Passive Structural Control
Project Report Ⅰ&Ⅱ
Team 4

指導教授　　張國鎮教授

學生　　R06521212 蔡東樺

R06521217 乃宥然

R06521219 高翊書

R06521227 劉德謙

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Chapter 1 基本資料

1.1 前言

這次的案例目標是嘉義市東區六層辦公大樓，進行加裝被動消能元件，以確保層間變位角，符合設計需求。

這次報告使用 ETABS 及 PISA3D 建立空構架模型，並設計、加裝三種阻尼及三種隔震器，並進行動力分析，以確保設計滿足要求。最後再利用 PISA3D 進行非線性動力歷時分析，並將結果相互比對。

1.2 工作分配

Project Ⅰ	
ETABS Model Building	劉德謙
PISA3D Model Building	劉德謙
Preliminary Design	高翊書
Viscoelastic Damper (VE)	高翊書
Linear Viscous Damper (LVD)	蔡東樺
Nonlinear Viscous Damper (NVD)	乃宥然
Organize Data	蔡東樺
Project Ⅱ	
Friction Pendulum System (FPS)	乃宥然
High Damping Rubber Bearing (HDRB)	高翊書
Lead Rubber Bearing (LRB)	劉德謙
Organize Data	蔡東樺

1.3 結構物資訊

(1)工址：嘉義市(東區)

(2)第二類地盤，考慮近斷層因子($N_A = 1.37$, $N_V = 1.44$, $N_{A_M} = 1.30$, $N_{V_M} = 1.48$)

(3)結構物尺寸：六層樓

(4)功能：辦公用建築大樓

(5)結構系統：韌性抗彎矩構架 SMRF (鋼結構)

(6)結構細部資訊(表中提供的靜載重已考慮結構靜載重與其他外加靜載重)

表、樓層資料與設計載重(Unit：t、m^2)

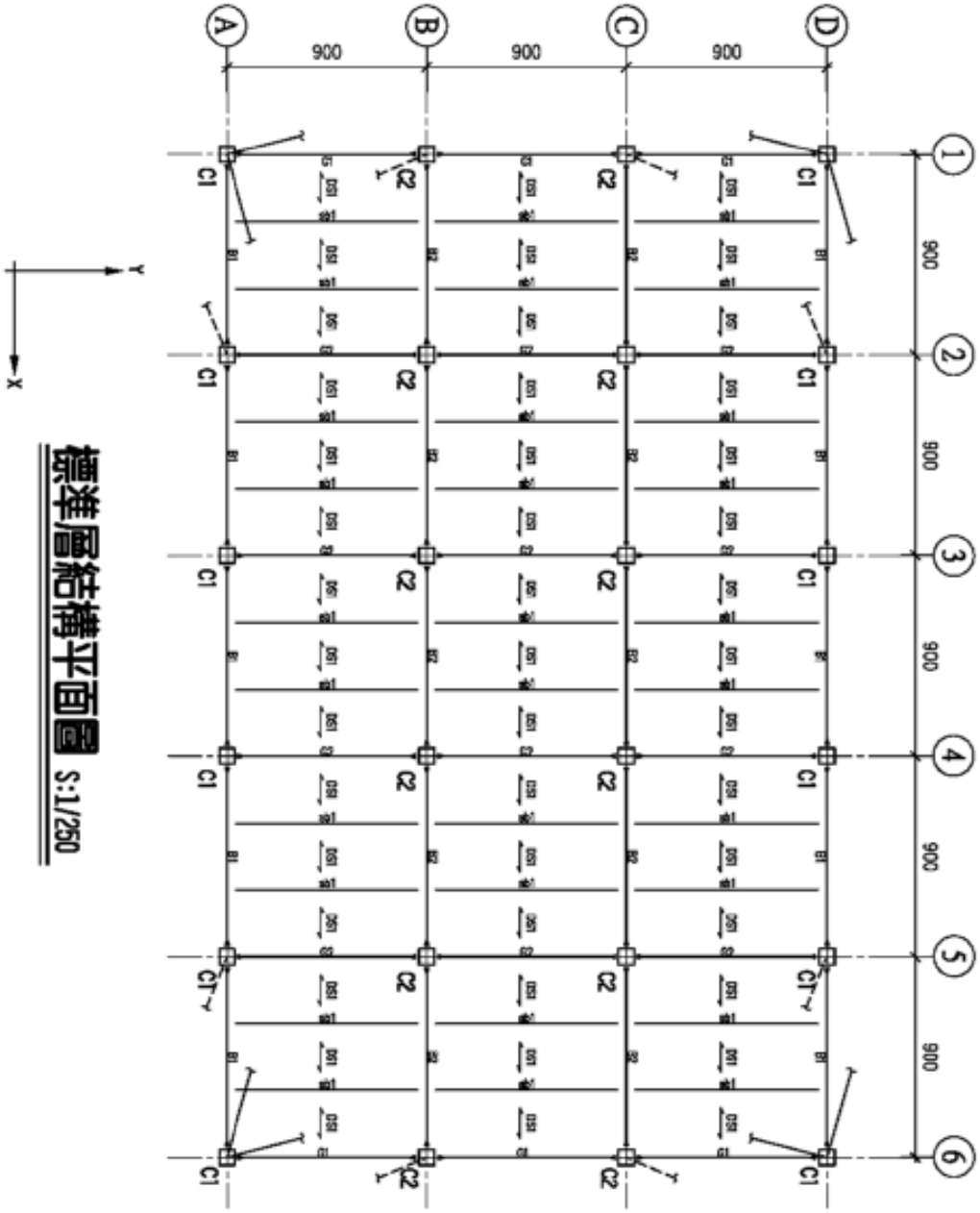
Story	Height (m)	Area (m^2)	Dead load		Live load (t/m^2)
			Weight (t)	(t/m^2)	
RF	-	1215	911.25	0.75	0.5
6F	4.0	1215	850.5	0.7	0.3
5F	4.0	1215	850.5	0.7	0.3
4F	4.0	1215	850.5	0.7	0.3
3F	4.0	1215	850.5	0.7	0.3
2F	4.5	1215	850.5	0.7	0.3
	Total weight : 5163.75 t				

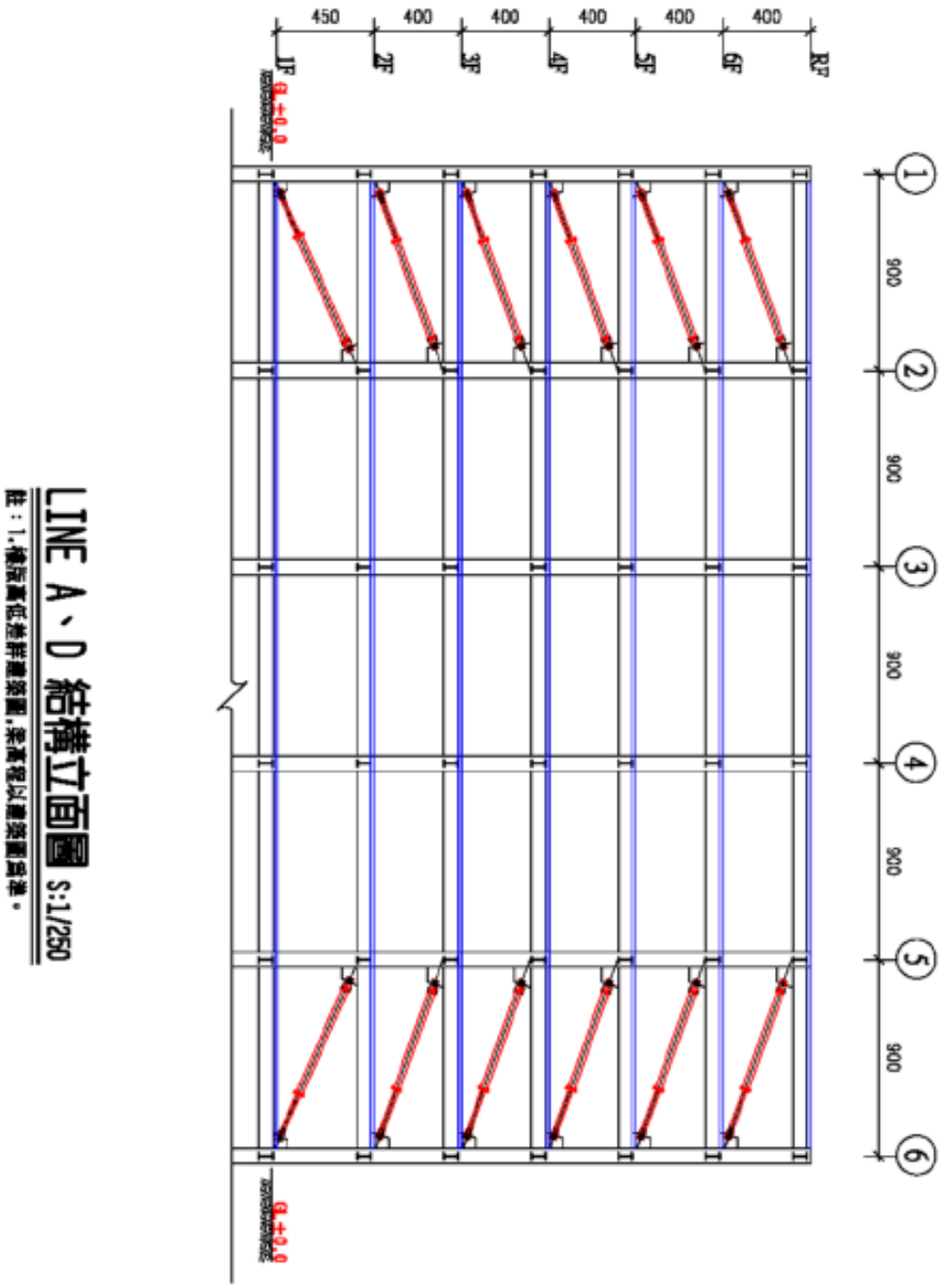
表、梁與桁斷面

Story	Section #	Dimension (mm)	A36 Steel
2F ~ RF	B1	H 600 x 250 x 12 x 18	F_y = 2500 kg/cm^2
	B2	H 600 x 200 x 9 x 12	
	G1, G2	H 600 x 250 x 12 x 22	
	sb1	H 450 x 200 x 9 x 14	

表、柱斷面

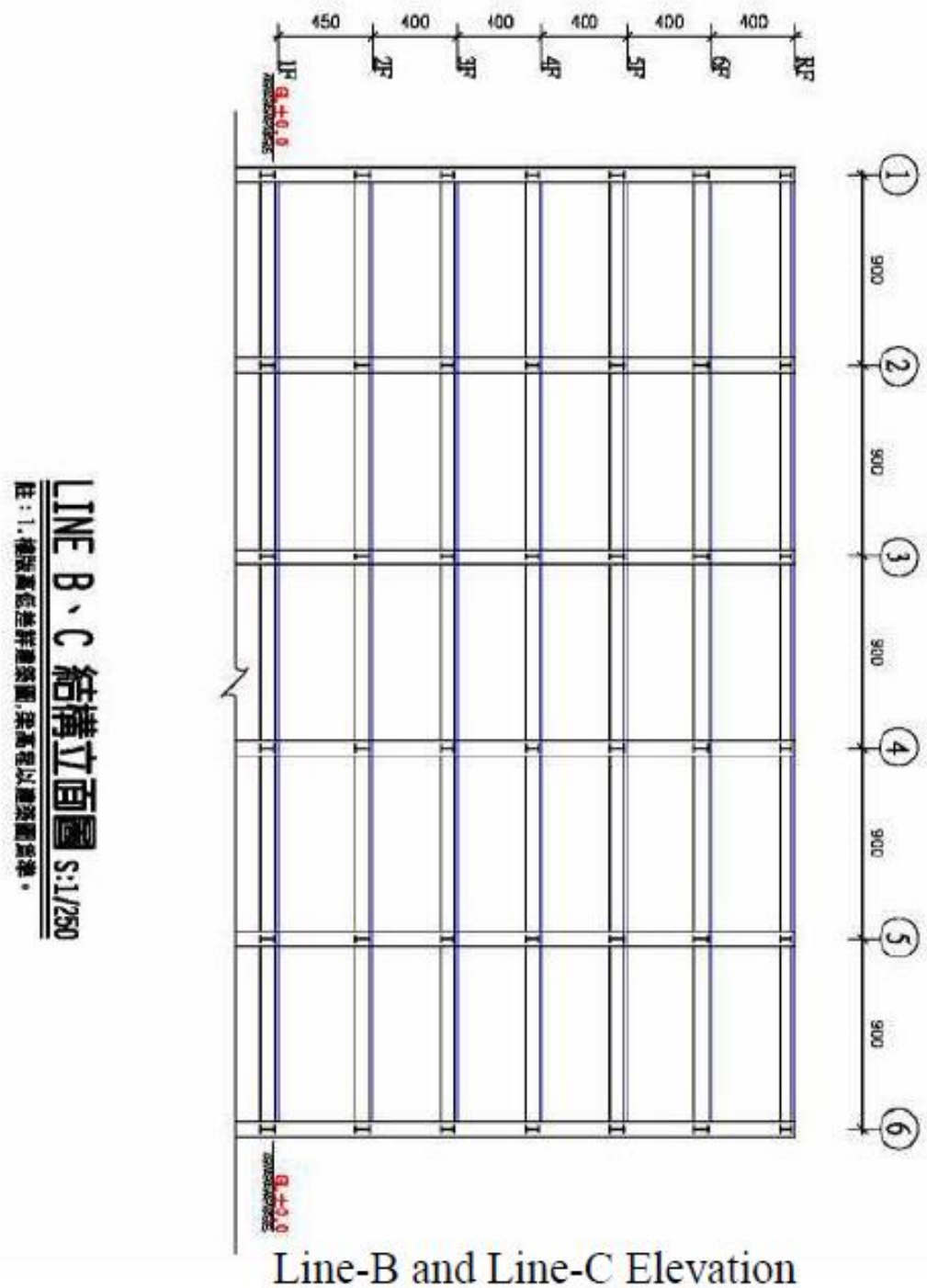
Story	Section #	Dimension (mm)	A36 Steel
1F ~ 2F	C1	Box 700 x 700 x 22 x 22	F_y = 2500 kg/cm^2
3F ~ 6F	C1	Box 600 x 600 x 25 x 25	
1F ~ 2F	C2	Box 650 x 650 x 22 x 22	
3F ~ RF	C2	Box 600 x 600 x 20 x 20	


A
B
C
D
900
900
900
1
2
3
4
5
6
900
900
900
900
900
900
C1
C2
C1
C2
C1
C2

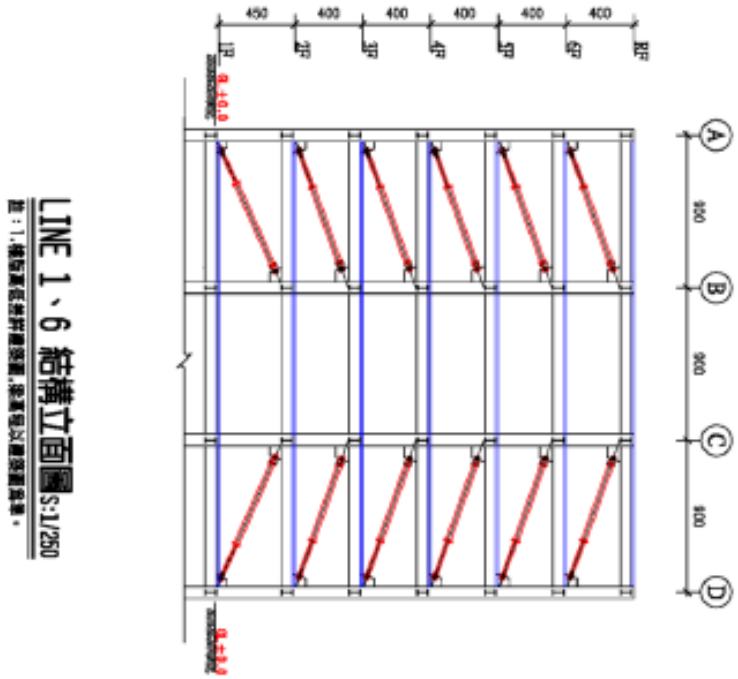


Line-A and Line-D Elevation

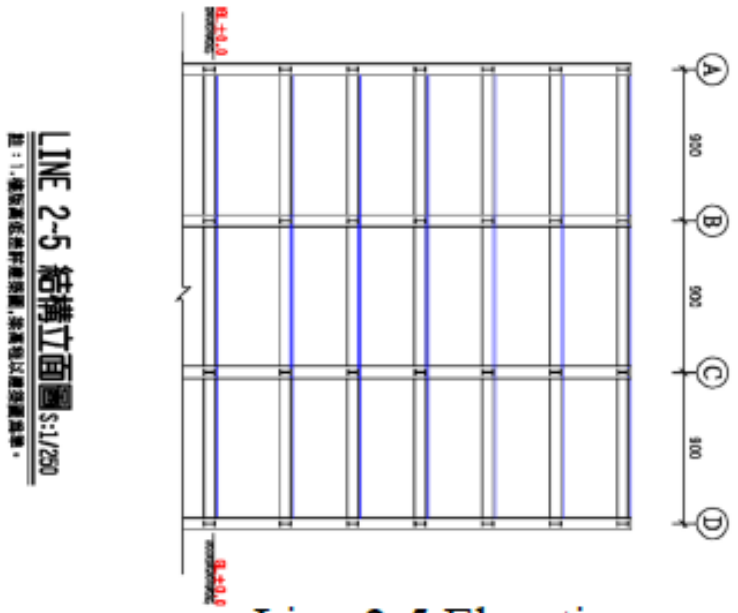
圖、結構立面圖(LINE A、D)



圖、結構立面圖(LINE B、C)



Line-1 and Line-6 Elevation



Line-2-5 Elevation

圖、結構立面圖

Project Ⅰ

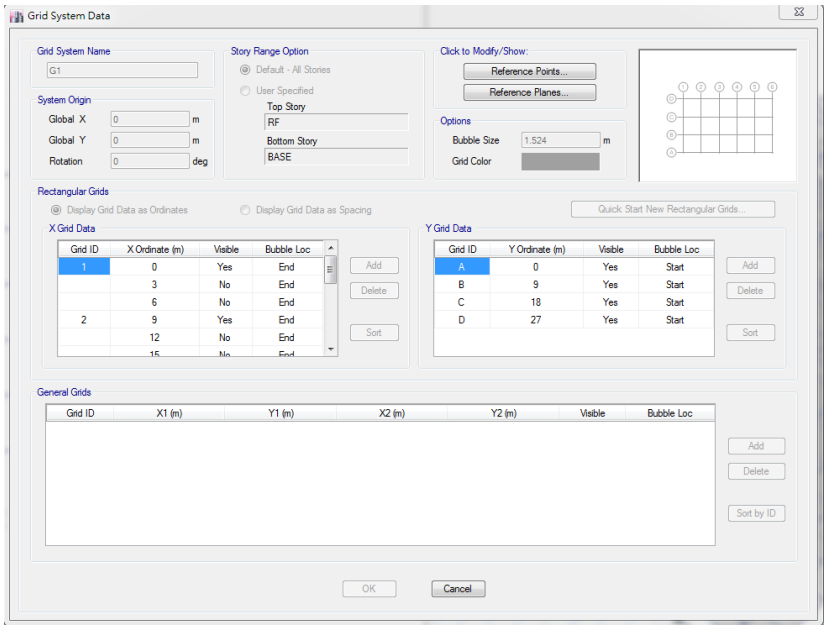
設計目標

Team	Max. Drift Ratio	VE γ =300%	Linear Viscous Damper	Nonlinear Viscous Damper
1	0.010	VE-1，T=20°		α= 0.3
2	0.010	VE-2		α= 0.6
3	0.012	VE-1，T=30°	α= 1.0	α= 0.3
4	0.012	VE-2		α= 0.6
5	0.015	VE-1，T=20°		α= 0.3

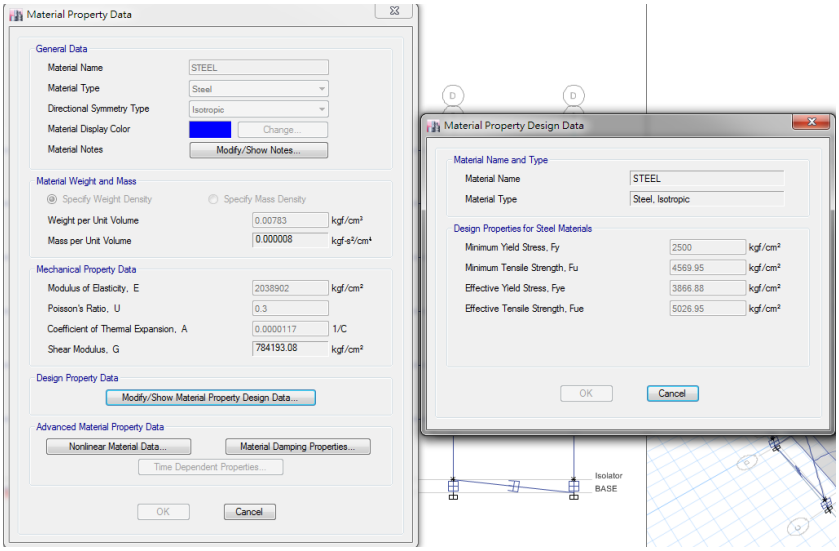
本組為第四組，最大層間位移限制為 0.012

Chapter 2 ETABS 建模

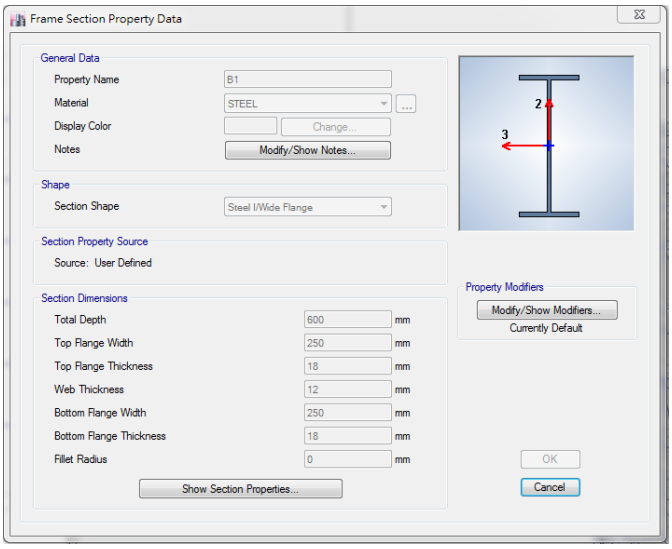
2.1 定義網格



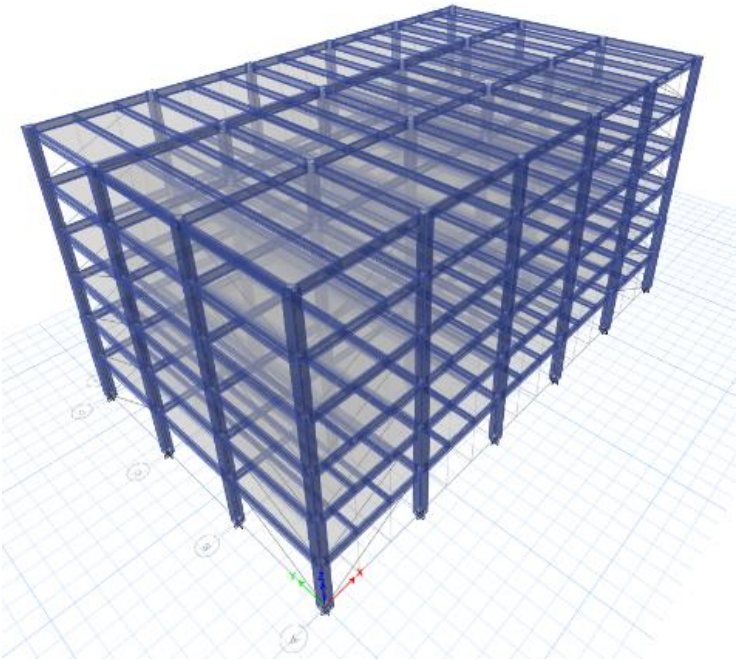
2.2 材料定義



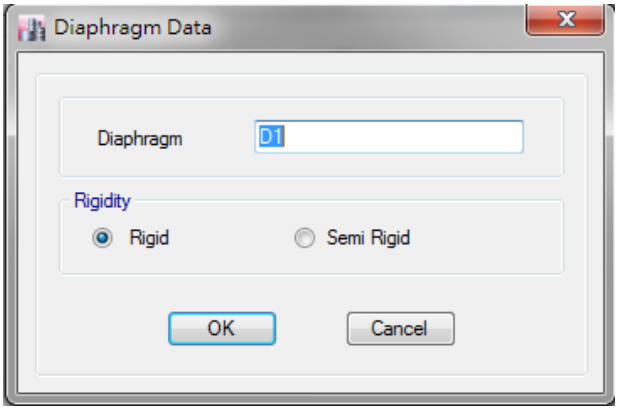
2.3 斷面設定



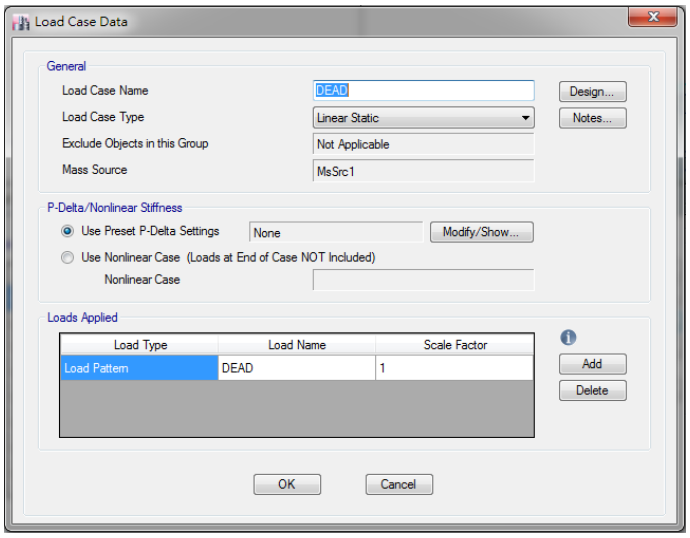
2.4 繪製模型

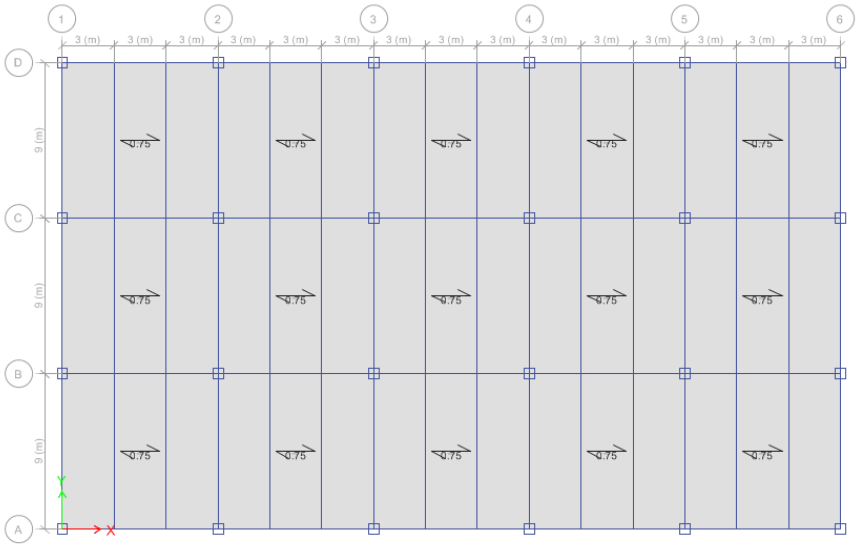


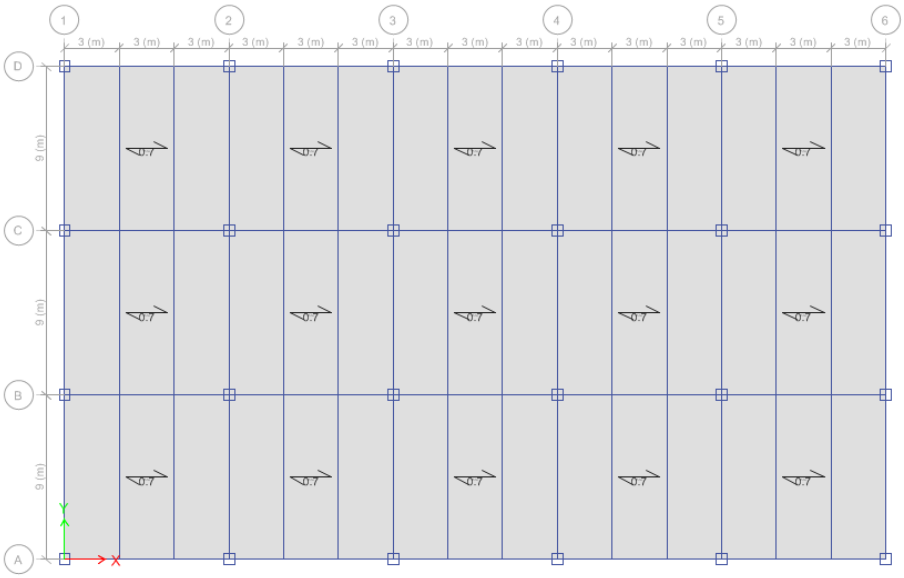
2.5 設定 diaphragm

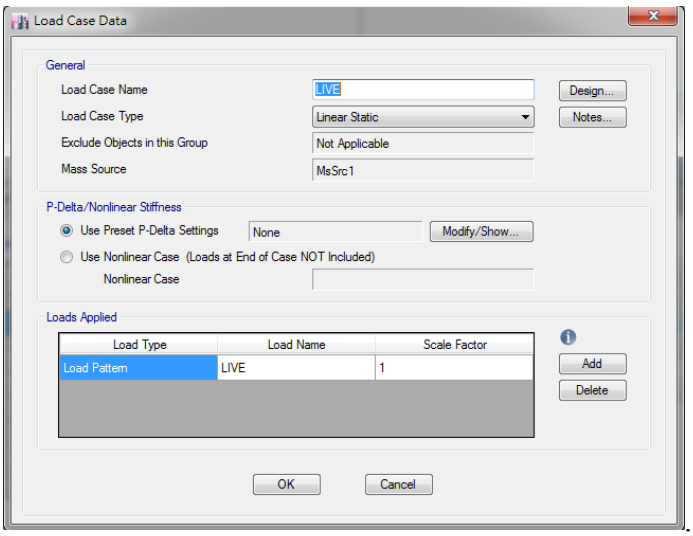


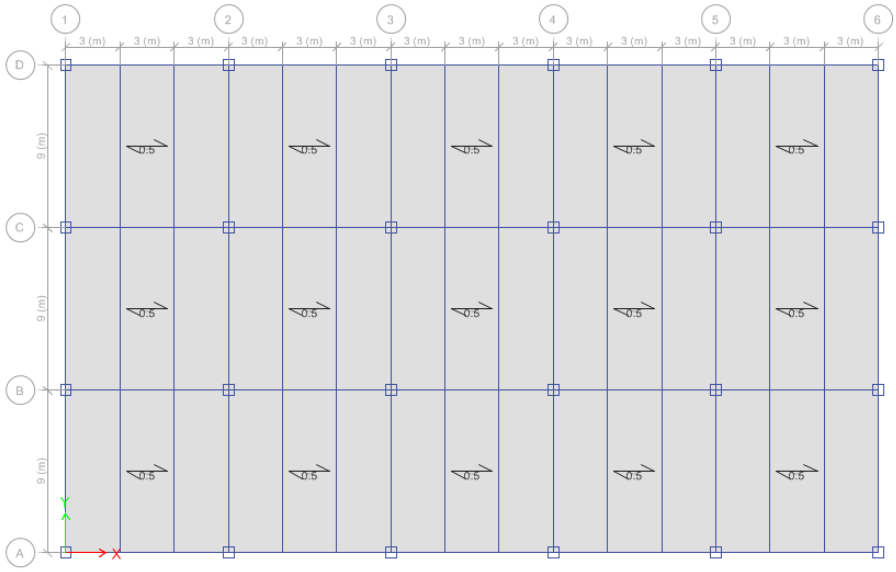
2.6 定義載重


Load Case Data
General
Load Case Name
DEAD
Design...
Load Case Type
Linear Static
Notes...
Exclude Objects in this Group
Not Applicable
Mass Source
MsSrc1
P-Delta/Nonlinear Stiffness
Use Preset P-Delta Settings
None
Modify/Show...
Use Nonlinear Case (Loads at End of Case NOT Included)
Nonlinear Case
Loads Applied
Load Type
Load Name
Scale Factor
Load Pattern
DEAD
1
Add
Delete
OK
Cancel


1
2
3
4
5
6
3 (m)
D
C
B
A
9 (m)
0.75


1
2
3
4
5
6
3 (m)
D
C
B
A
9 (m)
0.7


Load Case Data
General
Load Case Name
LIVE
Design...
Load Case Type
Linear Static
Notes...
Exclude Objects in this Group
Not Applicable
Mass Source
MsSrc1
P-Delta/Nonlinear Stiffness
Use Preset P-Delta Settings
None
Modify/Show...
Use Nonlinear Case (Loads at End of Case NOT Included)
Nonlinear Case
Loads Applied
Load Type
Load Name
Scale Factor
Load Pattern
LIVE
1
Add
Delete
OK
Cancel


1
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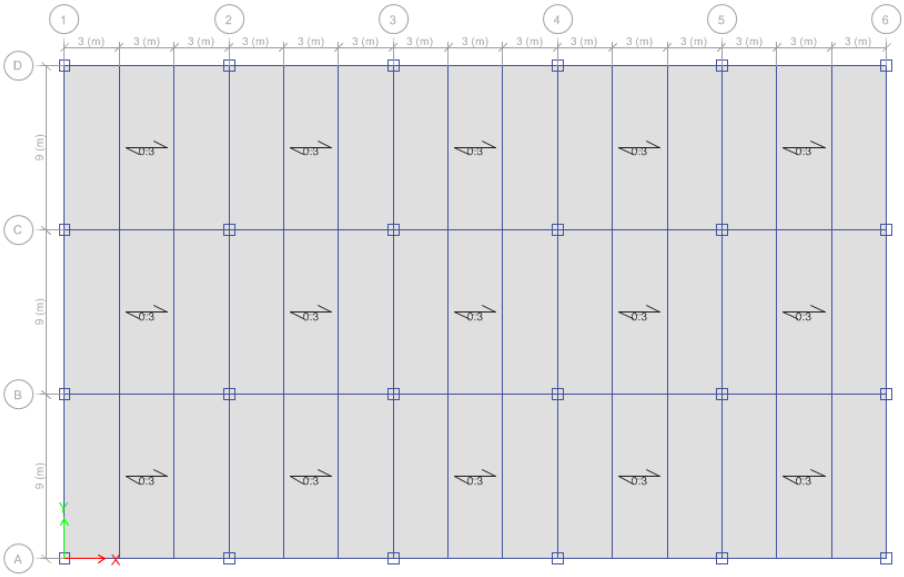
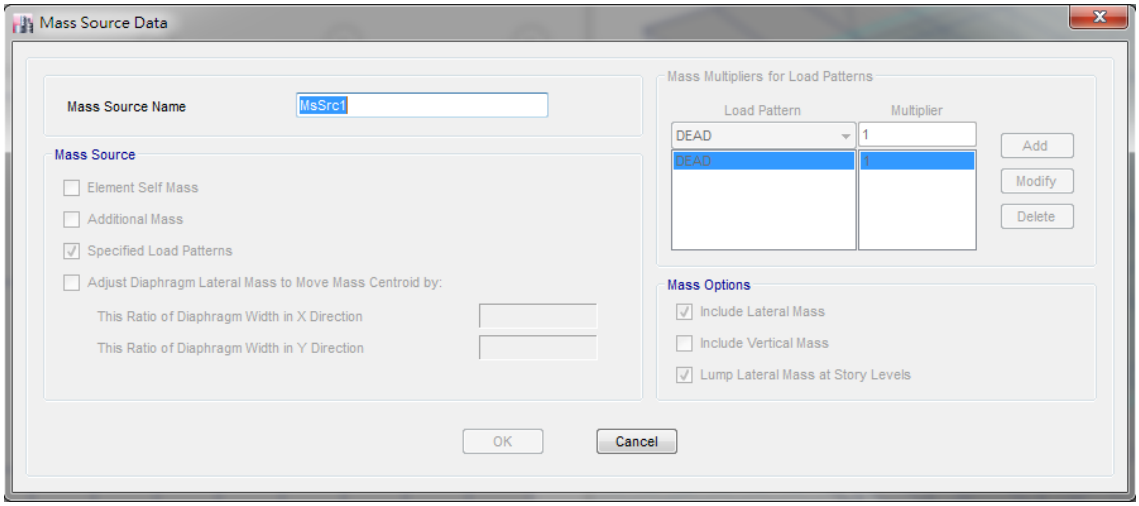
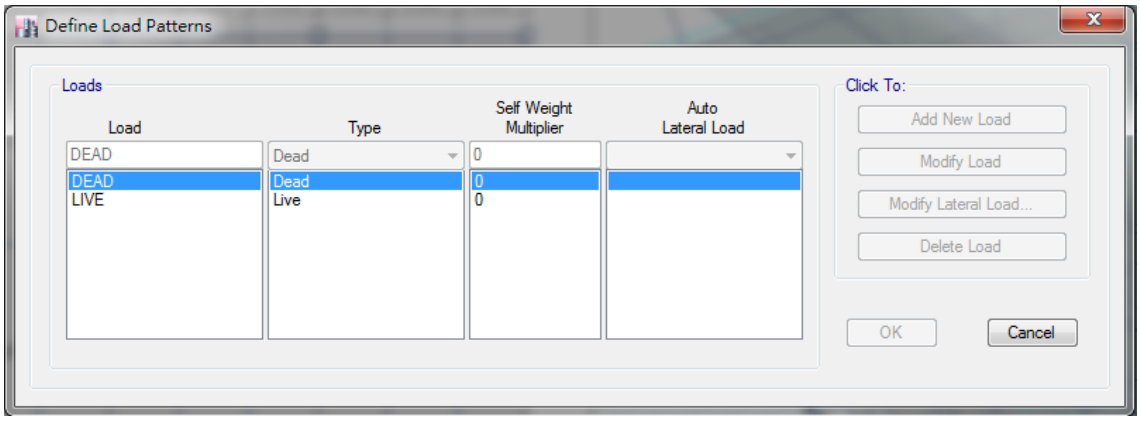
4
5
6
3 (m)
D
C
B
A
9 (m)
0.5


1
2
3
4
5
6
3 (m)
D
C
B
A
9 (m)
0.3

2.7 定義質量來源





2.8 模態分析

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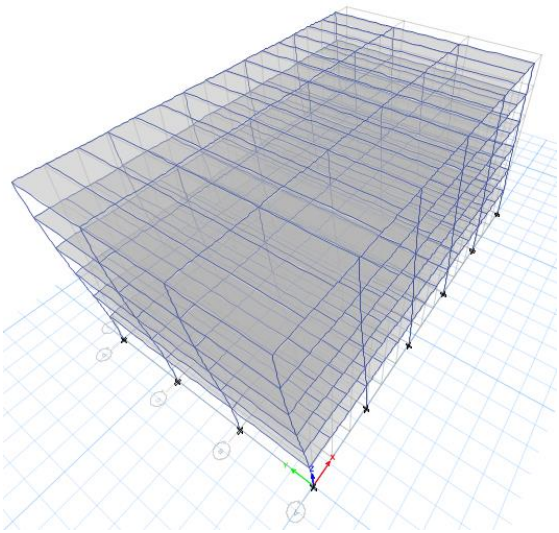	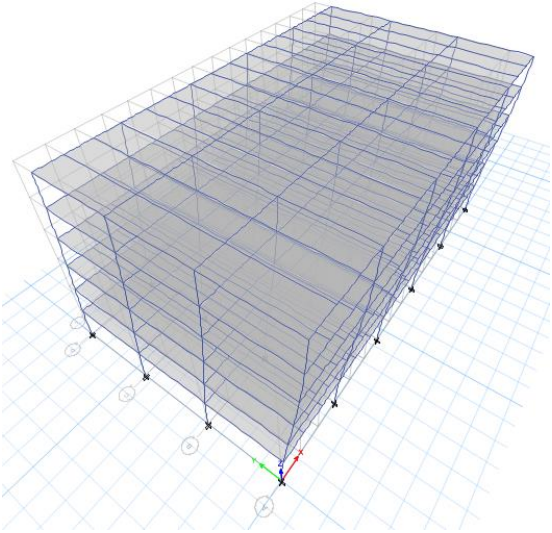

3rd mode	4th mode
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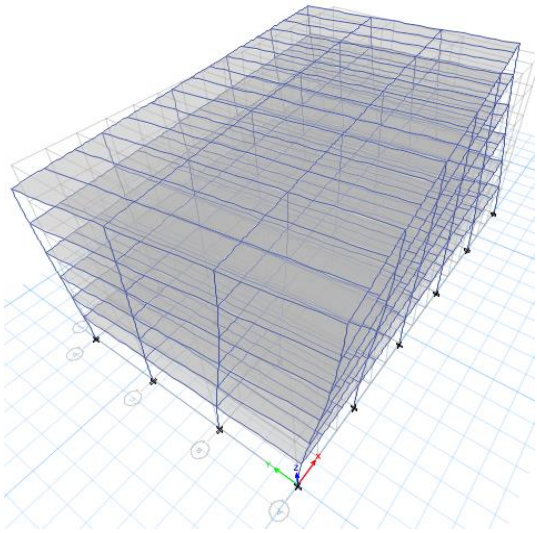	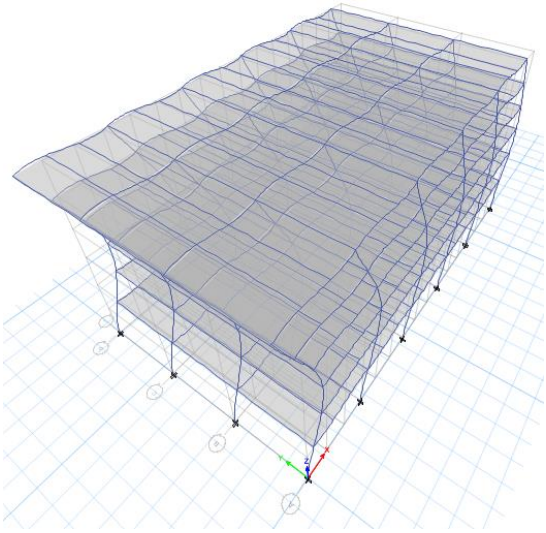
5th mode	6th mode
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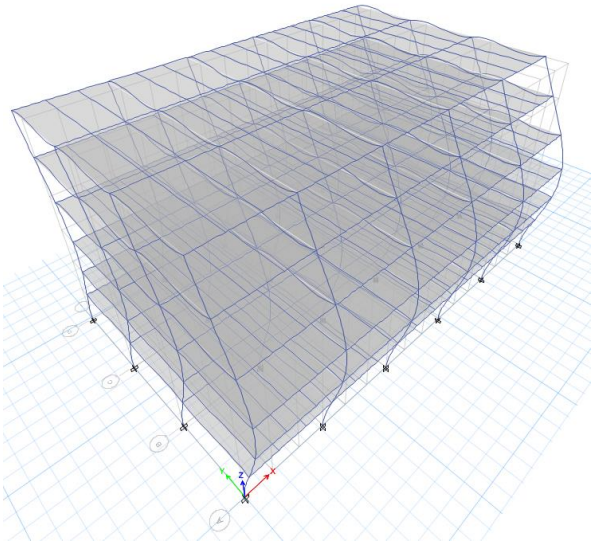
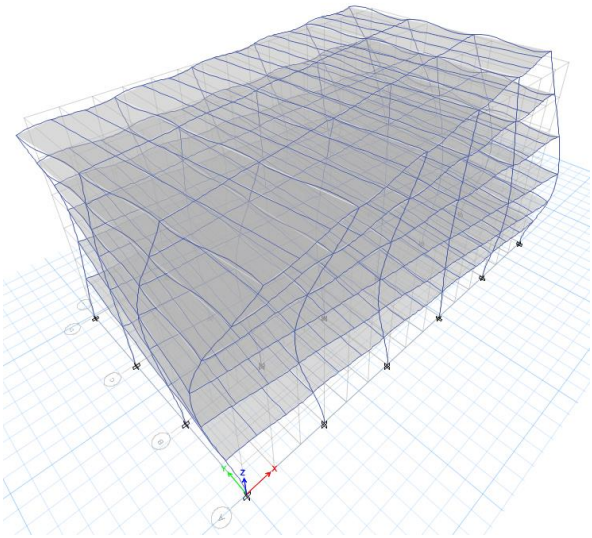
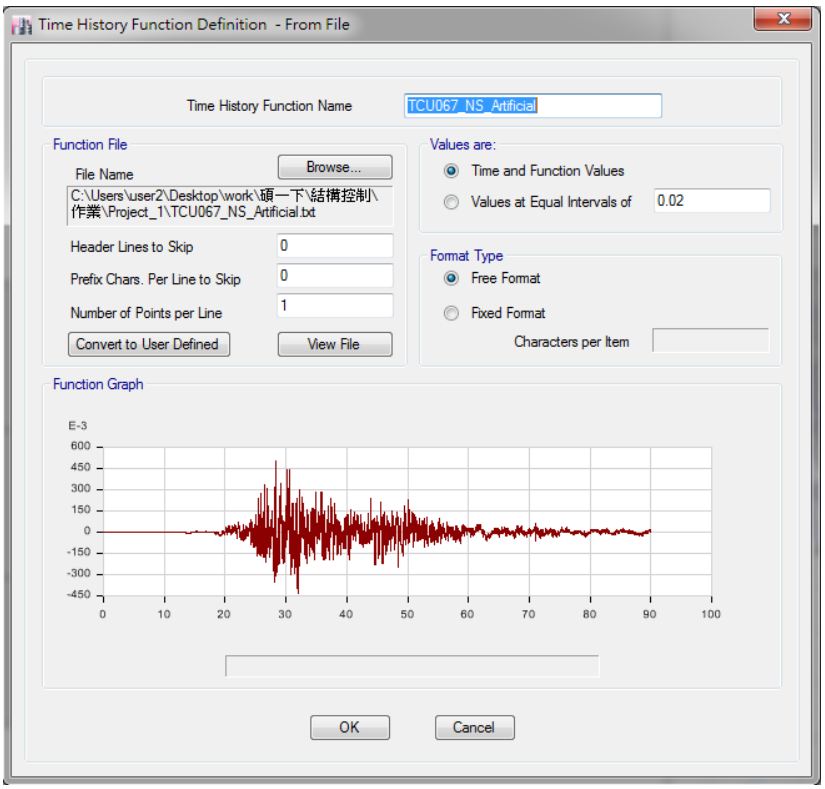
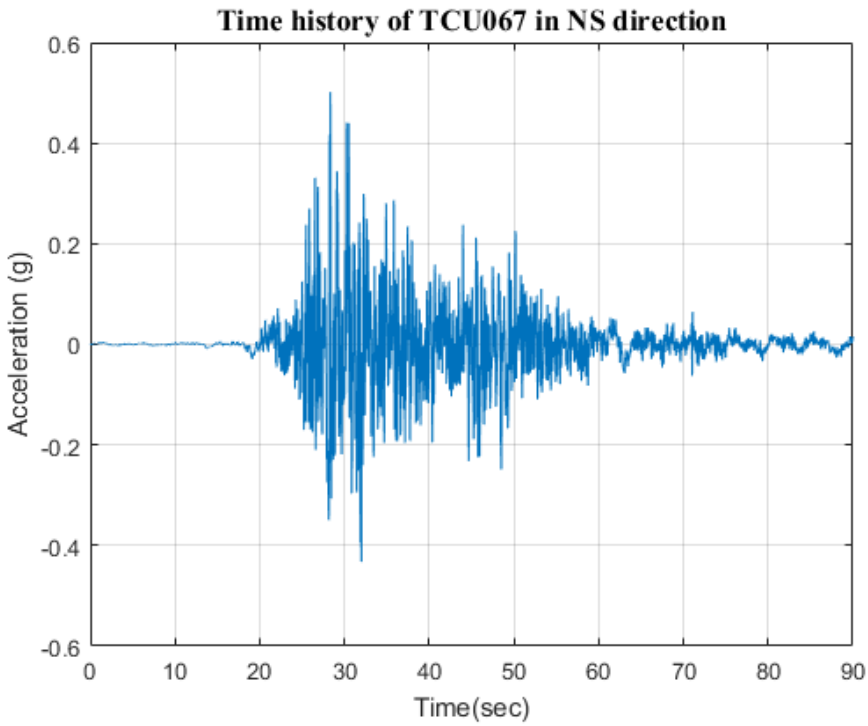
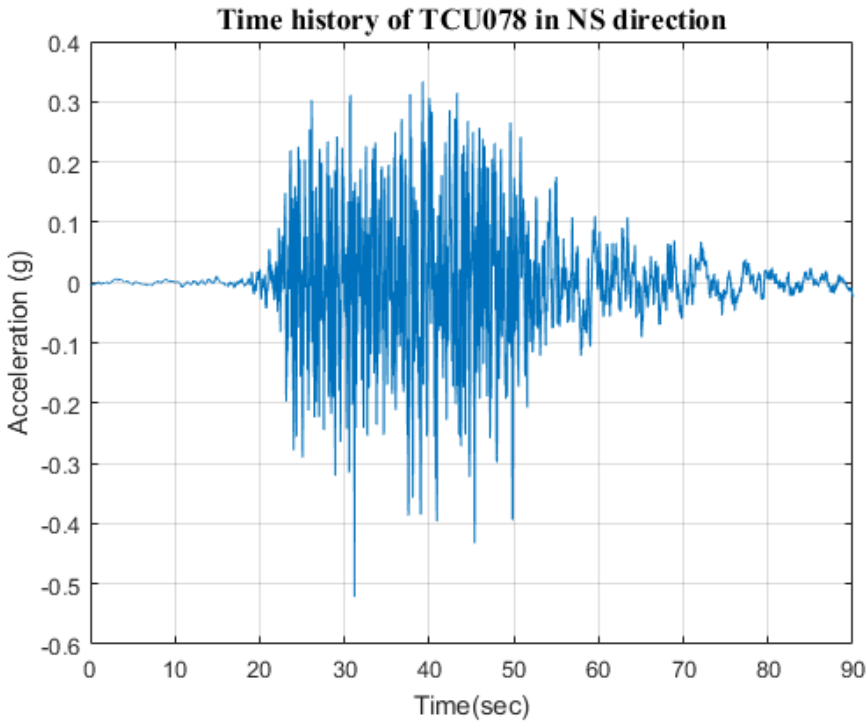
	

2.9 輸入歷時資料


Time History Function Definition - From File
Time History Function Name
TCU067_NS_Artificial
Function File
File Name
Browse...
C:\Users\user2\Desktop\work\頭一下\結構控制\作業\Project_1\TCU067_NS_Artificial.txt
Header Lines to Skip
0
Prefix Chars. Per Line to Skip
0
Number of Points per Line
1
Convert to User Defined
View File
Values are:
Time and Function Values
Values at Equal Intervals of
0.02
Format Type
Free Format
Fixed Format
Characters per Item
Function Graph
E-3
600
450
300
150
0
-150
-300
-450
0
10
20
30
40
50
60
70
80
90
100
OK
Cancel


Time history of TCU067 in NS direction
Acceleration (g)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
10
20
30
40
50
60
70
80
90
Time(sec)


Time history of TCU078 in NS direction
Acceleration (g)
Time(sec)
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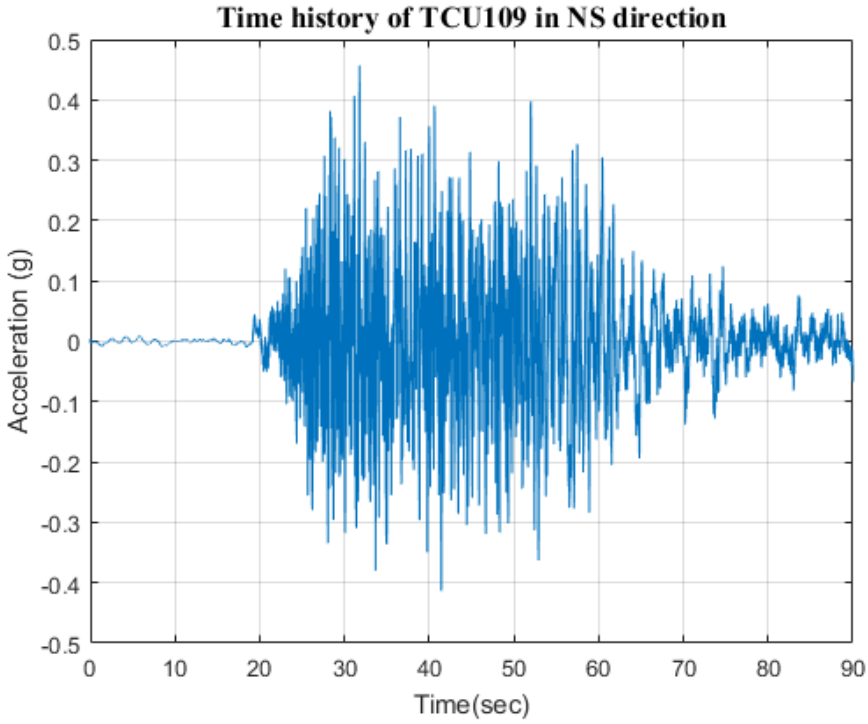
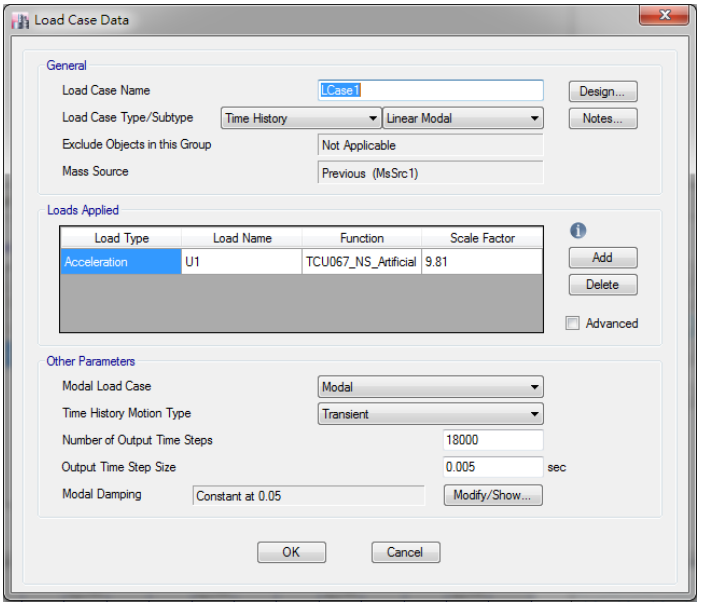
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
0
10
20
30
40
50
60
70
80
90


Time history of TCU109 in NS direction
Acceleration (g)
Time(sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
60
70
80
90

2.10 設定 Load Cases



Chapter 3 PISA3D 建模

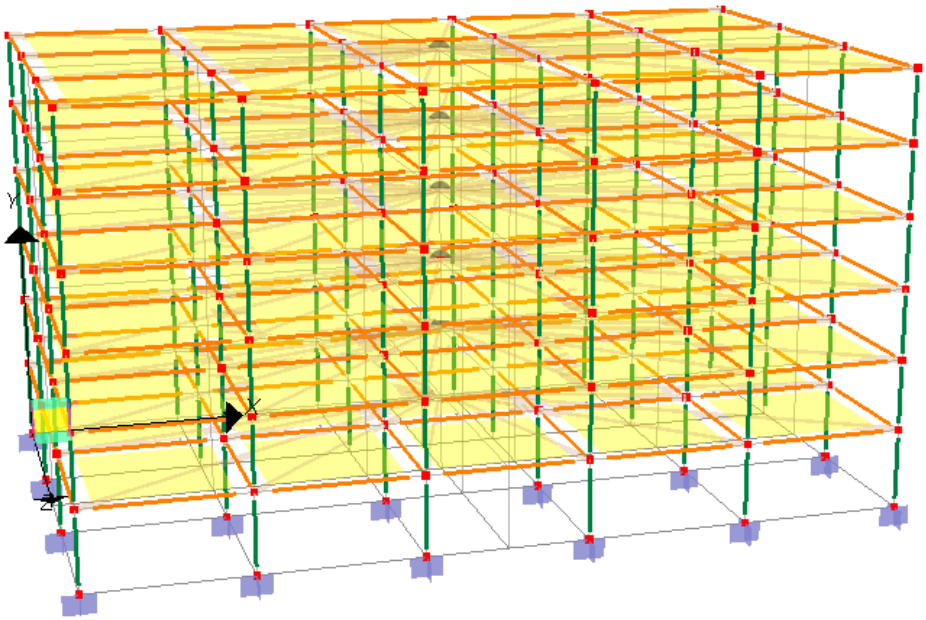
3.1 選用因素

隨著耐震設計規範的發展，動力分析的需求也越來越高。PISA3D (Platform of Inelastic Structural Analysis for 3D Systems)，著重於非線性的歷時分析。在分析的過程中，當結構物發展出塑鉸時，PISA 3D 會自動輸入塑鉸以及其位置，而且相較於 SAP2000 或是 ETABS 有較快的運算速度。

3.2 移除小梁

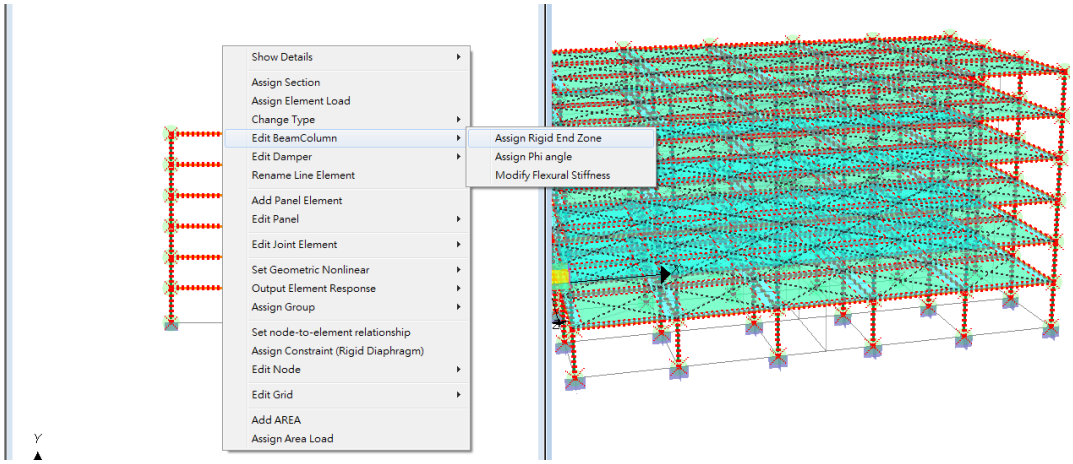
由於 PISA3D 的分析點數需小於 200，故將模型中的小梁移除，並確認模態無太大改變。

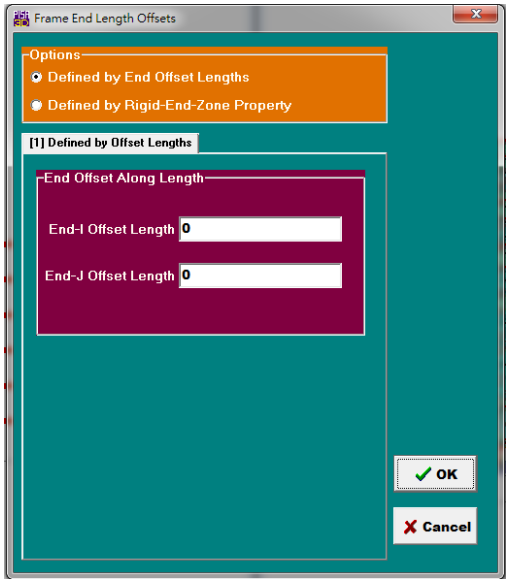
3.3 從 ETABS 輸出模型.s2k 檔輸入 PISA3D



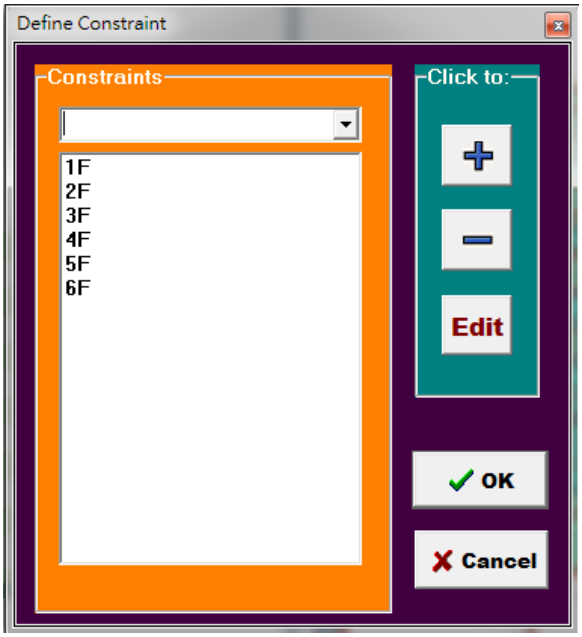
3.4 檢查單位及中間點質量是否相同

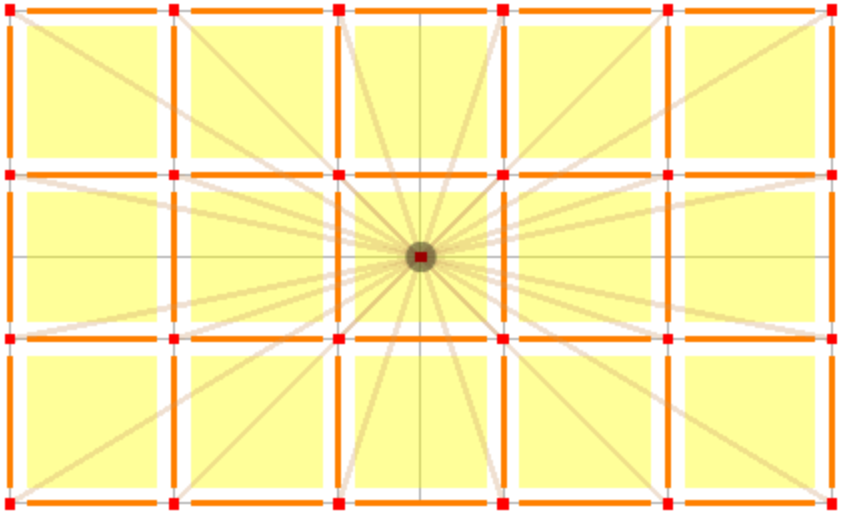
3.5 刪除 Rigid end offset



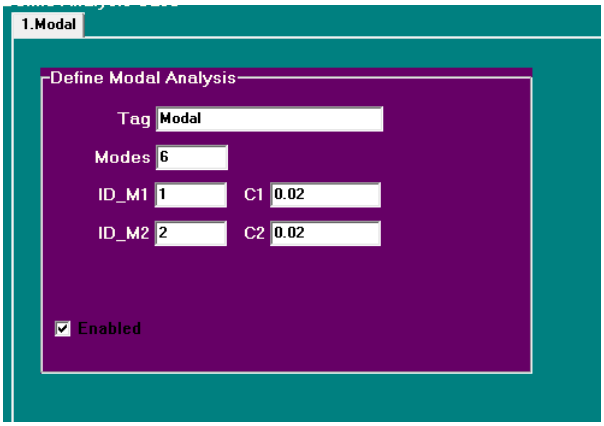


3.6 設定 Rigid Diaphragm





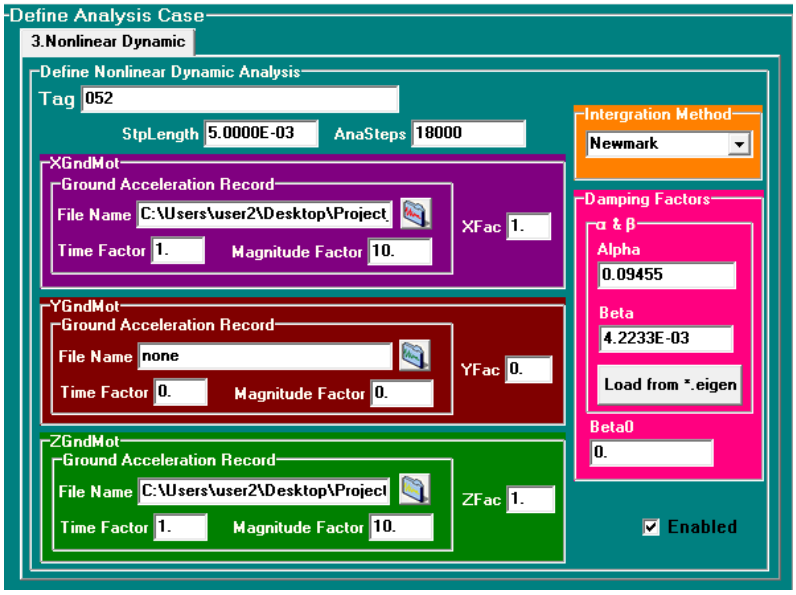
3.7 模態分析

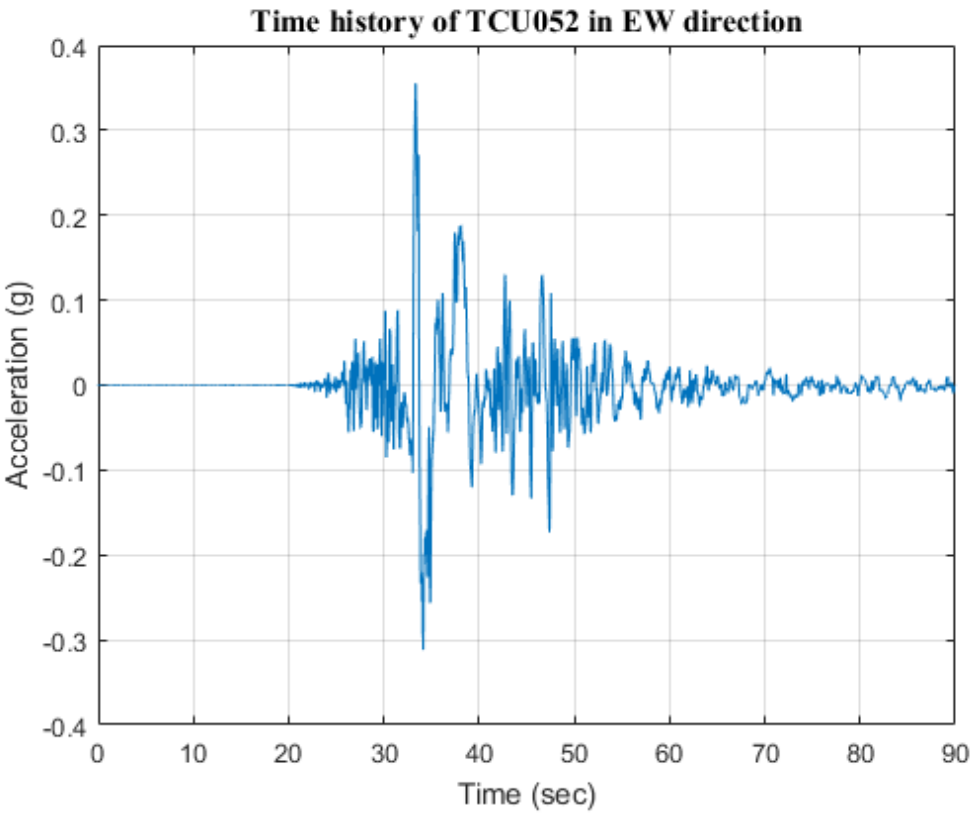


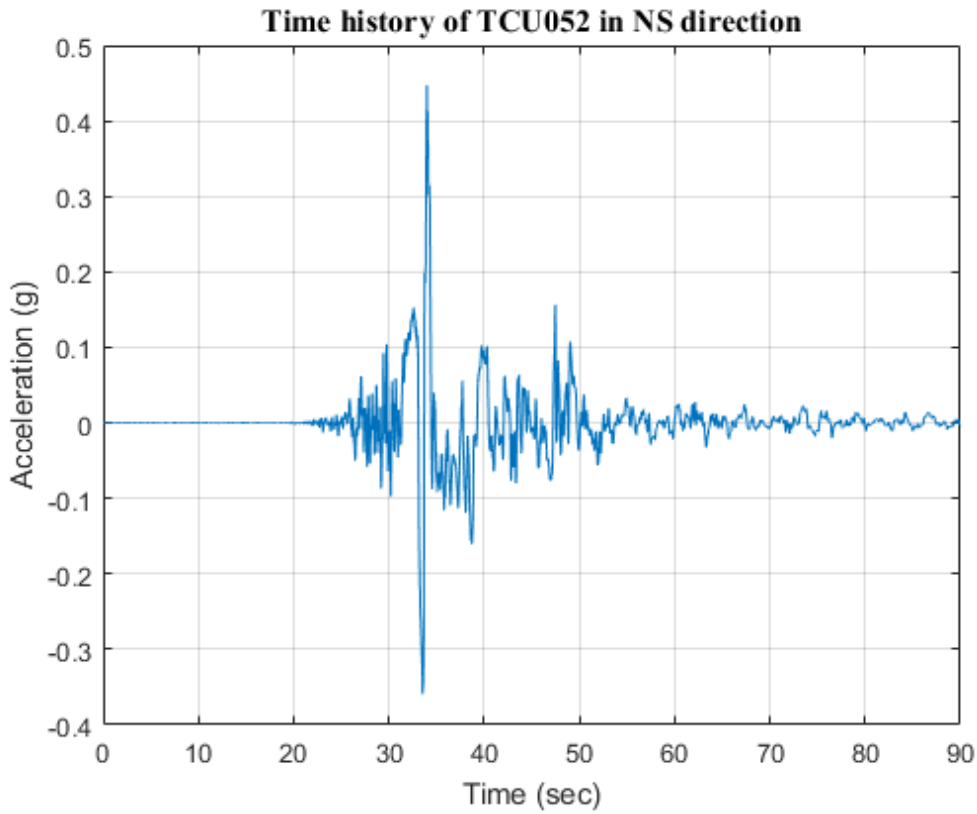

```
Natural Period

Period of Mode 1  = 1.3849E+000  Sec.
Period of Mode 2  = 1.2734E+000  Sec.
Period of Mode 3  = 1.0744E+000  Sec.
Period of Mode 4  = 4.1096E-001  Sec.
Period of Mode 5  = 3.8424E-001  Sec.
Period of Mode 6  = 3.2415E-001  Sec.
```

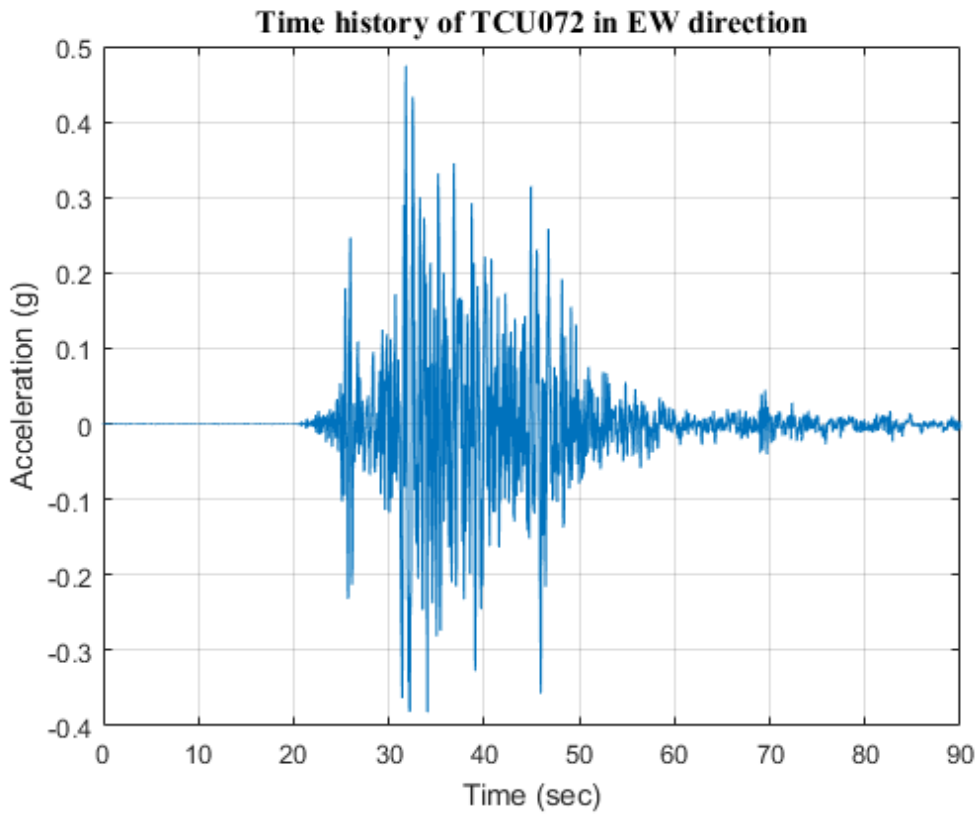
Period(s)	ETABS	PISA3D
1st mode	1.386	1.385
2nd mode	1.275	1.273
3rd mode	1.075	1.074
4th mode	0.411	0.411
5th mode	0.385	0.384
6th mode	0.324	0.324

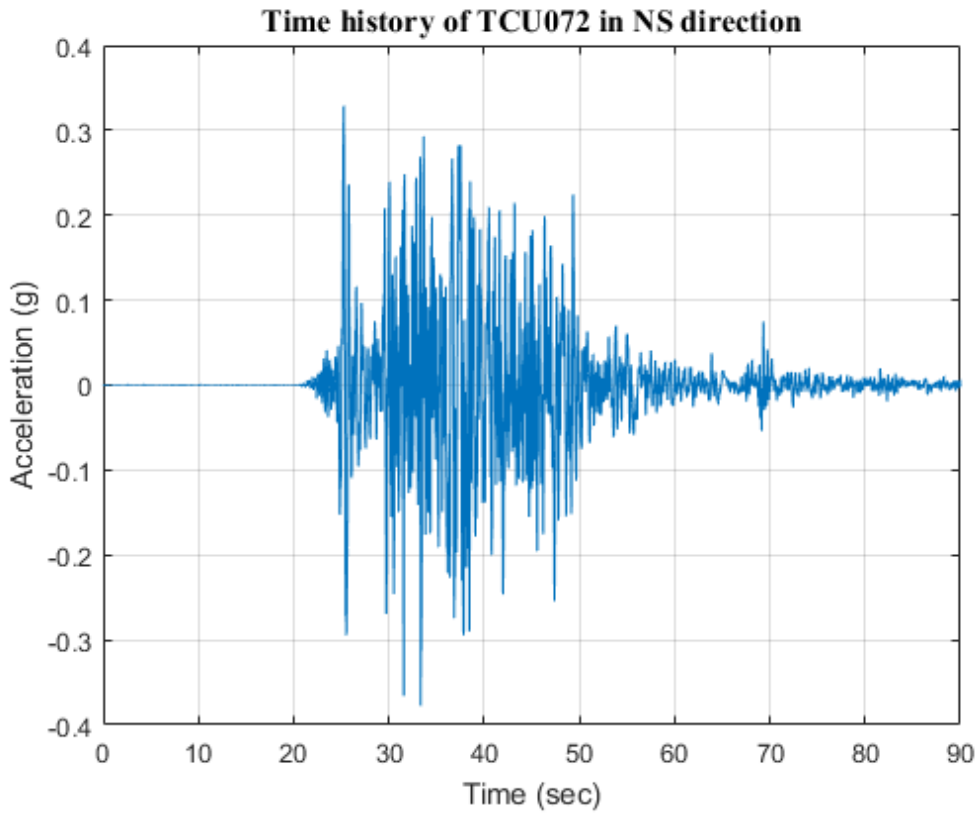
3.8 加入非線性歷時

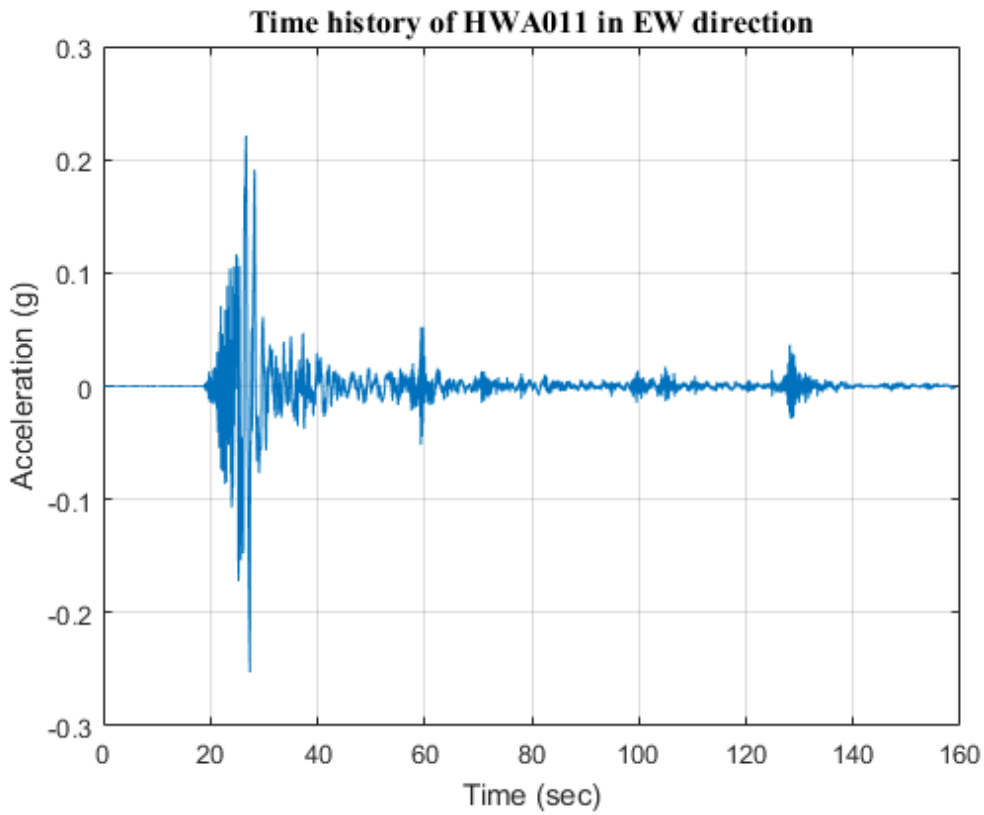

Define Analysis Case
3.Nonlinear Dynamic
Define Nonlinear Dynamic Analysis
Tag 052
StpLength 5.0000E-03
AnaSteps 18000
Intergration Method
Newmark
XGndMot
Ground Acceleration Record
File Name C:\Users\user2\Desktop\Project
Time Factor 1.
Magnitude Factor 10.
XFac 1.
Damping Factors
α & β
Alpha
0.09455
Beta
4.2233E-03
Load from *.eigen
Beta0
0.
YGndMot
Ground Acceleration Record
File Name none
Time Factor 0.
Magnitude Factor 0.
YFac 0.
ZGndMot
Ground Acceleration Record
File Name C:\Users\user2\Desktop\Project
Time Factor 1.
Magnitude Factor 10.
ZFac 1.
Enabled

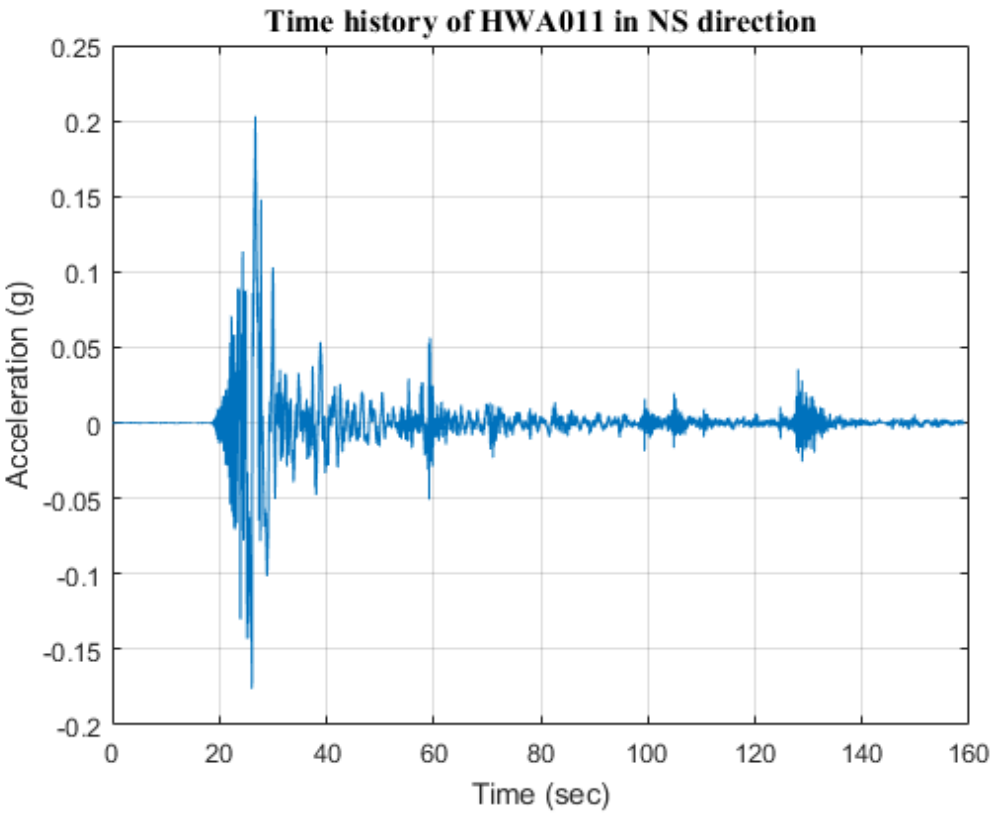

Time history of TCU052 in EW direction
Acceleration (g)
Time (sec)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70
80
90


Time history of TCU052 in NS direction
Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70
80
90


Time history of TCU072 in EW direction
Acceleration (g)
Time (sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70
80
90


Time history of TCU072 in NS direction
Acceleration (g)
Time (sec)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
10
20
30
40
50
60
70
80
90


Time history of HWA011 in EW direction
Acceleration (g)
Time (sec)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
20
40
60
80
100
120
140
160

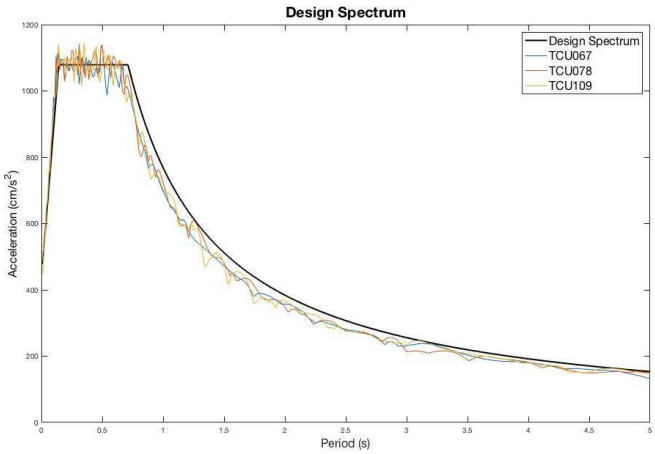


Chapter 4 初步設計

我們先了解本結構物有關規範與地震歷時大致的反應，並透過三筆地震歷時，來了解結構物大約在多少阻尼比下會通過本組所需要的層間變位角 1.2%的限制，由這過程得到的初步分析阻尼比，可提供我們接下來設計時一個參考的設計目標阻尼比

4.1 反應譜與地震歷時設計目標阻尼比

將題目要求三筆地震歷時 TCU067、078、109 透過 State Space method 轉成反應譜與規範反應譜進行疊圖，確認題目所給三筆地震反應譜為符合規範所要求的反應譜



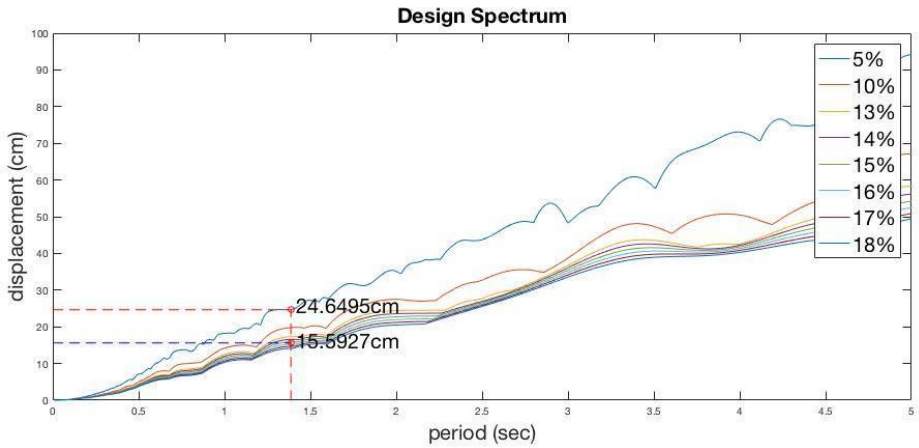
4.2 找出 critical case

將三筆地震歷時放進模型分析，輸出層間位移角，找出 critical case，為長向 TCU078

	Bare frame					
story	TCU067		TCU078		TCU109	
	Long.	Tans.	Long.	Tans.	Long.	Tans.
RF	0.0099	0.0077	0.0117	0.0096	0.0102	0.0084
6	0.0131	0.0107	0.0155	0.0135	0.0139	0.0121
5	0.0159	0.0140	0.0176	0.0166	0.0165	0.0156
4	0.0177	0.0161	0.0181	0.0180	0.0174	0.0174
3	0.0164	0.0157	0.0158	0.0165	0.0154	0.0156
2	0.0090	0.0090	0.0084	0.0093	0.0081	0.0086
1	0	0	0	0	0	0

4.3 進行試誤

將各加速度反應譜轉成位移反應譜，並由結構物週期及規定之層間變位角，找出第一次試誤設計阻尼比，將其輸入空構架，確認層間變位角是否滿足 0.012 的限制，若沒通過則放大阻尼比進行第二次試誤，直到找出滿足層間變位角小於 0.012 的阻尼比，則此阻尼比視為我們透過初步設計找出之設計目標阻尼比



4.4 得到設計目標阻尼比

由於空構架在 0.02 阻尼比下有最大層間變位角：長向 0.0181(TCU078)，經過我們初步分析結果得知，滿足層間變位角小於 0.012 之最小阻尼比為長向 16%，因此將這個結果的長向 16%視為我們的設計目標阻尼比。

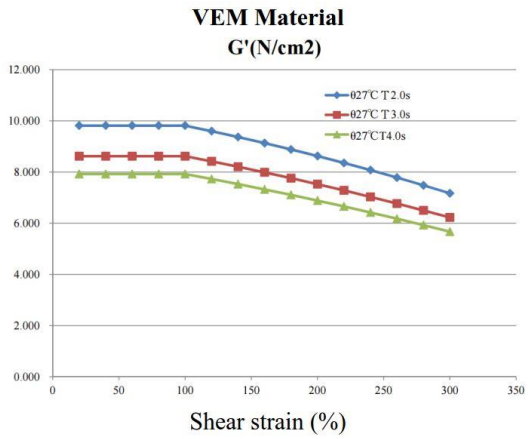
由於我們的結構是長向主控，因此設計以長向為主要設計方向，並用長向的參數應用到短向，也會檢核短向是否符合需求。

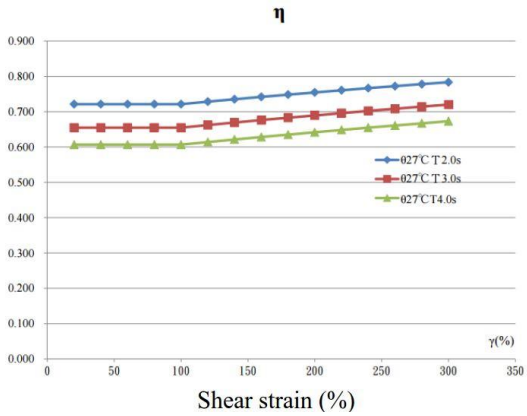
Chapter 5 黏彈性阻尼器 Viscoelastic Damper (VE)

5.1 設計阻尼參數

初步設計目標在前章已有詳述，即長向及短向都用 16%。

黏彈性阻尼的材料性質中，我們利用空構架的週期與剪應變來求得參數，藉此可以得到 Loss factor 以及 G'，分別為 0.668178 與 5635.56N/cm^2。





5.2 求得目標週期

利用目標阻尼比與以下的公式來推導目標週期，再進行試誤以求得目標勁度係數與目標阻尼係數使模型週期與目標週期誤差最小。所需要的參數為空構架的結構週期，以及材料性質途中所得到的 η，將參數輸入至 ETABS 來推算結構物的目標週期。

5.3 計算勁度與阻尼係數

通常是改變 A/t，算出 K，並輸入到模型裡跑模態算週期。這裡利用公式反推出需要的週期，並且在模型裡面直接改 K 值看模態的週期，等到週期符合後在回推 A/t 以及 C_d 值。

原始構架週期:

$$T_0 = 1.386\ s$$

算所需週期:

$$\xi_r = \xi_c + \frac{(\eta - \xi_c)}{2}\left(1 - \frac{\omega_r^2}{\omega_{sr}^2}\right) = \xi_c + \frac{(\eta - \xi_c)}{2}\left(1 - \frac{T^2}{T_0^2}\right) = 16\%$$

$$T = 1.032\ s$$

在模型裡迭代求出 K 值

$$K = 7608060\ (\text{N/m}) = \text{G}'\frac{A}{t} \qquad \frac{A}{t} = 1.35\ m$$

$$\eta = \frac{G''}{G'} \qquad G'' = 37655572.1$$

$$C_d = \frac{G'' \times A}{\omega \times t} = 11213634.1\ (\text{N-s/m})$$

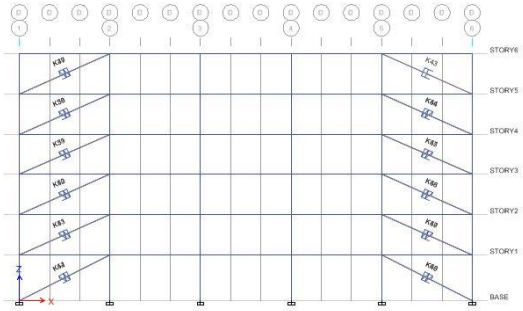
最後可整理長向與短向所需之勁度與阻尼係數值如下:

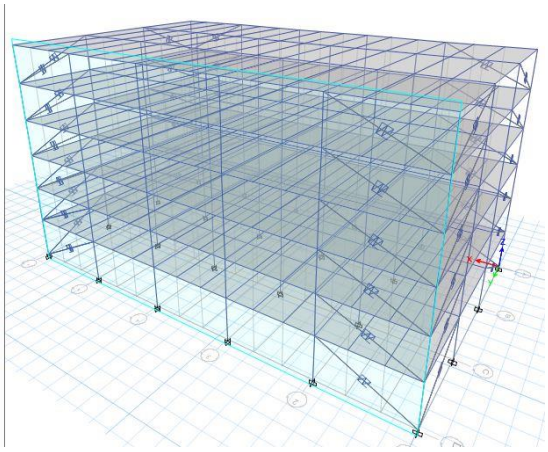
	Stiffness(kN/m)	Damping Coefficient(kN-s/m)
Long direction	7608	11213.6

因為長向為控制向，所以 Y 向 VE 一樣使用此參數，結果也能符合限制。

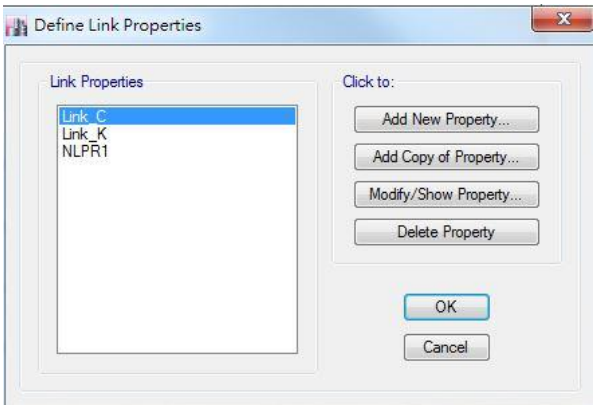
5.4 ETABS 分析

於 ETABS 分析程式中繪製阻尼器，並設置決定之參數。

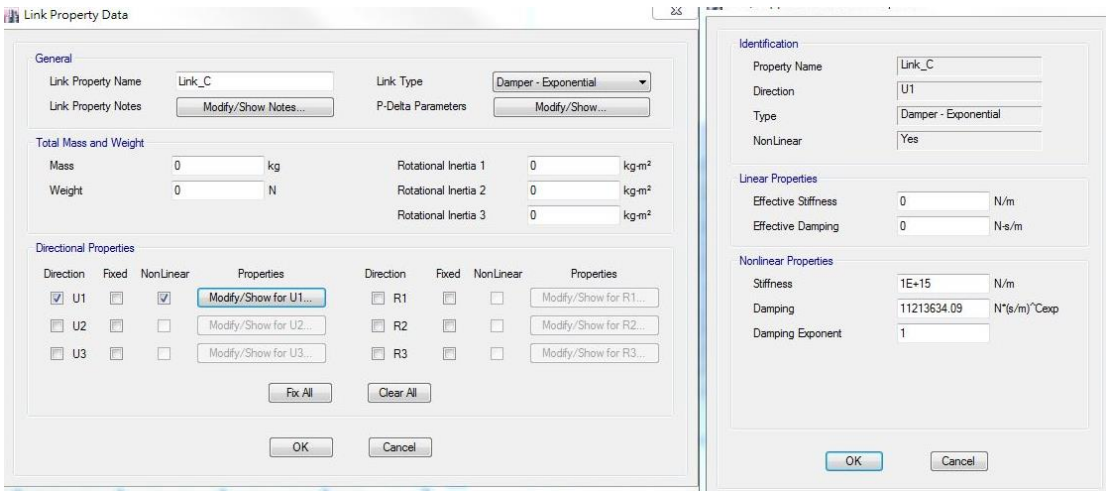




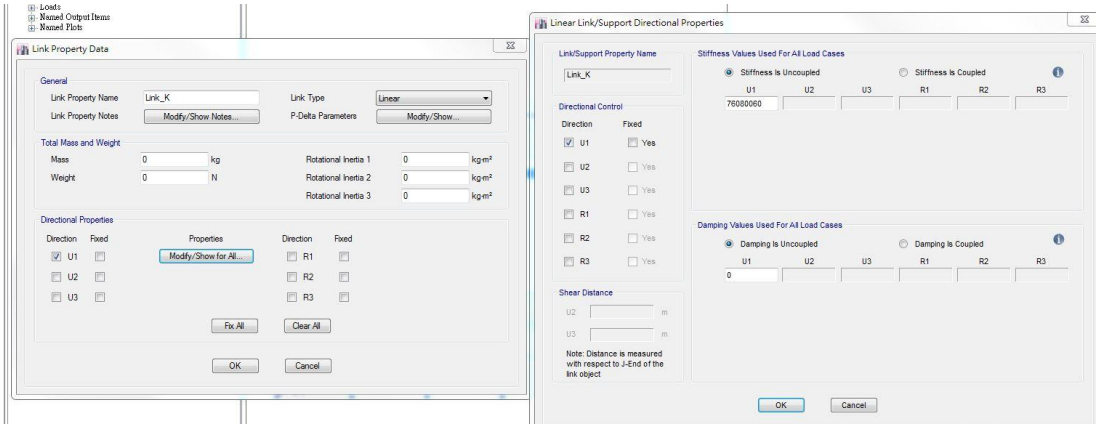
設定勁度與阻尼 LINK



阻尼器之勁度設定



阻尼器之阻尼係數設定



5.5 計算阻尼設計面積

設定阻尼器的勁度以及阻尼係數後，厚度可以從最大層間變位角與樓高、擺放位置等幾何關係來求得，接著就能從勁度來推估阻尼的設計面積。

$$K_d = G' \frac{nA}{t}$$

$$\text{Max drift} = 0.008$$

$$t = \text{Max drift} \times h \times \frac{\cos\theta}{\gamma} = 0.008 \times 4 \times \frac{9/\sqrt{9^2+4^2}}{3} = 0.009747\ m$$

$$\frac{nA}{t} = 1.35m$$

$$nA = 1.35 \times 0.009747 = 0.01316\ m^2$$

$$A = 0.01316\ m^2$$

每一片阻尼厚度為 0.9747cm，一隻阻尼器有四片阻尼，分別將勁度帶入上面公式後可以得到面積為 0.01316m^2。將阻尼器設定為正方形，則設計阻尼長度與寬度為 0.115m。

5.6 阻尼之設計參數

η	0.668
G'(N/cm^2)	5635.56
kd(kN/m)	7608
Cd(kN*s/m)	11213.6
nA/t ratio (m)	1.35
thickness(m)	0.9747
Num. of layers	4
Area(cm^2)	131.6

Chapter 6 線性黏性阻尼器 Linear Viscous Damper (LVD)

6.1 阻尼係數計算

含線性黏性阻尼器結構物的有效阻尼比計算公式如下：

$$\xi = \xi_0 + \xi_{viscous} = \xi_0 + \frac{T\sum c_j \phi_{r,j}^2 cos^2\theta_j}{4\pi\sum m_i \phi_i^2}$$

其中，T 為週期，$\phi_{r,j}^2$ 表示第 j 個阻尼器的相對模態平方，θ_j 表示第 j 個阻尼器的傾角，$m_i\phi_i^2$則為第 i 層的質量與模態平方的乘積，針對阻尼器所需提供的阻尼比部分，將阻尼係數c_j提出改寫成：

$$c_j = \frac{4\pi\xi\sum m_i \phi_i^2}{T\sum \phi_{r,j}^2 cos^2\theta_j}$$

首先，針對空構架模態分析，獲得結構物第一模態與第二模態(分別對應長項與短向)的週期與模態，再將模態正規化並利用各樓層關係計算相對模態。

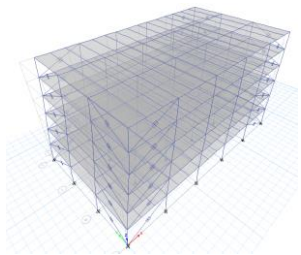
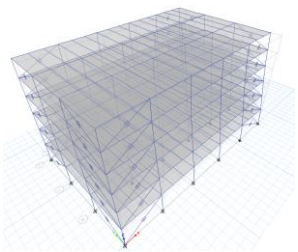
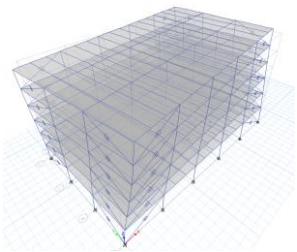
Story	Mass(ton)	Longitudinal Direction		Transverse Direction	
		Normalize Mode Shape	Relative Mode Shape	Normalize Mode Shape	Relative Mode Shape
RF	92.92164	1.000	0.107	1.000	0.100
6F	86.72686	0.893	0.156	0.900	0.151
5F	86.72686	0.738	0.200	0.749	0.198
4F	86.72686	0.538	0.222	0.551	0.223
3F	86.72686	0.316	0.198	0.328	0.203
2F	86.72686	0.118	0.118	0.126	0.126

6.2 結構物週期與模態

由於非線性黏性阻尼器本身不提供勁度，因此可以前三個模態的週期與未加阻尼器時相同。

Period(sec)	1st Mode	2nd Mode	3rd Mode
Bare Frame	1.386	1.275	1.075
Bare Frame with Nonlinear VD	1.386	1.275	1.075

而結構物三個模態分別為長向、短向及扭轉，反應情形如下：

1st Mode	2nd Mode	3rd Mode
		

Chapter 7 非線性黏性阻尼器 Nonlinear Viscous Damper (NVD)

7.1 阻尼係數計算

非線性黏性阻尼器結構物的有效阻尼比計算公式如下：

$$\xi_{eff} = \xi_0 + \xi_{viscous} = \xi_0 + \frac{\sum \lambda_j c_j \phi_{r,j}^{1+\alpha} cos^{1+\alpha}\theta_j}{2\pi A^{1-\alpha}\omega^{2-\alpha}\sum m_i \phi_i^2}$$

其中，ω為角頻率，$\phi_{r,j}^2$表示第 j 個阻尼器的相對模態平方，θ_j表示第 j 個阻尼器的傾角，$m_i\phi_i^2$則為第 i 層的質量與模態平方的乘積，A 為最大頂層位移，本組之 α 為 0.6。

針對阻尼器所需提供的阻尼比部分，將阻尼係數c_j提出改寫成：

$$c_j = \frac{2\pi\xi A^{1-\alpha}\omega^{2-\alpha}\sum m_i \phi_i^2}{\lambda \sum \phi_{r,j}^{1+\alpha} cos^{1+\alpha}\theta_j}$$

首先，針對空構架模態分析，獲得結構物第一模態與第二模態(分別對應長項與短向)的週期與模態，再將模態正規化並利用各樓層關係計算相對模態。

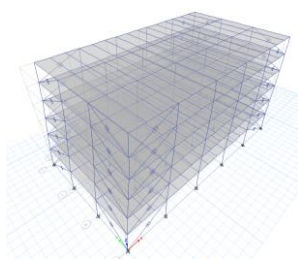
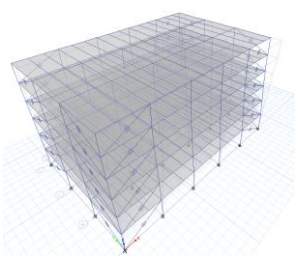
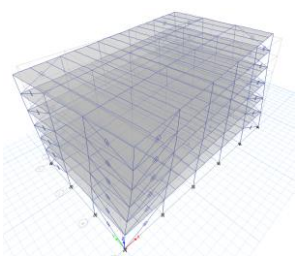
Story	Mass(ton)	Longitudinal Direction		Transverse Direction	
		Normalize Mode Shape	Relative Mode Shape	Normalize Mode Shape	Relative Mode Shape
RF	92.92164	1.000	0.107	1.000	0.100
6F	86.72686	0.893	0.156	0.900	0.151
5F	86.72686	0.738	0.200	0.749	0.198
4F	86.72686	0.538	0.222	0.551	0.223
3F	86.72686	0.316	0.198	0.328	0.203
2F	86.72686	0.118	0.118	0.126	0.126

7.2 結構物週期與模態

由於非線性黏性阻尼器本身不提供勁度，因此可以前三個模態的週期與未加阻尼器時相同。

Period(sec)	1st Mode	2nd Mode	3rd Mode
Bare Frame	1.386	1.275	1.075
Bare Frame with Nonlinear VD	1.386	1.275	1.075

而結構物三個模態分別為長向、短向及扭轉，反應情形如下：

1st Mode	2nd Mode	3rd Mode
		

Chapter 8 減震設計比較

8.1 線性分析數據比較

LVD

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	LVD	%	Bare frame	LVD	%	Bare frame	LVD	%
067	0.2700	0.1253	46.41	1.6367	1.0035	61.31	9.502	4.717	49.64
078	0.2662	0.1758	66.04	1.3923	0.8552	61.42	10.647	4.561	42.84
109	0.3214	0.1885	58.65	1.6144	0.8445	52.31	7.973	3.629	45.52
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	LVD	%	Bare frame	LVD	%	Bare frame	LVD	%
067	0.2518	0.1263	50.16	1.7387	1.0438	60.03	8.161	7.040	86.26
078	0.2412	0.1483	61.48	1.6896	0.8049	47.64	10.426	7.269	69.72
109	0.2907	0.1911	65.74	1.6535	0.8736	52.83	8.818	6.233	70.68

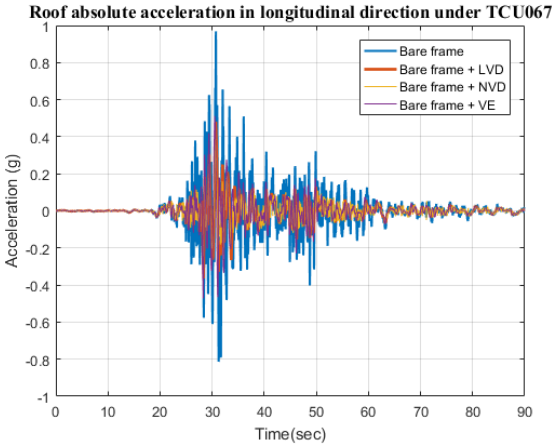
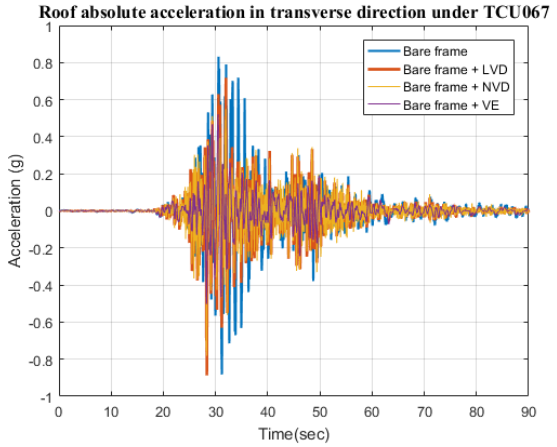
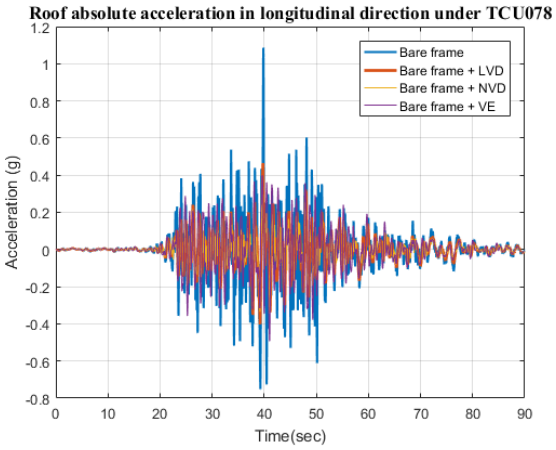
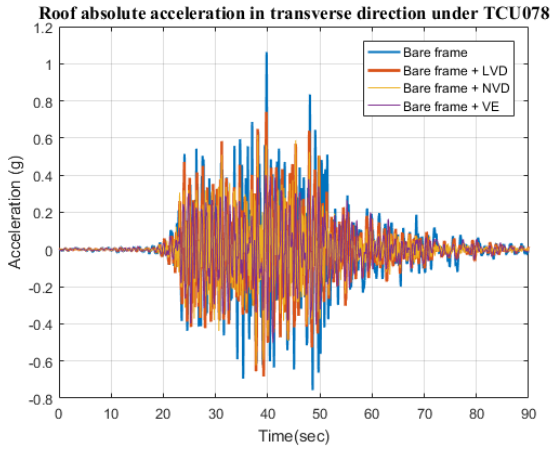
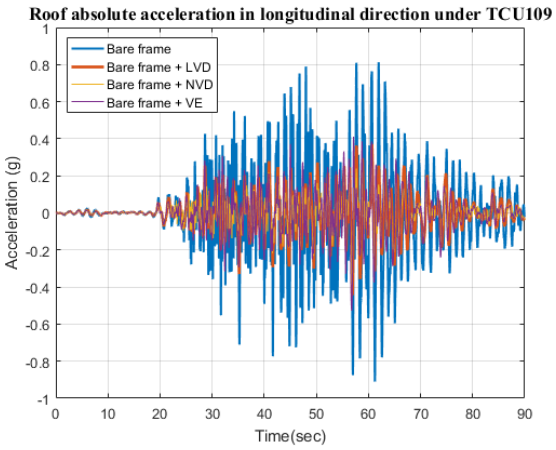
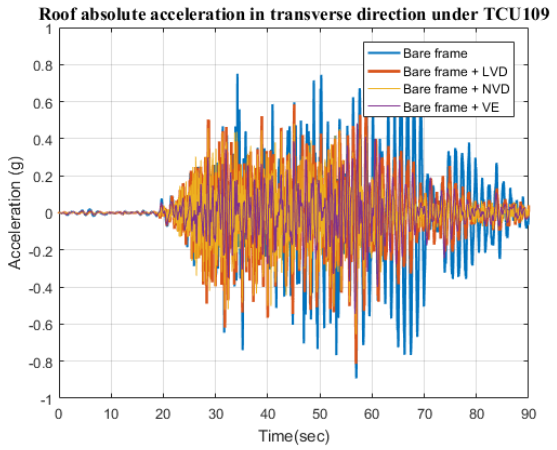
VE

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	VE	%	Bare frame	VE	%	Bare frame	VE	%
067	0.2700	0.1367	50.63	1.6367	0.7831	47.85	9.502	5.013	52.76
078	0.2662	0.1274	47.86	1.3923	0.7224	51.89	10.647	4.851	45.56
109	0.3214	0.1444	44.93	1.6144	0.9575	59.31	7.973	5.179	64.96
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	VE	%	Bare frame	VE	%	Bare frame	VE	%
067	0.2518	0.1269	50.40	1.7387	0.835	48.02	8.161	5.115	62.68
078	0.2412	0.1239	51.37	1.6896	0.7295	43.18	10.426	4.917	47.16
109	0.2907	0.1363	46.89	1.6535	0.9738	58.89	8.818	5.343	60.59

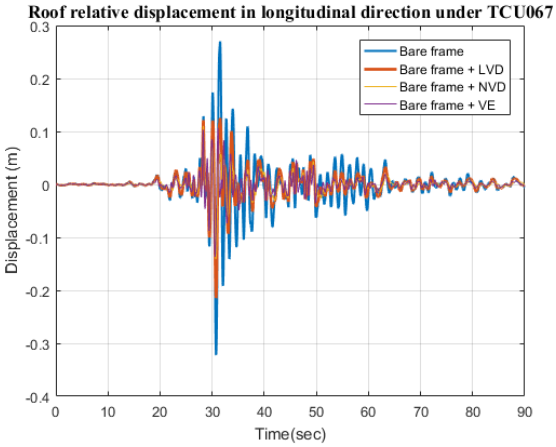
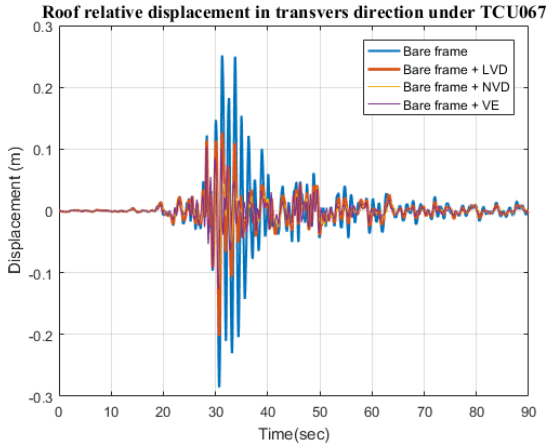
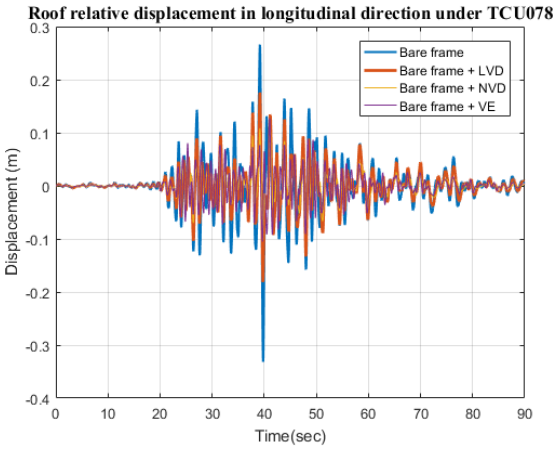
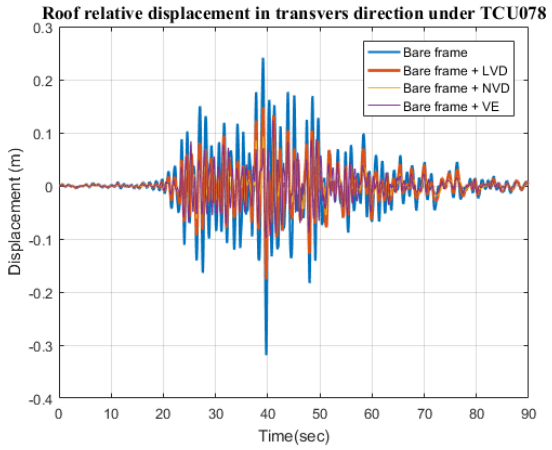
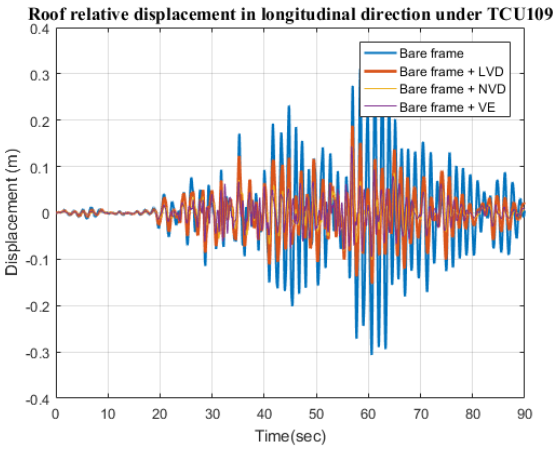
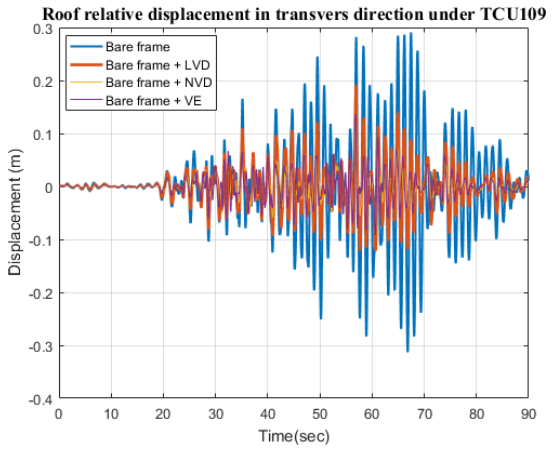
NVD

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	NVD	%	Bare frame	NVD	%	Bare frame	NVD	%
067	0.2700	0.1409	52.19	1.6367	0.6483	39.61	9.502	3.8886	40.92
078	0.2662	0.1087	40.83	1.3923	0.5405	38.82	10.647	3.4059	31.99
109	0.3214	0.1447	45.02	1.6144	0.5675	35.15	7.973	3.7857	47.48
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	NVD	%	Bare frame	NVD	%	Bare frame	NVD	%
067	0.2518	0.1197	47.54	1.7387	0.6125	35.23	8.161	7.6632	93.90
078	0.2412	0.0955	39.59	1.6896	0.5424	32.10	10.426	6.1153	58.65
109	0.2907	0.1282	44.10	1.6535	0.6119	37.01	8.818	6.4271	72.89

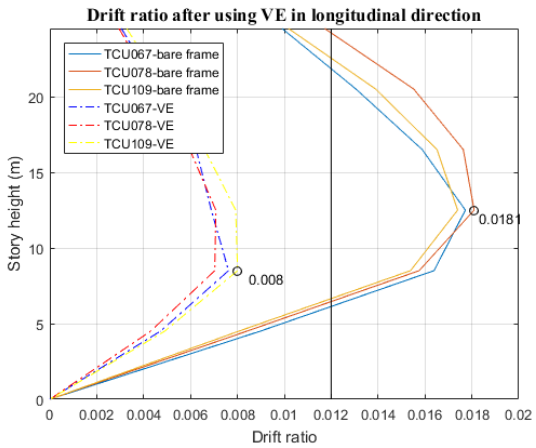
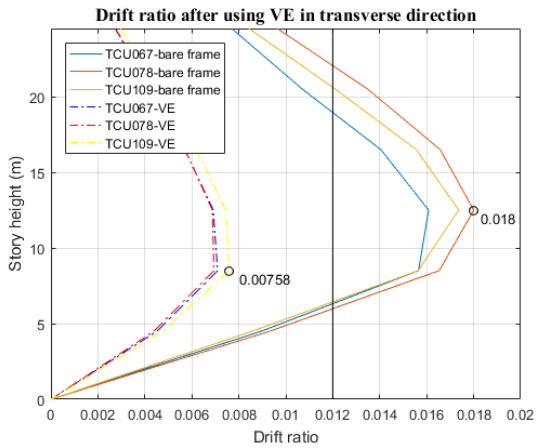
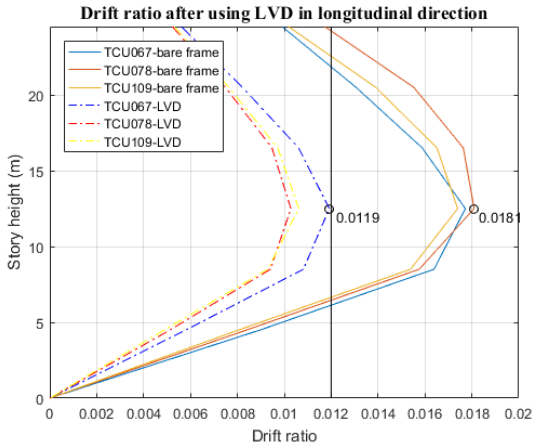
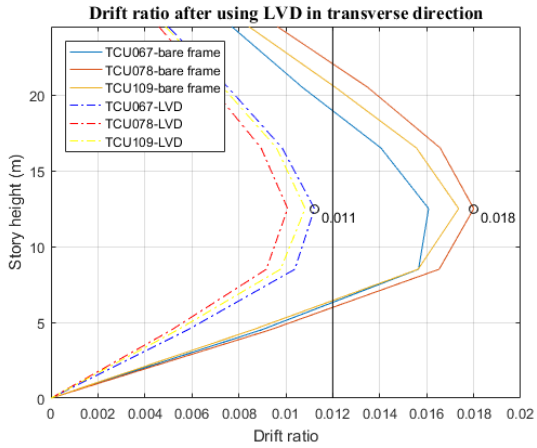
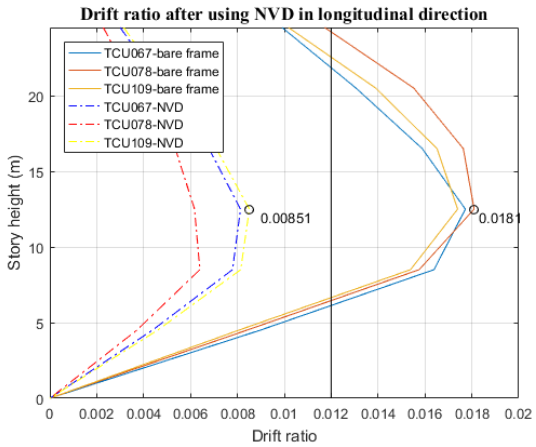
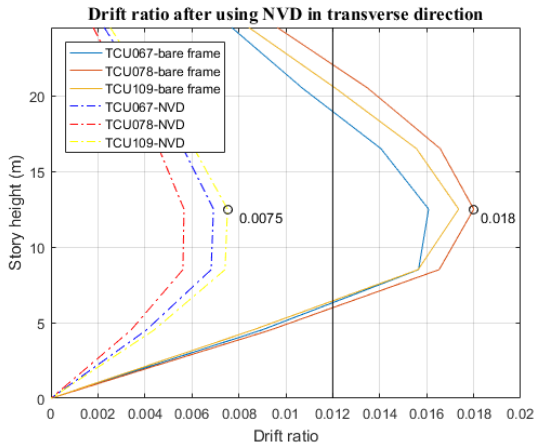
8.2 線性分析加速度反應比較

	X 向	Y 向
TCU067		
TCU078		
TCU109		

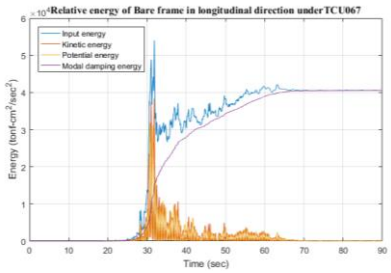
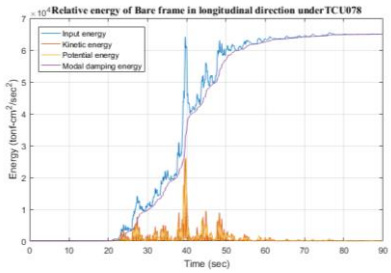
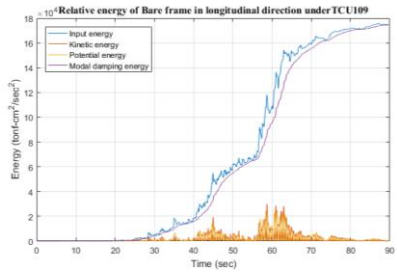
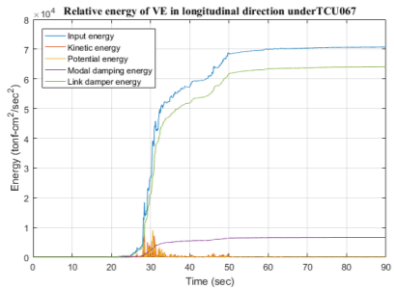
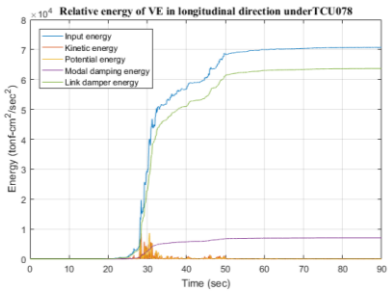
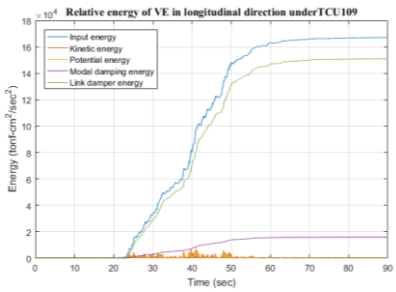
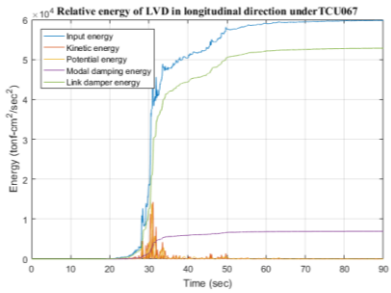
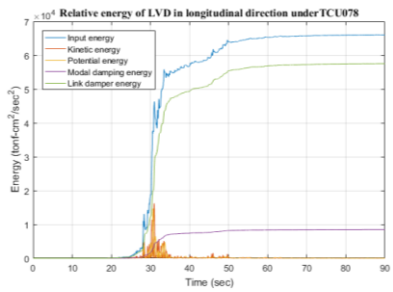
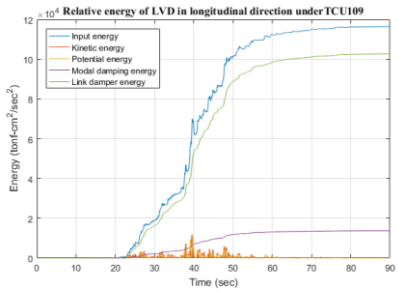
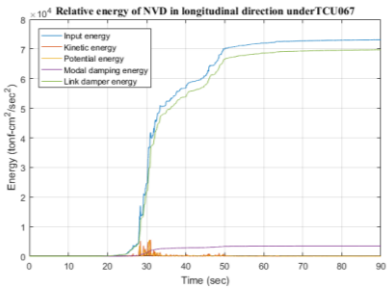
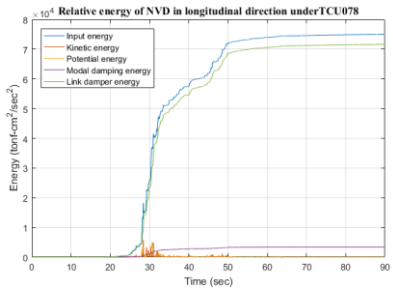
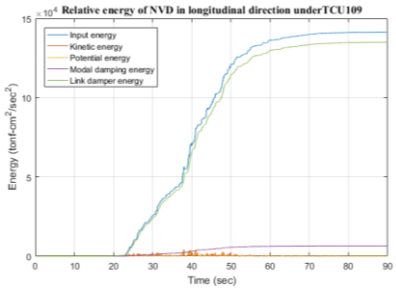
8.3 線性分析位移反應比較

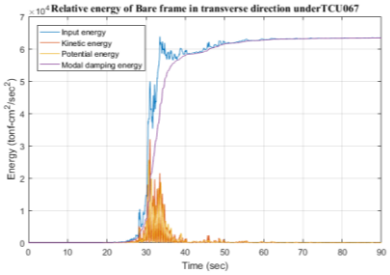
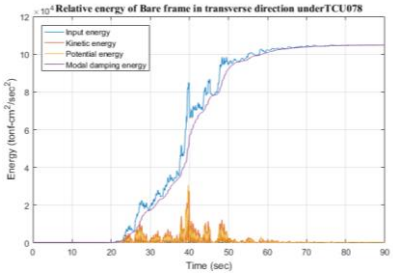
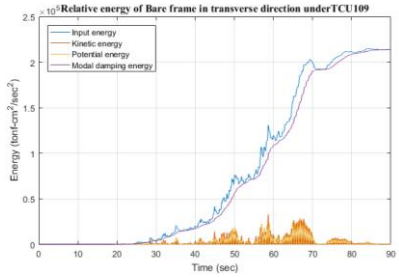
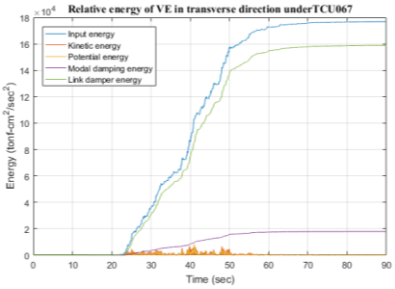
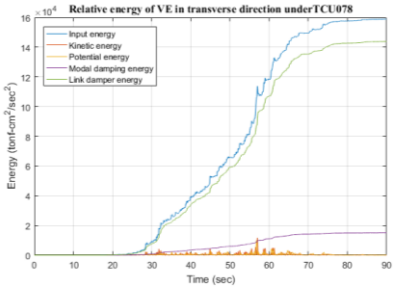
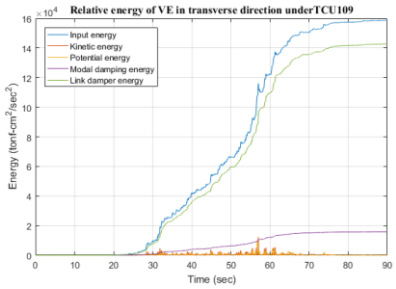
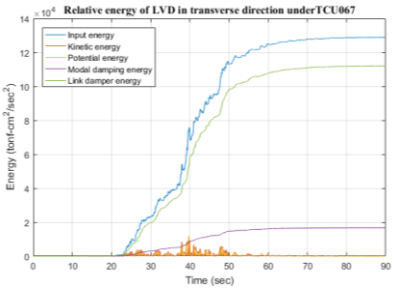
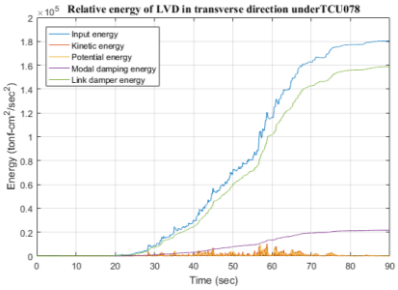
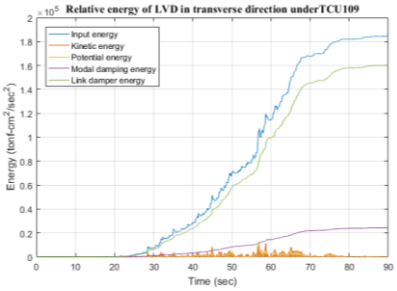
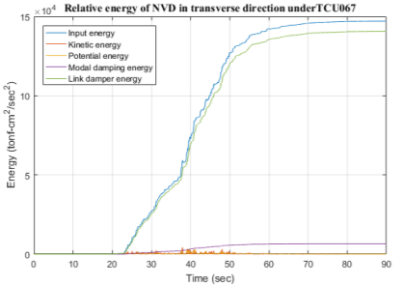
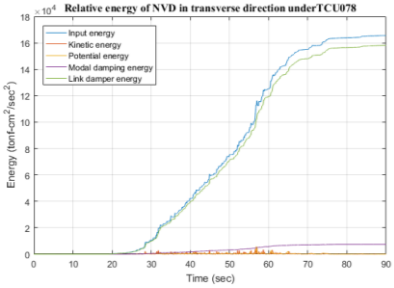
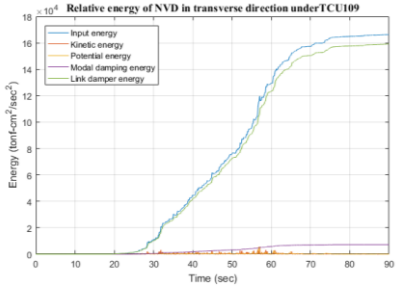
	X 向	Y 向
TCU067		
TCU078		
TCU109		

8.4 線性分析層間位移比較

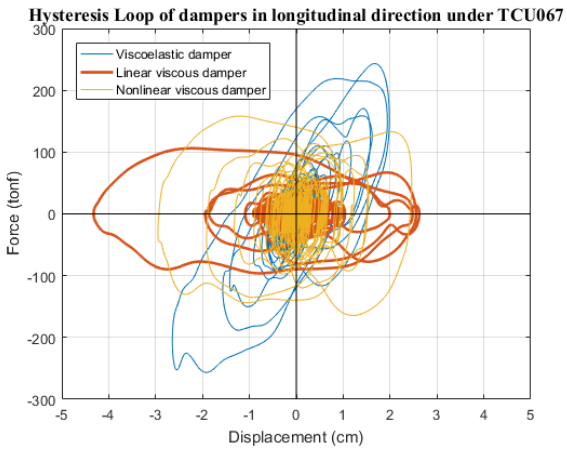
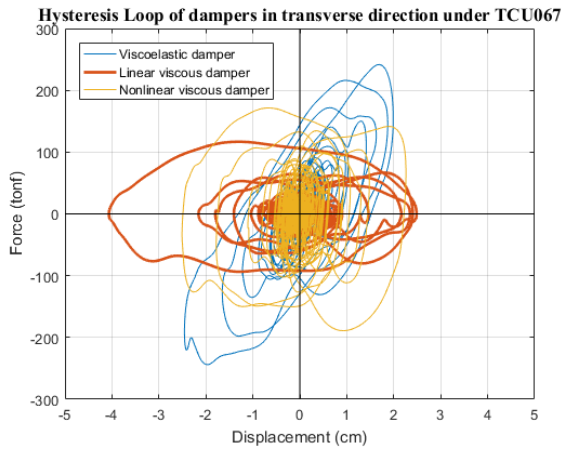
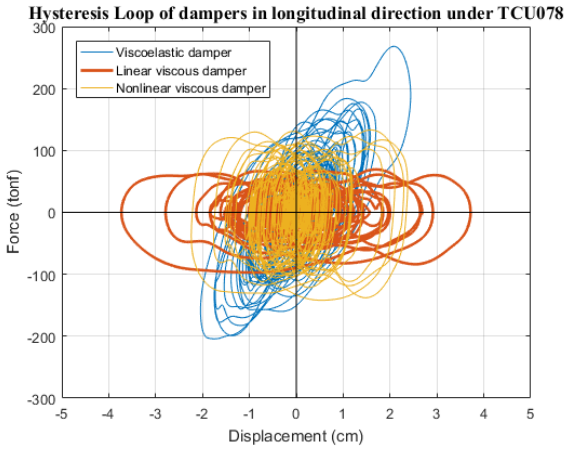
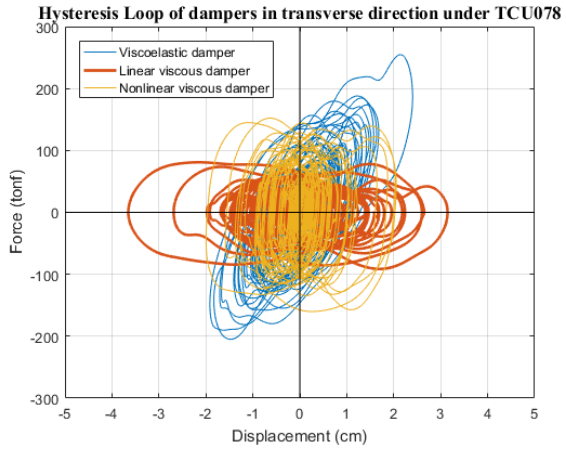
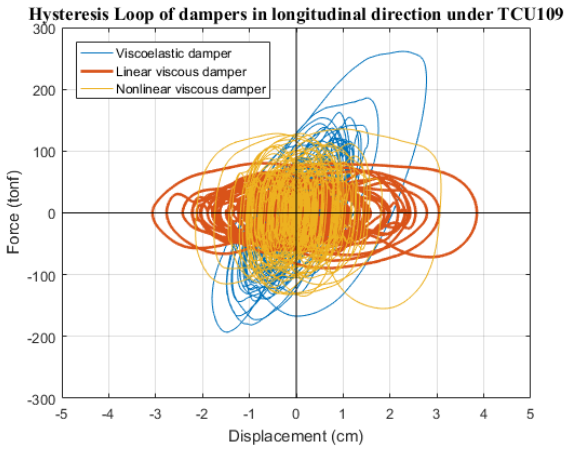
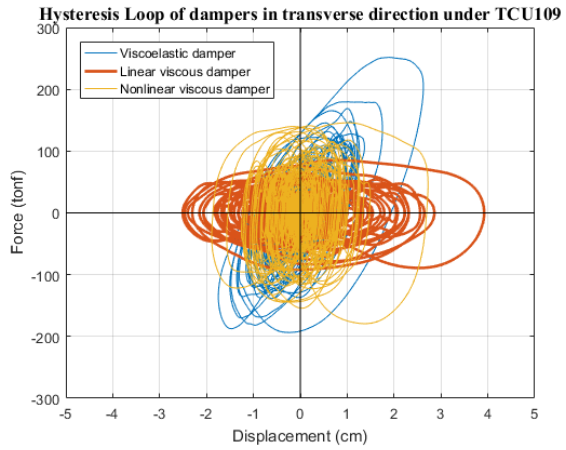
	X 向	Y 向
VE		
LVD		
NVD		

8.5 線性分析能量比較

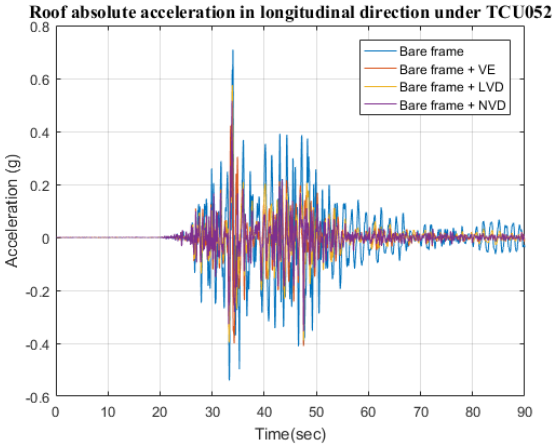
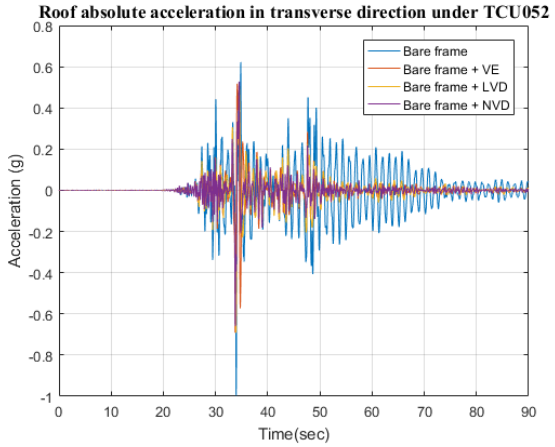
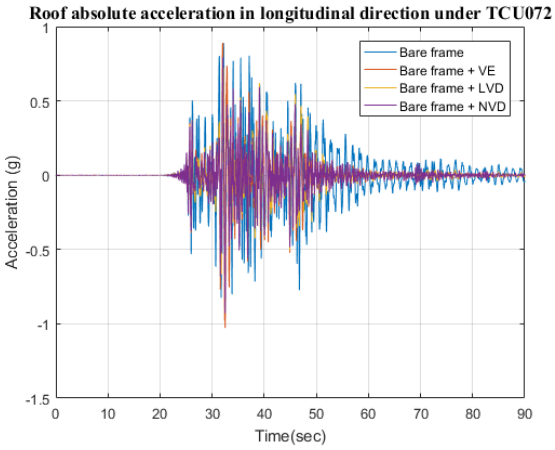
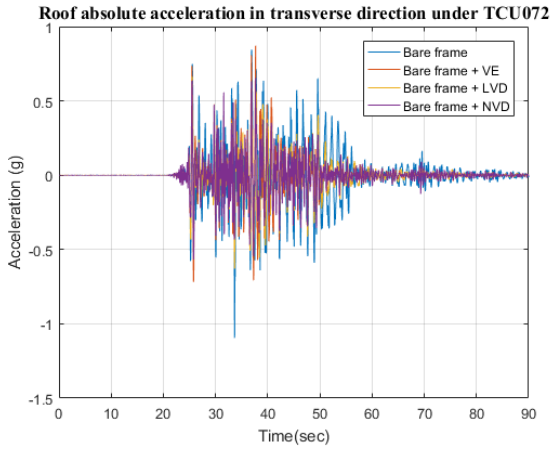
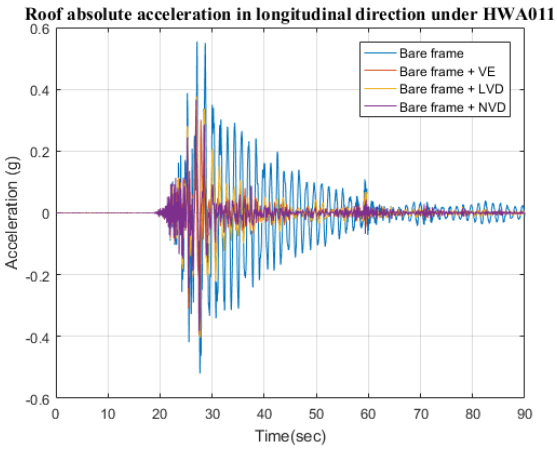
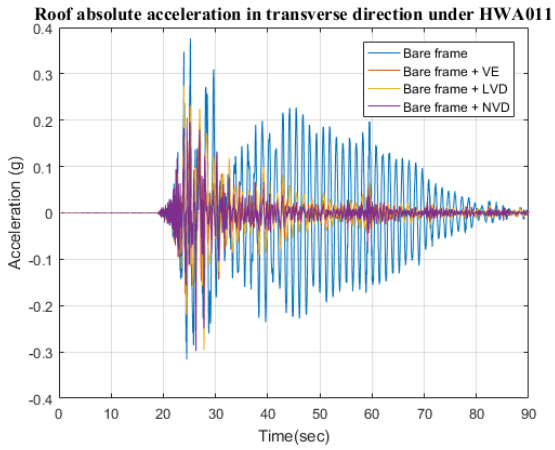
X 向	TCU067	TCU078	TCU109
Bare frame			
VE			
LVD			
NVD			

Y 向	TCU067	TCU078	TCU109
Bare frame			
VE			
LVD			
NVD			

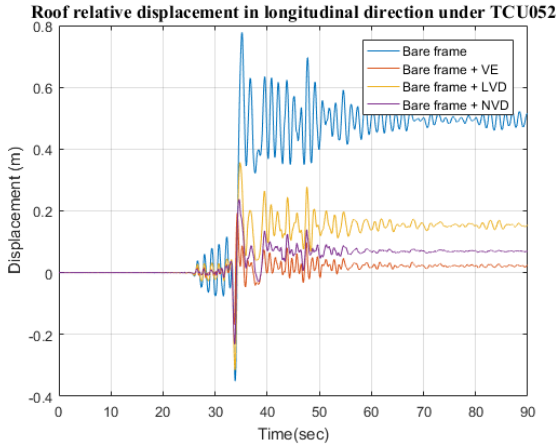
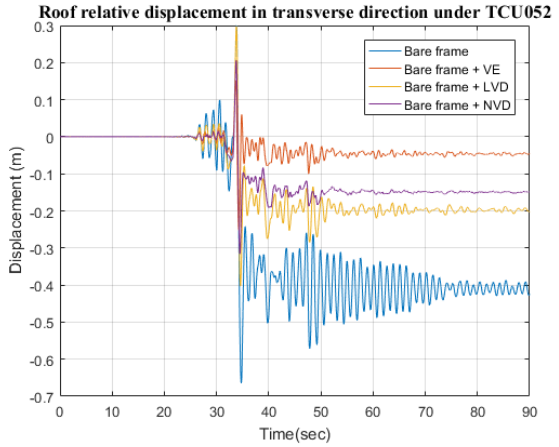
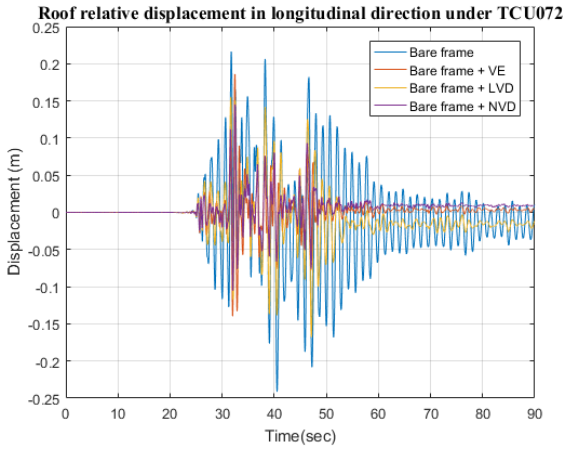
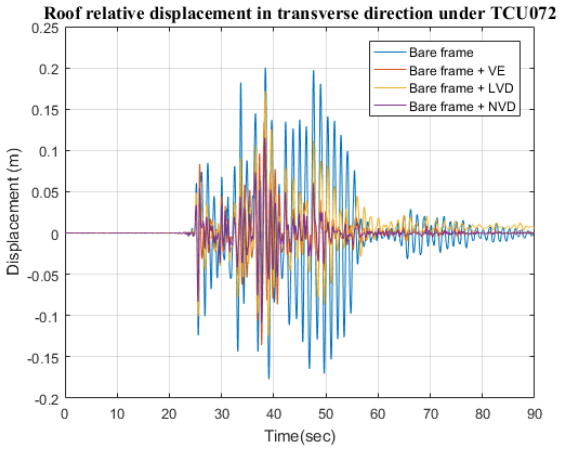
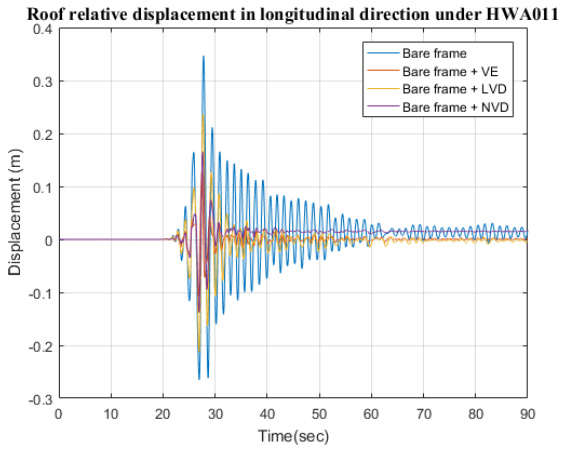
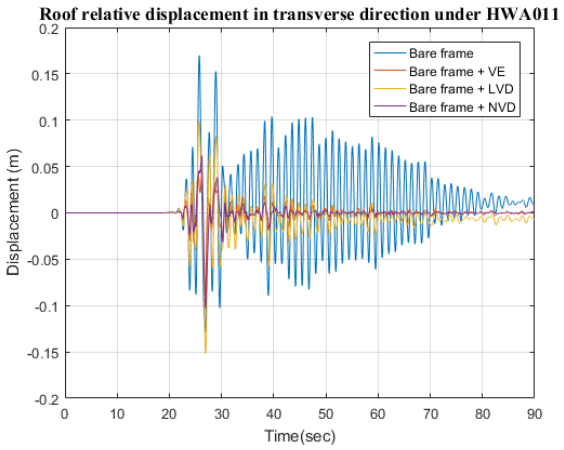
8.6 線性分析遲滯迴圈比較

	X 向	Y 向
TCU067		
TCU078		
TCU109		

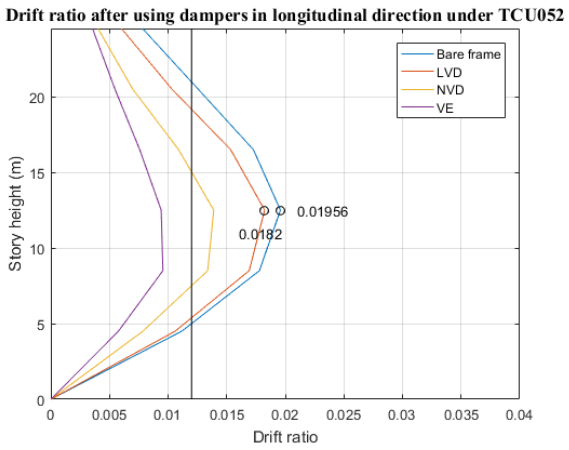
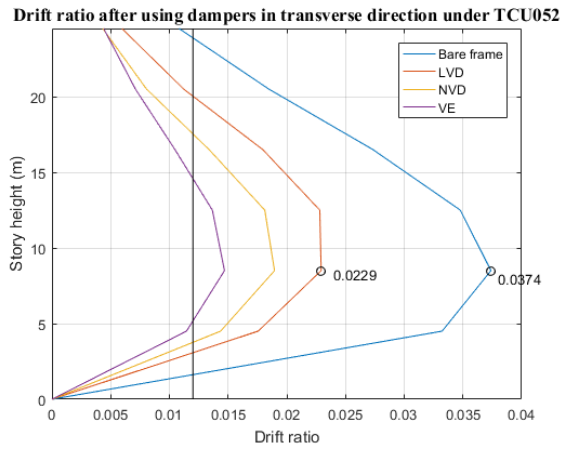
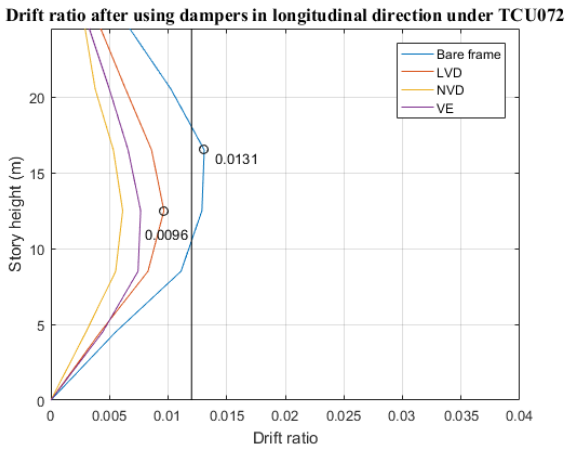
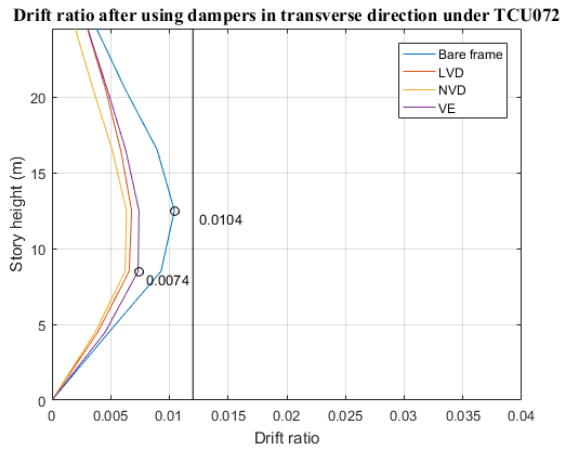
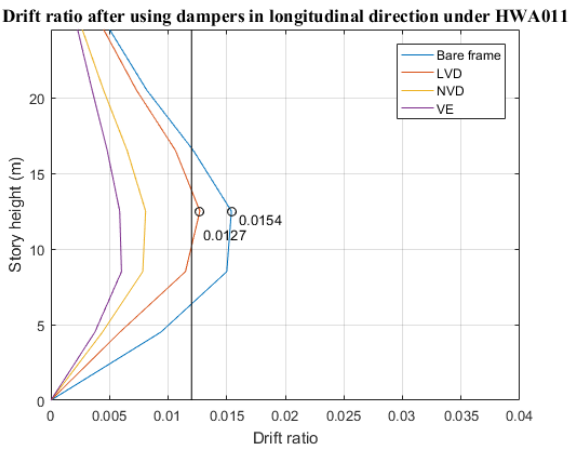
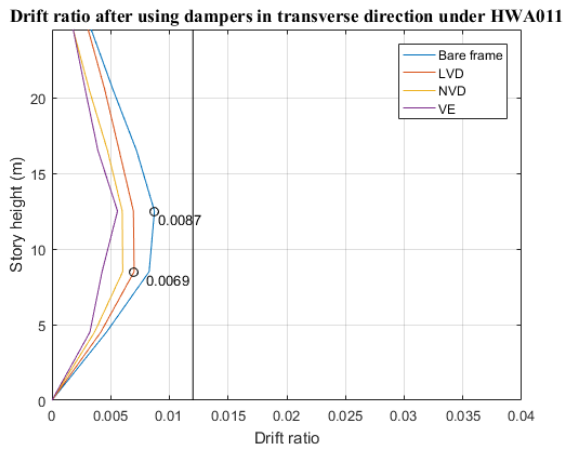
8.7 非線性分析加速度反應比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

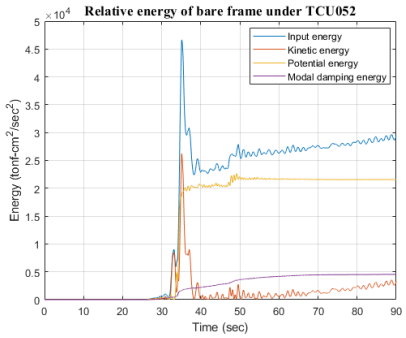
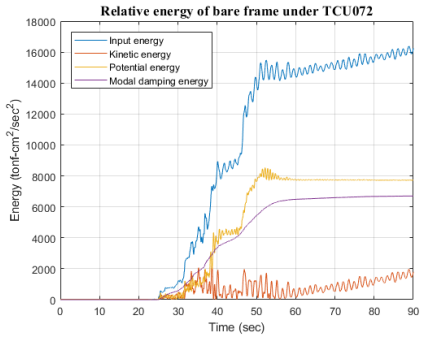
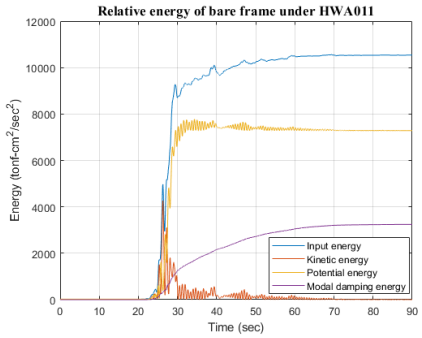
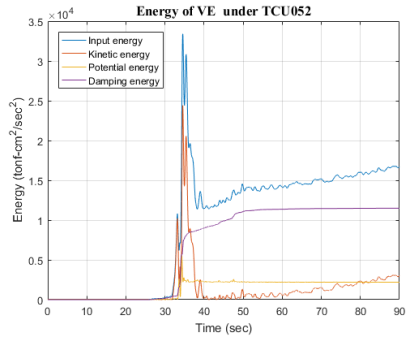
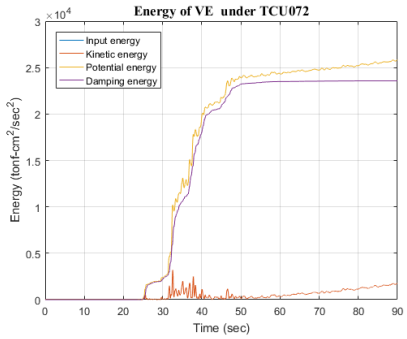
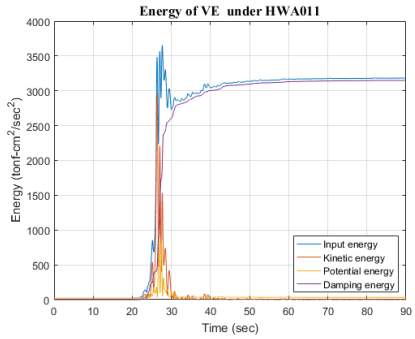
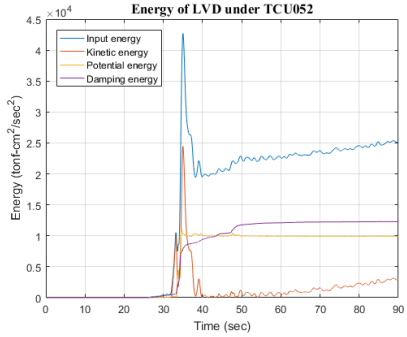
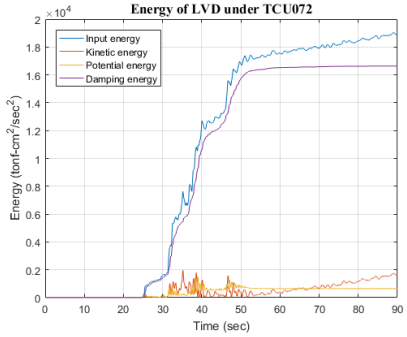
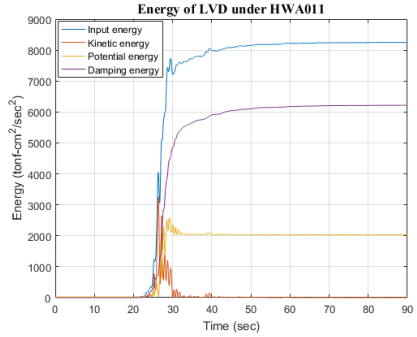
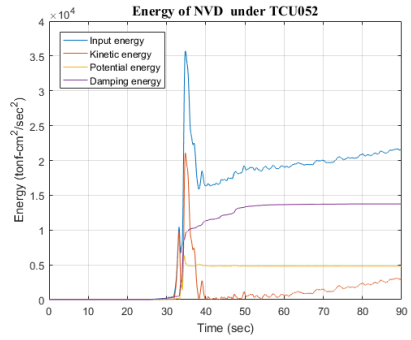
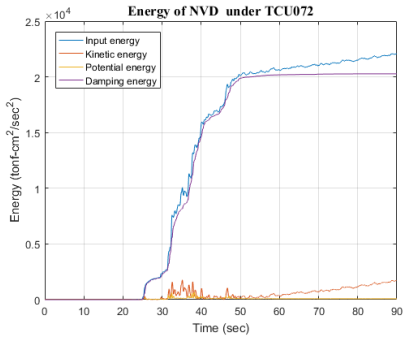
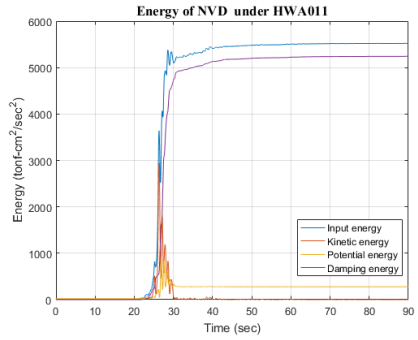
8.8 非線性分析位移反應比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

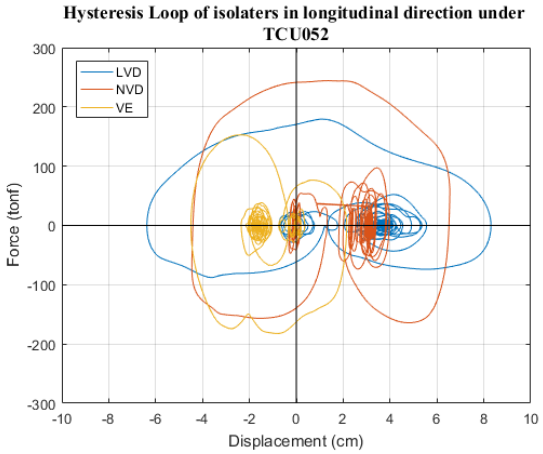
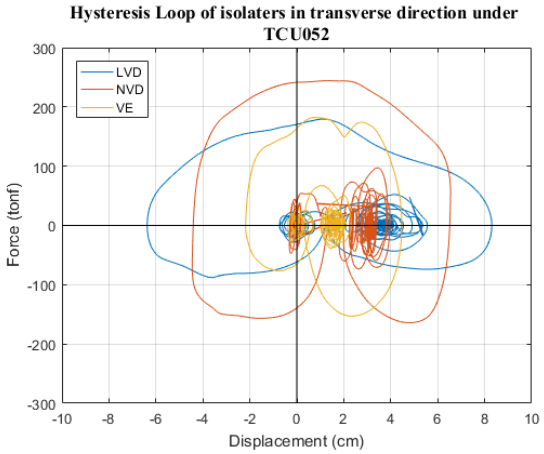
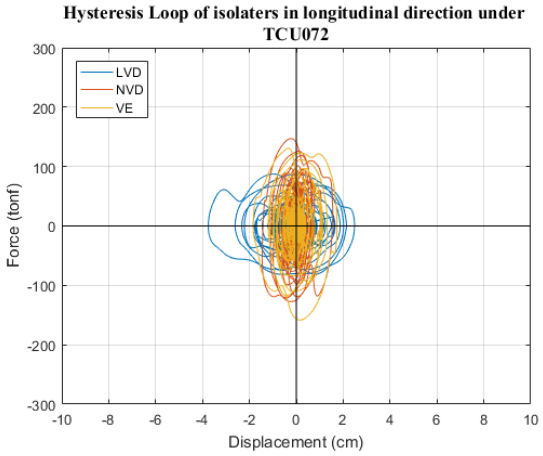
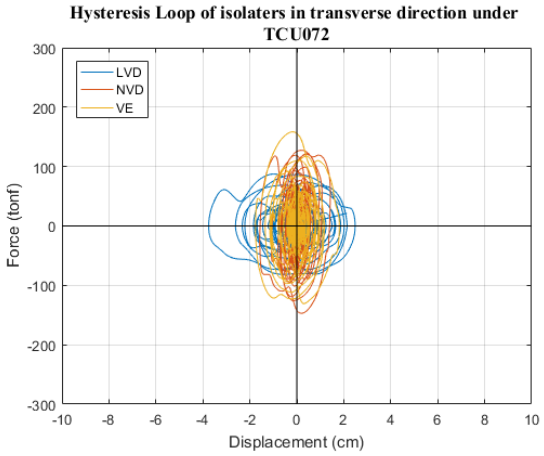
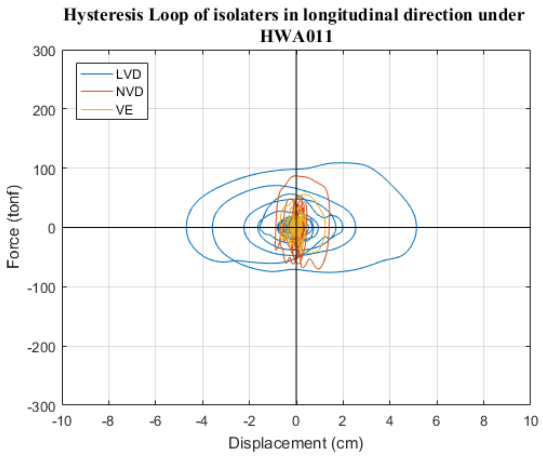
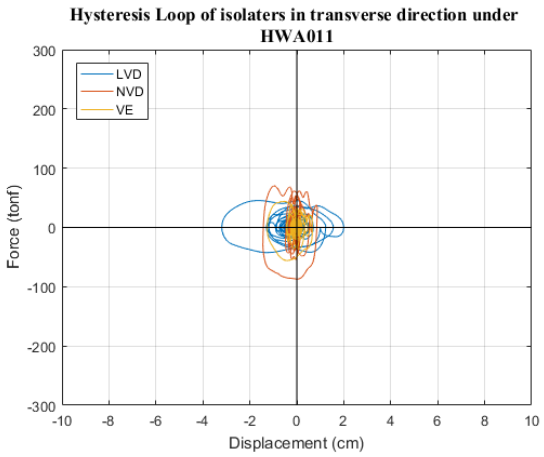
8.9 非線性分析層間位移比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

8.10 非線性分析能量比較

	TCU052	TCU072	HWA
Bare frame			
VE			
LVD			
NVD			

8.11 非線性分析遲滯迴圈比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

Chapter 9 討論與結論

1. 將三種阻尼器經 PISA3D 非線性動力分析結果進行比較，其中頂樓層間位移與頂樓絕對位移的分別疊圖可看出，空構架反應最大，NVD 與 VE 效果相近反應最好，而 VE 與 LVD 折減效果相近，但 VE 結果略好。
2. NVD 是偏正方形，LVD 是橢圓，VE 因為有勁度所以是斜橢圓，形狀都跟理論穩合。
3. 大地震下會超過限制 0.012，最大甚至到 0.0229
4. 近斷層跟遠域斷層在此建物下無太大差異，可以從花蓮地震跟 TCU072 相比得知，TCU052 層間位移會很大是因為其本身就是較大的地震
5. 非線性會看到雙圓心是因為有塑鉸產生永久位移的關係。
6. 非線性的遲滯迴圈較小，是因為塑鉸也產生消能的行為而也有消能的效果。而從圖可以看出 LVD 的遲滯迴圈似乎較穩定，不會因為地震歷時不同而有太大的消能差異。

Project Ⅱ

設計目標

(1) Equivalent Periods：T_{eD} = 2.5-3.5 (sec)

(2)

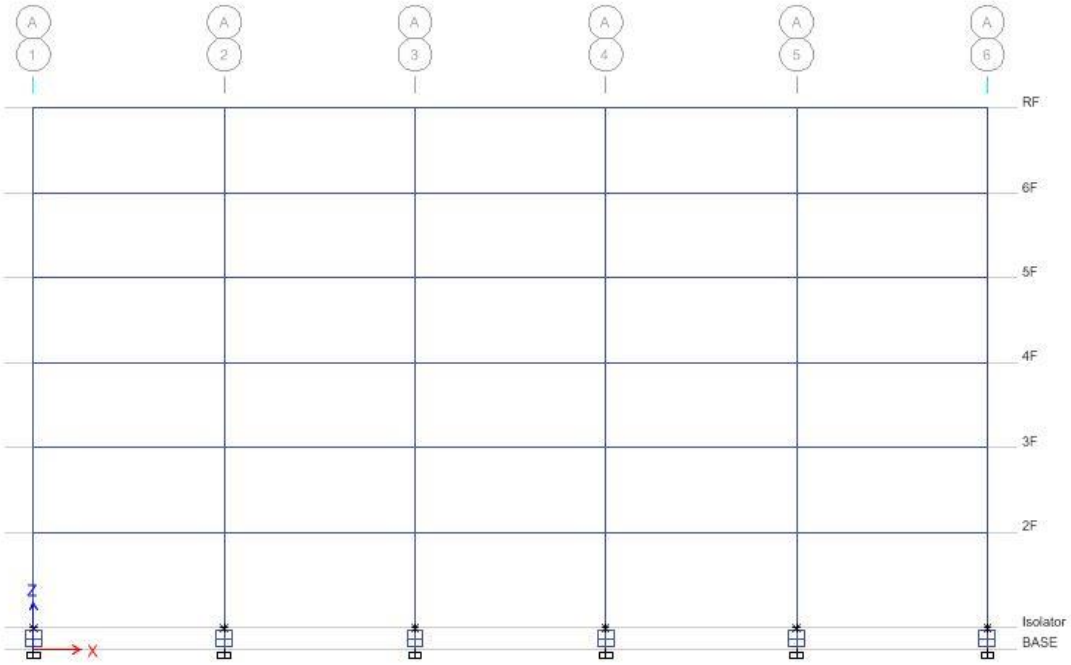
Team	$D_{TD} \leq$ (cm)	IRHD	$\sigma_c \leq$ (kgf/cm^2)
1	25	40	150
2	30	40	150
3	25	50	150
4	30	50	150
5	25	60	150

本組為第四組，D_{TD} 限制為 30cm

Chapter 10 ETABS 建模

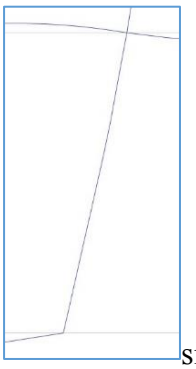
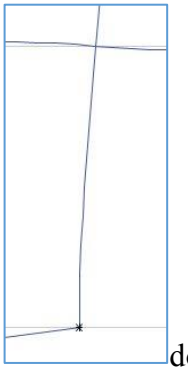
10.1 加隔震層

加一層隔震層高度為 1m



10.2 支承設定

底部設定為 fixed，接一樓的地方也要限制 Rotation 才會是 Double Curvature。


single

double

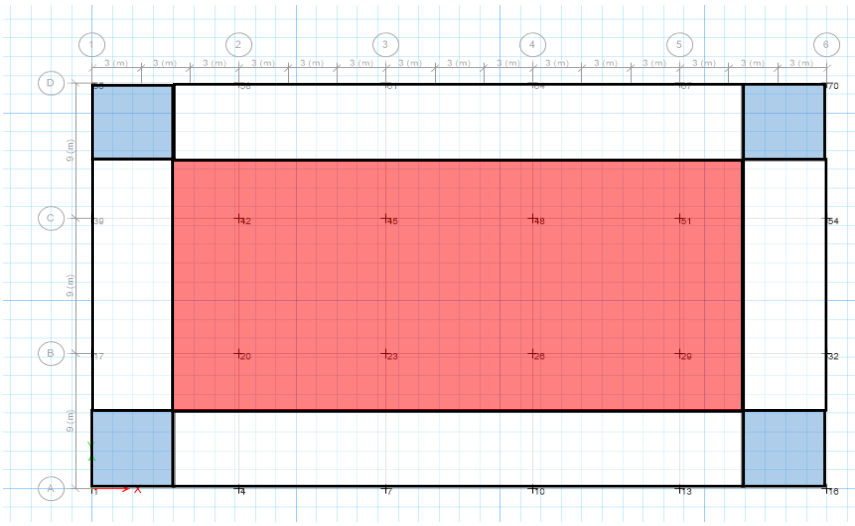
Chapter 11 FPS

11.1 基本參數

11.1.1 支承軸壓 Weight

因為 FPS 的消能機制是摩擦，其摩擦力大小與正向力成正比，並依照不同軸壓設計三種不同的 FPS，下圖的藍、白、紅不同色塊分別代表 Type1 到 Type3 不同 FPS 的分佈，其軸壓分別為 W1=87.6tf、W2=171.0tf 及 W3=341.5tf。

$$K_{eff} = \frac{W}{R} + \frac{\mu W}{D}$$



Label	tonf
1	87.5997
16	87.5997
55	87.5997
70	87.5997
17	170.9929
32	170.9929
39	170.9929
54	170.9929
4	174.4702
13	174.4702
58	174.4702
67	174.4702
7	174.7421
10	174.7421
61	174.7421
64	174.7421
20	341.4667
29	341.4667
42	341.4667
51	341.4667
23	341.6658
26	341.6658
45	341.6658
48	341.6658

11.1.2 設計位移 D_D

假設最大允許位移 D_{TD} 為 0.3m，若考慮偏心 $e = 0.05 * \max(b, d)$，則可依據下式反求所需之未偏心設計位移 D_D

$$D_D = \frac{D_{TD}}{1 + \frac{12ey}{b^2 + d^2}}$$

上式中，其質心到邊界長度 y 可依據不同方向而有所不同，故可依據方向不同而推算出不同的設計位移 $D_{D,x}$ 及 $D_{D,y}$，為保守設計取兩者較小值為設計位移

$$D_D = \min(D_{D,x}, D_{D,y}) = \min(0.2649, 0.2458) = 0.2458m$$

11.1.3 隔震後之有效週期 T_{eff}

依照規定其隔震後有效週期需限制在 11.5~3.5 秒的區間，我們選定 3.2 秒做為設計週期，並在進入模型後，確認小於 3.5 秒。

11.1.4 支承有效阻尼比 β_{eff}

取 30% (前一章節提過，這裡就不贅述了)。

11.1.5 小結

Type	W(tf)	D_D(m)	T_{eff}(s)	β_{eff}	μ
FPS1	87.5997	0.2458	3.2	0.3	0.045
FPS2	170.9929				
FPS3	341.4667				

其中關於摩擦系數 μ 的選定稍後會提到。

11.2 設計參數

11.2.1 曲率半徑 R

曲率半徑可決定如下式

$$\beta_{eff} = \frac{area\ \ of\ \ hysteresis\ \ loop}{2\pi K_{eff} D^2} = \frac{4\mu wD}{2\pi[(W/g)D + \mu w]D}$$

$$= \frac{2}{\pi} \frac{\mu}{(D/R) + \mu}$$

$$R = 4.3812m$$

11.2.2 有效勁度 K_{eff}

$$K_{eff} = \frac{W}{R} + \frac{\mu W}{D}$$

$$K_{eff} = 34.4105 \quad 67.1686 \quad 134.1333\ tf/m$$

11.2.3 等效降伏勁度 K_1 與水平勁度 K_H

利用如下經驗公式求得 K_1

$$K_H = \frac{W}{R}$$

$$K_1 = 51K_H$$

$$K_H = 18.1949 \quad 35.5162 \quad 70.9245\ tf/m$$

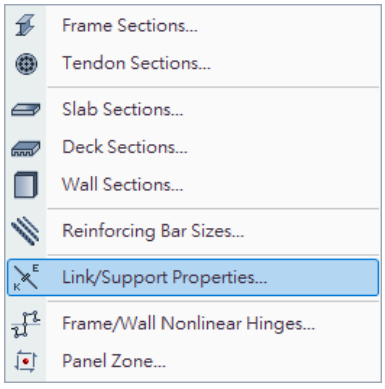
$$K_1 = 927.94 \quad 1811.32 \quad 3617.15\ tf/m$$

11.2.4 小結

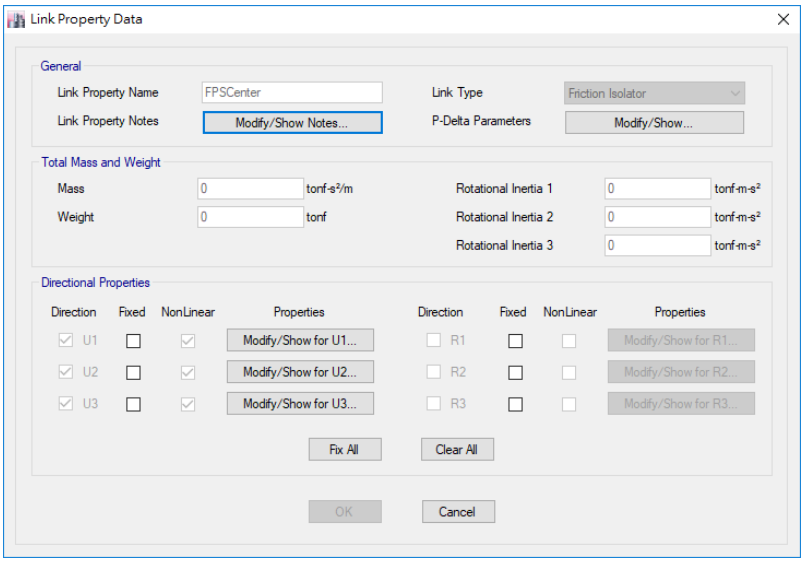
Type	T	R(m)	W(tf)	K_{eff}(tf/m)	K_H(tf/m)	K_1(tf/m)
FPS1	3.2	4.3812	87.5997	34.4105	18.1949	927.94
FPS2			170.9929	67.1686	35.5162	1811.32
FPS3			341.4667	134.1333	70.9245	3617.15

11.3 ETABS 模型建立

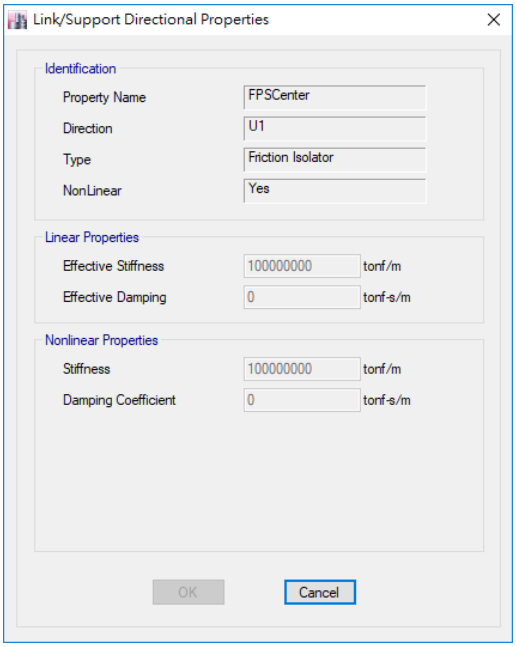
11.3.1 建立非線性 Link 元素特性



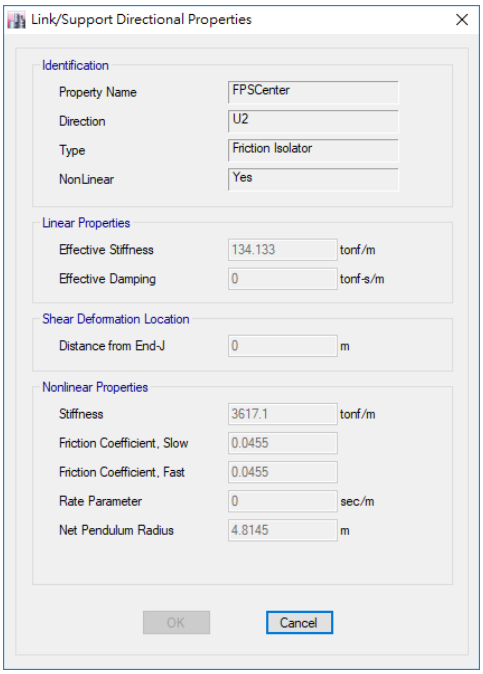
圖、新定義非線性 Link



圖、選擇 Friction Isolator 並勾選 U1~3 自由度與 Nonlinear



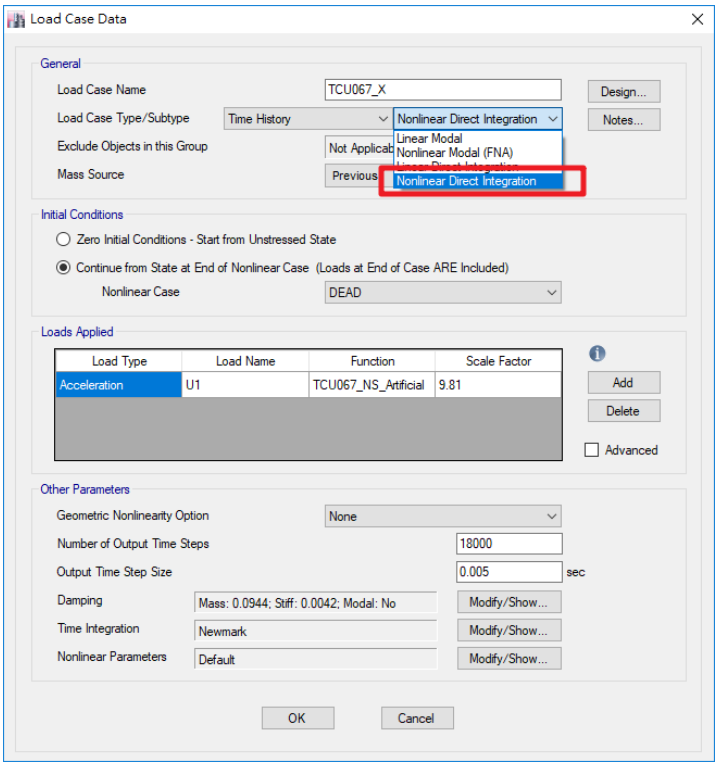
圖、在 U1 軸向性質輸入極大勁度值



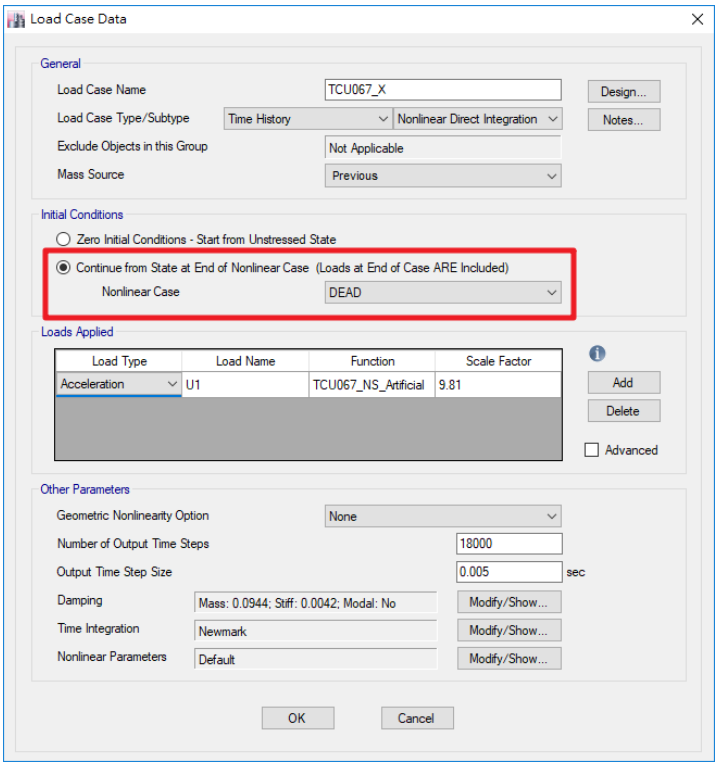
圖、定義 U2 及 U3 側向性質

11.3.2 歷時分析設定

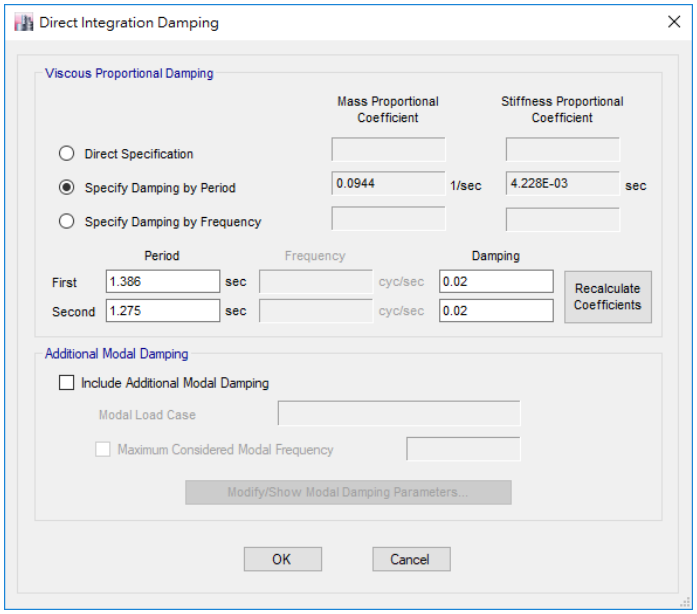
在進行歷時分析時，需特別在震波歷時分析前先行對 FPS 施加軸壓，若在無施加軸壓下進行歷時分析，則 FPS 在無軸壓正向力下無法產生回復力及摩擦力，即會得出極大的相對位移之不合理的解。



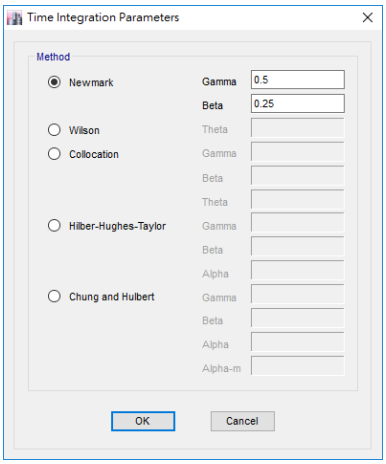
圖、選擇 Nonlinear Direct Integration



圖、選擇所有地震歷時皆須接續軸壓分析



圖、設定結構 Damping



圖、選擇 Newmark 分析方式會跑比較快

11.4 FPS 設計檢核

11.4.1 檢核自復位能力

利用公式檢核 FPS 自復位能力

$$D_D = 0.2458 > \mu R = 0.2191\, m => ok.$$

11.4.2 檢核模態週期 T

根據上述設計參數建立 FPS 隔震模型，進行模態分析，須符合規範落於 2.5 秒至 3.5 秒。

Period(sec)	1st Mode	2nd Mode
FPS	3.449	3.414

11.4.3 檢核隔震層位移

利用 TCU072、TCU078 及 TCU109 三筆震波進行非線性動力歷時分析，檢核三筆之最大隔震層位移不得超過 0.2458m 的位移限制，若超出限制則可選擇設置斜撐、調高 FPS 等效阻尼比 β_{eff} 或在隔震層增設黏滯型阻尼器(VD)。

11.4.4 檢核最大層間位移角

根據規範對於隔震建物之設計目標，隔震建物在最大考量設計地震力下(MCE)可允許些微降伏或保持彈性，在此以受震後仍保持彈性為設計目標，即限制隔震層上部結構之最大層間位移角不得超過 0.5%。

Chapter 12 HDRB & LRB 方法一

12.1 設計流程及步驟

12.1.1 計算支撐墊荷載：

Total weight (2F-RF) = 5163.75 (Ton)

12.1.2 決定設計週期，T_{eD}:

假設設計的目標週期為 2.5 秒

總設計位移需小於 30cm

12.1.3 決定設計位移 D_D:

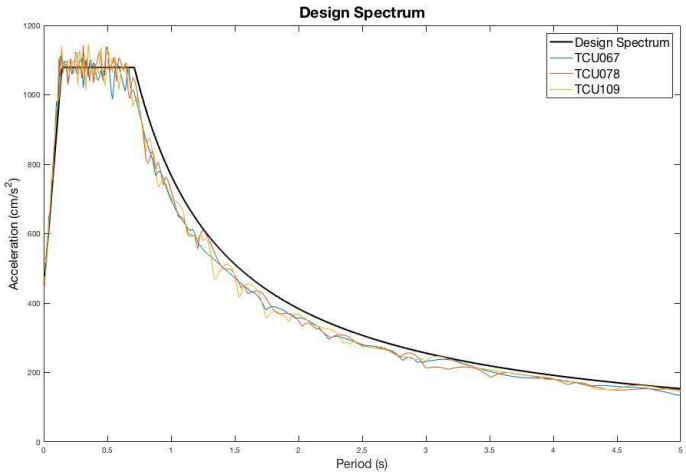
$$D_{TD} = D_D\left(1 + y\frac{12e}{b^2 + d^2}\right)$$

- D_{TD} is total displacement,
- e is horizontal eccentricity between center of mass of superstructure and center of rigidity of isolation system, plus accidental eccentricity. In this project, we get its equal to 5% of short and long direction of building.
- b and d are width and length of building, respectively.

DTD (cm)	30	0.3			
(m)	**y**	**e**	**b**	**d**	**DD**
X	13.5	1.35	27	45	0.27793
Y	22.5	2.25	27	45	**0.24578**

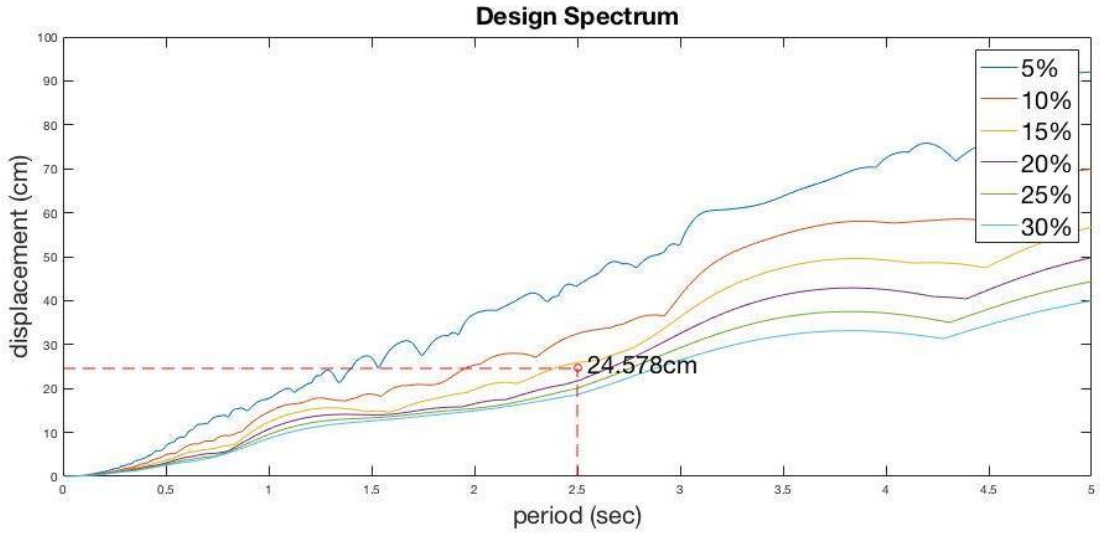
所以我們得到我們的設計位移為 24.578 cm

12.1.4 決定設計阻尼比



三筆地震設計地震擬合設計反應譜。將三筆地震轉成位移反應譜，並由我們的設計位移 24.578cm 及週期 2.5 秒，根據三筆地震，找出最大所需所需阻尼比約為 24%，所以我們保守取 30%去設計。

原因有二，一是因為反應譜是來自單自由度，加上上部結構太軟拉長了週期，因此單看反應譜會不保守。二是我們擬合的是加速度反應譜，位移反應譜的部分有待商榷。因此保守估計阻尼比為 30%



12.1.5 計算單顆支撐墊有效勁度 K_{eff}:

$$K_{eff} = \frac{4\pi^2}{T_e^2}\frac{W}{g} = \frac{4\pi^2}{2.5^2}\frac{2458.32}{9.81} = 1359044\ \mathrm{N/m}$$

*Step7~Step12 代到 matlab 解方程式

12.1.6 計算特徵強度 Q_D:

$$Q_d$$

12.1.7 計算降伏後勁度 K_d:

$$K_d = \frac{K_{eff}D_D - Q_d}{D_D}$$

12.1.8 彈性勁度 K_u:

$$K_u = \frac{K_d}{\alpha_b}$$

$$\text{其中我們假設}\alpha_b = 0.1$$

12.1.9 計算降伏強度 F_y:

$$F_y = \frac{Q_d}{1 - \alpha_b}$$

12.1.10 計算降伏位移 D_y:

$$D_y = \frac{F_y}{K_u}$$

12.1.11Matlab 解方程式:

$$4Q(D_d - D_y)/(2\pi(K_d D_d + Q)D_d) = 0.3$$

```
syms Q
k2=keff-Q/Dd;
k1=k2/alpha;
Dy=Q/(k1-k2);
Fd=Dd*keff;
Q=min(vpa(solve(4*Q*(Dd-Dy)/(2*pi*(k2*Dd+Q)*Dd)==xi,Q),7));
```

$$Q = 181333\ N/m$$

代回去公式求得各個值

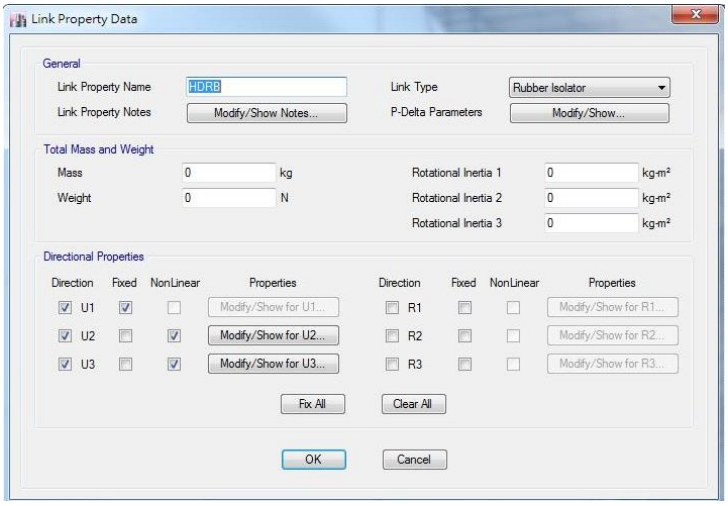
$$K_u = 6212570\ N/m$$
$$K_d = 621257\ N/m$$
$$D_y = 0.0324\ m$$
$$F_y = 201482\ N$$

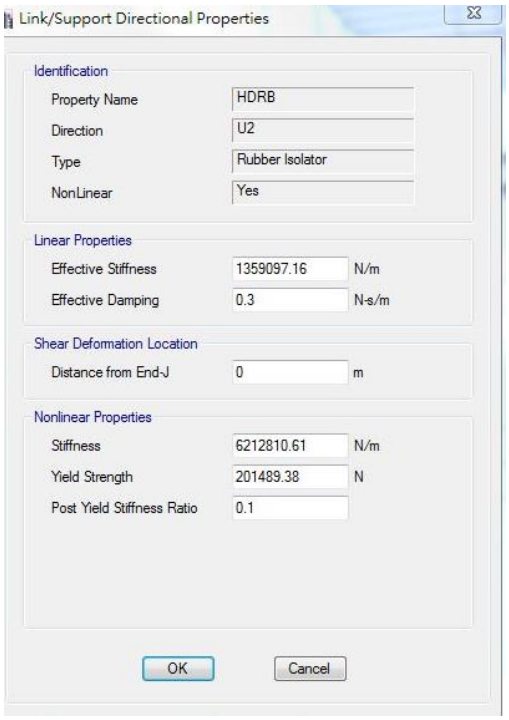
12.2 建模過程

設定 LRB/HDRB 性質

Define / Link properties / Add new properties

鎖住垂直向，並在水平兩項設定支撐墊性質





12.3 隔震層位移檢核

檢核隔震層位移是否滿足設計位移的要求

LRB&HDRB

(m)	DD	0.24578
TCU072	X	0.15938
	Y	0.14093
TCU078	X	0.17855
	Y	0.20637
TCU109	X	0.15655
	Y	0.15377

於各筆地震歷時下，隔震層位移皆小於設計位移，所以我們不需要在隔震層加阻尼器控制。此時 LRB 及 HDRB 中結構物周期長向為 2.805 秒，短向 2.76 秒。但是因為上部要是彈性。

12.4 上部結構層間位移控制

隔震結構在 475 年地震下，上部要是彈性。假設上部彈性反應位移要小於 0.005%，發先上部結構的位移反應太大因此週期要拉長。

12.5 模型調整

因為沒有達到上部結構層間的位移控制，因此有兩種做法，一是調整隔震層參數，二是上部結構加勁。因為是設計題，故不調整原本設計模型，而是採用調整隔震層參數

因此我們調整，把週期拉長。發現週期拉長，隔震層位移會變大，但上部位移會變小。

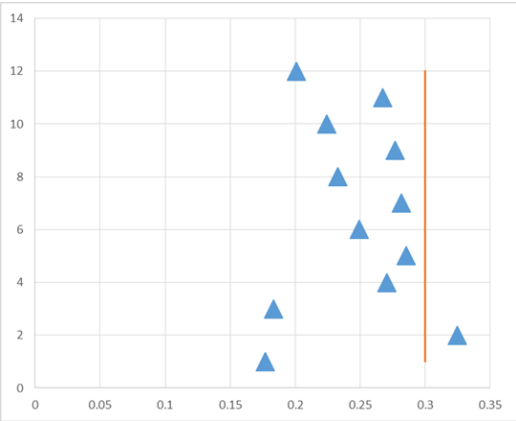
改變阻尼比變大，隔震層位移會變小，上部結構層間位移會變大。

改變α值可以同時讓位移跟隔震變小。

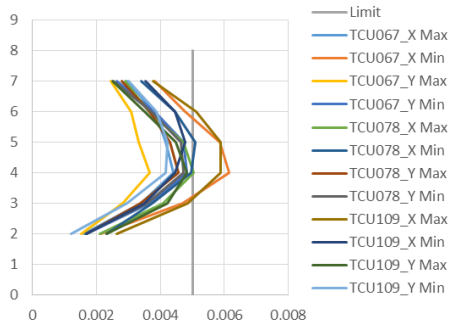
	Isolator Disp.	Superstructure Disp.	influences
T 變大	變大	變小	Max.
ξ 變大	變小	變大	Middle
α 變小	變小	變小	Min

12.6 設計結果

T=3　D_d=0.24578　阻尼比=30%　α = 0.5



只有在一筆地震下超過 D_{TD} 限制



只有兩筆地震歷超過 0.005，但也只有 0.006 而已

發現若不改變上部結構，不是隔震層位移太大就是上部結構層間位移太大，兩者是相牴觸的，所以很難調整到想要的結果，這即是嘗試後發現最有效的結果。而且若上部結構考量到樓板跟非結構物的影響，也不會有安全疑慮。因此此結果為合理可接受的

12.7 LRB 細部設計

經由前面初步鉛心橡膠支承設計可得下表，設計位移 D_D 為 0.246 公尺，週期為 2.5 秒。

Keff(N/m)	Qd(N)	Kd(N/m)	Ku(N/m)	Fy(N)
829495	118506	347331	2894430	134666

Step 1 : Determine G, E and correction factor k

Step 2 : Determine γ_{max} and calculate $T_r = \frac{D_D}{\gamma_{max}}$

Step 3 : Determine f_{py} and calculate $A_p = \frac{Q_d}{f_{py}}$

Step 4 : Determine $S \Rightarrow \frac{E(1+2kS^2)}{G} \geq 400$

Step 5 : Calculate A_{re0}, A_{re1} and A_{re2}

$\frac{P_{DL+LL}}{A_{re0}} \leq 80kg/cm^2$, $6S\frac{P_{DL+LL}}{E_c A_{re1}} \leq \frac{EB}{3}$, $A_{re2} = \frac{K_{eff}T_r}{G}$

Step 6 : Determine $A_r = \max(A_{re0}, A_{re1}, A_{re2})$

Step 7 : Calculate t_i and $N = T_r/t_i$

Rectangular : $S = \frac{LB}{2(L+B)t_i}$, Circular : $S = \frac{d}{4t_i}$

Step 8 : Calculate $t_s \geq \frac{2(t_i + t_{i+1})P_{DL+LL}}{A_{re}F_s}$

Step 9 : Calculate $h = T_r + (N-1)t_s$

Step 10 : Check shear strain, rollover and stability of lead-rubber bearings

$6S\frac{P_{DL+LL}}{E_c A_{re}} \leq \frac{EB}{3}$, $\frac{\gamma_{sc}}{\gamma_{eq}} + \frac{\gamma_{sr}}{} \leq 0.75$

$D_D \leq \frac{P_{DL+LL}L - Q_d h}{K_d h + P_{DL+LL}}$, $\frac{P_{DL+LL}}{A_r} < \frac{GSL}{2.5T_r}$

Step 11 : Check $1.25 \leq H_p/d_p \leq 5.0$

12.7.1 設計參數的定義

利用材料性質得到 E、k 以及 G。

Team	$D_{TD} \leq$ (cm)	IRHD	$\sigma_c \leq$ (kgf/cm^2)
1	25	40	150
2	30	40	150
3	25	50	150
4	30	50	150
5	25	60	150

12.7.2 橡膠總厚度

假設$\gamma_{max} = 150\%$ 、$T = 28$ ℃

$$\gamma_{max} = \frac{D}{T_r} \rightarrow T_r = \frac{D}{\gamma_{max}} = \frac{0.246}{150\%} = 0.164\ m$$

12.7.3 設計鉛心

Let $f_{py} = \frac{90\ kgf}{cm^2} = 8829000\ N/m^2$

$$A_p = \frac{Q_d}{f_{py}} = \frac{118506}{8829000} = 0.0115\ m^2$$

use $d_p = 16\ cm = 0.16\ m$

12.7.4 設計橡膠支承墊的斷面積 A 與斷面尺寸

$$\sigma_c = \frac{P_{DL} + P_{LL}}{A_{re0}} \leq \frac{150\ kgf}{cm^2} = 14715000\ N/m^2$$

$$A_{re0} \geq (2458320 + 1142250)/14715000 = 0.2447\ m^2$$

12.7.5 由橡膠支承墊在靜載重下(DL+LL)估算橡膠支承墊面積

$$\frac{E(1+2kS^2)}{G} \geq 400$$

S>=8.89 use $\boxed{S=20}$

$$E_c = E \times (1 + 2kS^2)$$

Ec=2200000*(1+2*0.73*20^2)*10^4/1000/9.81=1.287e+9 N/m^2

$$6S\frac{P_{DL+LL}}{E_c A_{re1}} \leq \frac{EB}{3}$$

$$Are1 >= 6 \times 20 \times (2458320 + 1142250)/1.287e9\ m^2 = 0.2014\ m^2$$

A_{r2}：

$$A_{r2} = \frac{K_{eff} \times T_r}{G} = 0.2124\ m^2$$

$$A_{re} = \mathrm{Max}(A_{re0}, A_{re1}, A_{re2})$$

Are=Are0=0.2447 $m^2 = 0.25\ m^2$

12.7.6 使用圓形支承墊，設計尺寸

$$A_{re} = \frac{d^2}{4}(\beta - sin\beta)$$

$$\beta = 2cos^{-1}\left(\frac{\Delta_s}{d}\right) = 2.0660$$

選擇圓形斷面 Areo=0.25m^2, Δ_s=0.24578m

>> d=0.97 m, Ar=0.739 m^2

選擇斷面尺寸 ： 直徑 0.97 m , Ar=0.739m^2, Are=0.279m^2

12.7.7 橡膠層數以及厚度計算：

$$S = \frac{d}{4t_i} \rightarrow 20 = \frac{0.97}{4t_i} \rightarrow t_i = 0.0121\ m$$

$$T_r = N \times t_i \rightarrow 0.1639 = N \times 0.0121 \rightarrow N = 13.514 \rightarrow \text{取 } N = 14\text{層}$$

$$T_r = N \times t_i = 14 \times 0.0121 = 0.1698m$$

12.7.8 鋼板厚度計算：

$$t_s \geq \frac{2 \times (t_i + t_{i+1}) \times P_{DL+LL}}{A_{re} \times F_s}$$

其中 $F_s = 0.6 \times F_y = 0.6 \times 28000 = 16800\ tf/m^2 = 164808000\ N/m^2$

Ts>= 2*(0.0121+0.0121)*(2458320+1142250)/(0.279*164808000)=0.0038m

=3.8 mm

選擇 $t_s = 4.00\ mm$

12.7.9 總高度計算：

假設上層下層鋼板厚度皆為 2.5 公分，則得到橡膠支承墊總高度：

$$h = T_r + 13 \times t_s + 2 \times 0.025 = 0.2717m = 27.17\ cm$$

12.7.10 穩定性以及檢應變檢核：

(1)垂直承載力所造成的剪應變檢核：

$$\gamma_c = 6S\frac{P_{DL+LL}}{E_c A_{re1}} \leq \frac{EB}{3}$$

6*20*(2458320+1142250) /(1.287e9*0.279)=1.2033<5/3=1.667 (OK)

(2)考慮地震力與不同載重組合的效應

$$\gamma_{sc} + \gamma_{eq} + \gamma_{sr} \leq 0.75EB$$

$$6S\frac{P_{DL+LL}}{E_c A_{re1}} + \frac{D_{TM}}{Nt_i} + \frac{B^2.\theta}{2.t_i T_r} \leq 0.75EB$$

1.2033+(0.24578/0.1698)+0=2.6512<3.75 (OK)

(3)防止支承傾覆：

$$\delta_{roll-out} = 0.5\frac{P_{DL+SLL+EQ}.d - Q_d C_{qv} C_{qs} h}{P_{DL+SLL+EQ} + K_d C_{kv} C_{ks}.h} > D_{TM} = 1.5D$$

0.5*(2458320*0.97-1142250*0.2717)/ (2458320+829490*0.2717)

=0.3522>=0.24578 (OK)

(4)穩定度要求：

$$\sigma_c = \frac{P}{A} \leq \sigma_{cr} = \frac{GSL}{\gamma_{max} T_r} = \frac{GSL}{\gamma_{max} N t_i}$$

36005750/0.739=4872344<670000*20*0.97/2.5/0.1698=29257143 (OK)

(5)鉛心尺寸：

$$1.25 \leq \frac{H_p}{d_p} = \frac{0.2458}{0.16} = 1.5361\ (OK)$$

12.7.11 LRB design details:

Design Results	
LRB type	LRB1
Required of diameter – d of circular section	0.97 m
Total high of LRB	27 cm
The number of rubber	14
Thickness of rubber layer	1.21cm
The number of steel	13
Thickness of steel layer	4mm
Thickness of top and bottom steel plate	2.5cm

12.8 HDRB 細部設計

經由前面初步鉛心橡膠支承設計可得下表，設計位移 D_D 為 0.246 公尺，週期為 2.5 秒。

Keff(N/m)	Qd(N)	Kd(N/m)	Ku(N/m)	Fy(N)
829495	118506	347331	2894430	134666

12.8.1 設計參數的定義

利用材料性質得到 E、k 以及 G。

Team	$D_{TD} \leq$ (cm)	IRHD	$\sigma_c \leq$ (kgf/cm^2)
1	25	40	150
2	30	40	150
3	25	50	150
4	30	50	150
5	25	60	150

12.8.2 橡膠總厚度

假設$\gamma_{max} = 150\%$、$T = 28\,℃$

$$\gamma_{max} = \frac{D}{T_r} \rightarrow T_r = \frac{D}{\gamma_{max}} = \frac{0.246}{150\%} = 0.164\,m$$

12.8.3 設計橡膠支承墊的斷面積 A 與斷面尺寸

$$\sigma_c = \frac{P_{DL} + P_{LL}}{A_{re0}} \leq \frac{80\,kgf}{cm^2} = 7848000\,N/m^2$$

$$A_{re0} \geq (2458320 + 1142250)/14715000 = 0.4588\,m^2$$

12.8.4 由橡膠支承墊在靜載重下(DL+LL)估算橡膠支承墊面積

$$\frac{E(1+2kS^2)}{G} \geq 400$$

S>=8.89 use $\boxed{S=20}$

$$E_c = E \times (1 + 2kS^2)$$

Ec=2200000*(1+2*0.73*20^2)*10^4/1000/9.81=1.287e+9 N/m^2

$$6S\frac{P_{DL+LL}}{E_c A_{re1}} \leq \frac{EB}{3}$$

$$\text{Are1} >= 6 \times 20 \times (2458320 + 1142250)/1.287\text{e}9\ \text{m}^2 = 0.2014\ m^2$$

A_{r2}：

$$\text{A}_{\text{r2}} = \frac{K_{eff} \times T_r}{G} = 0.2124\ \text{m}^2$$

$$\text{A}_{\text{re}} = \text{Max}(A_{re0}, A_{re1}, A_{re2})$$

$$\text{Are=Are0=0.4588}\ \ \text{m}^2 = 0.46\ \text{m}^2$$

12.8.5 使用圓形支承墊，設計尺寸

$$\text{A}_{\text{re}} = \frac{d^2}{4}(\beta - sin\beta)$$

$$\beta = 2cos^{-1}\left(\frac{\Delta_s}{d}\right) = 2.0660$$

選擇圓形斷面 Areo=0.279m^2, Δ_s=0.24578m

>> d=0.97 m, Ar=0.739 m^2

選擇斷面尺寸 ： 直徑 0.97 m , Ar=0.739m^2, Are=0.279m^2

12.8.6 橡膠層數以及厚度計算：

$$\text{S} = \frac{\text{d}}{4t_i} \rightarrow 20 = \frac{0.97}{4t_i} \rightarrow t_i = 0.0121\ m$$

$$T_r = N \times t_i \rightarrow 0.1639 = N \times 0.0121 \rightarrow \text{N} = 13.514 \rightarrow \text{取 N} = 14\text{層}$$

$$T_r = N \times t_i = 14 \times 0.0121 = 0.1698m$$

12.8.7 鋼板厚度計算：

$$t_s \geq \frac{2 \times (t_i + t_{i+1}) \times P_{DL+LL}}{A_{re} \times F_s}$$

其中 $\text{F}_\text{s} = 0.6 \times \text{F}_\text{y} = 0.6 \times 28000 = 16800\ tf/m^2 = 164808000\ N/m^2$

Ts>= 2*(0.0121+0.0121)*(2458320+1142250)/(0.279*164808000)=0.0038m

=3.8 mm

選擇 $\text{t}_\text{s} = 4.00\ mm$

12.8.8 總高度計算：

假設上層下層鋼板厚度皆為 2.5 公分，則得到橡膠支承墊總高度：

$$\text{h} = \text{T}_\text{r} + 13 \times t_s + 2 \times 0.025 = 0.2717m = 27.17\ cm$$

12.8.9 穩定性以及檢應變檢核：

(1)垂直承載力所造成的剪應變檢核：

$$\gamma_c = 6S\frac{P_{DL+LL}}{E_c A_{re1}} \leq \frac{EB}{3}$$

6*20*(2458320+1142250) /(1.287e9*0.279)=1.2033<5/3=1.667 (OK)

(2)考慮地震力與不同載重組合的效應

$$\gamma_{sc} + \gamma_{eq} + \gamma_{sr} \leq 0.75EB$$

$$6S\frac{P_{DL+LL}}{E_c A_{re1}} + \frac{D_{TM}}{Nt_i} + \frac{B^2.\theta}{2.t_i T_r} \leq 0.75EB$$

1.2033+(0.24578/0.1698)+0=2.6512<3.75 (OK)

(3)防止支承傾覆：

$$\delta_{roll-out} = 0.5\frac{P_{DL+SLL+EQ}.d - Q_d C_{qv} C_{qs} h}{P_{DL+SLL+EQ} + K_d C_{kv} C_{ks}.h} > D_{TM} = 1.5D$$

0.5*(2458320*0.97-1142250*0.2717)/ (2458320+829490*0.2717)

=0.3522>=0.24578 (OK)

(4)穩定度要求：

$$\sigma_c = \frac{P}{A} \leq \sigma_{cr} = \frac{GSL}{\gamma_{max} T_r} = \frac{GSL}{\gamma_{max} N t_i}$$

36005750/0.739=4872344<670000*20*0.97/2.5/0.1698=29257143 (OK)

12.8.10 HDRB design details:

Design Results	
HDRB type	HDRB1
Required of diameter – d of circular section	0.97 m
Total high of HDRB	27 cm
The number of rubber	14
Thickness of rubber layer	1.21cm
The number of steel	13
Thickness of steel layer	4mm
Thickness of top and bottom steel plate	2.5cm

*跟 LRB 結果雷同。

Chapter 13 HDRB & LRB 方法二

13.1 設計過程

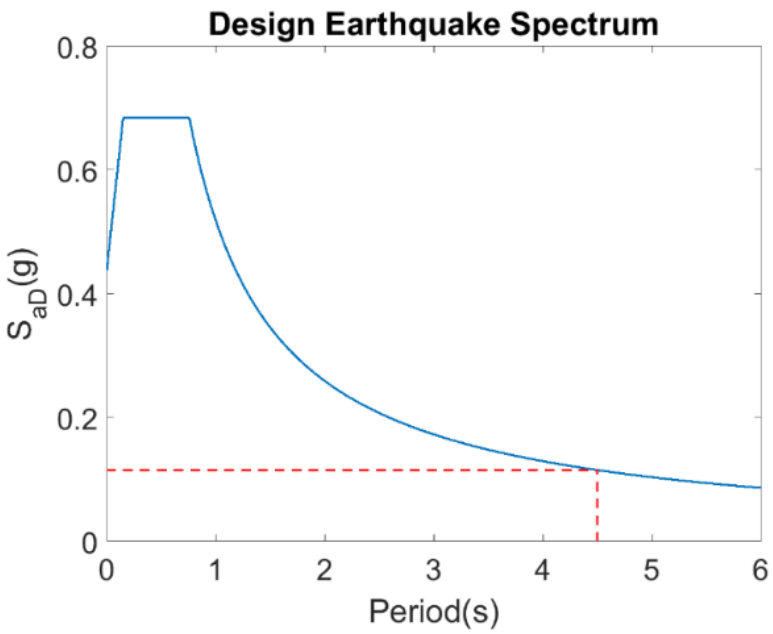
13.1.1 決定 W、T、ξ、α

經過實驗，將重量分為三種設計三種隔震器及利用平均重量設計一種隔震器的結果會一樣，所以我們採用平均重量設計

因為總共有24個隔震器，所以W = 5163.75/24 = 215.156 (tf)

設定α = 0.1，調整T及ξ以改變得到的數據

13.1.2 由設計反應譜中，決定週期推得 S_{aD}



13.1.3 D_D、K_{eff}

由下列公式求得 D_D、K_{eff}

$$D_D = \frac{g}{4\pi^2 B} S_{aD} T_{eD}^2$$

$$K_{eff} = \frac{4\pi^2}{T_{eD}^2} \times \frac{W}{9.81}$$

13.1.4 Q

由下列公式解 Q

$$K_2 = K_{eff} - \frac{Q}{D_D}$$

$$K_1 = \frac{K_2}{\alpha}$$

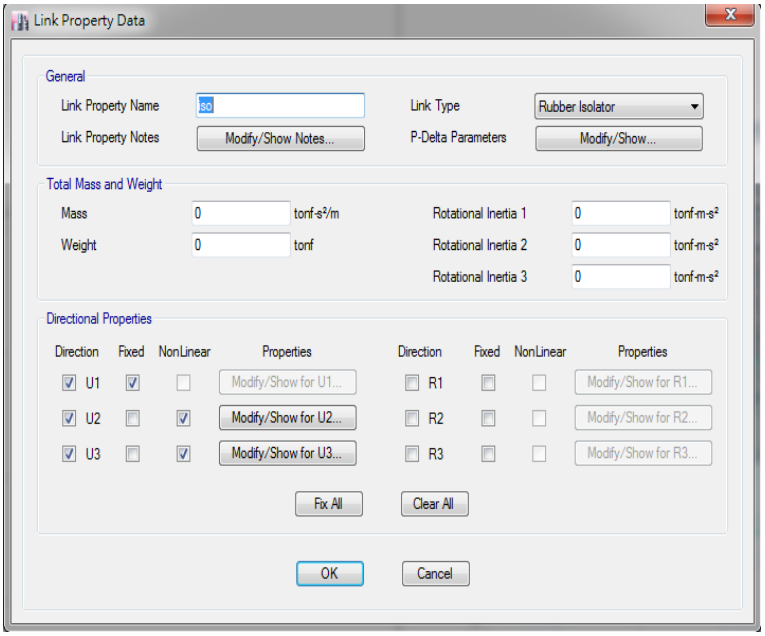
$$D_y = \frac{Q}{\mathrm{K}_1 - \mathrm{K}_2}$$

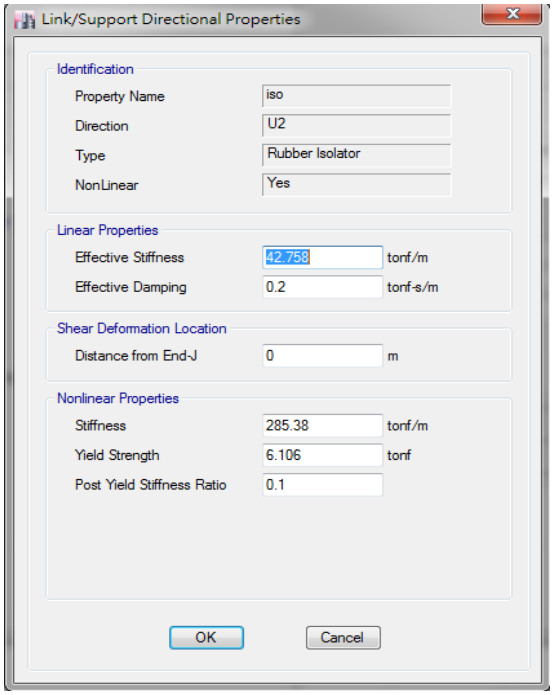
$$\xi = \frac{4Q(D_D - D_y)}{2\pi K_{eff} {D_D}^2}$$

13.1.5 K_1、F_y

將求得的 Q 值再帶入上列的公式，求得 K_1、F_y

13.1.6 將 K_{eff}、ξ、K_1、F_y、α輸入 ETABS 之隔震器參數





13.1.7 調整 T、ξ進行試誤，使上部結構保持彈性，層間位移小於 0.005

得到數據結果為

T = 4.5 (s)

K_{eff} = 42.7582 (tf/m)、ξ = 0.2

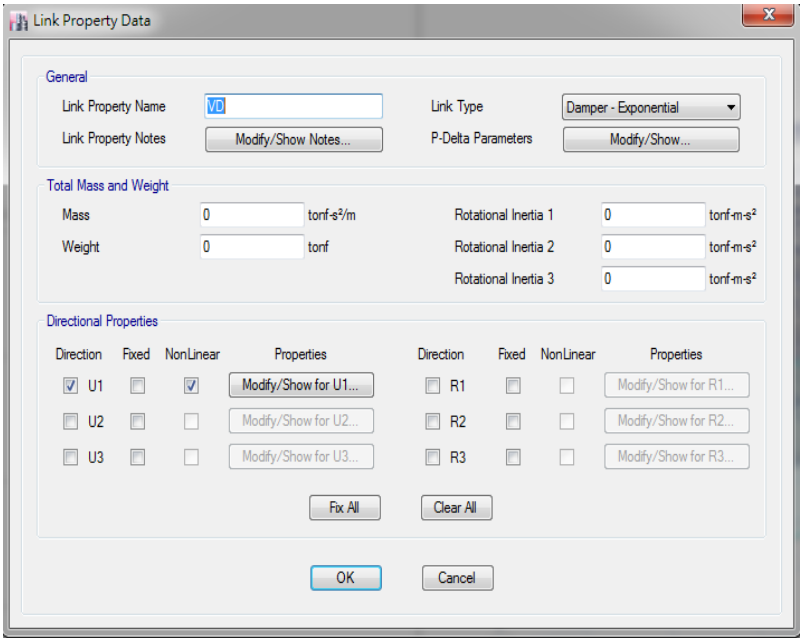
K_1 = 285.3802 (tf/m)

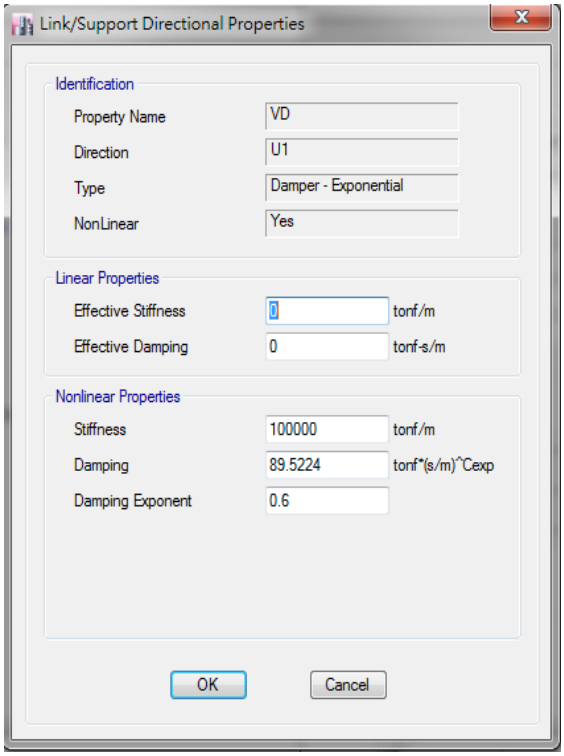
F_y = 6.106 (tf)、α = 0.1

13.1.8 為使隔震層之 D_D 符合規定小於 0.2458m，在不影響結構週期的情況下，在隔震層加入 VD damper

Cd = 89.5224 (t-s/m)

ξ = 50%





Chapter 14 隔震設計比較

14.1 線性分析數據比較

FPS

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	FPS	%	Bare frame	FPS	%	Bare frame	FPS	%
067	0.27	0.1011	37.43	1.6367	0.849	51.87	9.502	3.6647	38.57
078	0.2662	0.0884	33.20	1.3923	0.808	58.03	10.647	3.5628	33.46
109	0.3214	0.0908	28.26	1.6144	0.773	47.88	7.973	3.02	37.88
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	FPS	%	Bare frame	FPS	%	Bare frame	FPS	%
067	0.2518	0.0796	31.63	1.7387	0.722	41.53	8.161	3.3899	41.54
078	0.2412	0.0973	40.35	1.6896	0.855	50.60	10.426	3.7863	36.32
109	0.2907	0.0804	27.64	1.6535	0.792	47.90	8.818	3.3275	37.74

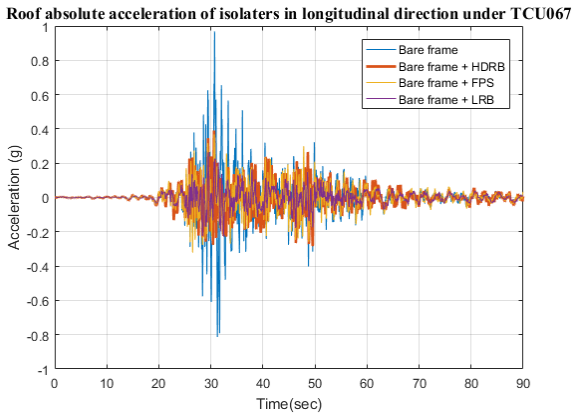
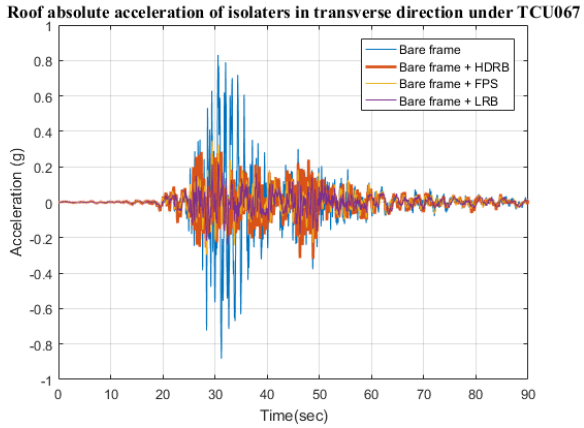
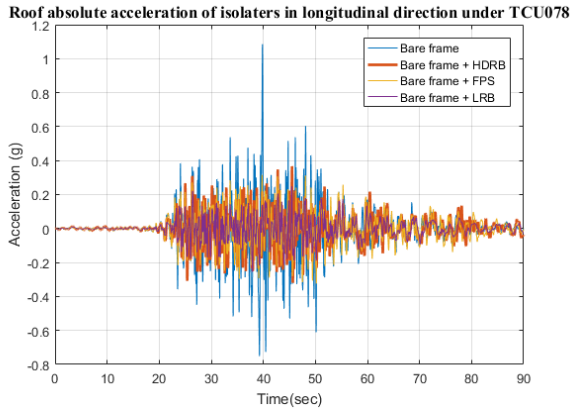
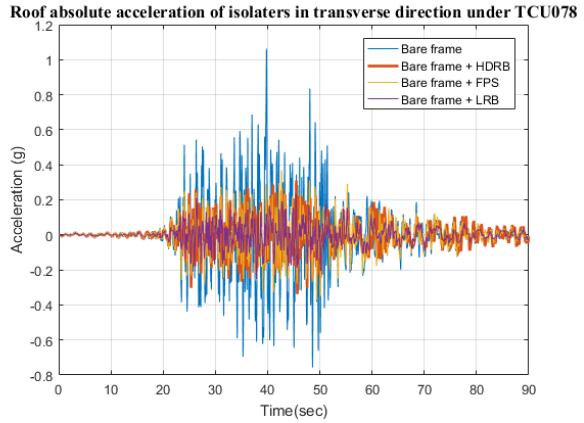
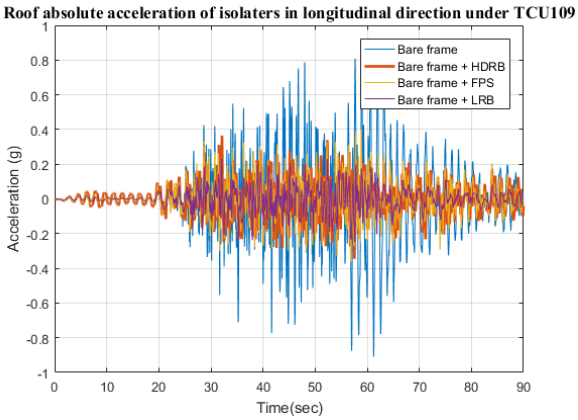
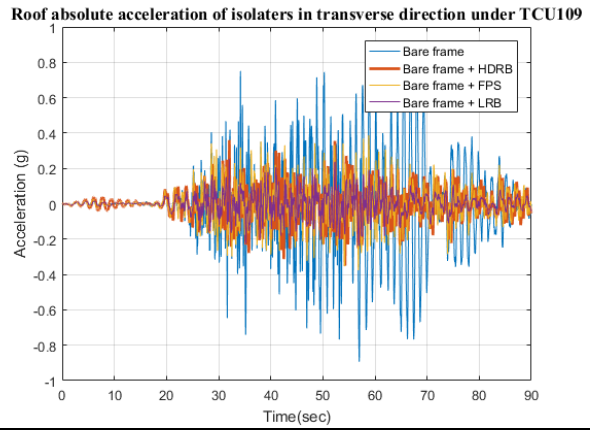
LRB

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	LRB	%	Bare frame	LRB	%	Bare frame	LRB	%
067	0.27	0.2492	92.30	1.6367	0.7899	48.26	9.502	2.589	27.25
078	0.2662	0.2285	85.84	1.3923	0.7459	53.57	10.647	2.437	22.89
109	0.3214	0.1769	55.04	1.6144	0.8901	55.14	7.973	2.266	28.42
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	LRB	%	Bare frame	LRB	%	Bare frame	LRB	%
067	0.2518	0.2341	92.97	1.7387	0.7506	43.17	8.161	2.227	27.29
078	0.2412	0.2131	88.35	1.6896	0.7471	44.22	10.426	2.301	22.07
109	0.2907	0.1721	59.20	1.6535	0.8381	50.69	8.818	2.476	28.08

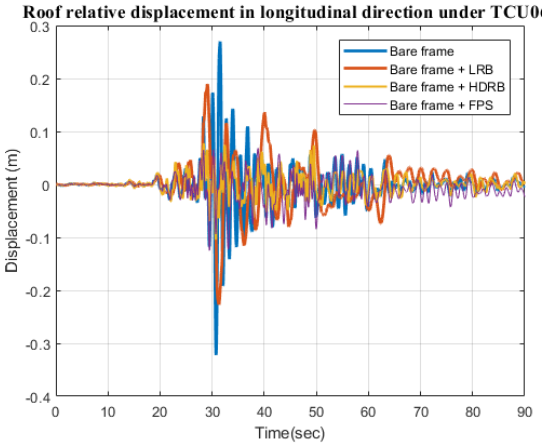
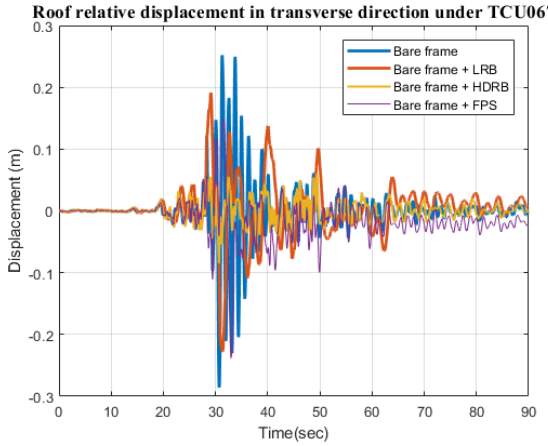
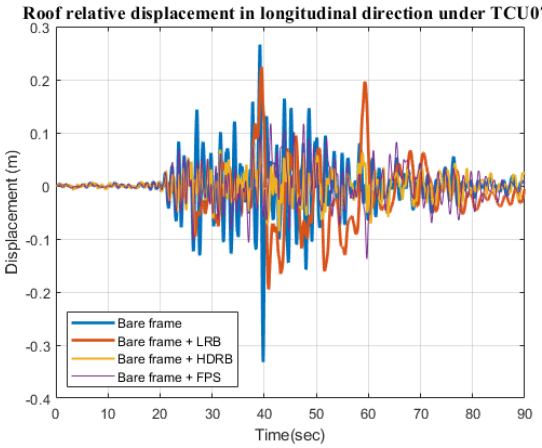
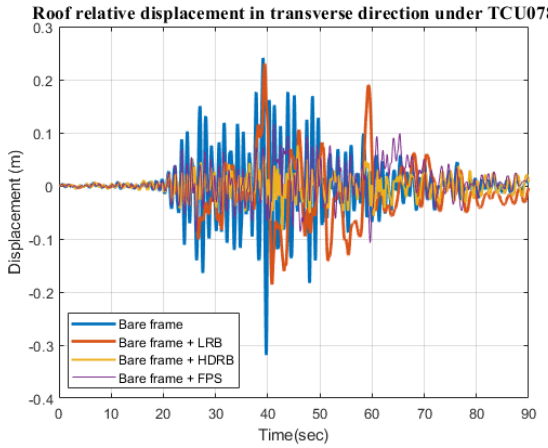
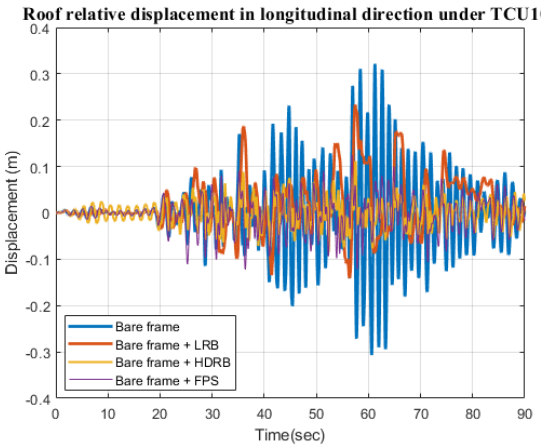
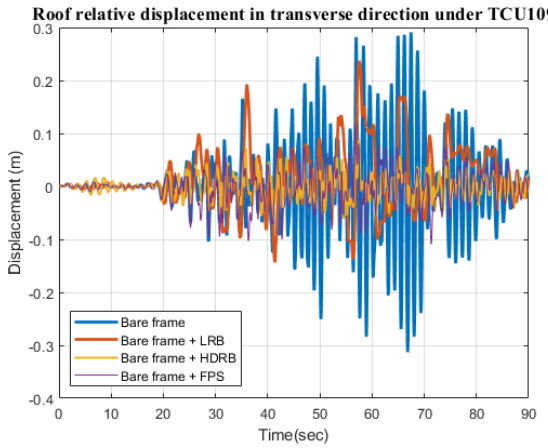
HDRB

EQ X	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	HDRB	%	Bare frame	FPS	%	Bare frame	HDRB	%
067	0.27	0.2288	84.74	1.6367	0.8457	51.67	9.502	6.735	70.88
078	0.2662	0.2872	107.89	1.3923	0.8332	59.84	10.647	6.406	60.17
109	0.3214	0.2262	70.38	1.6144	0.9112	56.44	7.973	5.952	74.65
EQ Y	Relative Displacement		Ratio	Relative Velocity		Ratio	Absolute Acceleration		Ratio
	Bare frame	FPS	%	Bare frame	FPS	%	Bare frame	HDRB	%
067	0.2518	0.262	104.05	1.7387	0.8272	47.58	8.161	6.772	82.98
078	0.2412	0.2946	122.14	1.6896	0.8155	48.27	10.426	5.788	55.52
109	0.2907	0.1996	68.66	1.6535	0.9102	55.05	8.818	5.629	63.84

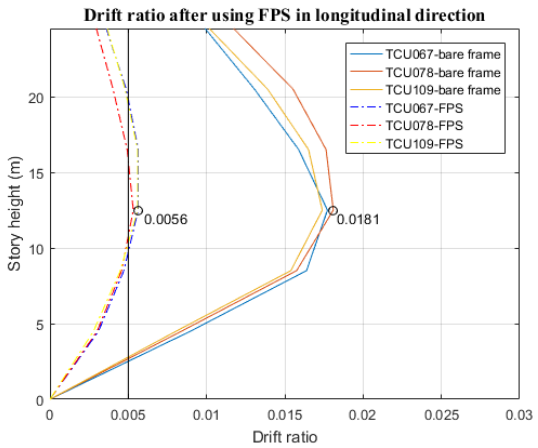
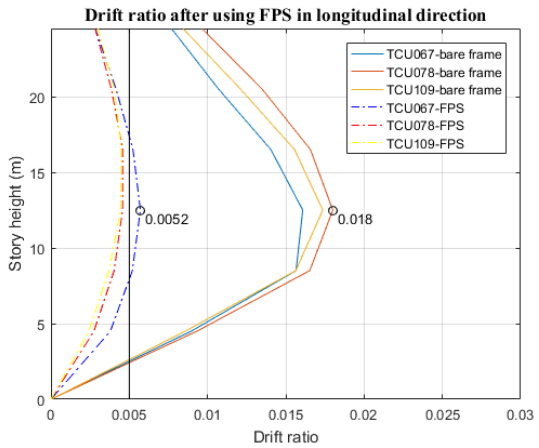
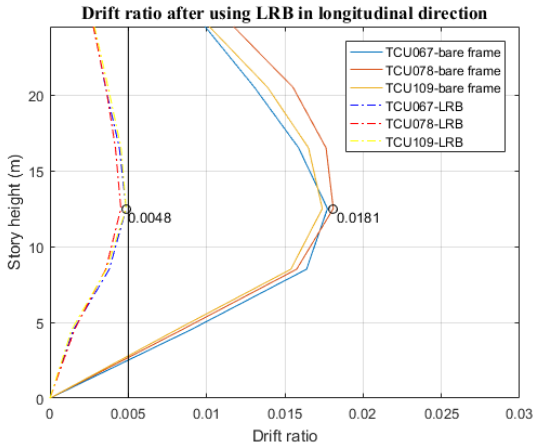
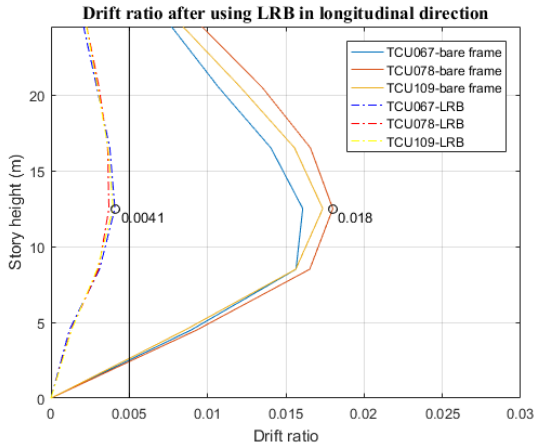
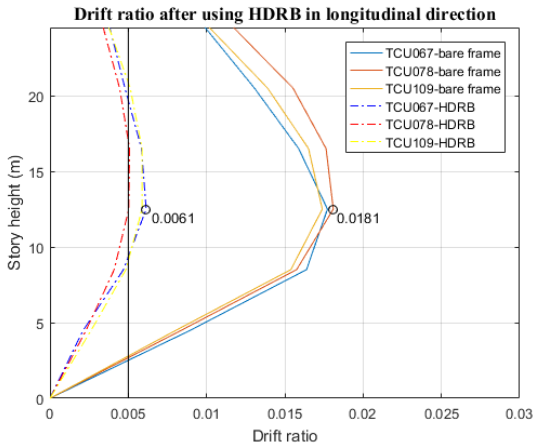
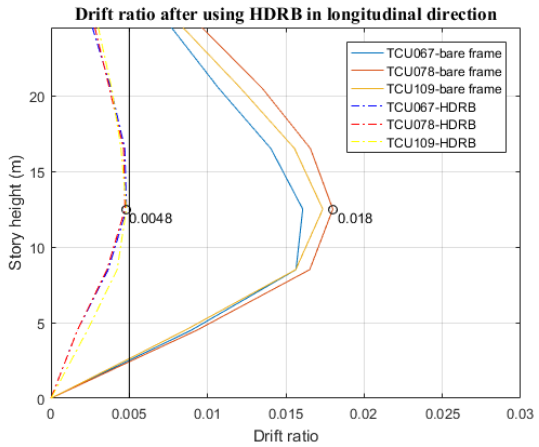
14.2 線性分析加速度反應比較

	X 向	Y 向
TCU067		
TCU078		
TCU109		

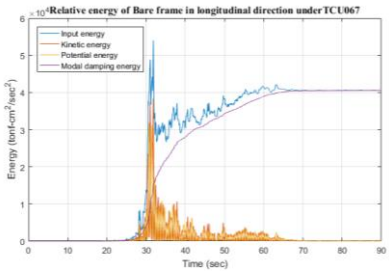
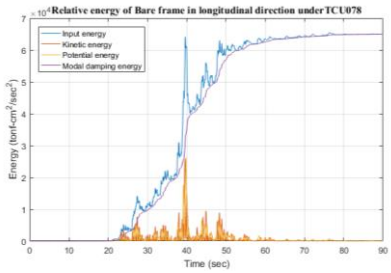
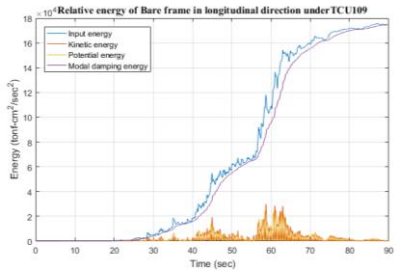
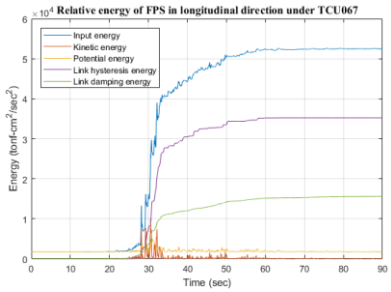
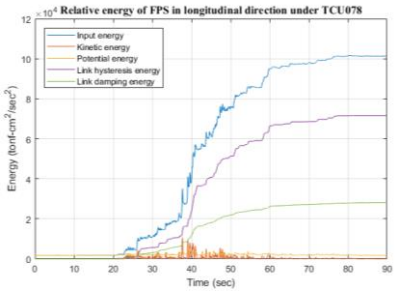
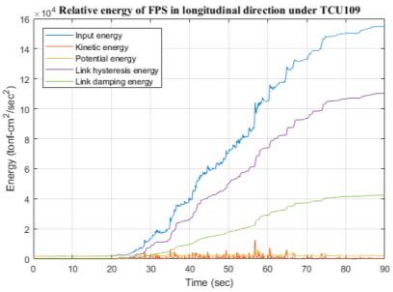
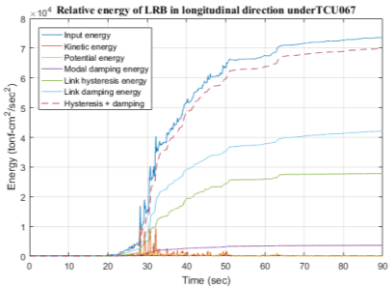
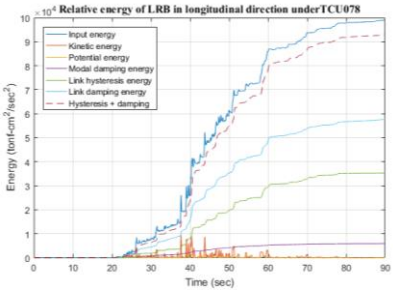
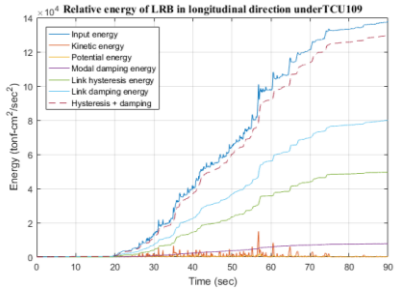
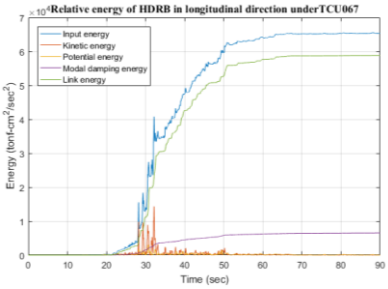
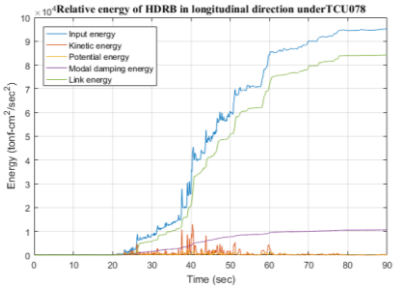
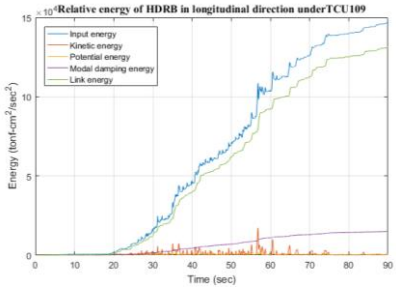
14.3 線性分析位移反應比較

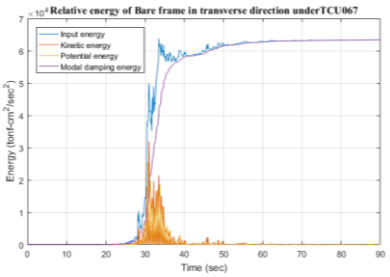
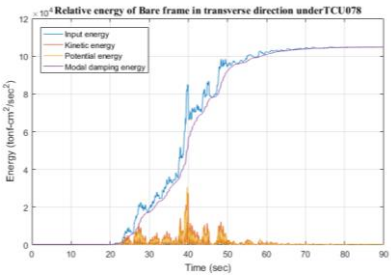
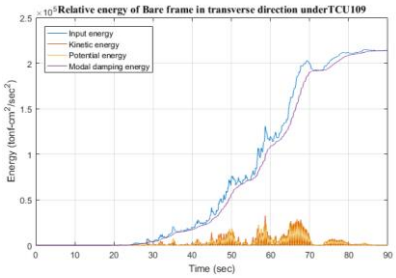
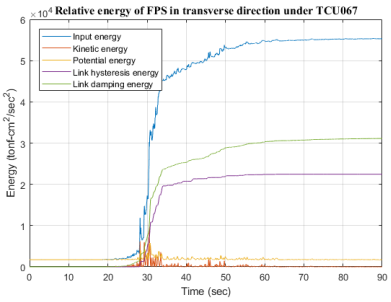
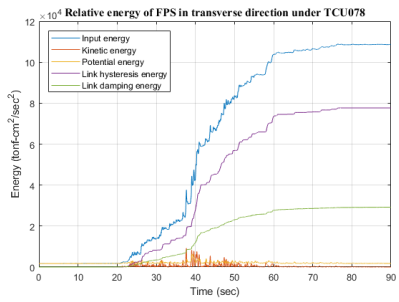
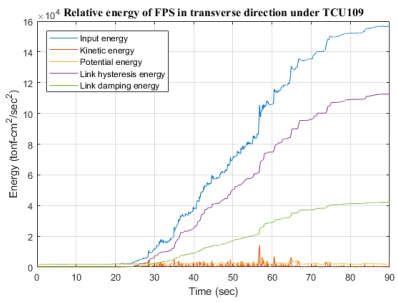
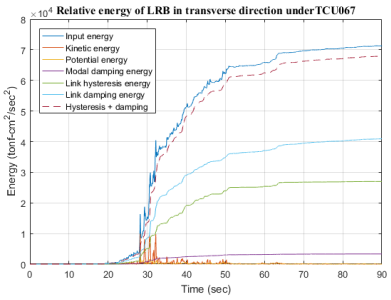
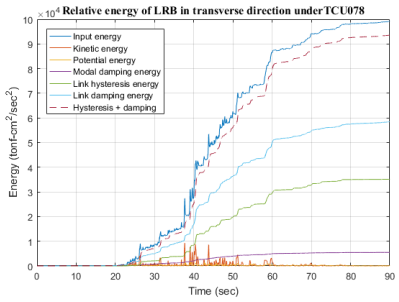
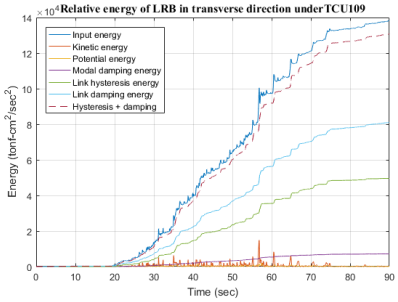
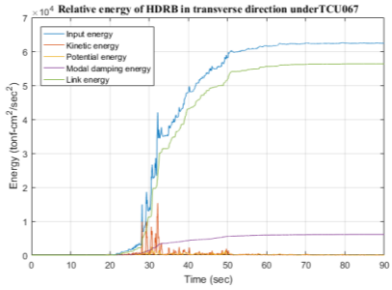
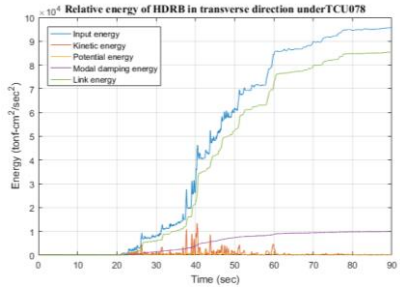
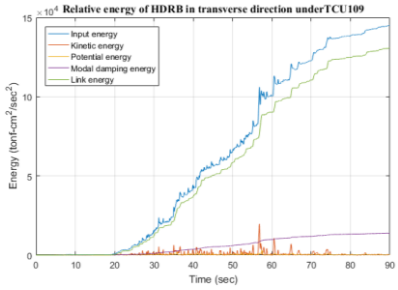
	X 向	Y 向
TCU067		
TCU078		
TCU109		

14.4 線性分析層間位移比較

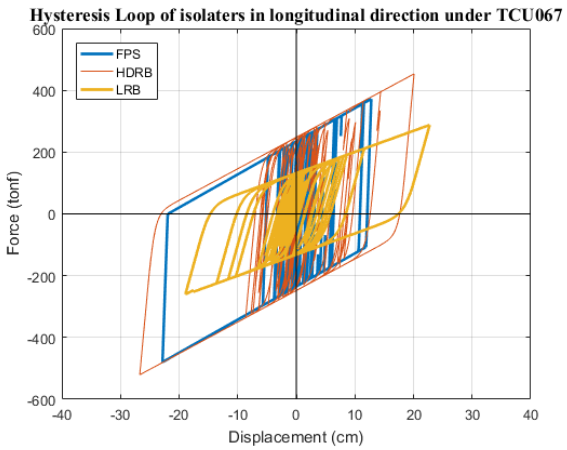
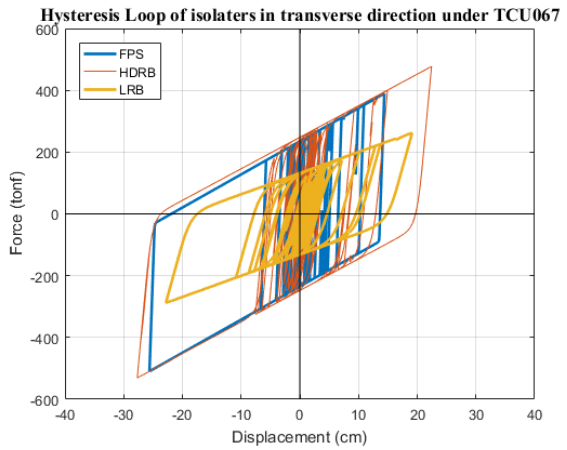
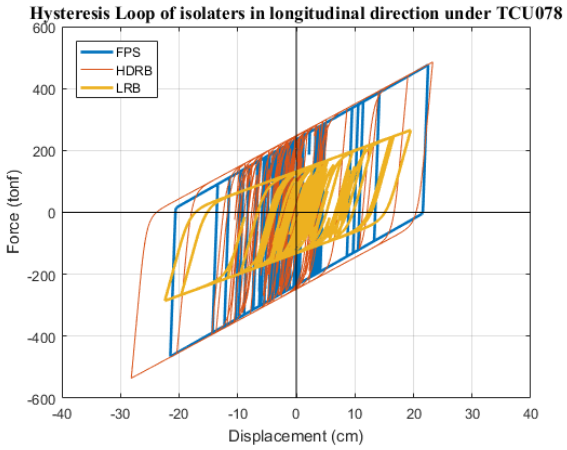
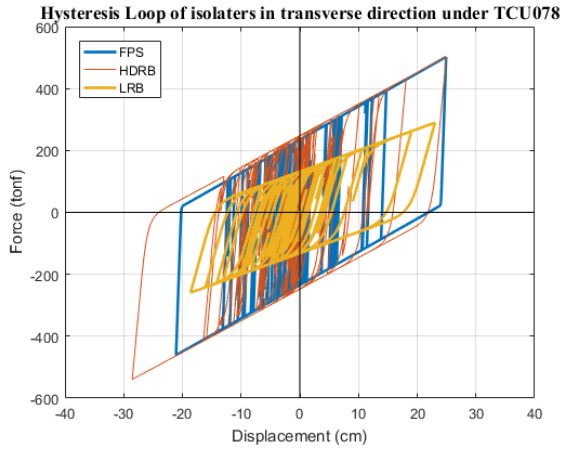
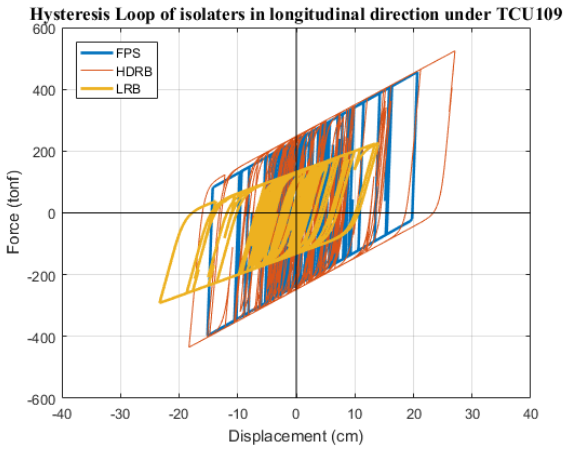
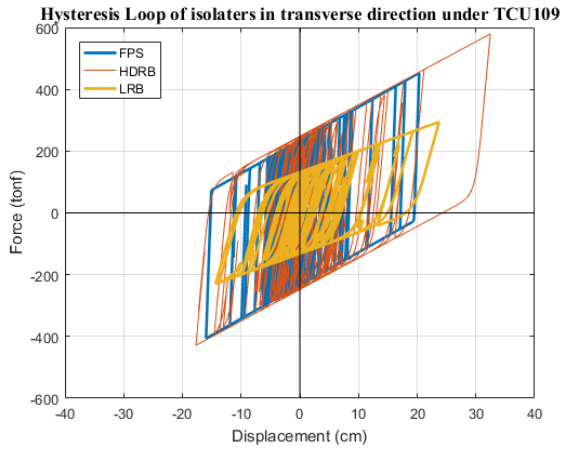
	X 向	Y 向
FPS		
LRB		
HDRB		

14.5 線性分析能量比較

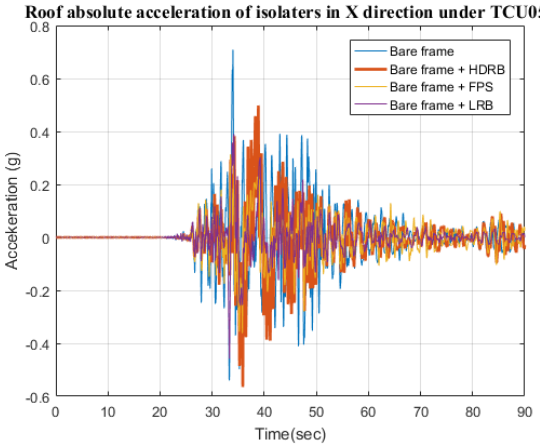
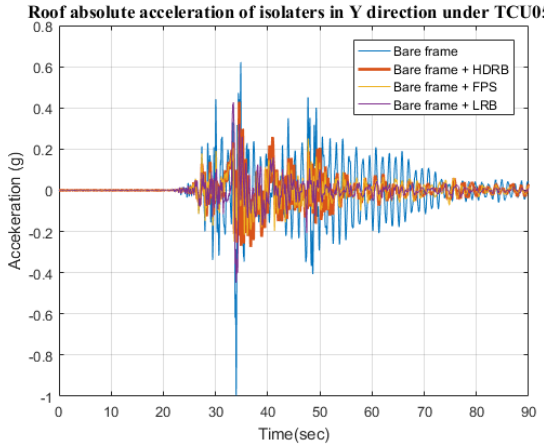
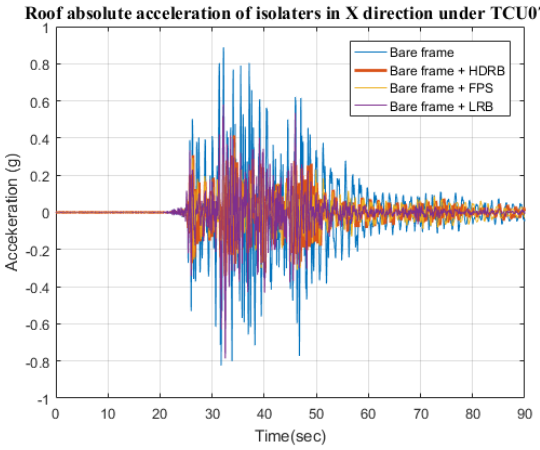
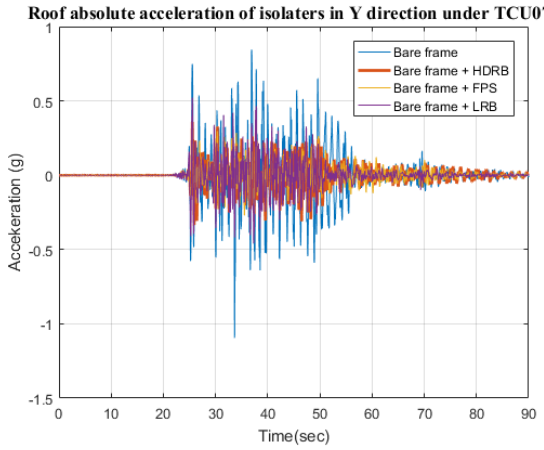
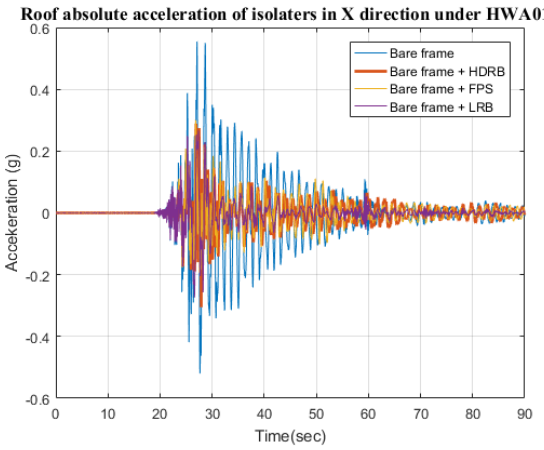
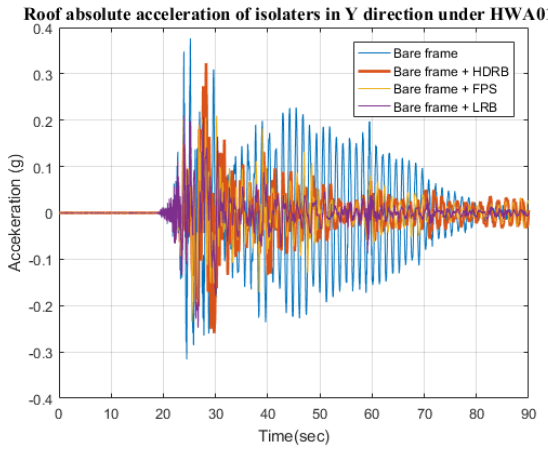
X 向	TCU067	TCU078	TCU109
Bare frame			
FPS			
LRB			
HDRB			

Y 向	TCU067	TCU078	TCU109
Bare frame			
FPS			
LRB			
HDRB			

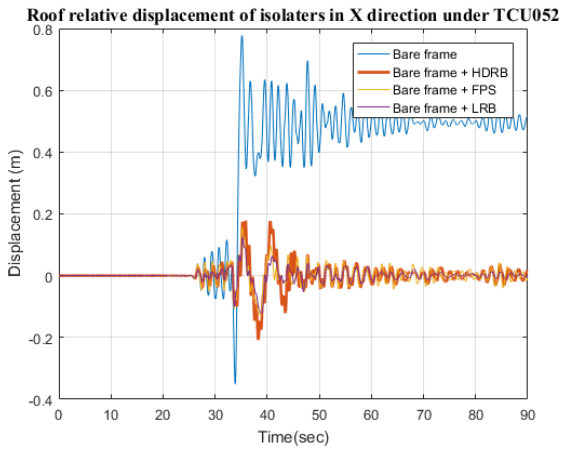
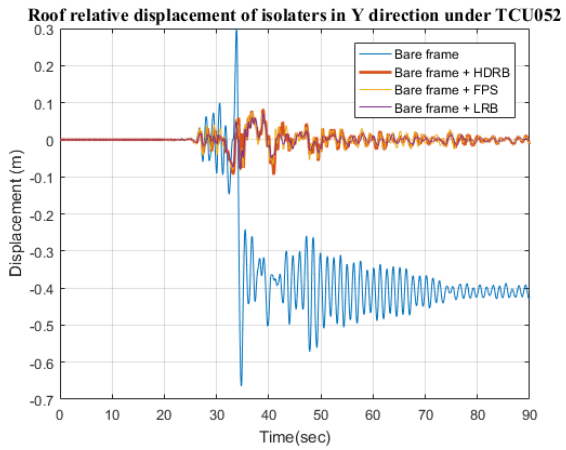
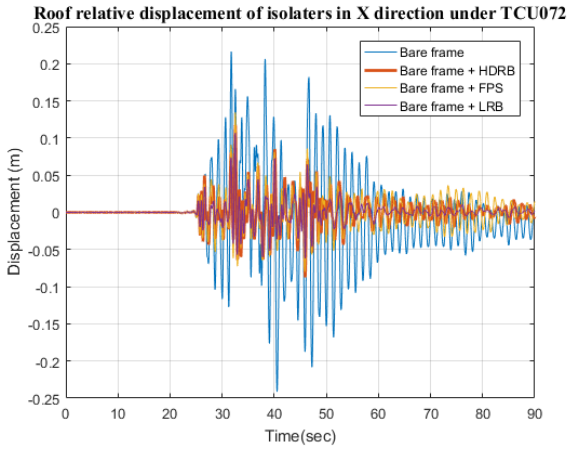
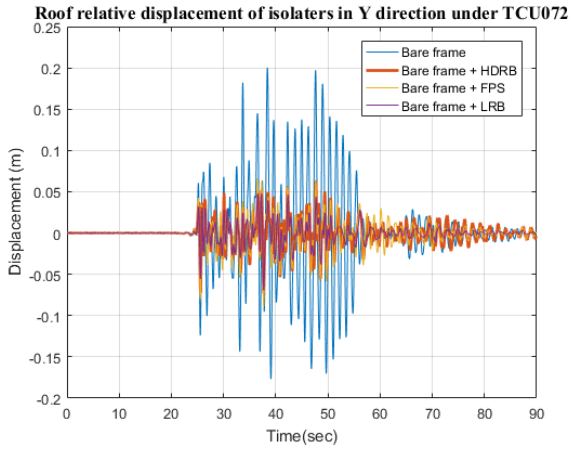
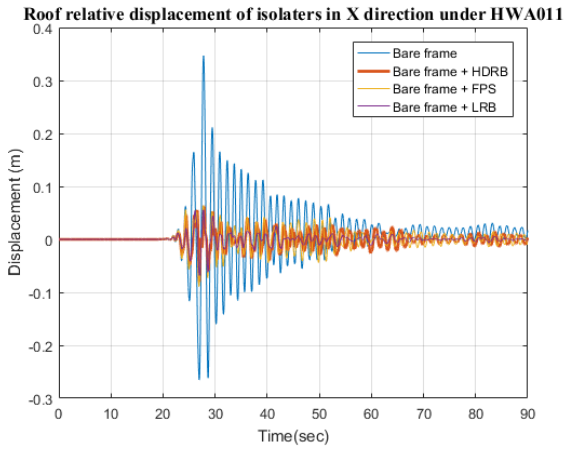
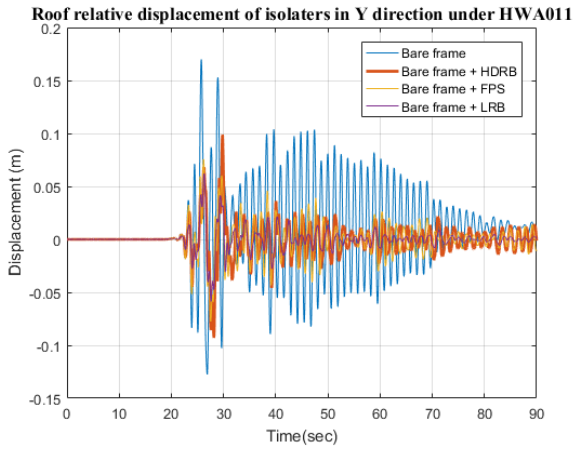
14.6 線性分析遲滯迴圈比較

	X 向	Y 向
TCU067		
TCU078		
TCU109		

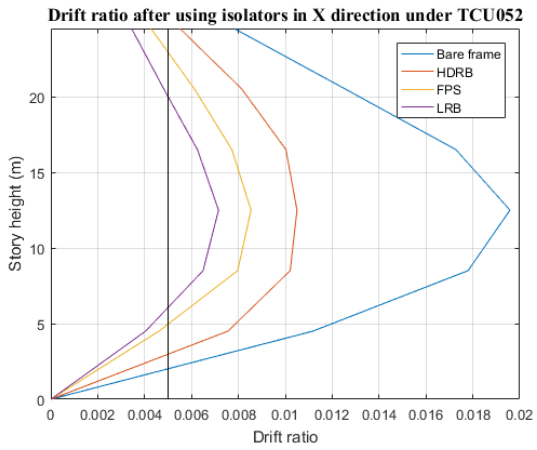
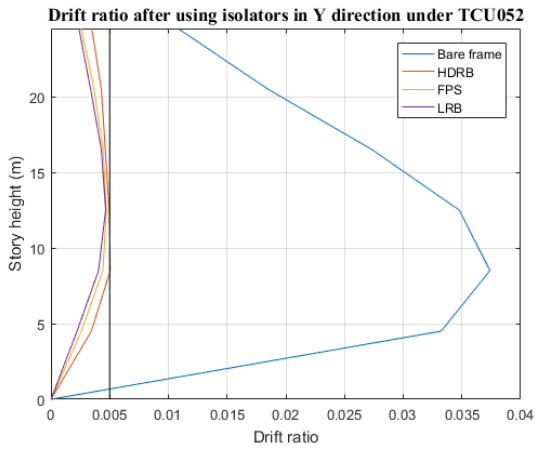
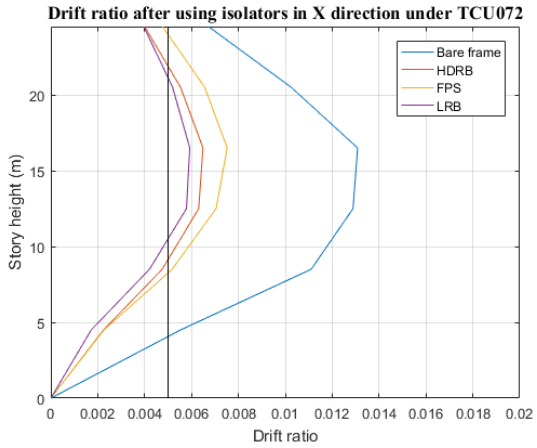
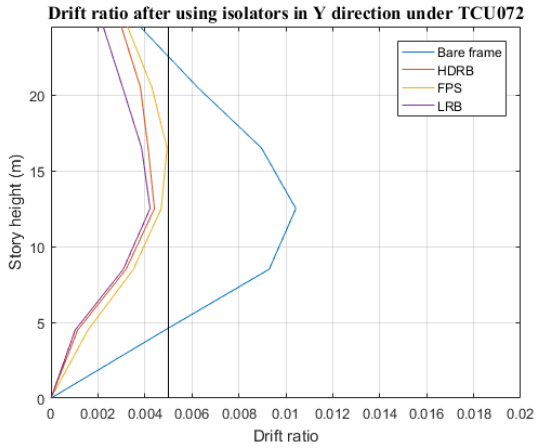
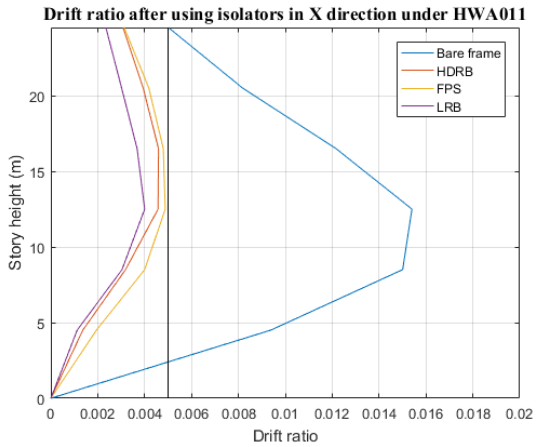
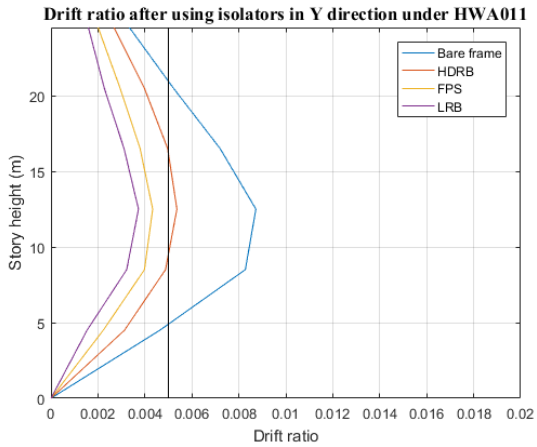
14.7 非線性分析加速度反應比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

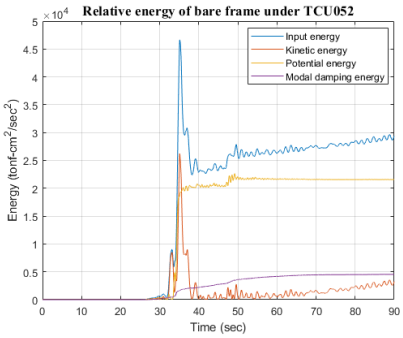
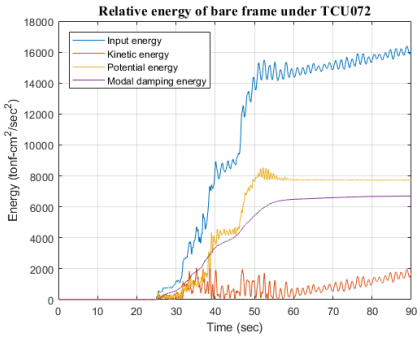
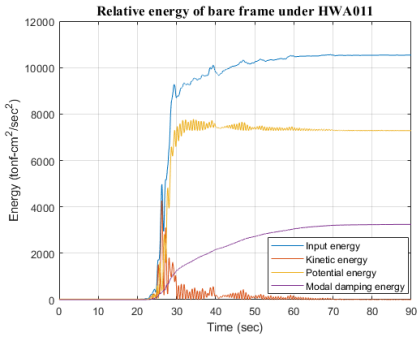
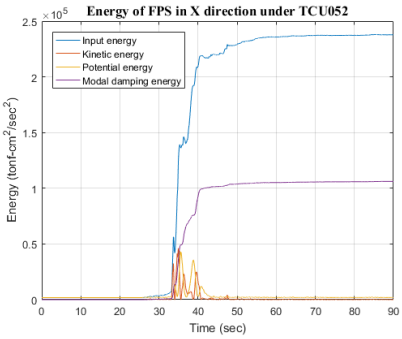
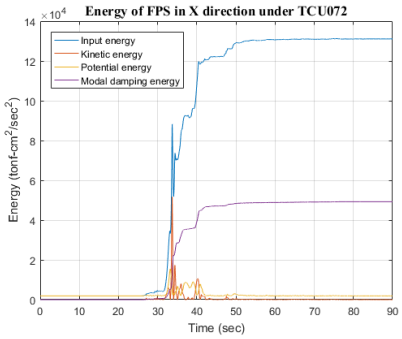
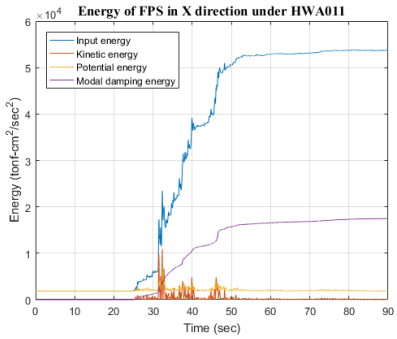
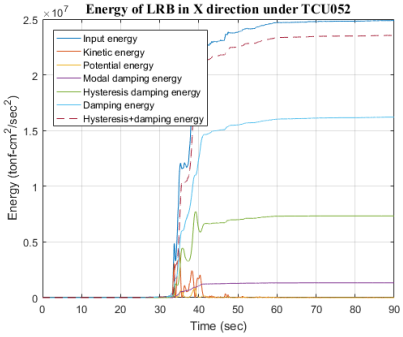
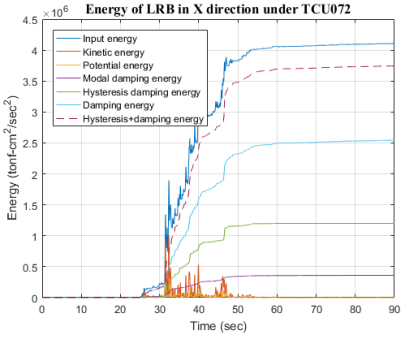
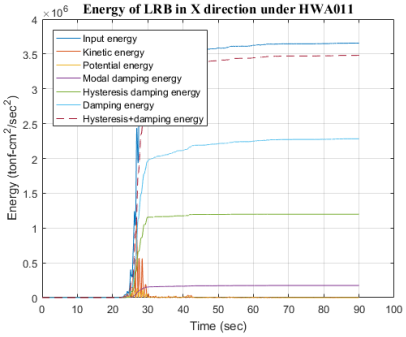
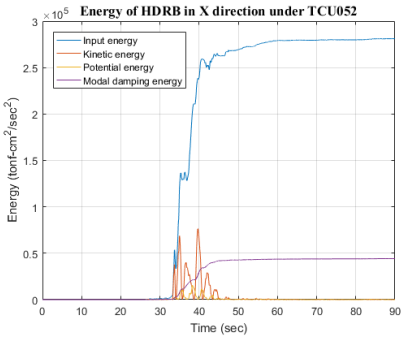
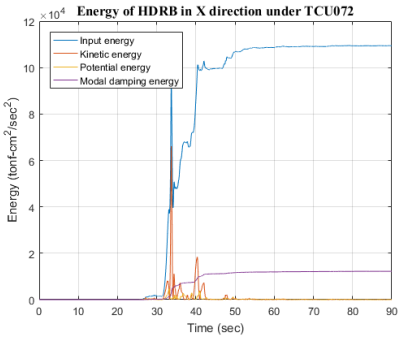
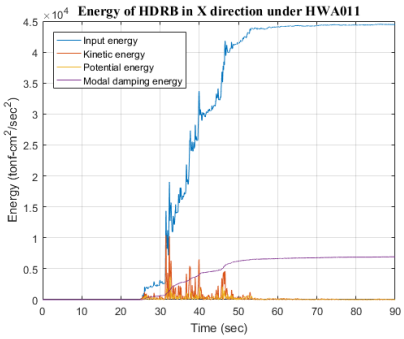
14.8 非線性分析位移反應比較

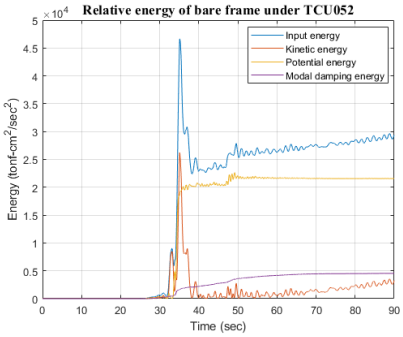
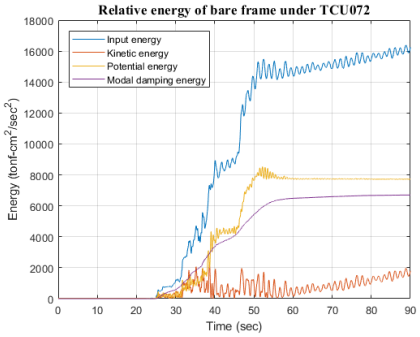
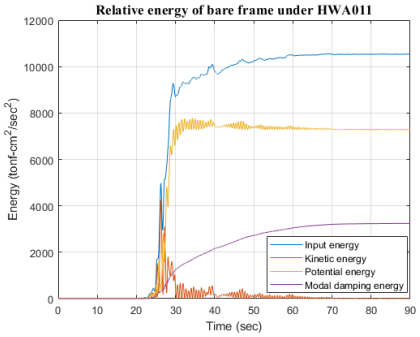
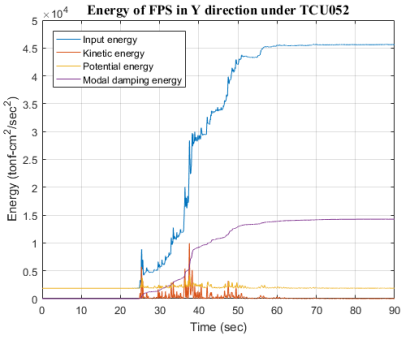
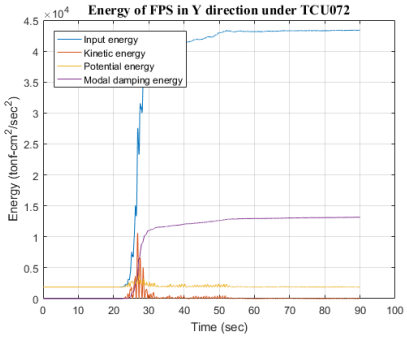
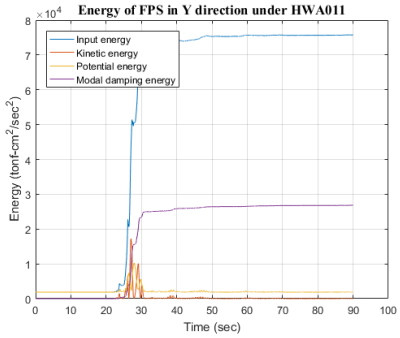
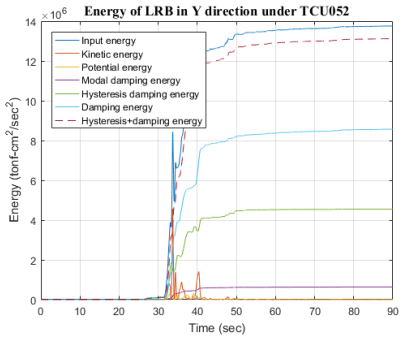
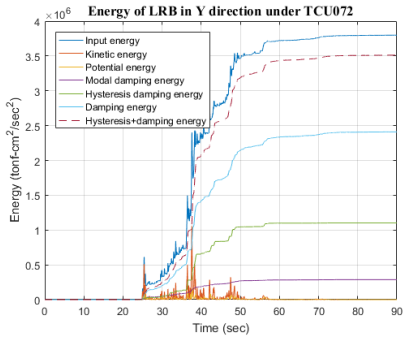
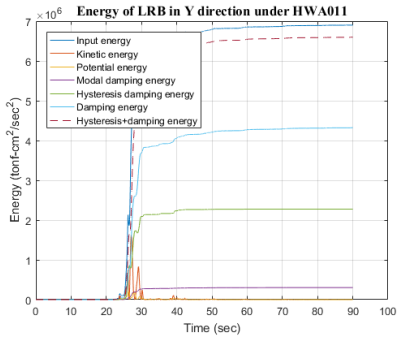
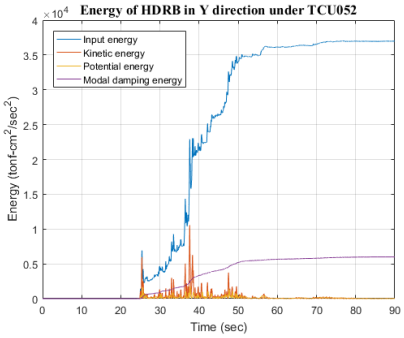
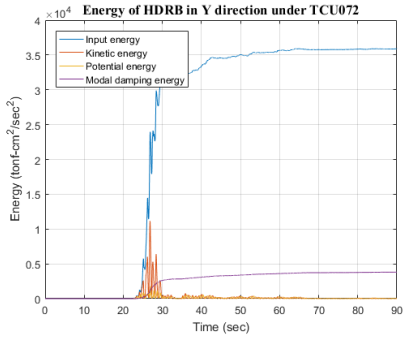
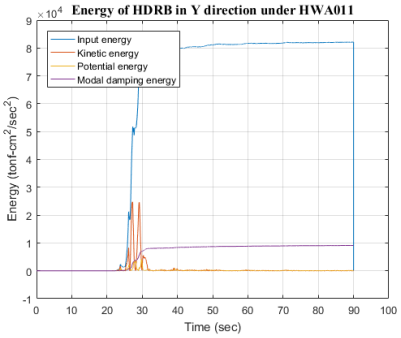
	X 向	Y 向
TCU052		
TCU072		
HWA		

14.9 非線性分析層間位移比較

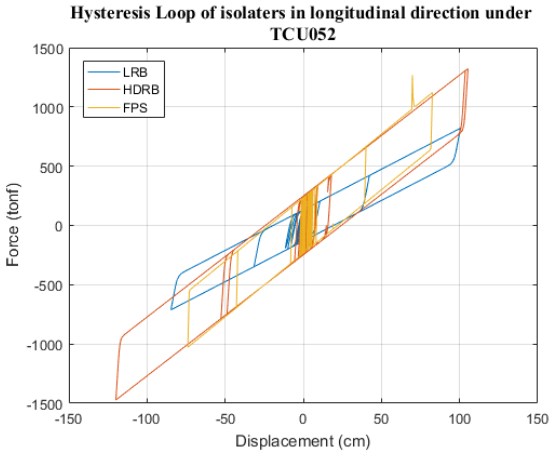
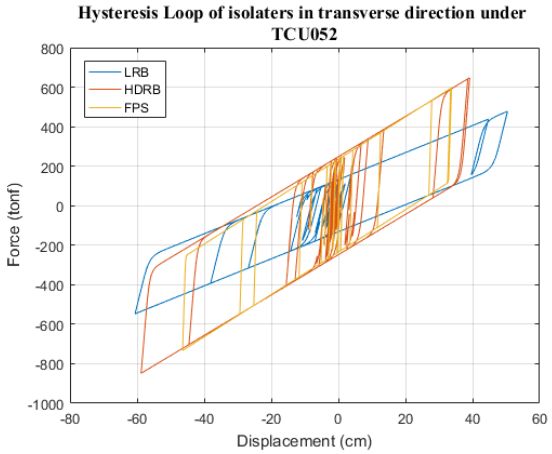
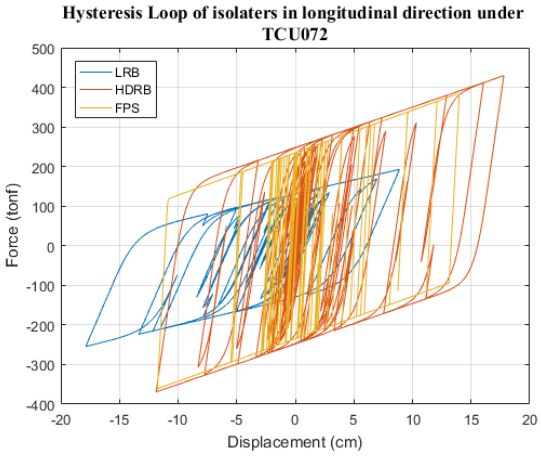
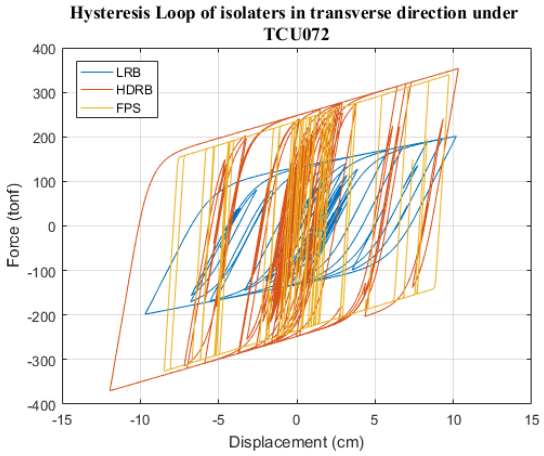
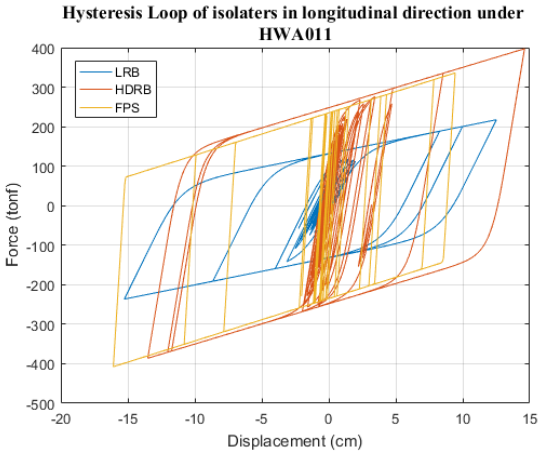
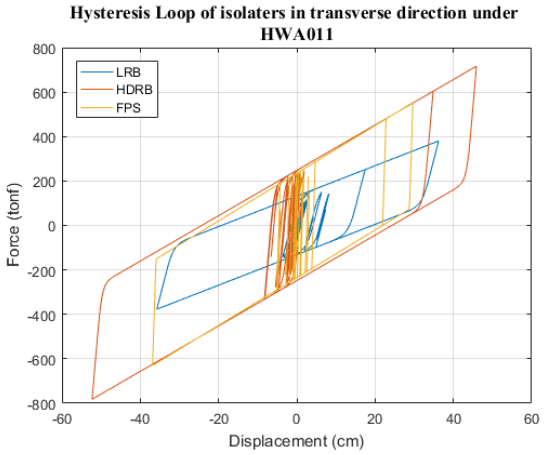
	X 向	Y 向
TCU052		
TCU072		
HWA		

14.10 非線性分析能量比較

X 向	TCU052	TCU072	HWA
Bare frame			
FPS			
LRB			
HDRB			

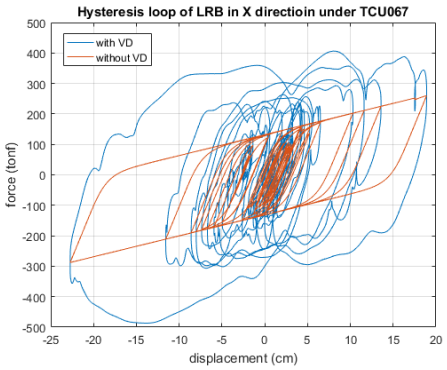
Y 向	TCU052	TCU072	HWA
Bare frame			
FPS			
LRB			
HDRB			

14.11 非線性分析遲滯迴圈比較

	X 向	Y 向
TCU052		
TCU072		
HWA		

Chapter 15 討論與結論

1. 在設計 LRB 及 HDRB 的第二種方法時，發現加入 VD damper 時，雖然會使隔震層之位移下降，但也會增加些許的上部結構層間位移，因此在減少隔震層位移與上部結構的層間位移之間要找到平衡點。
2. 隔震位移的遲滯迴圈行為參數可以用代數解，非常快，而不需要迭代。
3. 關於隔震設計的模型 Try&Error 較麻煩，因為改變 T 會改變 D，改變 ξ 也會改變 D，而 D 的限制在此題為長週期情況下也較為嚴格(因為上部結構太軟，需要拉長週期才可維持彈性)，所以需要把 T ξ 跟 D 的關係建立好成程式，以利模型的更動。
4. 綜合 Etabs 與 PISA3D，VE、LVD 及 NVD 皆可有效降低位移及加速度反應，使結構物反應折減，對於結構物損壞可降低，使用者感受較舒適。可觀察出隔震的效果優於減震，但因為標準不同，所以僅供參考。
5. 從歷時圖可以看出 TCU052 的折減效果不佳，但三筆地震力都沒有產生永久位移，所以推斷是沒有產生塑鉸，所以仍處於彈性階段。
6. 將裝阻尼器之後，結構物所受之地震能量主要由阻尼器吸收，相較於空構架主要透過結構變形消能，加裝阻尼器可提高結構物進入降伏的門檻。而隔震則是讓上部結構都維持在彈性的情況下，即便連大地震也沒到降伏強度，也因此不用進入非線性動力歷時分析。
7. 發現隔震層位移跟上部結構層間位移是互相牴觸的，很難兩個都同時有好的迭代趨勢，因此了解週期跟阻尼比對隔震層位移跟上部結構層間位移的影響，需要找到一個最好的解可以盡量符合題目需求。
8. 發現隔震的 α 變小，對於隔震層位移跟上部結構層間位移都有好的影響，初步認定 α 越小，可能會區像類似 FPS 的行為，而且隔震層位移跟上部結構層間位移都有會下降，但真實行為有待更多分析以及實驗佐證。
9. FPS 跟塑鉸在 ETABS 分析模型中，都要在非線性的「直接積分」方法下才會正常發揮效果。
10. PISA3D 跑非線性歷時分析比其他商用軟體快很多，差別在於 PISA3D 的非線性計算方式較快。
11. FPS 跟 HDRB 從遲滯迴圈看起來效果接近，而 LRB 因為有加 VD damper 所以有一部份能量為 damper 所吸收，所以遲滯迴圈較小。



圖為將 VD 計算入遲滯迴圈之示意圖，比較可以發現，有不少的能量為 VD 所吸收。

12. 近斷層會有較大的隔震層位移，甚至會超過一公尺，因為近斷層有長週期脈衝。
13. 從非線性的 Drift 可以看出 TCU052 跟 HWA 比 TCU072 遠域地震大，但是因為三筆地震力沒有正規化過，所以並不能從這裡看出近斷層有絕對的影響。