

建築物實施耐震能力評估及補強講習會

非線性歷時分析於耐震評估 與消能補強之應用

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102年6月29日



報告內容

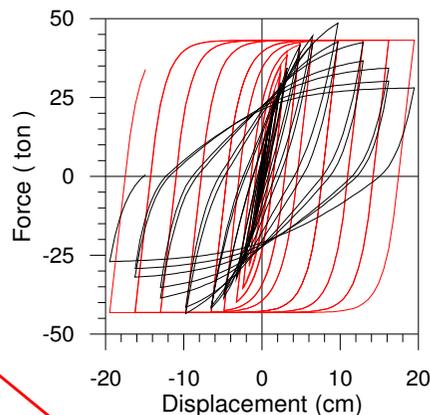
1. 由 FEMA440看側推分析與歷時分析
2. 非線性歷時分析範例
3. 消能補強分析



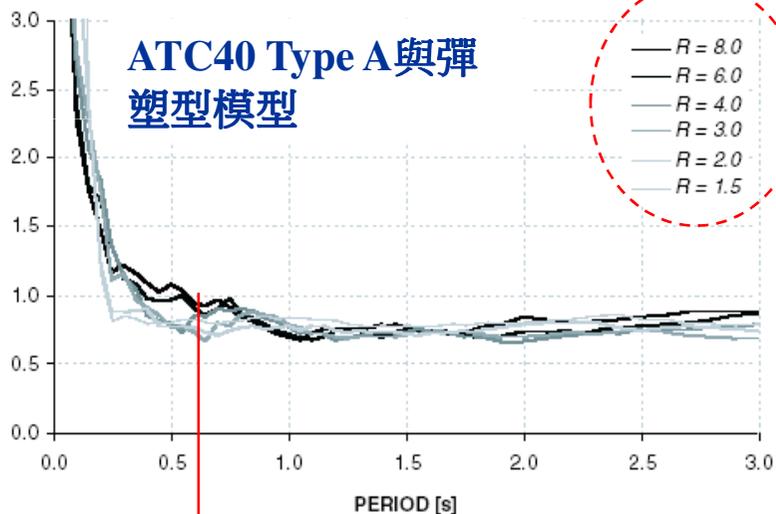
FEMA 440 (ATC55): 位移誤差探討

R=彈性需求/降伏強度比

$$R = \frac{S_a}{V_y / W} C_m$$



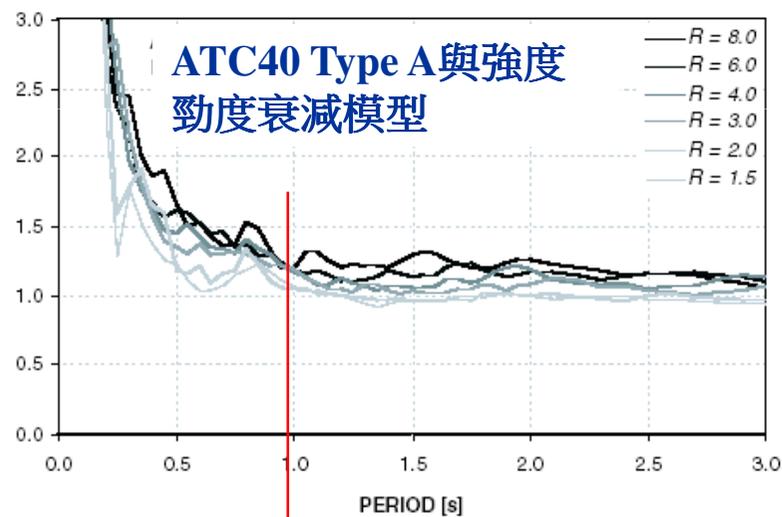
ATC40位移/歷時分析位移



ATC40 於
T<0.5s 平均
高估約
200%

ATC40 於T>0.6s 低
估約25%

ATC40位移/歷時分析位移



ATC40 任何週期皆高估位移反應



FEMA 440 (ATC55):改良容量震譜法分析(1)

1. 有效阻尼(β_{eff})

2. 評估方法

For $\mu < 4.0$:

$$\beta_{\text{eff}} = A(\mu - 1)^2 + B(\mu - 1)^3 + \beta_0$$

For $4.0 \leq \mu \leq 6.5$:

$$\beta_{\text{eff}} = C + D(\mu - 1) + \beta_0$$

For $\mu > 6.5$:

$$\beta_{\text{eff}} = E \left[\frac{F(\mu - 1) - 1}{F(\mu - 1)^2} \right] \left(\frac{T_{\text{eff}}}{T_0} \right)^2 + \beta_0$$

3. 等效週期(T_{eff})

For $\mu < 4.0$:

$$T_{\text{eff}} = \left[G(\mu - 1)^2 + H(\mu - 1)^3 + 1 \right] T_0$$

For $4.0 \leq \mu \leq 6.5$:

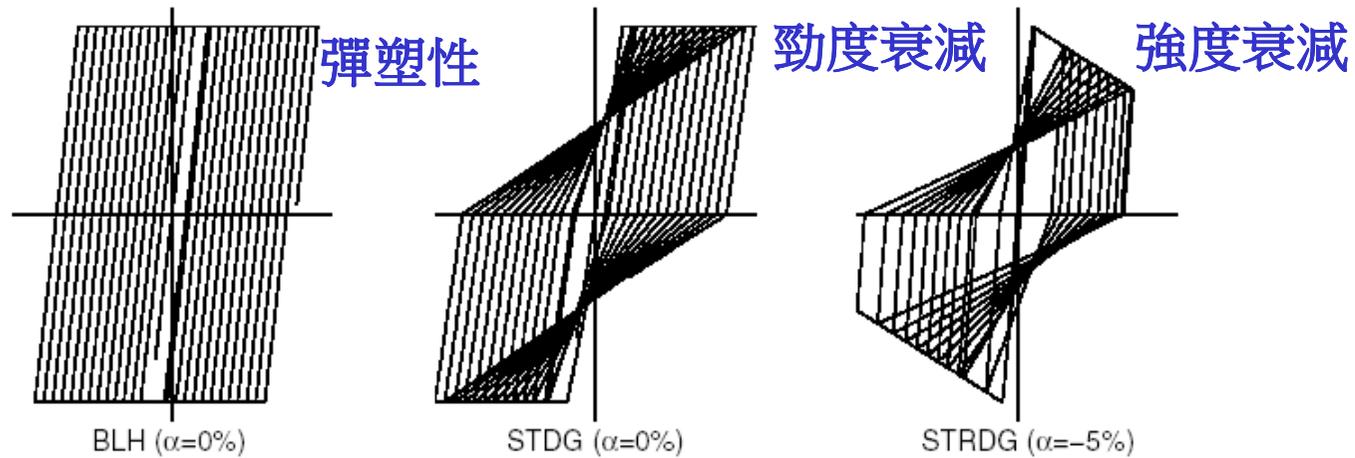
$$T_{\text{eff}} = \left[I + J(\mu - 1) + 1 \right] T_0$$

For $\mu > 6.5$:

$$T_{\text{eff}} = \left\{ K \left[\sqrt{\frac{(\mu - 1)}{1 + L(\mu - 2)}} - 1 \right] + 1 \right\} T_0$$



ATC55:改良容量震譜法分析(2)



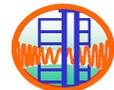
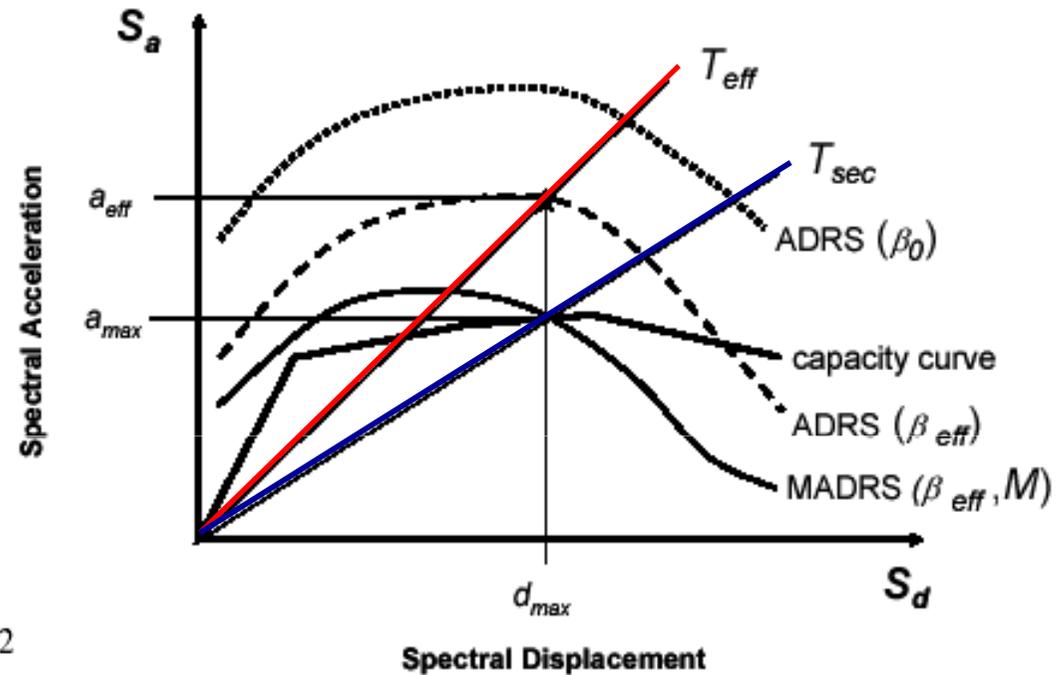
Model	α (%)	A	B	C	D	E	F
Bilinear hysteretic	0	3.2	-0.66	11	0.12	19	0.73
Bilinear hysteretic	2	3.3	-0.64	9.4	1.1	19	0.42
Bilinear hysteretic	5	4.2	-0.83	10	1.6	22	0.40
Bilinear hysteretic	10	5.1	-1.1	12	1.6	24	0.36
Bilinear hysteretic	20	4.6	-0.99	12	1.1	25	0.37
Stiffness degrading	0	5.1	-1.1	12	1.4	20	0.62
Stiffness degrading	2	5.3	-1.2	11	1.6	20	0.51
Stiffness degrading	5	5.6	-1.3	10	1.8	20	0.38
Stiffness degrading	10	5.3	-1.2	9.2	1.9	21	0.37
Stiffness degrading	20	4.6	-1.0	9.6	1.3	23	0.34
Strength degrading	-5 ^a	5.6	-1.3	14	0.61	22	0.90
Strength degrading	-3 ^a	5.3	-1.2	14	0.69	24	0.90

ATC55:改良容量震譜法分析(3)

$$M = \frac{a_{\text{eff}}}{a_{\text{max}}}$$

$$\frac{T_{\text{sec}}}{T_0} = \sqrt{\frac{\mu}{1 + \alpha(\mu - 1)}}$$

$$M = \left(\frac{T_{\text{eff}}}{T_{\text{sec}}}\right)^2 = \left(\frac{T_{\text{eff}}}{T_0}\right)^2 \left(\frac{T_0}{T_{\text{sec}}}\right)^2$$



ATC55:改良容量震譜法分析(4)

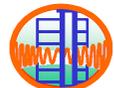
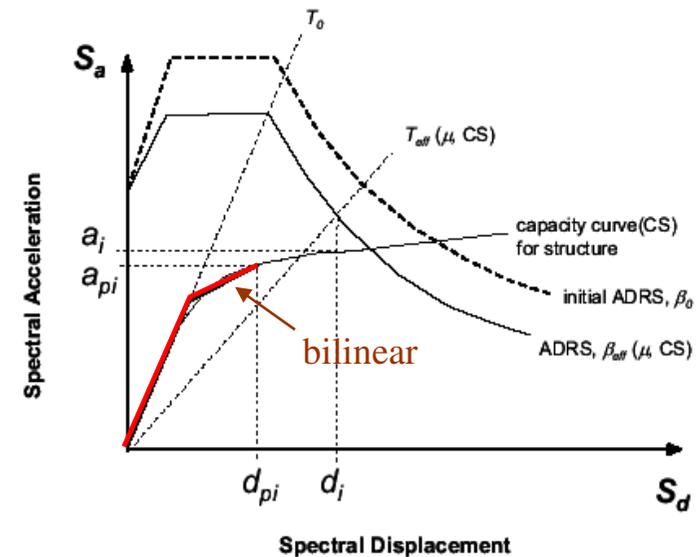
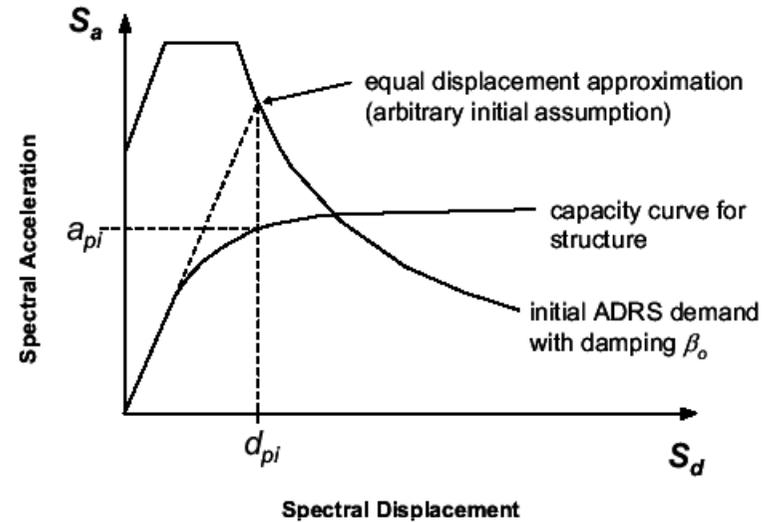
步驟:

- (1) 選擇設計反應譜(包括基礎組尼)
- (2) 轉成ADRS格式
- (3) 建立容量曲線及選擇初始性能點 a_{pi}
- (4) 建立等值雙線性模型及計算 α
- (5) 計算 a_{pi} 點之 β_{eff} 及 T_{eff}
- (6) 以 β_{eff} 折減ADRS
- (7) 以 T_{eff} 決定位移 d_i , 並與 d_{pi} 比較

$$\alpha = \frac{\left(\frac{a_{pi} - a_y}{d_{pi} - d_y} \right)}{\left(\frac{a_y}{d_y} \right)} \quad \mu = \frac{d_{pi}}{d_y}$$

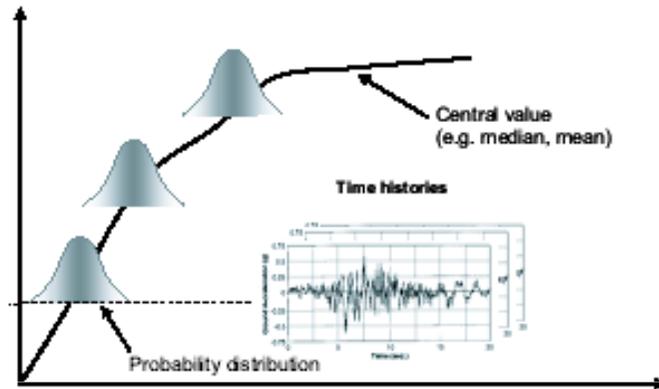
$$(S_a)_\beta = \frac{(S_a)_{5\%}}{B(\beta_{eff})}$$

$$B = \frac{4}{5.6 - \ln \beta_{eff} \text{ (in \%)}}$$



FEMA 440 (ATC55):單自由度系統

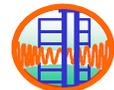
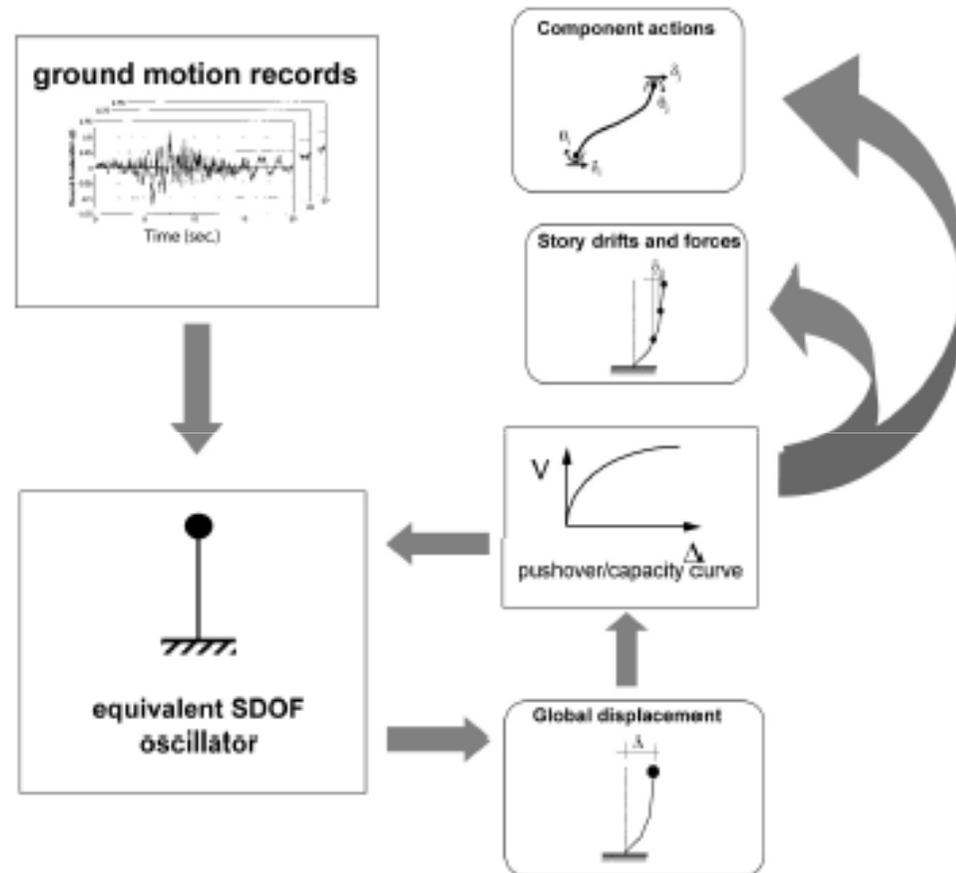
譜加速度



結構變位

進一步之考量:

1. 多自由度之影響
2. 地震與結構不確定性之考量

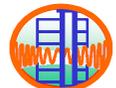


Nonlinear Time History Analysis

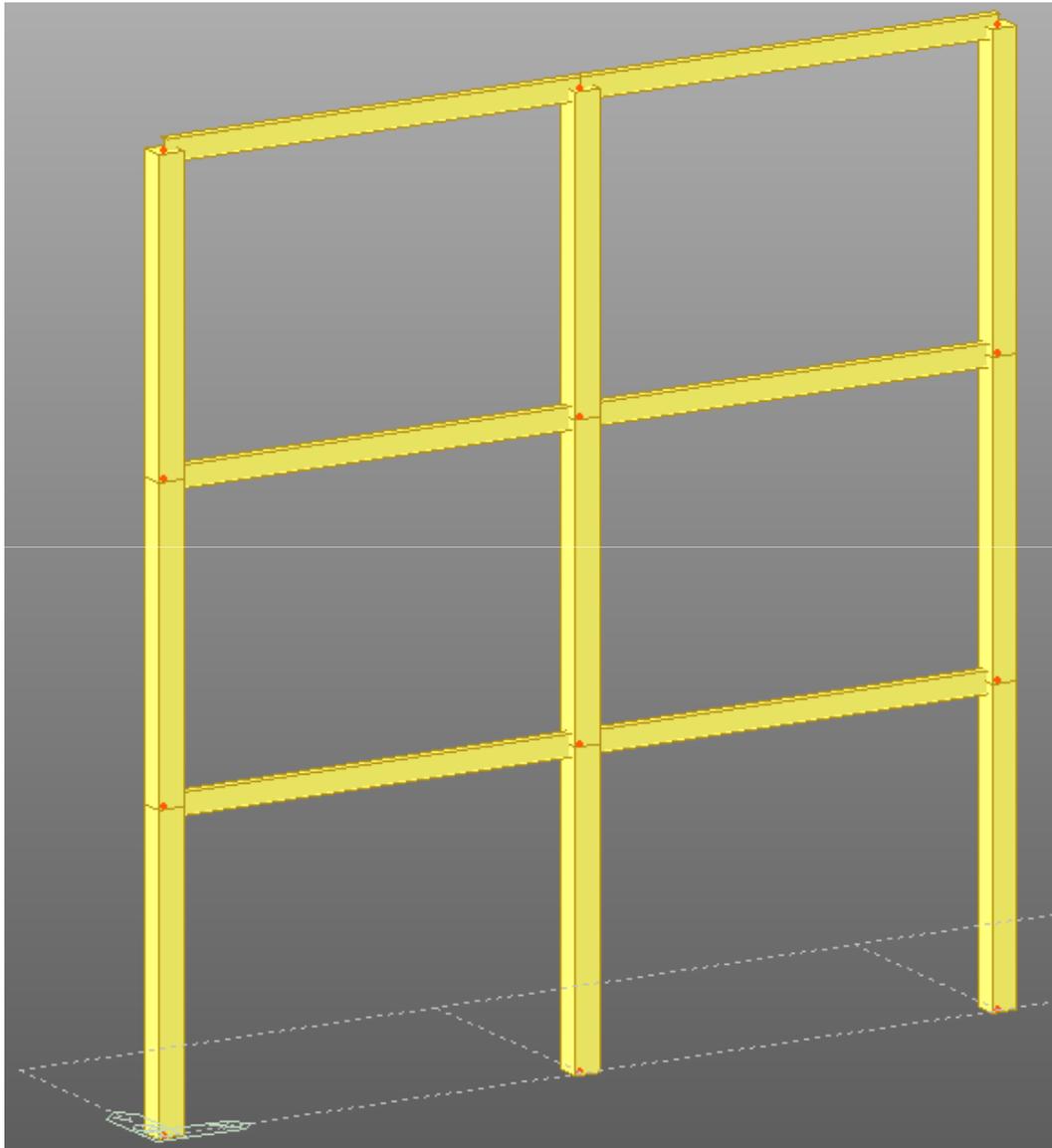


歷時分析之步驟

1. 建立結構模型
2. 設定桿件塑鉸(Kinematic hardening, Takeda, Wen, ...)
3. 選擇地震歷時紀錄
4. 檢查結構整體層間變位(如小於2%), 及桿件使用韌性
5. 樓板加速度值



分析示範例



Steel Beam:

H 250x125x7.5x12.5

RC Column:

30x30; rebar 8#6

Nodal masses:

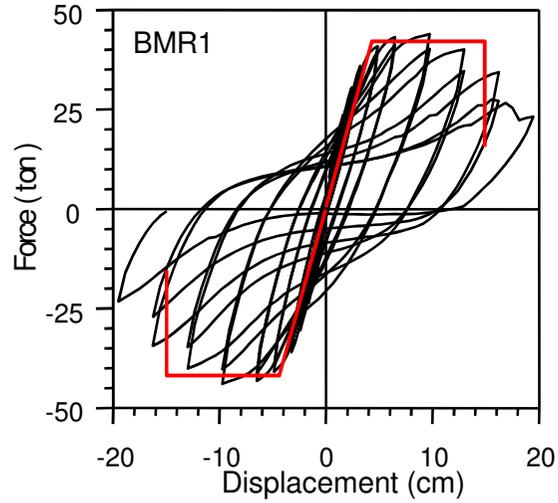
1 tf/g

周期= 1.15 sec

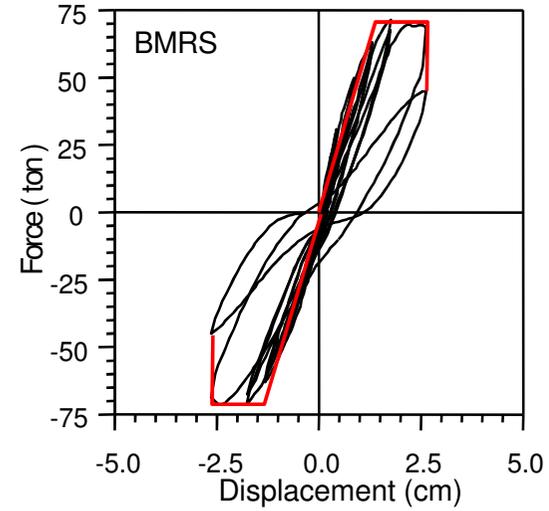


遲滯模型

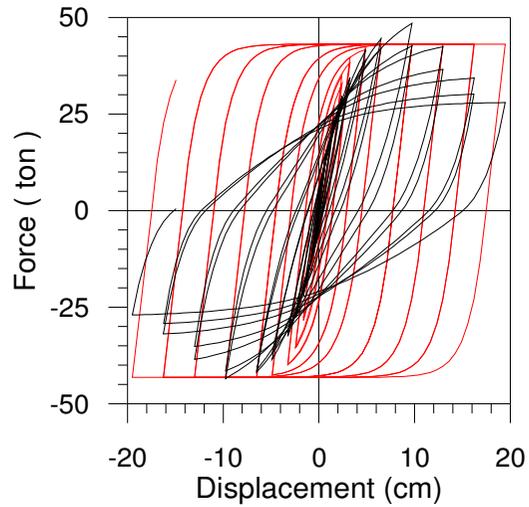
彎矩破壞



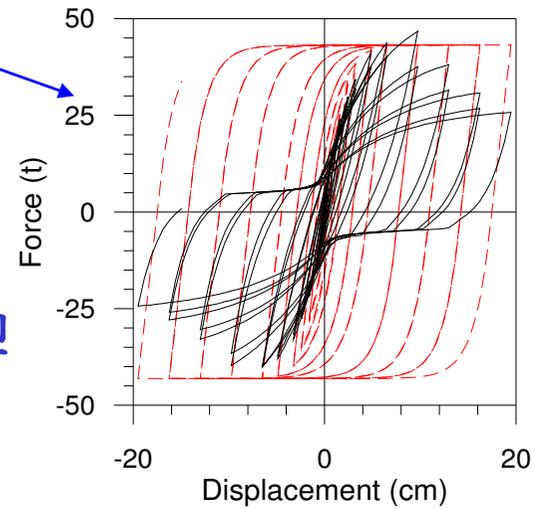
剪力破壞



勁度、強度衰減與擠壓模型

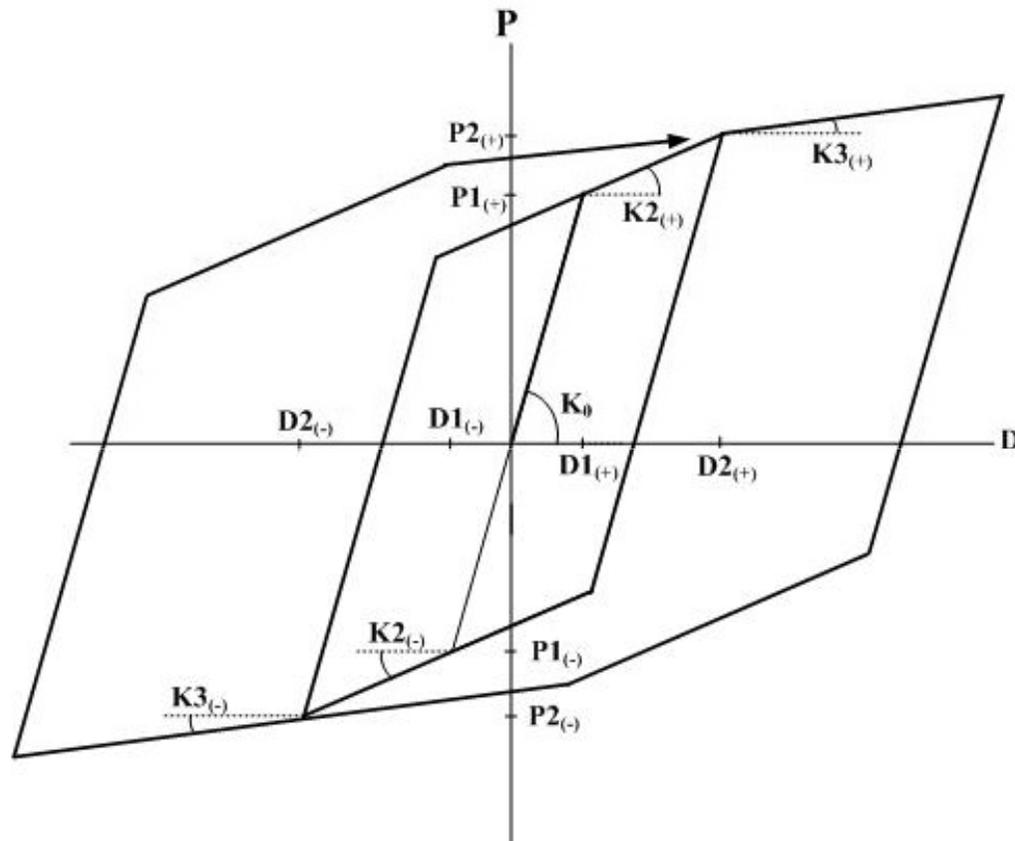


勁度、強度衰減模型



遲滯模型 (鋼梁彎矩塑鉸)

■ Kinematic hardening type hysteresis model



Kinematic Hardening hysteresis model

Kinematic Hardening
Origin-oriented
Peak-oriented

Clough
Degrading Trilinear
Takeda
Takeda Tetralinear
Modified Takeda
Modified Takeda Tetralinear

Normal Bilinear

Elastic Bilinear

Elastic Trilinear

Elastic Tetralinear

SLIP Bilinear

SLIP Bilinear/Tension

SLIP Bilinear/Compression

SLIP Trilinear

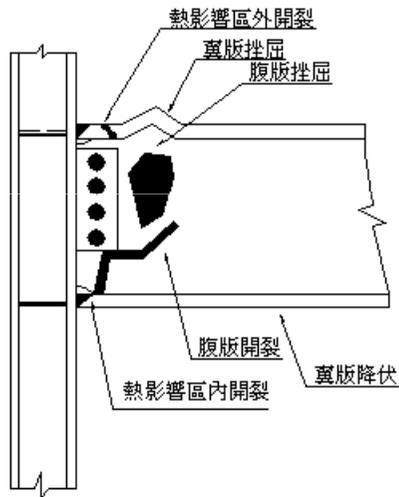
SLIP Trilinear/Tension

SLIP Trilinear/Compression

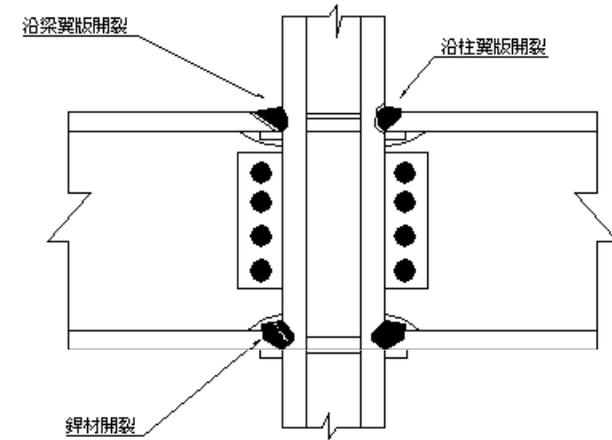
Response points at the initial loading move along a trilinear skeleton curve. The unloading stiffness is identical to the elastic stiffness. It shows the tendency of strength increase with the increase in loading. This is used to model the Bauschinger effect of metallic materials. Accordingly, it is cautioned that energy dissipation may be overestimated for concrete. Due to the characteristic of the model, only the positive (+) and negative (-) symmetry is permitted for the strength reduction ratios after yielding.

鋼結構模擬

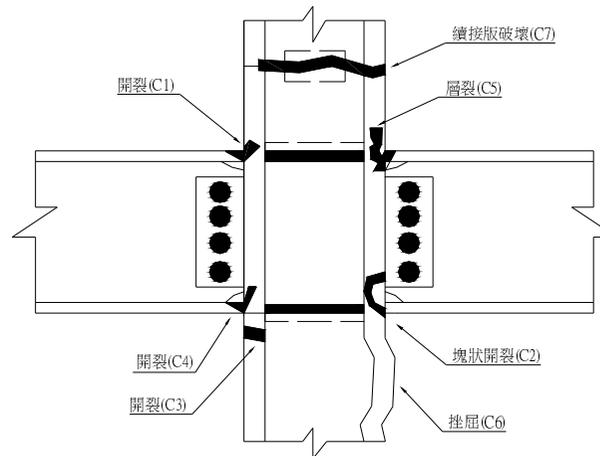
- ⇒ 北嶺地震發現損壞多發生於翼板銲接-腹板栓接之抗彎接頭
- ⇒ 結構之模擬方式 (構材之強度與變形能力估算並不容易)



梁破壞模式



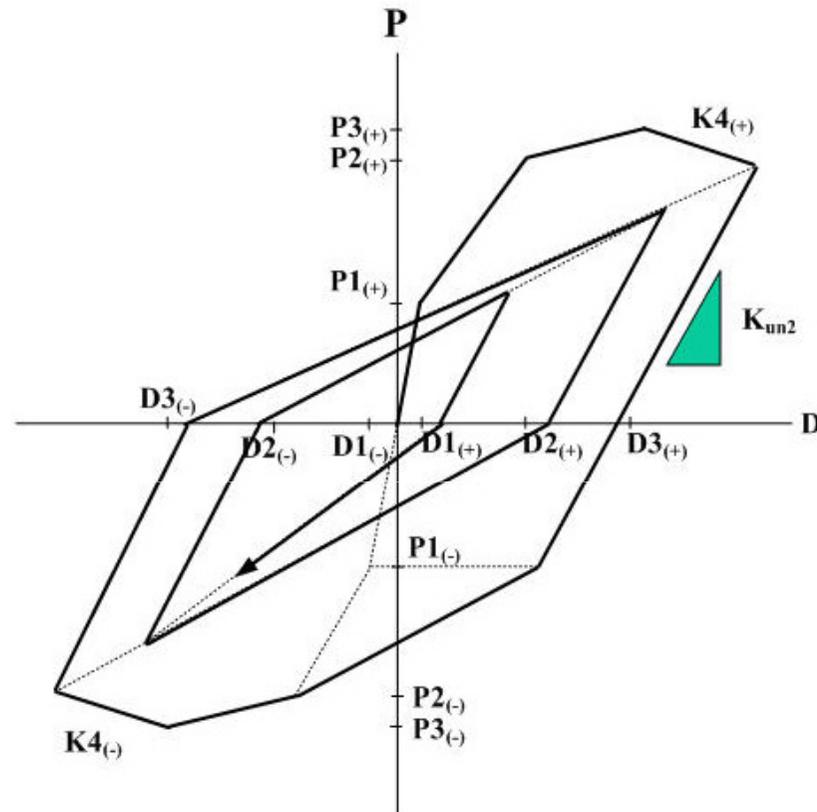
銲道破壞



柱破壞模式

遲滯模型 (RC柱-M PH)

■ Takeda Tetra Linear type hysteresis model



Takeda Tetra Linear hysteresis model

- Response points at the initial loading move along a tetralinear skeleton curve.
- If the current displacement or deformation, D , does not exceed $D3$, the hysteresis rules are identical to the Original Takeda hysteresis.
- If the current displacement or deformation, D , exceeds $D3$, response points move along the slope $K4$. For unloading, response points move by the same rules as the Original Takeda hysteresis.

Add/Modify Inelastic Hinge Properties

Name :

Description :

Yield Strength(Surface) Calculation Method
 User Input Auto-Calculation

Type

Beam-Column

Lumped

Distributed

Spring

Truss

Definition

Skeleton

Fiber

Interaction Type

None

P-M in Strength Calculation

P-M-M in Status Determination

Material

Type : Steel RC

SRC(filled)

SRC(encased)

User Defined

Code :

Name :

Member

Type : Beam Column Brace

Element Position : I M J

Section Name :

Component Properties

Component	Hinge Location	Hysteresis Model
<input type="checkbox"/> Fx	Center	Kinematic Hardening
<input type="checkbox"/> Fy	I	Kinematic Hardening
<input type="checkbox"/> Fz	I	Kinematic Hardening
<input type="checkbox"/> Mx	I	Kinematic Hardening
<input checked="" type="checkbox"/> My	I&J	Kinematic Hardening
<input type="checkbox"/> Mz	I	Kinematic Hardening

Yield Surface Properties... Fiber Name :

OK Cancel Apply

Directional Hinge Properties : Kinematic Hardening

Type
 Symmetric Asymmetric

Yield Properties
 Input Method
 User Input Auto-Calculation

Input Type
 Strength - Stiffness Reduction Ratio
 Strength - Yield Displacement

Yield Strength

	(+)	(-)	
P1	9.77149405	9.77149405	tonf*m
P2	11.1672157	11.1672157	tonf*m

Stiffness Reduction Ratio

	(+)	(-)
Alpha1	0.5	0.5
Alpha2	0.05	0.05

Primary Curve

Deformation Indexes

Ductility Factor : D/D1 D/D2

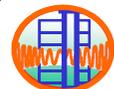
Hinge Status

Level	(+)	(-)
1	0.5	0.5
2	1	1
3	2	2
4	4	4
5	8	8

Initial Stiffness
 6EI/L 3EI/L 2EI/L
 User tonf*m
 Elastic Stiffness
 Skeleton Curve

OK Cancel

Steel Beam



RC or SRC(encased) Yield Surface Properties

Add/Modify Inelastic Hinge Properties

Name :

Description :

Yield Strength(Surface) Calculation Method
 User Input Auto-Calculation

Type: Beam-Column
 Lumped
 Distributed
 Spring
 Truss

Definition: Skeleton
 Fiber

Interaction Type: None
 P-M in Strength Calculation
 P-M-M in Status Determination

Material: Type: Steel RC
 SRC(filled)
 SRC(encased)
 User Defined

Member: Type: Beam Column Brace
Element Position: I M J

Code :

Name :

Section Name :

Component Properties

Component	Hinge Location	Hysteresis Model
<input type="checkbox"/> Fx	Center	Kinematic Hardening
<input type="checkbox"/> Fy	I	Kinematic Hardening
<input type="checkbox"/> Fz	I	Kinematic Hardening
<input type="checkbox"/> Mx	I	Kinematic Hardening
<input checked="" type="checkbox"/> My	I&J	Takeda
<input checked="" type="checkbox"/> Mz	I&J	Takeda

Yield Surface Properties... Fiber Name :

OK Cancel Apply

on for the 1st P-M Interaction Curve

PC(c)	PCBy	PCBz	MCy,max	MCz,max
1.47586672	194.87741318	194.87741318	9.1844011938	9.1844011938

I-P-M Interaction Curves

PY(c)	PYBy	PYBz	MYy,max	MYz,max
1.54236156	98.834630334	98.834630331	15.737039509	15.737039509

or plotting P-M curve : Compression(+), Tension(-)

2nd P-M Interaction Curves : 1st 2nd

2nd P-M Interaction Curve			
about y-axis		about z-axis	
PYBy	M	P-PYBz	M
.....	PY-PYBz	MYz,max
.....	MYy,max
1	0	1	0
41898	0.650427	0.541898	0.650427
105192	0.766131	0.405192	0.766131
63152	0.861207	0.263152	0.861207
124647	0.942	0.124647	0.942
0	1	0	1
111388	0.97913	0.111388	0.97913
89614	0.899444	0.285614	0.899444
193848	0.706626	0.493848	0.706626
807596	0.297142	0.807596	0.297142
1	0	1	0

Approximation of Yield Surface Shape

Type of Input : User Input Auto-calculation

Surface	Beta y		Beta z		Gamma	Alpha
	(t)	(c)	(t)	(c)		
1st	1.54324	1.54324	1.54324	1.54324	1.1	1.4
2nd	1.682	1.5464	1.682	1.5464	1	

$$\left(\frac{|M_y|}{M_{y,max}}\right)^{\text{Gamma}_y} + \left(\frac{P-P_{By}}{P_{max}-P_{By}}\right)^{\text{Beta}_y} = 1$$

$$\left(\frac{|M_z|}{M_{z,max}}\right)^{\text{Gamma}_z} + \left(\frac{P-P_{Bz}}{P_{max}-P_{Bz}}\right)^{\text{Beta}_z} = 1$$

$$\left(\frac{|M_y|}{M_{y,max}}\right)^{\text{Alpha}_y} + \left(\frac{|M_z|}{M_{z,max}}\right)^{\text{Alpha}_z} = 1$$

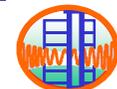
Beta y : for the 1st & 2nd surface
Beta z : for the 1st & 2nd surface
Pmax = PC, PY
FBy = PCBy, PYBy
FBz = PCBz, PYBz
My,max = MCy,max, MYy,max
Mz,max = MCz,max, MYz,max

Interaction Curves and Approximated Yield Surfaces

Plot : P-My

Legend :
Interaction Curve
1st (blue line)
2nd (green line)
Approximated Yield Surface
1st (blue line)
2nd (green line)

RC Column



Directional Hinge Properties : Takeda

Type
 Symmetric Asymmetric

Yield Properties
 Input Method
 User Input Auto-Calculation

Input Type
 Strength - Stiffness Reduction Ratio
 Strength - Yield Displacement

Yield Strength

	(+)	(-)	
P1	16975.0868	16975.0868	kN*mm
P2	109614.398	109614.398	kN*mm

Stiffness Reduction Ratio

	(+)	(-)
Alpha1	0.35	0.35
Alpha2	0.05	0.05

Deformation Indexes
 Ductility Factor : D/D1 D/D2

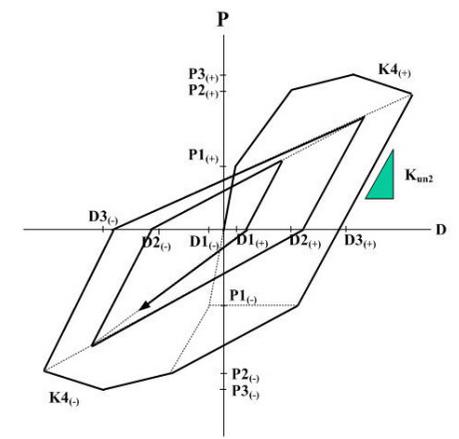
Hinge Status

Level	(+)	(-)
1	0.5	0.5
2	1	1
3	2	2
4	4	4
5	8	8

Initial Stiffness
 6EI/L 3EI/L 2EI/L
 User 9806.65 kN*mm
 Elastic Stiffness
 Skeleton Curve

Unloading Stiffness Parameter
 Exponent in Unloading Stiffness Calculation : 0.4
 Inner Loop Unloading Stiffness Reduction Factor : 1

OK Cancel



對剪力破壞控制則調小勁度折減係數



Add/Modify Time History Load Cases

General
 Name : Description :

Analysis Type
 Linear
 Nonlinear

Analysis Method
 Modal
 Direct Integration
 Static

Time History Type
 Transient
 Periodic

End Time : sec Time Increment : sec
 Step Number Increment for Output :

Order in Sequential Loading
 Subsequent to Load Case
 Initial Element Forces(Table)
 Cumulate D/V/A Results Keep Final Step Loads Constant

Damping
 Damping Method :
 Direct Specification of Modal Damping
 Damping Ratio for All Modes
 Modal Damping Overrides

Mode	Damping Ratio
1	

Time Integration Parameters
 Newmark Method : Gamma Beta
 Constant Acceleration Linear Acceleration User Input

Nonlinear Analysis Control Parameters
 Perform Iteration

OK Cancel Apply

Iteration Control

Iteration Parameters
 Permit Convergence Failure
 Minimum Step Size : sec
 Maximum Iteration :
 Convergence Criteria : Displacement Norm
 Force Norm
 Energy Norm

Boundary Nonlinear Analysis
 Runge Kutta Method :
 Fehlberg Method (Stepsize sub-division for Non-convergence Control)
 Cash-Karp Method (Adaptive Stepsize Control)
 Tolerance :

OK Cancel

預加D.L.
 Direct integration 比Model 準確

Id/Modify/Show Time History Functions

Function Name

T2-I-1

Import

Earthquake

Heel Drop

	Time (sec)	Function (g)
1	0.0100	0.0165
2	0.0200	0.0174

Time Function Data Type

Normalized Accel.

Acceleration

Force

Moment

Normal

Scale Factor

Scale Factor

1

Maximum Value

0

g

Gravity

9.806

m/sec^2

Graph Options

X-axis log scale

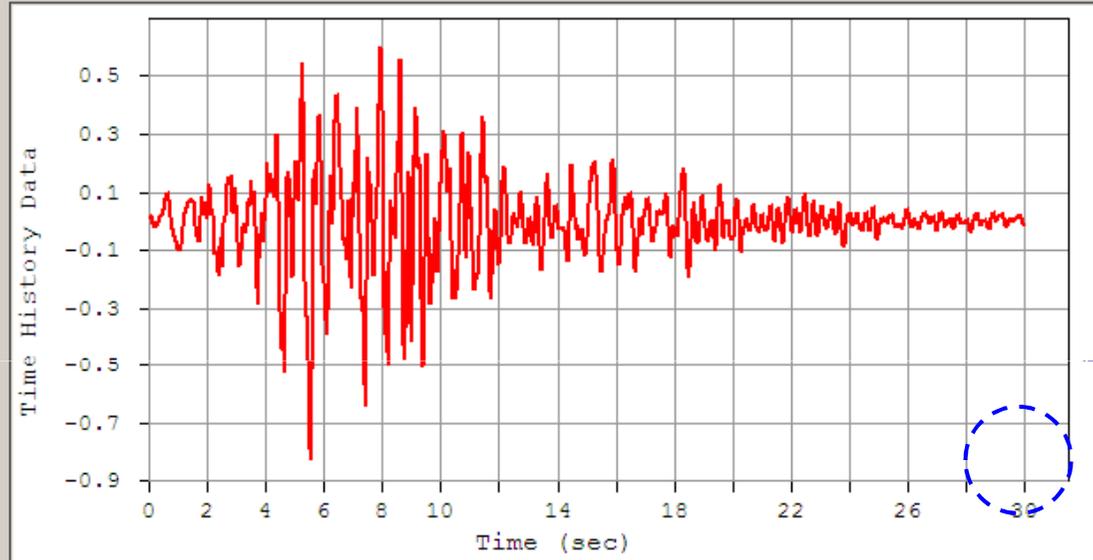
Y-axis log scale

F.F.T

Generate Earthquake Acceleration Record

Earthquake :

- 1940, El Centro Site, 270 Deg
- 1952, Hollywood Storage P.E., Vertical
- 1971, San Fernando, 69 Deg
- 1971, San Fernando, 159 Deg
- 1971, San Fernando, Down
- 1979, James RD. El Centro, 220 Deg
- 1979, James RD. El Centro, 310 Deg
- 1979, James RD. El Centro, Up
- 1985, Mexico City, Station 1, 180 Deg
- 1985, Mexico City, Station 1, 270 Deg
- 1994, Northridge, Sylmar County Hosp., 90 Deg
- 1994, Northridge, Santa Monica, City Hall Grounds, 0 Deg
- 1994, Northridge, Santa Monica, City Hall Grounds, 90 Deg
- 1994, Northridge, Arleta and Nordhoff Fire Station, 90 Deg
- 1989, Loma Prieta, Oakland Outer Wharf, 270 Deg
- 1989, Loma Prieta, Oakland Outer Wharf, 0 Deg
- 1971, San Fernando Pocomo Dam, 196 Deg
- 1971, San Fernando Pocomo Dam, 286 Deg
- 1966, Parkfield Cholame, Shandon, 40 Deg
- 1966, Parkfield Cholame, Shandon, 130 Deg
- 1971, San Fernando 8244 Orion Blvd., 90 Deg
- 1971, San Fernando 8244 Orion Blvd., 180 Deg
- Method of Seismic Intensity- level -Type I
- Method of Seismic Intensity- level -Type II
- Method of Seismic Intensity- level -Type III
- T1-I-1 (1978, MIYAGI-Coast, LG)
- T1-I-2 (1978, MIYAGI-Coast, TR)
- T1-I-3 (1993, HOKKAIDO-S/W_Coast, LG)
- T1-II-1 (1968, HYUGANADA-Coast, LG)
- T1-II-2 (1968, HYUGANADA-Coast, TR)
- T1-II-3 (1994, HOKKAIDO-EastCoast, TR)
- T1-III-1 (1983, NIHONKAI-Central, TR)
- T1-III-2 (1983, NIHONKAI-Central, LG)
- T1-III-3 (1994, HOKKAIDO-EastCoast, LG)
- T2-I-1 (1995, HYUGOKEN_South, NS)**
- T2-I-2 (1995, HYUGOKEN_South, EW)
- T2-I-3 (1995, HYUGOKEN_South, NS)
- T2-II-1 (1995, HYUGOKEN_South, NS)
- T2-II-2 (1995, HYUGOKEN_South, EW)
- T2-II-3 (1995, HYUGOKEN_South, N30W)
- T2-III-1 (1995, HYUGOKEN_South, N12W)
- T2-III-2 (1995, HYUGOKEN_South, NS)
- T2-III-3 (1995, HYUGOKEN_South, EW)



1995, HYUGOKEN_South, NS)

Earthquake Response Spectrum...



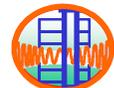
OK

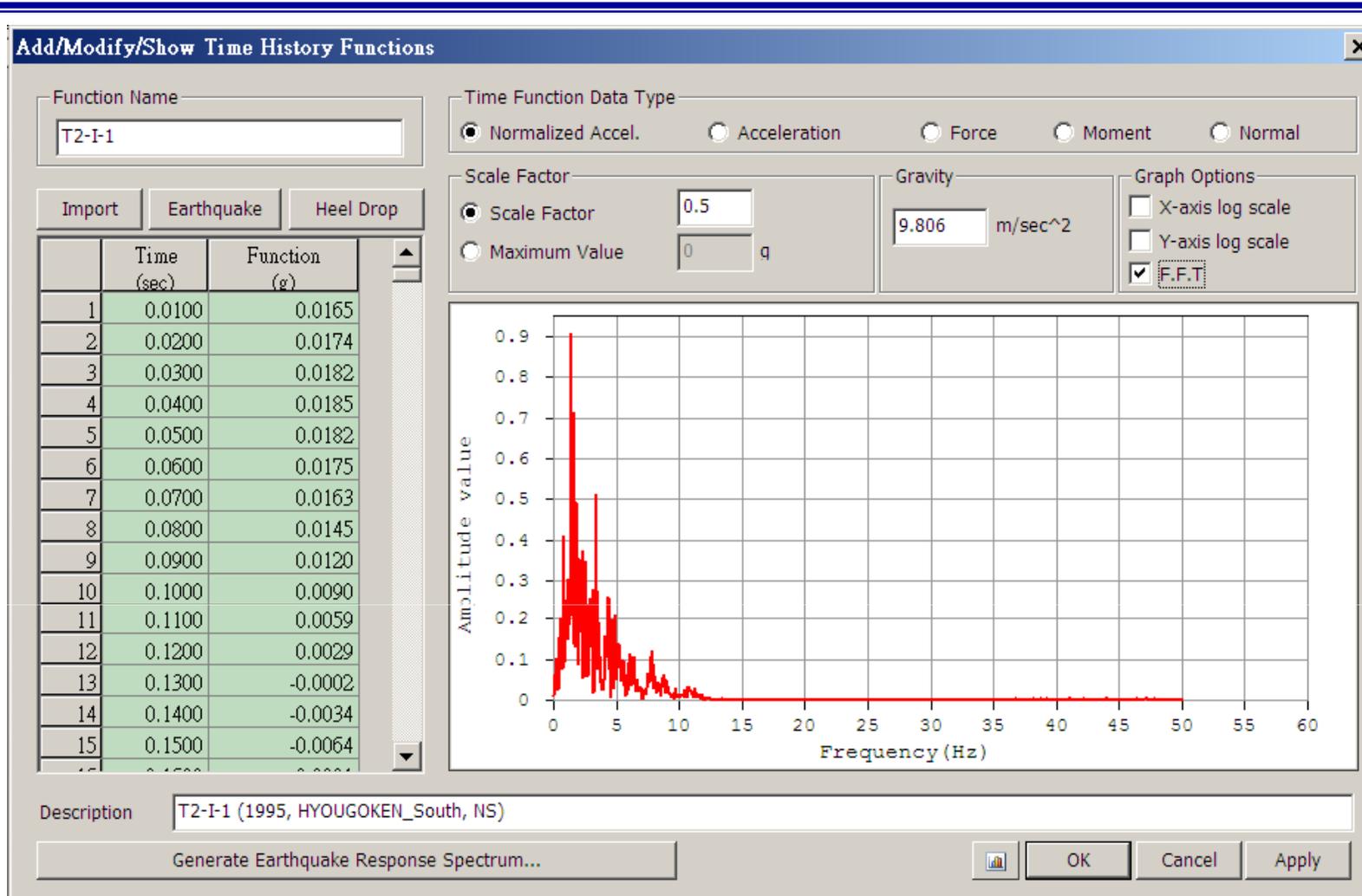
Cancel

Apply

Normalized Accel. : 以g為單位

Acceleration : 以m/sec^2 為單位





Scale factor = 0.5 ; input PGA = $0.5 \times 0.8g = 0.4g$

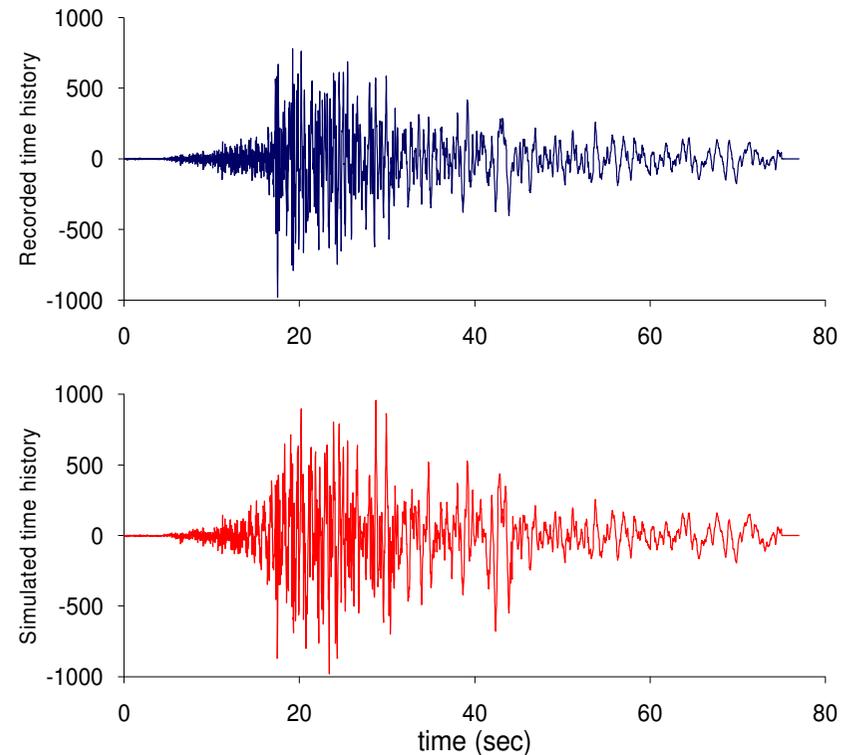
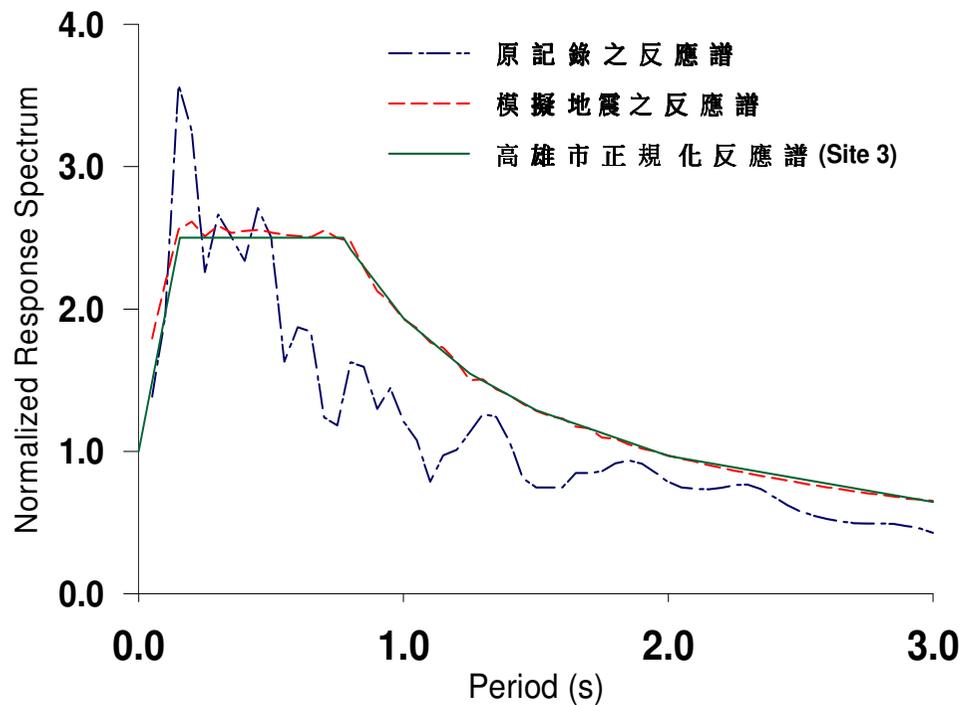
Sa/2.5 為 EPA; PGA/(1.1~1.2) 才約為 EPA; 故 EPA = $0.4/1.2 = 0.33g$



3.6.1 輸入地震要求

至少三個與設計反應譜相符之水平地震紀錄，其應能確切反映工址設計地震(或最大考量地震)之地震規模、斷層距離與震源效應。

針對任一個水平地震紀錄，計算其5%阻尼之反應譜。同時，調整地震紀錄使得位於 $0.2T$ 至 $1.5T$ 週期範圍內任一點之譜加速度值不得低於設計譜加速度值之90%及於此週期範圍內之平均值不得低於設計譜加速度值之平均值，其中 T 為建物基本模態之振動週期。



採用95年12屏東地震**主震**，測站KAU(高雄氣象站)之EW向(東西向)記錄為原始地震記錄，調整成與高雄市規範site-3反應譜相符之地震記錄

Tree Menu

Time History Analysis Data

Time History Result Function

Define Function

Graph Function

Step Function

Displ/Vel/Accel by Story

Add New Function

Function List

Name	Type
d1f	Graph-Displacement
d2f	Graph-Displacement
d3f	Graph-Displacement
drift-2f	Graph-Displacement
drift-3f	Graph-Displacement

Back

Modify

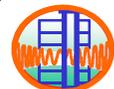
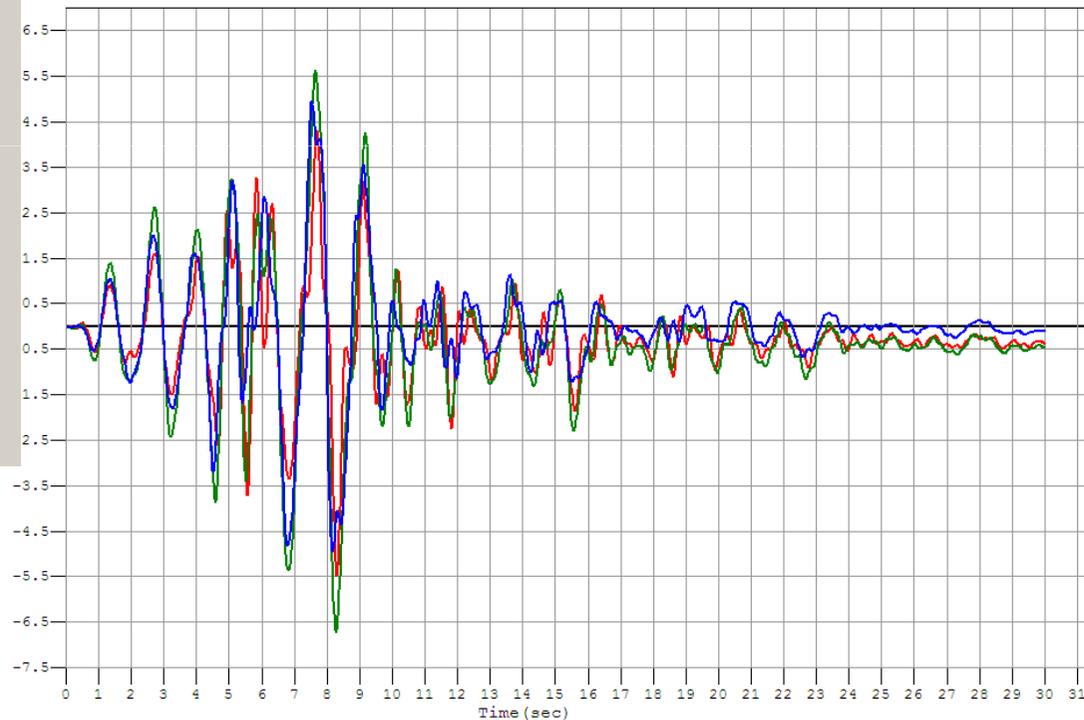
Delete

Close

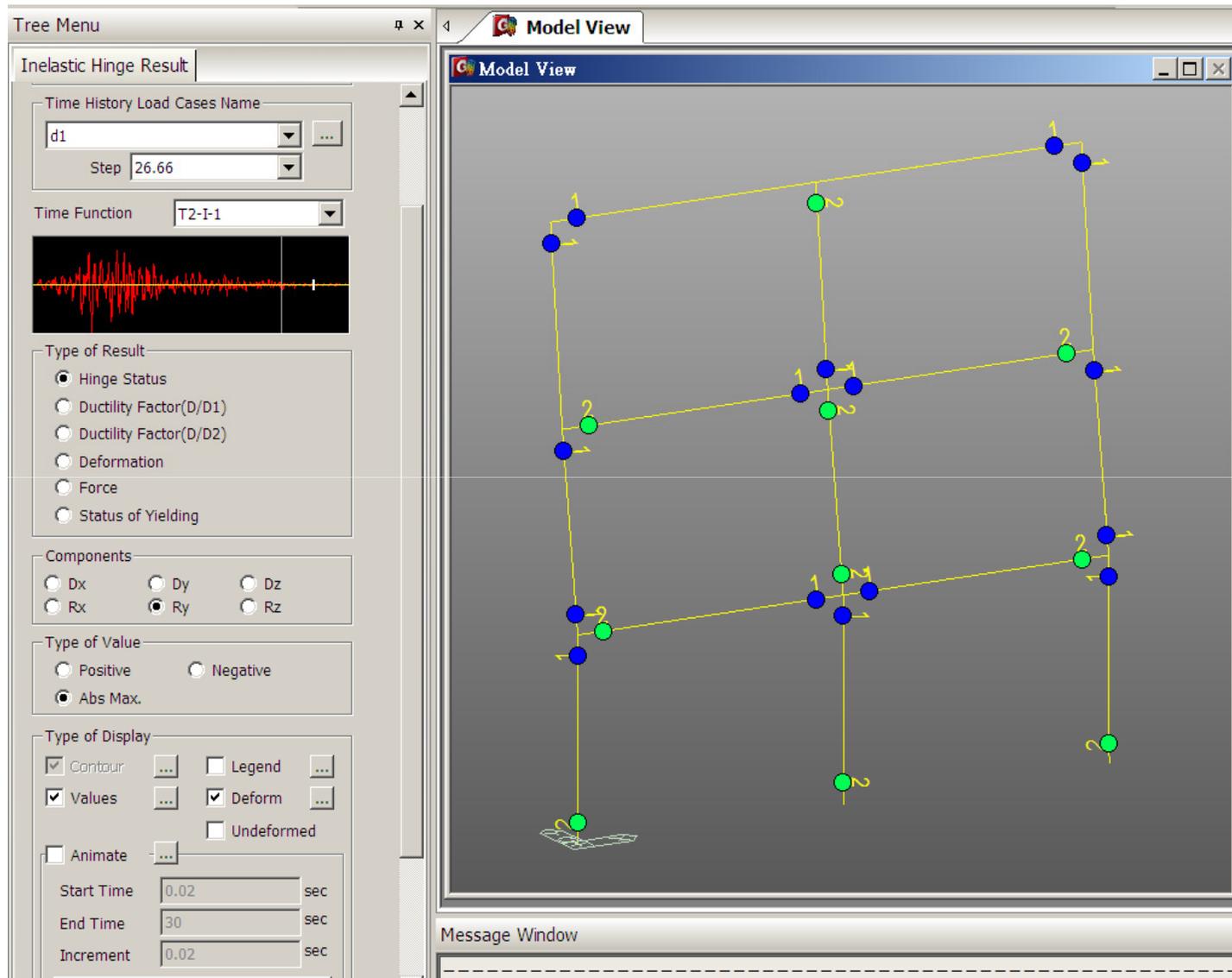
層間變位角檢核:

最大變位角=6.5/350 = 1.8% (OK)

History Graph

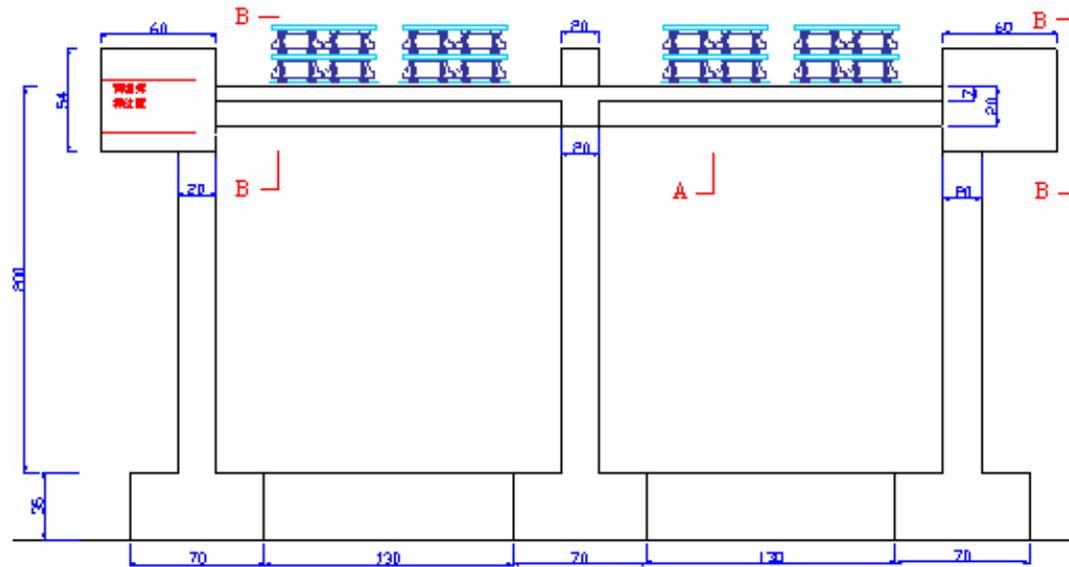
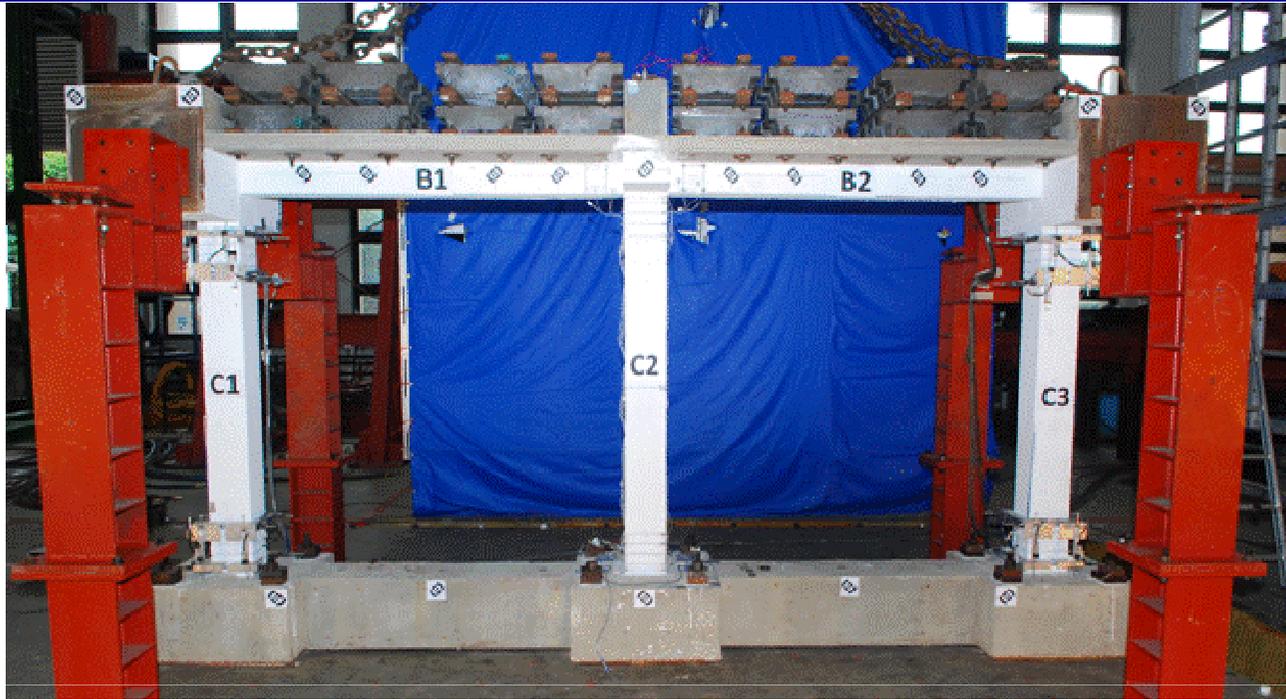


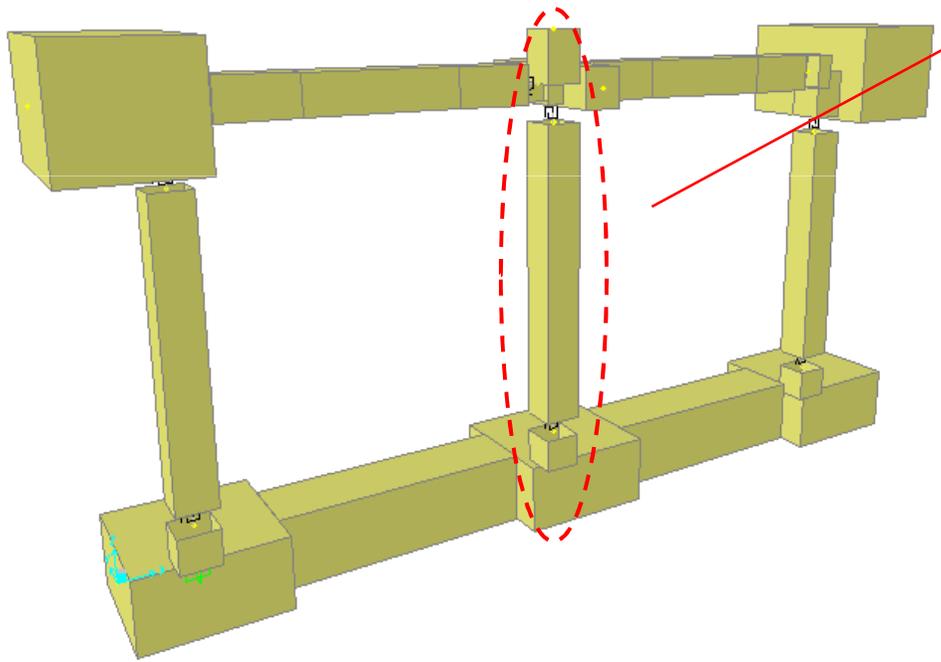
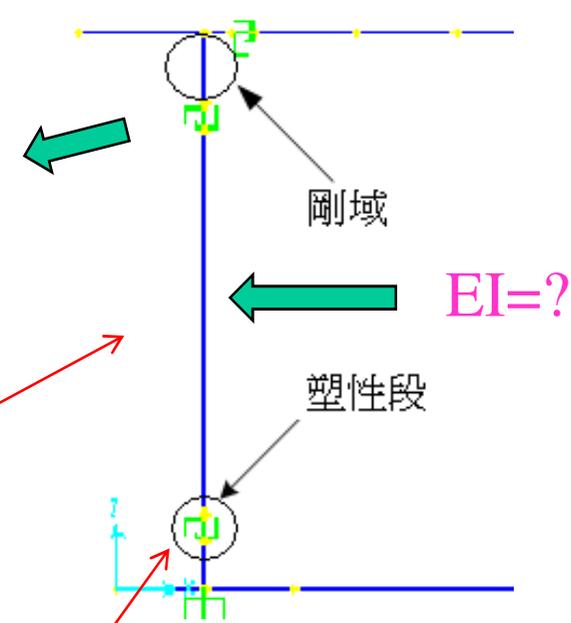
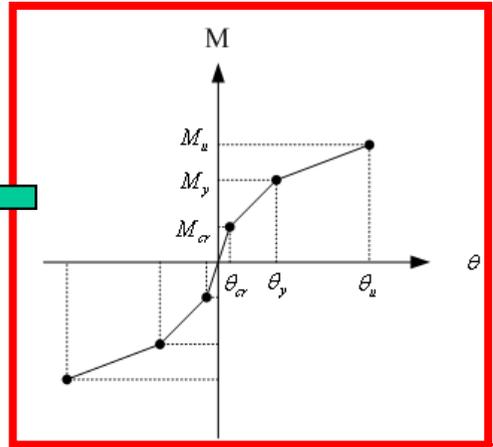
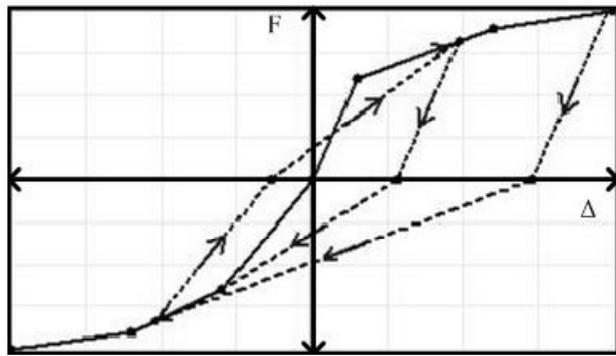
歷時分析塑鉸狀態



混凝土構架之振動台試驗 與模擬分析



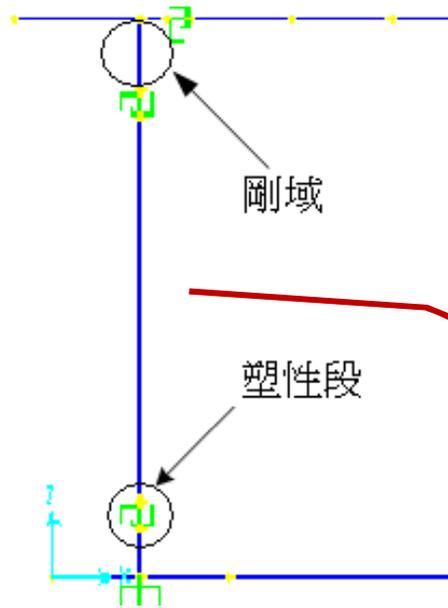




$$L_p = 0.5d + 0.05z$$
 $d = \text{斷面有效深度}$
 $z = \text{臨界斷面至反曲點之距離}$

模擬之單層雙跨RC構架立體圖

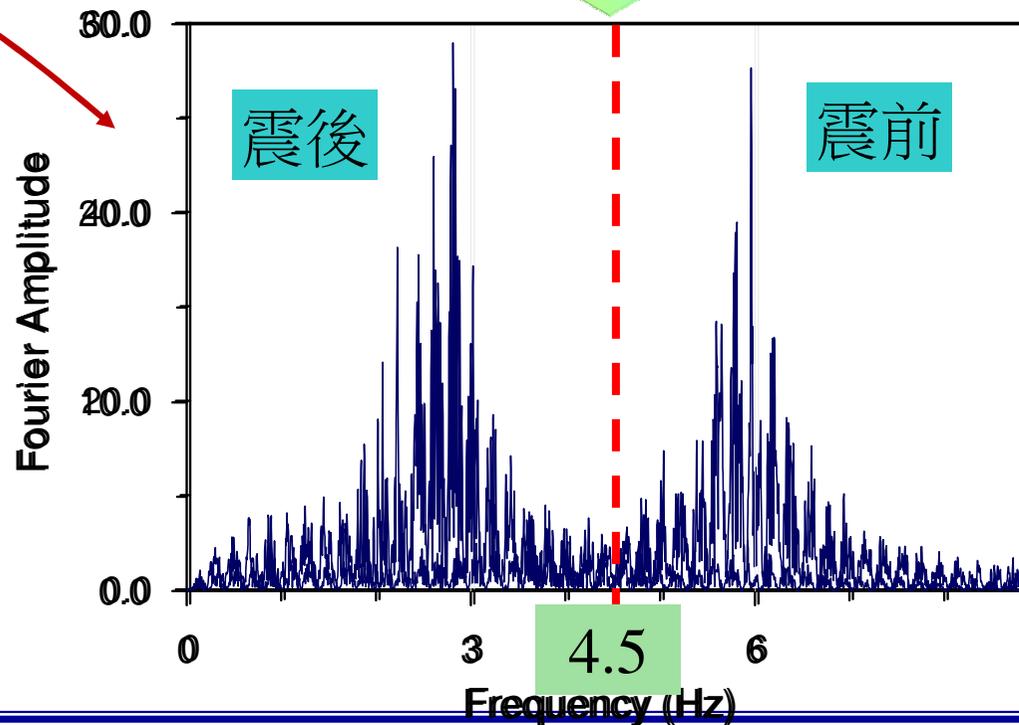
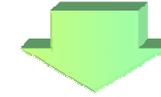
調整構材勁度



模態分析

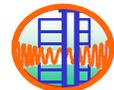


EI值調整設定



分析之採用勁度

$$EI_e = (EI_g + EI_{cr}) / 2$$



Identification

Property Name: LINK

Direction: R3

Type: MultiLinear Plastic

NonLinear: Yes

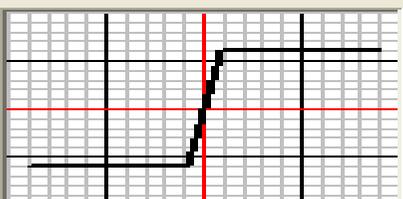
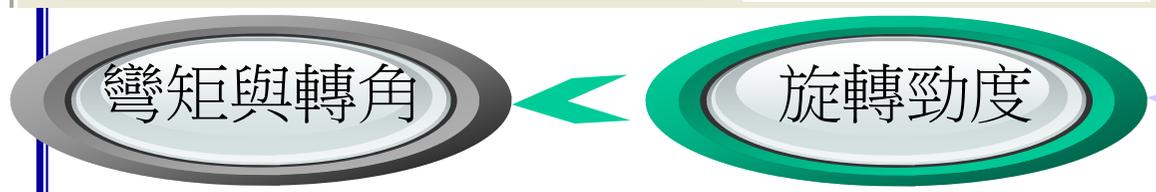
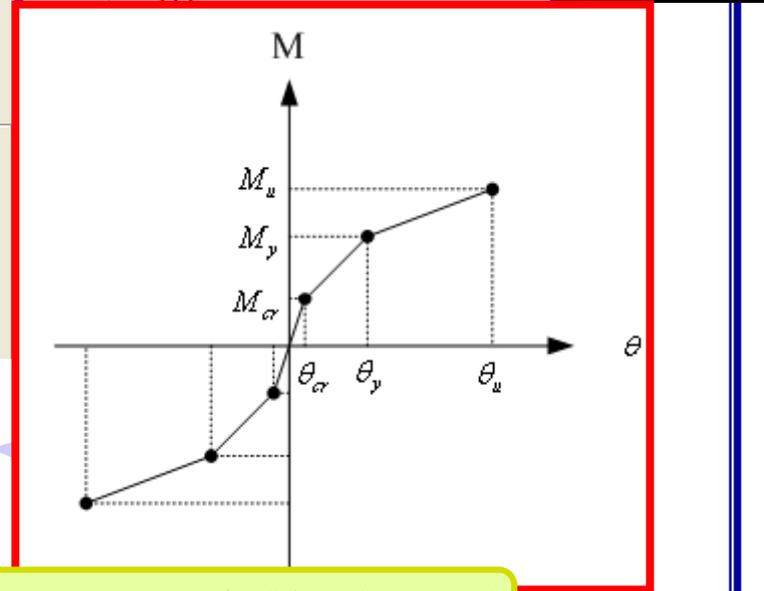
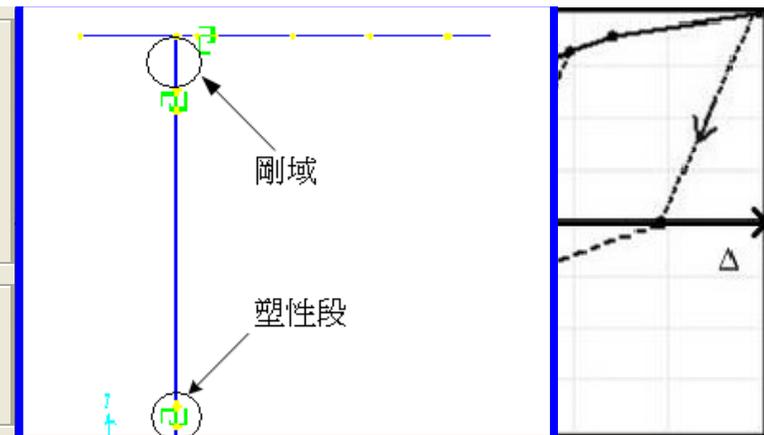
Properties Used For Linear Analysis Cases

Effective Stiffness: 0.

Effective Damping: 0.

Multi-Linear Force-Deformation Definition

	Rotation	Moment
1	-10.	-1.
2	-1.	-1.
3	0.	0.
4	1.	1.
5	10.	1.

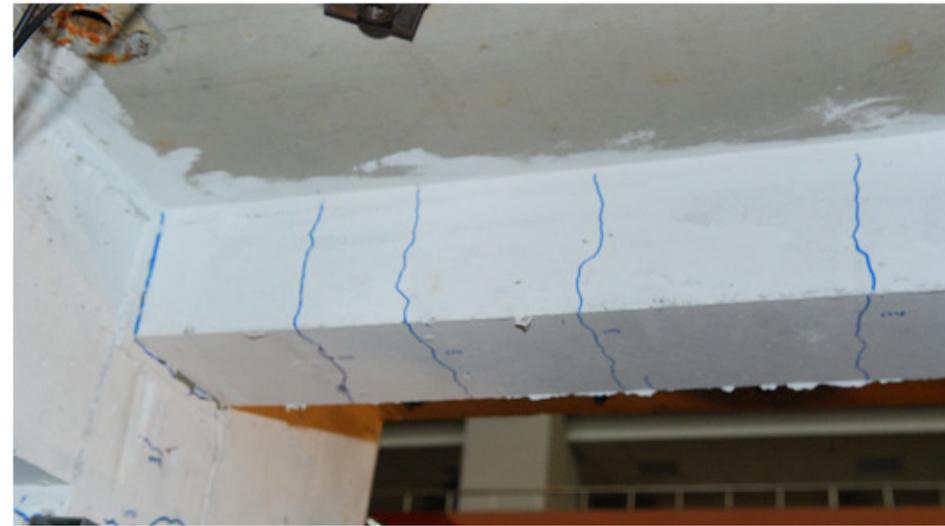
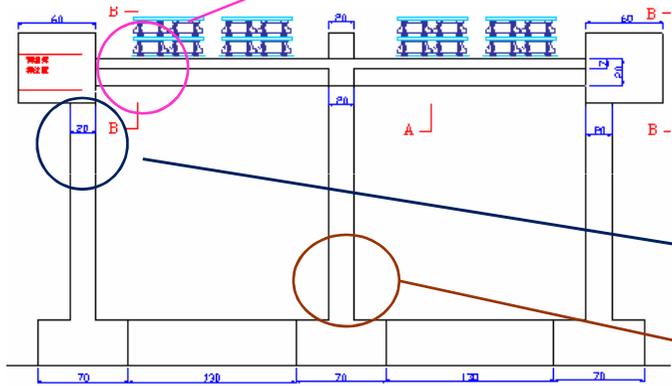



NEWMARK 直接積分法

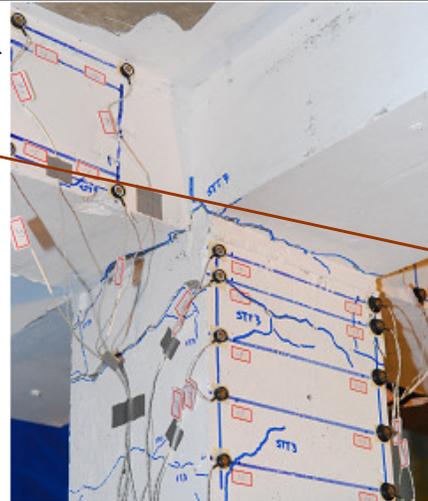


非線性動力直接積分歷時分析

RCF3(TCU082, PGA=1.3g)試驗後之破壞情況



構架梁端部



構架之柱上端



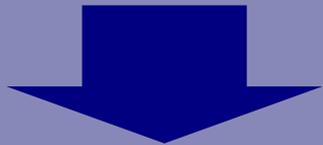
構架之柱下端

RCF3

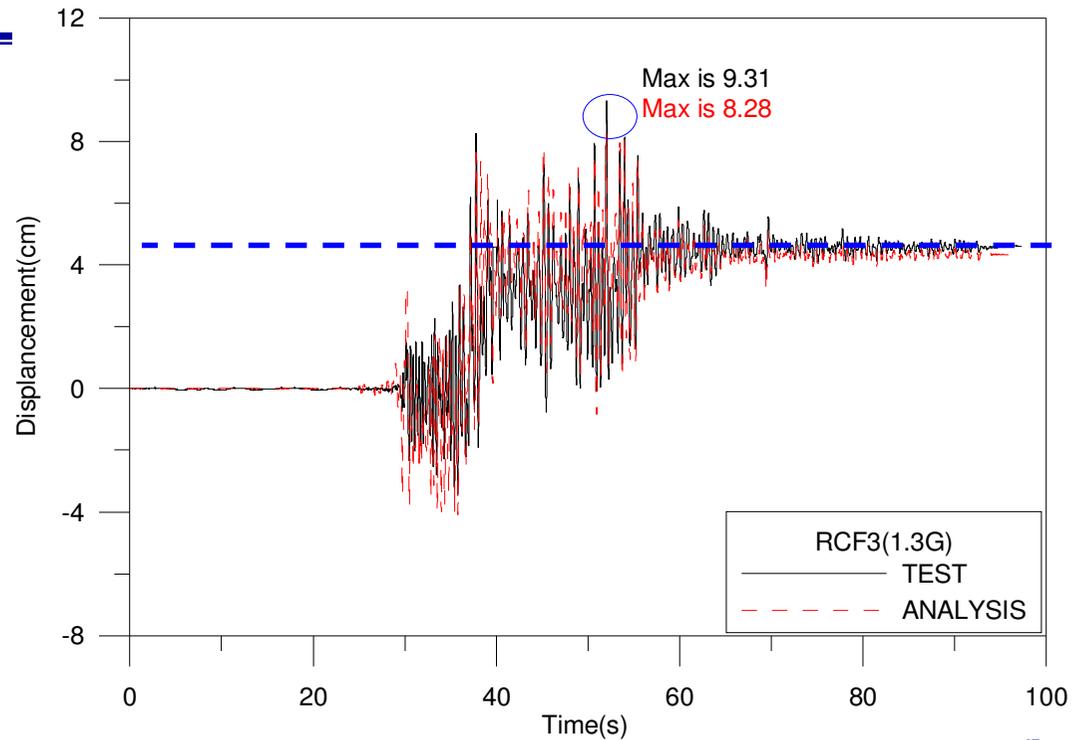
相對樓層位移動態反應比對

TCU082(1.3g) RCF3

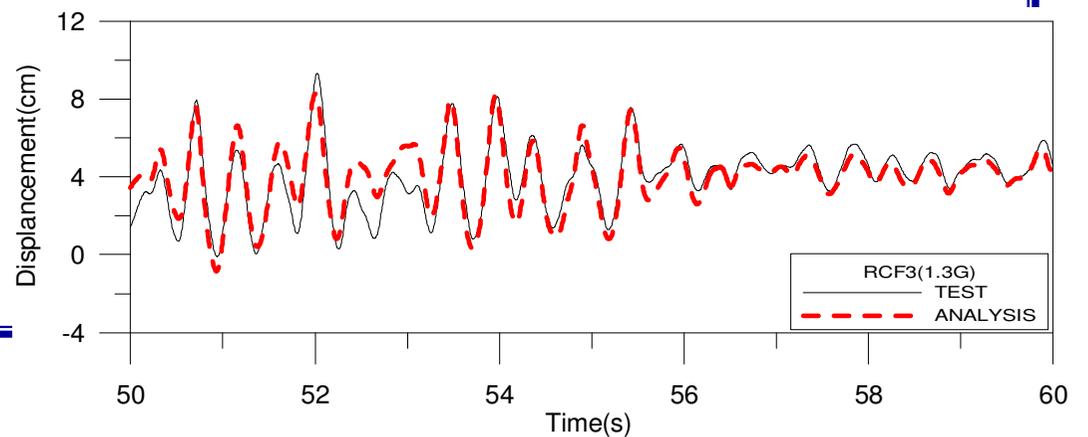
實驗:於52秒左右有最大值9.3公分、永久位移4.4公分。
分析:於52秒左右有最大值8.2公分、永久位移4.2公分。



重疊比對其分析之最大樓層位移減少1.0公分、永久位移降低0.2公分，且頻率近似相同。

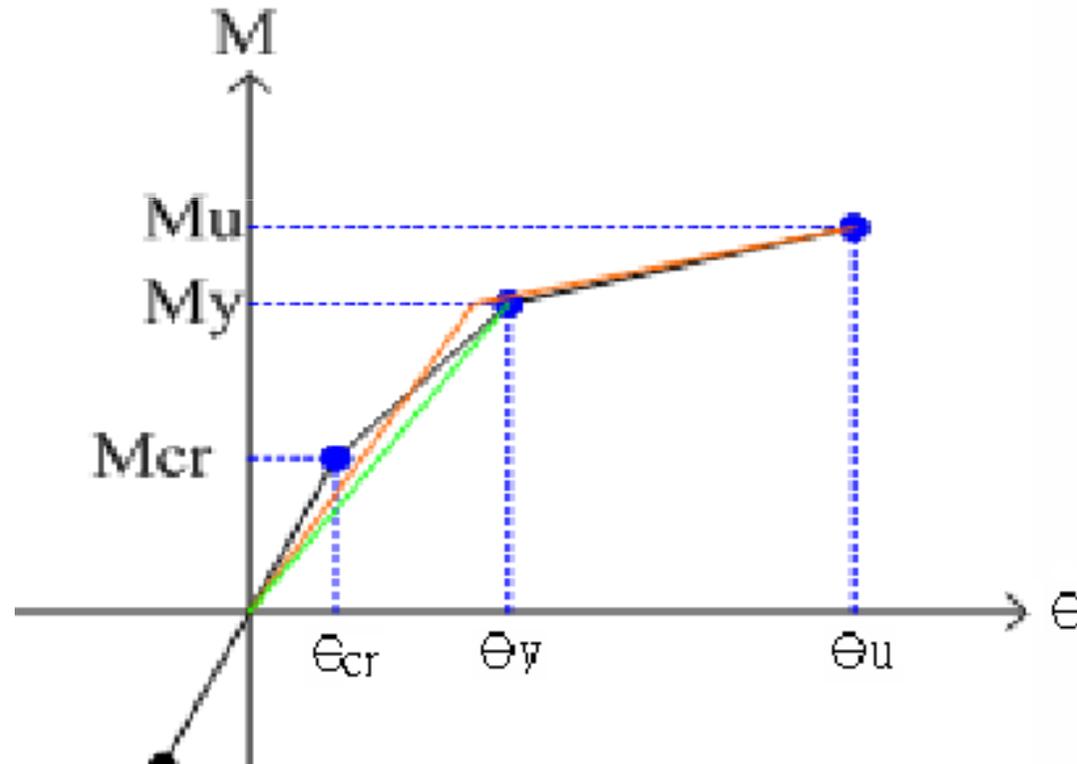
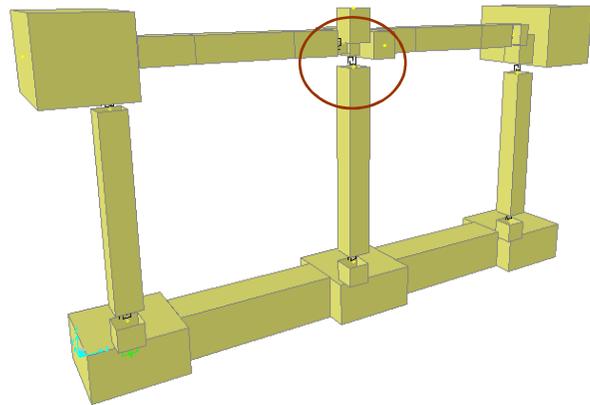


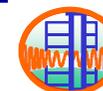
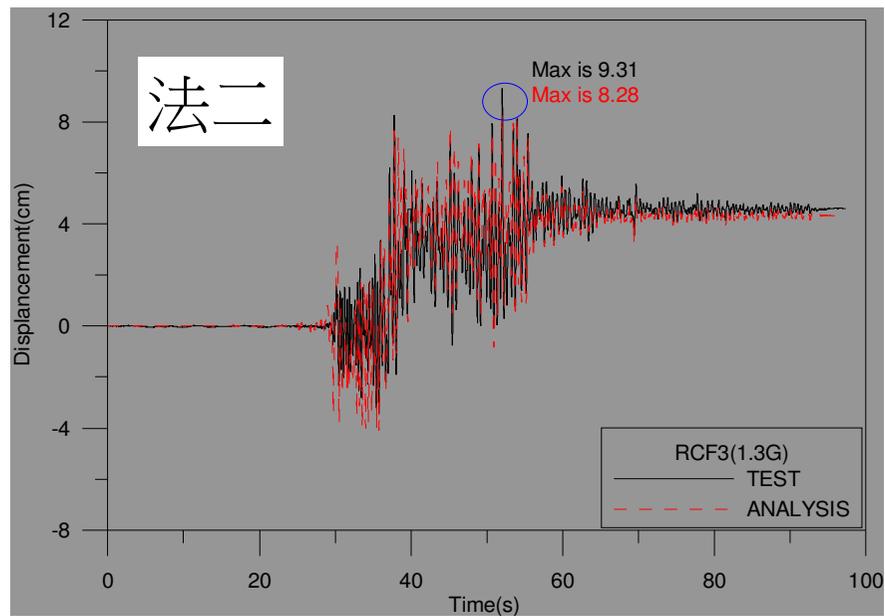
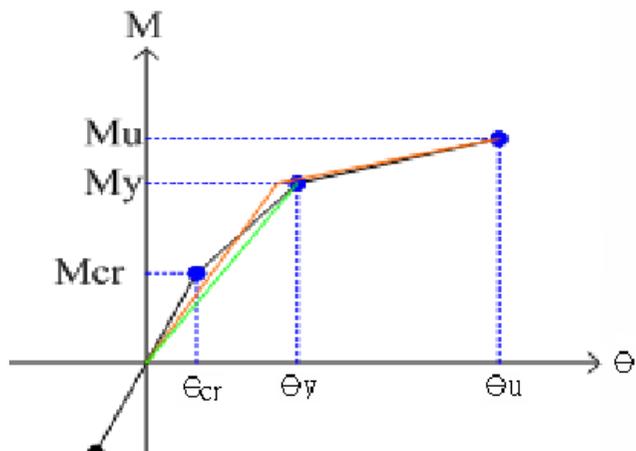
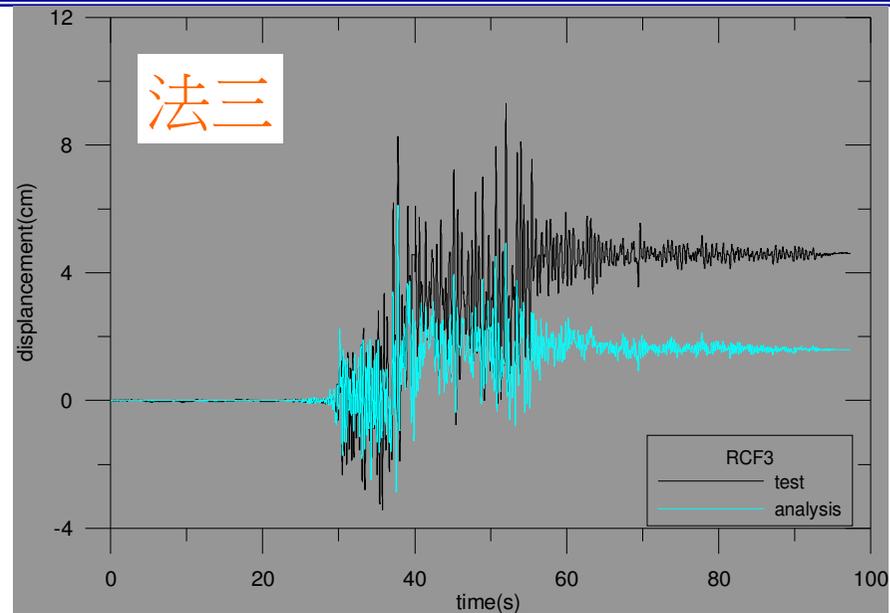
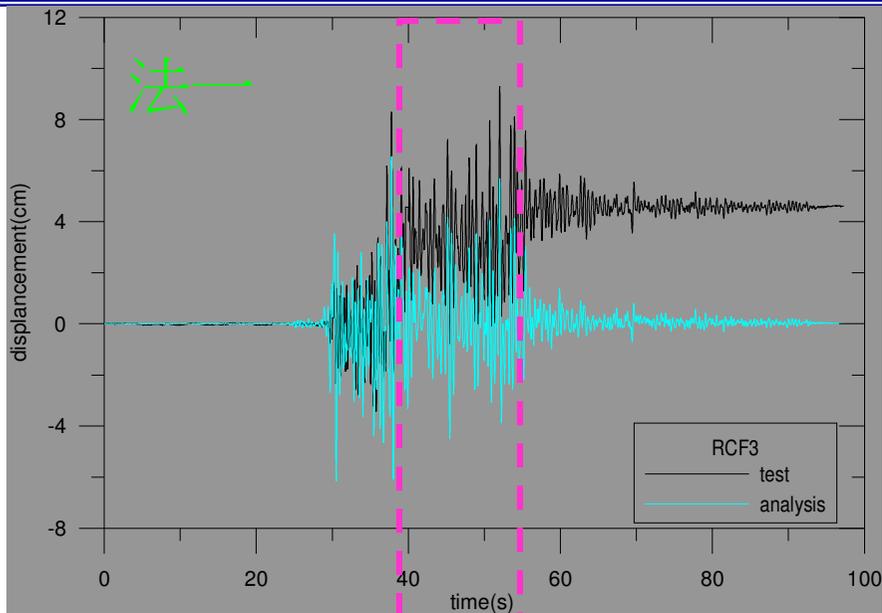
取其中30~60秒放大觀察

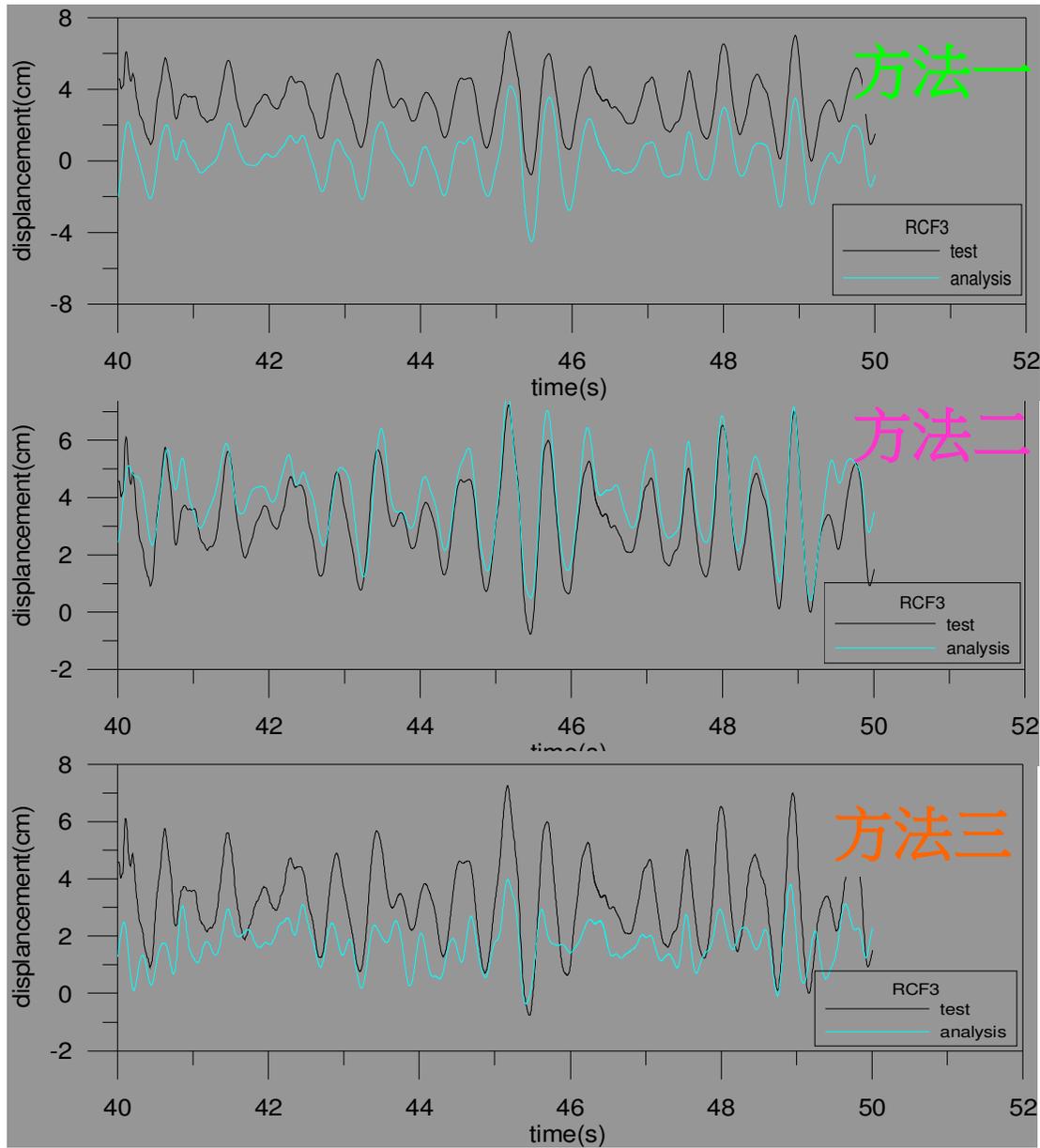


討論 M- θ 關係

- ❖ 方法一:採用 M_y 、 M_u 兩段斜率進行分析
- ❖ 方法二:採用 M_{cr} 、 M_y 、 M_u 三段斜率進行分析
- ❖ 方法三:採用法一 M_{cr} 與 M_y 間之切線斜率等面積進行分析







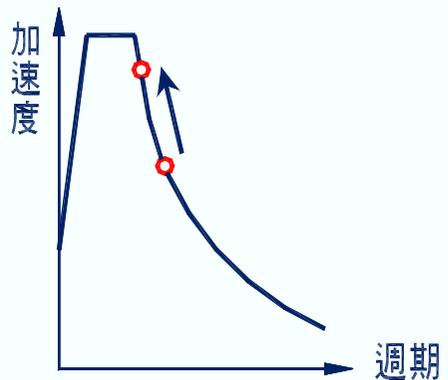
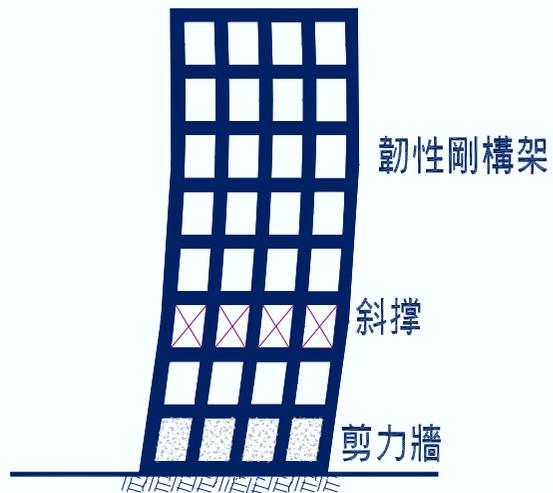
開裂行為之模擬
(Mcr)影響分析甚大

使用阻尼器之減震結構設計

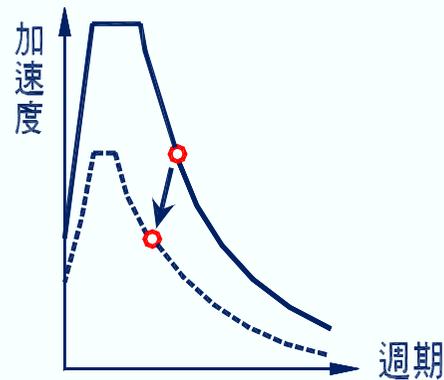
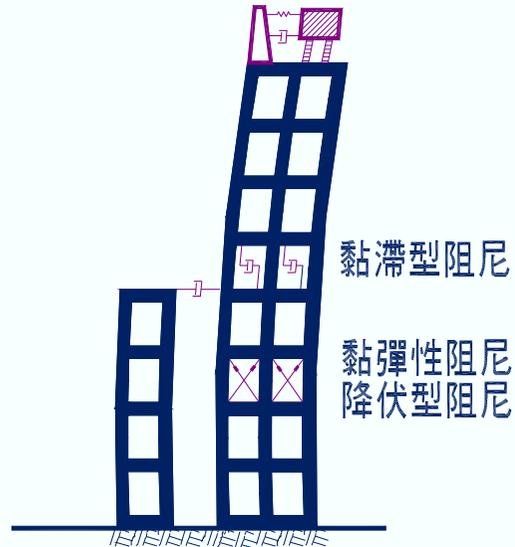


耐震設計方式

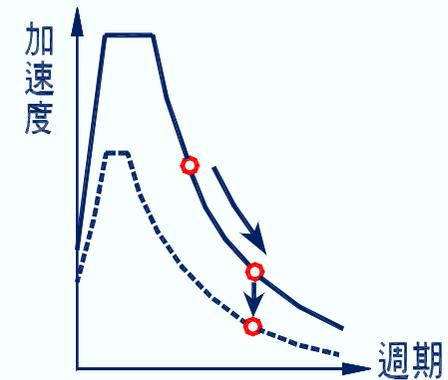
(1) 韌性需求設計



(2) 減震設計



(3) 隔震設計

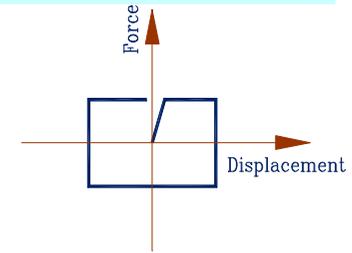


取自聯邦工程顧問資料

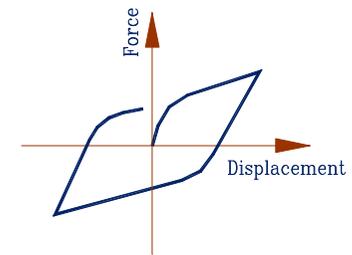
被動消能元件種類

位移型：

(1) 摩擦式

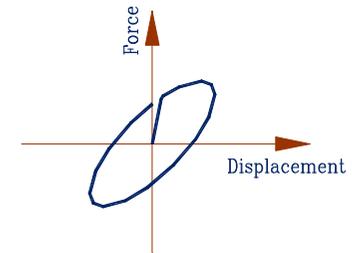


(2) 金屬降伏式

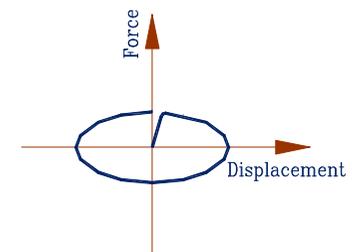


速度型：

(3) 黏彈式



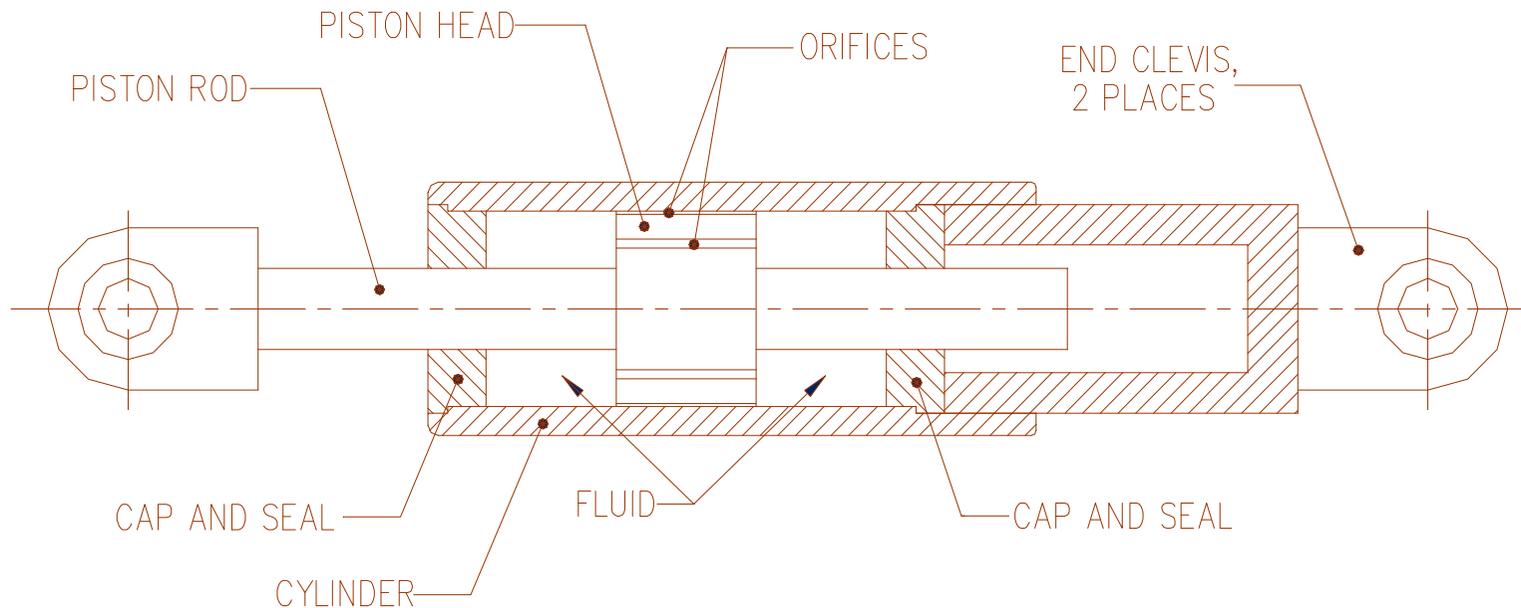
(4) 黏滯式 (Viscous)



Viscous Dampers



Longitudinal Cross Section of A Fluid Damper



- The difference of the pressure between each side of the piston head results in the damping force.
- The damping constant of the damper can be determined by adjusting the configuration of the orifice of the piston head.

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

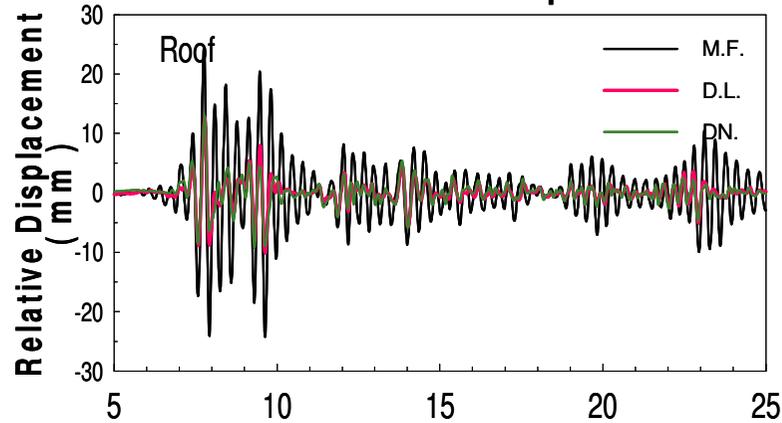
三層樓之兩跨乘兩跨
空間鋼筋混凝土構架



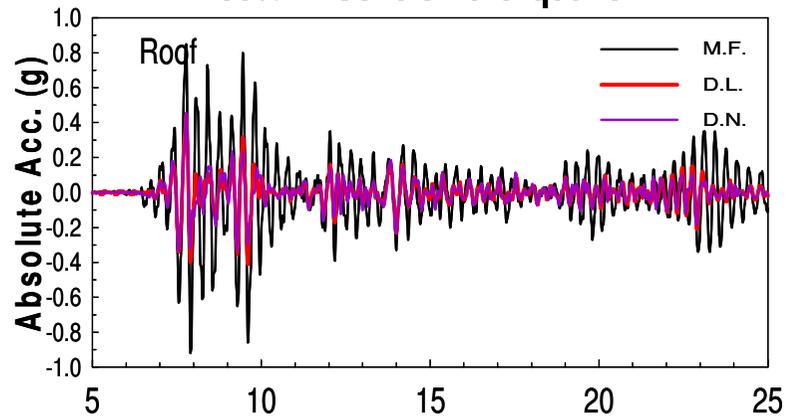
Response History

Diagonal-Damper-Brace

80% El Centro Earthquake

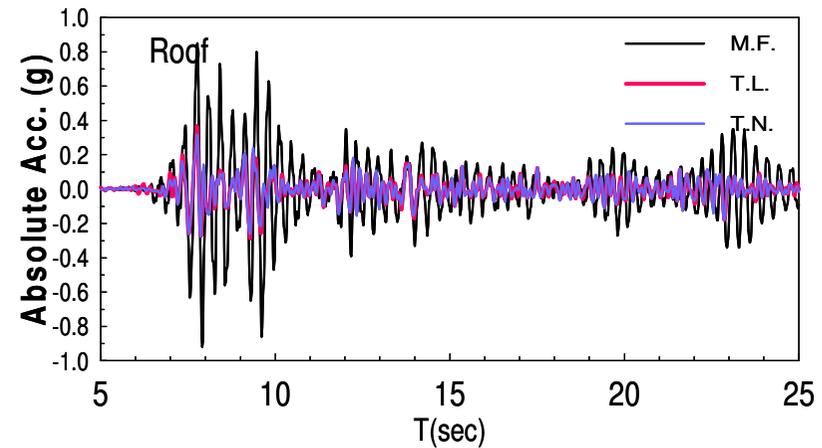
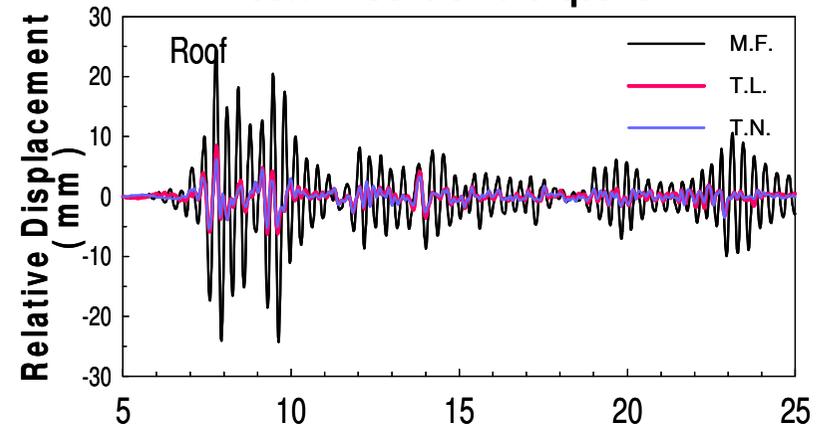


80% El Centro Earthquake



Toggle-Brace-Damper

80% El Centro Earthquake



Force-Velocity Relationship of Viscous Dampers

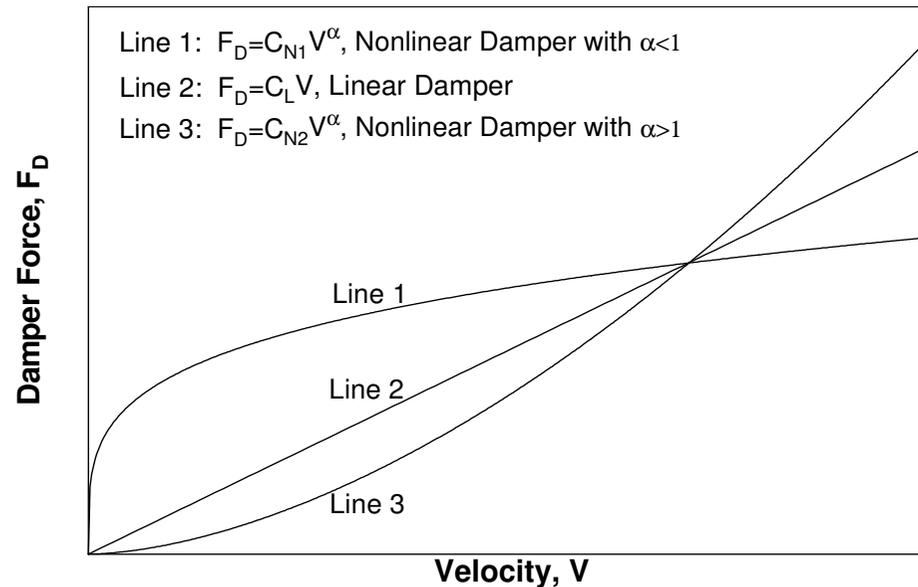
$$F_D = C |\dot{u}|^\alpha \operatorname{sgn}(\dot{u})$$

$\alpha = 1$

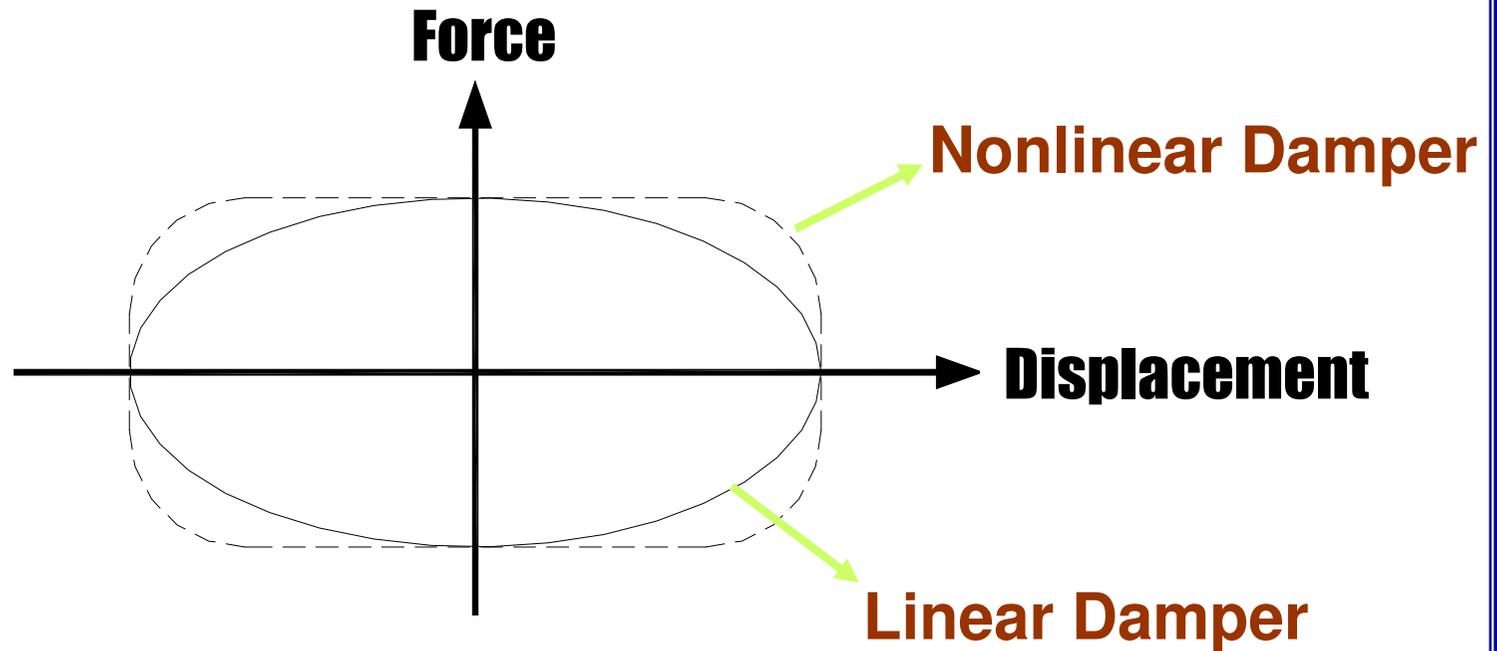
Linear Viscous Dampers

$0 < \alpha < 1$

Nonlinear Viscous Dampers



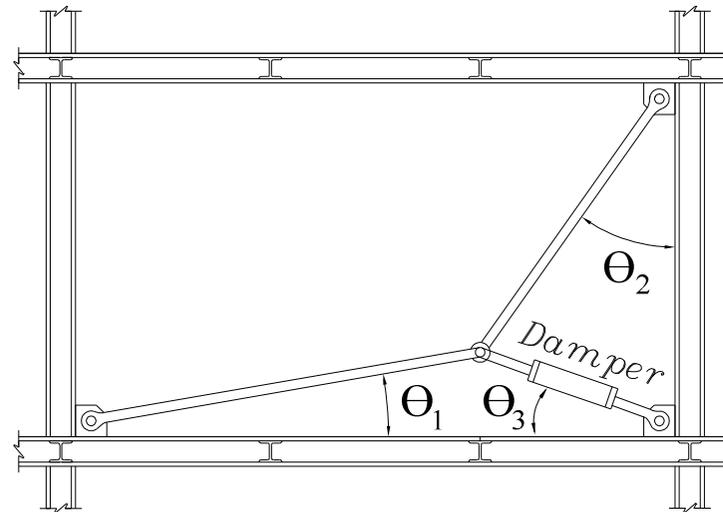
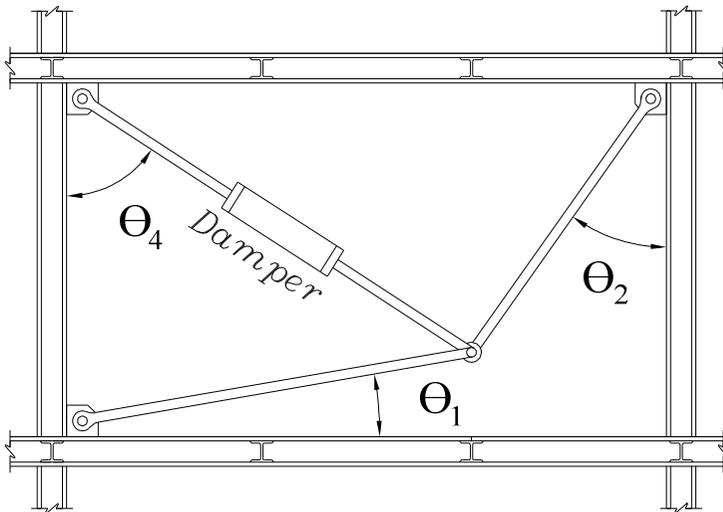
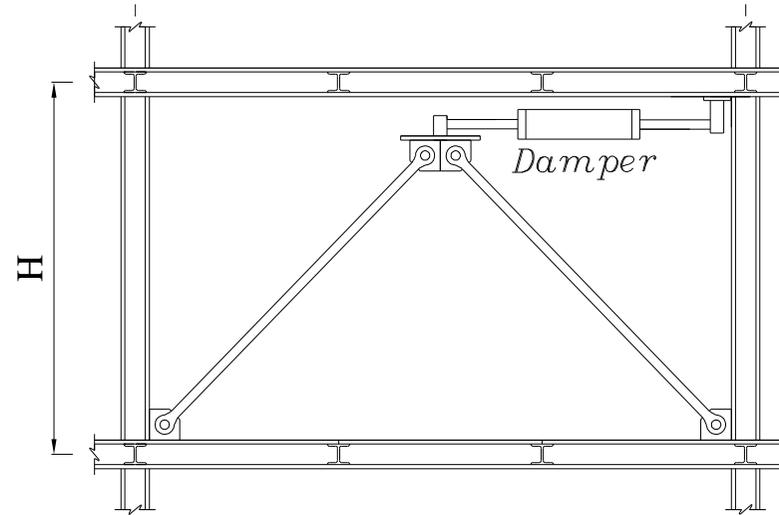
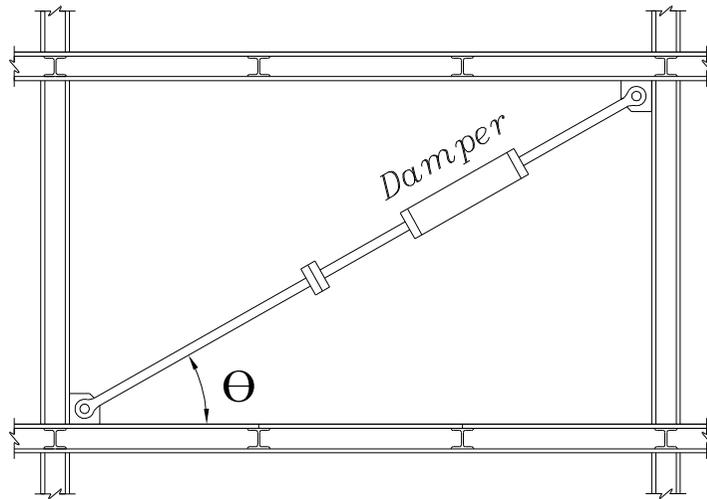
Hysteresis Loops of Viscous Dampers (Sinusoidal Motion)



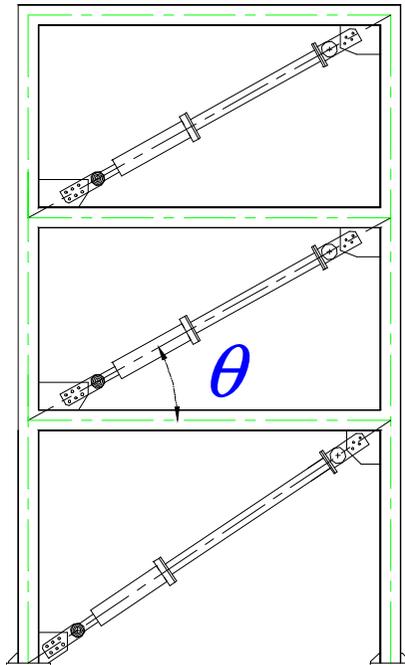
No storage stiffness!

Viscous dampers won't change the natural frequency of the primary structure.

Typical Installation Scheme of Viscous Dampers



MDOF System with Linear Viscous Dampers



MDOF System with Linear Viscous Dampers

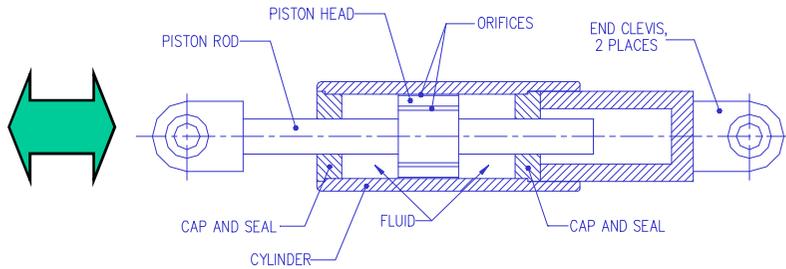
SDOF $\xi_d = \frac{W_D}{2\pi W_s}$

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

MDOF $\xi_d = \frac{\sum \text{all dampers } W_D}{2\pi W_s}$



Energy Dissipated by Linear Viscous Dampers (in one cycle of sinusoidal vibration)



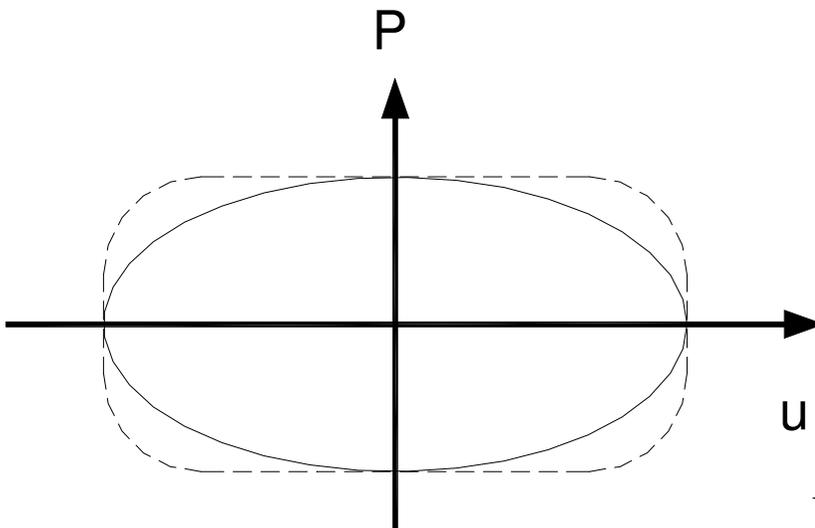
$$u = u_0 \sin \omega t$$

$$P = P_0 \sin(\omega t + \delta) = C\dot{u}$$

$$W_D = \oint F_D du = \oint C\dot{u} du = \int_0^{2\pi/\omega} C\dot{u}^2 dt$$

$$= C u_0^2 \omega^2 \int_0^{2\pi} \cos^2 \omega t d(\omega t)$$

$$= \pi C u_0^2 \omega$$



MDOF System with Linear Viscous Dampers

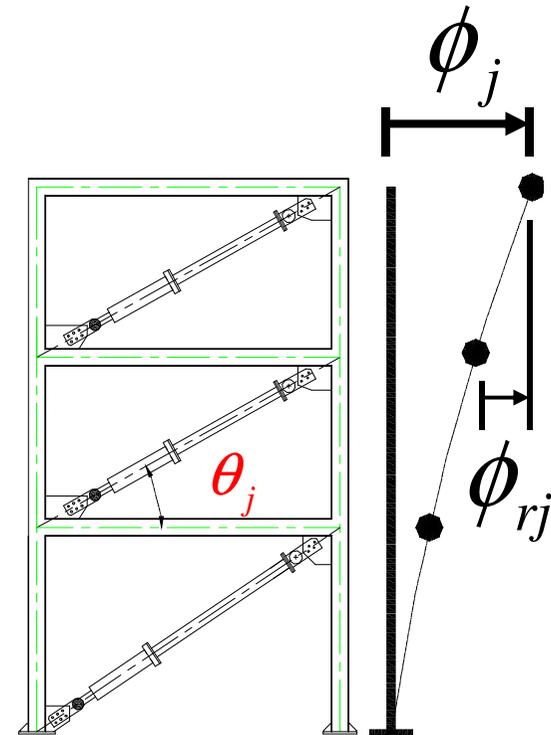
Considering the First Mode of Vibration

$$\xi_d = \frac{\sum_j W_j}{2\pi W_s}$$

$$\sum_j W_j = \sum_j \pi C_j u_j^2 \omega_0 = \frac{2\pi^2}{T} \sum_j C_j \phi_{rj}^2 \cos^2 \theta_j$$

$$W_s = \Phi_1^T [K] \Phi_1 = \Phi_1^T \omega^2 [m] \Phi_1$$

$$= \sum_i \omega^2 m_i \phi_i^2 = \frac{4\pi^2}{T^2} \sum_i m_i \phi_i^2$$



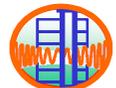
MDOF System with Linear Viscous Dampers

Effective Damping Ratio of A Structure with Linear Viscous Dampers

$$\xi_{eff} = \xi_0 + \frac{\frac{2\pi^2}{T} \sum_j C_j \phi_{rj}^2 \cos^2 \theta_j}{2\pi \frac{4\pi^2}{T^2} \sum_i m_i \phi_i^2}$$
$$= \xi_0 + \frac{T \sum_j C_j \phi_{rj}^2 \cos^2 \theta_j}{4\pi \sum_i m_i \phi_i^2}$$

皆為平方, 大小不影響

MDOF System with Linear Viscous Dampers



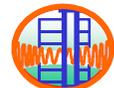
Energy Dissipated by Nonlinear Viscous Dampers

$$\begin{aligned}
 W_D &= \oint F_D du = \int_0^{2\pi/\omega} F_D \dot{u} dt && \longleftarrow F_D = C \dot{u}^\alpha \\
 &= \int_0^{2\pi/\omega} |C \dot{u}^{1+\alpha}| dt && \longleftarrow \dot{u} = \omega u_0 \sin \omega t \\
 &= C (\omega u_0)^{1+\alpha} \int_0^{2\pi/\omega} |\sin^{1+\alpha} \omega t| dt \\
 \text{Let } \omega t = 2\theta &&& \Longrightarrow dt = \frac{2}{\omega} d\theta
 \end{aligned}$$

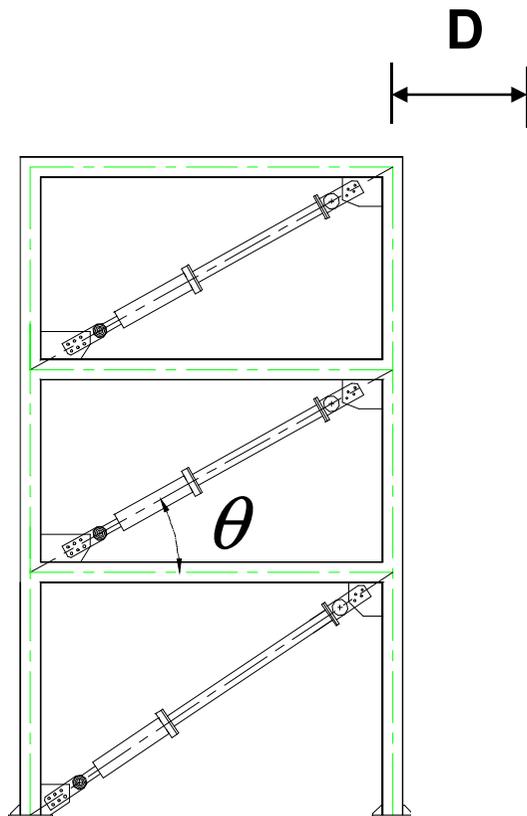
$$\begin{aligned}
 W_D &= C (\omega u_0)^{1+\alpha} \frac{2}{\omega} \int_0^\pi |\sin^{1+\alpha} 2\theta| d\theta \\
 &= 2^{2+\alpha} C \omega^\alpha u_0^{1+\alpha} \int_0^{\pi/2} 2 \sin^{1+\alpha} \theta \cos^{1+\alpha} \theta d\theta \\
 &= 2^{2+\alpha} C \omega^\alpha u_0^{1+\alpha} \frac{\Gamma^2(1+\alpha/2)}{\Gamma(2+\alpha)}
 \end{aligned}$$

$$\begin{aligned}
 W_D &= \lambda C \omega^\alpha u_0^{1+\alpha} \\
 \lambda &= 2^{2+\alpha} \frac{\Gamma^2(1+\alpha/2)}{\Gamma(2+\alpha)}
 \end{aligned}$$

SDOF System with Nonlinear Viscous Dampers



Effective Damping Ratio of A Structure with Nonlinear Viscous Dampers



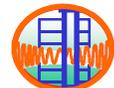
$$\xi_{\text{eff}} = \xi_0 + \frac{T^{2-\alpha} \sum_j \lambda C_j \phi_{rj}^{1+\alpha} \cos^{1+\alpha} \theta_j}{(2\pi)^{3-\alpha} D^{1-\alpha} \sum_i m_i \phi_{i/i}^2}$$



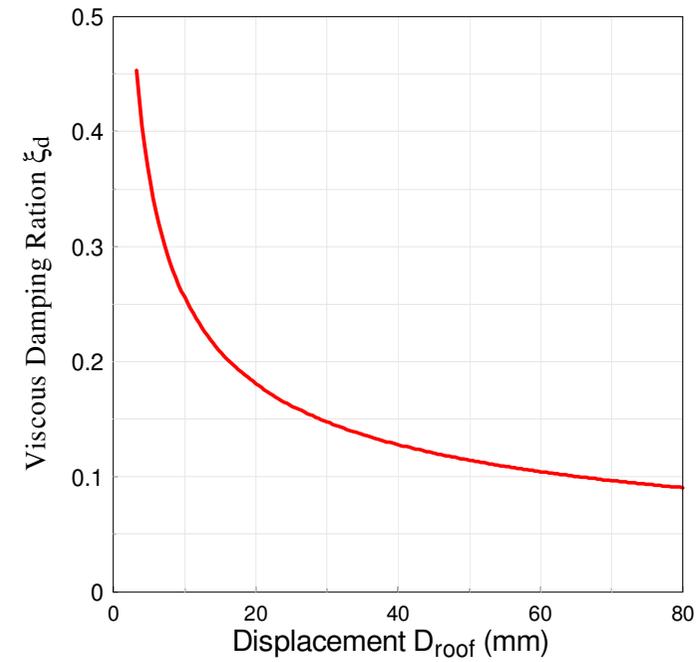
$$1-\alpha=2-(1+\alpha)$$

Displacement Dependent

MDOF System with Nonlinear Viscous Dampers



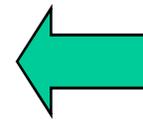
Shaking Table Test



黏性阻尼器之設計

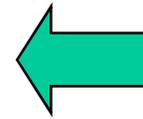
Elastic Response

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



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

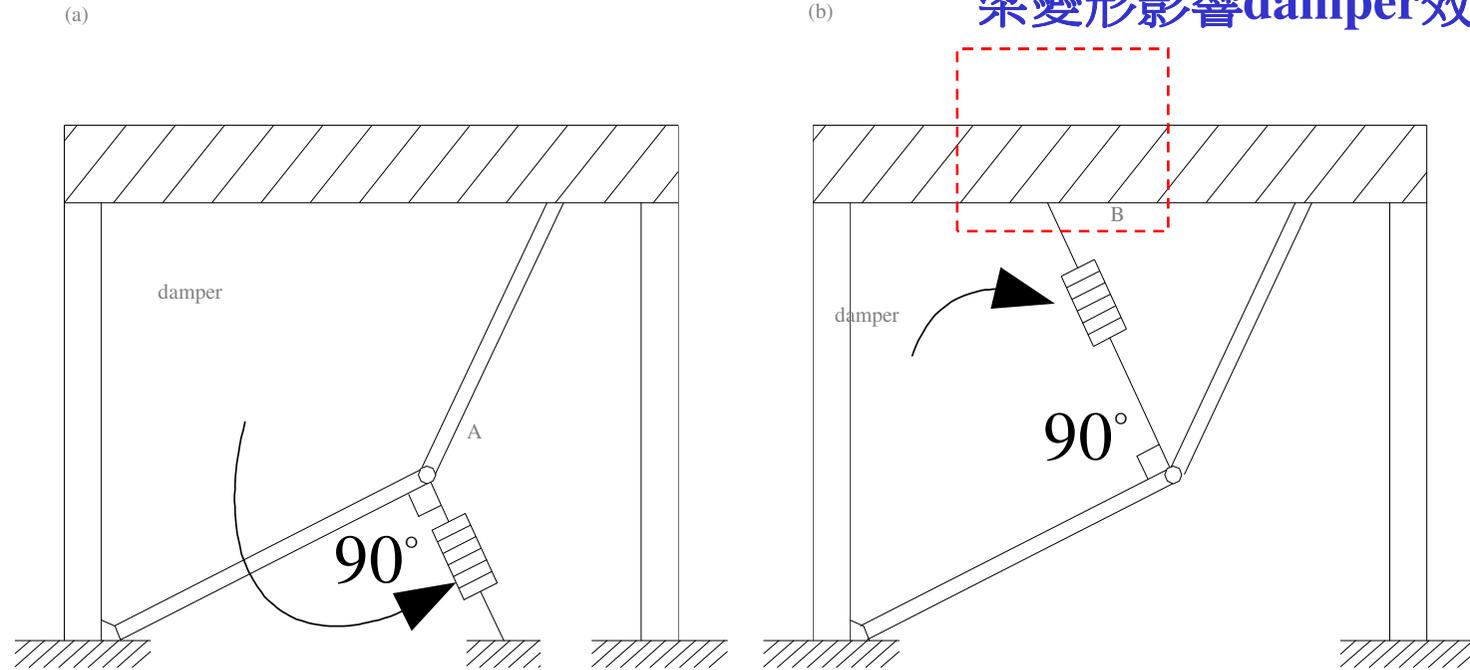
位移設計法

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

$$D = \Gamma_1 S_d$$



Toggle-Brace-Dampers



Lower Toggle-Brace Damper

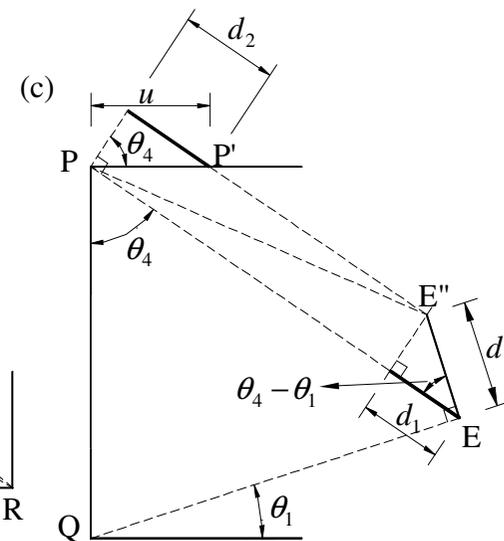
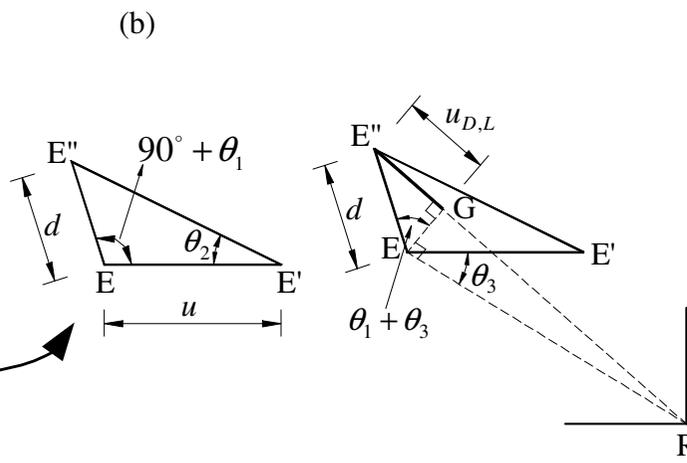
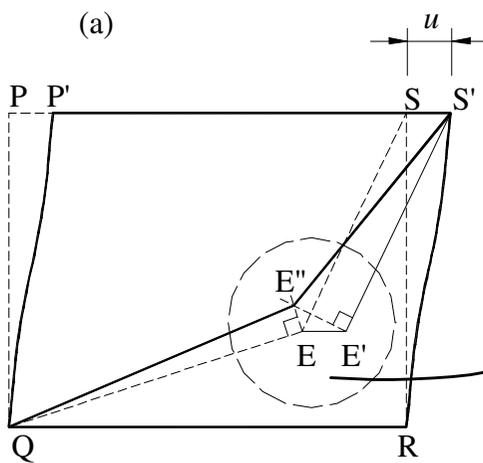
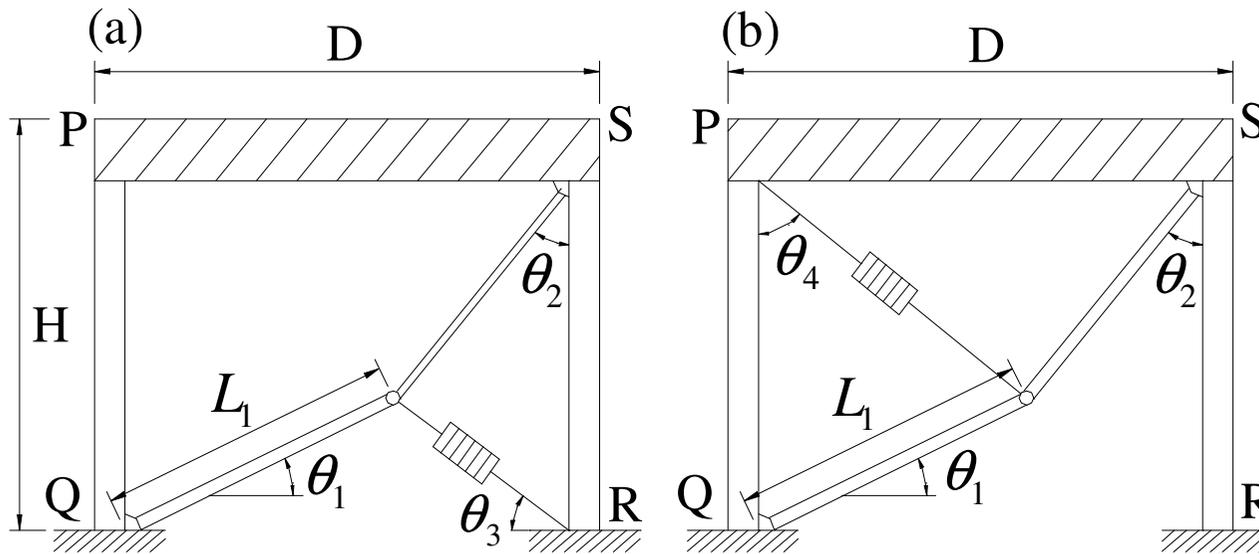
Upper Toggle-Brace-Damper

MCEER



Lower Toggle-Brace-Damper

Upper Toggle-Brace-Damper



Linear Toggle-Brace-Damper

$$\xi_d = \frac{T \sum_j C_j \phi_{rj}^2 f_j^2}{4\pi \sum_i m_i \phi_i^2}$$

Nonlinear Toggle-Brace-Damper

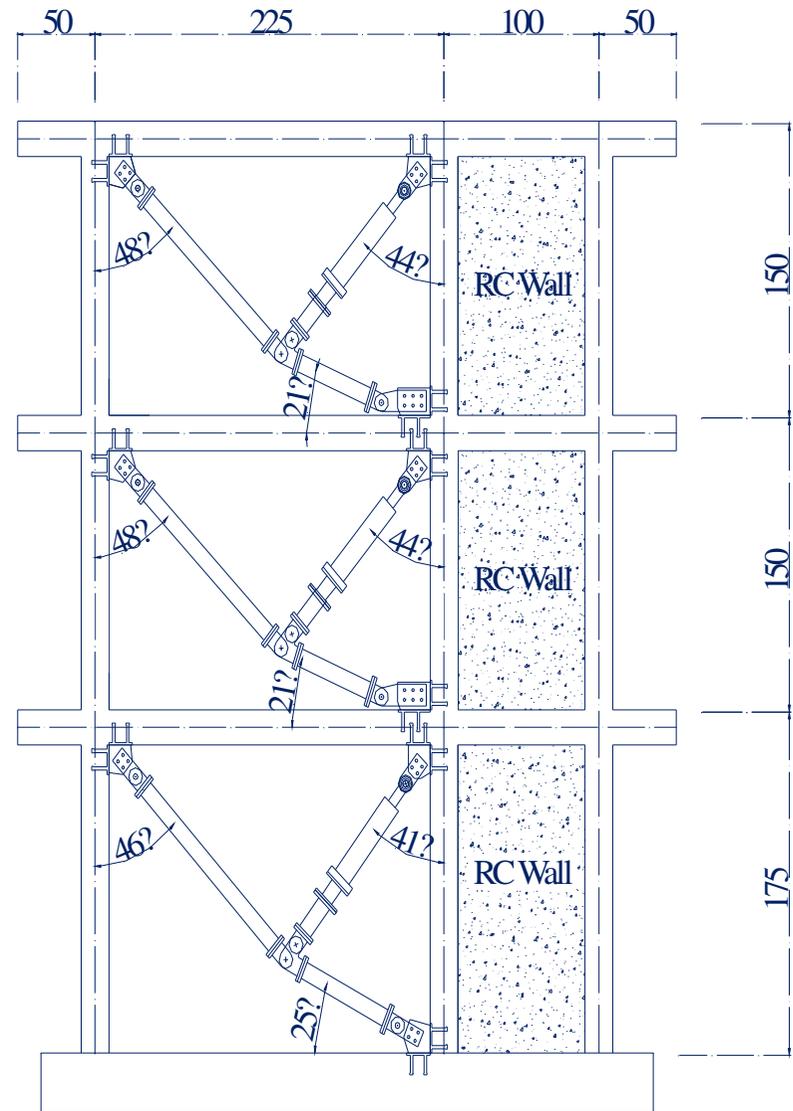
$$\xi_d = \frac{T^{2-\alpha} \lambda \sum_j C_j (f_j \phi_{rj})^{1+\alpha}}{(2\pi)^{3-\alpha} A^{1-\alpha} \sum_i m_i \phi_i^2}$$

$$f_U = \frac{u_{D,U}}{u} = \frac{\sin \theta_2}{\cos(\theta_1 + \theta_2)} \cos(\theta_4 - \theta_1) + \sin \theta_4 \quad \text{(Upper Toggle)}$$

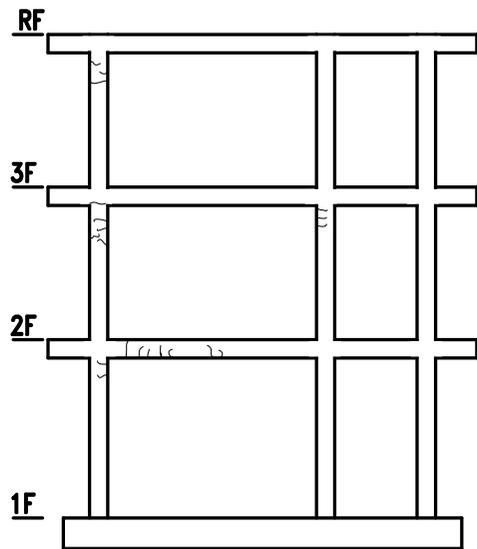
增加damper效果, 但亦增加斜撐
受力, 需注意面外挫屈

$$f_L = \frac{u_{D,L}}{u} = \frac{\sin \theta_2 \sin(\theta_1 + \theta_3)}{\cos(\theta_1 + \theta_2)} \quad \text{(Lower Toggle)}$$

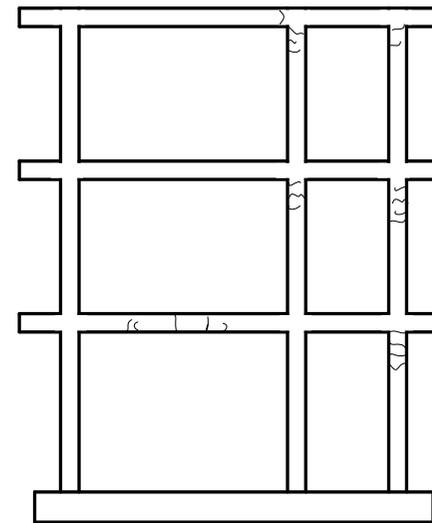
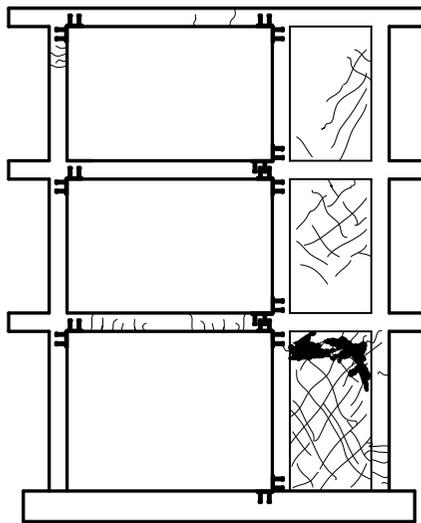




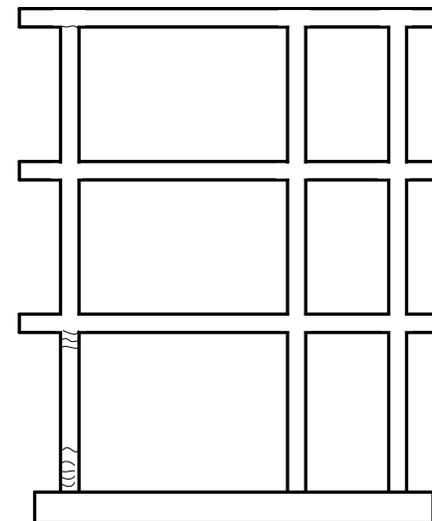
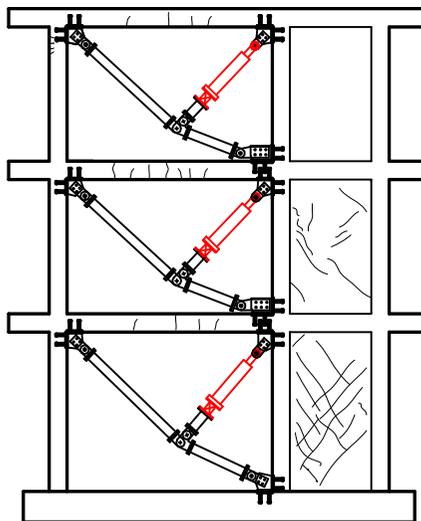
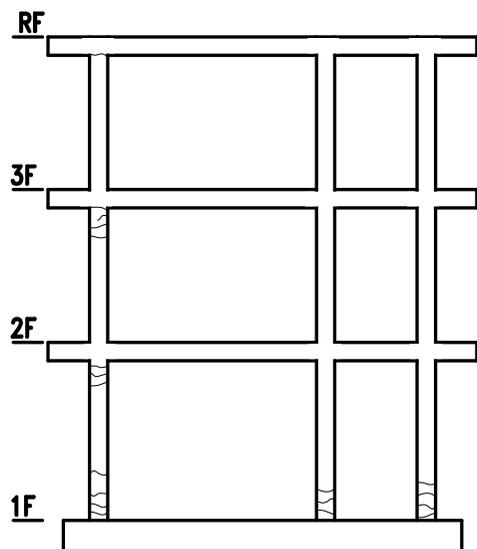
(a) w/o dampers



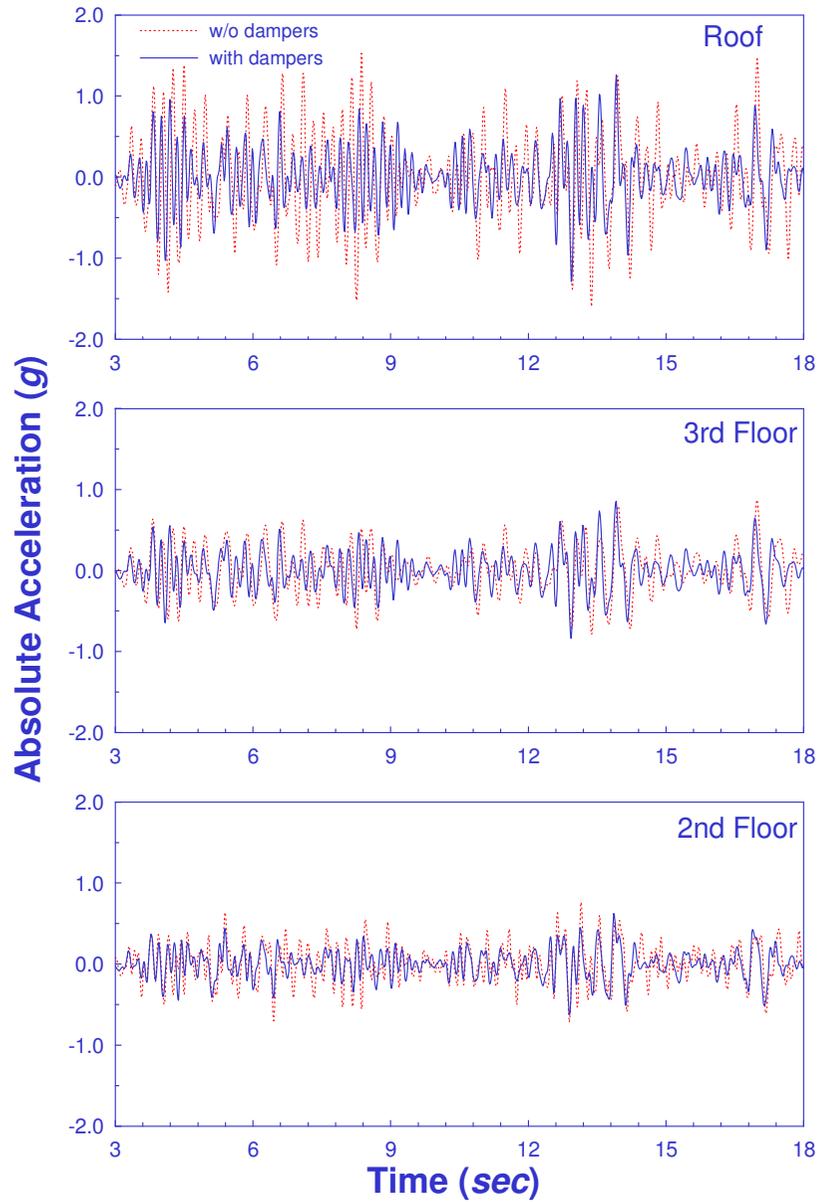
After 300% TCU078



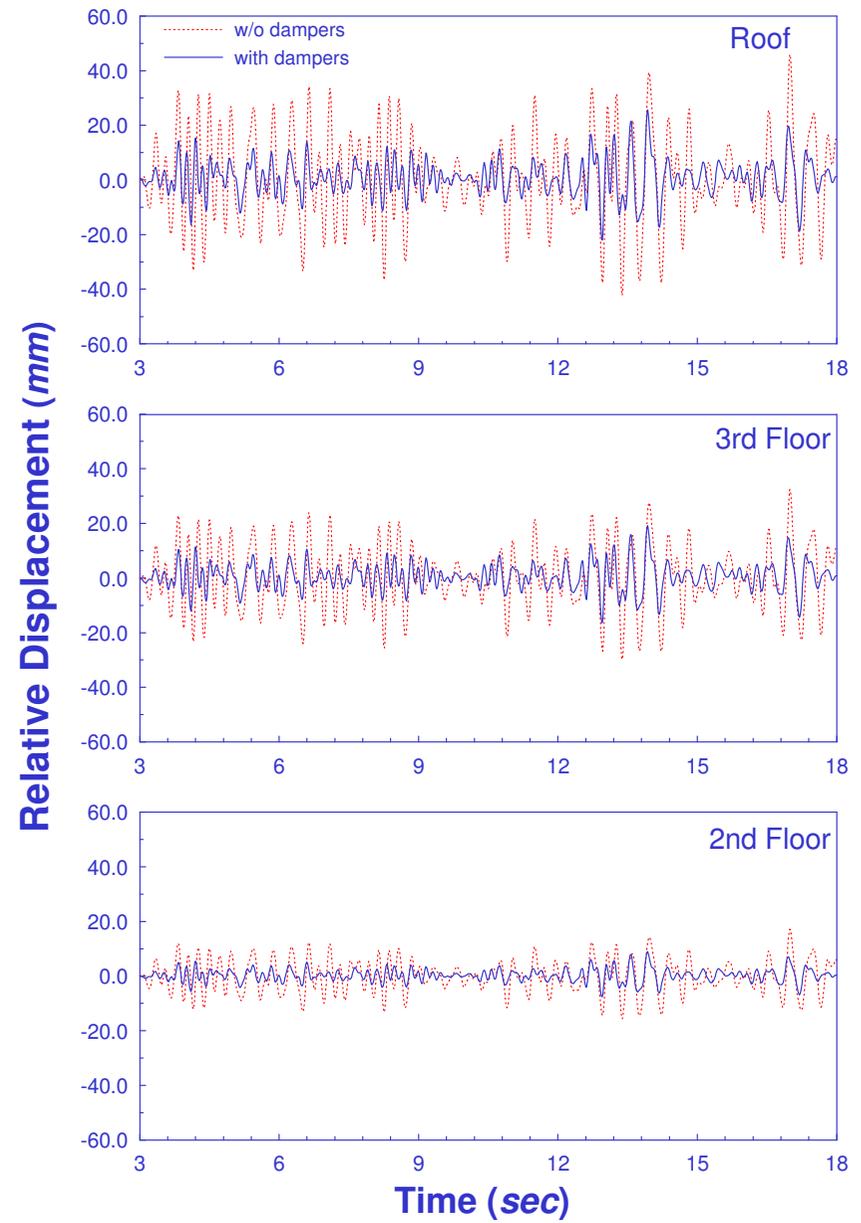
(b) with dampers



300% TCU078EW Test



300% TCU078EW Test



Viscous Damper 之設計



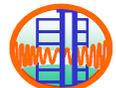
線性靜力分析程序

- (第一步驟) 決定設計阻尼比(如10%)
- inherent damping β (5%) + viscous damping β_v (10%) = effective damping β_{eff} (15%)
- 含消能元件結構構架於最大考量地震下保持彈性 (hysteretic damping = 0)

- (第二步驟) 構架耐震設計
- 以設計地震考慮 β_{eff} (15%) 阻尼修正因子折減之**基底剪力設計**
- **設結構保持彈性**

- (第三步驟) 地震豎向力分佈
- 考慮整體結構等效阻尼比 β_{eff} ，依據規範將最大考量地震作用基底剪力進行**豎向力分佈**

- (第四步驟) 垂直持續載重+側向靜力分析求得各層樓之側向層間變位



- (第五步驟) 設計阻尼常數C值

- 利用步驟4分析之各層樓層間變位，求各層**阻尼器之軸向變形**，配合結構基本振態角頻率 ω 可求得各層**阻尼器之速度值(V)**
- 以下式計算**均勻分配(uniform distribution)**決定各層樓之C值

$$\beta_v = \frac{\sum_j W_{vj}}{4\pi W_k} \quad \sum W_{vj} = \left(\frac{2\pi}{T_s}\right)^\alpha \sum \lambda C_j |\Delta_{rj} \cos \theta_j|^{1+\alpha} \quad W_K = \frac{1}{2} \sum_i F_i u_i$$

- (第六步驟) 多次迭代後, 決定Damper最大出力與衝程容量

- 速度型阻尼器之力學行為與速度相關，理應進行**動力分析程序設計**較為適當
- 建議初步設計完成後，應**至少進行線性動力分析**作為檢核



線性靜力分析程序 (考慮結構本身遲滯消能)

$$\beta_{eff} = \beta + \frac{\sum_j W_{Vj} + \sum_i W_{F_i}}{4\pi W_k}$$

$$\beta_{eff} = \beta + \frac{\pi \sum_j C_j u_{rj}^2 \cos^2 \theta_j + T / (2\pi) \sum_i W_{F_i}}{T \sum_i F_i u_i}$$

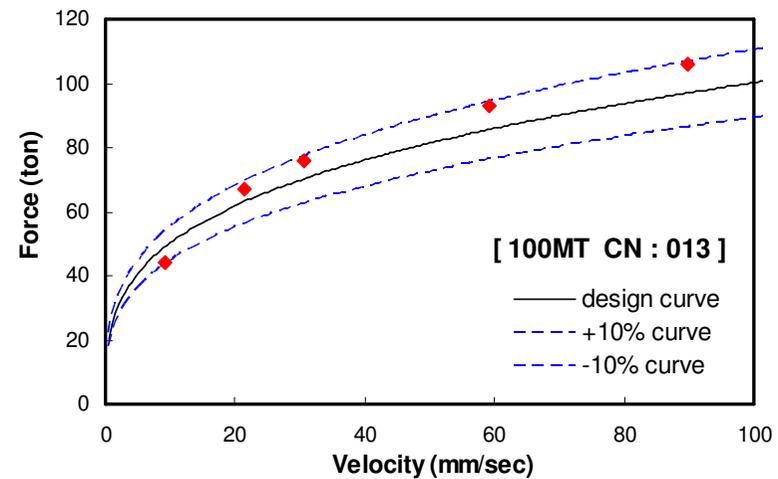
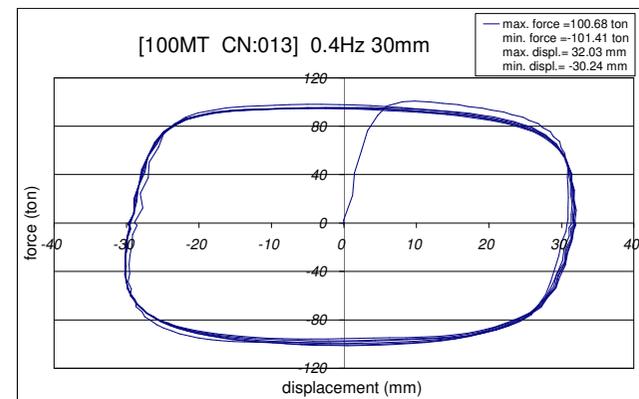


加裝 Viscous Damper 動力歷時反應分析



Viscous Damper 測試

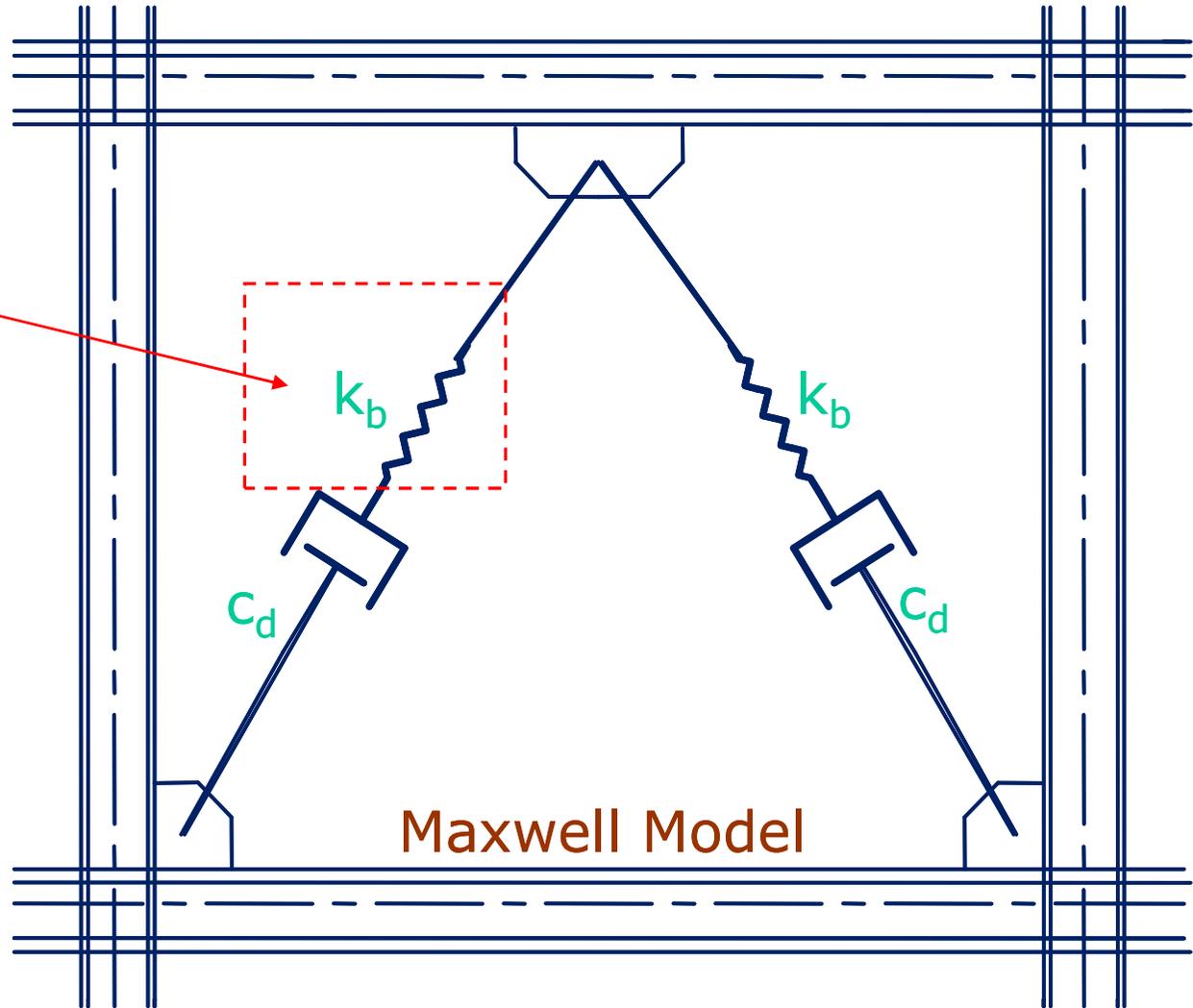
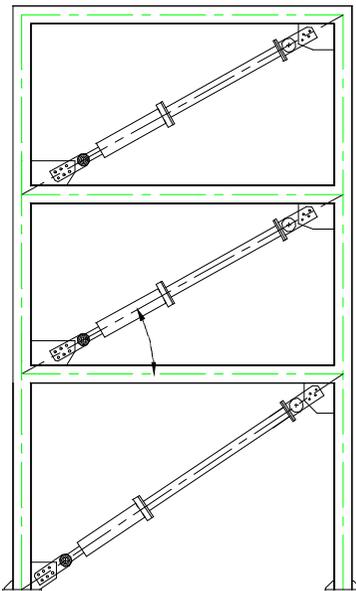
試驗要求: 阻尼器的速度-出力曲線中，在各種不同速度情況下，出力之試驗值與設計值差異不得超過 $\pm 15\%$ 。



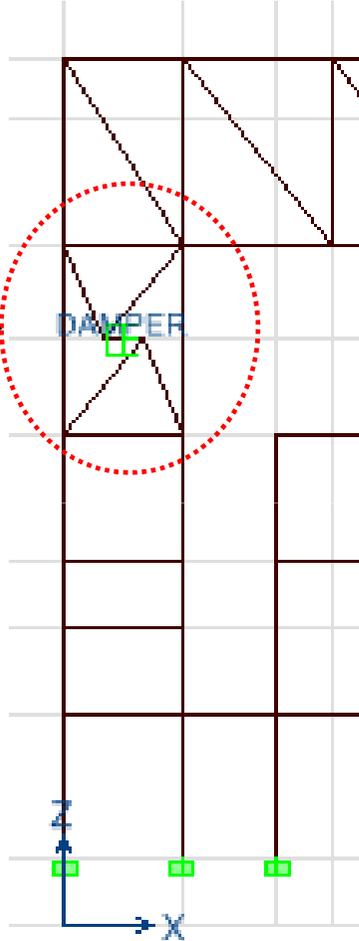
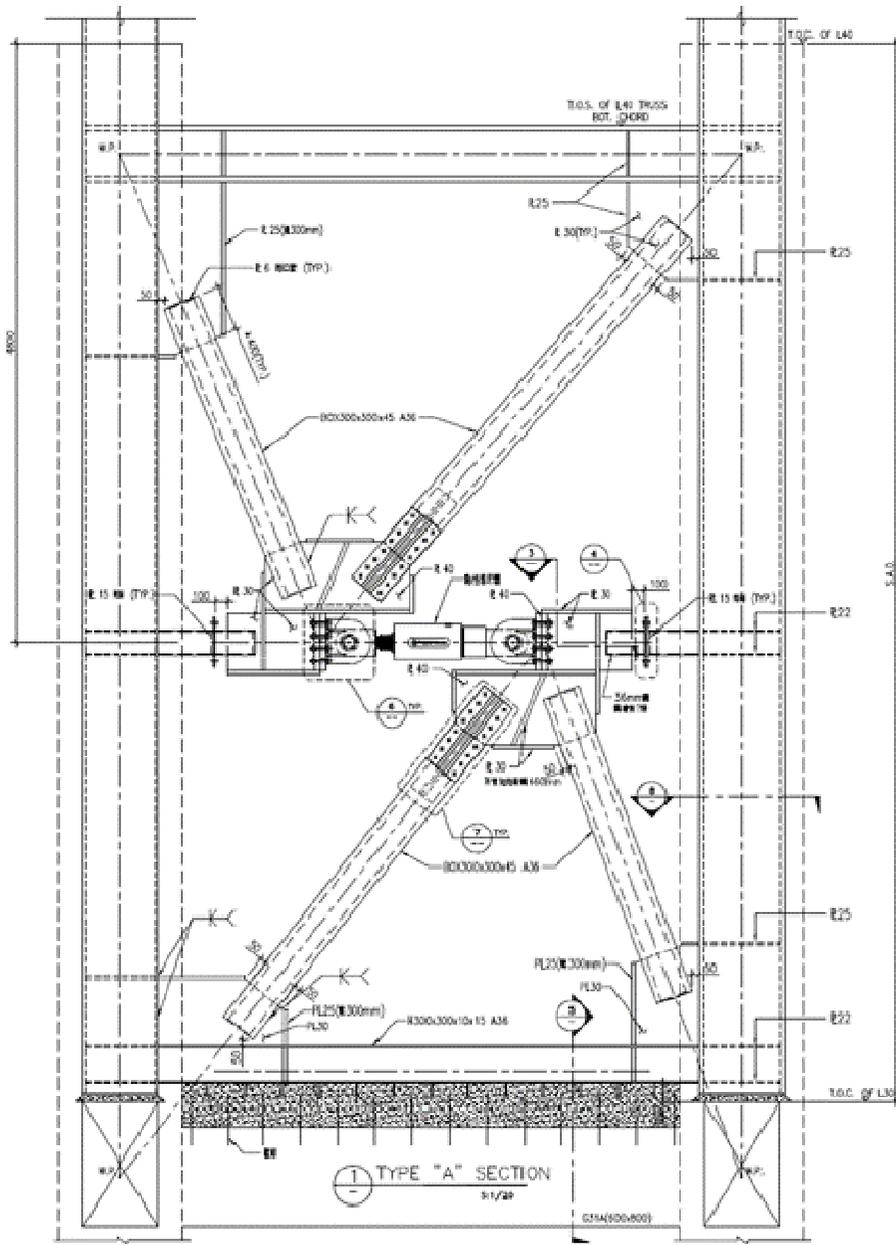
FVD 模擬模式

斜撐勁度

- 影響反應甚大
- 需準確模擬



斜撐勁度 影響反應甚大, 需準確模擬



補強設計

- 輸入地震: 採日本阪神地震加速度記錄

$$\phi = [0.457, 0.326, 0.135]$$

$$\alpha = 0.3$$

有效阻尼比提升10%

設計位移 $D = 10 \text{ cm}$

$$\theta = 35^\circ$$

阻尼器特性:

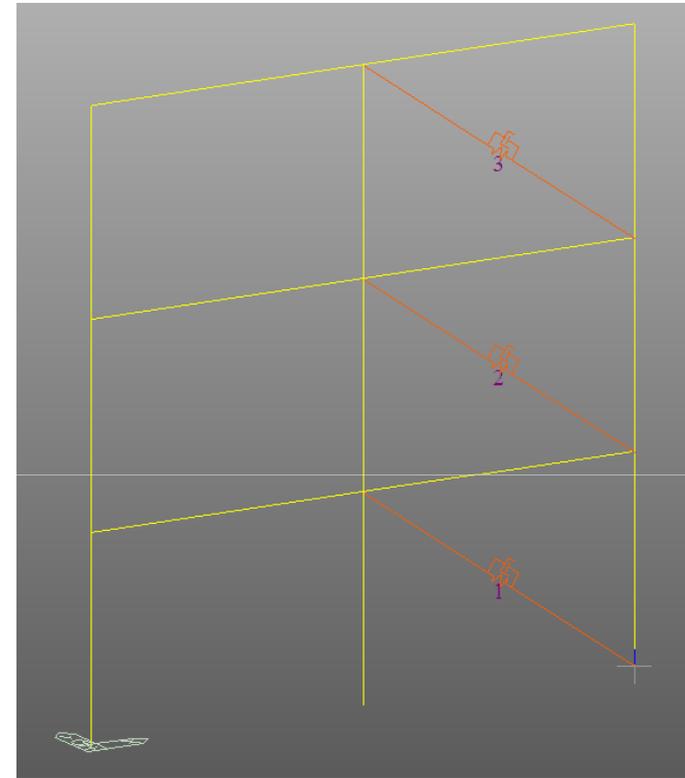
$$F = 24 V^{0.3}$$

F = 阻尼力(KN, 最大出力約140KN)

V = 速度(mm/s)

阻尼器配置: 3支

斜撐剛度 $k = 8.35 \text{ kN/mm}$



$$\xi_{eff} = \xi_0 + \frac{T^{2-\alpha} \sum_j \lambda C_j \phi_j^{1+\alpha} \cos^{1+\alpha} \theta_j}{(2\pi)^{3-\alpha} D^{1-\alpha} \sum_i m_i \phi_i^2}$$



Define General Link Properties

Name	Application Type	Property Type	Description
v1	Force	Viscoelastic Dam...	

Add/Modify General Link Properties

Name :

Application Type : Element Force

Property Type :

Description :

Self Weight Use Mass

Total Weight : kN Total Mass : kN/q

Linear Properties

DOF	Effective Stiffness	Effective Damping
<input checked="" type="checkbox"/> Dx	<input type="text" value="0"/> kN/mm	<input type="text" value="0.00049033"/> kN*sec/mm
<input type="checkbox"/> Dy	<input type="text" value="0"/> kN/mm	<input type="text" value="0"/> kN*sec/mm
<input type="checkbox"/> Dz	<input type="text" value="0"/> kN/mm	<input type="text" value="0"/> kN*sec/mm
<input type="checkbox"/> Rx	<input type="text" value="0"/> kN*mm/[rad]	<input type="text" value="0"/> kN*mm*sec/[rad]
<input type="checkbox"/> Ry	<input type="text" value="0"/> kN*mm/[rad]	<input type="text" value="0"/> kN*mm*sec/[rad]
<input type="checkbox"/> Rz	<input type="text" value="0"/> kN*mm/[rad]	<input type="text" value="0"/> kN*mm*sec/[rad]

Nonlinear Properties

DOF	Properties...>>
<input checked="" type="checkbox"/> Dx	<input type="button" value="Properties...>>"/>
<input type="checkbox"/> Dy	<input type="button" value="Properties..."/>
<input type="checkbox"/> Dz	<input type="button" value="Properties..."/>
<input type="checkbox"/> Rx	<input type="button" value="Properties..."/>
<input type="checkbox"/> Ry	<input type="button" value="Properties..."/>
<input type="checkbox"/> Rz	<input type="button" value="Properties..."/>

Shear Spring Location

Distance Ratio From End I Dy : Dz :

Viscoelastic Damper Type Nonlinear Spring

Damper Type

Maxwell Model

Kelvin(Voigt) Model

Damper-Brace Assembly Model(Maxwell+Kelvin)

Nonlinear Properties

Damping (Cd) : kN

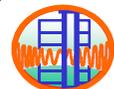
Reference Velocity (V0) : mm/sec

Damping Exponent (s) :

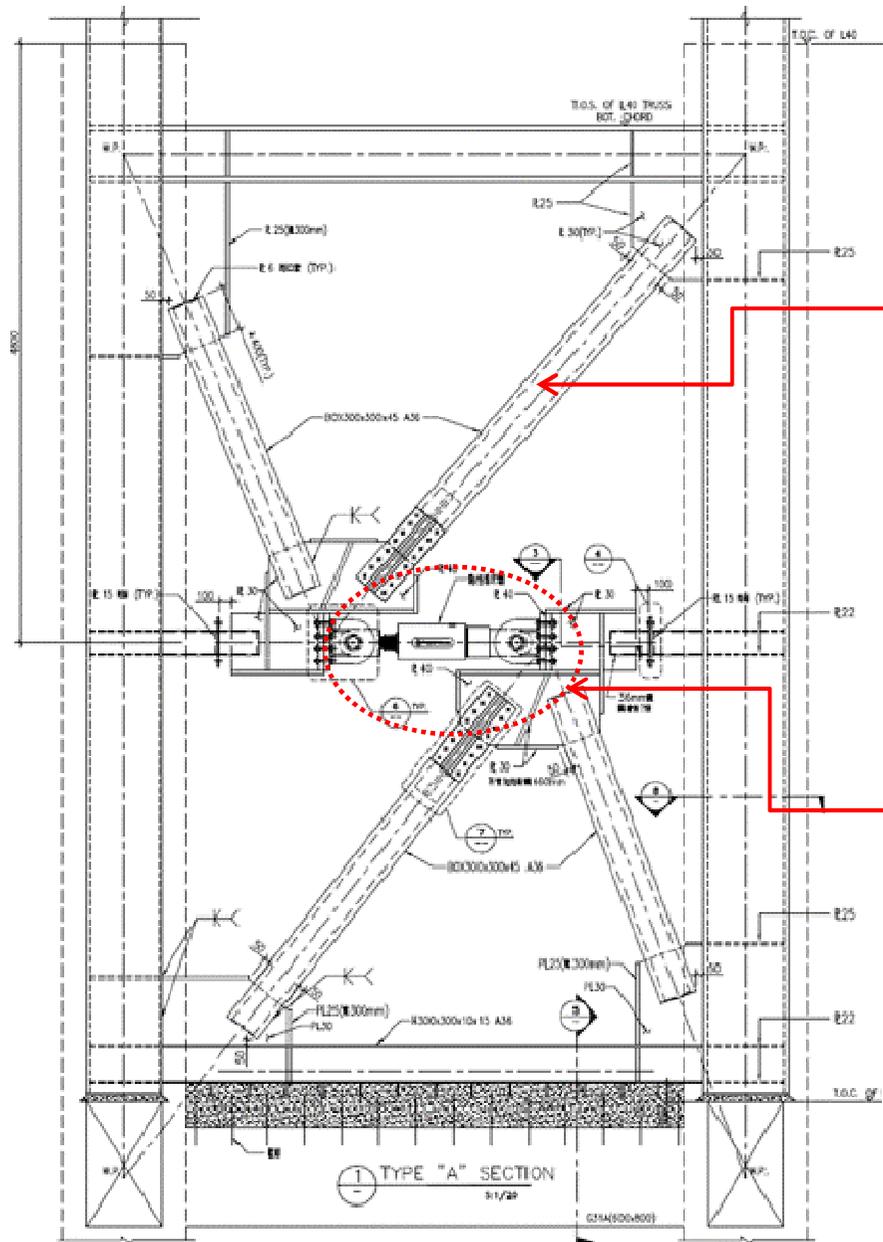
Bracing Stiffness (kb) : kN/mm

$$f = c_d \cdot \text{sign}(\dot{d}_d) \cdot \left| \frac{\dot{d}_d}{V_0} \right|^s + k_b d_b$$

$$d = d_d + d_b$$

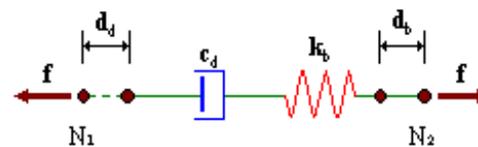
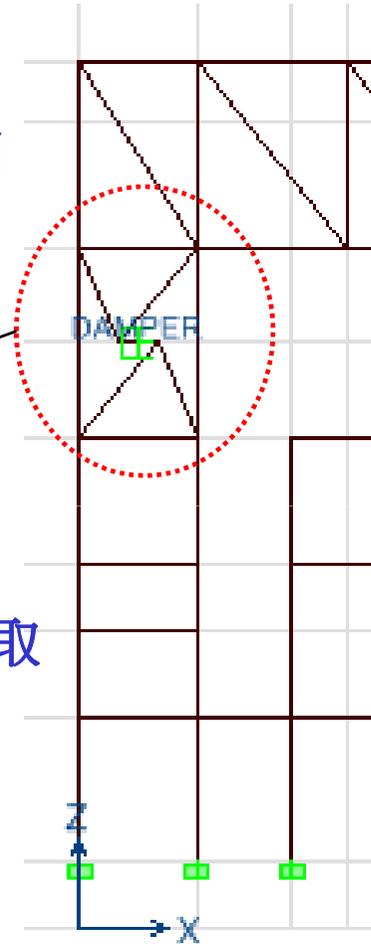


斜撐勁度 影響反應甚大, 需準確模擬



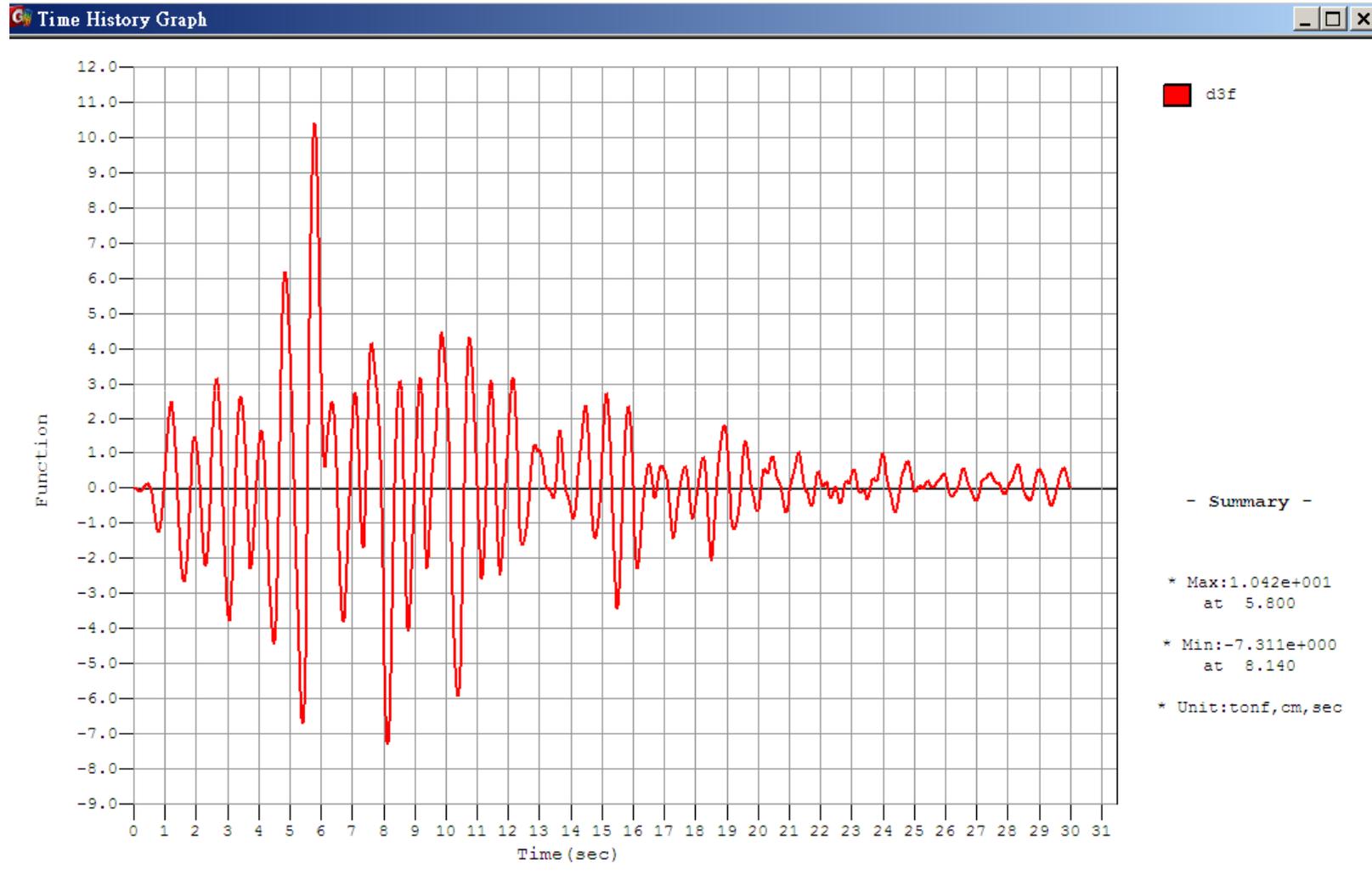
斜撐勁度與束制條件依實模擬

Damper之 k_b 取一相對大值



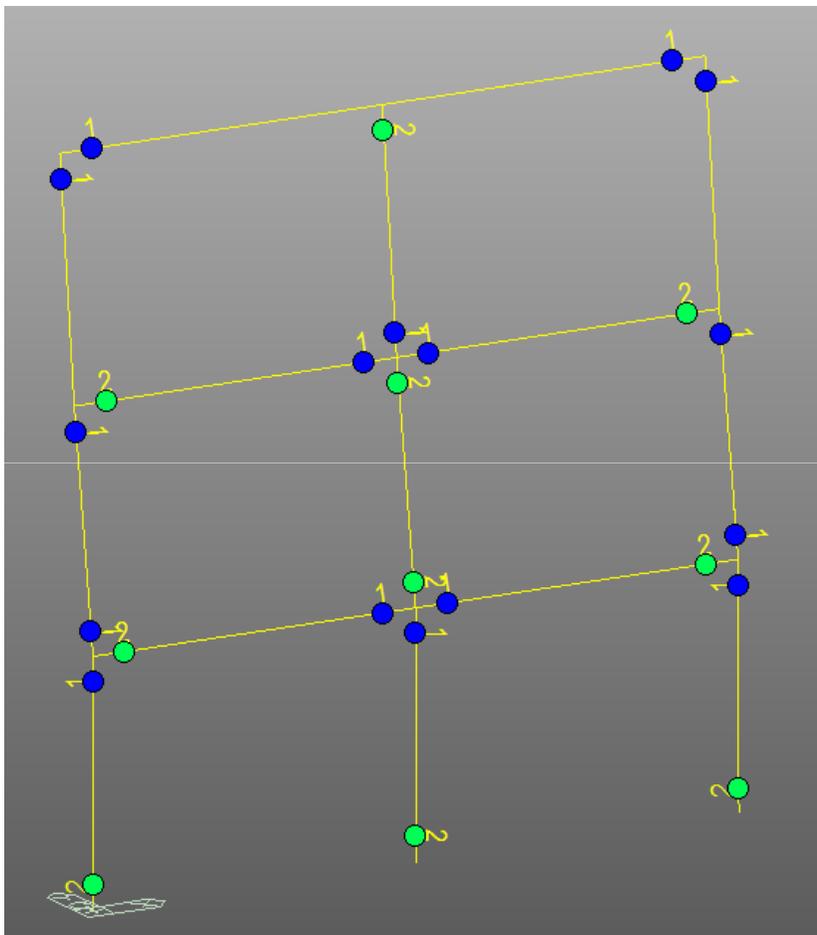
屋頂位移歷時

Max. displacement = 10.4 cm, 與設計位移相差不多

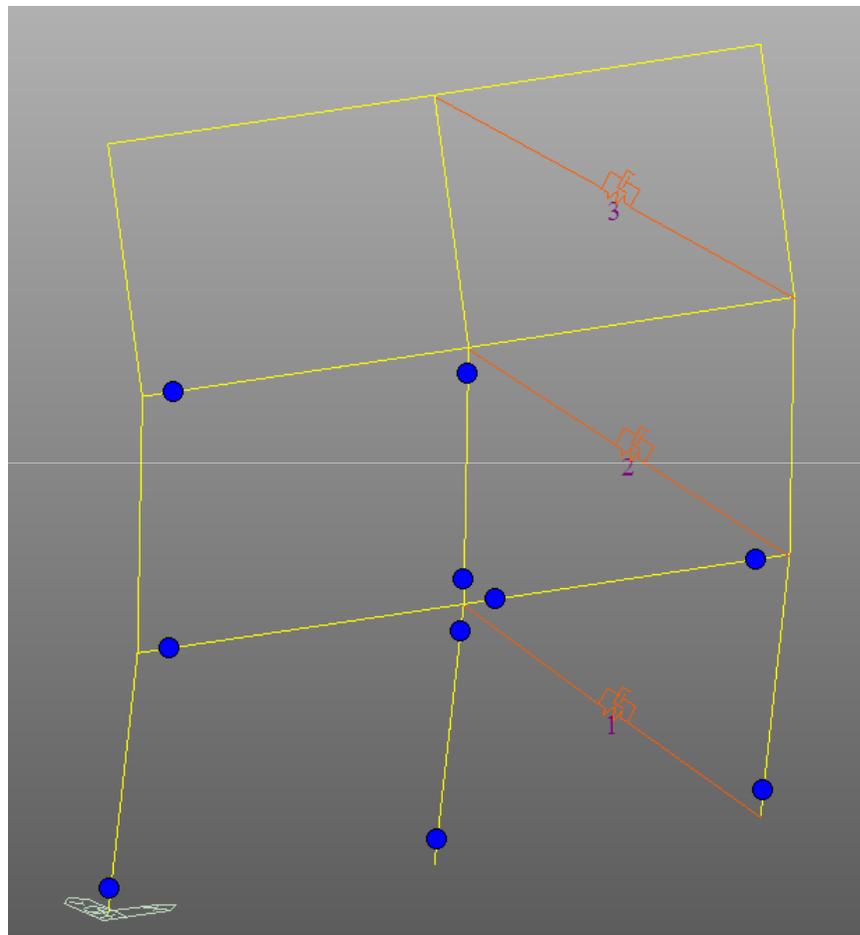


Plastic hinge 狀態

Bare frame



Damped frame



Damper 之遲滯迴圈

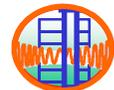


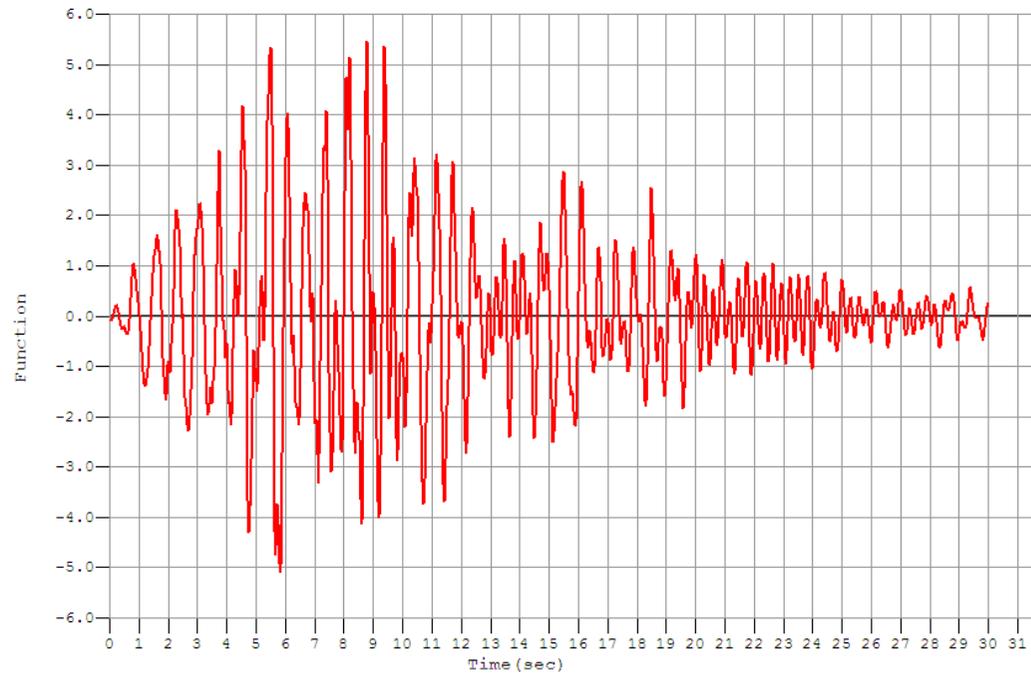
Unit: kN, mm

PGA = 400 gal

位移量 32 mm

=> 施工與斜撐構材精度要求高





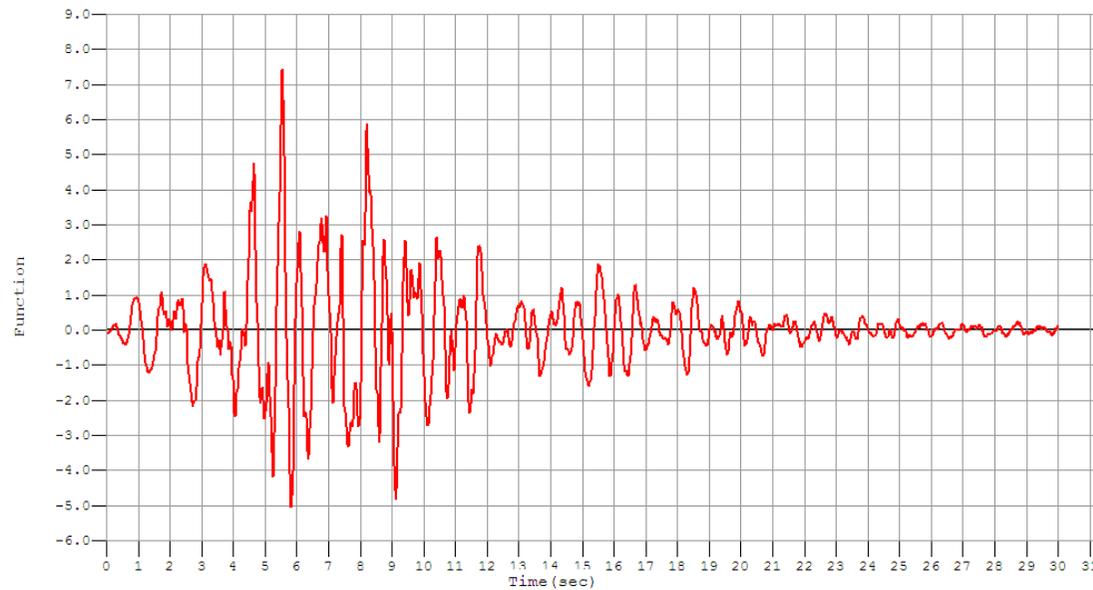
■ 3F-A

屋頂加速度比較

Damped frame

- Summary -

* Max: 5.450e+000
at 5.780
* Min: -5.092e+000
at 5.820
* Unit: kN,m,sec

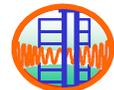


■ 3F-A

Bare frame

- Summary -

* Max: 7.422e+000
at 5.560
* Min: -5.045e+000
at 5.840
* Unit: tonf,m,sec



加裝 Viscoous Damper 反應分析

阻尼器特性:

$$F = 240 V^{0.3}$$

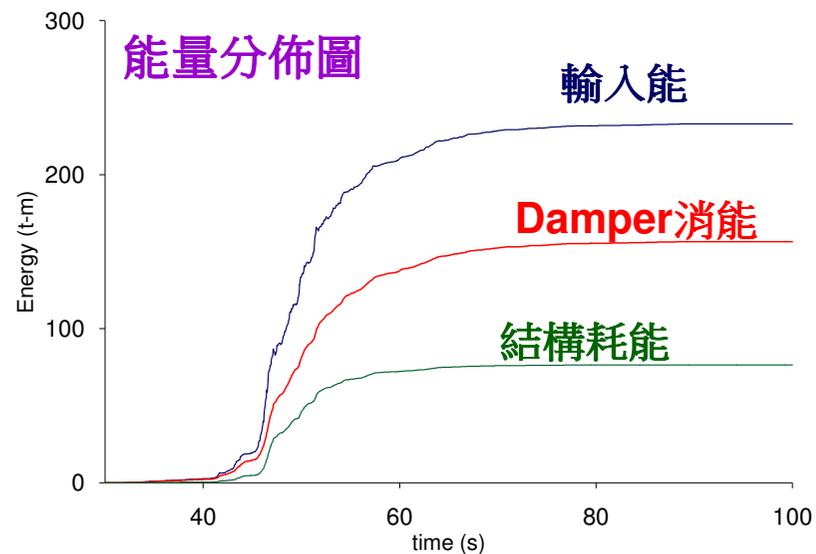
F= 阻尼力(KN, 最大出力約1400KN)

V=速度(mm/s)

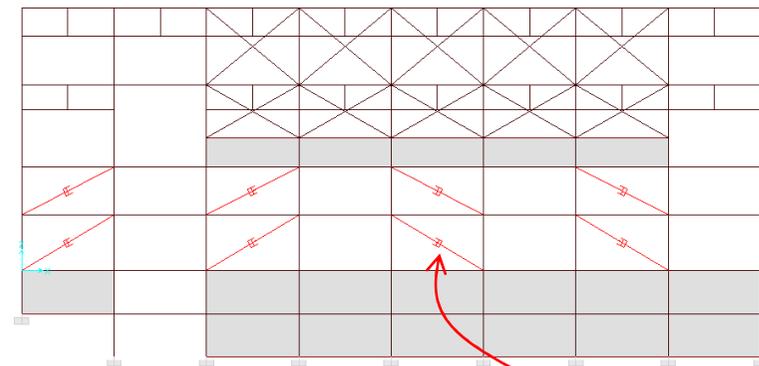
阻尼器配置:

X向及Y向兩側各8支; 共32支

(有效阻尼比可提升約10%)

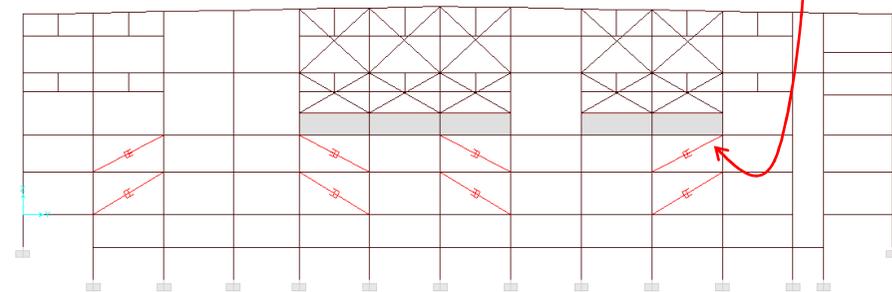


X(NS)向damper配置圖



damper

Y(EW)向damper配置圖

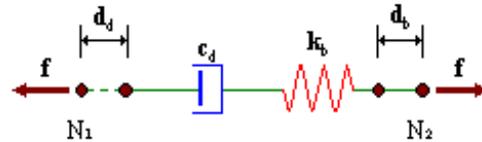


Viscous Damper 輸入

阻尼器特性:

$$F = 240 V^{0.3} ;$$

V=速度(mm/s)



單位選擇: KN, mm

阻尼器本身勁度

Link/Support Property Data

Link/Support Type: Damper

Property Name: Damper

Total Mass and Weight: Mass: 0, Weight: 0

Rotational Inertia 1: 0, Rotational Inertia 2: 0, Rotational Inertia 3: 0

Direction	Fixed	NonLinear	Properties
<input checked="" type="checkbox"/> U1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	Modify/Show for U1...
<input type="checkbox"/> U2	<input type="checkbox"/>	<input type="checkbox"/>	Modify/Show for U2...
<input type="checkbox"/> U3	<input type="checkbox"/>	<input type="checkbox"/>	Modify/Show for U3...
<input type="checkbox"/> R1	<input type="checkbox"/>	<input type="checkbox"/>	Modify/Show for R1...
<input type="checkbox"/> R2	<input type="checkbox"/>	<input type="checkbox"/>	Modify/Show for R2...
<input type="checkbox"/> R3	<input type="checkbox"/>	<input type="checkbox"/>	Modify/Show for R3...

Buttons: Fix All, Clear All, Advanced..., Display Color, OK, Cancel

Identification

Property Name: d-240

Direction: U1

Type: Damper

NonLinear: Yes

Properties Used For Linear Analysis Cases

Effective Stiffness: 0

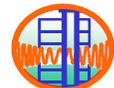
Effective Damping: 0

Properties Used For Nonlinear Analysis Cases

Stiffness: 240000

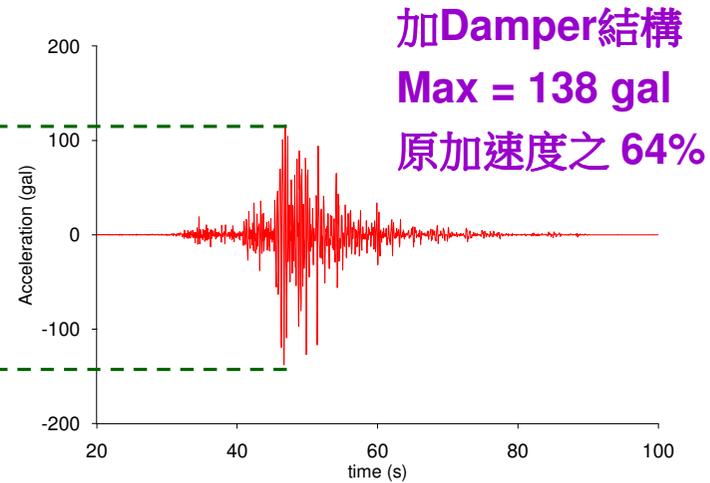
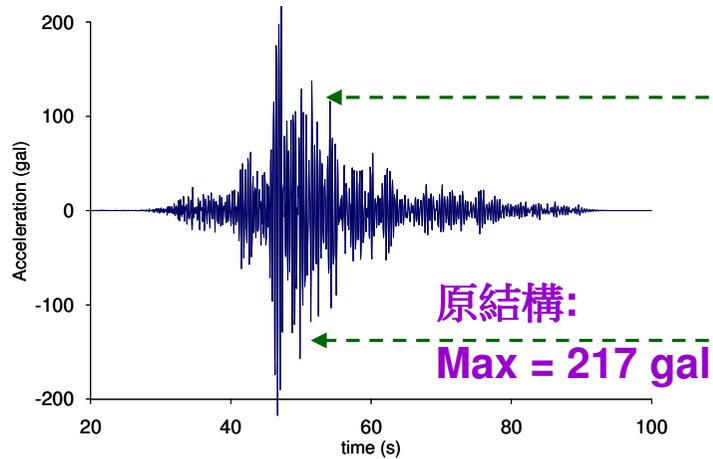
Damping Coefficient: 240

Damping Exponent: 0.3

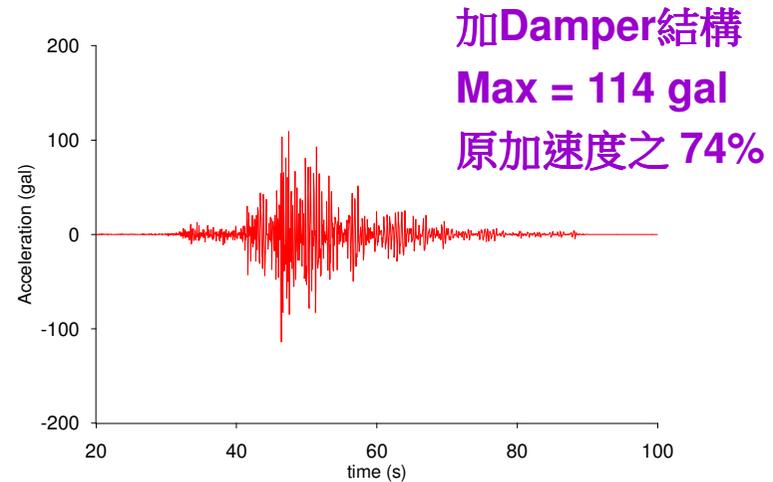
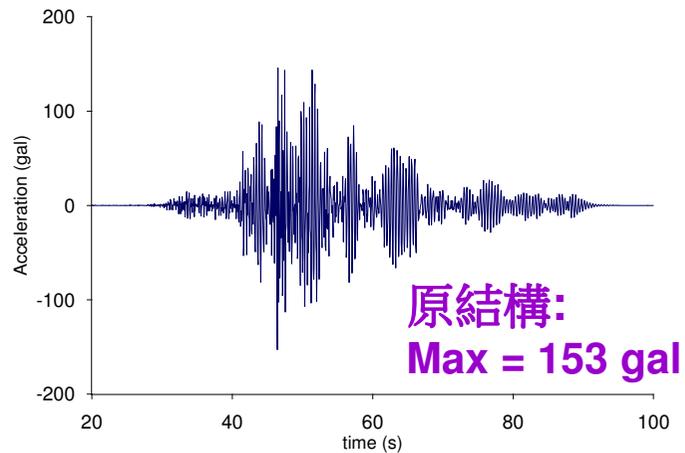


加裝 Viscous Damper 前後加速度反應比較

NS向樓板加速度比較圖



EW向樓板加速度比較圖



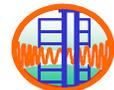
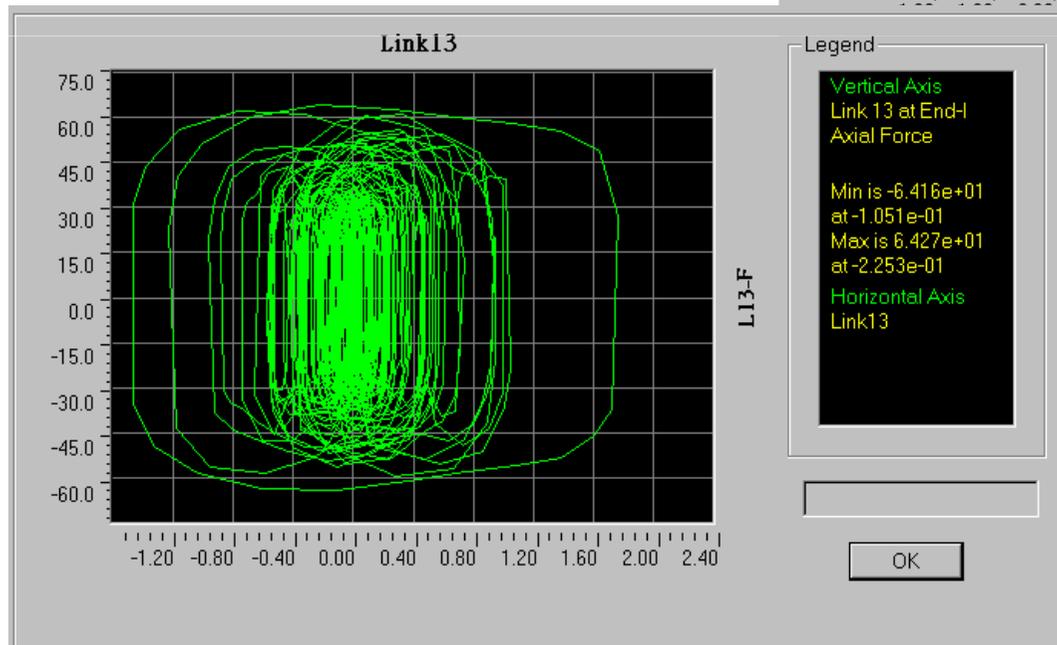
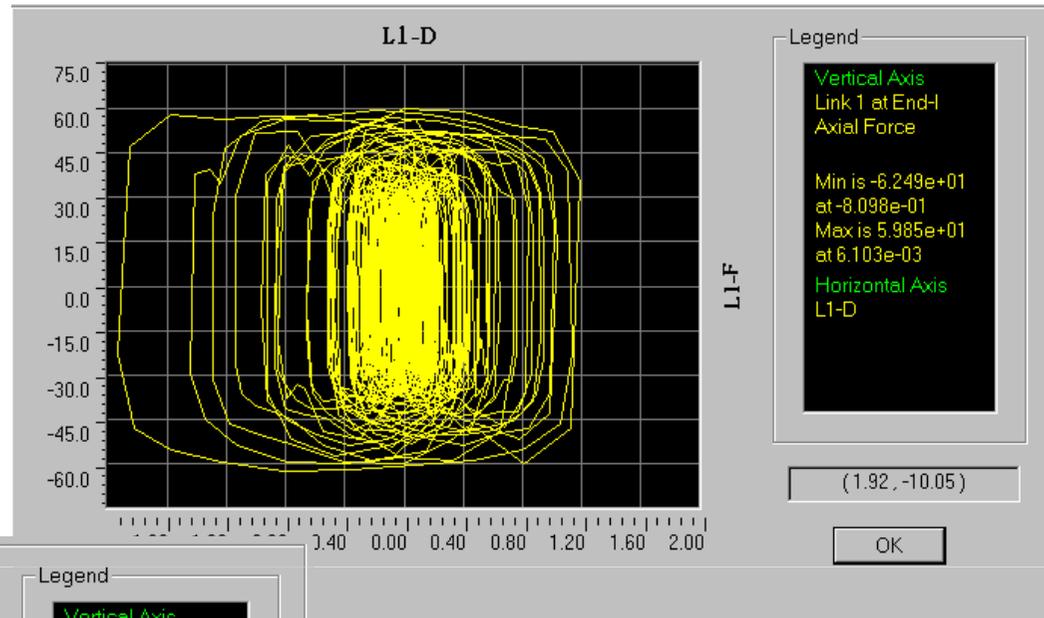
Viscous Damper 遲滯圈

單位: t, mm

PGA =80 gal

位移量僅1.6 mm

=> 施工與斜撐構材精度要求高



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報告完畢 謝謝!

