公路橋梁耐震能力評估與補強講習會

隔震評估與補強案例

報告人：洪曉慧

國家地震工程研究中心副研究員

2010/5/12

報告內容

- 橋梁簡介
- 橋梁現況耐震能力評估
- 橋梁隔震補強設計與評估
- 考量基礎彈簧之橋梁耐震評估與補強

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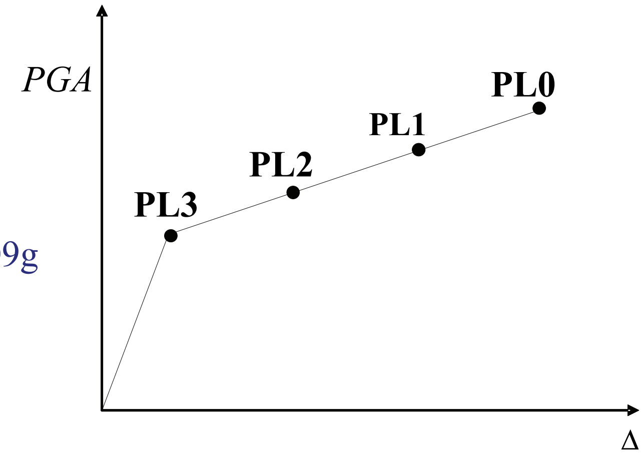
橋梁工址與性能目標

- 工址： 彰化縣 埔鹽鄉 第二類地盤 無斷層
- 工址參數： $S_S^D = 0.7$ $S_1^D = 0.4$ $F_a = 1.0$ $F_v = 1.4$
- 工址地震水平譜加速度係數：$S_{DS} = 0.7$ $S_{D1} = 0.56$
- 採用之設計規範版本： 76年版
- 性能目標：
  - 中度地震達 PL3
  - 設計地震達 PL1

設計地震 $Z = 0.4\ S_{DS} = 0.28g$

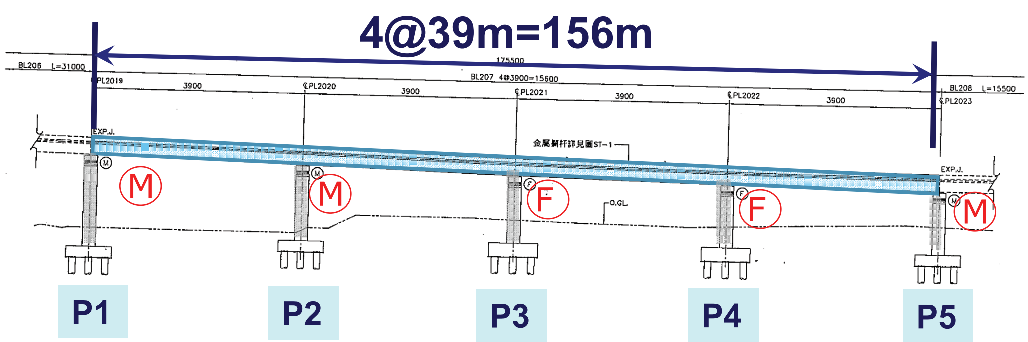
中度地震 $Z = 0.4S_{DS} / 3.25 \fallingdotseq 0.09g$

PL3 > 0.09 g
PL1 > 0.28 g



橋梁基本資料

- 四跨連續預力箱型梁橋
- 鋼筋混凝土單柱式橋墩



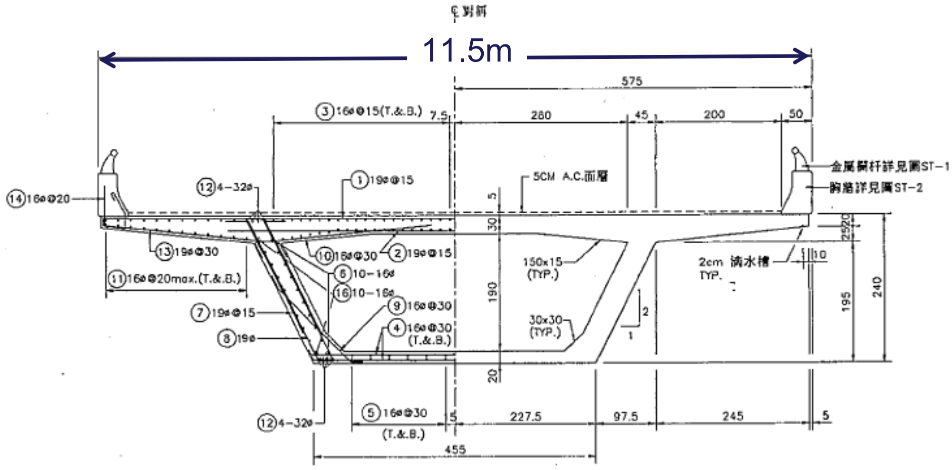
柱高 14.5m 13.6m 12.02m 11.19m 11.19m

混凝土強度:

上部結構：350kg/cm^2

下部結構： 280kg/cm^2

主梁斷面圖

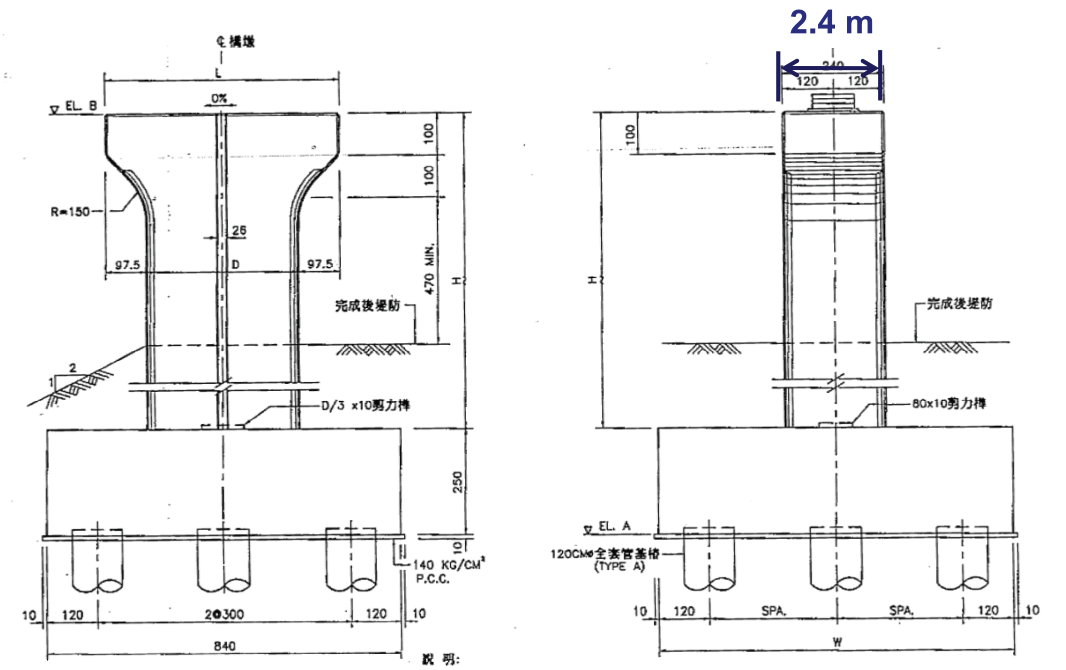


$A = 15.3238\ m^2$

$I_2 = 69.9671\ m^4$

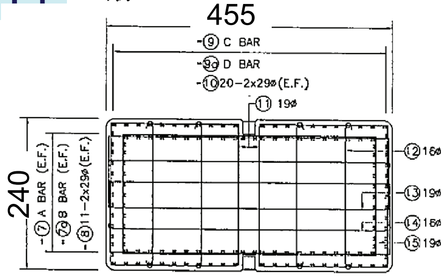
$I_3 = 7.7696 m^4$

橋墩立面圖

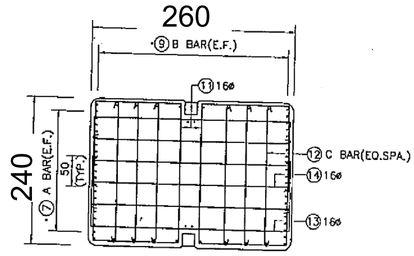


柱斷面配筋圖

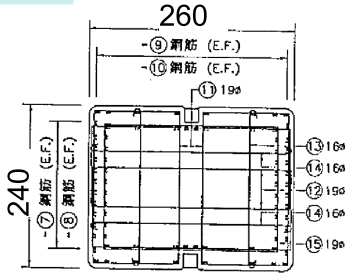
P1 主筋比: 0.021



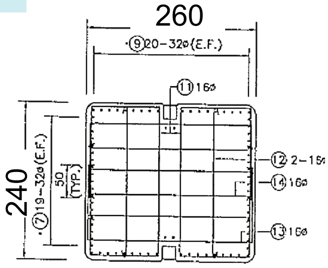
P2 主筋比: 0.013



P3,P4 主筋比: 0.033



P5 主筋比: 0.010



主筋強度　　4200kgf/cm^2

箍筋/繫筋強度　2800 kgf/cm^2。

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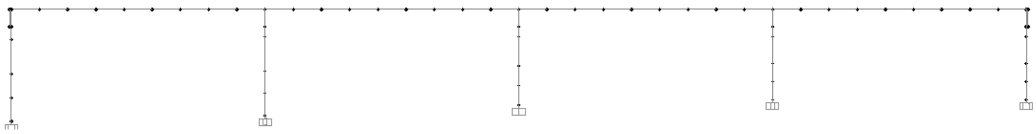
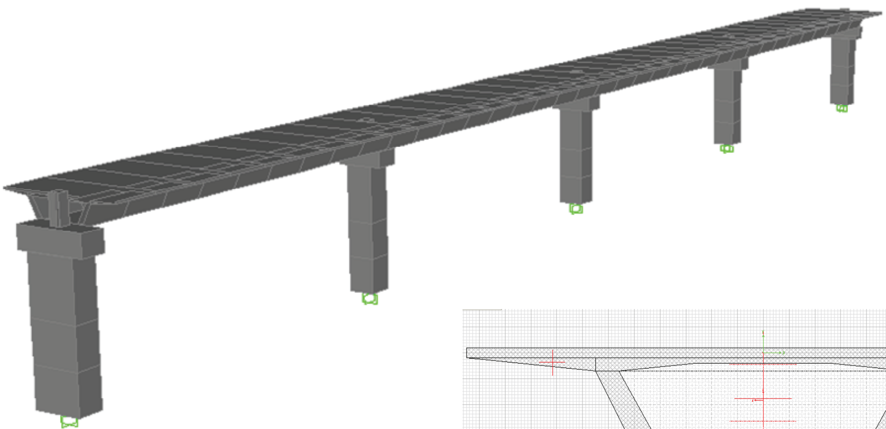
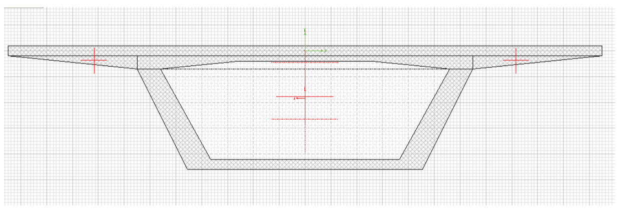
SAP2000N 分析模型 (1/2)







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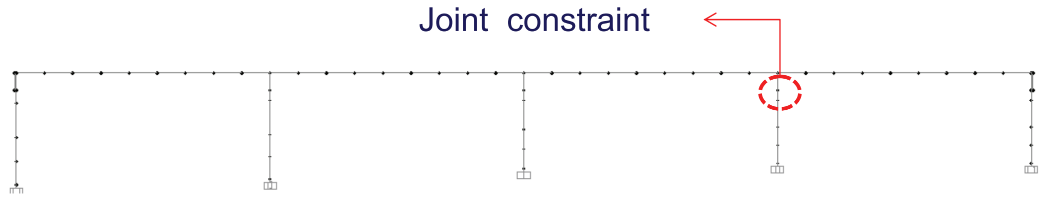
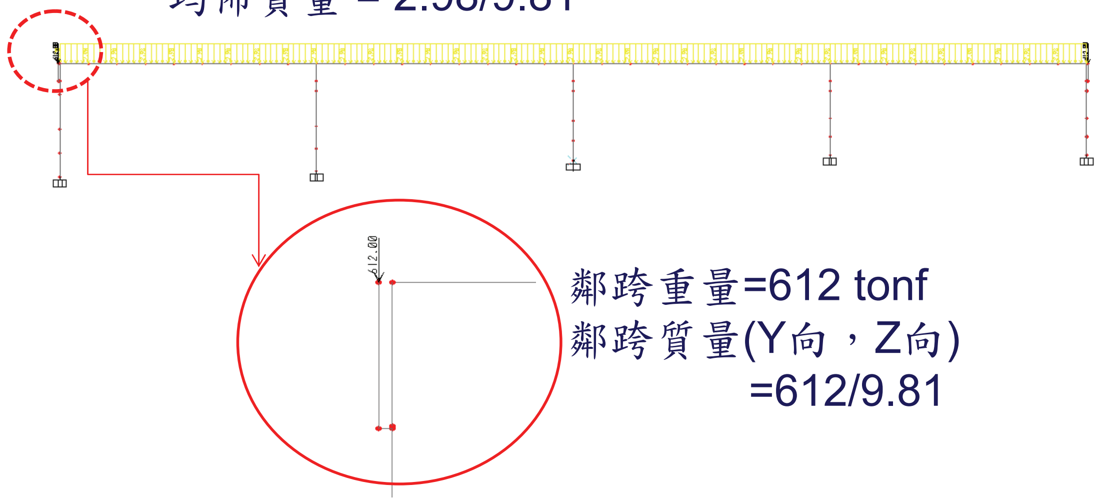
SAP2000N 分析模型 (2/2)



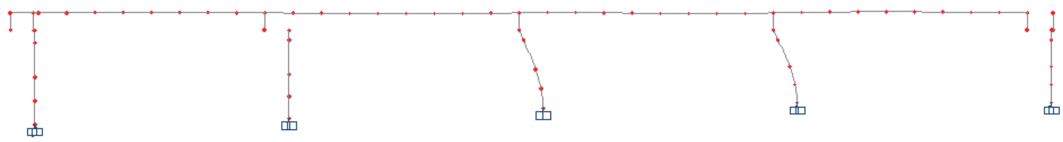
均佈載重 = 2.98 tonf/m
均佈質量 = 2.98/9.81



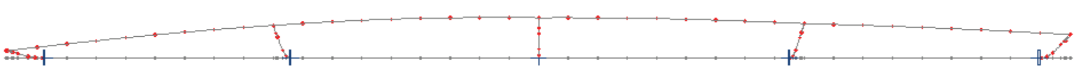
鄰跨重量=612 tonf
鄰跨質量(Y向，Z向)
=612/9.81

模態分析

- 行車向模態
- 模態質量參與係數 = 0.88
- Period = 0.956 sec



- 垂直行車向模態
- 模態質量參與係數 = 0.83
- Period = 0.819 sec



現況耐震能力評估

塑性鉸之設定

- 混凝土組成律：Kawashima 模式
- 鋼筋組成率:完全彈塑性模型

Input : *.SECT

hanbou.SECT - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

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$UnitKGF-CM

$ Section Definitions
$ Name  Type   Width   Height  Cover  Fc'          Fy           Fsy          SNo    Spacing EL(2)  EL(3)  Angle
$       RECT   (cm)    (cm)    (cm)   (kgf/cm^2)   (kgf/cm^2)   (kgf/cm^2)          (cm)    (cm)   (cm)   (deg.)
COLP1   RECT   455.00  240.00  5.00   280.00       4200.00      2800.00      #11    15.00   30.00  30.00  0
COLP2   RECT   260.00  240.00  5.00   280.00       4200.00      2800.00      #10    15.00   30.00  30.00  0
COLP3   RECT   260.00  240.00  5.00   280.00       4200.00      2800.00      #11    15.00   30.00  30.00  0
COLP4   RECT   260.00  240.00  5.00   280.00       4200.00      2800.00      #11    15.00   30.00  30.00  0
COLP5   RECT   260.00  240.00  5.00   280.00       4200.00      2800.00      #10    15.00   30.00  30.00  0


$ Steels Location
$ Name  SteelsLoc
COLP1   8.5(#10*48)14.5(#9*40)225.5(#9*40)231.5(#10*48)24(#10*4)40(#10*4)56(#10*4)72(#10*4)88(#10*4)104(#10*4)120(#10*4)136(#10*
COLP2   8.5(#11*20)231.5(#11*20)19.2(#11*2)30.4(#11*2)41.6(#11*2)52.8(#11*2)64(#11*2)75.2(#11*2)86.4(#11*2)97.6(#11*2)108.8(#11*
COLP3   8.5(#10*32)14.5(#10*24)225.5(#10*24)231.5(#10*32)25.4(#10*4)42.6(#10*4)59.8(#10*4)77(#10*4)94.2(#10*4)111.4(#10*4)128.6(
COLP4   8.5(#10*32)14.5(#10*24)225.5(#10*24)231.5(#10*32)25.4(#10*4)42.6(#10*4)59.8(#10*4)77(#10*4)94.2(#10*4)111.4(#10*4)128.6(
COLP5   8.5(#10*20)231.5(#10*20)19.2(#10*2)30.4(#10*2)41.6(#10*2)52.8(#10*2)64(#10*2)75.2(#10*2)86.4(#10*2)97.6(#10*2)108.8(#10*
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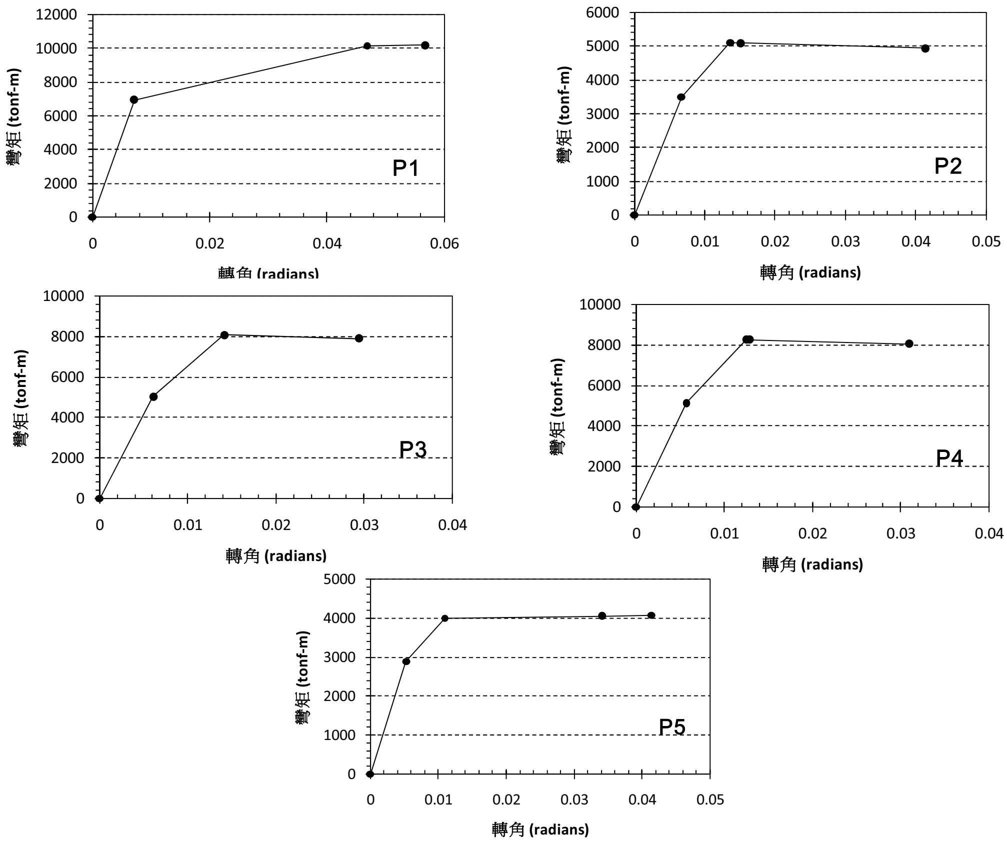
Output : *.PH

行車向 (X-向) 柱底塑鉸性質 (*.PH)



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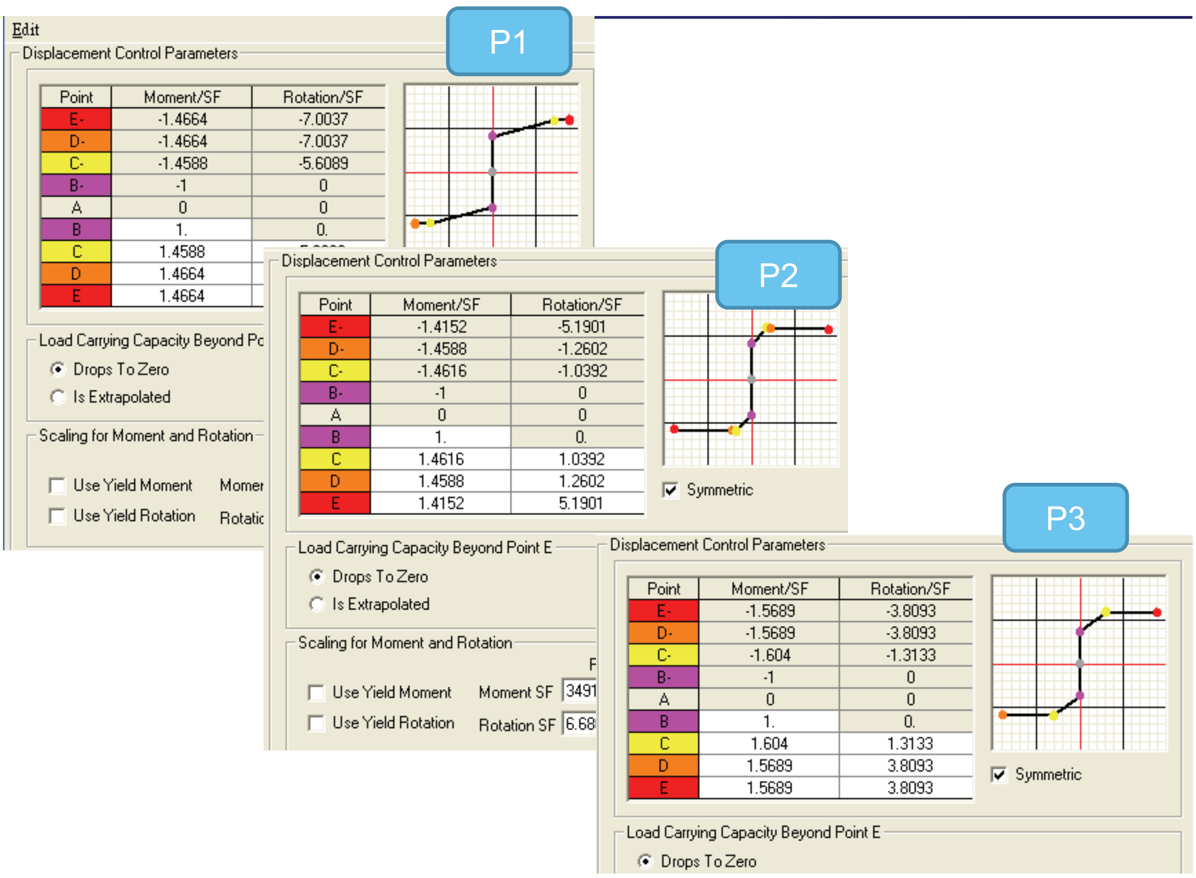
X-向 塑性鉸之設定



P1

Point	Moment/SF	Rotation/SF
E-	-1.4664	-7.0037
D-	-1.4664	-7.0037
C-	-1.4588	-5.6089
B-	-1	0
A	0	0
B	1.	0.
C	1.4588	
D	1.4664	
E	1.4664	

P2

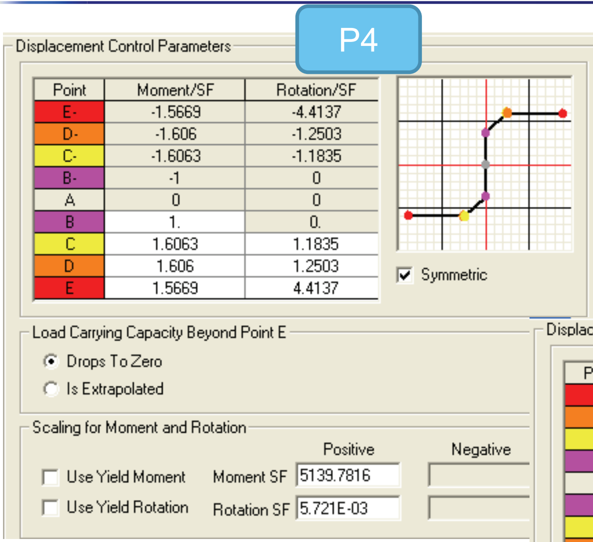
Point	Moment/SF	Rotation/SF
E-	-1.4152	-5.1901
D-	-1.4588	-1.2602
C-	-1.4616	-1.0392
B-	-1	0
A	0	0
B	1.	0.
C	1.4616	1.0392
D	1.4588	1.2602
E	1.4152	5.1901

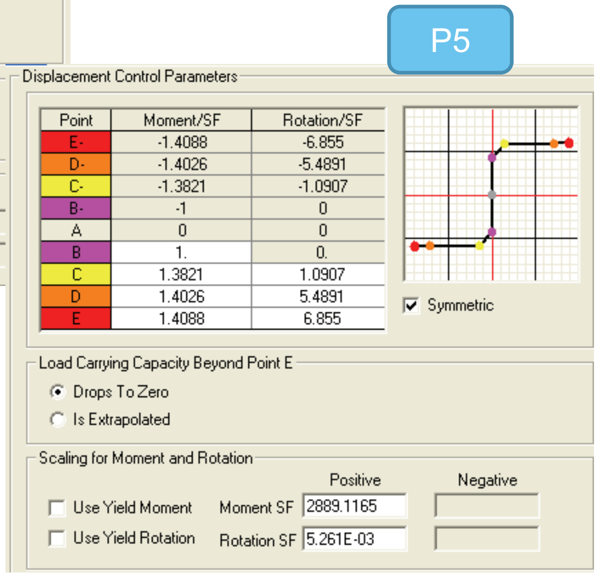
P3

Point	Moment/SF	Rotation/SF
E-	-1.5689	-3.8093
D-	-1.5689	-3.8093
C-	-1.604	-1.3133
B-	-1	0
A	0	0
B	1.	0.
C	1.604	1.3133
D	1.5689	3.8093
E	1.5689	3.8093

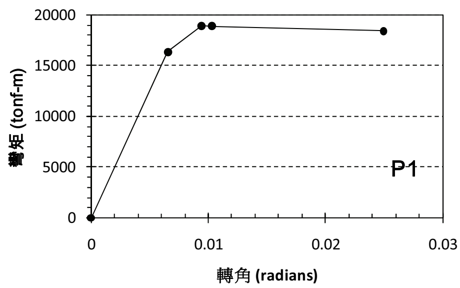
NCREE

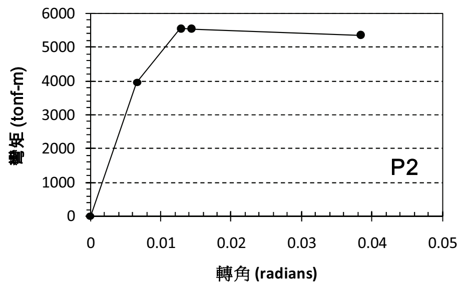
X-向 塑性鉸之設定

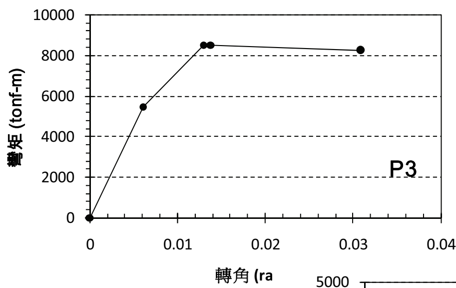


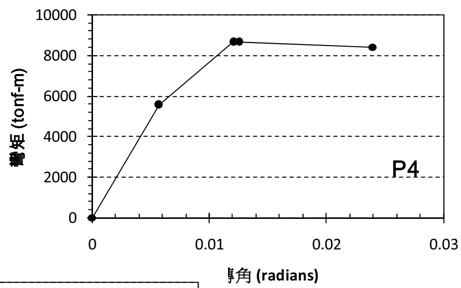


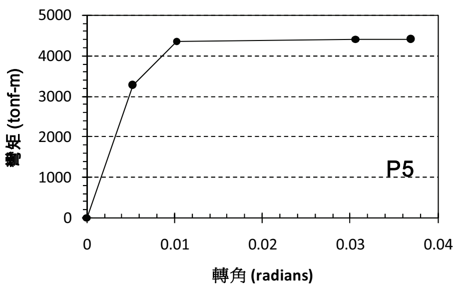
垂直行車向 (Y-向) 柱底塑鉸性質









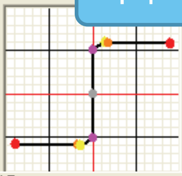


Y-向 塑性鉸之設定

P1

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.1265	-2.804
D-	-1.1551	-0.5669
C-	-1.1568	-0.4389
B-	-1	0
A	0	0
B	1.	0.
C	1.1568	[illegible]
D	1.1551	
E	1.1265	



Load Carrying Capacity Beyond

- (•) Drops To Zero
- ( ) Is Extrapolated

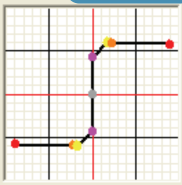
Scaling for Moment and Rotation

- [ ] Use Yield Moment Mom
- [ ] Use Yield Rotation Rota

P2

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.3525	-4.7774
D-	-1.3997	-1.1549
C-	-1.4027	-0.9314
B-	-1	0
A	0	0
B	1.	0.
C	1.4027	0.9314
D	1.3997	1.1549
E	1.3525	4.7774



- [x] Symmetric

Load Carrying Capacity Beyond Point E

- (•) Drops To Zero
- ( ) Is Extrapolated

Scaling for Moment and Rotation

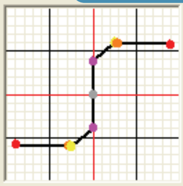
Positiv

- [ ] Use Yield Moment Moment SF 3962.
- [ ] Use Yield Rotation Rotation SF 6.648E-03

P3

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.5111	-4.0738
D-	-1.5554	-1.2679
C-	-1.5576	-1.1335
B-	-1	0
A	0	0
B	1.	0.
C	1.5576	1.1335
D	1.5554	1.2679
E	1.5111	4.0738



- [x] Symmetric

Load Carrying Capacity Beyond Point E

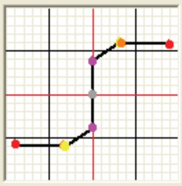
- (•) Drops To Zero
- ( ) Is Extrapolated

Y-向 塑性鉸之設定

P4

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.5079	-3.2116
D-	-1.5561	-1.2133
C-	-1.5582	-1.1266
B-	-1	0
A	0	0
B	1.	0.
C	1.5582	1.1266
D	1.5561	1.2133
E	1.5079	3.2116



- [x] Symmetric

Load Carrying Capacity Beyond Point E

- (•) Drops To Zero
- ( ) Is Extrapolated

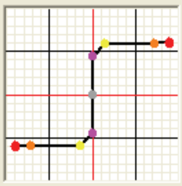
Scaling for Moment and Rotation

		Positive	Negative
[ ] Use Yield Moment	Moment SF	5574.	
[ ] Use Yield Rotation	Rotation SF	5.686E-03	

P5

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.3462	-6.0495
D-	-1.3415	-4.8459
C-	-1.3264	-0.9606
B-	-1	0
A	0	0
B	1.	0.
C	1.3264	0.9606
D	1.3415	4.8459
E	1.3462	6.0495



- [x] Symmetric

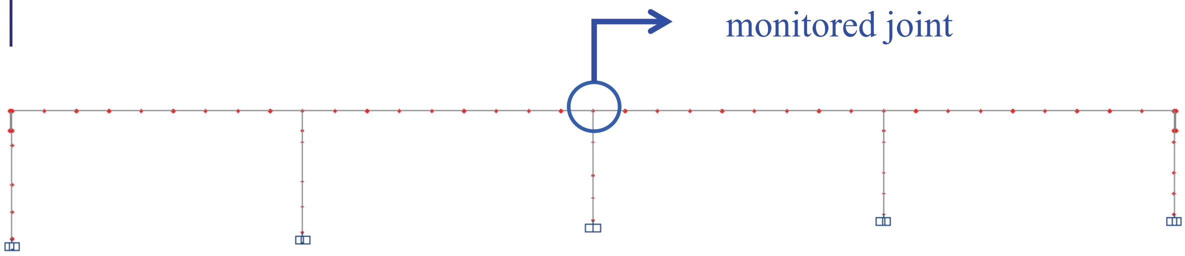
Load Carrying Capacity Beyond Point E

- (•) Drops To Zero
- ( ) Is Extrapolated

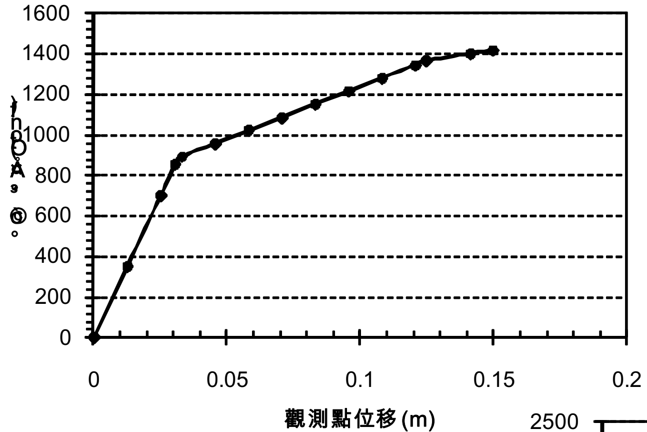
Scaling for Moment and Rotation

		Positive	Negative
[ ] Use Yield Moment	Moment SF	3282.	
[ ] Use Yield Rotation	Rotation SF	5.232E-03	

側推分析觀測點

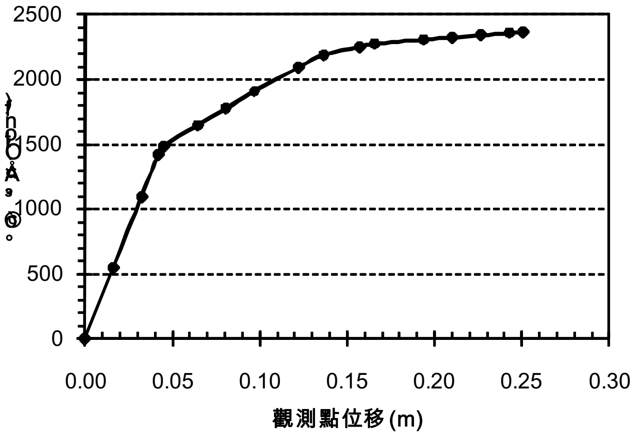


側推容量曲線 (base shear vs. monitored dis.)

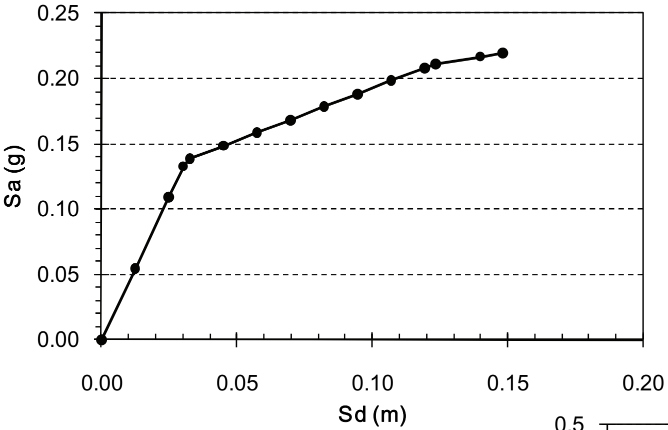


X – Dir.

Y – Dir.

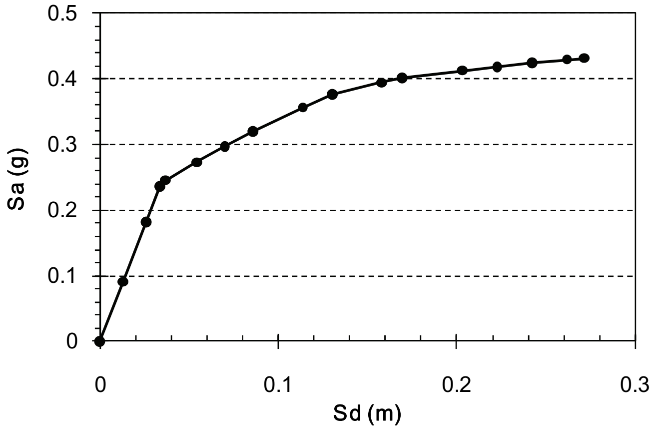


容量譜曲線 (capacity spectrum)



X – Dir.

Y – Dir.



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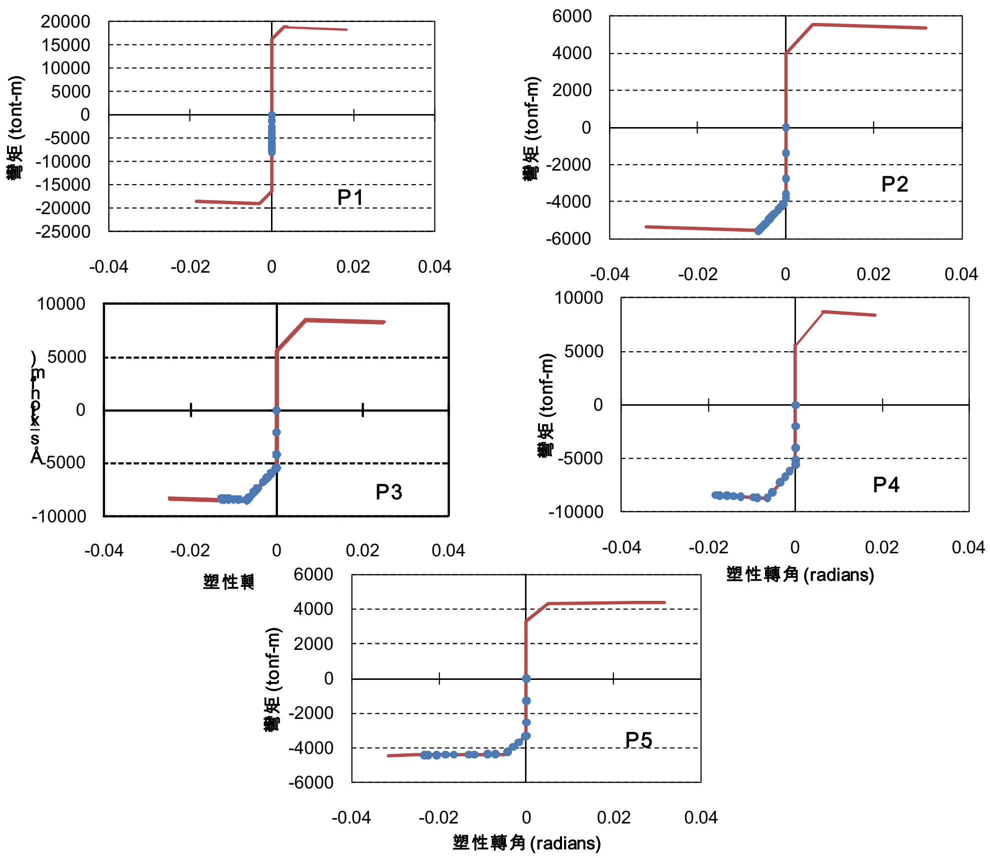
垂直行車向 (Y-向) 柱底塑鉸發展狀況



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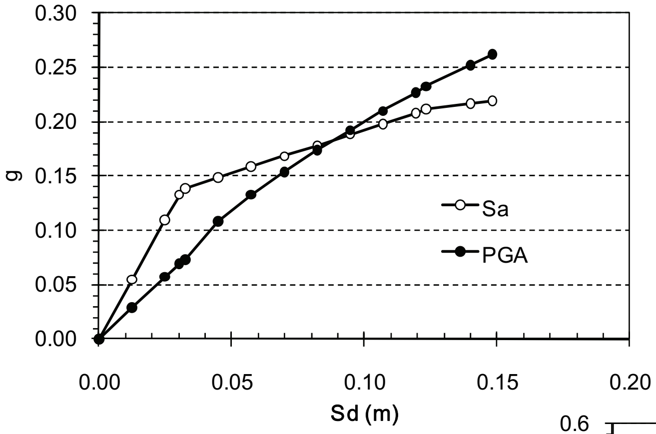
容量譜曲線與對應之最大地表加速度

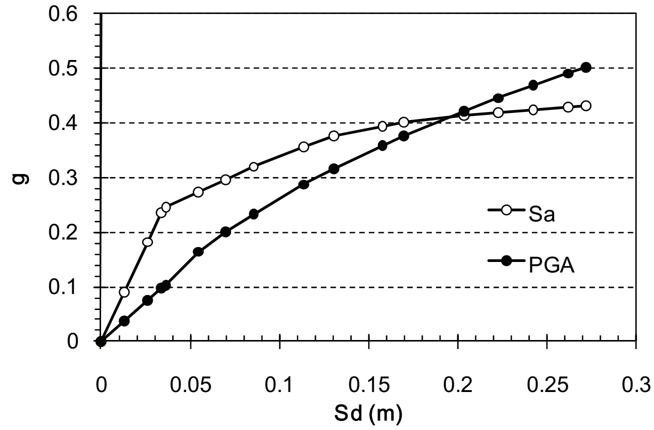
NCREE



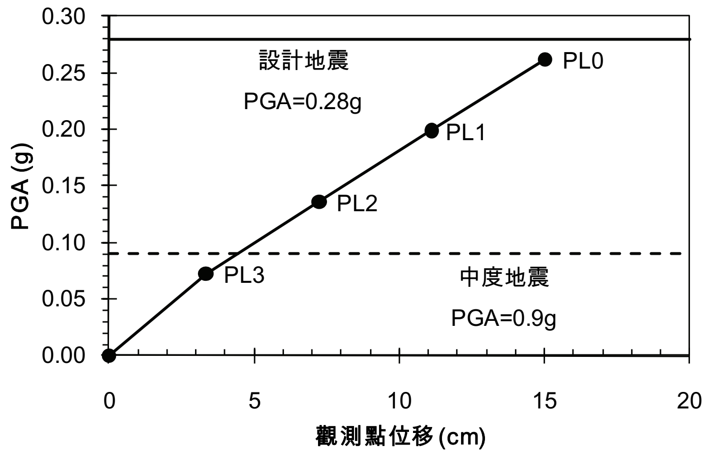
X – Dir.

阻尼修正因子 κ = 0.33

Y – Dir.



耐震性能曲線

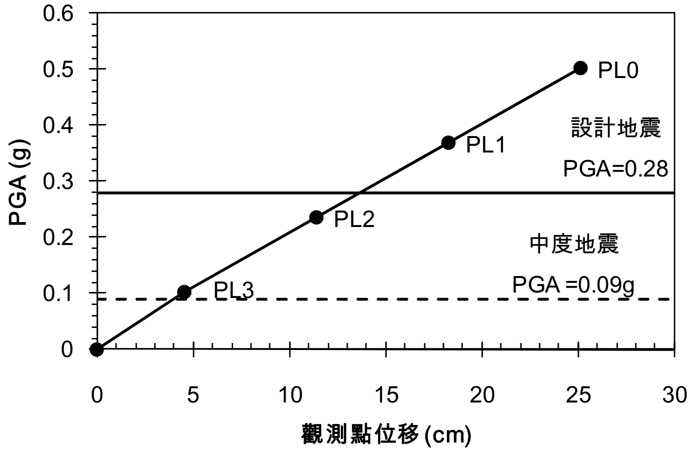


X – Dir.

PL1 < 0.28 g
PL3 < 0.09g
須補強

Y – Dir.

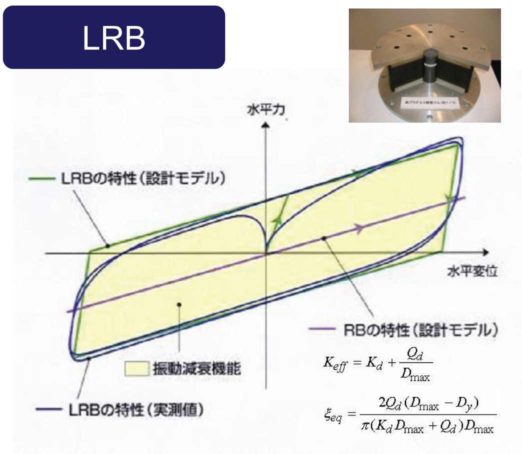
PL1 > 0.28 g
PL3 > 0.09g
ok



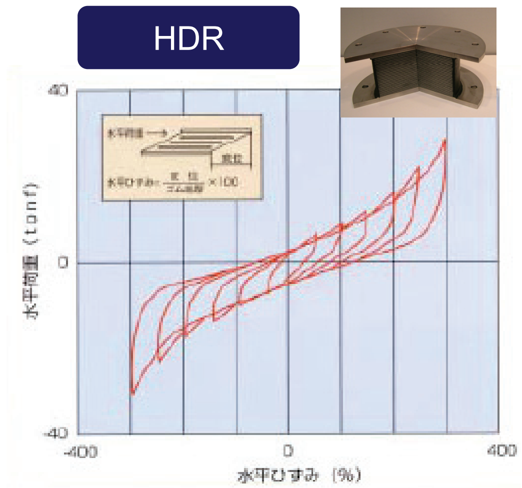
隔震補強設計與評估

隔震支承遲滯迴圈

LRB



HDR



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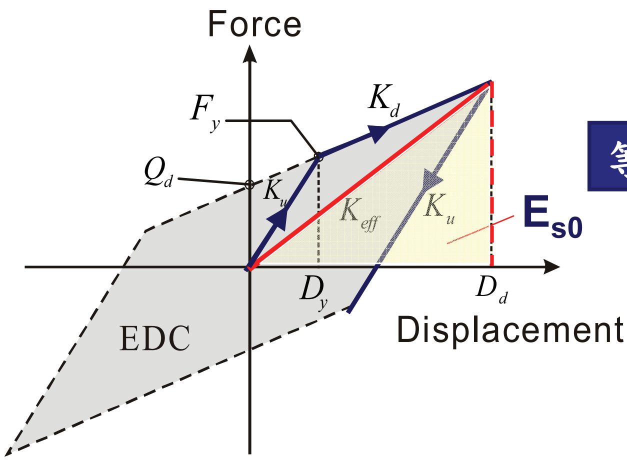
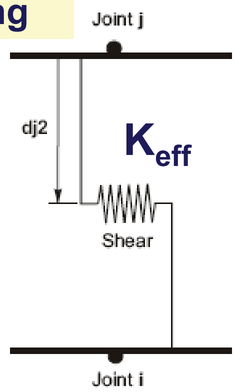
隔震支承之理想化

雙線性系統



等效線性系統

spring



damper

$$\xi_{eq} = \frac{1}{4\pi}\frac{EDC}{E_{s0}} = \frac{1}{2\pi}\frac{EDC}{K_{eff} D_d^2}$$

K_u : 初始勁度
K_d : 後降伏勁度
Q_d : 特徵強度
EDC: 每一迴圈之消散能量

隔震設計靜力分析步驟

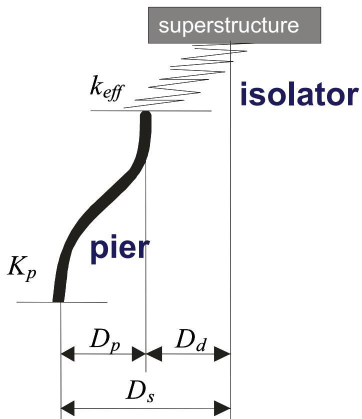
- Step 1: 假設隔震橋梁設計位移 D_s
- Step 2: 計算隔震器的設計位移 $D_{d,i}$

$$D_{d,i} = D_S - D_{P,i}$$
$$D_{P,i} = \frac{F_{d,i}}{K_{P,i}} = \frac{Q_d + K_d D_S}{K_{P,i} + K_d}$$

- Step 3: 計算各隔震器有效勁度 K_{eff}
  與等效阻尼 ξ_{eq}
  並計算各支承-墩柱系統等效勁度 K_e
- Step 4: 計算隔震橋梁有效週期 T_e 與等效阻尼 ξ_e
- Step 5: 計算隔震橋梁設計位移 D_s

$$D_s = S_{aD}(T_e, \xi_e) T_e^2 g / 4\pi^2$$

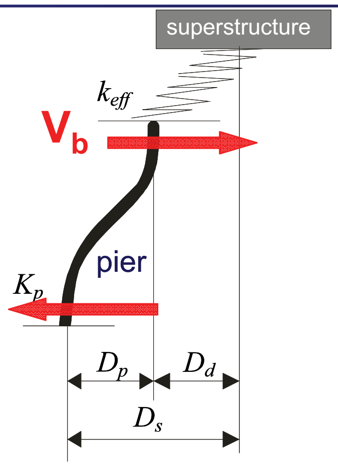
- 疊代steps 2 to 5 直到 D_s 收斂



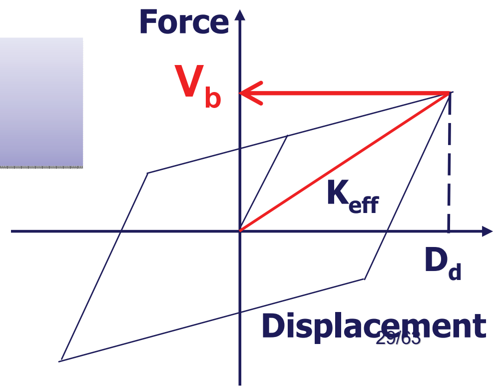
柱底反力之計算

$$V_{b,i} = \sum_j K_{eff,i} D_{d,i}$$

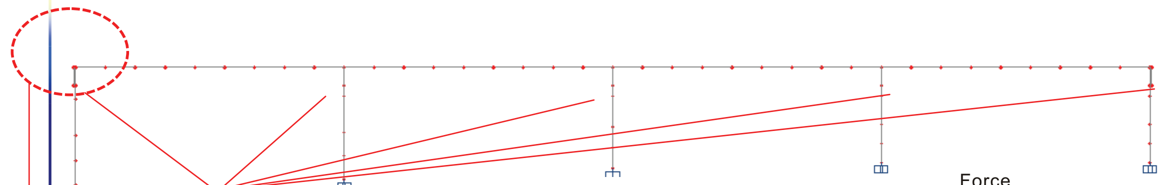
$$M_{b,i} = V_{b,i} H_i$$



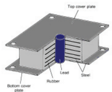
- **性能目標：**
  設計地震下橋柱保持彈性

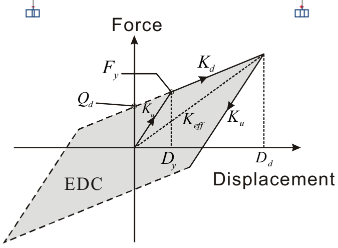


隔震支承基本性質



鄰跨配置相同支承





	P1	P2	P3	P4	P5
Q_d (t)	35	70	70	70	35
K_d (tf/m)	300	600	600	600	300
α	0.05	0.05	0.05	0.05	0.05
D_y (m)	0.0061	0.0061	0.0061	0.0061	0.0061
K_p (tf/m)	12947	8966	12987	16096	16096

$(3EI_y)/H^3$

靜力分析- 第一次疊代

Step 1：假設 D_s = 0.5m.

Step 2 and 3

	P1	P2	P3	P4	P5
D_P (m)	0.027	0.039	0.027	0.022	0.022
D_d (m)	0.473	0.461	0.473	0.478	0.478
K_{eff} (tf/m)	374.0	751.7	748.1	746.5	373.2
ξ_{eq}	0.124	0.127	0.124	0.123	0.123
K_e (tf/m)	707.2	693.6	707.3	713.4	713.4

Step 4: 隔震橋梁有效週期 T_e = 2.91 sec

隔震橋梁等效阻尼 ξ_e = 0.12

Step 5: 阻尼修正係數 B_1= 1.3

$S_{aD} = 0.56/(T_e \times B_1)=0.148$

$D_s = S_{aD} T_e^2 g/4\pi^2 = 0.312$ m $\neq$ 0.5 m

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靜力分析- 第七次疊代

Step 1：假設Ds = 0.249m.

Step 2 and 3

	P1	P2	P3	P4	P5
D_P (m)	0.016	0.023	0.016	0.013	0.013
D_d (m)	0.233	0.227	0.233	0.236	0.236
K_{eff} (tf/m)	449.9	908.8	899.8	896.0	448.0
ξ_{eq}	0.207	0.210	0.206	0.205	0.205
K_e(tf/m)	841.4	825.1	841.5	848.7	848.7

Step 4: 隔震橋梁有效週期 T_e = 2.673 sec

隔震橋梁等效阻尼 ξ_e = 0.196

Step 5: 阻尼修正係數 B_1= 1.491

$S_{aD} = 0.56/(T_e \times B_1)=0.141$

Ds = 0.249 m = 0.249 m → Converge

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靜力分析結果

柱底剪力與彎矩

$$V_{b,i} = \sum \mathrm{K}_{eff,i} D_{d,i}$$

$$M_{b,i} = V_{b,i} H_i$$

substructures: V_b (tf), M_b (t-m)

isolators: Design displacement D_d (m), K_{eff} (tf/m), EDC (t-m)

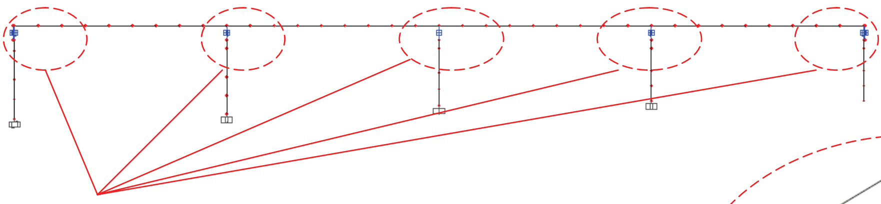
	P1	P2	P3	P4	P5
V_b (tf)	210.6	206.0	210.1	211.9	211.9
M_b (t-m)	3045.9	2801.7	2525.3	2371.1	2371.1
Design displacement D_d (m)	0.233	0.227	0.233	0.236	0.236
K_{eff} (tf/m)	449.9	908.8	899.8	896.0	448.0
EDC (t-m)	31.83	61.76	63.67	64.51	32.25

M_b 均小於柱底降伏彎矩

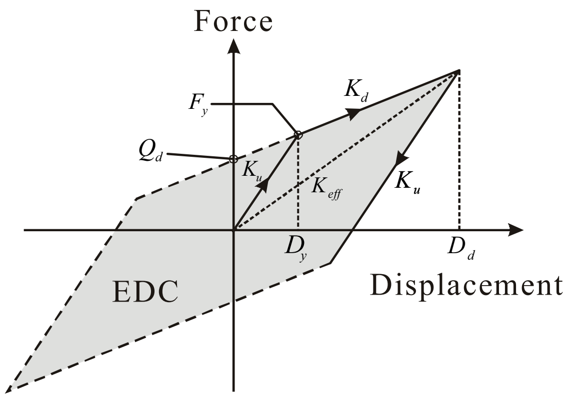
→ 設計地震下橋柱保持彈性

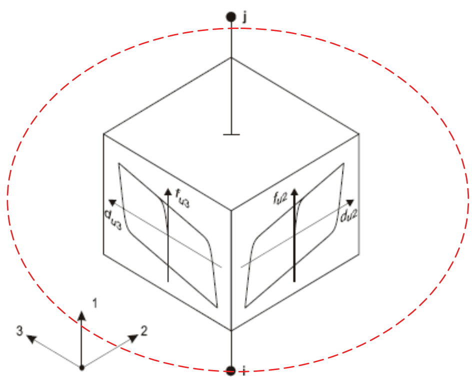
隔震支承模擬

SAP2000N 分析模型



Nonlinear link element (Rubber isolator)



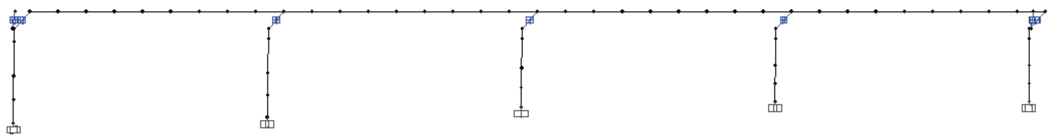


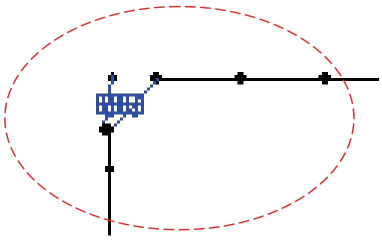
Sap 2000N

模態分析

行車向模態

- 模態質量參與係數 = 0.79
- Period =施加於2.72 sec



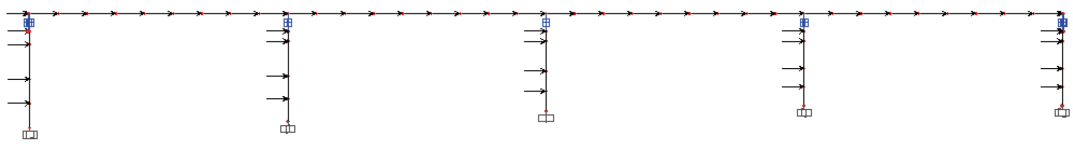


鄰跨質量 施加於X,Y,Z 三向

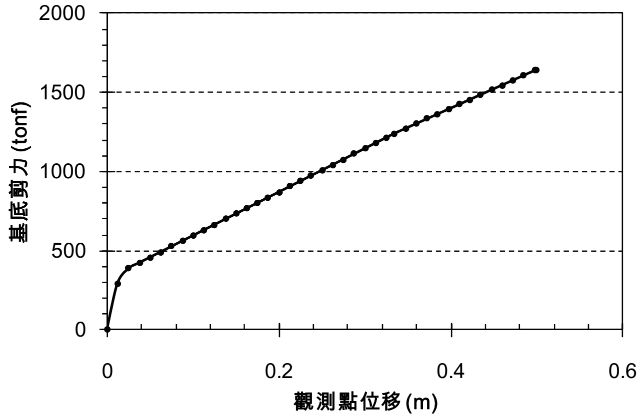
非線性側推分析

以靜力分析法所訂之設計總橫力分佈進行側推

$$p_e(x) = \frac{w(x)u(x)}{\int w(x)u(x)dx} V$$

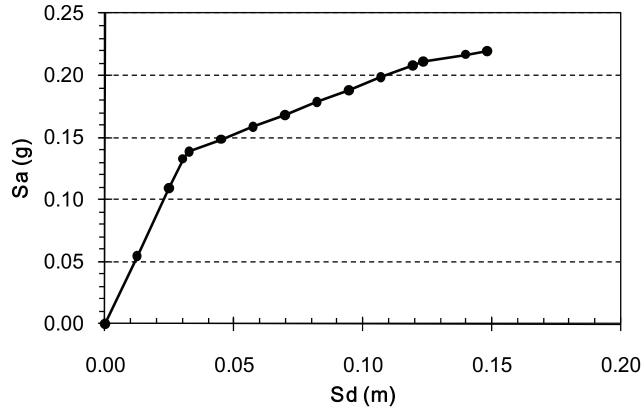


側推分析曲線



側推容量曲線

容量譜曲線



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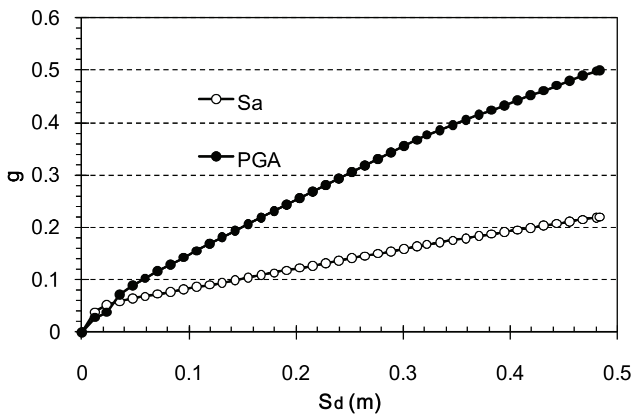
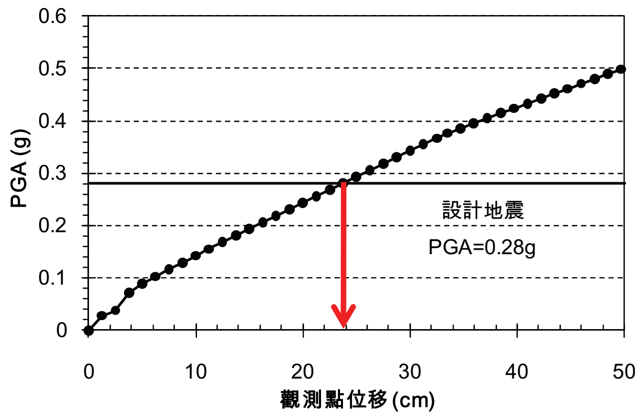
隔震橋梁性能檢核(I)



設計地震對應之位移
0.238 m

容量譜曲線與對應之最大地表加速度

阻尼修正因子 $\kappa = 1$



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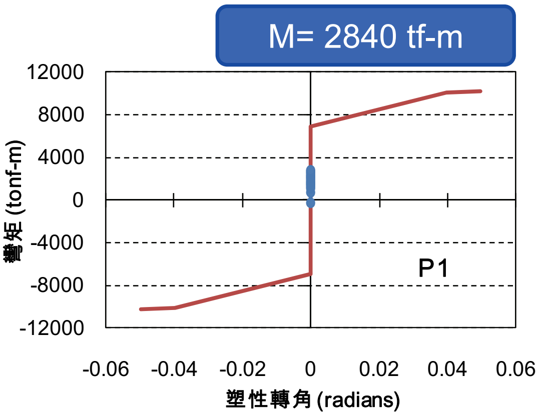
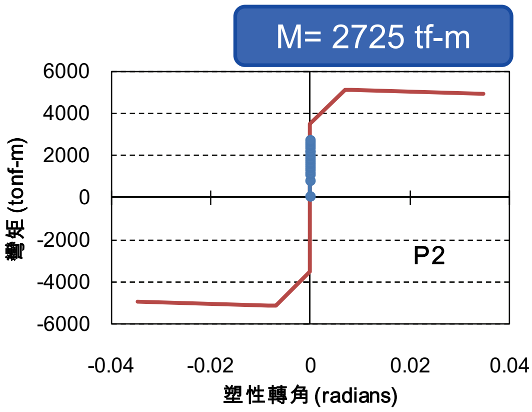
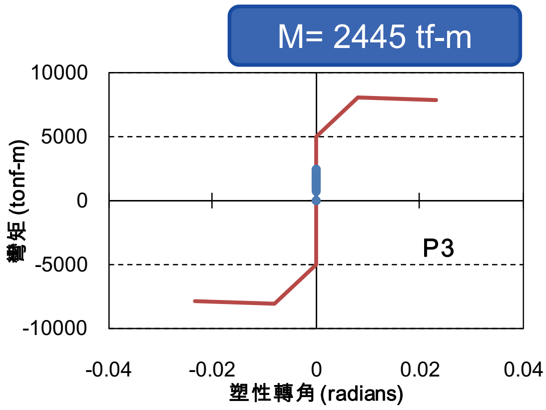
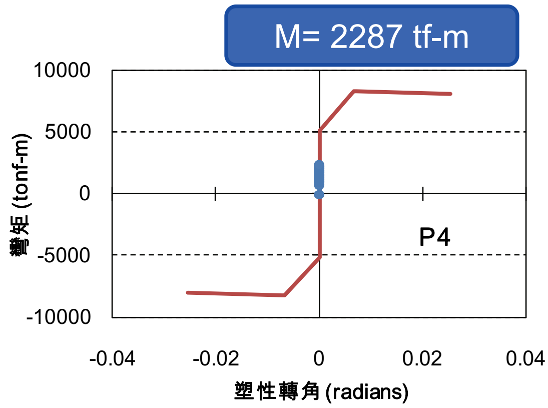
隔震橋梁性能檢核 (II)

NCREE



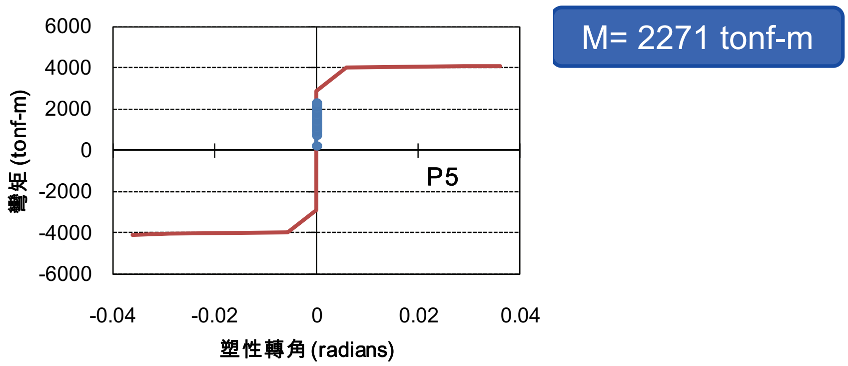






隔震橋梁性能檢核 (III)

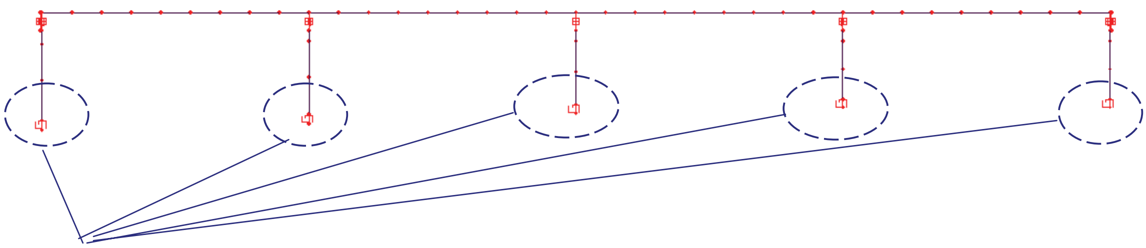
NCREE



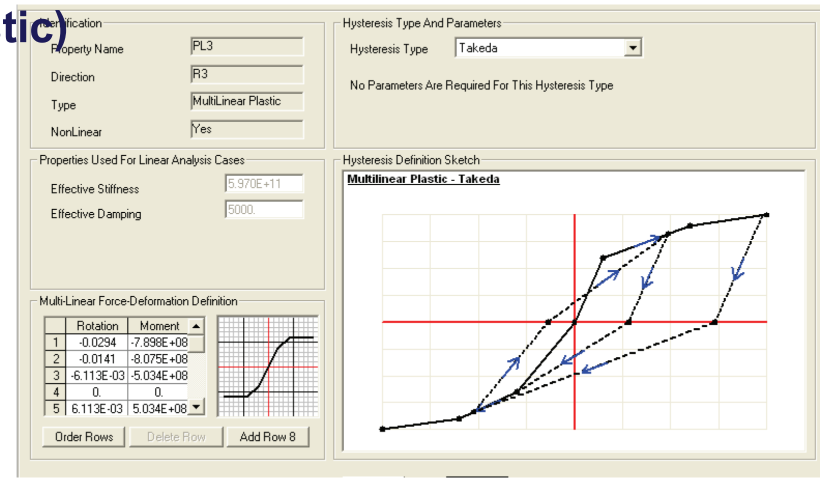
M_b (t-m)	P1	P2	P3	P4	P5
非線性側推分析	2840	2725	2445	2287	2271
靜力分析	3046	2802	2525	2371	2371

隔震橋梁非線性歷時分析

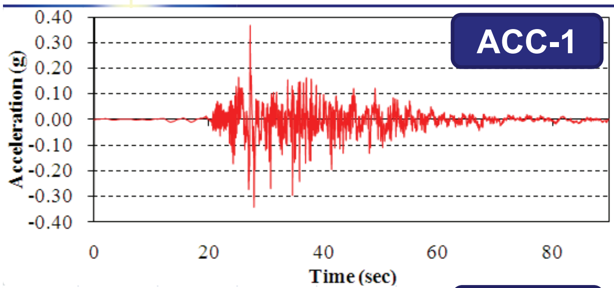
NCREE

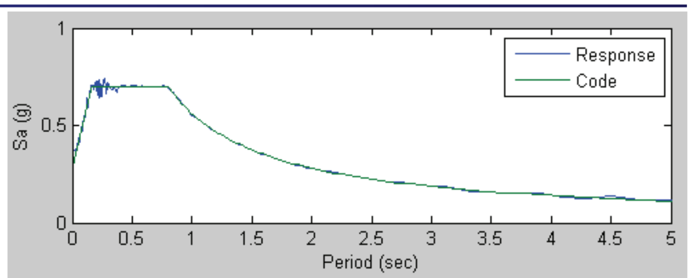


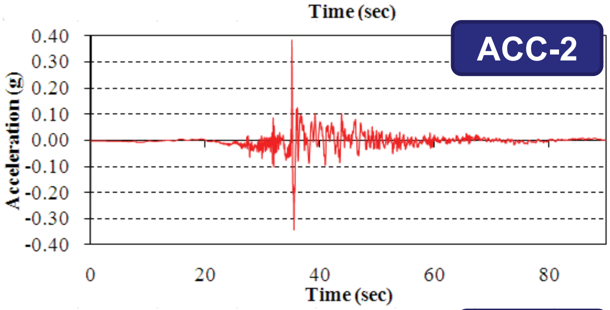
Nonlinear link element
(Multilinear Plastic)

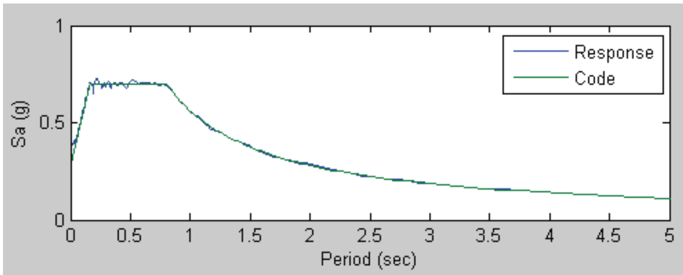


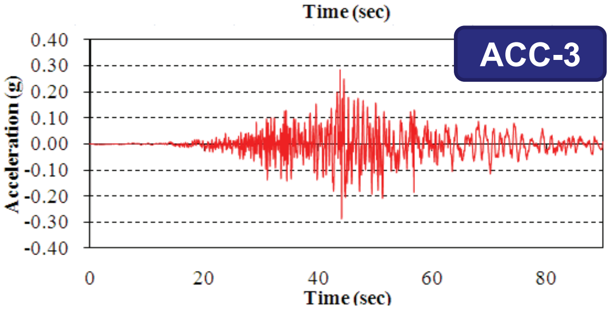
與設計反應譜相符之地震紀錄

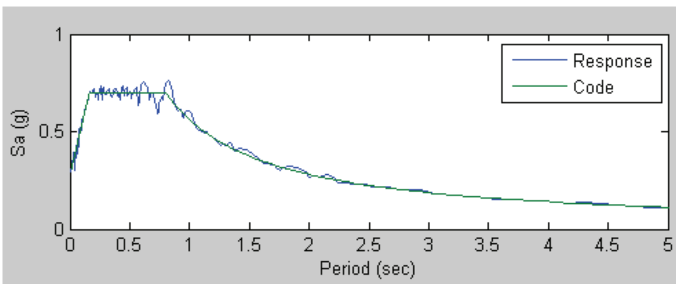




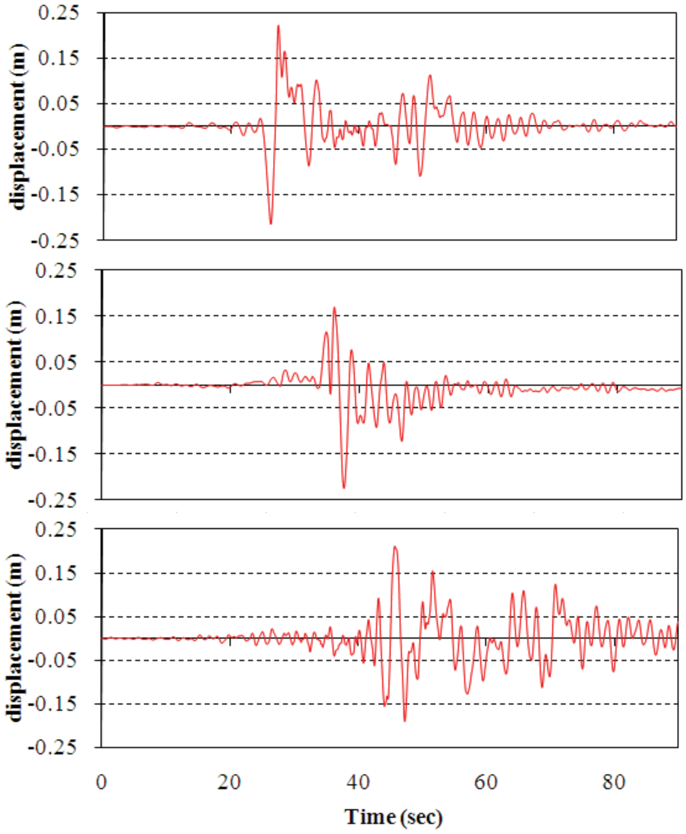








觀測點位移歷時



Max Ds =22.1 cm

Max Ds =22.5 cm

Max Ds =21.1 cm

柱底彎矩比較

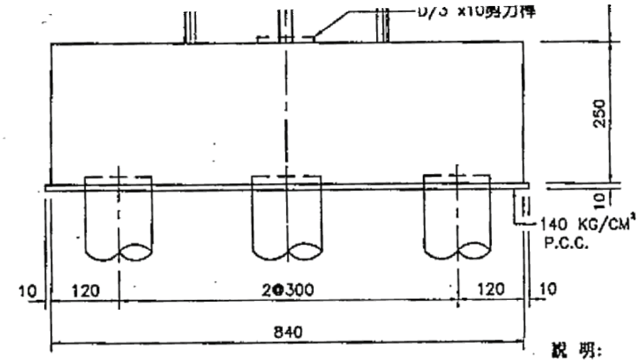
M_b (t-m)	P1	P2	P3	P4	P5
非線性側推分析	2840	2725	2445	2287	2271
靜力分析	3046	2802	2525	2371	2371
acc-1	2611	2178	2109	2030	1944
acc-2	2552	2291	2239	2128	1995
acc-3	2832	2273	2116	1993	2009

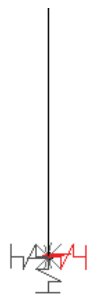
靜力分析最保守

考量基礎彈簧之橋梁耐震評估與補強

考量基礎彈簧之橋梁耐震評估

- 標準貫入試驗*N*值為30
- 30m長之120cmφ全套管場鑄基樁3×3=9支
- 基樁間距為3 m





$K_x = K_y$= 1174141 tf/m，
$K_{\theta y} = K_{\theta x}$ = 5490275 tf-m/rad，
K_z = 530144 tf/m

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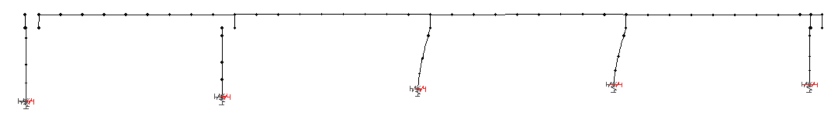
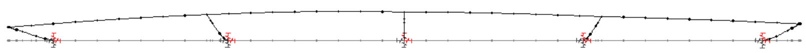
模態分析

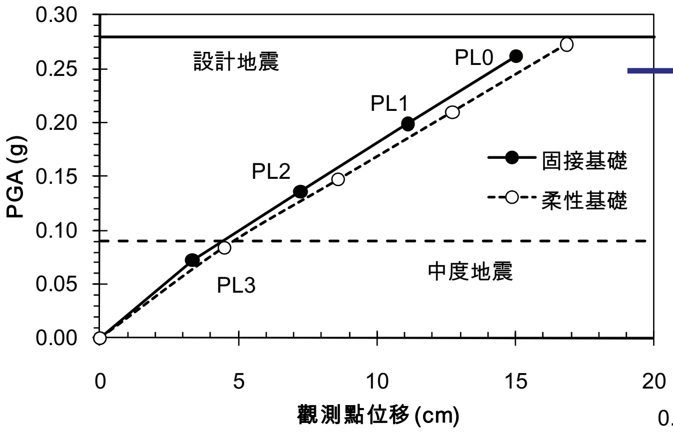
- 行車向 Period = 1.112 sec (0.956 sec)



- 垂直行車向 Period = 0.957 sec (0.819 sec)



固接基礎橋梁與柔性基礎橋梁耐震性能曲線之比較



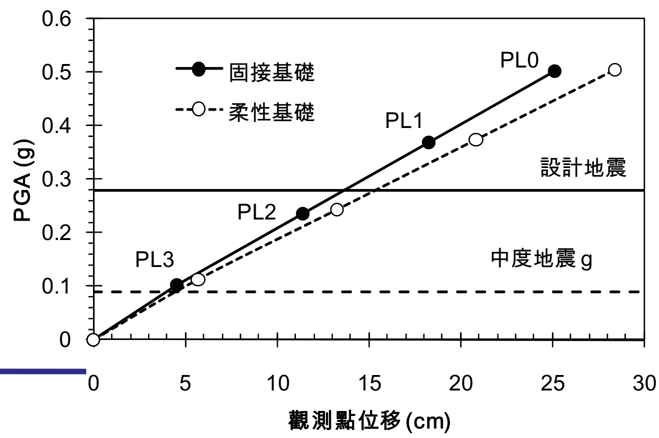
X – Dir.

柔性基礎橋梁可承受之最大地表加速度高於固接基礎橋梁，但同時其位移也增加

位移準則

$$\Delta_i \le 0.2\frac{M_u}{P}$$

Y – Dir.



隔震補強靜力分析結果（柔性基礎橋梁）

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柔性基礎橋梁

	P1	P2	P3	P4	P5
Vb (tf)	211.9	207.8	211.9	213.7	213.7
Mb (t-m)	3073.3	2826.1	2547.2	2391.7	2391.7
Design displacement D_d (m)	0.237	0.230	0.237	0.240	0.240

$D_s = 0.252$ m，$T_e = 2.687$ sec

固接基礎橋梁

	P1	P2	P3	P4	P5
Vb (tf)	210.6	206.0	210.1	211.9	211.9
Mb (t-m)	3045.9	2801.7	2525.3	2371.1	2371.1
Design displacement D_d (m)	0.233	0.227	0.233	0.236	0.236

$D_s = 0.249$ m，$T_e = 2.673$sec

簡報完畢
敬請指教