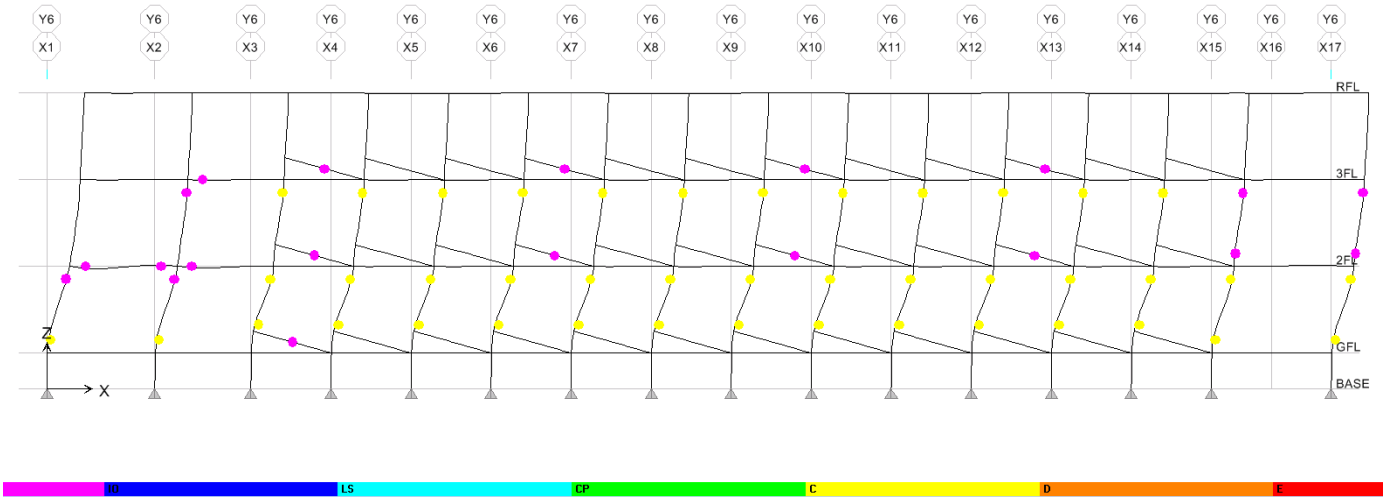
性能目標判定準則：軸力破壞準則

- **Y5-Frame (第 11 步)**



性能目標判定準則：軸力破壞準則

- **Y6-Frame (第 11 步)**



性能目標判定準則

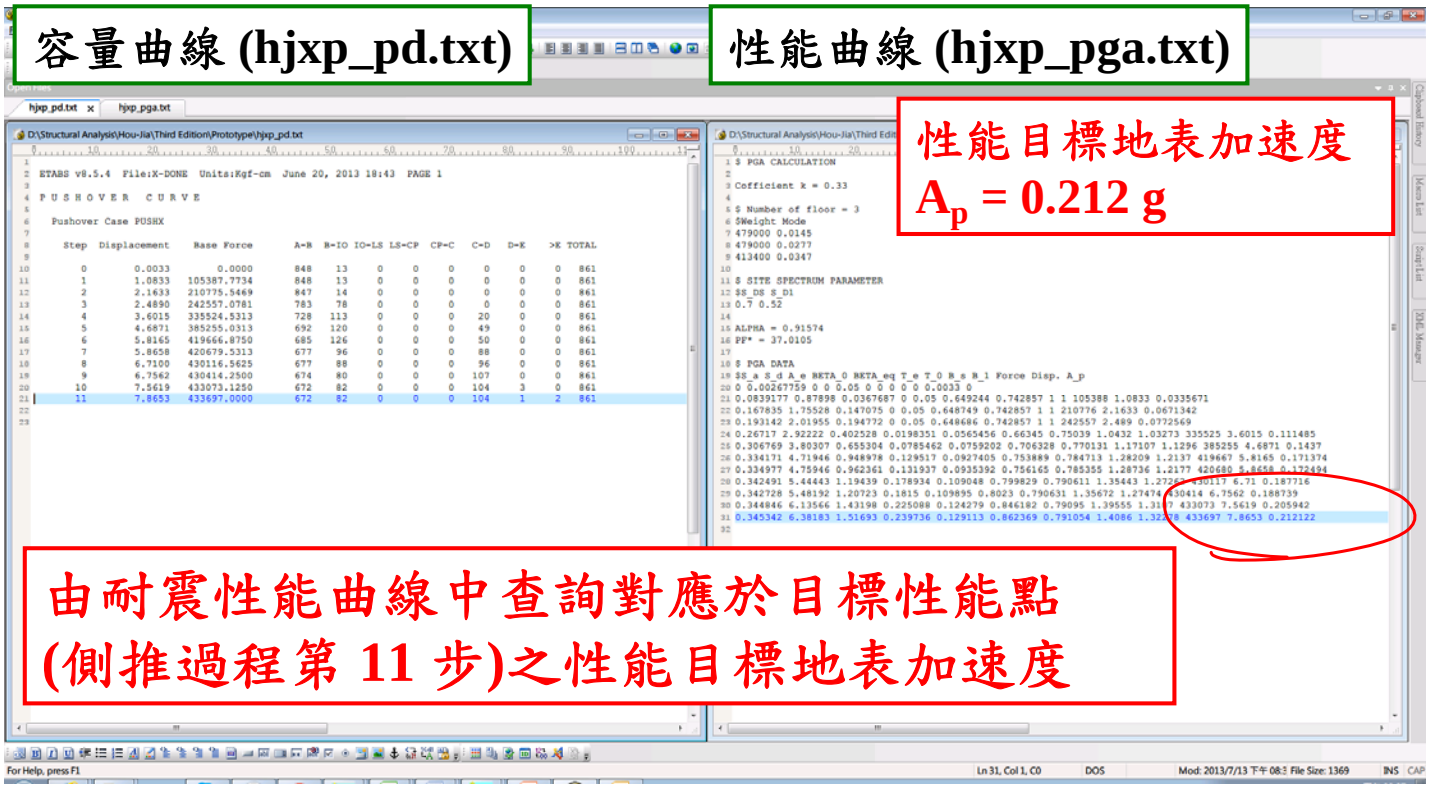
	強度準則	位移準則	軸力破壞準則
一般用途校舍	V_{max} (第 11 步)	*Inter Story Drift* (1.29 %)	無

由強度準則決定性能目標地表加速度 A_p

性能目標耐震性能曲線

容量曲線 (hjxp_pd.txt)

性能曲線 (hjxp_pga.txt)



性能目標地表加速度

475 年回歸期設計地表加速度 $A_T = 0.4S_{DS} = 0.28$ g

	強度準則	位移準則	軸力破壞準則
一般校舍	$V_{max} = 433.697$ tf $A_p = 0.212$ g	*Inter Story Drift* RFL：0.25 % < 2 % 2FL：0.63 % < 2 % 1FL：1.29 % < 2 %	無

Capacity-**D**emand **R**atio = A_p / A_T

= 0.212 g / 0.28 g = 0.757 < 1

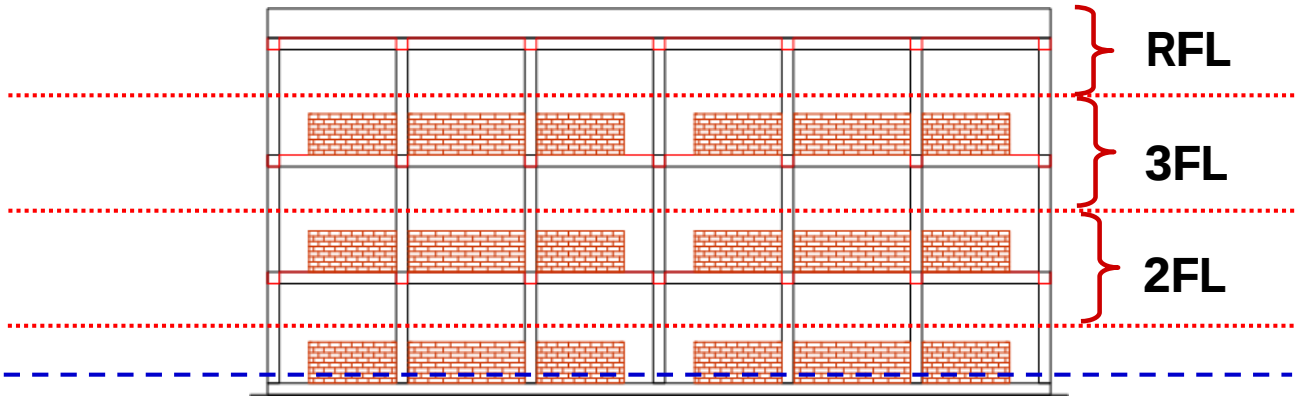
→ 該棟校舍需進行耐震補強

分析結果檢核

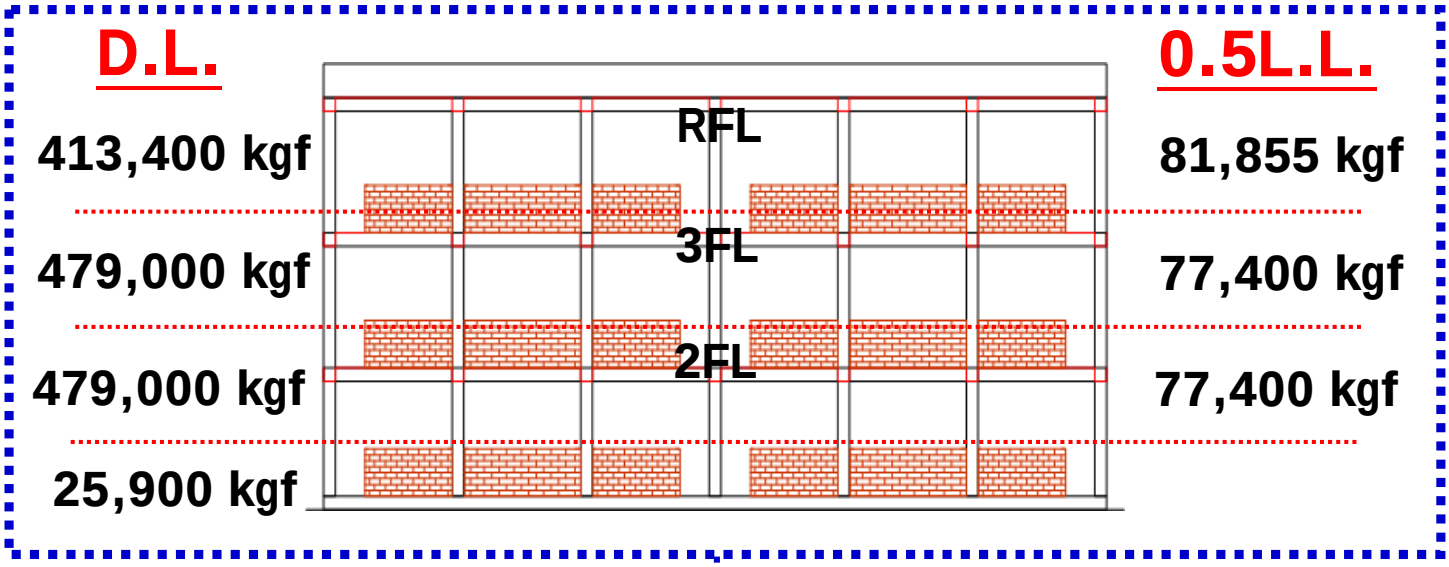
1.柱軸力檢核
2.非線性鉸位置檢核
3.非線性鉸參數檢核
4.破壞模式檢核
5.極限基底剪力檢核
6.性能目標地表加速度檢核

1.柱軸力檢核

1.柱軸力檢核：以各樓層**構件體積和**×**混凝土單位重**估算各樓層**靜重**，加上**二分之一活載**，再加上**底層之半柱重量**，應與結構靜力分析所得之**柱底軸重和**相近。



1.柱軸力檢核



D.L.+0.5L.L.
=1,633,955 kgf

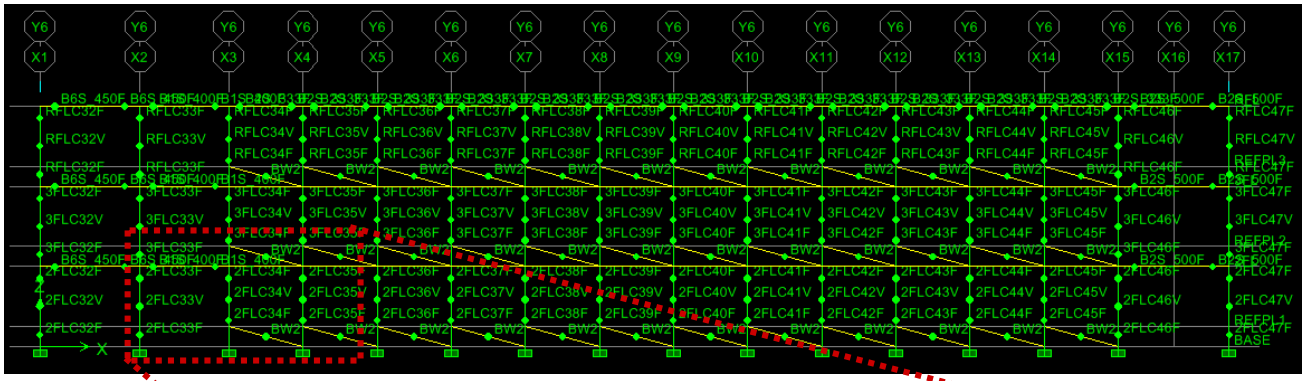
1.柱軸力檢核

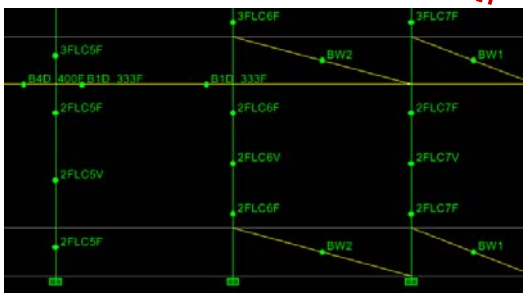
$Story	Column	Loc	P
2FL	C1	0	-13202.9
2FL	C2	0	-25931.9
2FL	C3	0	-18915.3
2FL	C4	0	-33346
2FL	C5	0	-43354.1
2FL	C6	0	-63891.7
2FL	C7	0	-64307.5
2FL	C8	0	-51439.3
2FL	C9	0	-64445.9
2FL	C10	0	-64530.4
2FL	C11	0	-51928.7
2FL	C12	0	-64976.5
2FL	C13	0	-65031.1
2FL	C14	0	-52203.6
2FL	C40	0	-24894.3
2FL	C41	0	-33207.5
2FL	C42	0	-33089.3
2FL	C43	0	-24552.1
2FL	C44	0	-32784.2
2FL	C45	0	-31638
2FL	C46	0	-20803.3
2FL	C47	0	-10648.8

ETABS分析柱底軸力和
1,580,468 kgf

D.L.+0.5L.L.
=1,633,955 kgf

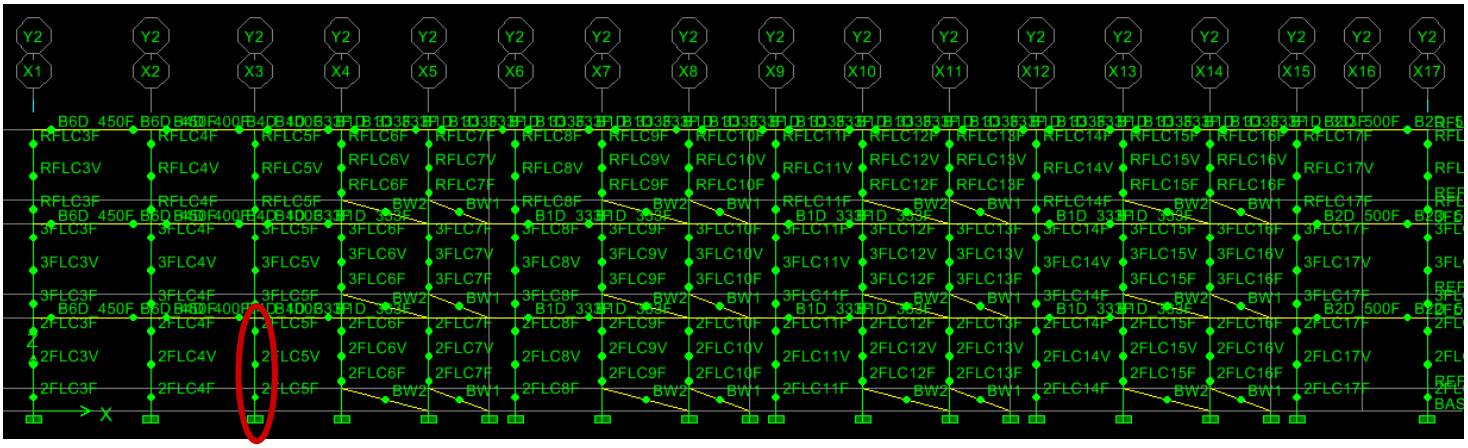
2.非線性鉸位置檢核





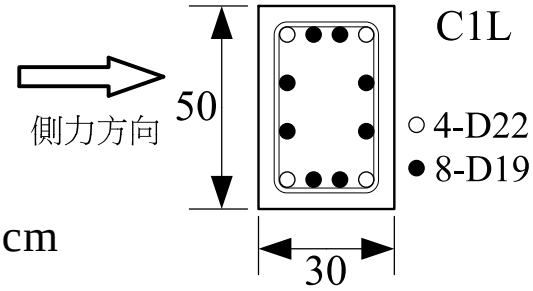
3.非線性鉸參數檢核

取一構件之斷面、材料及軸力，手算檢核非線性鉸數是否與執行Colph.exe、Bwph.exe之結果相同。



3.非線性鉸參數檢核

例：**2FLC5F(M3非線性鉸)**



柱承受軸力 $P = 43{,}320$ kgf

柱斷面彎矩強度 $M_n = 1.35 \times 10^6$ kgf-cm

有效柱高 $H = 300$ cm

$$A_{st} = 2 \times 0.713 = 1.426\,\text{cm}^2$$

$$I = \frac{bh^3}{12} = \frac{50 \times 30^3}{12} = 1.125 \times 10^5\ \text{cm}^4$$

3.非線性鉸參數檢核

$$V_b = \frac{2M_n}{H} = \frac{2\times1.35\times10^6}{300} = 9000\,\text{kgf}$$

$$k = \frac{12(EI)_c}{H^3} = \frac{12(0.7\times15000\sqrt{160})\times1.125\times10^5}{300^3} = 6640$$

$$\Delta_y = \frac{V_b}{k} = \frac{9000}{6640} = 1.36\,\text{cm}$$

$$\nu_m = \frac{V_b}{bd} = \frac{9000}{50\times24} = 7.503\,\text{kgf}/\text{cm}^2$$

柱箍筋量比：

$$\rho'' = \frac{A_{st}}{b\times s} = \frac{1.426}{50\times25} = 0.001141$$

3.非線性鉸參數檢核

由式(4.1) $$\frac{\Delta_s}{H} = \frac{3}{100} + 4\rho'' - \frac{1}{133}\frac{\nu_m}{\sqrt{f_c'}} - \frac{1}{40}\frac{P}{A_g f_c'} = 0.026 \geq \frac{1}{100}$$

$\therefore$ D$_s$ = 0.026? 300 7.8 cm

由式(4.2) $$\frac{\Delta_a}{H} = \left(\frac{4}{100}\right)\frac{1+\tan^2\theta}{\tan\theta + P\left(\dfrac{s}{A_h f_{yh} d_c \tan\theta}\right)} = 0.027$$

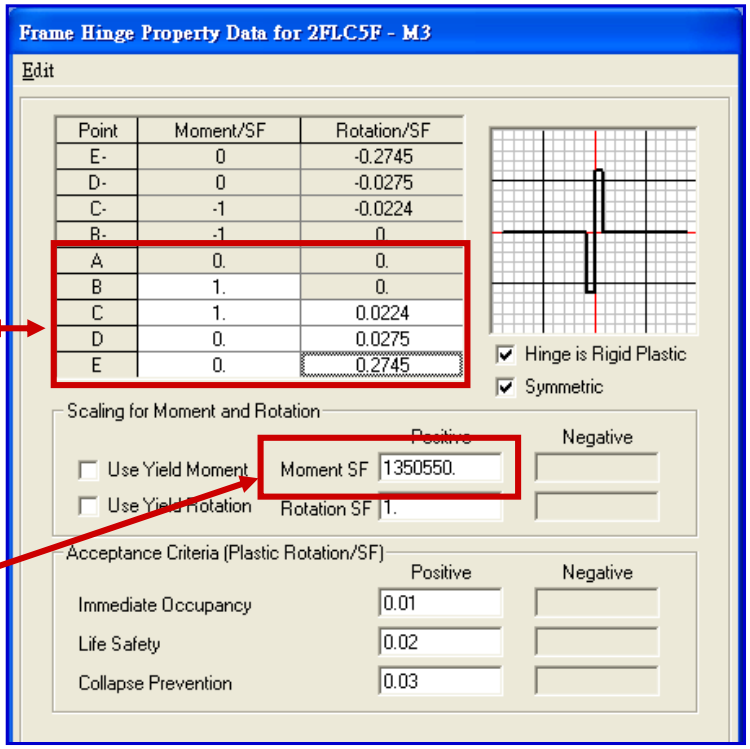
$$\therefore\ a = \frac{\Delta_s - \Delta_y}{H} = 0.026 - 0.0045 = 0.022$$

$$b = \max\left(\frac{\Delta_a}{H}, \frac{\Delta_s}{H}\right) = 0.027$$

Points	Moment/SF	Rotation/SF
A	0	0
B	1	0
C	1	0.022
D	0	0.027
E	0	0.27

3.非線性鉸參數檢核

Points	Moment/SF	Rotation/SF
A	0	0
B	1	0
C	1	0.022
D	0	0.027
E	0	0.27

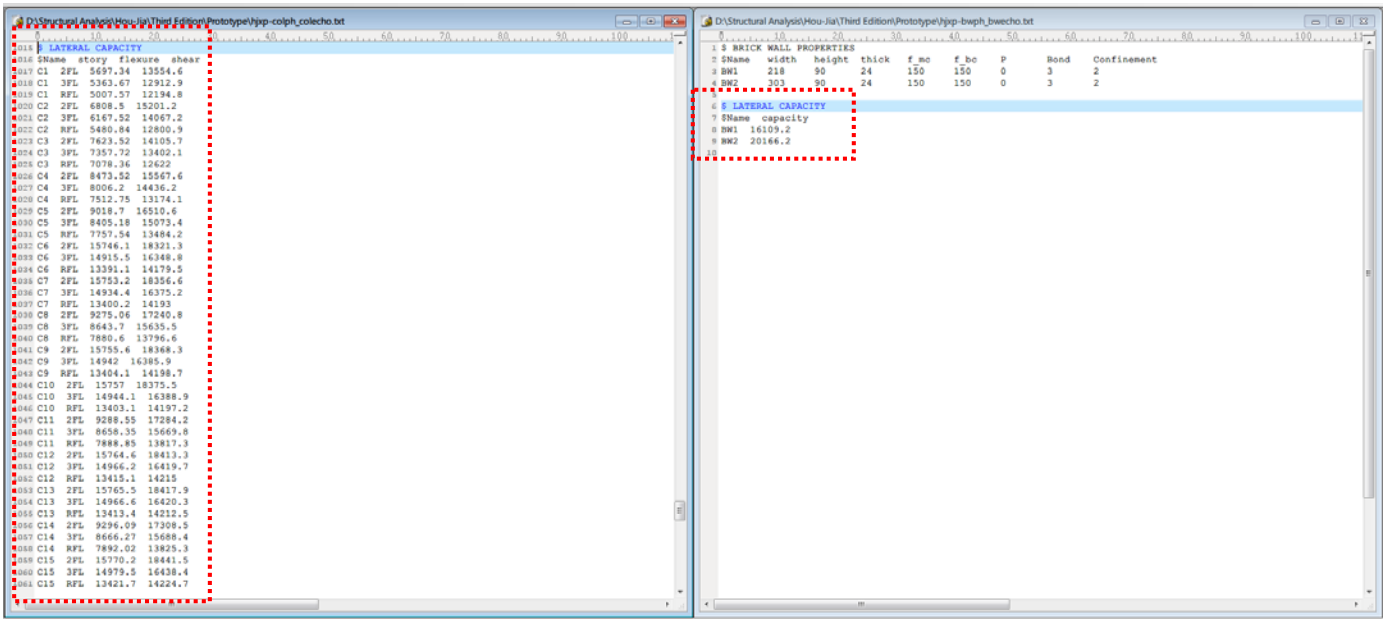


Moment SF

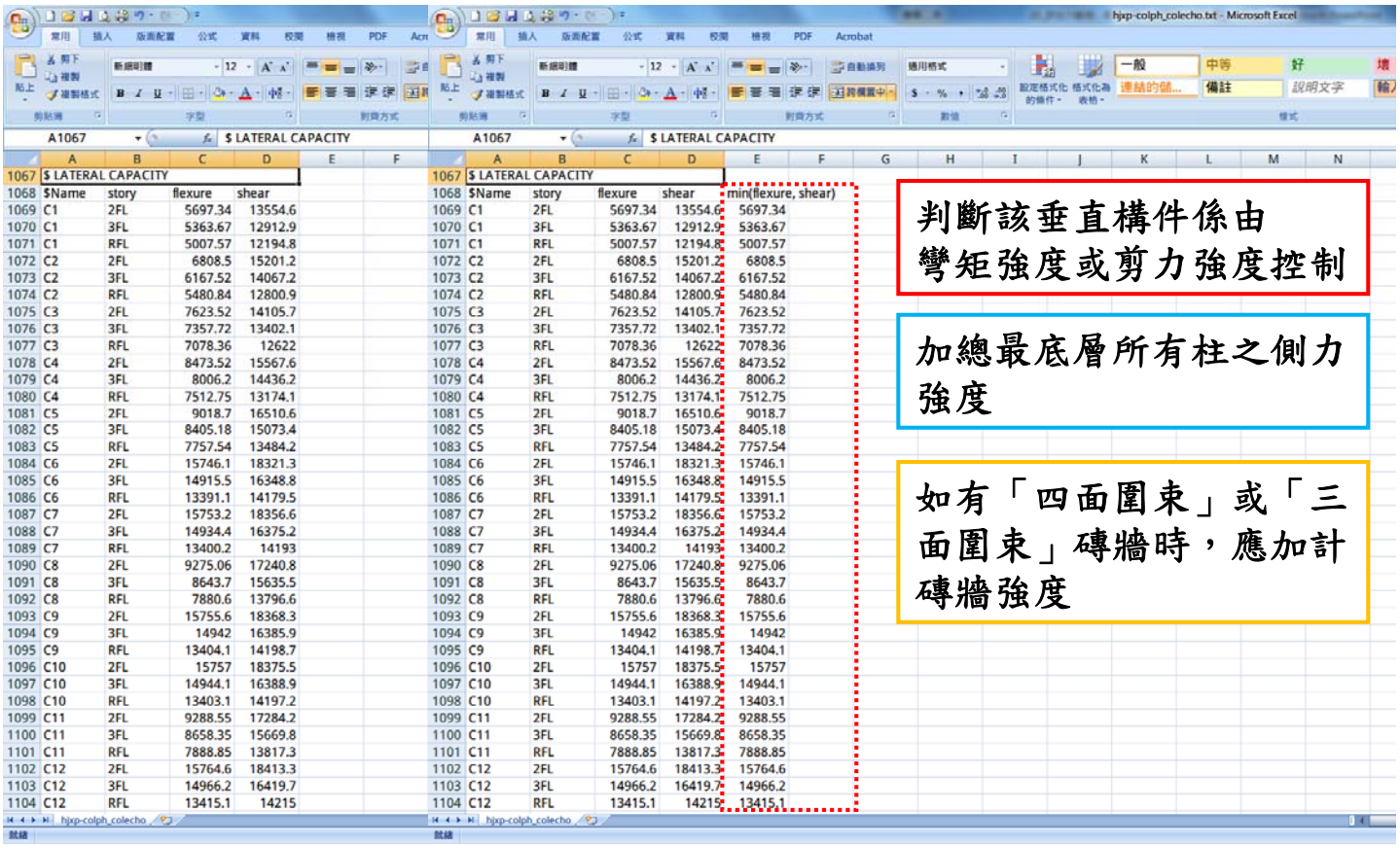
$$M_n = 1.35 \times 10^6 \text{ kgf-cm}$$

4.檢核側力強度是否合理

- 執行自動計算 RC 梁、柱 (COLPH.exe) 及磚牆等值斜撐 (BWPH.exe) 非線性鉸程式後出現 colecho 文字檔可供檢核之用



4.垂直構件可抵抗之側力強度



	$Name	story	flexure	shear	min(flexure, shear)
1067	$ LATERAL CAPACITY				
1068	$Name	story	flexure	shear	min(flexure, shear)
1069	C1	2FL	5697.34	13554.6	5697.34
1070	C1	3FL	5363.67	12912.9	5363.67
1071	C1	RFL	5007.57	12194.8	5007.57
1072	C2	2FL	6808.5	15201.2	6808.5
1073	C2	3FL	6167.52	14067.2	6167.52
1074	C2	RFL	5480.84	12800.9	5480.84
1075	C3	2FL	7623.52	14105.7	7623.52
1076	C3	3FL	7357.72	13402.1	7357.72
1077	C3	RFL	7078.36	12622	7078.36
1078	C4	2FL	8473.52	15567.6	8473.52
1079	C4	3FL	8006.2	14436.2	8006.2
1080	C4	RFL	7512.75	13174.1	7512.75
1081	C5	2FL	9018.7	16510.6	9018.7
1082	C5	3FL	8405.18	15073.4	8405.18
1083	C5	RFL	7757.54	13484.2	7757.54
1084	C6	2FL	15746.1	18321.3	15746.1
1085	C6	3FL	14915.5	16348.8	14915.5
1086	C6	RFL	13391.1	14179.5	13391.1
1087	C7	2FL	15753.2	18356.6	15753.2
1088	C7	3FL	14934.4	16375.2	14934.4
1089	C7	RFL	13400.2	14193	13400.2
1090	C8	2FL	9275.06	17240.8	9275.06
1091	C8	3FL	8643.7	15635.5	8643.7
1092	C8	RFL	7880.6	13796.6	7880.6
1093	C9	2FL	15755.6	18368.3	15755.6
1094	C9	3FL	14942	16385.9	14942
1095	C9	RFL	13404.1	14198.7	13404.1
1096	C10	2FL	15757	18375.5	15757
1097	C10	3FL	14944.1	16388.9	14944.1
1098	C10	RFL	13403.1	14197.2	13403.1
1099	C11	2FL	9288.55	17284.2	9288.55
1100	C11	3FL	8658.35	15669.8	8658.35
1101	C11	RFL	7888.85	13817.3	7888.85
1102	C12	2FL	15764.6	18413.3	15764.6
1103	C12	3FL	14966.2	16419.7	14966.2
1104	C12	RFL	13415.1	14215	13415.1

判斷該垂直構件係由彎矩強度或剪力強度控制

加總最底層所有柱之側力強度

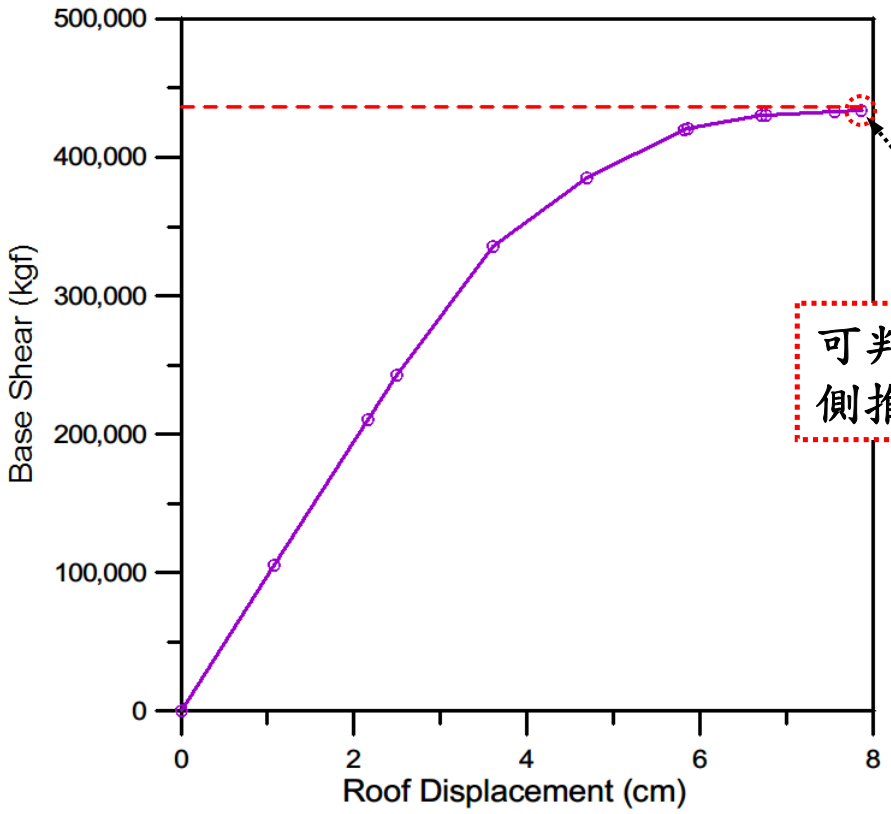
如有「四面圍束」或「三面圍束」磚牆時，應加計磚牆強度

4.最大側力強度之檢核

	撓曲強度	剪力強度	破壞模式	可抵抗側力強度
2FLC1	5697.34	13554.6	撓剪	5697.34
2FLC2	6808.5	15201.2	撓剪	6808.5
:	:	:	:	:
:	:	:	:	:
2FLC47	7644.14	13190.3	撓剪	7644.14
Σ 2FL Column Strength			436401.8 kgf	

V_{max} (ETABS) = 433697 kgf < 436401.8 kgf

4.最大側力強度之檢核



上限值：436401.8 kgf

分析值：433697 kgf

可判定已得最大基底剪力，側推分析結果應屬合理

結論

- 以側推分析建立建物之容量曲線，模擬基底剪力與屋頂位移在地震中反應之包絡線
- 容量震譜法轉換容量曲線，以建立性能曲線
- 依據校舍結構試驗，由允許損傷狀態決定性能目標
- 以性能曲線結合性能目標，決定性能目標地表加速度
- 比較性能目標地表加速度與475年設計地震等效地表加速度，判定建物耐震能力是否足夠