

橋梁減震評估 及補強案例

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九十九年五月十二日



國家地震工程研究中心
National Center for Research on Earthquake Engineering



國家地震工程研究中心
NATIONAL CENTER FOR RESEARCH ON
EARTHQUAKE ENGINEERING

公路橋梁耐震能力評估及
補強準則之研究

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報告編號：NCREE-09-028

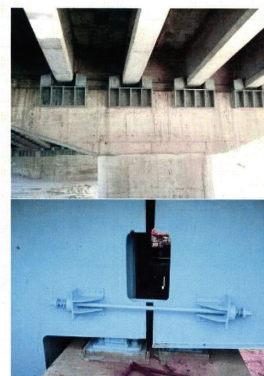
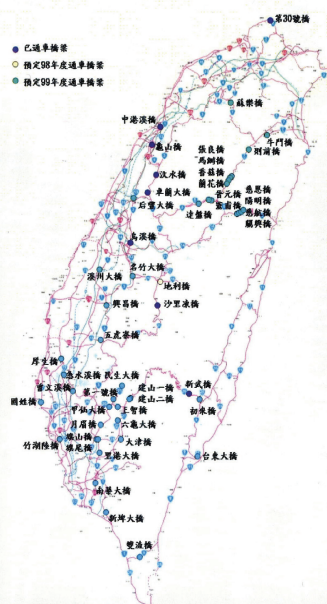
中華民國九十八年十二月



交通部公路總局

公路橋梁耐震評估及補強準則之研究

成果報告



National Center for Research on Earthquake Engineering
國家地震工程研究中心



中華民國九十八年十二月

報告大綱

- 案例橋梁基本資料說明
- SERCB-Bridge 側推分析
- 側推分析與非線性動力分析比較
- 減震補強基本概念
- 減震補強設計流程
- 補強後結構分析驗證
- 結論與建議

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橋梁基本資料

- 本案例橋梁假設為南投縣草屯鎮之省道重要橋梁，開工日期為78年3月1日，完工日期為80年2月28日。橋梁全長1公里，共有40座橋墩，每座相隔25公尺。
- 本橋於98年度進行橋梁耐震能力初步評估，落橋評估分數為45分，目前正進行防落長度擴座補強，已完成10處施工；強度韌性評估為63分，因高於60分，根據準則第三章須辦理詳細耐震能力評估。

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橋梁結構資料

■ 上部結構:

兩跨鉸接板連續化之預鑄預力混凝土梁，由6根I形梁所組成，橋面跨度25公尺、總寬為14公尺，淨寬13.1公尺，橋面版厚18公分、AC面層5公分。

■ 下部結構:

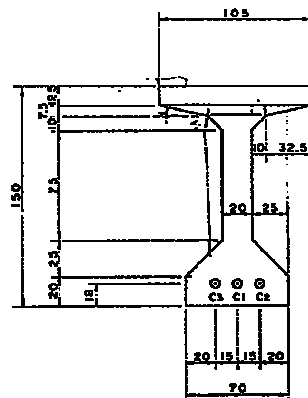
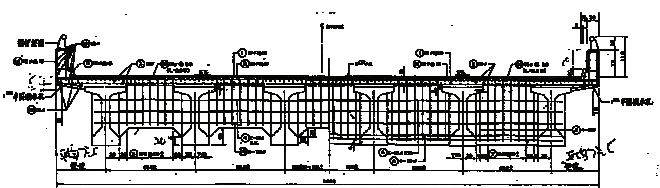
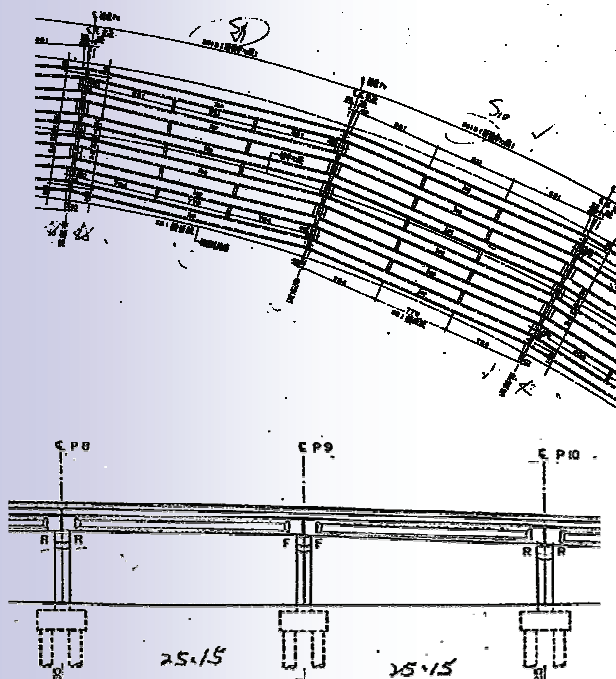
雙柱框架式橋墩，矩形斷面之寬度及深度為1.5與2公尺。本振動單元包含3根橋柱，沿里程增加方向編號依序為P8、P9、P10，帽梁高度1.6公尺，柱高（含帽梁）分別為7.8、7.6、7公尺。P8及P10橋墩上方相鄰兩跨之支承配置皆為滾（鋁）支承、P9橋墩則皆為鉸支承。

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橋梁平立面圖

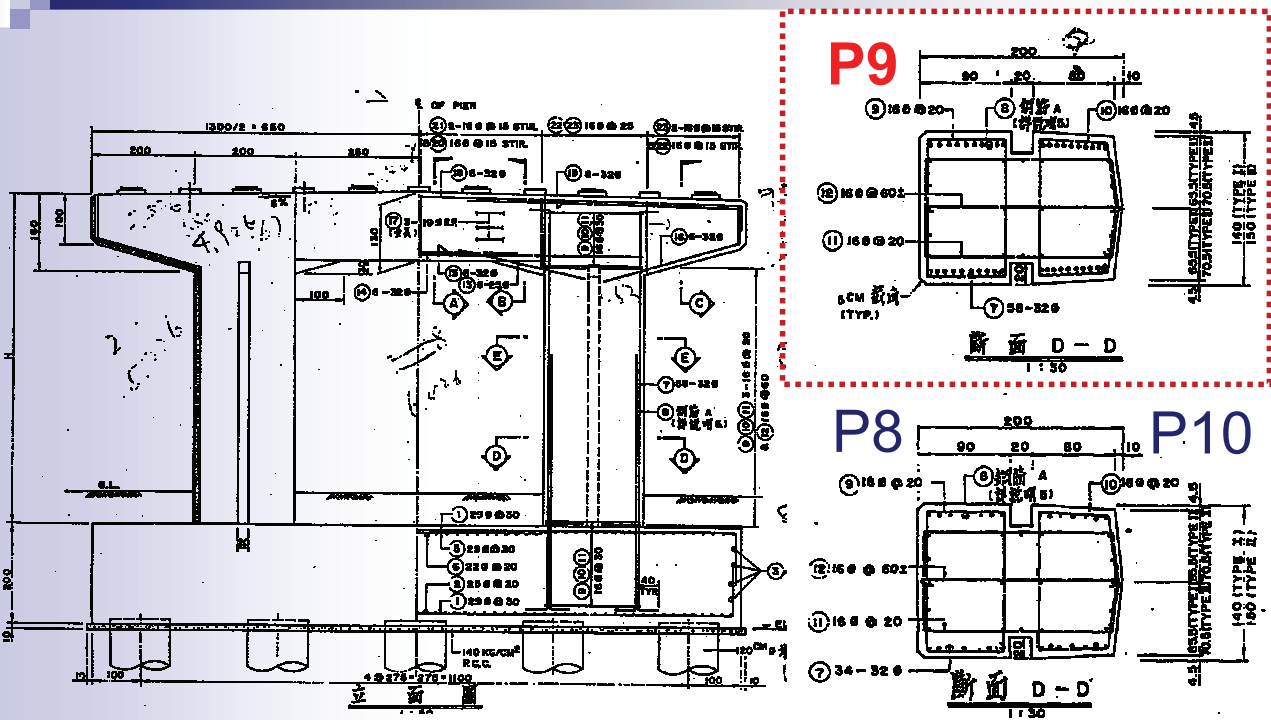


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橋柱平立面圖



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耐震性能目標

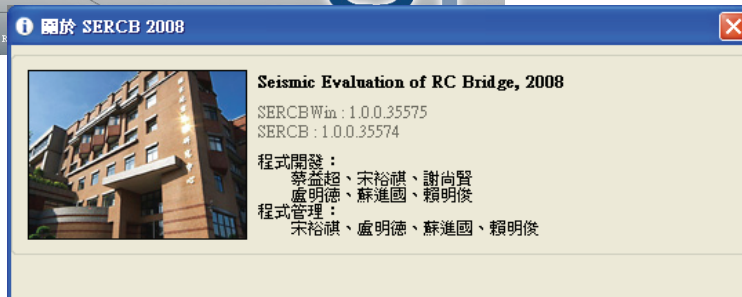
地震等級	採用之設計規範版本		
	84及89年版	49及76年版	49年版以前
中度地震	PL3	PL3	PL3
設計地震	PL2	PL1	PL1

$$S_{DS} = F_a (S_S^D N_A) = 1.0 \times 0.896 = 0.896$$

$$0.4S_{DS} = 0.4 \times 0.896 = 0.3584$$



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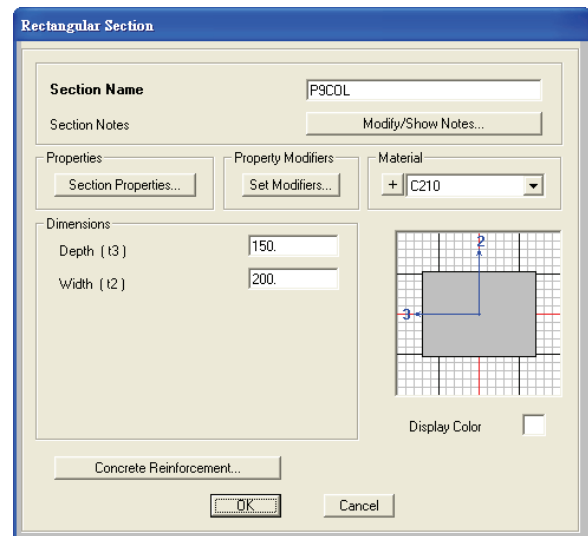
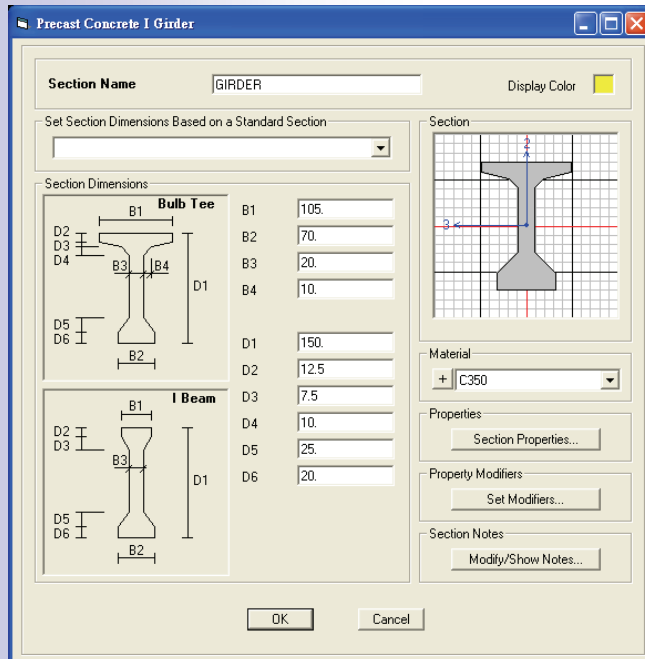


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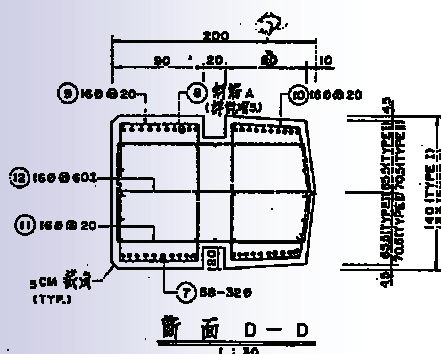
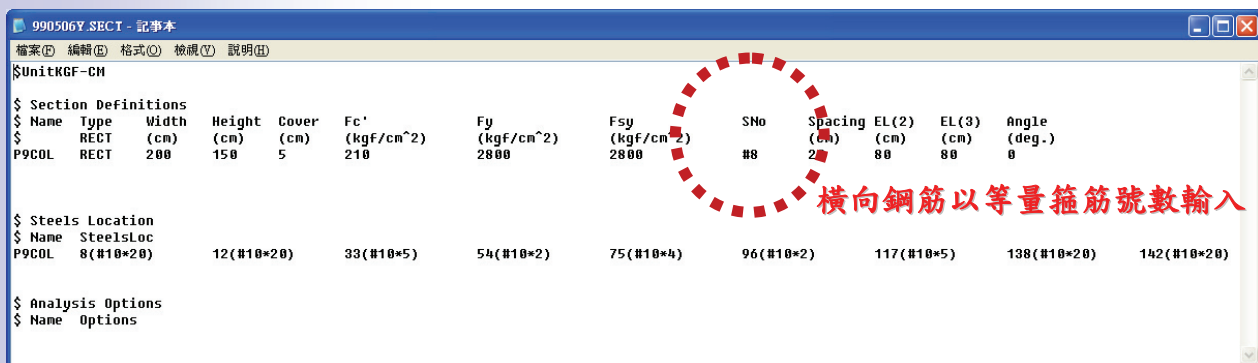
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斷面定義



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斷面資料檔 (*.SECT)



橋柱混凝土材料強度經鑽心取樣後平均值為**236 kgf/cm²**，分析時取原設計強度**210 kgf/cm²**；主筋、箍筋及繫筋強度依原設計強度皆取**2800 kgf/cm²**。

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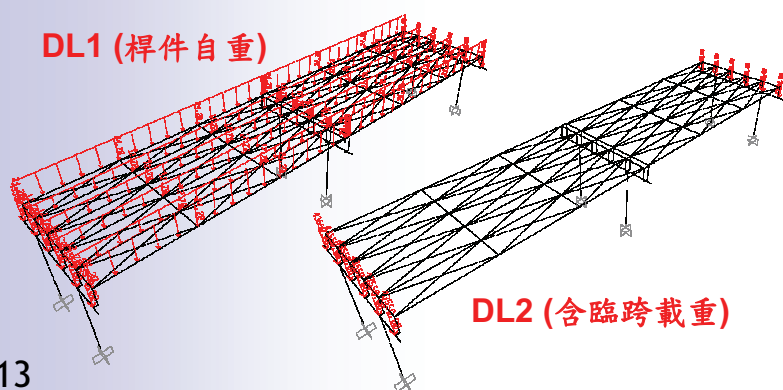
垂直載重之質量與載重定義

Define Loads

Load Name	Type	Self Weight Multiplier	Auto Lateral Load
DL1	DEAD	1	
DL1	DEAD	1	
DL2	OTHER	0	
JM	OTHER	0	
EQX	OTHER	0	

Click To:

DL1 (桿件自重)



DL2 (含臨時載重)

Define Mass Source

Mass Definition:
☐ From Element and Additional Masses
☒ From Loads
☐ From Element and Additional Masses and Loads

Define Mass Multiplier for Loads

Load	Multiplier
DL1	1.
DL1	1.
DL2	1.

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垂直載重之載重組合

Response Combination Data

Response Combination Name: DL

Notes:

Combination Type: Linear Add

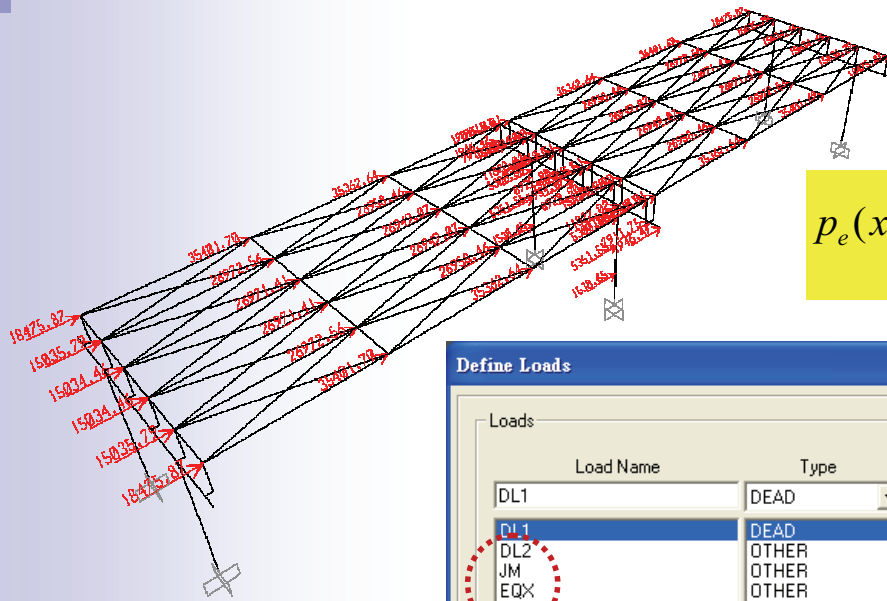
Define Combination of Case Results

Case Name	Case Type	Scale Factor
DL1	Linear Static	1.
DL1	Linear Static	1.
DL2	Linear Static	1.

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Earthquake Engineering

側向載重定義



側向載重分布

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

Define Loads

Load Name	Type	Self Weight Multiplier	Auto Lateral Load
DL1	DEAD	1	
DL2	DEAD	1	
JM	OTHER	0	
EQX	OTHER	0	

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內力資料檔 (*.BCF)

990507_760.BCF - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

\$Unit
kgf-cm

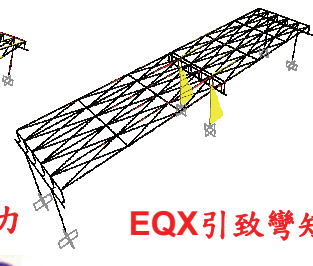
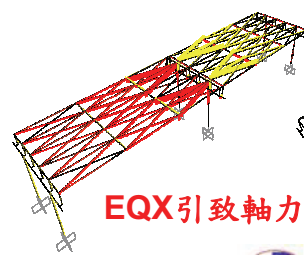
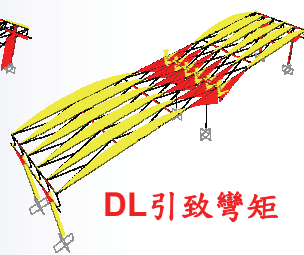
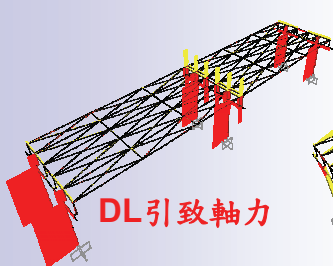
\$Beam / Column Definitions

\$Name	Type	Section	Height (cm)	FrameName
Column001	Column	P9COL	760.000	226I 228J
Column002	Column	P9COL	760.000	230I 232J

單柱式橋墩修正反曲點高度

\$Member Forces

\$Name	LoadCase	P(i) (kgf)	M(i) (kgf-cm)	Height(i) (cm)	P(j) (kgf)	M(j) (kgf-cm)	Height(j) (cm)
Column001	DL	-404914.6838	0.1	0.1	-404914.6838	0.1	760
	EQX	0.4972	91367191.5900	0.1	0.4972	451792761.9170	760
Column002	DL	-404914.6838	0.1	0.1	-404914.6839	0.1	760
	EQX	0.4948	91367190.0969	0.1	0.4948	451792763.5602	760

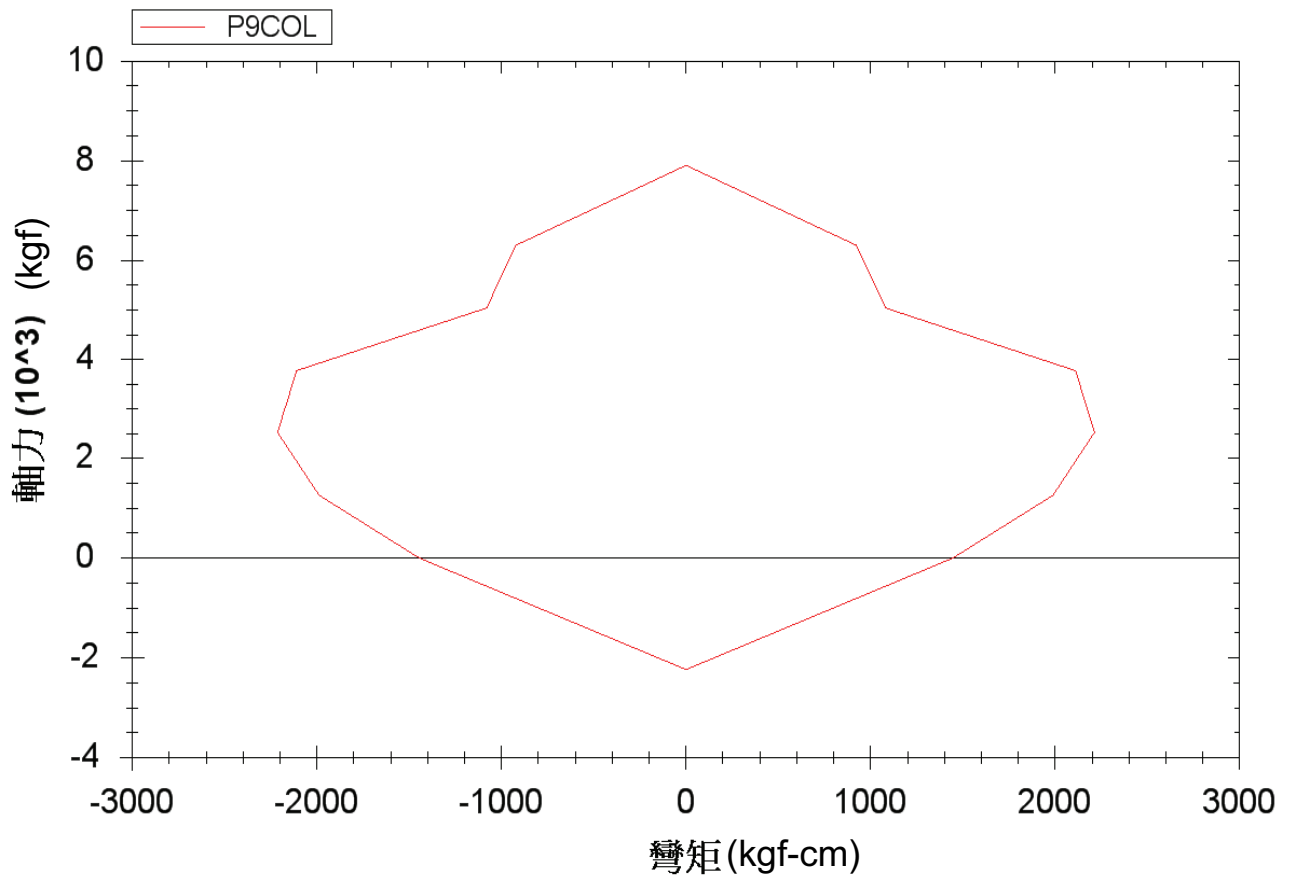


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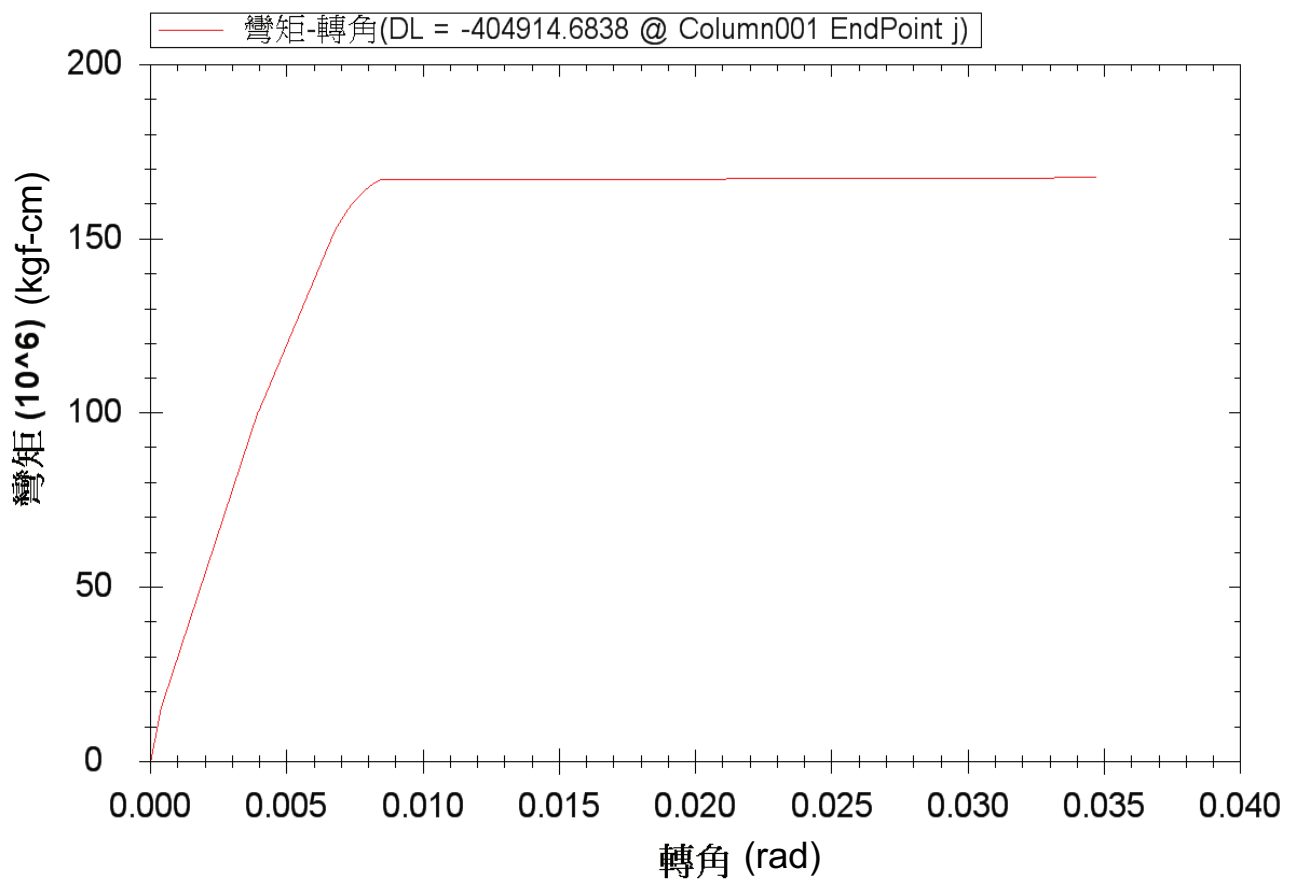


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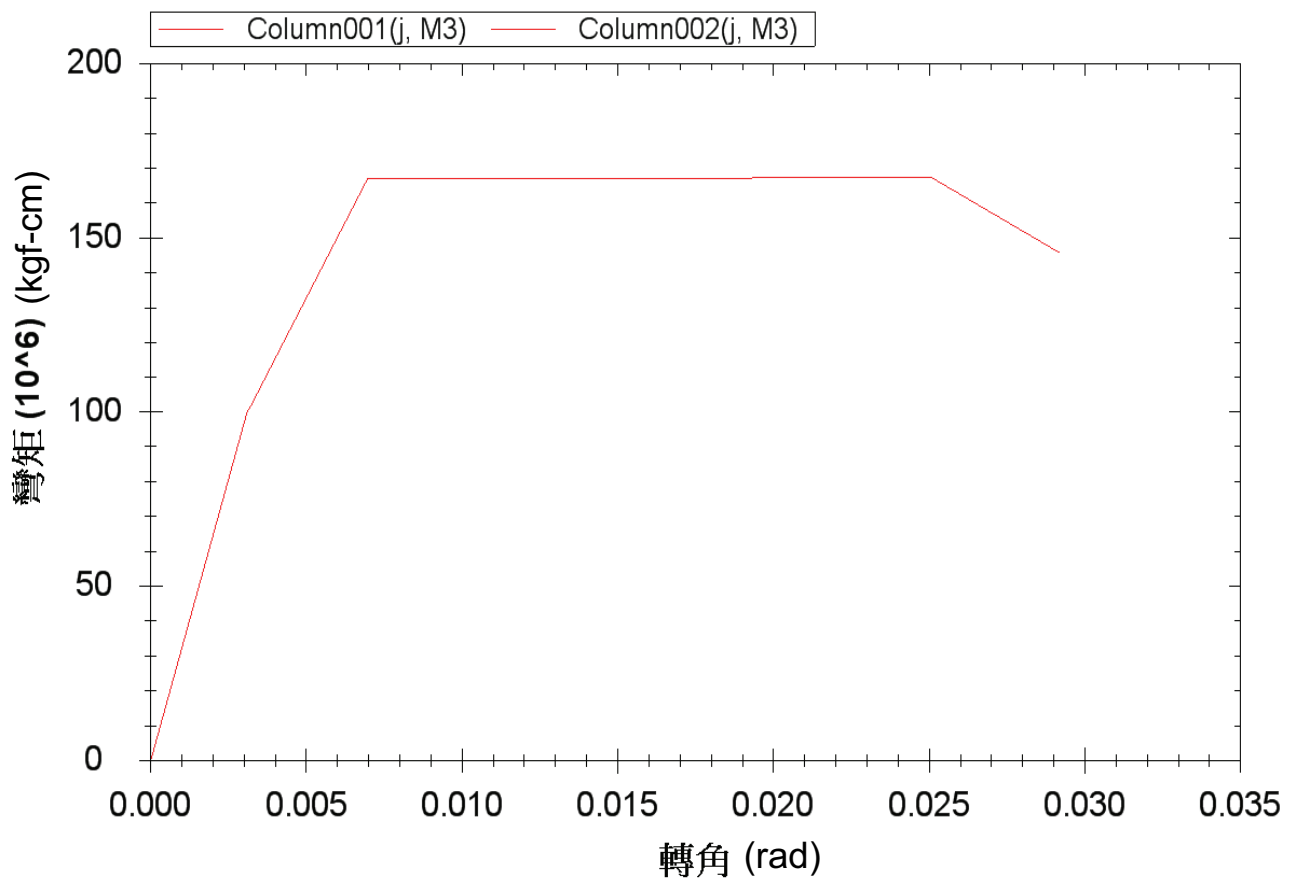
軸力-彎矩曲線



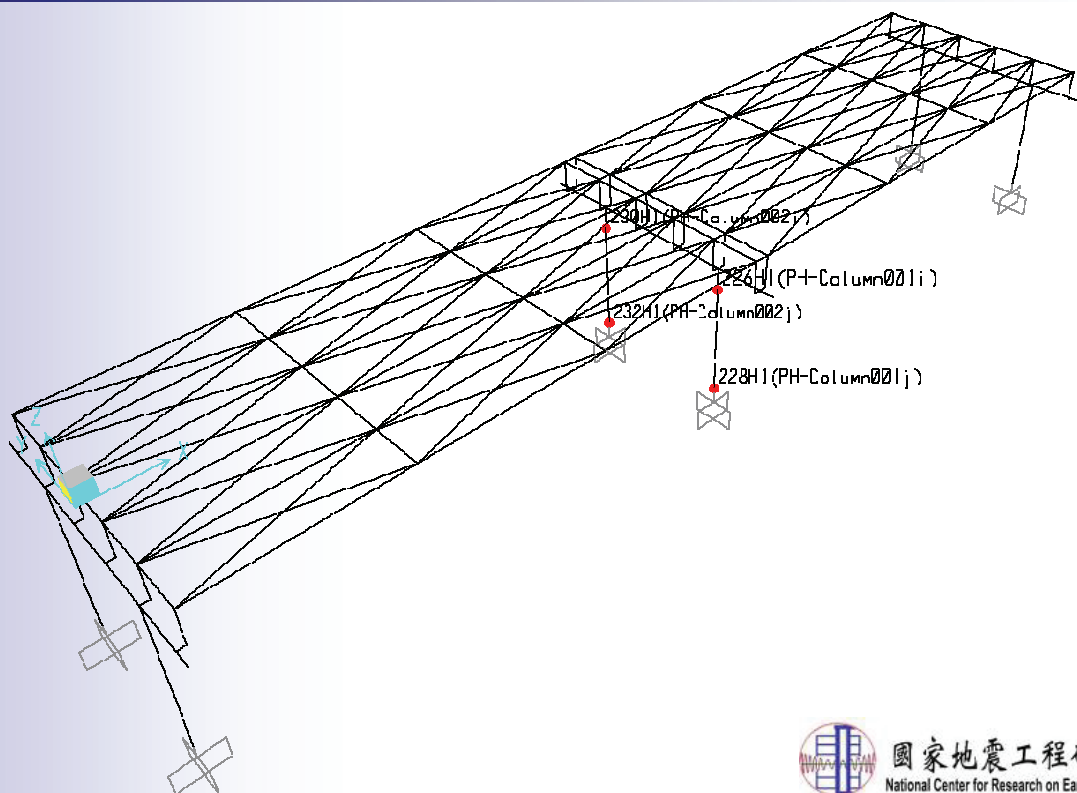
彎矩-轉角



構件塑鉸屬性



塑性鉸位置

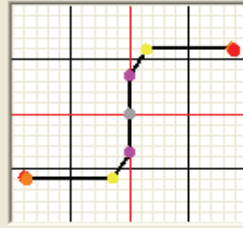


Frame Hinge Property Data for PH-Column001j - Moment M3

Edit

Displacement Control Parameters

Point	Moment/SF	Rotation/SF
E-	-1.6327	-7.6129
D-	-1.678	-7.4427
C-	-1.6719	-1.249
B-	-1	0
A	0	0
B	1	0
C	1.6719	1.249
D	1.678	7.4427
E	1.6327	7.6129



☒ Symmetric

Type

☒ Moment - Rotation

☐ Moment - Curvature

Hinge Length

☐ Relative Length

Load Carrying Capacity Beyond Point E

☒ Drops To Zero

☐ Is Extrapolated

Scaling for Moment and Rotation

☐ Use Yield Moment Moment SF 998295.3

☐ Use Yield Rotation Rotation SF 3.919E-03

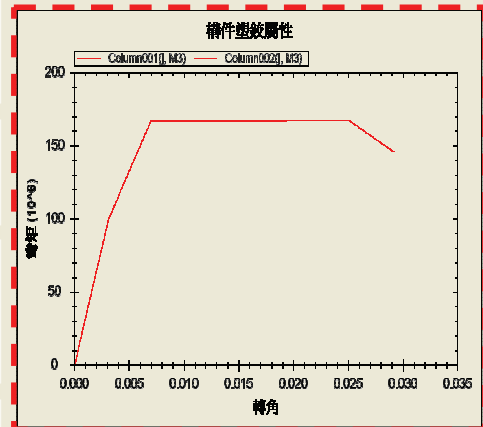
Acceptance Criteria (Plastic Rotation/SF)

☒ Immediate Occupancy 2.

☐ Life Safety 4.

☐ Collapse Prevention 6.

☐ Show Acceptance Criteria on Plot



OK

Cancel

側推分析-力量控制階段定義

Analysis Case Data - Nonlinear Static

Analysis Case Name: PUSHDL Set Def Name: Notes: Modify/Show...

Analysis Case Type: Static

Initial Conditions:

- ☒ Zero Initial Conditions - Start from Unstressed State
- ☐ Continue from State at End of Nonlinear Case

Important Note: Loads from this previous case are included in the current case

Modal Analysis Case:

All Modal Loads Applied Use Modes from Case: MODAL

Loads Applied:

Load Type	Load Name	Scale Factor
Load	DL1	1.
Load	DL1	1.
Load	DL2	1.

Add Modify Delete

Other Parameters:

Load Application: Full Load Modify/Show...

Results Saved: Final State Only Modify/Show...

Nonlinear Parameters: Default Modify/Show...

OK Cancel

Load Application Control for Nonlinear Static Analysis

Load Application Control:

- ☒ Full Load
- ☐ Displacement Control

Control Displacement:

- ☒ Use Conjugate Displacement
- ☐ Use Monitored Displacement

Load to a Monitored Displacement Magnitude of:

Monitored Displacement:

- ☒ DOF U1 at Joint 1
- ☐ Generalized Displacement

OK Cancel

側推分析-位移控制階段定義

Analysis Case Data - Nonlinear Static

Analysis Case Name: PUSHK Set Def Name: Modify/Show...

Notes: Modify/Show...

Analysis Case Type: Static

Initial Conditions:

- ☐ Zero Initial Conditions - Start from Unstressed State
- ☒ Continue from State at End of Nonlinear Case: PUSHDL

Important Note: Loads from this previous case are included in the current case.

Modal Analysis Case: All Modal Loads Applied Use Modes from Case: MODAL

Loads Applied:

Load Type	Load Name	Scale Factor
Load	EQX	1.
Load	EQX	1.

Buttons: Add, Modify, Delete

Geometric Nonlinearity Parameters:

- ☒ None
- ☐ P-Delta
- ☐ P-Delta plus Large Displacements

Other Parameters:

Load Application: Displ Control Modify/Show...

Results Saved: Multiple States Modify/Show...

Nonlinear Parameters: Default Modify/Show...

Buttons: OK, Cancel

Load Application Control for Nonlinear Static Analysis

Load Application Control:

- ☐ Full Load
- ☒ Displacement Control

Control Displacement:

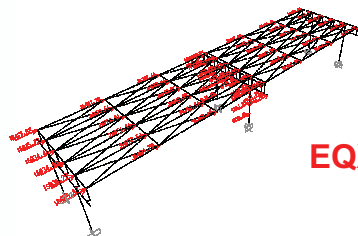
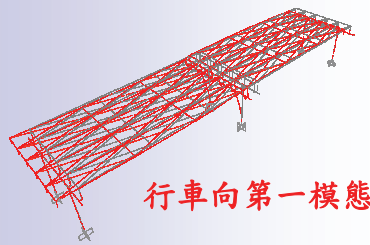
- ☐ Use Conjugate Displacement
- ☒ Use Monitored Displacement

Load to a Monitored Displacement Magnitude of: 20.

Monitored Displacement:

- ☒ DOF: U1 at Joint: 80
- ☐ Generalized Displacement

Buttons: OK, Cancel



規則性橋梁側力施加方式
可選擇分析方向之第一模態
或依規範定義之側向載重



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工址條件定義(*.PAP)

990506Y.PAP - 記事本

檔案(F) 編輯(E) 格式(O) 檢視(V) 說明(H)

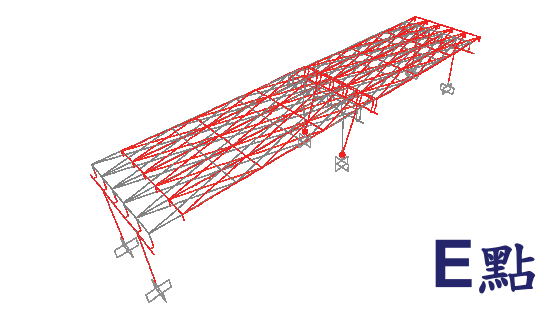
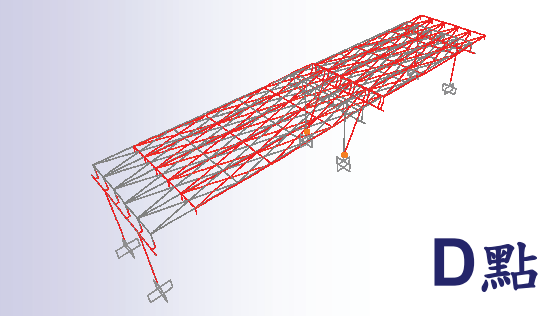
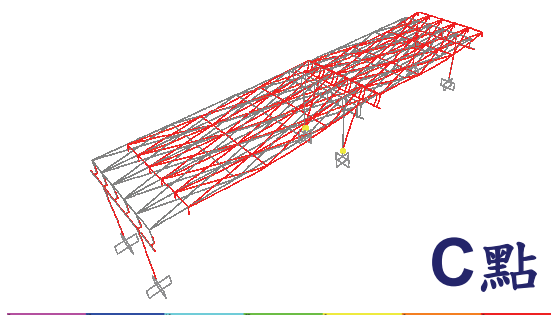
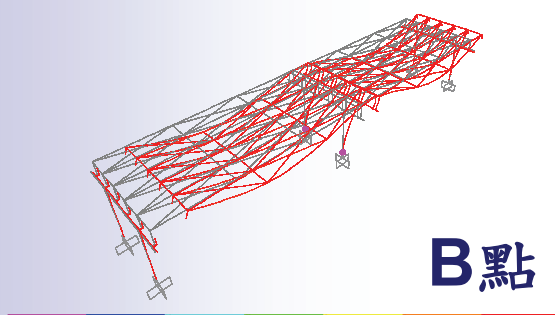
Location	Site Class	Seismicity	Importance	Design Earthquake	Design Earthquake	Design Earthquake
南投縣 草屯鎮 *	第三類地盤	1	1	49及76年版	重要橋樑	I=1.2
南投縣 草屯鎮 *	第三類地盤	1	2/3	49及76年版	重要橋樑	I=1.2
南投縣 草屯鎮 *	第三類地盤	1	1/3	49及76年版	重要橋樑	I=1.2



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側推分析塑性鉸發展



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側推分析曲線資料輸出 (*.BFD)

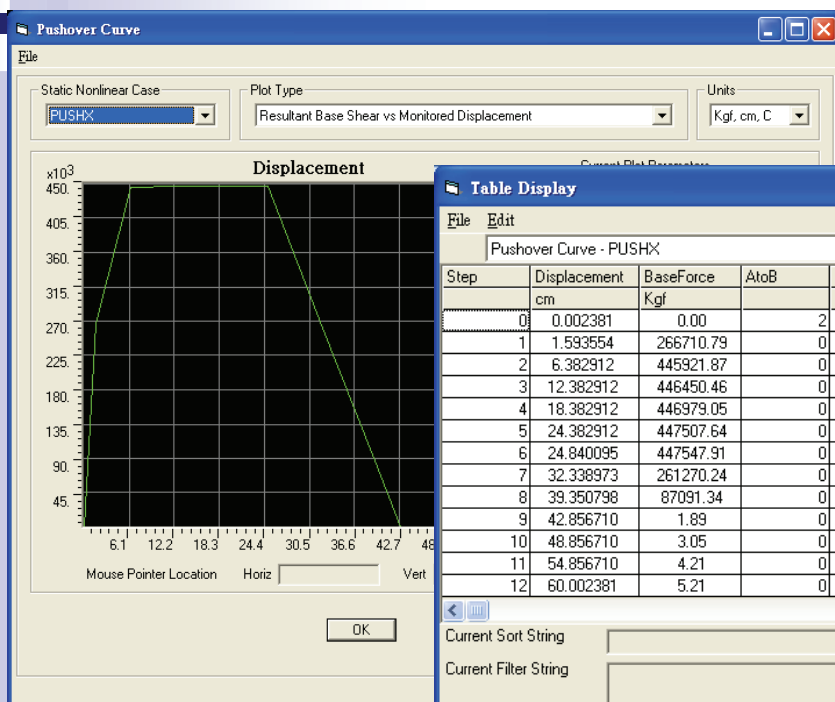


Table Display

Pushover Curve - PUSHX

Step	Displacement cm	BaseForce Kgf	AtoB	BtoD	DtoLS	LStoCP	CF
0	0.002381	0.00	2	0	0	0	0
1	1.593554	266710.79	0	2	0	0	0
2	6.382912	445921.87	0	0	0	0	0
3	12.382912	446450.46	0	0	0	0	0
4	18.382912	446979.05	0	0	0	0	0
5	24.382912	447507.64	0	0	0	0	0
6	24.840095	447547.91	0	0	0	0	0
7	32.338973	261270.24	0	0	0	0	0
8	39.350798	87091.34	0	0	0	0	0
9	42.856710	1.89	0	0	0	0	0
10	48.856710	3.05	0	0	0	0	0
11	54.856710	4.21	0	0	0	0	0
12	60.002381	5.21	0	0	0	0	0

Current Sort String
Current Filter String

990507_760.BFD - 記事本

Units: kgf-cm

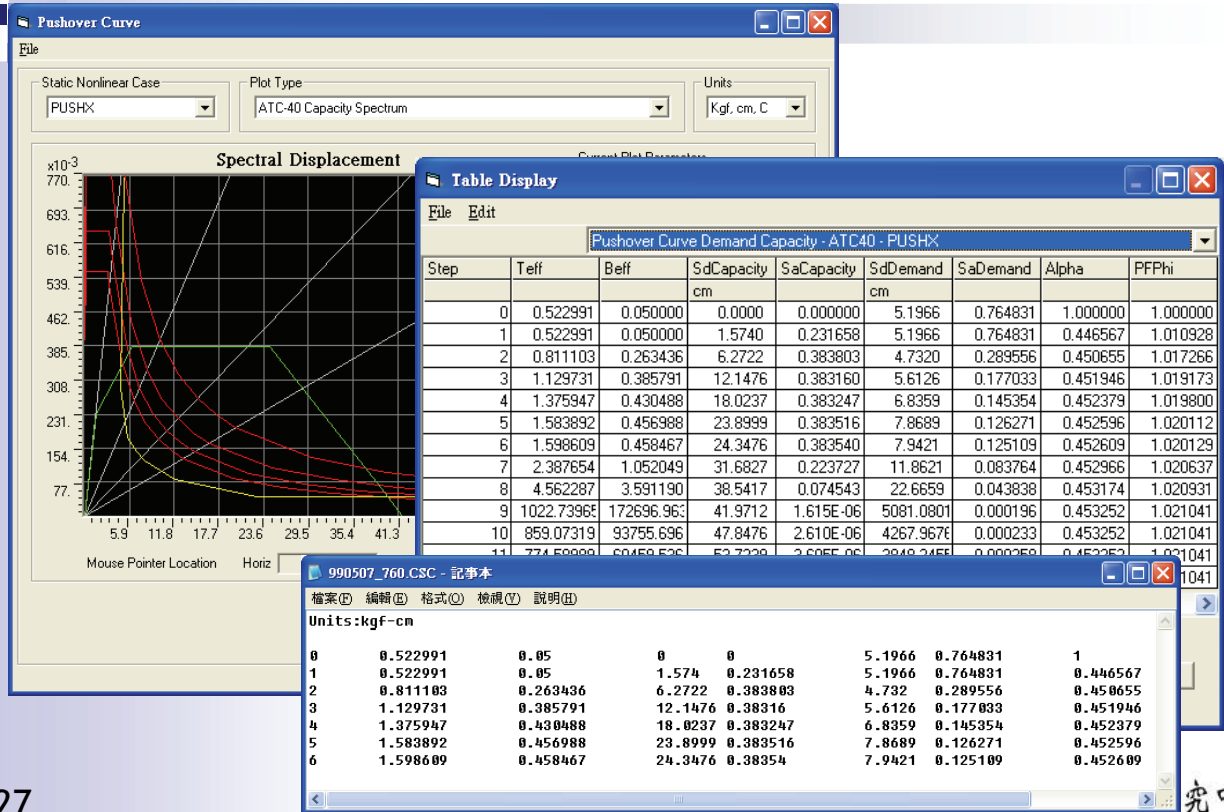
0	0.002381	0
1	1.593554	266710.79
2	6.382912	445921.87
3	12.382912	446450.46
4	18.382912	446979.05
5	24.382912	447507.64
6	24.840095	447547.91

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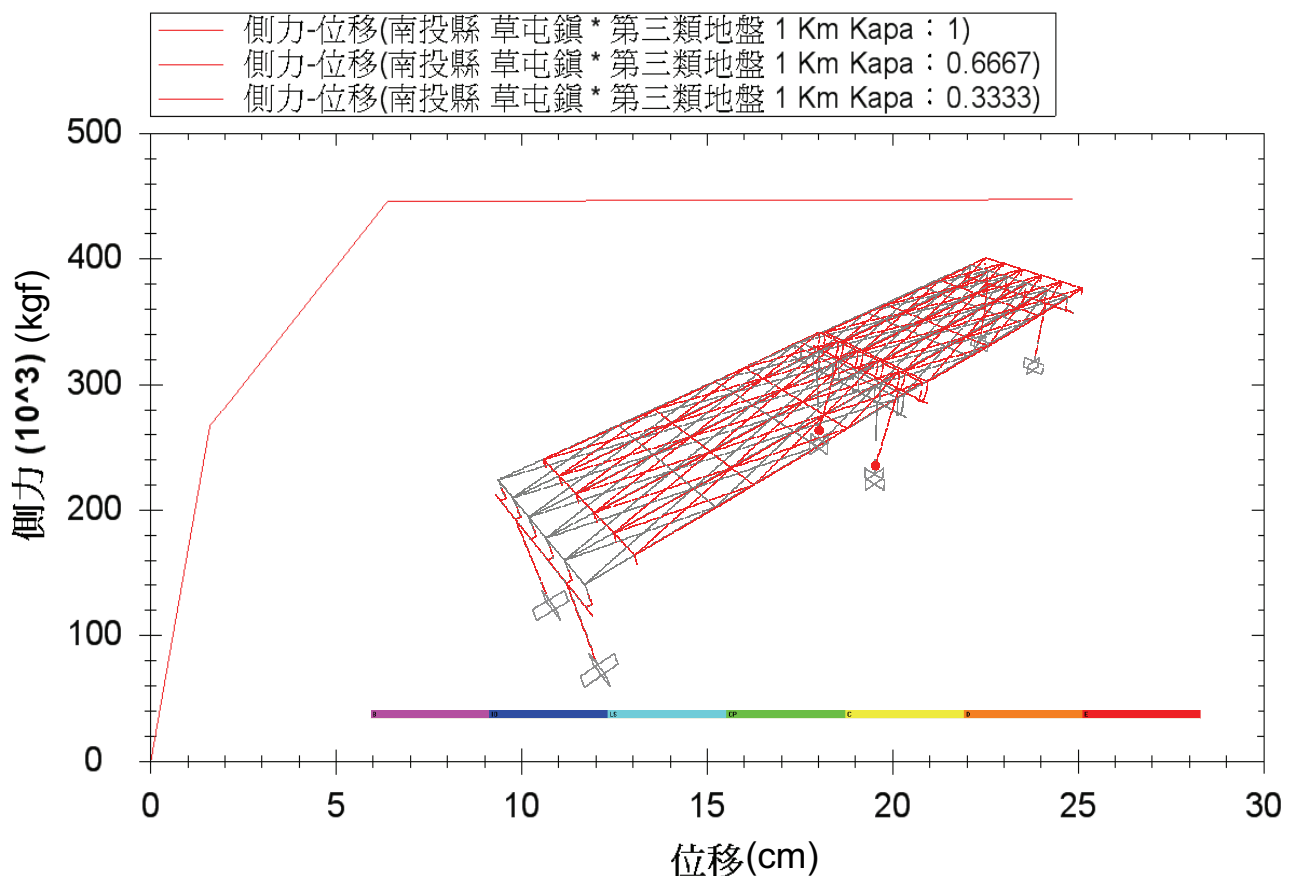
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容量震譜曲資料輸出(*.CSC)

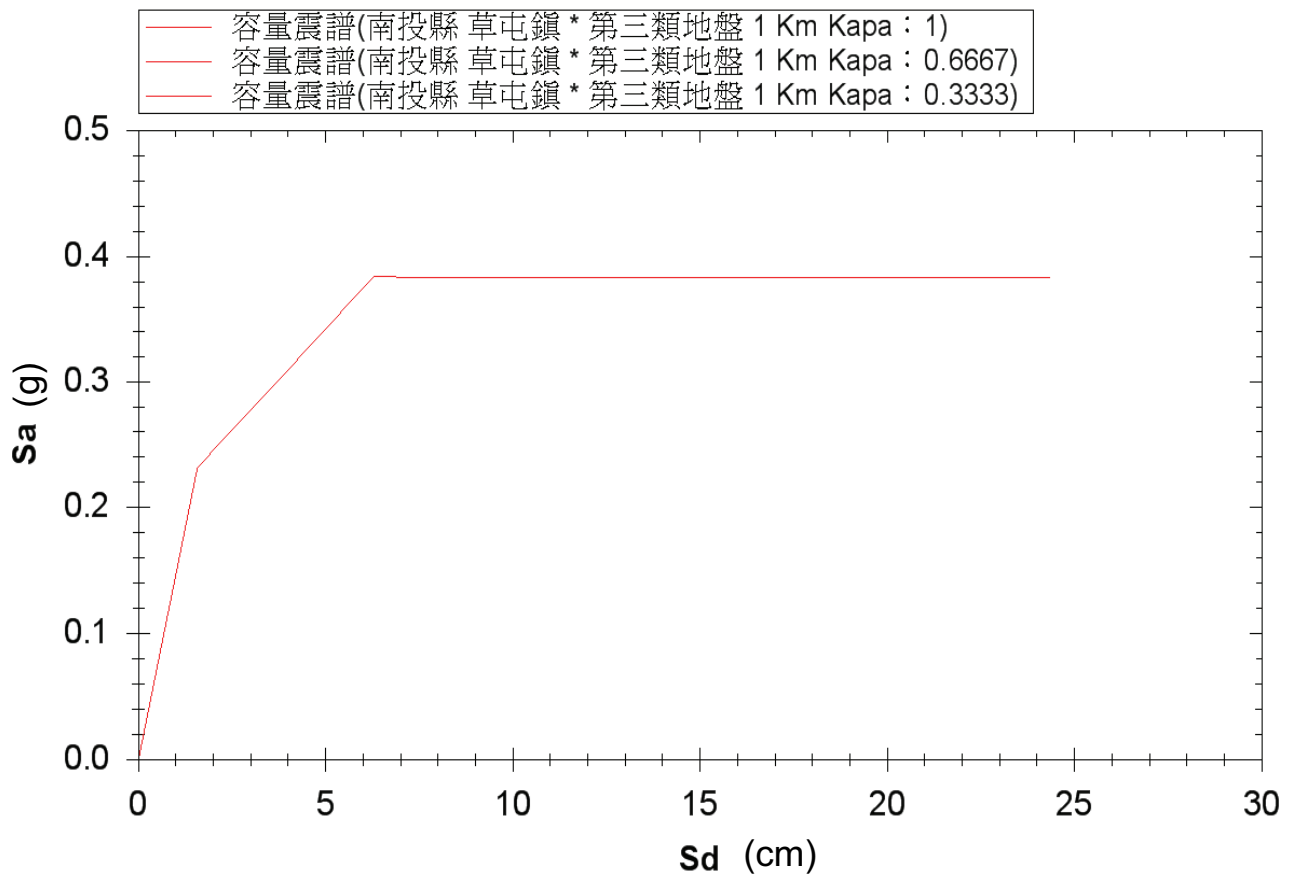


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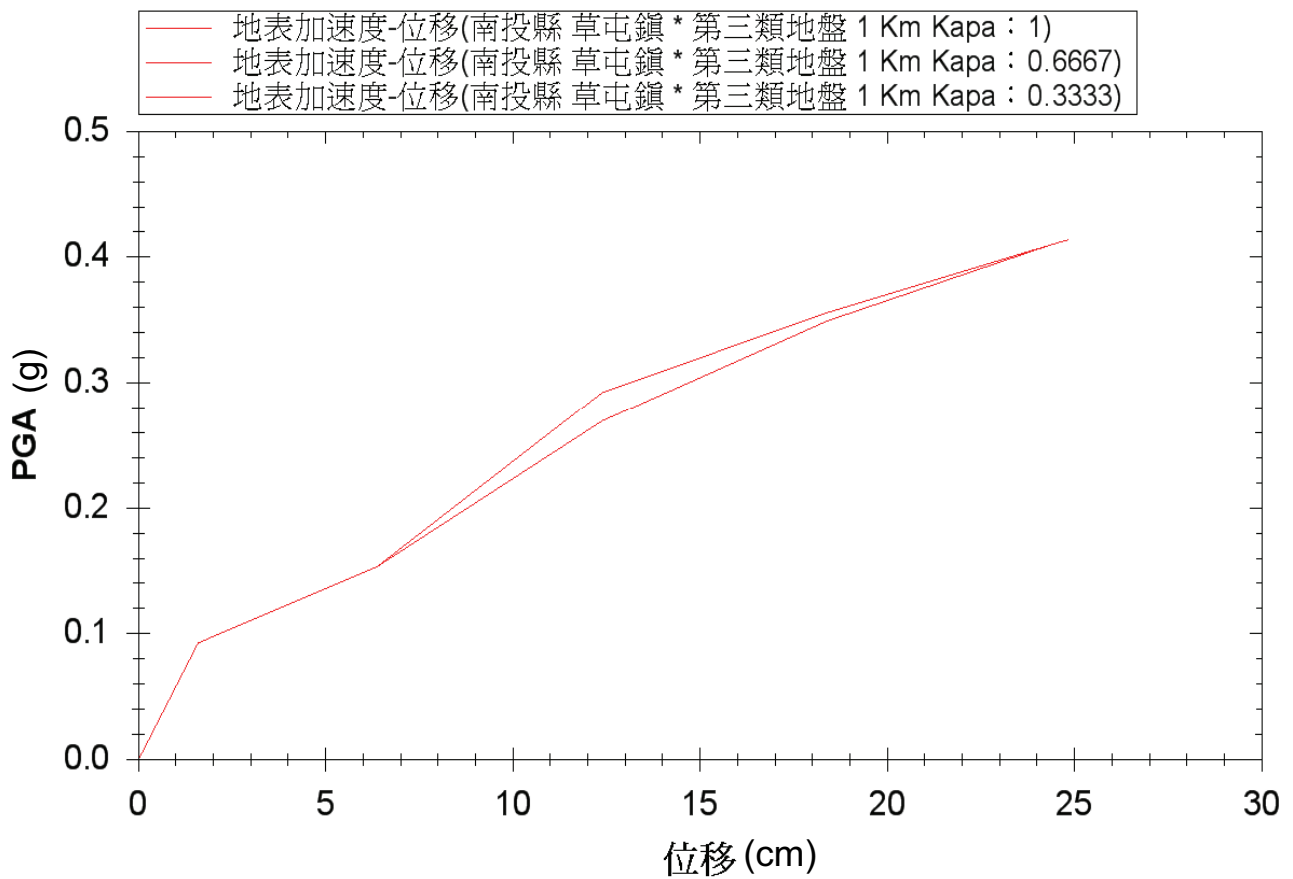
側力-位移



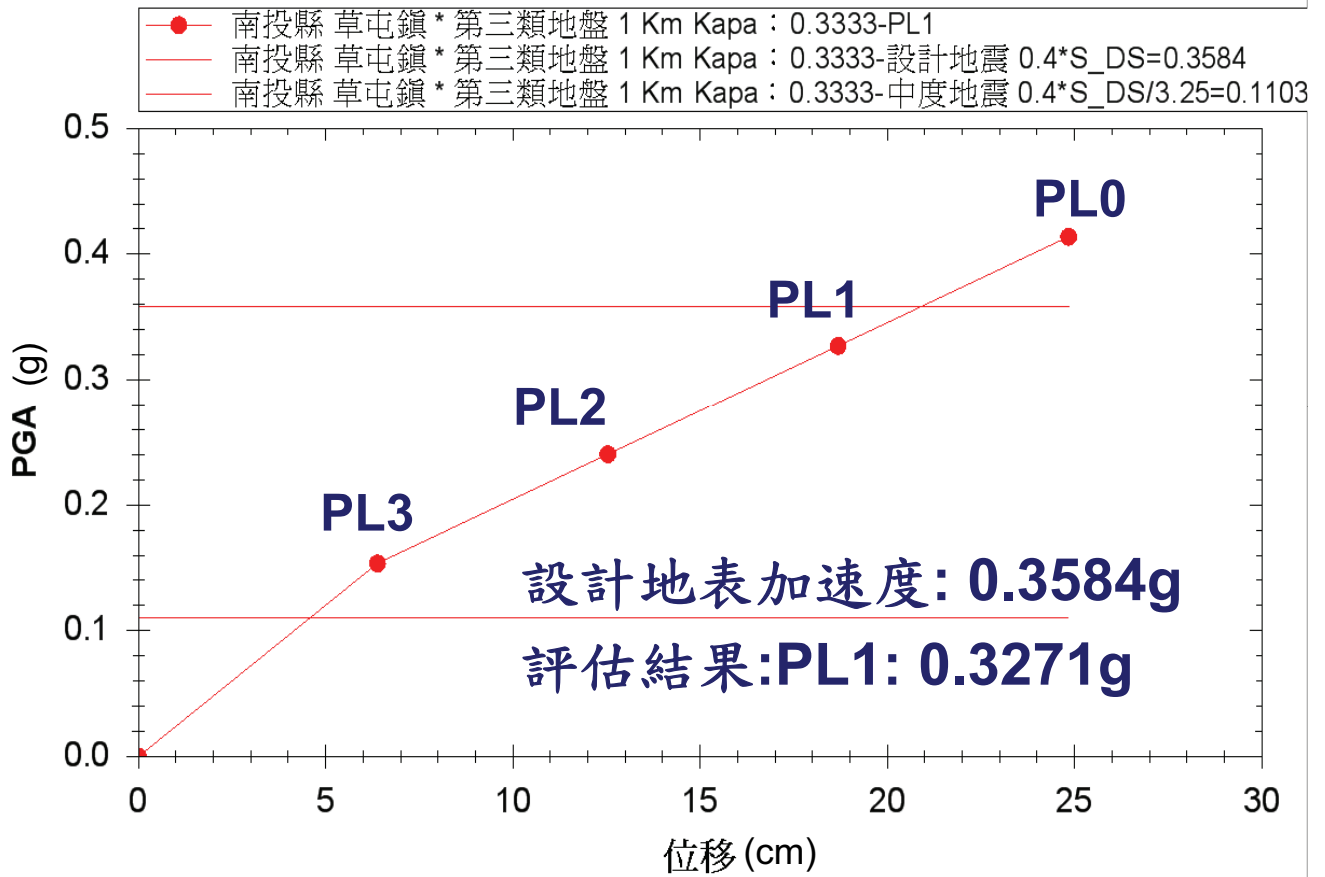
容量震譜



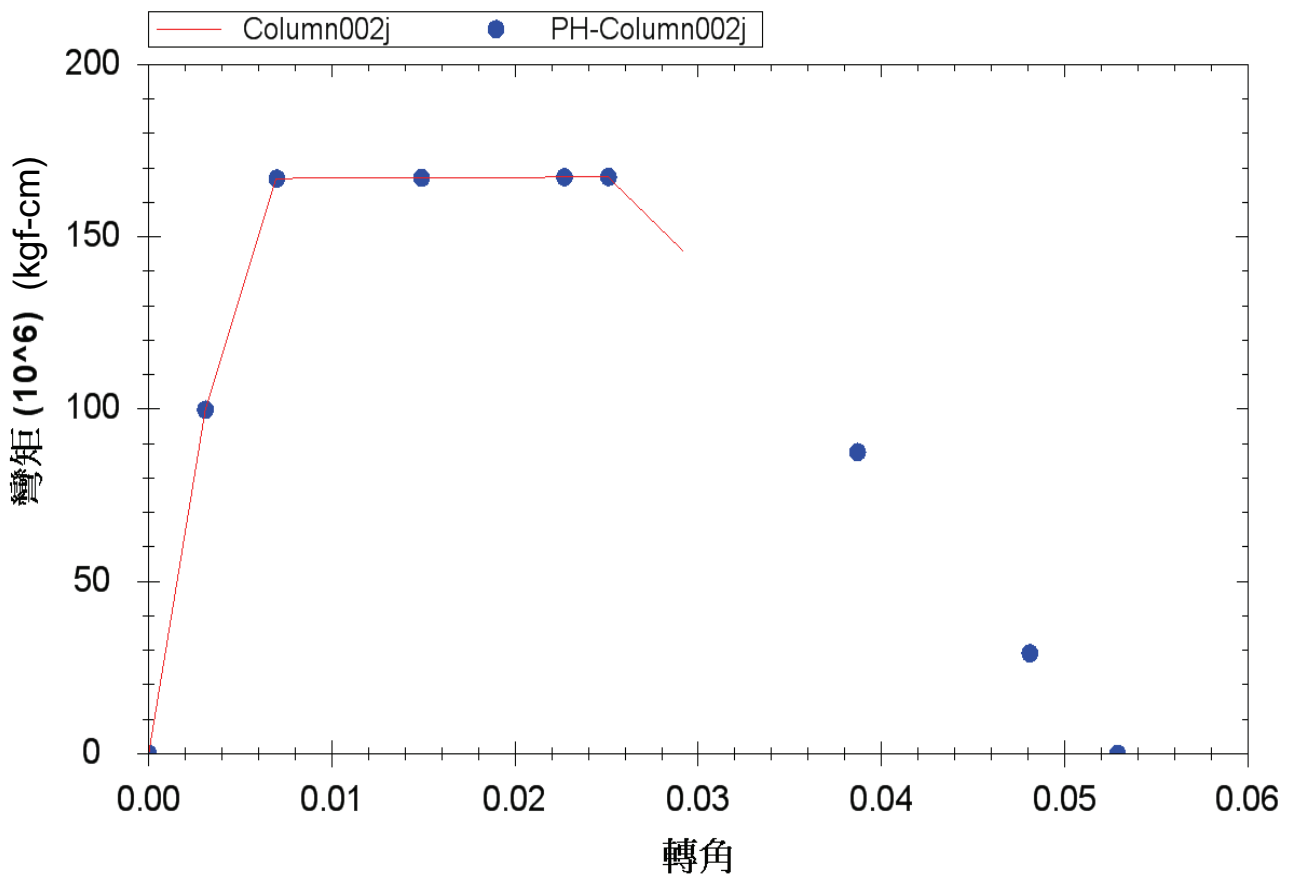
地表加速度-位移



性能目標

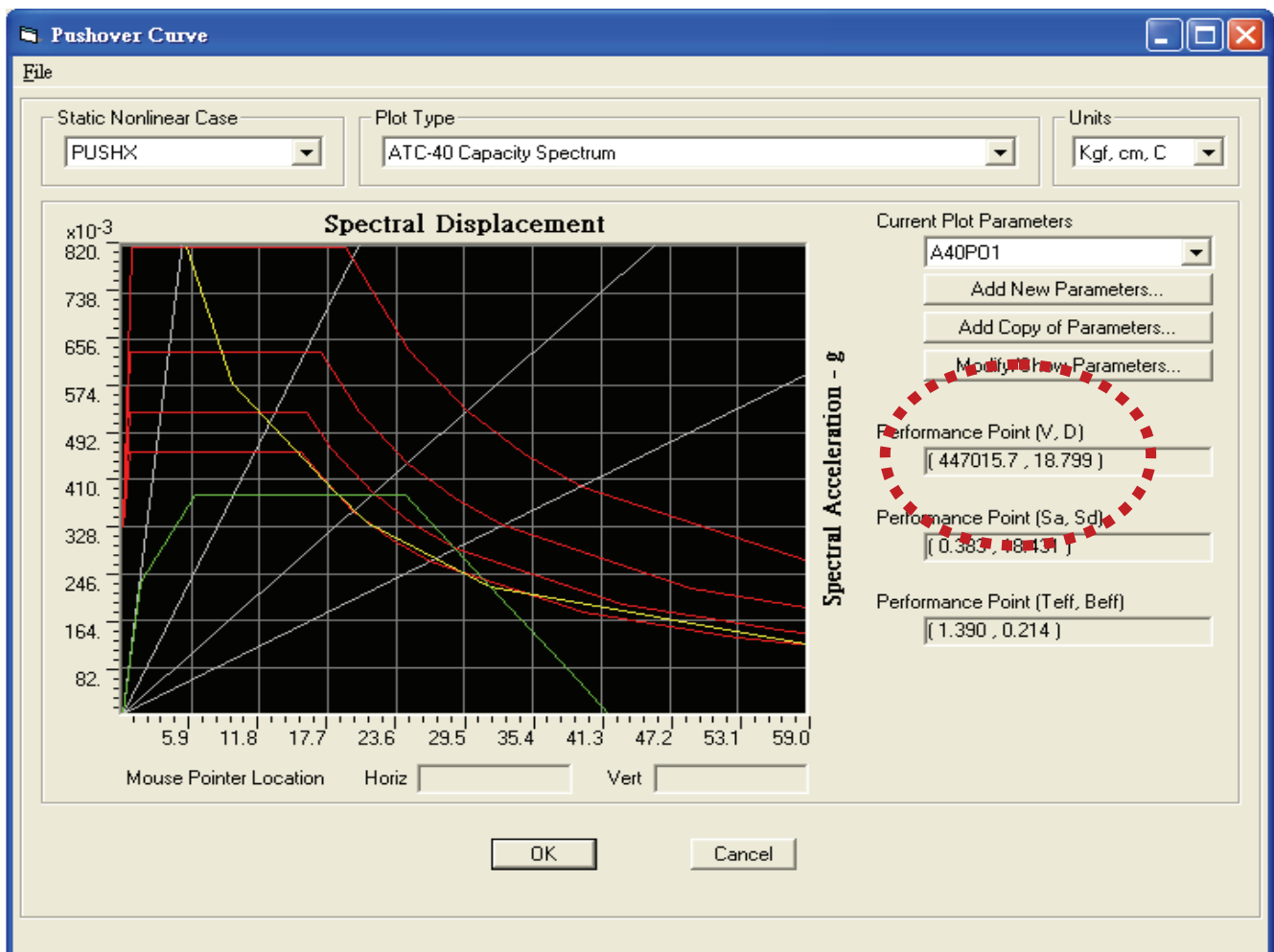
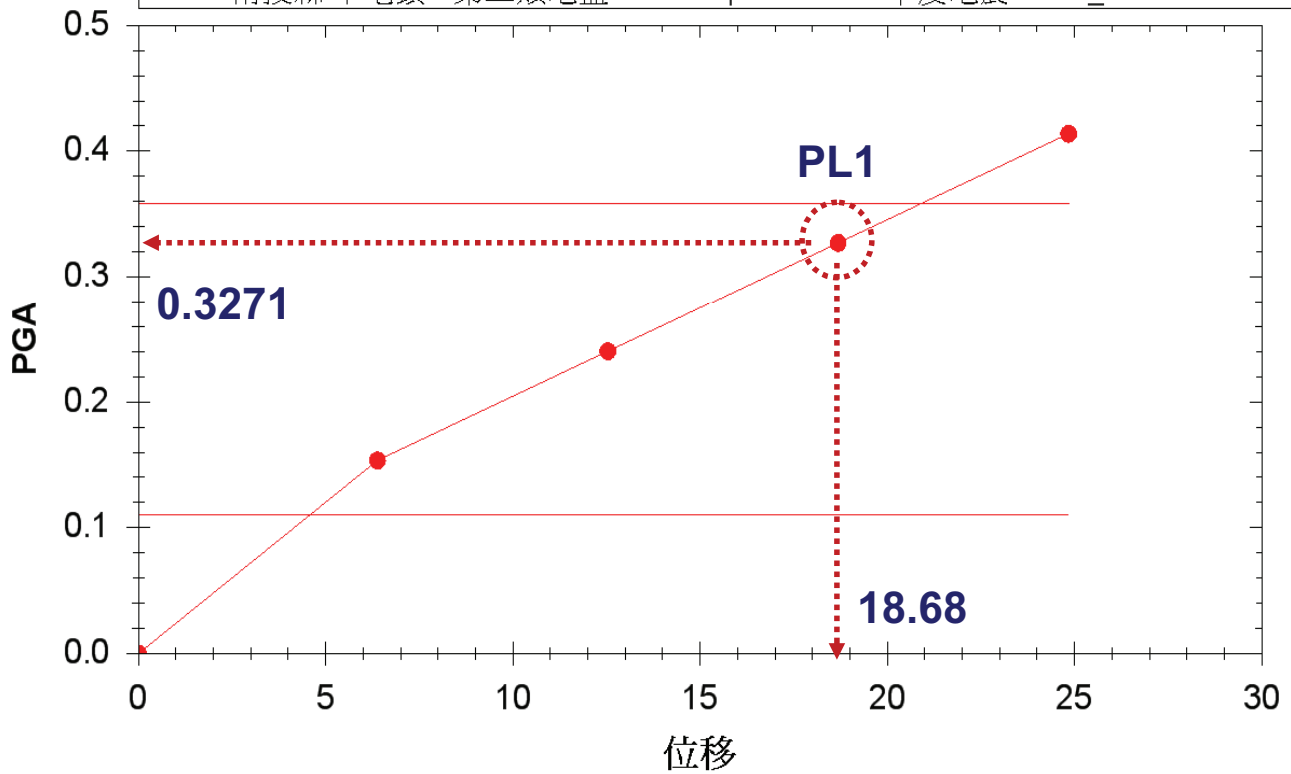


構件塑鉸發展狀態



性能目標

- 南投縣 草屯鎮 * 第三類地盤 1 Km Kapa : 0.3333-PL1
- 南投縣 草屯鎮 * 第三類地盤 1 Km Kapa : 0.3333-設計地震 $0.4 \cdot S_{DS} = 0.3584$
- 南投縣 草屯鎮 * 第三類地盤 1 Km Kapa : 0.3333-中度地震 $0.4 \cdot S_{DS} / 3.25 = 0.1103$



Parameters For ATC-40 Capacity Spectrum

Pushover Parameters Name
Name: A40PD1 Units: Kgf, cm, C

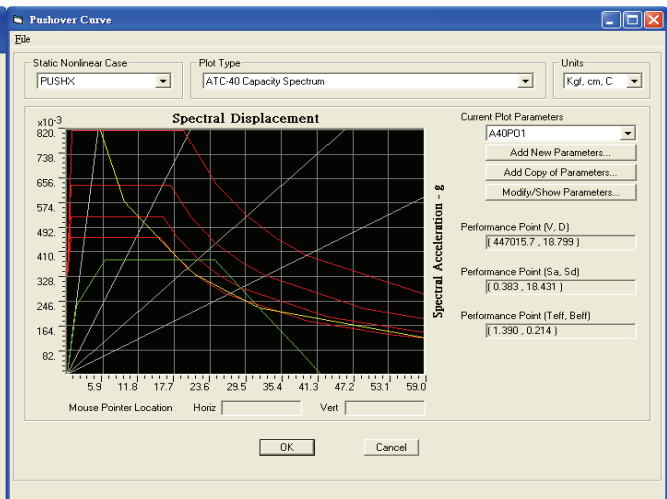
Plot Axes
☒ Sa - Sd ☐ Sa - T ☐ Sd - T Set Axis Data...

Demand Spectrum Definition
☐ Function ☒ User Coeffs Ca: 0.3271 Cv: 0.7965

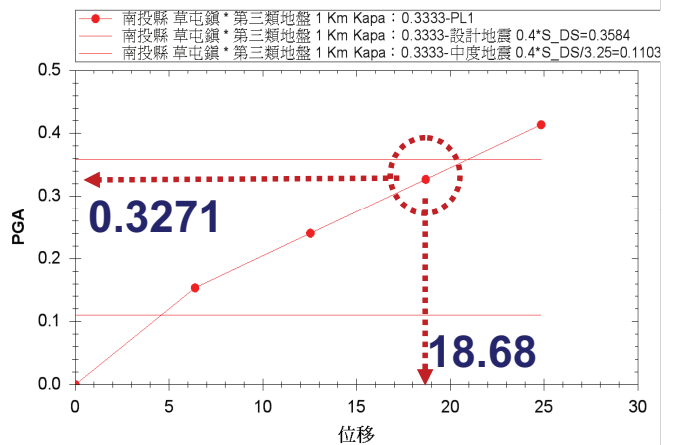
Damping Parameters Definition
Inherent + Additional Damping: 0.05
Structural Behavior Type: ☒ A ☐ B ☒ C ☐ User Modify/Show...

Items Visible On Plot
☒ Show Capacity Curve Color: █
☒ Show Family of Demand Spectra Color: █
Damping Ratios: 0.05 0.1 0.15 0.2
☒ Show Single Demand Spectrum (ADRS) (Variable Damping) Color: █
☒ Show Constant Period Lines at 0.5 1. 1.5 2. Color: █
Reset Default Colors

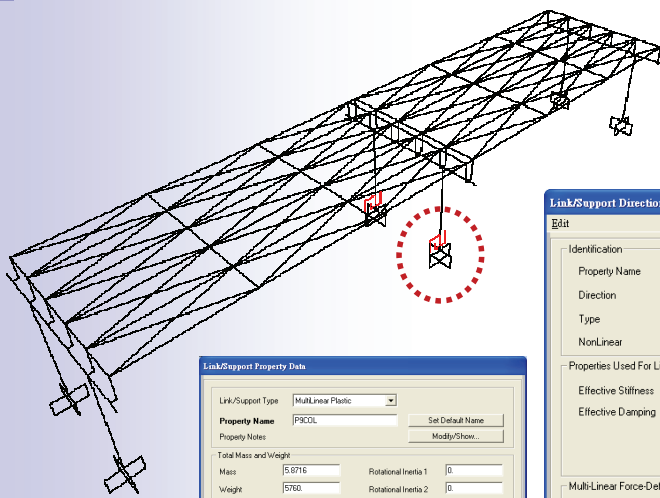
Update Plot
OK Cancel



性能目標



橋柱非線性元素設定



RC橋柱採用Takeda模式
非線性元素長度等於塑鉸區長度

Link/Support Property Data

Link/Support Type: MultiLinear Plastic
Property Name: PRCOL Set Default Name
Property Notes: Modify/Show...

Total Mass and Weight
Mass: 5.6716 Rotational Inertia 1: 0
Weight: 5760 Rotational Inertia 2: 0
Rotational Inertia 3: 0

Factors For Line, Area and Solid Springs
Property is Defined for This Length in a Line Spring: 1
Property is Defined for This Area in Area and Solid Springs: 1

Directional Properties
Direction: Fixed Non-Linear Properties
☒ U1 ☒ U2 ☒ U3 ☒ R1 ☒ R2 ☒ R3
Fix All Clear All

OK Cancel

Link/Support Directional Properties

Identification
Property Name: PRCOL
Direction: R3
Type: MultiLinear Plastic
NonLinear: Yes

Properties Used For Linear Analysis Cases
Effective Stiffness: 1.834E+10
Effective Damping: 0

Hysteresis Type And Parameters
Hysteresis Type: Takeda
No Parameters Are Required For This Hysteresis Type

Hysteresis Definition Sketch
MultiLinear Plastic - Takeda

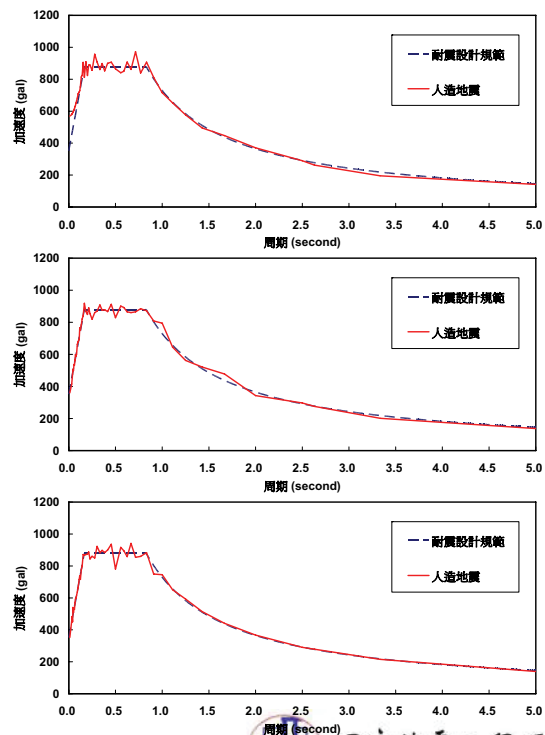
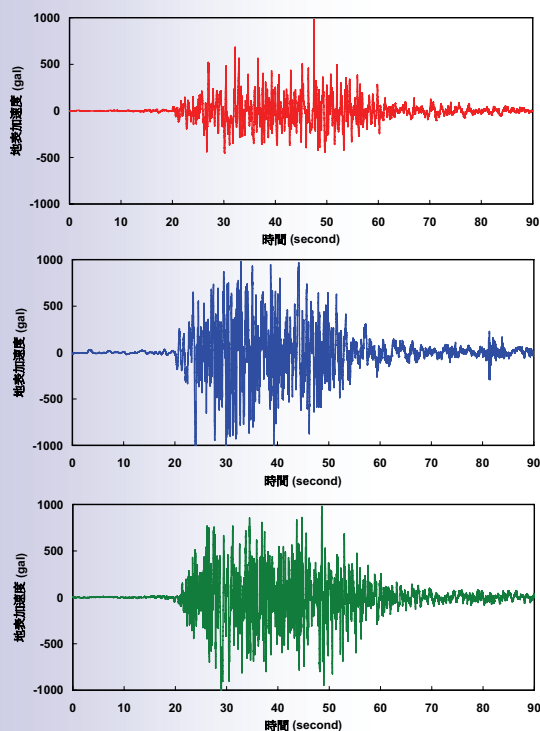
Multi-Linear Force-Deformation Definition

Rotation	Moment
1 -0.0338	-1.630E+08
2 -0.0331	-1.675E+08
3 -8.814E-03	-1.669E+08
4 0	0
5 8.814E-03	1.669E+08

Order Rows Delete Row Add Row 8

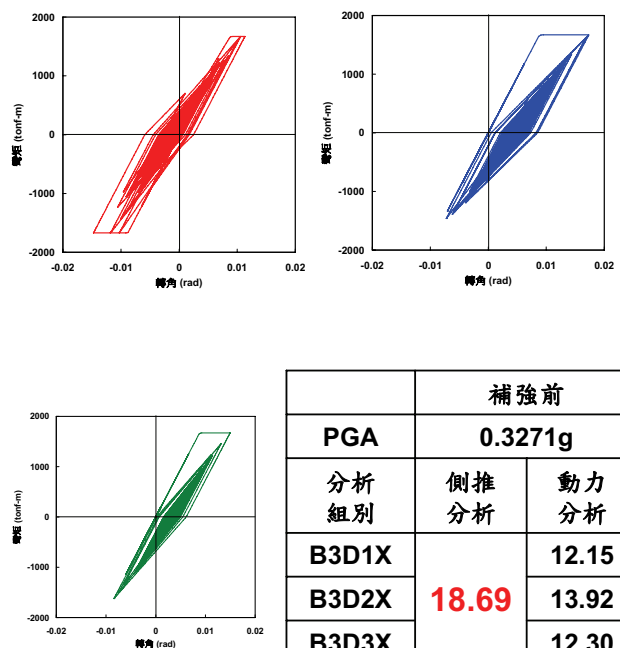
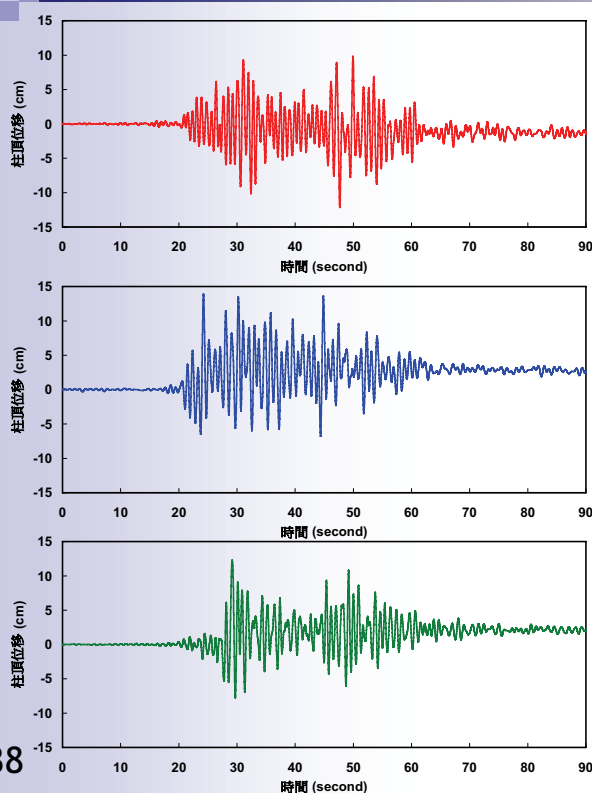
OK Cancel

人造地震加速度歷時



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橋柱最大位移及塑性鉸遲滯迴圈



	補強前	
PGA	0.3271g	
分析組別	側推分析	動力分析
B3D1X	18.69	12.15
B3D2X		13.92
B3D3X		12.30

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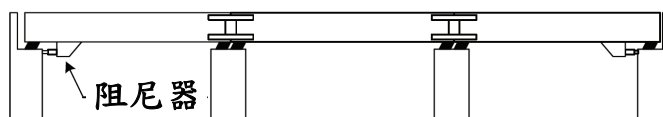
減震補強工法準則條文與解說

5.1.4 減震補強工法

橋梁使用消能元件進行減震補強，參考 97 年版公路橋梁耐震設計規範相關規定進行減震設計。減震補強如圖 5-4 所示。

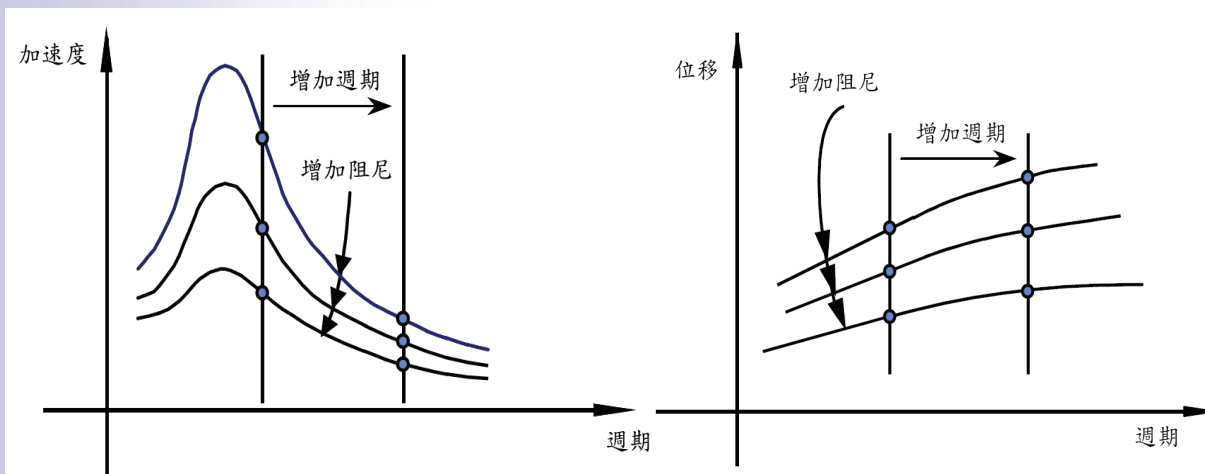
【解說】：

減震補強依據交通部 97 年版公路橋梁耐震設計規範第七章之規定，進行消能系統之設計與檢核。消能元件之分析應包括消能元件之特性及其平面與立面之配置，且應能反映振動頻率、環境及溫度等因素之影響。所有消能元件之力學特性須經試驗驗證與設計參數相符。

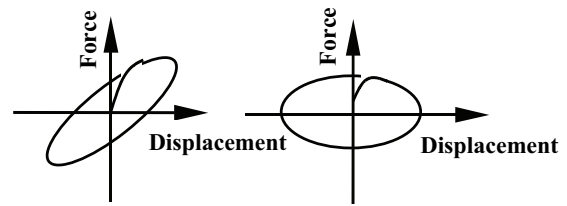


單自由度運動方程式

$$m\ddot{u} + \boxed{c\dot{u}} + ku = -m\ddot{u}_g$$



液態線性黏滯型阻尼器簡介



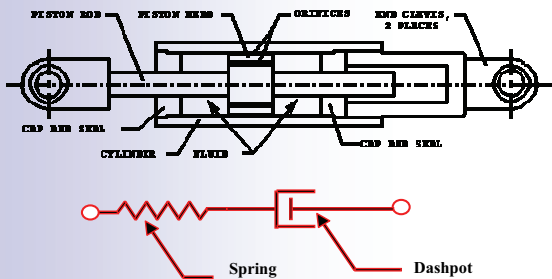
固態或液態黏彈性元件 液態黏滯元件

速度型消能元件之理想化受力與變形關係圖

阻尼力產生之機制：

活塞兩側液體之壓力差

改變液體之流動特性 →
產生不同之阻尼力性質

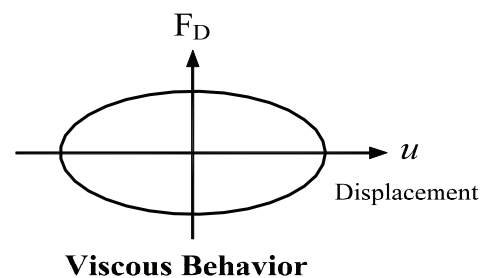
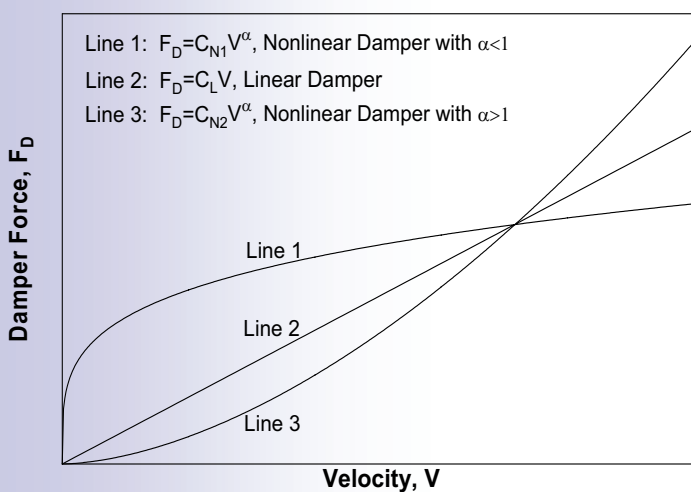


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液態線性黏滯型阻尼器力學行為



- ◆ 不具儲存勁度
- ◆ 不干擾結構之自然頻率
- ◆ 設計較為簡便
- ◆ 具90度之力-位移相位差

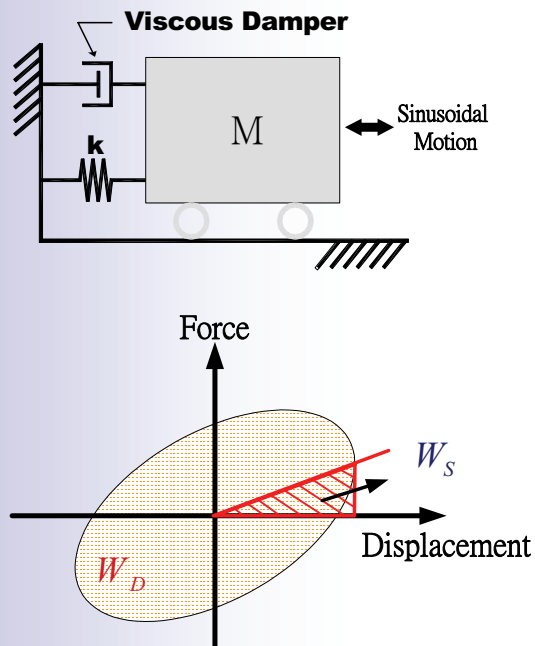
$$F_D = C |\dot{u}|^\alpha \text{sgn}(\dot{u})$$

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線性黏性阻尼器之等效阻比(FEMA規範)



$$\xi_d = \frac{W_D}{4\pi W_S}$$

MDOF: $\xi_{eff} = \xi_o + \frac{\sum W_j}{4\pi W_k}$

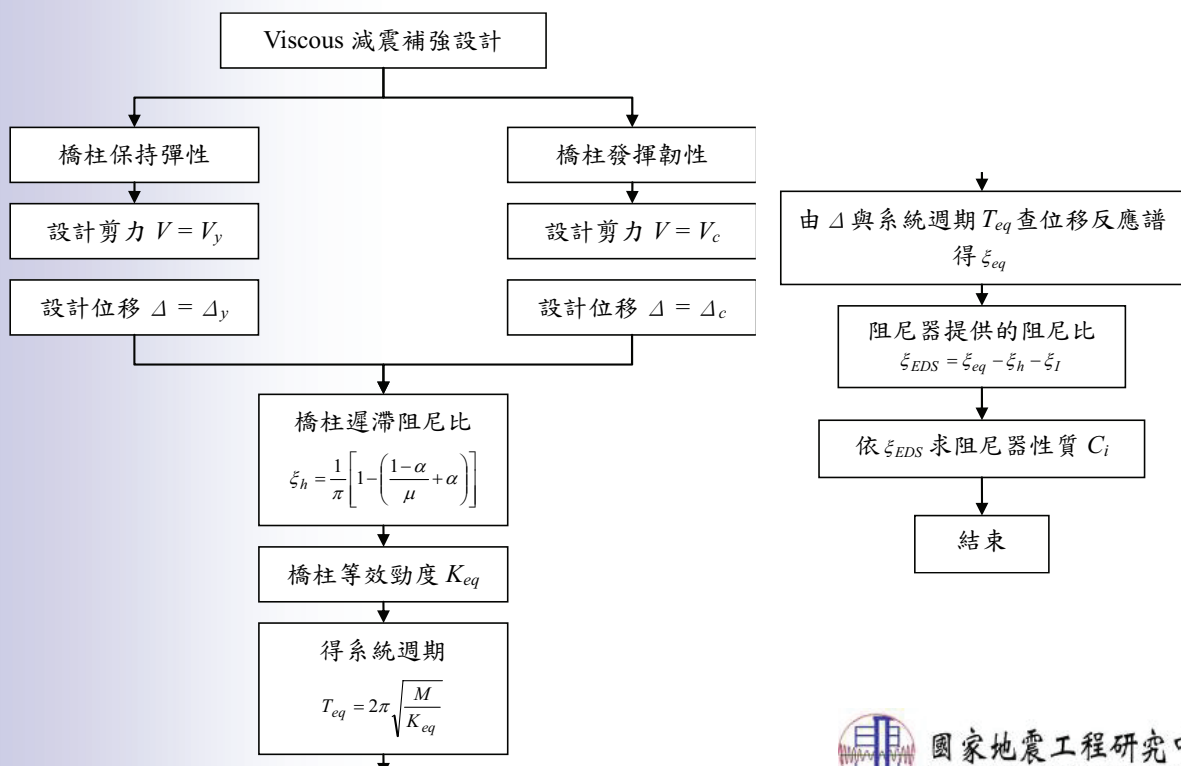
$$\xi_{eff} = \xi_o + \frac{T \sum C_j f_j^2 \phi_{rj}^2}{4\pi \sum m_i \phi_i^2}$$

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減震補強位移設計法



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簡化近似分析法

Table Display

Pushover Curve Demand Capacity - ATC40 - PUSHX

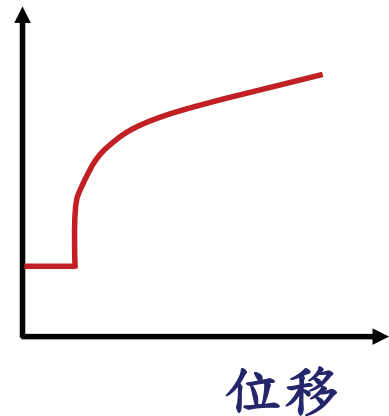
Step	Teff	Beff	SdCapacity	SaCapacity	SdDemand	SaDemand	Alpha	PFPphi
0	0.522991	0.050000	0.0000	0.000000	5.1966	0.764831	1.000000	1.000000
1	0.522991	0.050000	1.5740	0.231658	5.1966	0.764831	0.446567	1.010928
2	0.811103	0.200504	6.2722	0.383803	5.2787	0.323007	0.450655	1.017266
3	1.129731	0.282745	12.1476	0.383160	6.3936	0.201667	0.451946	1.019173
4	1.375947	0.311894	18.0237	0.383247	7.6562	0.162797	0.452379	1.019800
5	1.583892	0.330135	23.8999	0.383516	8.8132	0.141424	0.452596	1.020112
6	1.598609	0.331153	24.3476	0.383540	8.8951	0.140122	0.452609	1.020129
7	2.387654	0.739722	31.6827	0.223727	13.2856	0.093816	0.452966	1.020637
8	4.562287	2.487443	38.5417	0.074543	25.3858	0.049098	0.453174	1.020931
9	1022.7396	118869.354	41.9712	1.615E-06	5690.8097	0.000219	0.453252	1.021041
10	859.07319	64533.157	47.8476	2.610E-06	4780.1237	0.000261	0.453252	1.021041
11	774.58989	41615.021	53.7239	3.605E-06	4310.0350	0.000289	0.453252	1.021041
12	728.48217	30765.4526	58.7635	4.458E-06	4053.4787	0.000307	0.453252	1.021041

Current Sort String

Current Filter String

Done

等效阻尼比



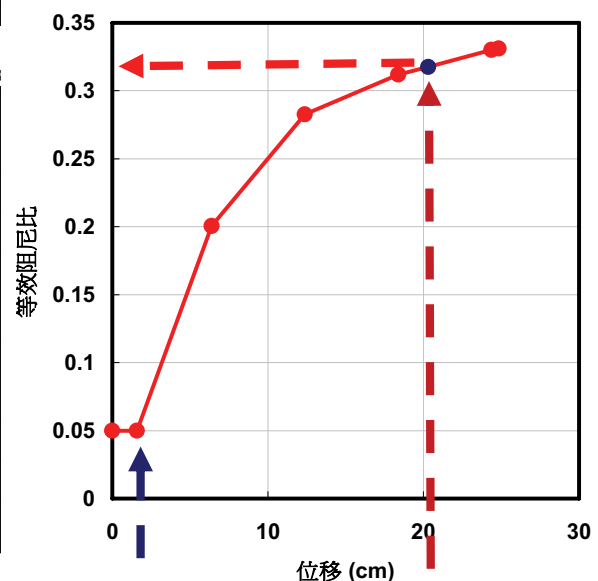
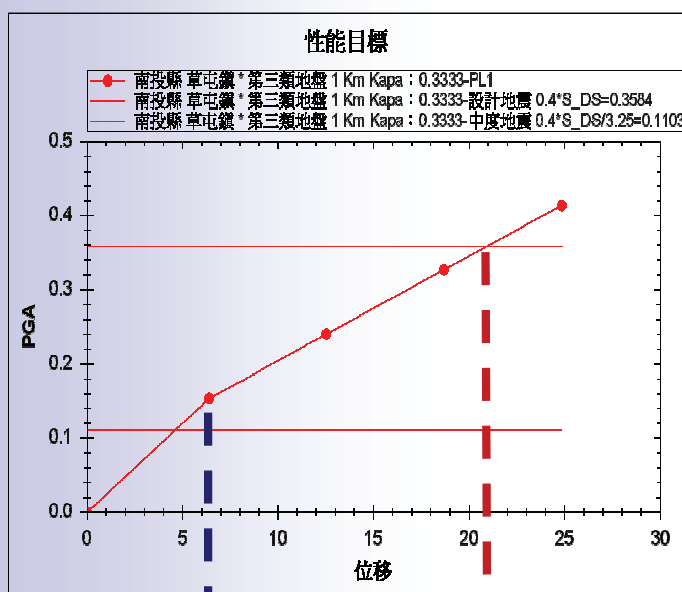
輸出容量震譜資料(結構類型 K=2/3)

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補強方案一：0.4S_{DS}結構保持彈性

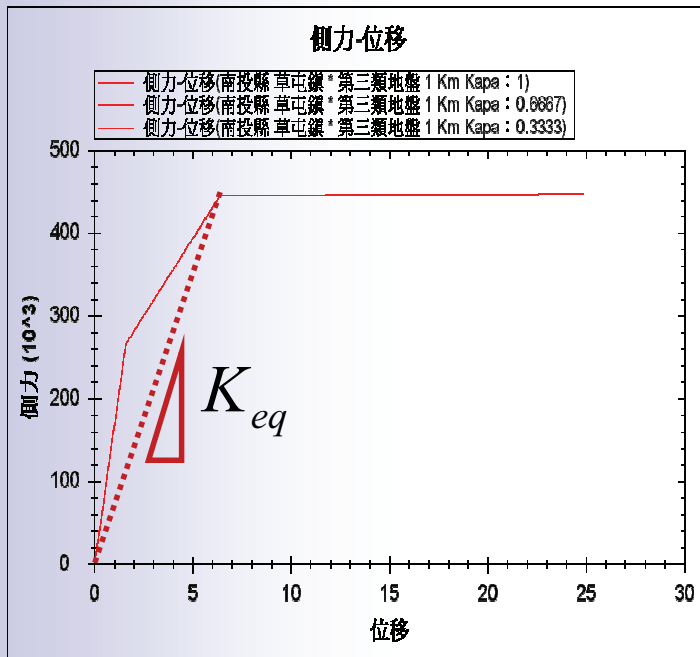


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補強方案一計算流程



$$K_{eq} = \frac{V}{D} = \frac{445922}{6.38} = 69861$$

$$M = \left(\frac{T}{2\pi} \right)^2 K_{eq}$$

$$= \left(\frac{0.8111}{2\pi} \right)^2 \times 69861 = 1163.92$$

$$\zeta_{EDS} = \frac{T \sum c_i \phi_{i,j}^2}{4\pi \sum \phi_i M \phi_i}$$

$$0.2678 \approx \frac{0.8111 \times 4 \times c \times 1^2}{4\pi \times 1 \times 1163.92 \times 1}$$

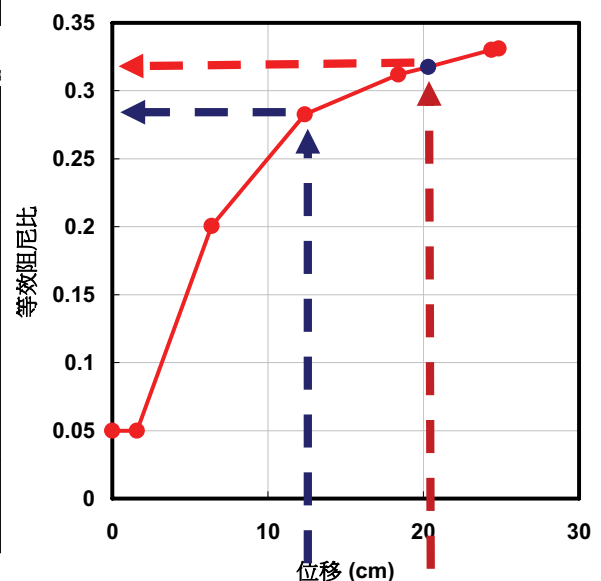
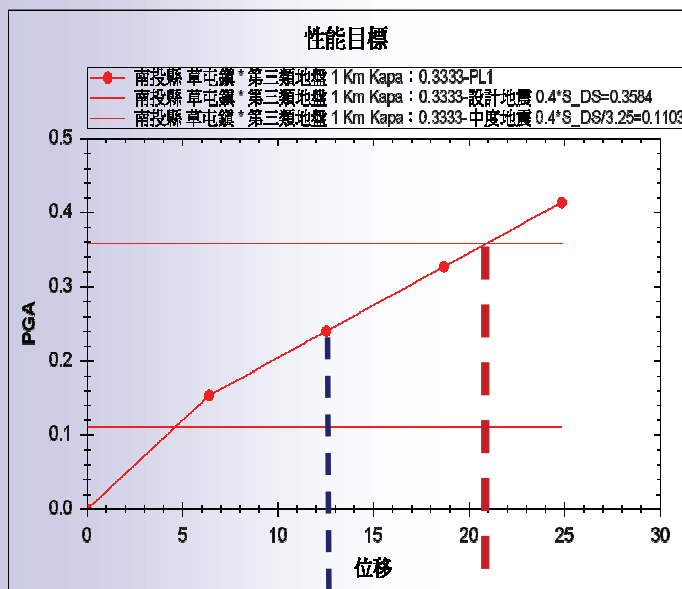
$$\Rightarrow c = 1207$$

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補強方案二: 0.4S_{DS}結構發揮韌性

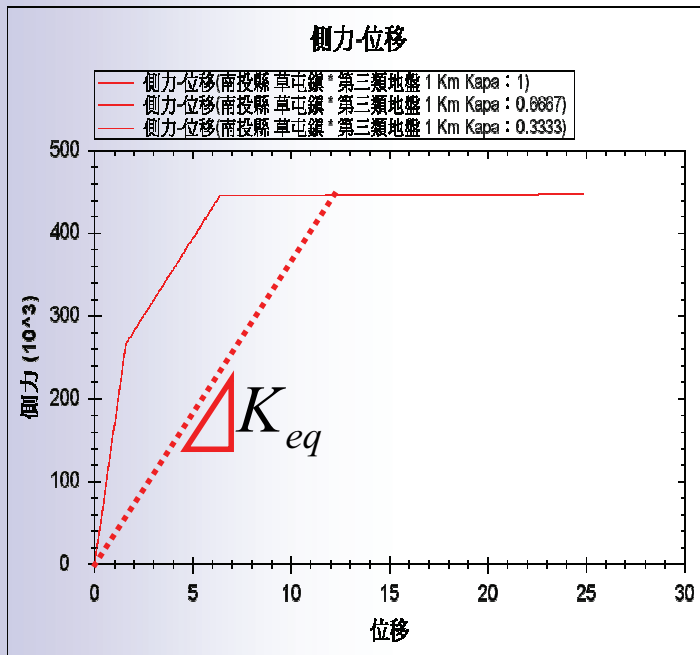


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補強方案二計算流程



$$K_{eq} = \frac{V}{D} = \frac{446450}{12.38} = 36053$$

$$M = \left(\frac{T}{2\pi} \right)^2 K_{eq}$$

$$= \left(\frac{1.1297}{2\pi} \right)^2 \times 36053 = 1165$$

$$\zeta_{EDS} = \frac{T \sum c_i \phi_{i,j}^2}{4\pi \sum \phi_i M \phi_i}$$

$$0.035 \approx \frac{1.1297 \times 4 \times c \times 1^2}{4\pi \times 1 \times 1165 \times 1}$$

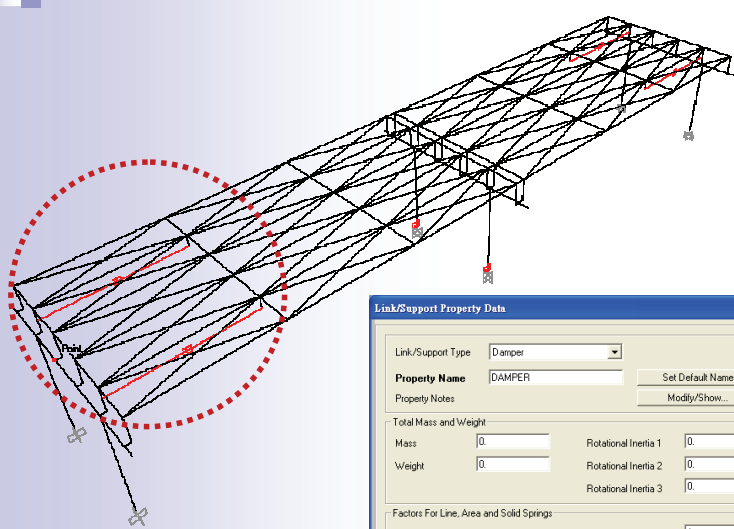
$$\Rightarrow c = 113$$

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阻尼器非線性元素設定



Link/Support Directional Properties

Identification

Property Name: DAMPER

Direction: U1

Type: Damper

NonLinear: Yes

Properties Used For Linear Analysis Cases

Effective Stiffness: 0.

Effective Damping: 0.

Properties Used For Nonlinear Analysis Cases

Stiffness: 1.000E+10

Damping Coefficient: 113.

Damping Exponent: 1.

Spring

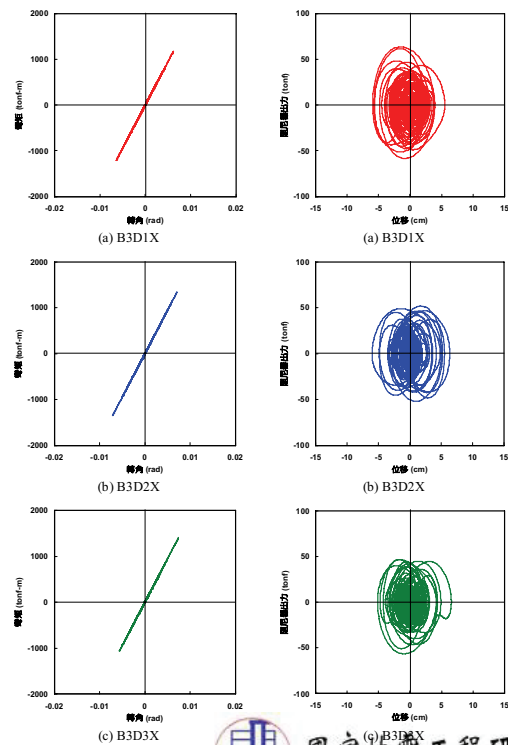
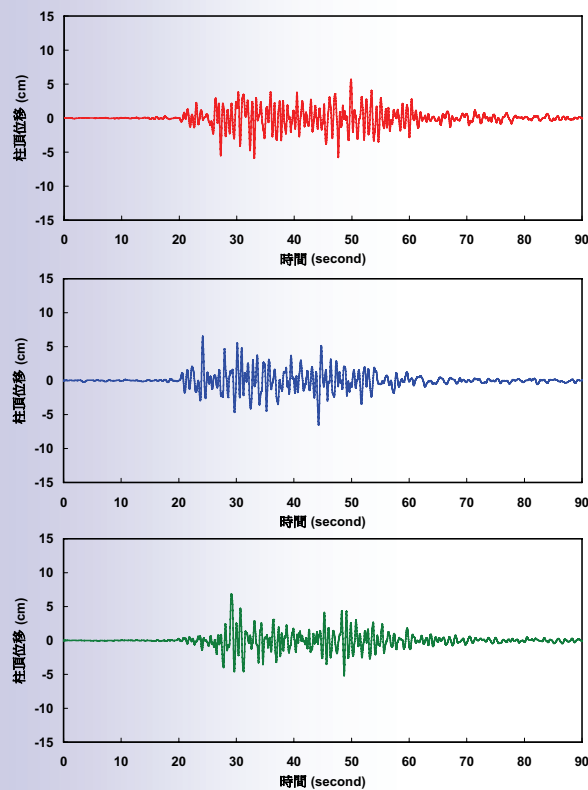
Dashpot

OK

Cancel

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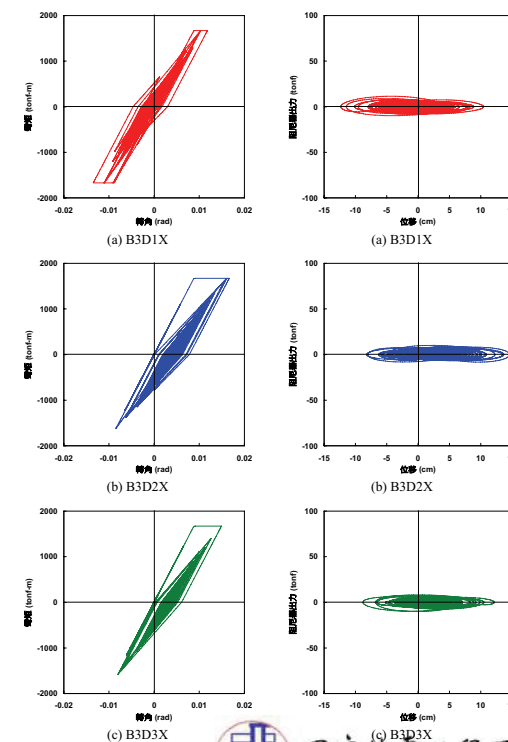
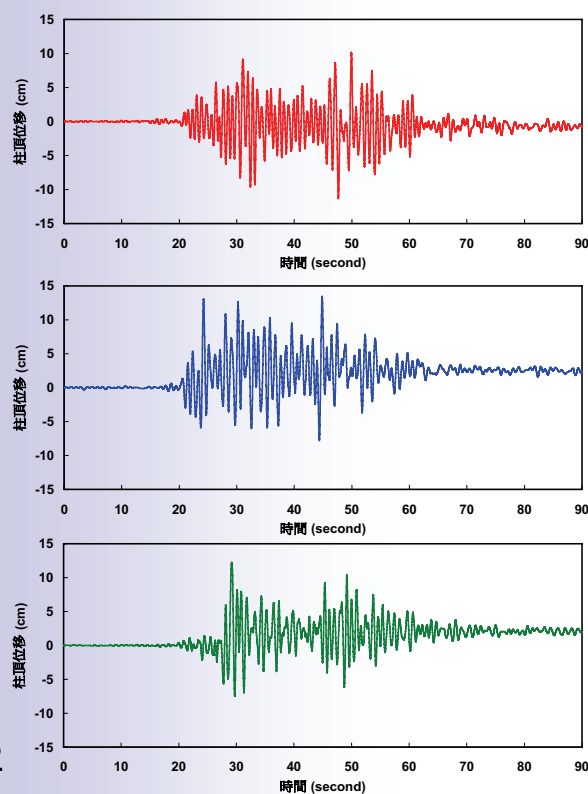
方案一補強後橋柱與阻尼器反應



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方案二補強後橋柱與阻尼器反應



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分析結果彙整

補強目標: $0.4S_{DS}$

方案一（結構保持彈性） 方案二（結構發揮韌性）

分析組別	側推分析 目標位移	動力分析	分析組別	側推分析 目標位移	動力分析
B3D1X	6.38	5.89	B3D1X	12.38	11.31
B3D2X		6.55	B3D2X		13.46
B3D3X		6.85	B3D3X		12.28

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結論



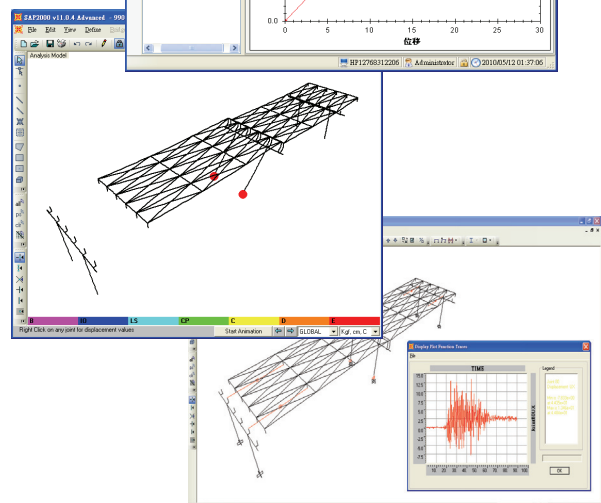
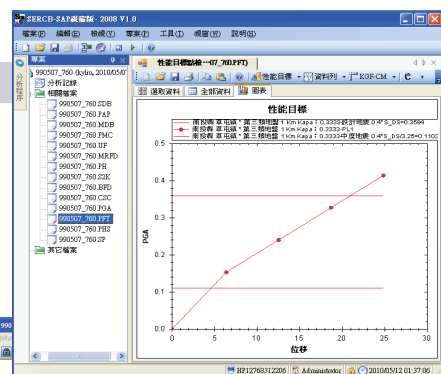
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NATIONAL CENTER FOR RESEARCH ON
EARTHQUAKE ENGINEERING

公路橋梁耐震能力評估及
補強準則之研究

張國鎮 蔡益超 張荻薇 宋裕祺 廖文義
柴駿甫 洪曉慧 劉光晏 吳弘明 戚樹人 陳彥豪

報告編號：NCREE-09-028

中華民國九十八年十二月



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National Center for Research on Earthquake Engineering

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參考資料

- 張國鎮、林哲毅、劉光晏、王瑞禎，「位移設計法於橋梁隔減震補強之應用」，結構工程，第十九卷，第四期，第21-43頁，民國93年12月。
- 黃震興、曾義軒、汪向榮，2005，「黏性阻尼器於橋梁隔減震之應用研究」，國家地震工程研究中心，報告編號：NCREE-05-025。



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