Viscous Damper Evaluation in High-Rise Building and Ideal Examples for Code Base Shear Reduction by Additional Viscous Damping

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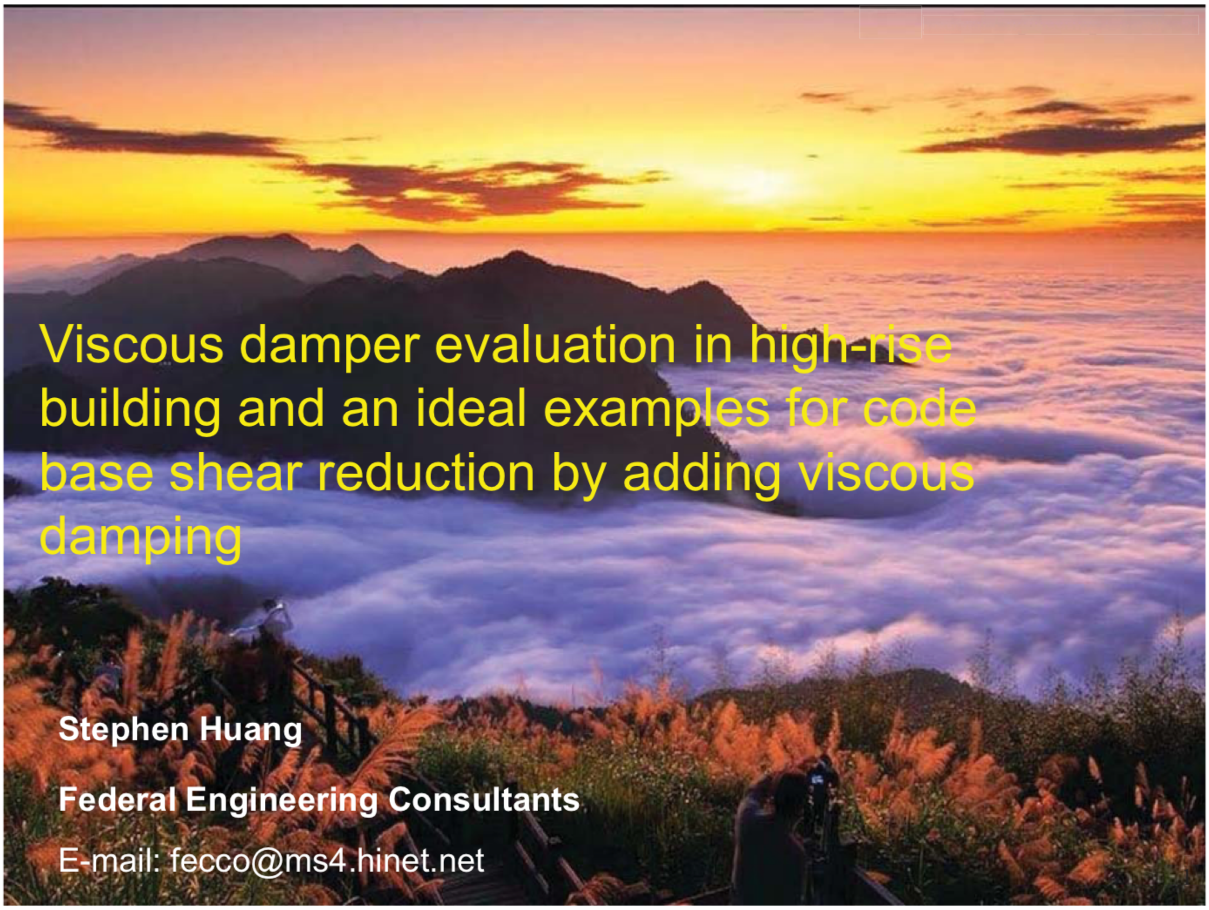
Structural Engineer (S.E.) of R.O.C

Experiences

- Winner of Excellence Young Engineer from R.O.C. Structural Engineering Society in 2006
- Ove Arup &Partner (CA) / Jae-Lien Engineering Consultant (TWN)
- Federal Engineering Consultant, Associates.

Stephen Huang is skilled at structural analysis, tall buildings, seismic resistance and energy absorb device design. His projects cover both public and private buildings, including multi-use projects, office and commercial buildings, hotels, institutional, educational and health facilities, arenas, parking structures, and residential buildings. He is also Involved in different construction materials of RC, SRC, Steel, Wood and Precast buildings, participated developing in passive energy dissipation system, deep excavation and top-down construction.

Stephen are currently a registered Structural Engineering of both Taipei & Taiwan Structure Engineering Association (TESA) and the member of the Chinese Taiwan Society for Earthquake Engineering (CTSEE) and the Chinese Society of Structural Engineering (CSSE). He also performs as a peer reviewer committee of Taipei Structure Engineering Association (TESA).



Viscous damper evaluation in high-rise building and an ideal examples for code base shear reduction by adding viscous damping

Stephen Huang

Federal Engineering Consultants

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Contain

- Familiar Passive Control Device in Taiwan
- Effective damping ratio of linear dampers
- Application of dampers in tall buildings
- Concerns of Damper replace Reinforcement
- Design Example For Building with FVD Damper

Type of passive control device

Displacement- dependent

(1) Friction


(2) Yielding

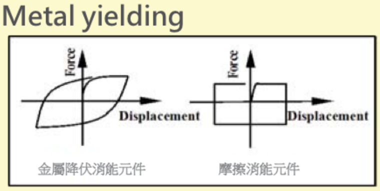
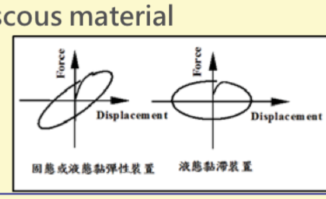


Velocity- dependent

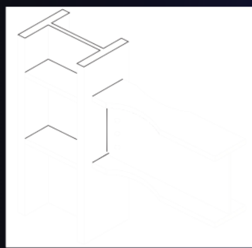
(3) Viscoelastic

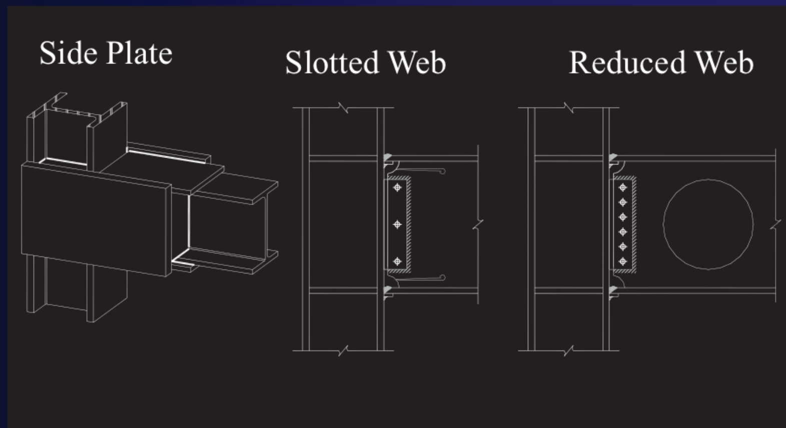

(4) Viscous

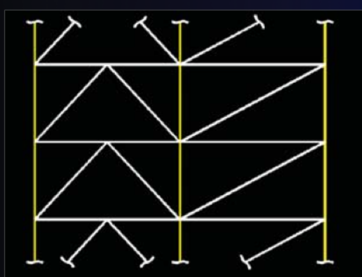
Displacement dependent vs. velocity dependent

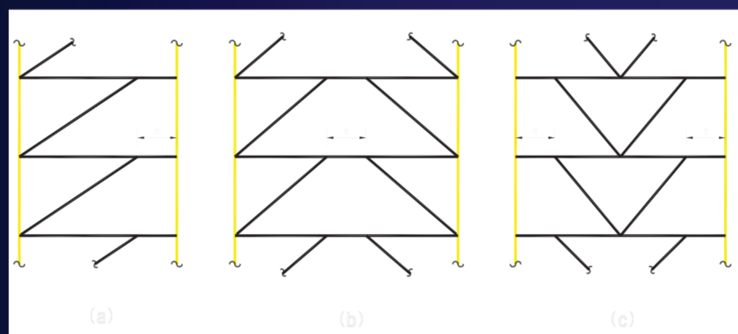
	Displacement dependent (BRB **device)**	Velocity dependent Viscous damper
Energy absorber	Metal yielding 	Viscous material 
Function occasion	Energy dissipation after metal yielding at moderate/severe earthquake	Works during service/moderate earthquake or severe severe Typhoon
Performance	Increase structural capacity, Reduce story drift by add stiffness and capacity	Reduce drift and acceleration, improve service-ability
Design method	Incorporated into entire frame analysis model for an integrity.	Maximum Reaction phases are different, Usually be treated as supplemental device.
Performance under (DBE)Design Basis Earthquake	Structure with adequate Ductility	Frame of damper might be damaged, efficiency decade significantly
Goal	Repairable under DBE earthquakes, and collapse prevention under MCE quakes	Improve performance under Wind and Seismic loads

General Energy absorber-displacement









General Energy absorber-displacement

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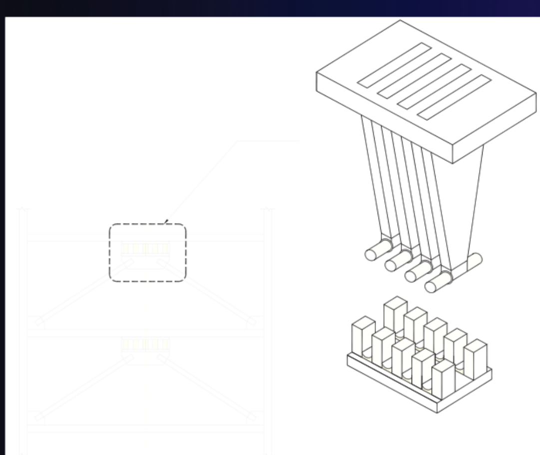
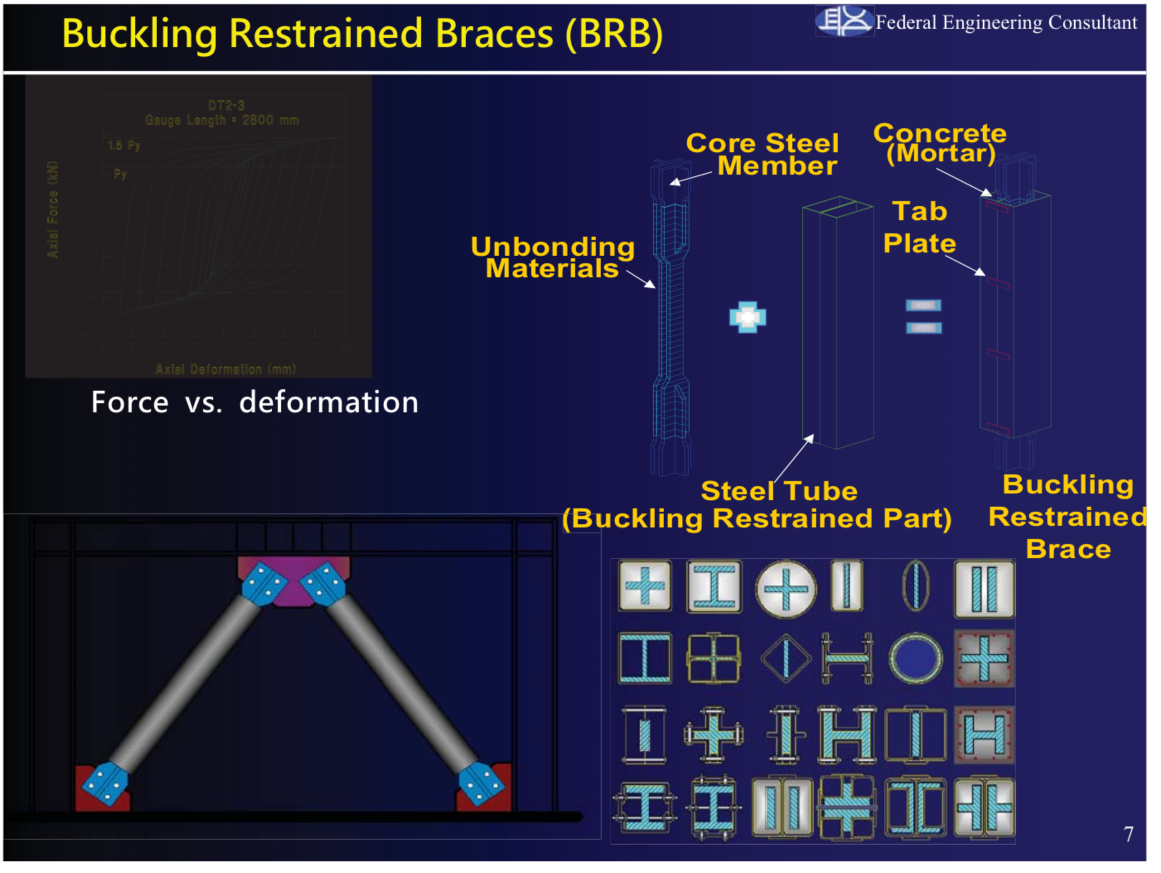
TADAS device





Buckling Restrained Braces (BRB)
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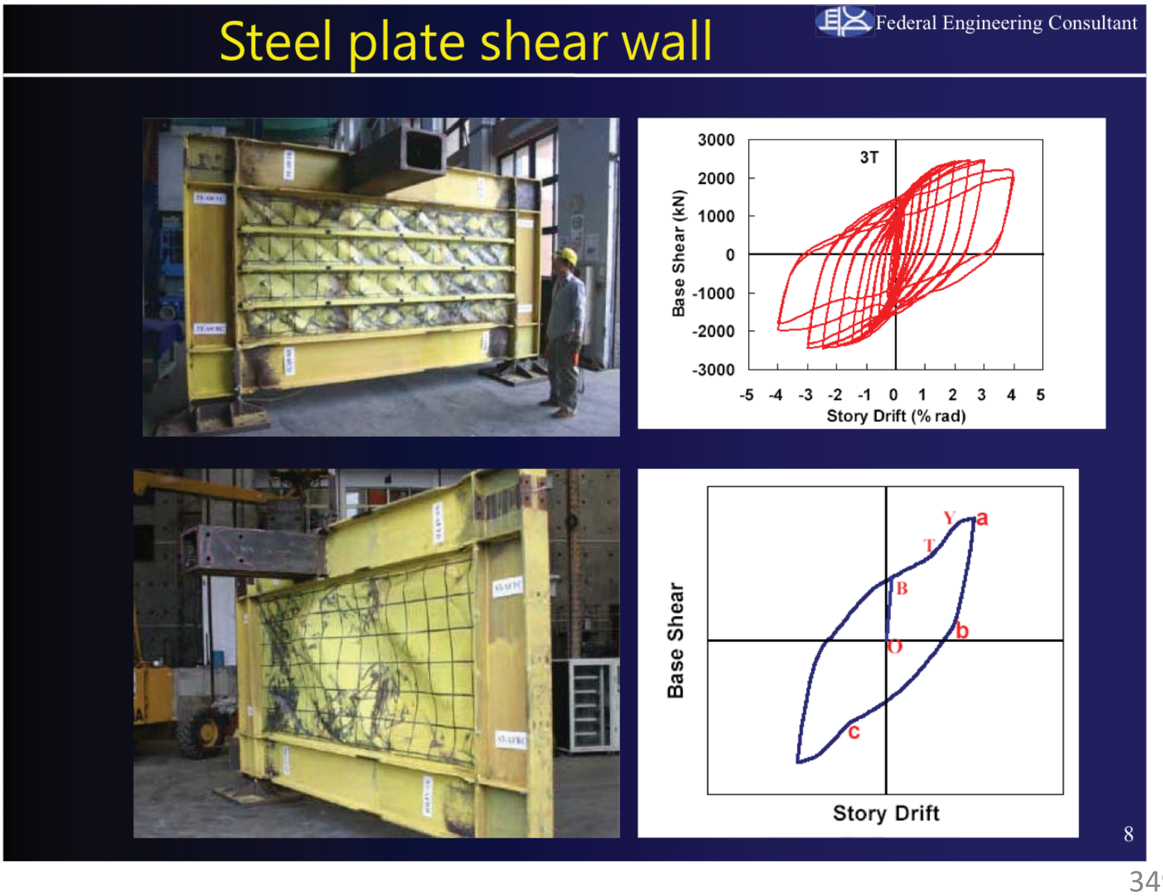
DT2-3
Gauge Length = 2800 mm
1.5 Py
Py
Axial Force (kN)
Axial Deformation (mm)
Force vs. deformation
Core Steel Member
Concrete (Mortar)
Tab Plate
Unbonding Materials
Steel Tube (Buckling Restrained Part)
Buckling Restrained Brace
7



Steel plate shear wall
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3T
Base Shear (kN)
3000
2000
1000
0
-1000
-2000
-3000
-5 -4 -3 -2 -1 0 1 2 3 4 5
Story Drift (% rad)
Base Shear
Story Drift
Y
a
T
B
O
b
c
8

Steel dual-core self-centering braces

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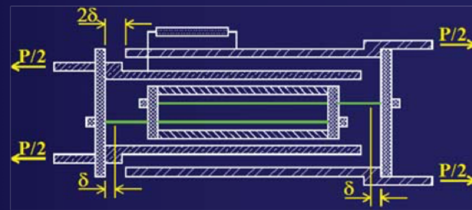

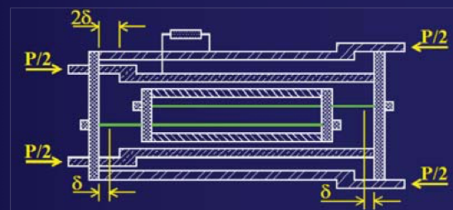

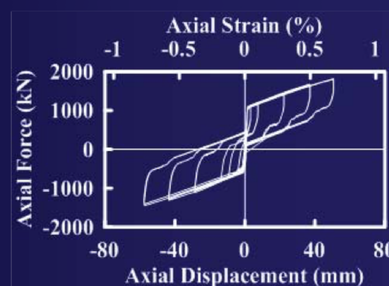

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Friction damper device

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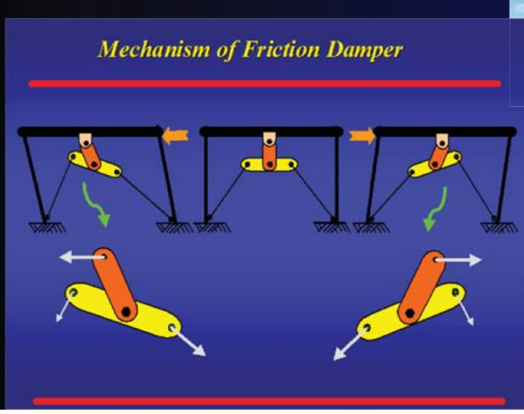

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Installation Scheme of friction type damper

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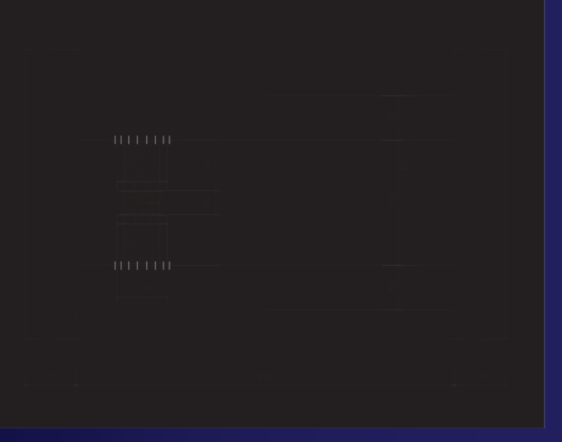

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Installation Scheme of friction type damper

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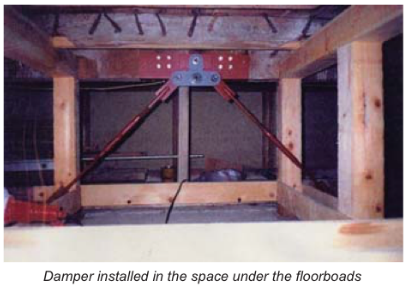
Yaguriji-Temple:Taishi-Do



Damper installed in the space under the floorboads

5-Storey Building in Japan
In collaboration with Takenaka Corp.
Constructed by Japan Takenaka corporation
2003

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Fluid viscous damper

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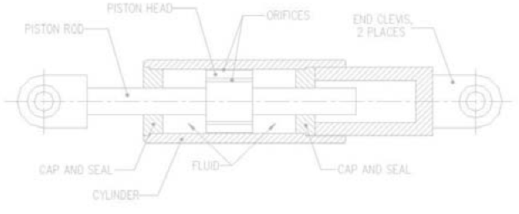

$$F = CV^{\alpha}$$

F = Force of FVD(t)

C = Damping Constant(t·sec$^{\alpha}$/cm$^{\alpha}$)

V = velocity(cm/sec或m/sec)

α= Exponential，0.3~1.0

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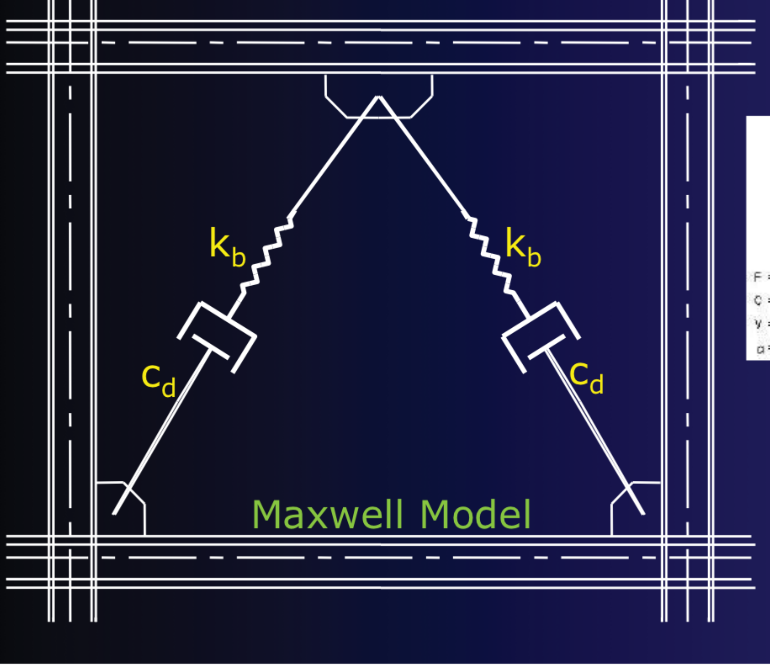
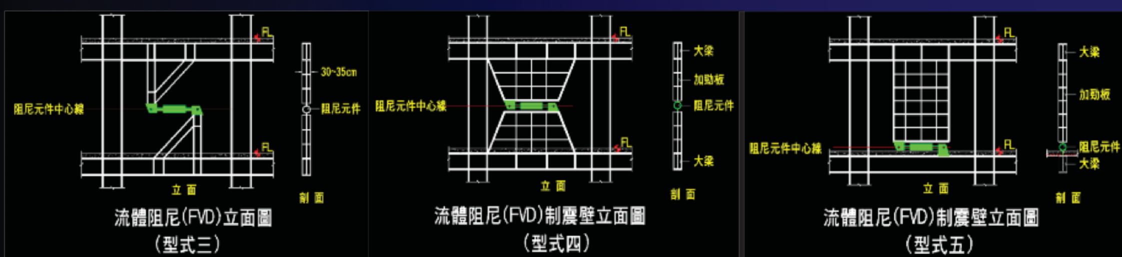
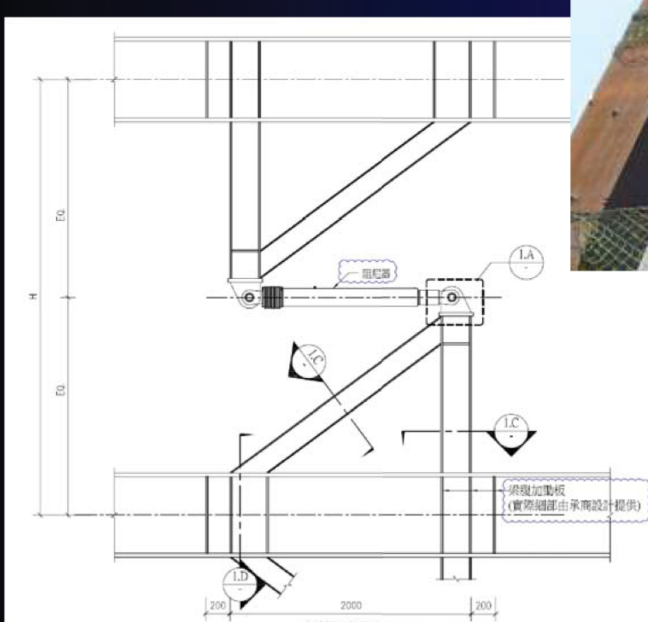
FVD modeling –series connection

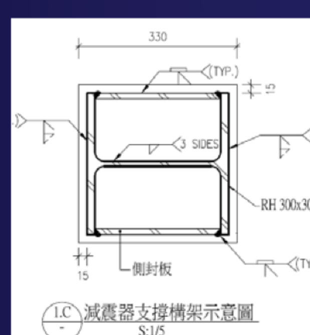


Arrangement of FVD - Wall type and Brace type

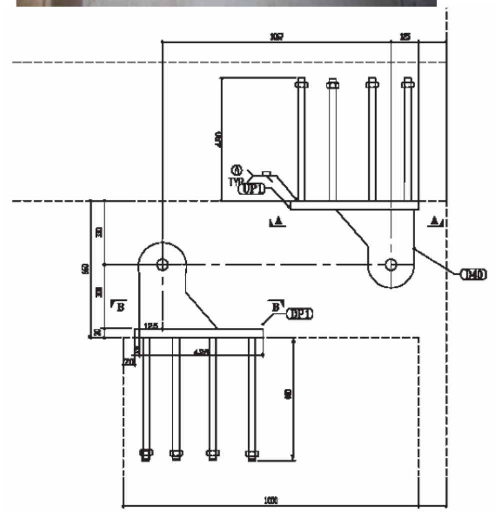


K type – narrow-sized
Preferred by architect

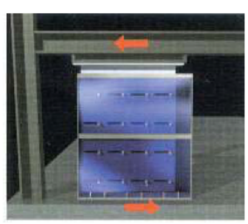




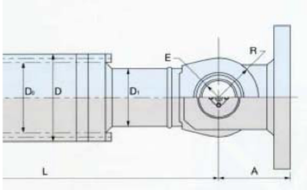
Inefficient layout – parallel to RC wall

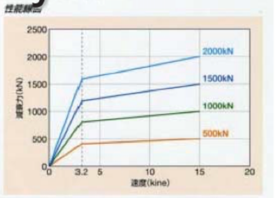


Viscous Damper-wall type

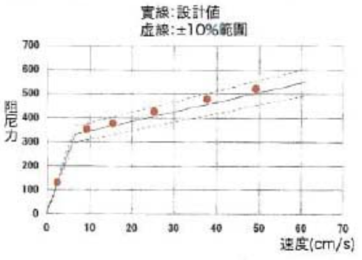


Bilinear vs. Exponential Fluid damper
More sensitive by ball joint

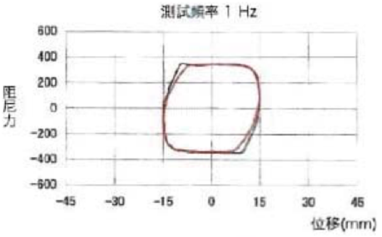


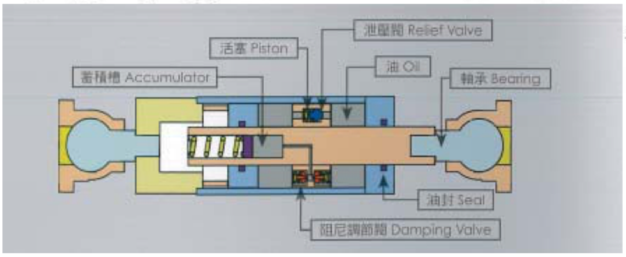


速度-阻尼力關係



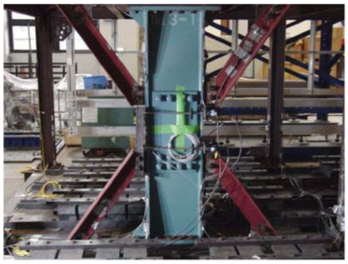
位移-阻尼力關係





V i s c o E l a s t i c M a t e r i a l

$$F = K_d D + C_d \dot{D}$$



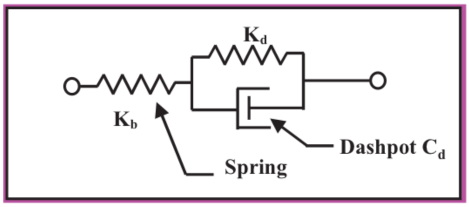
Kevin model

K_d : Device Stiffness

C_d : Damping coefficient

D : Relative displacement

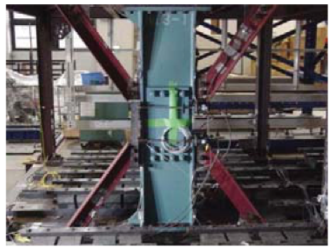
$\dot{D}$: Relative velocity between ends of device

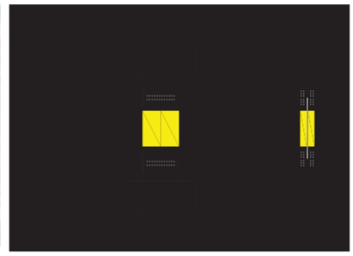


$$D_{ave} = \frac{|D^+| + |D^-|}{2}$$

Idealized force-deformation relationship for Visco-Elastic material

Visco-Elastic wall dampers





Visco-Elastic or High Damping Rubber wall

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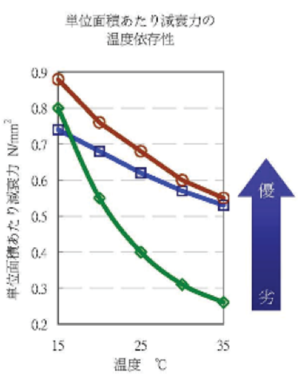

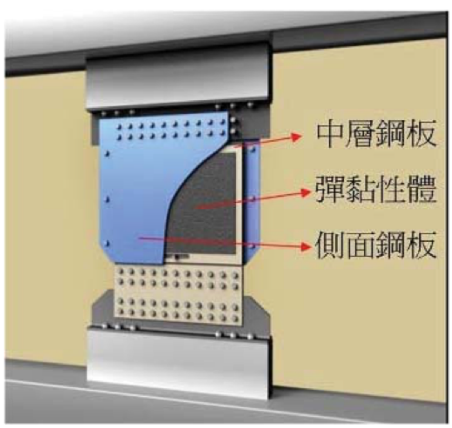

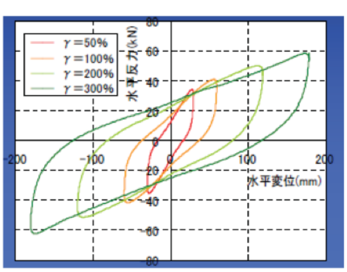

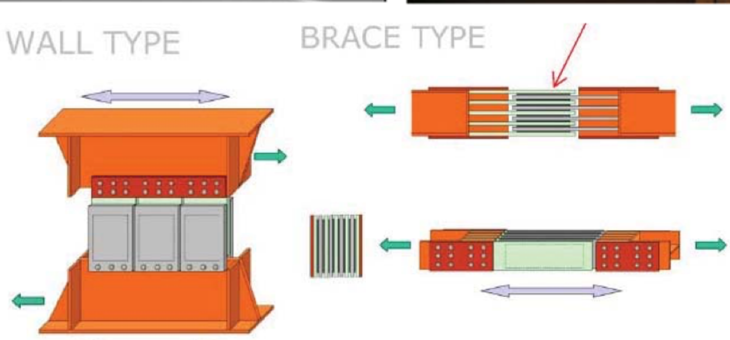

VEM wall damper on RC Framing

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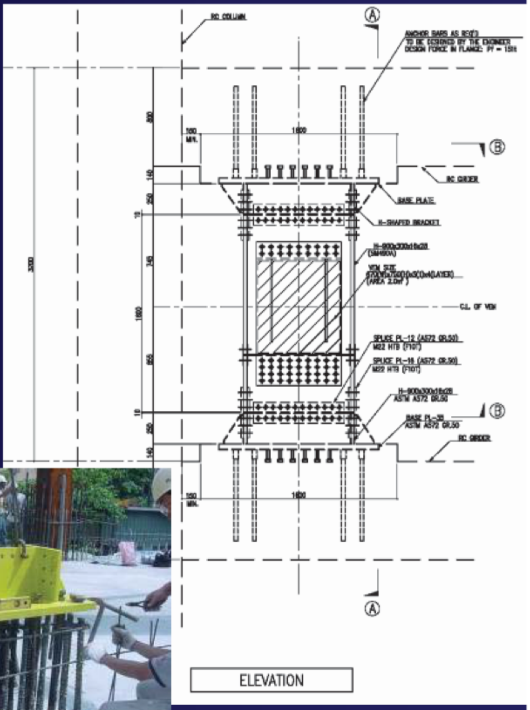

Dampers vs. RC Wall

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Contain

- Familiar Passive Control Device in Taiwan
- Effective damping ratio of linear dampers
- Application of dampers in tall buildings
- Concerns of Damper replace Reinforcement
- Design Example For Building with FVD Damper

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How to evaluate effective damping ratio for linear damper

- **Location：Taipei Neihu**
- **Stories：9 floors with 3 level basements**
- **Structural system：Steel MRF**
- **Floor area：81,100m2**
- **Building type：**

  Office at superstructure

  Parking lot at basement

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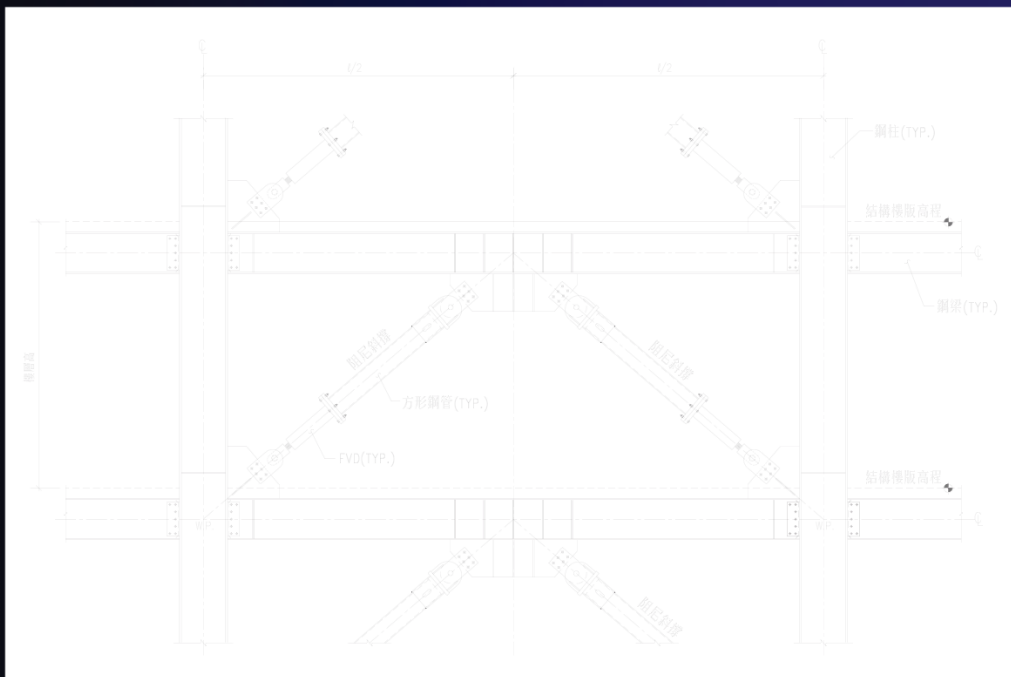
FVD installed with braces frame



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Schedule of FVDs with 10% damping ratio

Number	Damping force (kN)	Damping constant C(kN·s/m)	Stroke (mm)
1	300	3300	±50
2	450	4200	±50
3	600	5600	±50
4	1000	6900	±75
5	1000	8100	±75
6	1350	9500	±75
7	1350	11000	±75

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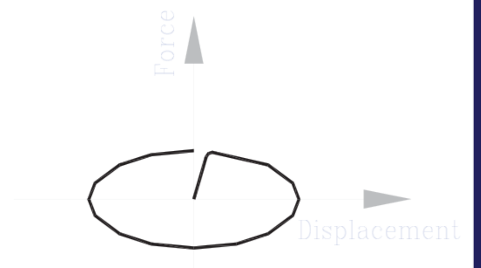
Effective Damping ratio contributed by FVD

Using floor's displacement to estimate the effect damping ratio as follows:

$$\beta_{eff} = \beta_0 + \frac{\sum_j W_j}{4\pi W_k}$$



Viscous fluid device

β_0 : Damping in structural frame, use 2% for steel frame

W_j : Work done by device j in one complete cycle corresponding to floor disp. δ_i

W_k : Maximum strain energy in the frame = $1/2 \sum_i F_i \delta_i$

F_i : Inertia force in level i

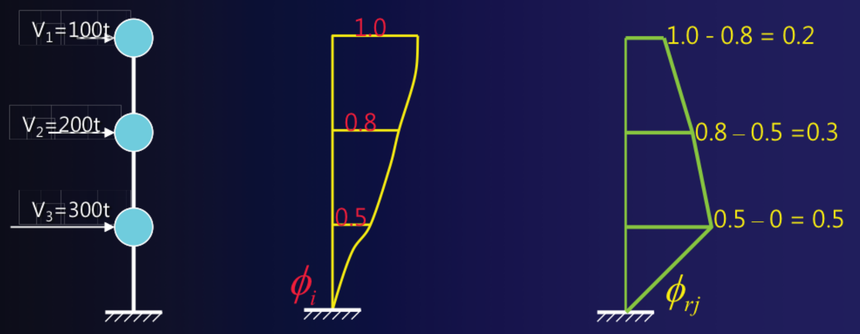
δ_i : floor displace in level i

Estimation of Damping ratio contributed by linear FVD

$$\beta_{eff} = \beta_0 + \Delta\beta = \beta_0 + \frac{\Sigma_j W_j}{4\pi W_k} = \beta_0 + \frac{T \Sigma_j C_j \phi_{rj}^2 \cos^2\theta_j}{4\pi \Sigma_i m_i \phi_i^2}$$

β_{eff} =Total effective damping ratio of structural frame with dampers
β_o =Inherent damping ratio of frame say 2%~5%
$\Delta\beta$ =Effective damping ratio conducted by FVD damper
W_j =Work done by device j in one complete
W_k =Maximum strain energy in the frame = ½ $\Sigma_i F_i \delta_i$
F_i =Inertia force in level i
δ_i =Floor displace in level i,
T =Fundamental Period of structure including all dampers stiffness
C_j =Damping constant for device j
ϕ_{rj} =The first mode relative displacement between the end of device j
θ_j =Angle of inclination of device j to the horizontal
m_i =mass of floor level i
ϕ_i =The first mode displace of floor level i

Assumption of damping constant of each floor



We had：Story Shear V_i · floor mass m_i · Period T=1.6 sec., FVD angle θ_j =23^0

Assum： $\frac{V_1}{C_1}=\frac{V_2}{C_2}=\frac{V_3}{C_3}$

analysis： $\frac{100}{C_1}=\frac{200}{C_2}=\frac{300}{C_3} \Rightarrow C_2 = 2C_1, C_3 = 3C_1$ $\quad \beta_{eff} = \beta + \frac{T\sum_j C_j \phi_{rj}^2 \cos^2\theta_j}{4\pi \sum_i m_i \phi_i^2}$

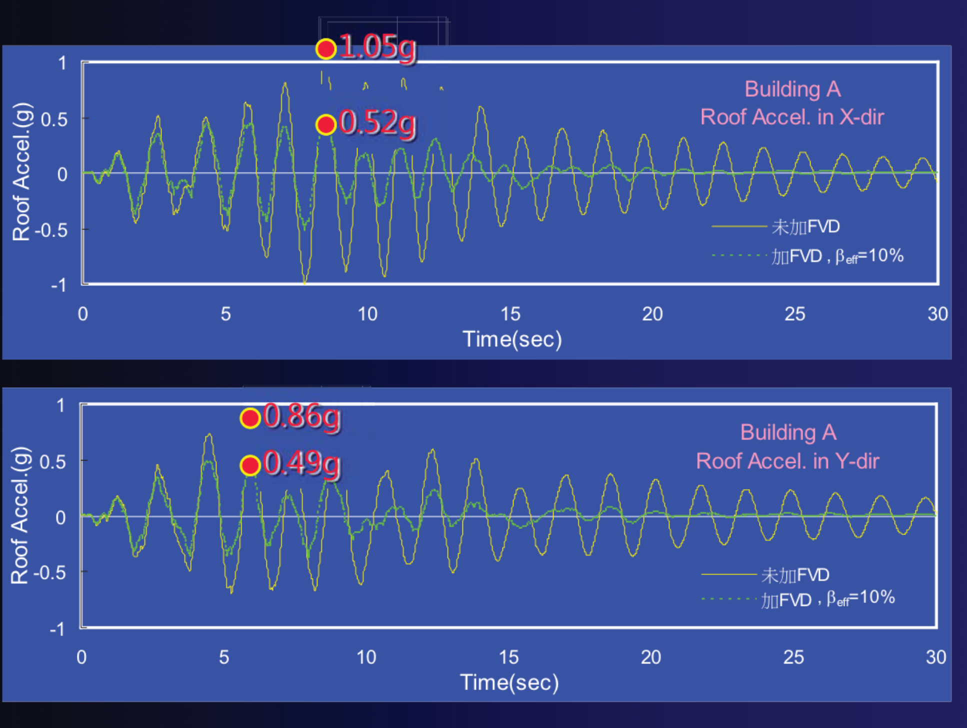
$$0.1 = 0.02 + \frac{1.6}{4\pi}\frac{6C_1\left[(0.2)^2+(0.3)^2+(0.5)^2\right](\cos^2 23^0)}{1.0\times1.0^2+2.0\times0.8^2+2.2\times0.5^2}$$

$C_1 = 0.92$ t·sec/m

$C_2 = 2\times0.92 = 1.84$ t·sec/m

$C_3 = 3\times0.92 = 2.76$ t·sec/m

Roof acceleration of Time History -Building A



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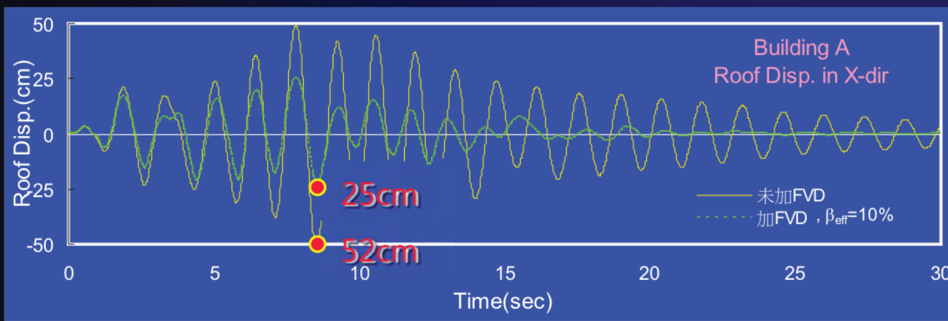
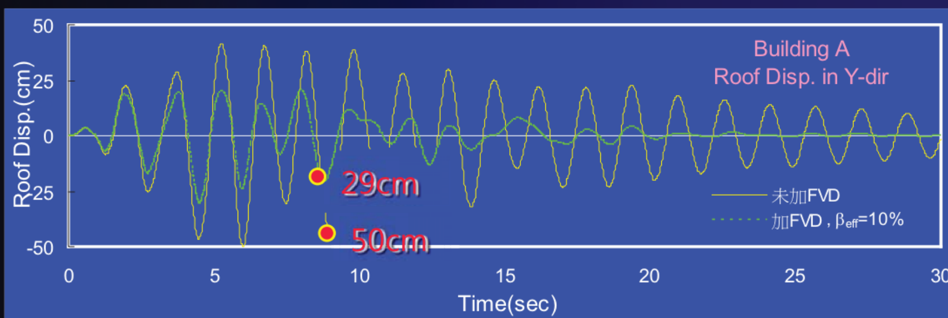
Roof displacement time history-Building A





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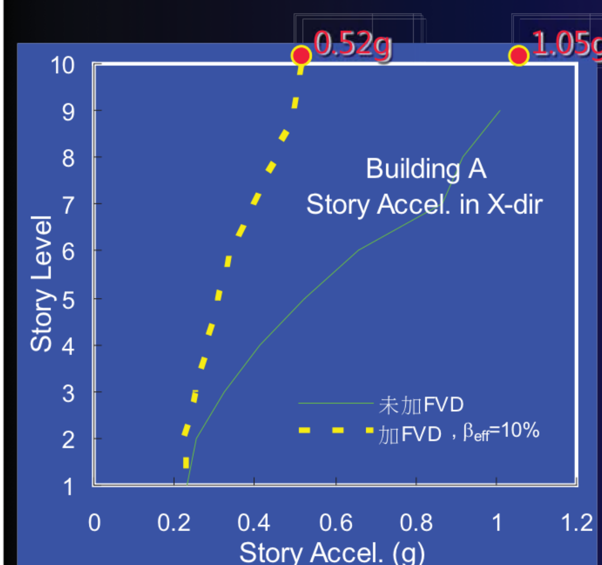
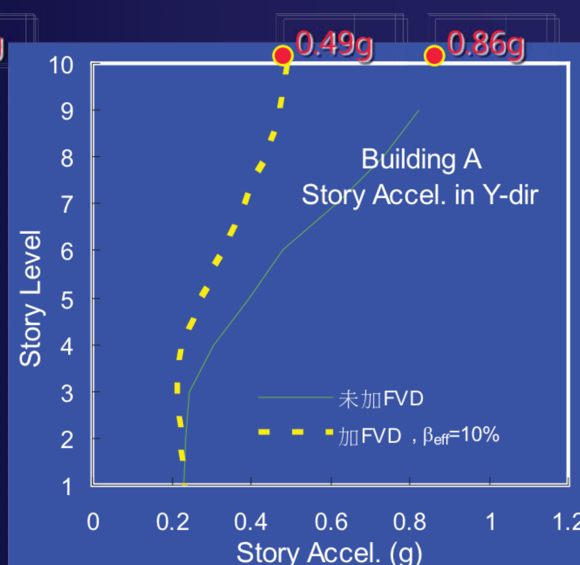
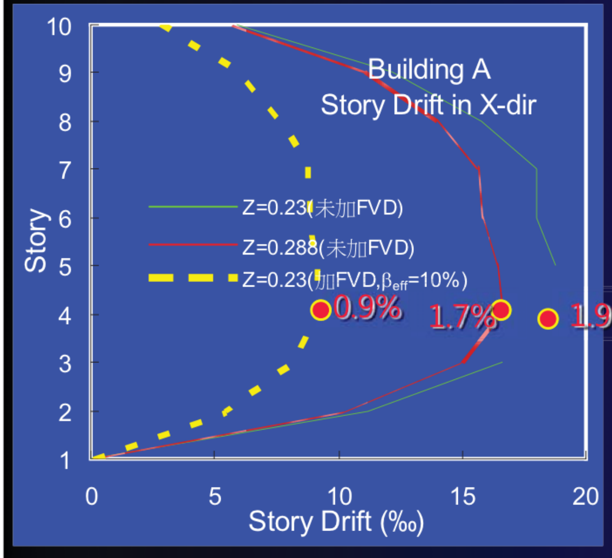
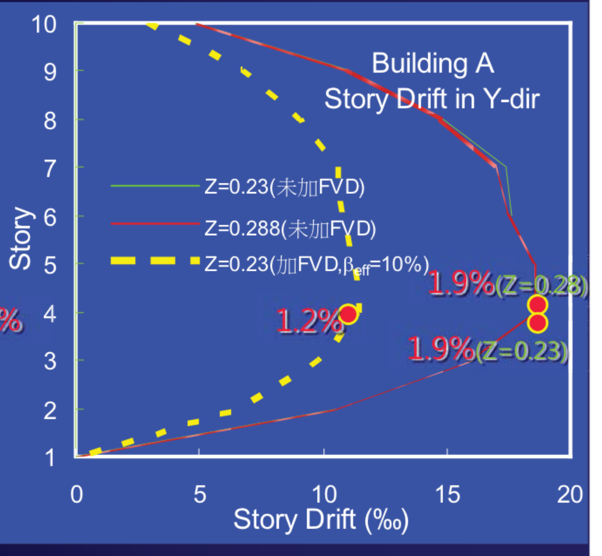
Floor acceleration-Building A





Story drift ratio -Building A





Note：If structural size enhanced from I = 1.0 to I = 1.25, seismic load increased due to short period, structural performance might not improve accordingly.

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Performance Comparison of Damping Ratio

Damping	Base-shear	Roof acceleration	Story drift	Cost of damper (US$)
2 %	Basis value	Basis value	Basis value	Basis value
10 %	51%	51%	51%	1.96 million
15 %	62%	61%	62%	2.60 million
20 %	66%	63%	66%	2.68 million
30 %	72%	67%	72%	3.72 million

Note：1. Value in table shows the deduction percentage. It is demonstrated as in X direction of tower A

2. If important factor increase to I=1.25 steel cost might increase US $40 million.

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Contain

- Familiar Passive Control Device in Taiwan
- Effective damping ratio of linear dampers
- **Application of dampers in tall buildings**
- Concerns of Damper replace Reinforcement
- Design Example For Building with FVD Damper

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Project In Taichung 29F/B5

- Location：Taichung
- Stories：29 Floors/B5
- Structural system：Steel
- Floors area：30,700m2
- Building Type：
  - Gymnasium at level 2~3
  - residential at level 4~29
  - Parking lot at basement

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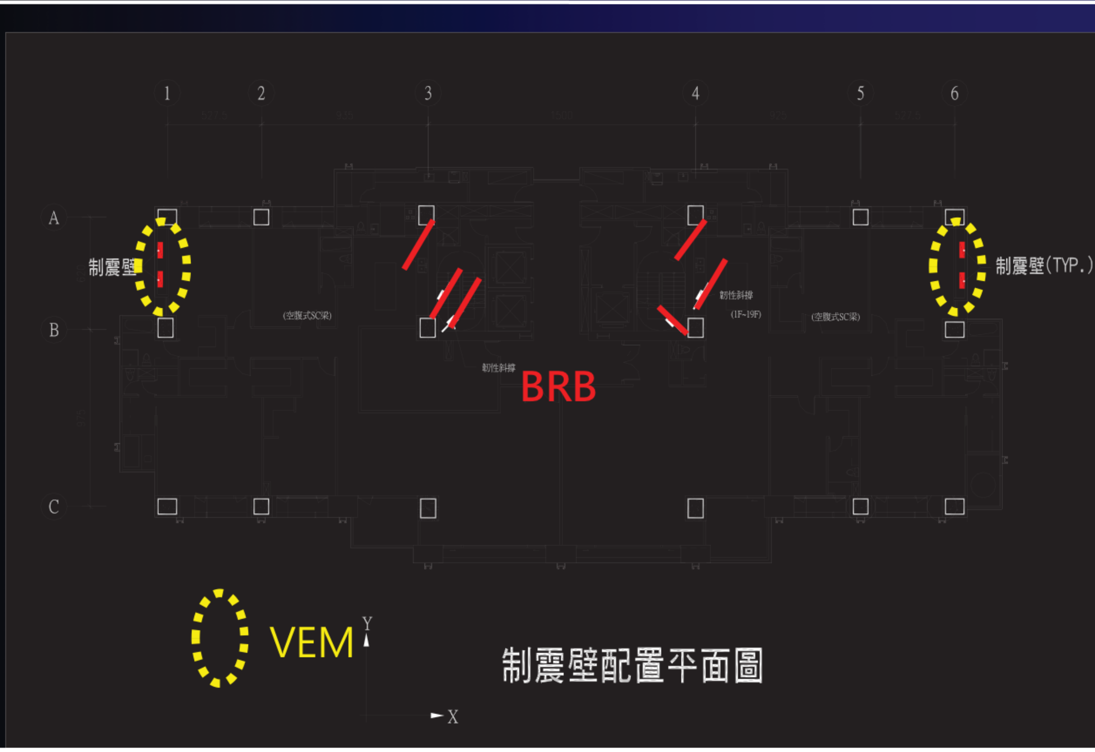
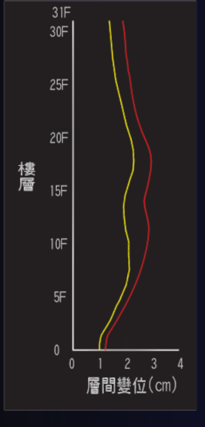
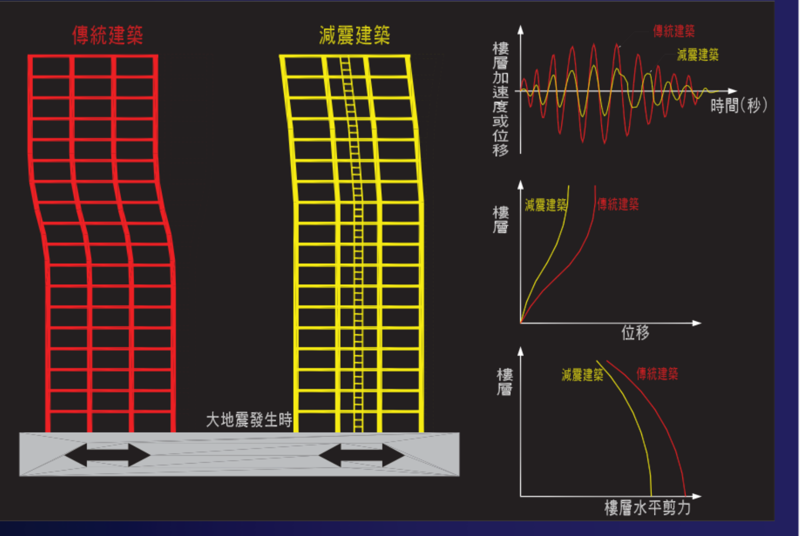
Typical Framing Layout of BRB and VEM



- What performance be improved ?
- Quantity ?
- Floor ?
- Perimeter or interior
- RC wall behind
- Customized or regular product

How to get velocity damper efficient





Schedule of VEMs for installed floors

Scheme	Arrangement per Floor	Floor	Total set
Basic	Bare Frame	--	--
A	4 sets in Y-dir	1~19F	76 sets
B	4 sets in Y-dir	1~15F	60 sets
C	4 sets in Y-dir	1~11F	44 sets
D	4 sets in Y-dir	6~16F	44 sets

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Performance of VEM for installed floors

	Bare frame	scheme A	scheme B	scheme C	scheme D
Floor Distribution	None	Lower 2/3	Lower 1/2	Lower 1/3	Middle 1/3
Deduction in base-shear	basic	20%	18%	15%	15%
Deduction in story drift	basic	24%	21%	15%	19%
Deduction in Rf acceleration	basic	45%	37%	24%	31%
Performance improved	--	O	O	Δ	Δ
Floor installed	--	1~19	1~15	1~11	6~16
Total sets	--	76	60	44	44

Symbol：O great　Δ Fair　X poor

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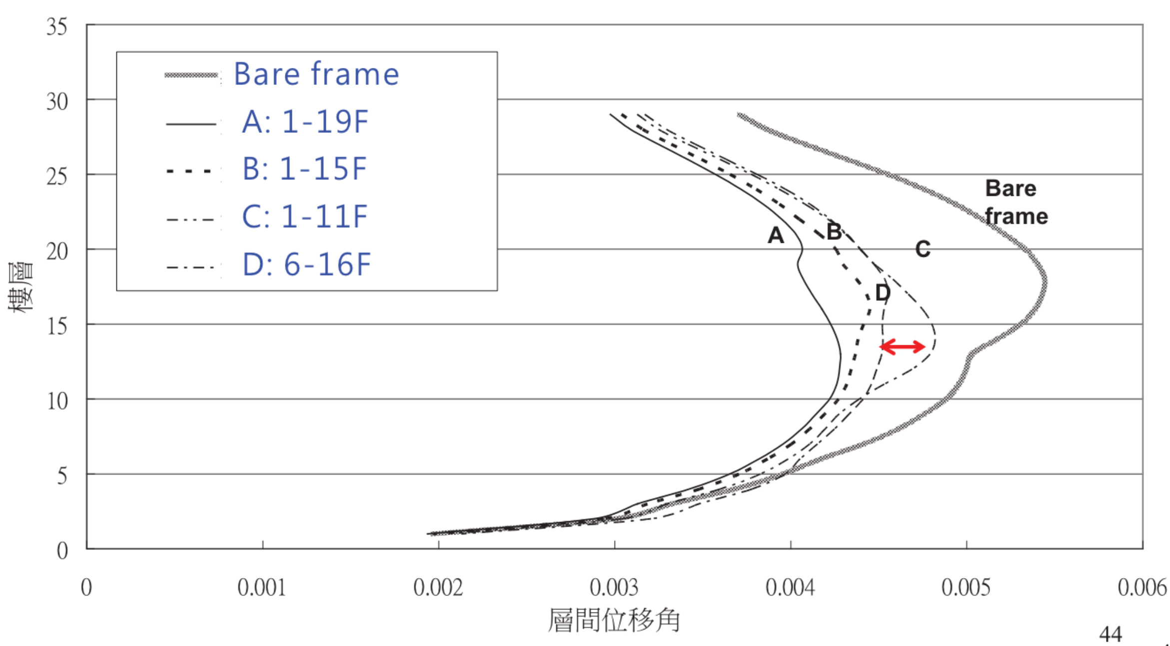
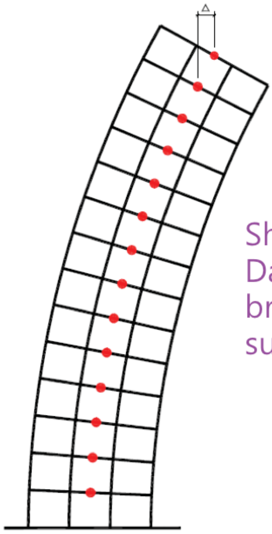
Story drift comparison for installed floors

層間位移角比較圖



Effective deformation (Δ_{rj}) of damper for higher floors



Δ = Shear deformation between floors +Tilted angle from bottom (No relative deformation within Damper)

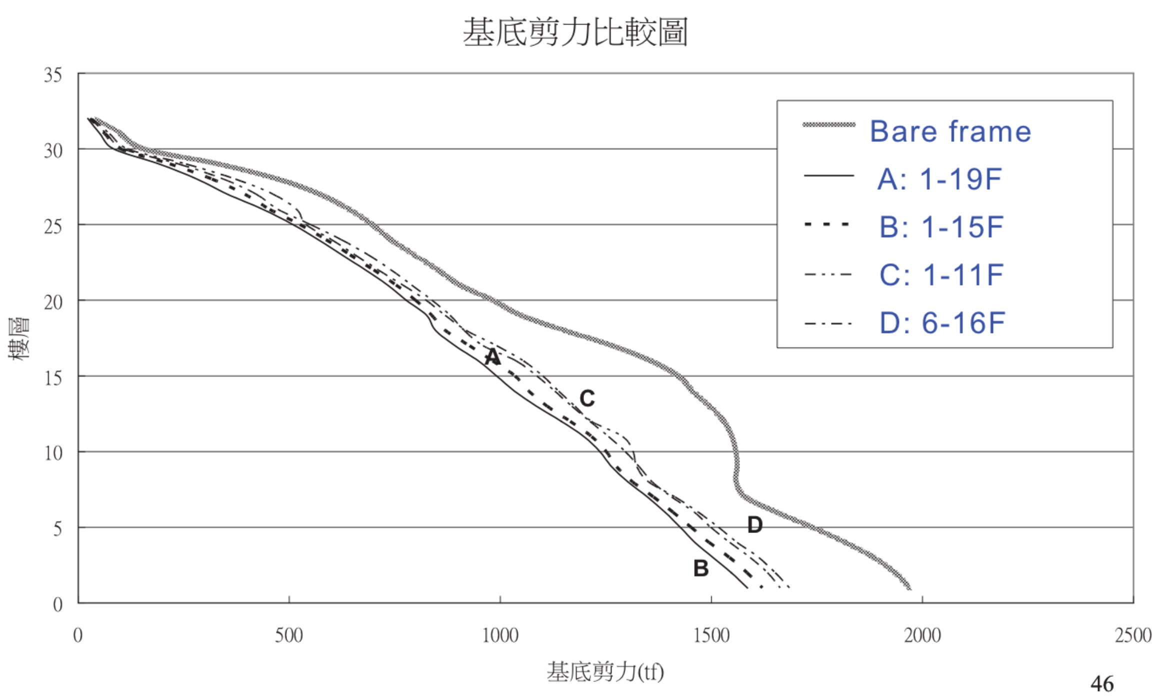
Shear deformation between floors= Damper deformation (Δ_{rj}) + brace deformation + supporting beam deformation

Stick model over estimate damper behavior due to including all story deformation to damper generously

Multi-stories frame

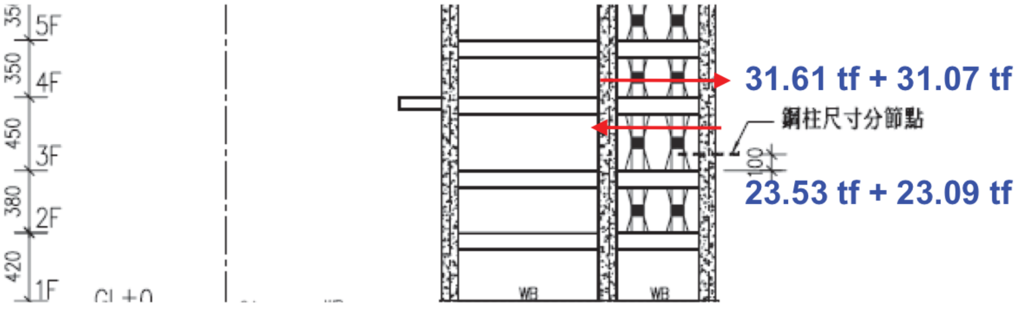
Simplified stick model

Story shear comparison for installed floors



Capacity check of moment from damper's shear

Shear in damper will cause additional moment to supporting beams, capacity of beam shall be checked under code base shear



Project in Taipei 22F/B3

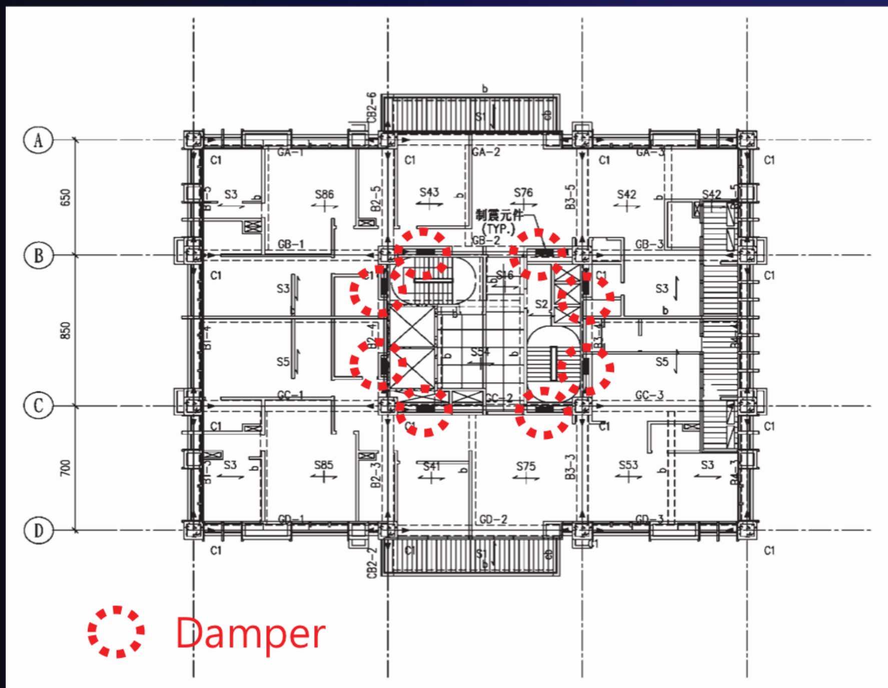
- **Location ：Taipei**
- **Stories：22 floors/B3**
- **Structural system：Steel**
- **Floors area：35,800m2**
- **Building type：**

  Gymnasium level 2

  residential level 3~22

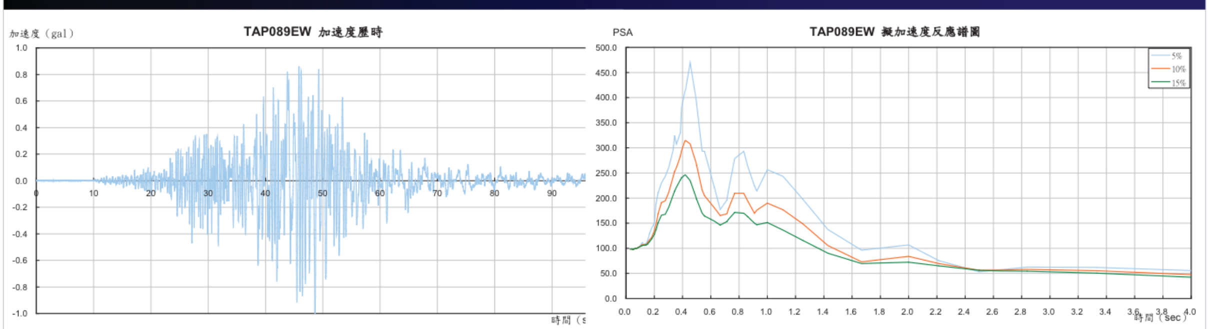
  parking lot at basement

Typical Floor layout with 8-dampers in service core



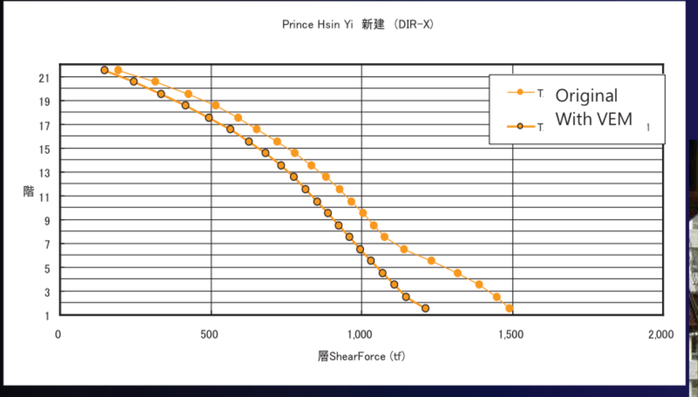
Performance Target of Building with different dampers

- 20% deduction of base shear
- 20% deduction of roof drift and acceleration
- 4 sets in each directions of each installed floors
- Provide required sets to meet target above



Natural seismic records nearby：W. H. elementary school 921 Jiji earthquake (TAP089) E-W records

Result of VEM (visco-elastic material) Dampers



19% deduction of base shear

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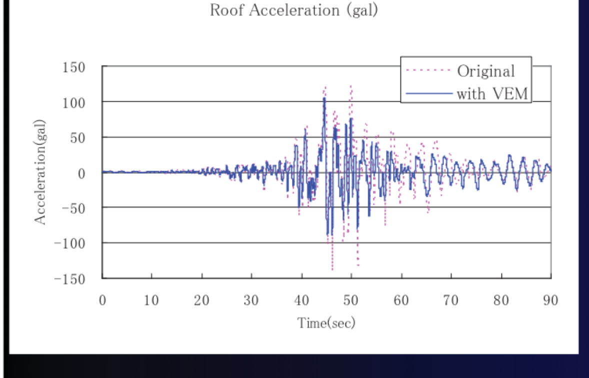
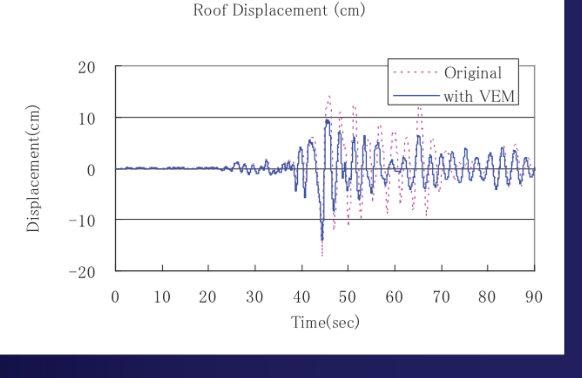
Result of VEM (visco-elastic material) Dampers





25% deduction of roof acceleration

18% deduction of roof displacement

Result of Friction type Dampers

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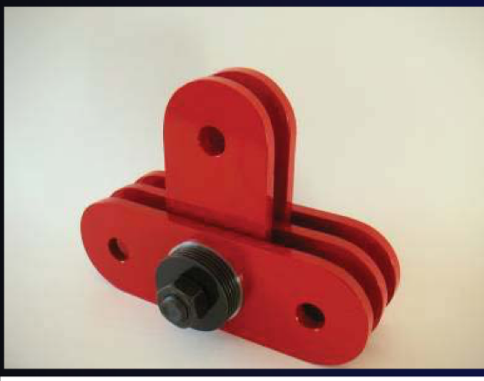

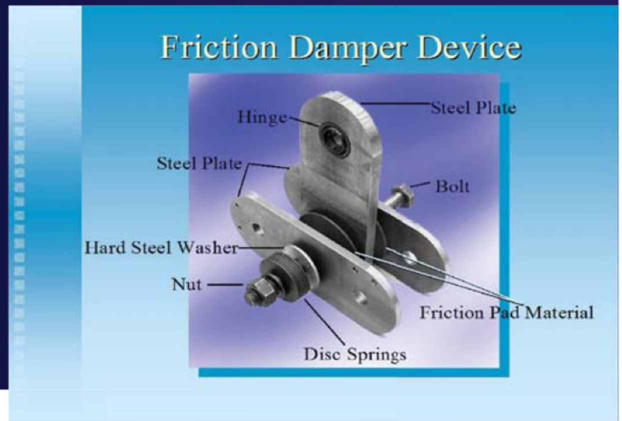

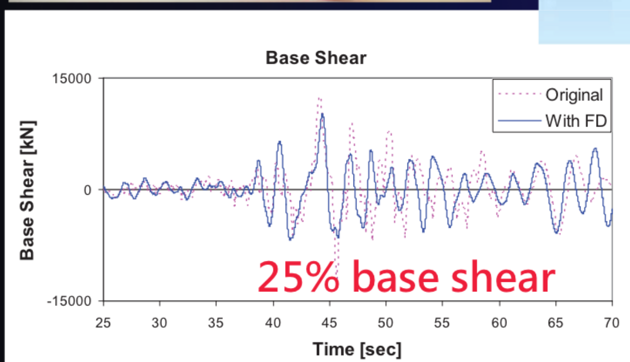

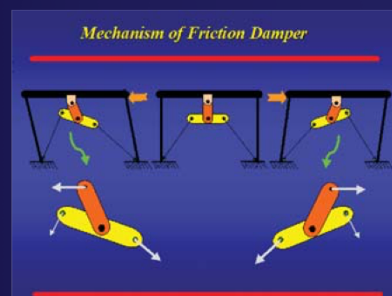

Result of Friction type Dampers

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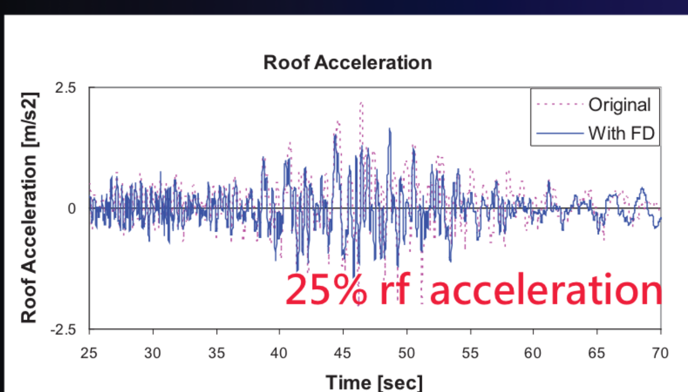

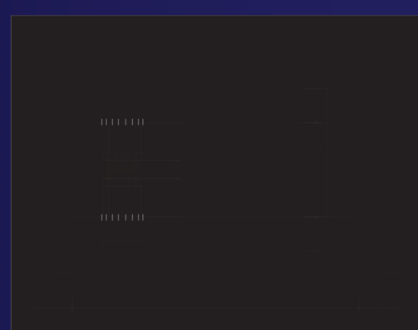

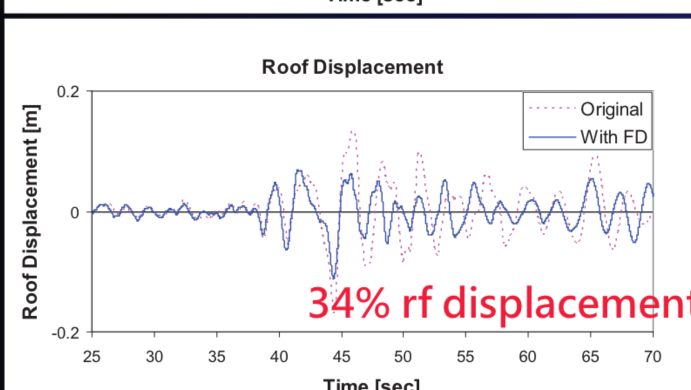

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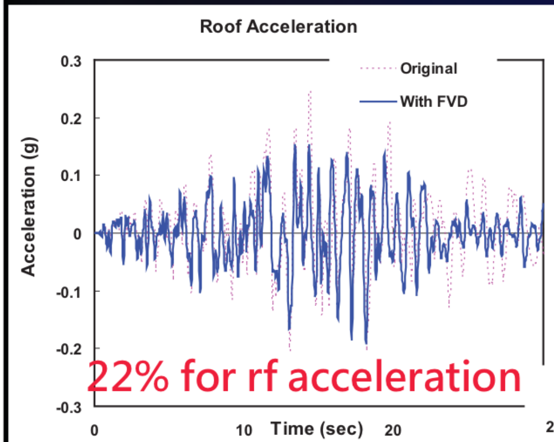
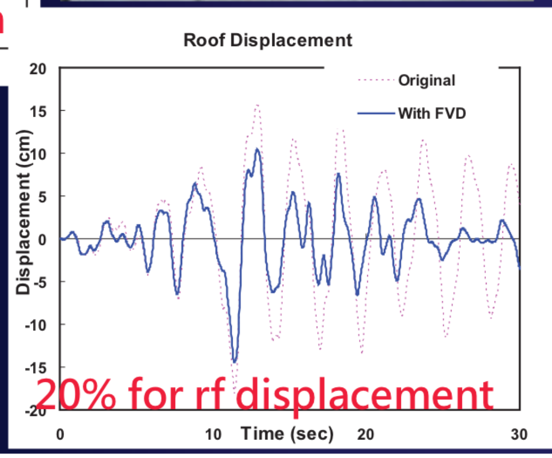
Result of FVD (Fluid Viscous Damper)





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Performance comparison for types of dampers

	Performance items	Deduction of Building with types of Dampers		
		Fluid viscous (FVD)	Friction (FD)	Visco-elastic (VEM)
1	Base shear	about 26%	about 25%	約19%
2	Rf acceleration	about 22%	about 25%	約25%
3	Rf displacement	about 20%	about 34%	約18%
4	Installed floor and the quantity be used	2F-14F 4 sets in each direction	2F-16F 4sets in each direction	2F-11F 4set each dir. 12F-18F 2sets each dir.
5	Total quantity	104 sets	120 sets	108 sets
6	Damper cost	104.5%	100%	105.2%

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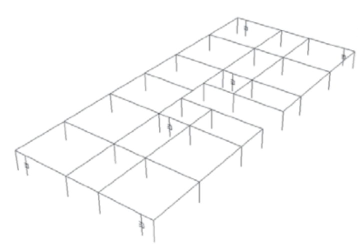
Contain

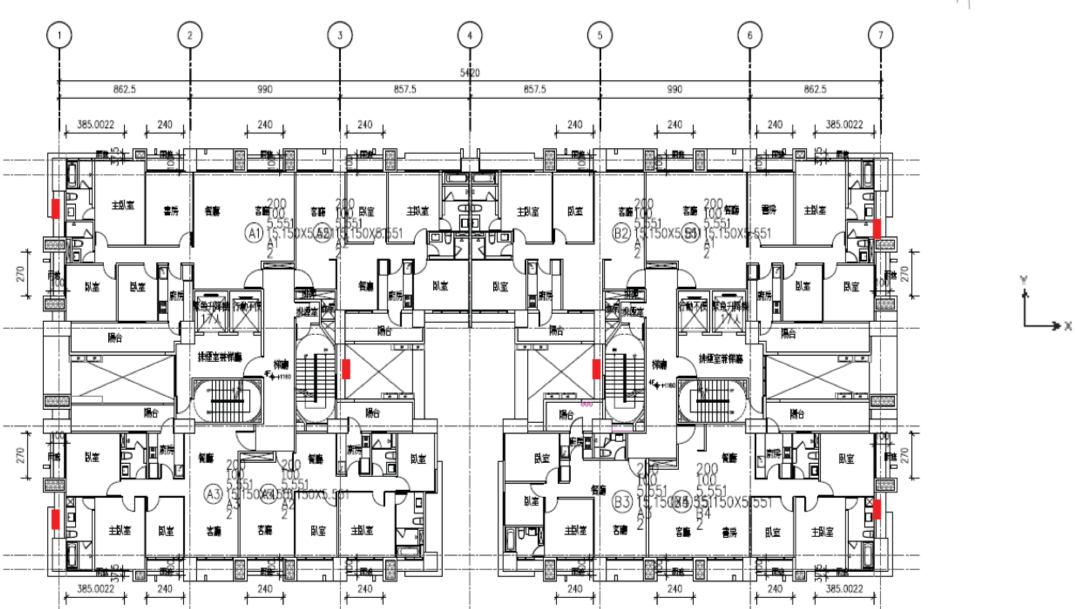
- Familiar Passive Control Device in Taiwan
- Effective damping ratio of linear dampers
- Application of dampers in tall buildings
- Concerns of Damper replace Reinforcement
- Design Example For Building with FVD Damper

Dampers arrangement In plan



6 Dampers
in Y direction

Stories with damper
Scheme A：3F~16F



921 and 331 earthquake records

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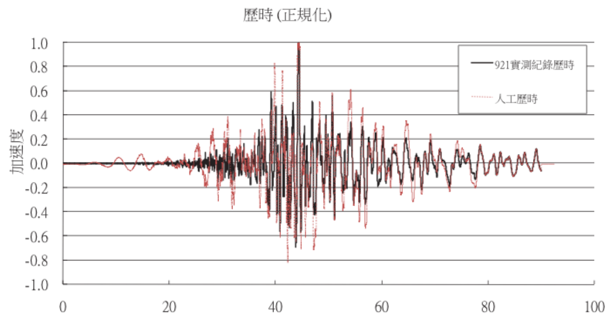
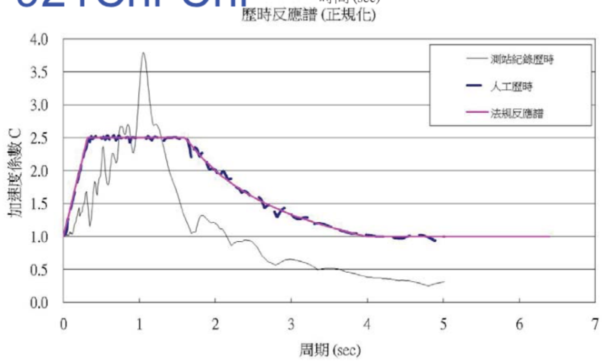
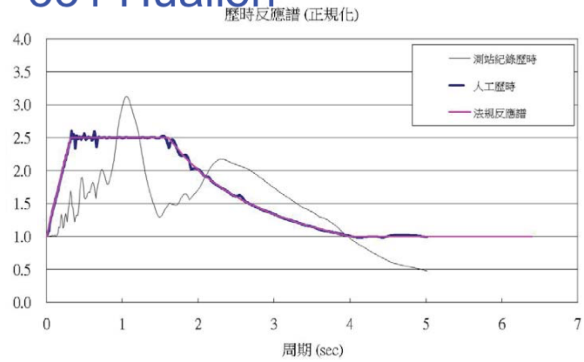


921Chi-Chi



331 Hualien



Compatible spectrum with code requirement

Comparison of story shear

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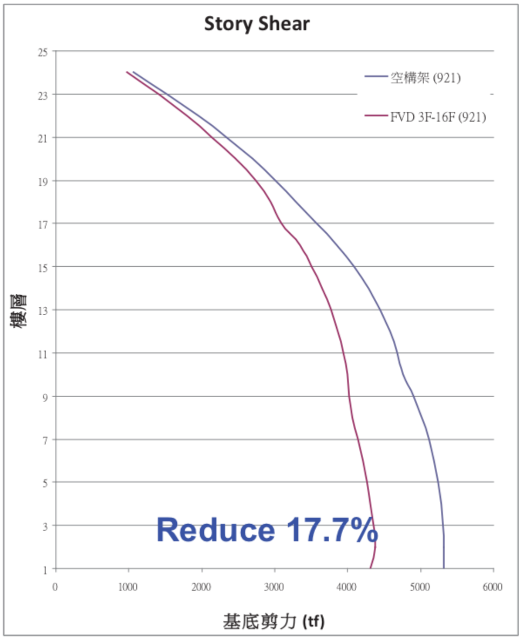
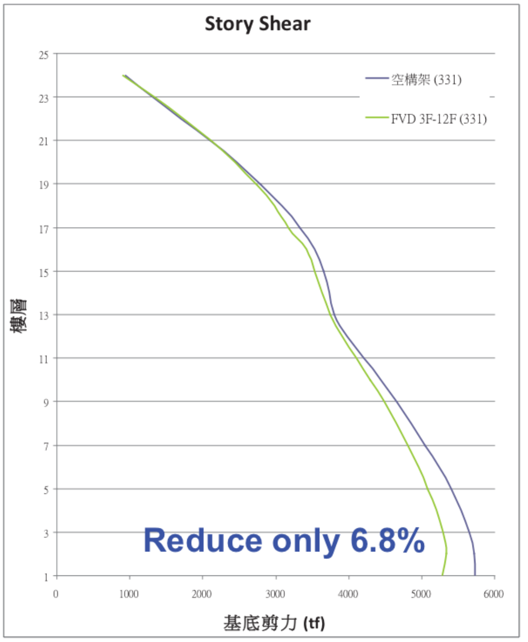


基底剪力 (tf)	Y向	
空構架 (921)	5322	基準
FVD構架 3F-16F (921)	4379	-17.7%

921Chi-Chi compatible quake



基底剪力 (tf)	Y向	
空構架 (311)	5730	基準
FVD構架 3F-16F (331)	5340	-6.8%

331 Hua-lien compatible quake

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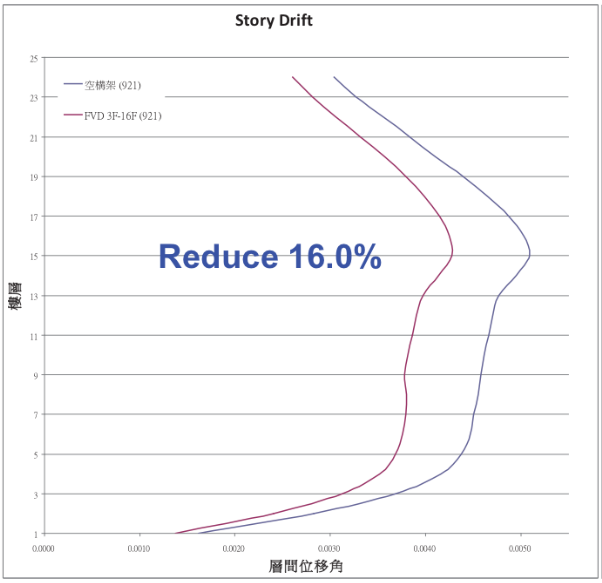
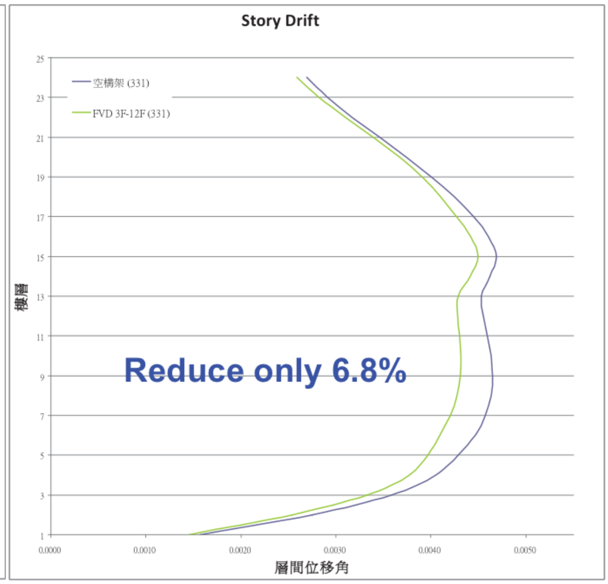
Comparison of story drift





層間位移	Y向	
空構架 (921)	0.0051	基準
FVD構架 3F-16F (921)	0.0043	-16.0%

921Chi-Chi compatible quake

層間位移	Y向	
空構架 (331)	0.0047	基準
FVD構架 3F-16F (331)	0.0045	4.2%

331 Hua-lien compatible quake

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The concerns of FVD Damper replace Steel

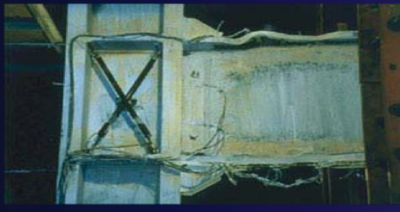
1. Uncertainty of Seismic Record's characters:

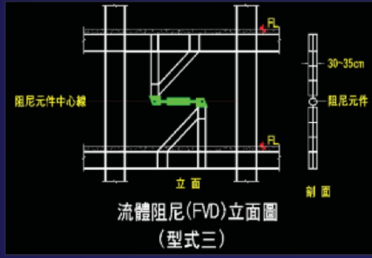
Two records, even from the same location, compatible to Code-basis design spectrum, the performance were still quite different !

2. Uncertainty of dampers performance In DBE or MCE severe earthquake：

Lots of plastic hinges occurs on Frame, Damper should be remained stability in all direction during large deformation。

FEMA: The components and the connections transferring forces between the energy dissipation devices shall be designed to remain linearly elastic for the 130% velocity correspond to MCE earthquake.





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The concerns of FVD Damper replace Reinforcement

1. Uncertainty of Seismic Record's characters:

   Two records, even from the same location, compatible to Code-basis design spectrum, the performance were still quite different !

2. Uncertainty of dampers function In DBE or MCE severe earthquake :

   Lots of plastic hinges might occur on Frame, Damper should be remained stability in all direction during large deformation 。

3. Uncertainty of Damping ratio evaluation :

   Currently we are using Energy Method to figure out the equivalent Damping ratio by fundamental translation modes. More research were expected for non-linear dynamic time history.

Most of viscous damper purpose: better serviceability

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Contain

- Familiar Passive Control Device in Taiwan
- Effective damping ratio of linear dampers
- Application of dampers in tall buildings
- Concerns of Damper replace Reinforcement
- Design Example For Building with FVD Damper

Design Example For Building with FVD Damper

- Structural outline
  - Location：High seismic zone with near fault effect
  - Scale：6 floors above grade with one level basement
  - Type：Office
  - Material：Steel structure
  - Seismic System：Moment Resistant Frame (SMRF) + FVD damper
  - Story Height 4.0m，Total 24.0m

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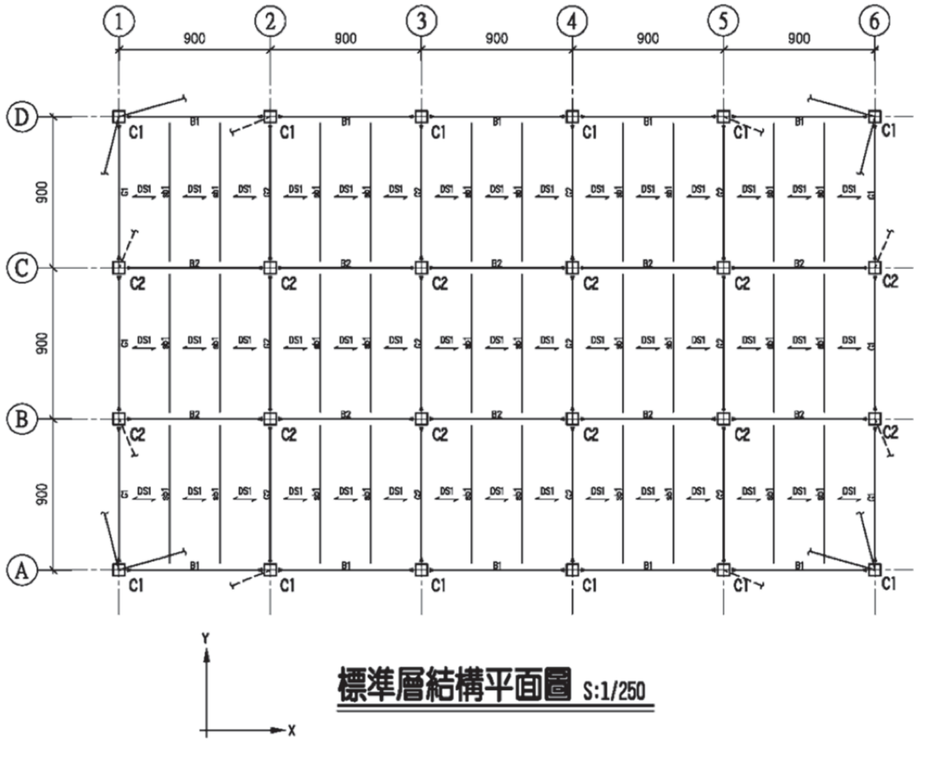
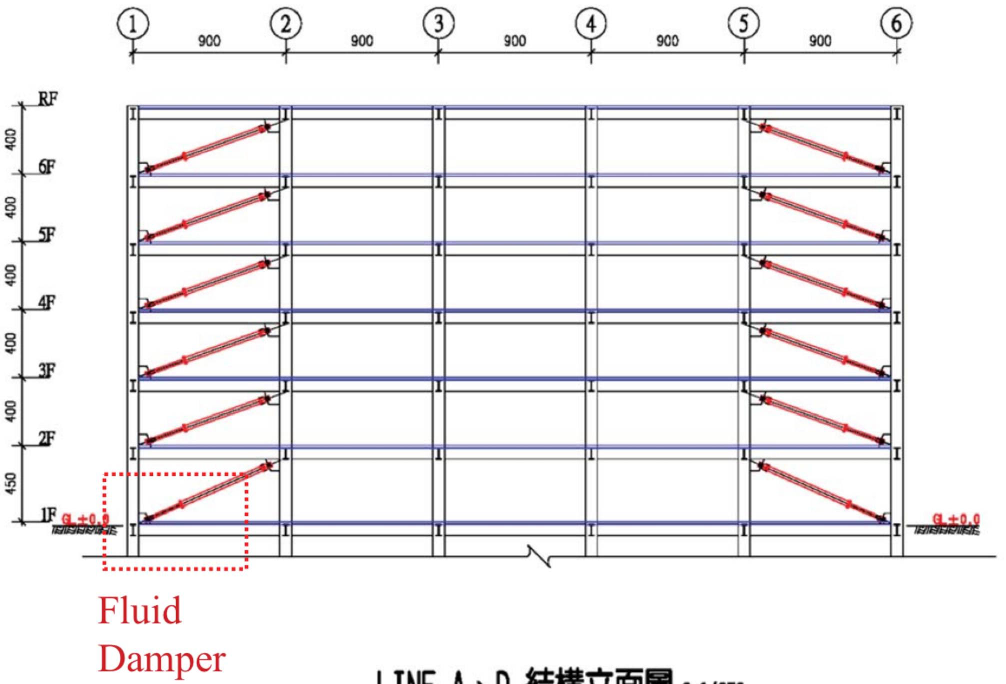
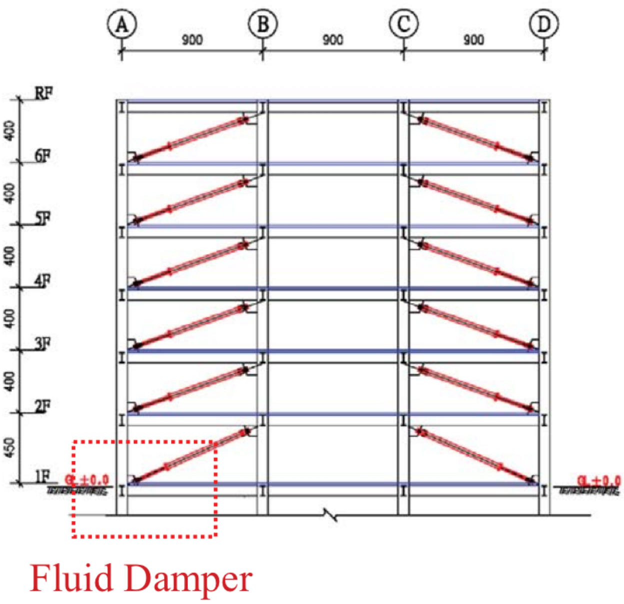


標準層結構平面圖 S:1/250



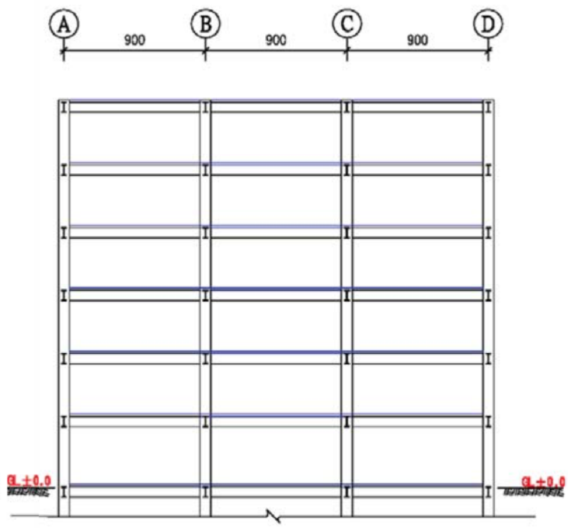
LINE A、D 結構立面圖 S:1/250

註：1.樓版高低差詳建築圖,梁高程以建築圖為準。



LINE 1、6 結構立面圖 S:1/250

註：1.樓版高低差詳建築圖,梁高程以建築圖為準。



LINE 2~5 結構立面圖 S:1/250

註：1.樓版高低差詳建築圖,梁高程以建築圖為準。

Design Spectral Acceleration Parameters

- Located on Chia-yi city, Spectral parameters are as follows ：
- $S^D{}_S = 0.8$ $S^D{}_1 = 0.45$ $S^M{}_S = 1.0$ $S^M{}_1 = 0.55$ [Table 2-1]
- Near Active fault : Mei-shan Fault
- Near Fault parameter $N_A = 1.37$, $N_V = 1.44$
  $N_{A\text{-}M} = 1.30$, $N_{V\text{-}M} = 1.48$ [Table 2-5-4]
- Site soil class is Type II, Site coefficient are as following
- DBE earthquake level (475 years returned Period) $F_a = 1.0$, $F_v = 1.2$
- MCE earthquake level (2500 years returned Period) $F_a = 1.0$, $F_v = 1.1$
- $S_{DS} = N_A F_a S^D{}_S = 1.096$ [Section 2.5]
- $S_{D1} = N_V F_v S^D{}_1 = 0.7776$
- $T^0{}_D = 0.709$ sec [Section2.6]
- $S_{MS} = N_{A\text{-}M} F_a S^M{}_S = 1.30$ [Section 2.5]
- $S_{M1} = N_{V\text{-}M} F_v S^M{}_1 = 0.8954$
- $T^0{}_M = 0.689$ sec [Section2.6]

Analysis Method of structure model include dampers

1 . Linear Procedure

Linear Static Procedure (LSP)

Linear Dynamic Procedure (LDP)

- Linear Procedure are only permitted if it can be demonstrated the frame system exclusive of the energy dissipation device REMAIN essentially linearly ELASTIC for the level of earthquake demand of interest after the effect damping are considered
- The effective damping ratio shall not exceed 30%

2 . Nonlinear Static Procedure (NSP)

3 . Nonlinear Dynamic Procedure (NDP)

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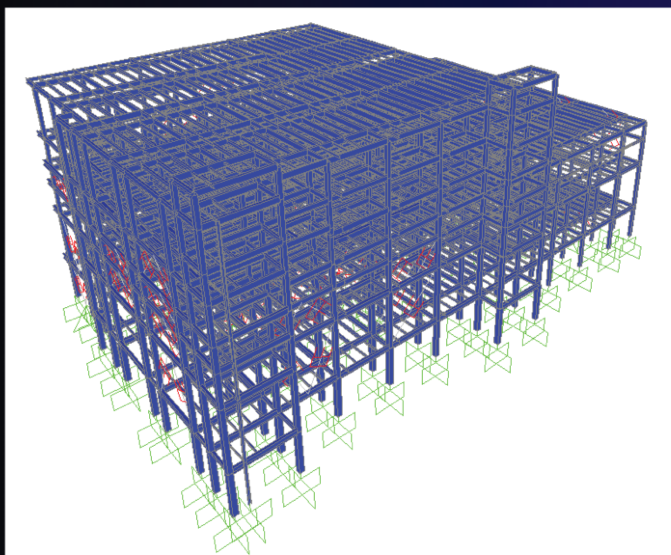
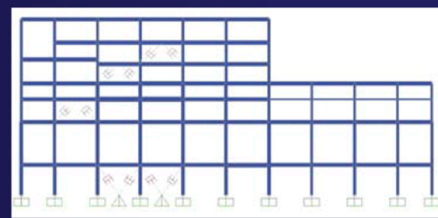
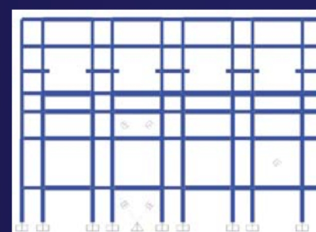
Nonlinear dynamic or pushover?







Need 2 weeks to complete one comprehensive nonlinear Time-History run

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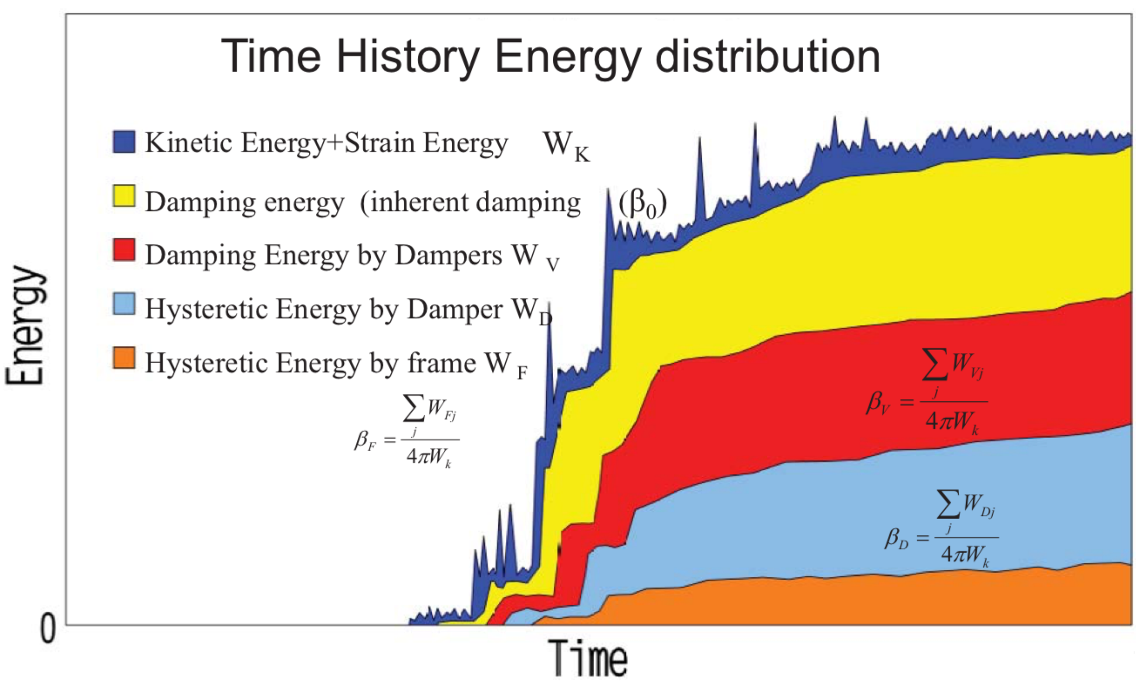
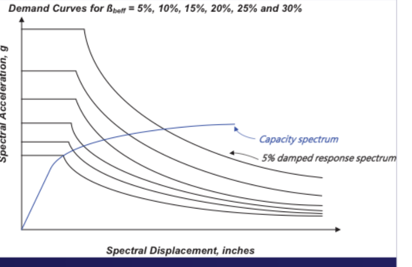
Equivalent Damping Ratio

Energy Distribution of DBE eqrthquake(475 years returned period)

Damping ratio varies with Earthquake Hazard level



- Structural Inherent Damping β_0 :
- Equivalent Hysteretic Damping of Displacement damper β_D : $\beta_D = \dfrac{\sum_j W_{Dj}}{4\pi W_k}$



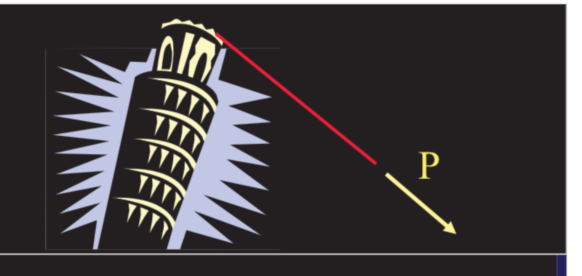
- Equivalent Viscous Damping of Velocity Damper β_V : $\beta_V = \dfrac{\sum_j W_{Vj}}{4\pi W_k}$
- Equivalent Hysteretic Damping of Frame β_F : $\beta_F = \dfrac{\sum_j W_{Fj}}{4\pi W_k}$

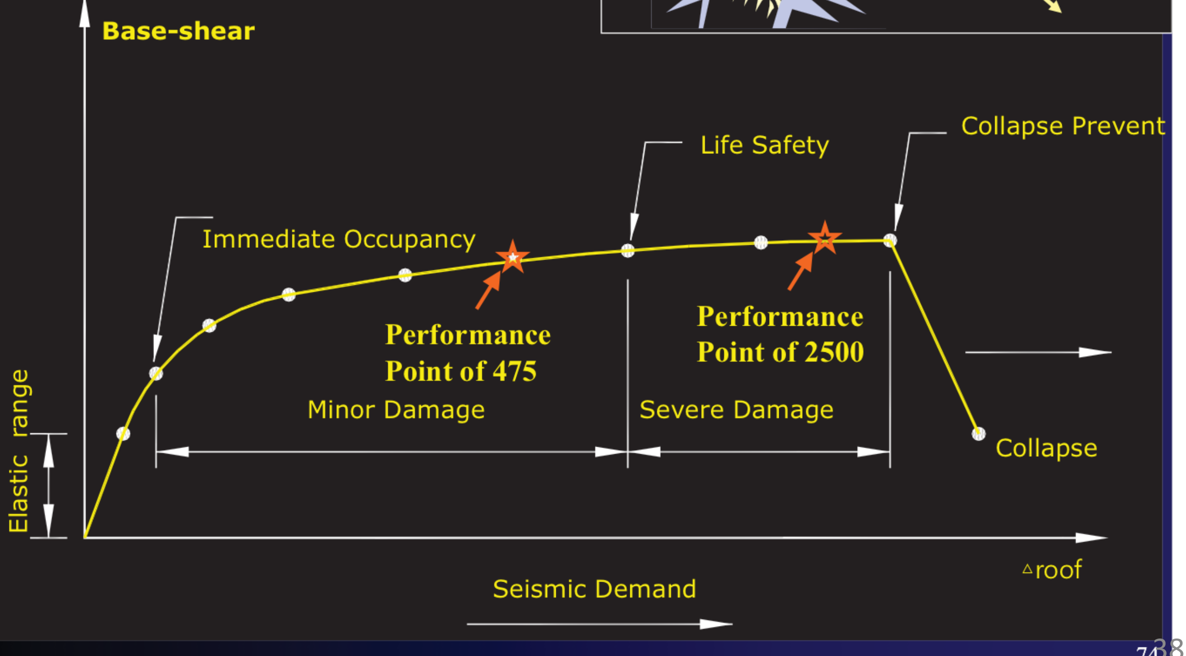
Total Damping of structural $\beta_{eff} = \beta_0 + \beta_D + \beta_V + \beta_F$

Where W_{Dj} 、 W_{Vj} 、 W_{Fj} are the work done by the *j* devices of Displacement damper, Velocity damper and Frame element in one complete cycle corresponding to specified floor displacement.

W_K is the maximum strain energy in frame $W_K = \dfrac{1}{2}\sum_i F_i u_i$

Performance Objective and Capacity Curve





Evaluated of Effect damping ratio at PT

$$\beta_V = \frac{\sum_j W_{Vj}}{4\pi W_k} = \xi_1 \quad \sum W_{Vj} = \left(\frac{2\pi}{T_S}\right)^{\alpha} \sum \lambda C_j \left|\Delta_{rj} \cos\theta_j\right|^{1+\alpha} \quad W_K = \frac{1}{2}\sum_i F_i u_i$$

W_{Vj} is the work done by the j devices of velocity damper in one complete cycle corresponding to floor displacement subject to performance point of concerned quake event.

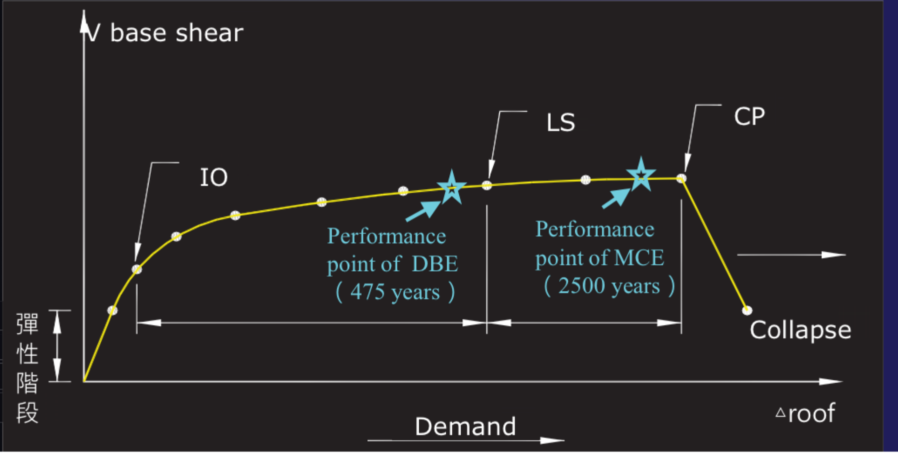
W_K is the maximum strain energy

T_s is the secant period corresponds to Performance point

$$\lambda = 2^{2+\alpha} \frac{\Gamma^2(1+\alpha/2)}{\Gamma(2+\alpha)}$$

Parameter λ

See Table C9-4 of FEMA 274



- Assuming the total viscous damping ratio ($\beta_0 + \beta_v$) are more than 15% , The Seismic base shear could be reduced by damping modification factor B. Based on the reduced shear, column could be designed as shown in table:

Story	label	Member size (mm)	Material
1F~2F	C1	Box 700×700×22×22	fy=2500 kg/cm²
3F~6F	C1	Box 600×600×25×25	
1F~2F	C2	Box 650×650×22×22	
3F~RF	C2	Box 600×600×20×20	

$$V = \frac{S_{aD}}{R} * IW \qquad S_{aD} = \frac{S_{DS}}{B_S} or \frac{S_{D1}}{B_1 T}$$

Damping modification factor B:

Damping Coefficients Bs and B1 as a Function of Effective Damping Ratio B

有效阻尼比ξ(%)	B_S	B_1
<2	0.80	0.80
5	1.00	1.00
10	1.33	1.25
20	1.60	1.50
30	1.79	1.63
40	1.87	1.70
>50	1.93	1.75

Taiwan Seismic code

Note: The damping coefficient should be based on linear interpolation for effective damping value other than those given.

Table 15.6-1
Damping Coefficient, B_{V+1}, B_{1D}, B_R, B_{1M}, B_{mD}, or B_{mM}

Effective Damping, β (percentage of critical)	B_{V+1}, B_{1D}, B_R, B_{1M}, B_{mD} or B_{mM} (where period of the structure $\le T_0$)
≤2	0.8
5	1.0
10	1.2
20	1.5
30	1.8
40	2.1
50	2.4
60	2.7
70	3.0
80	3.3
90	3.6
≤100	4.0

FEMA 450 and ASCE 41-06

$B_1 = 4/(5.6-\ln(100\beta))$

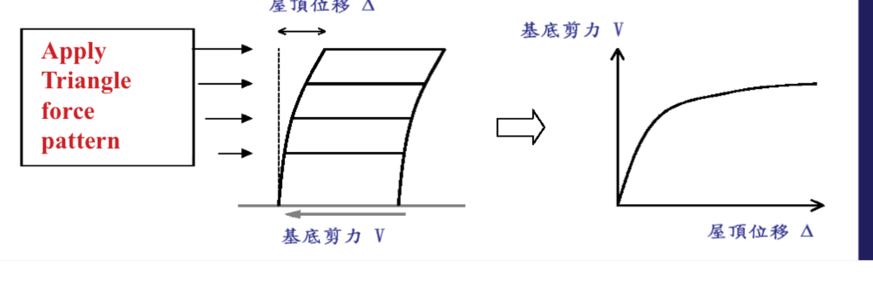
Pushover procedure
-- for Nonlinear Fluid Viscous Damper

(Step 1) Determine target viscous damping ratio, figure out member size and damper quantity and layout in plane and elevation, damper's parameter

- Target on total viscous β_{eff}=15%, calculate reduced code base shear with 15% damping by factor B, the reduced base shear, according to Taiwan code, should not less than 80% of normal code base shear of inherent 5% damping ratio.
- Arrange 4 sets of FVD in each direction each floor, $F=CV^{\alpha}$, α=0.3

(Step 2)Pushover analysis

- Apply sustained load 100%Dead load+50%live load as the initial load
- Apply vertically Triangle (or mode) force pattern to be the force incremental pattern in pushover analysis
- Transfer into ADRS(Acceleration-Displacement Response Spectra) and Capacity Spectrum and Input the Demand Spectrum (5% of MCE quake)

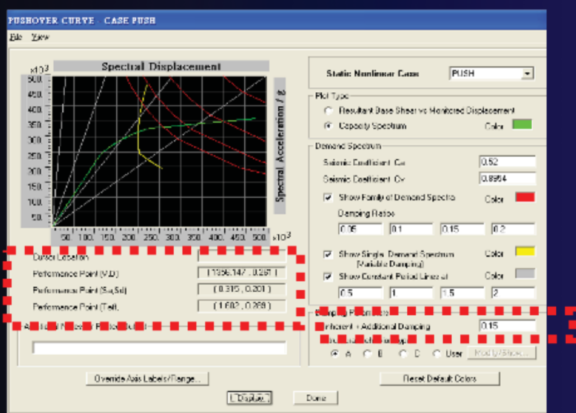


Pushover procedure
-- for Nonlinear Fluid Viscous Damper

(step 3) Assuming the viscous damping in MCE stage is equal to what we expected in step 1, where includes:

- Structural inherent damping β_0=5%
- Plus additional damping from viscous damper β_v=10%
- In put Damping ratio =$\beta_0+\beta_v$= 15% in the "Inherent damping ratio + additional damping ratio" dialog box

(Step 4) Perform the Pushover analysis to get the Performance point



- Roof displacement D=0.261m
- Base shear V=1356 t
- Total damping of entire structural $\beta_{eff} = \beta + \beta_v + \beta_h$ = 28.9%
- Structural foundamental period at performance point is Teff = 1.602 sec

Pushover procedure
-- for Nonlinear Fluid Viscous Damper

(Step 5) export for all the story drift in accordance with the Performance point

(Step 6) determine the damping constant (C, $F=CV^{\alpha}$) of each device in vertical arrangement

- Assume C is proportional to story shear where it installed , C1/V1≒C2/V2≒……≒Ci/Vi
- To simplfy in this case, C group into 3 types： C1~2F: C3~4F: C5~6F=9:8:5

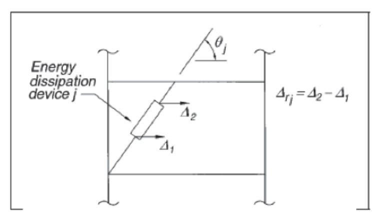


Figure C9-26 Definition of Angle and Relative Displacement of Energy Dissipation Device

(Step 7) Calculate the effective damping ratio β_v

- Through the roof displacement, story drift, to figure out the damper's deformation and the viscous work with the given damper's C and α value accordingly.

$$\beta_V = \frac{\sum_j W_{Vj}}{4\pi W_k} = \xi_1$$

W_{Vj} is the work done by the j devices of velocity damper in one complete cycle corresponding to floor displacement subject to performance point of concerned quake event.

$$\sum W_{Vj} = \left(\frac{2\pi}{T_S}\right)^{\alpha} \sum \lambda C_j \left|\Delta_{rj} \cos\theta_j\right|^{1+\alpha} \quad W_K = \frac{1}{2}\sum_i F_i u_i \quad \lambda = 2^{2+\alpha}\frac{\Gamma^2(1+\alpha/2)}{\Gamma(2+\alpha)}$$

Pushover procedure
-- for Nonlinear Fluid Viscous Damper

(Step 10) Iteration to convergence

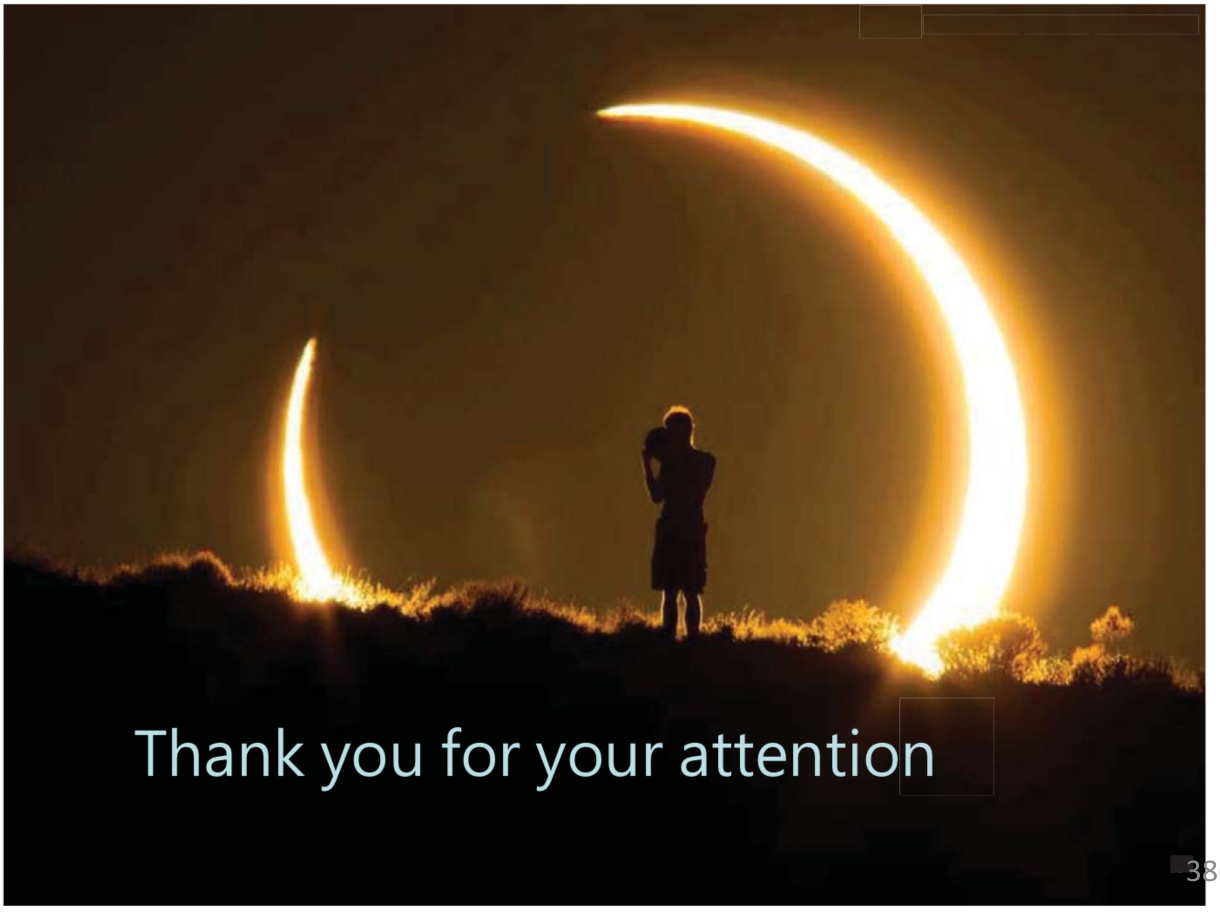
- Re-analysis pushover step3 by update calculated $\beta_{v,1}$ of step9 , Repeat step 3~8 till the calculated damping ratio $\beta_{v,i+1}$ of step9 in i+1 cycles is convergence, i.e. $abs(\beta_{v,i+1} - \beta_{v,i}) < tolerance$

(Step 11) Evaluated the capacity of FVDs in correspond to MCE quake event

- All dampers shall be capable of sustaining the force associated with velocity equal to 130% of the maximum calculated velocity for the device in MCE.
- Calculated the velocity demand (V) by damper's relative deformation and the secant fundamental period associated with the performance point of MCE, determine the FVD's force and stroke capacity

(Step12) The components and the connections transferring forces between the energy dissipation devices shall be designed to remain linearly elastic for the 130% velocity correspond to MCE earthquake.

	Damping constant C	Stroke	Nominal capacity F_D
RF	55.5	40	40
6F	55.5	40	40
5F	88.5	60	75
4F	88.5	60	75
3F	99.5	60	75
2F	99.5	60	75



Energy Dissipation vs. Isolation Design of High-Rise Mansion Buildings in Taipei Basin

Hsien-Kai Liu

Vice General Manager of New Structure Group & H.M Liao ARCH & Building Research Institute and Structure Engineer (S.E.) of R.O.C

Experiences

- Vice General Manager, NSG & HML ARCH.&BUILDING Research Institute (2017~ Present)
- Manager, NSG (2003~2017)

Hsien-Kai Liu joined NSG company in 2003. He has participated in the design of various types of structures, such as high-rise buildings, isolation structures, high-tech plants, structural reinforcement, energy dissipation design etc. He specializes in nonlinear structural analysis and seismic isolation design.

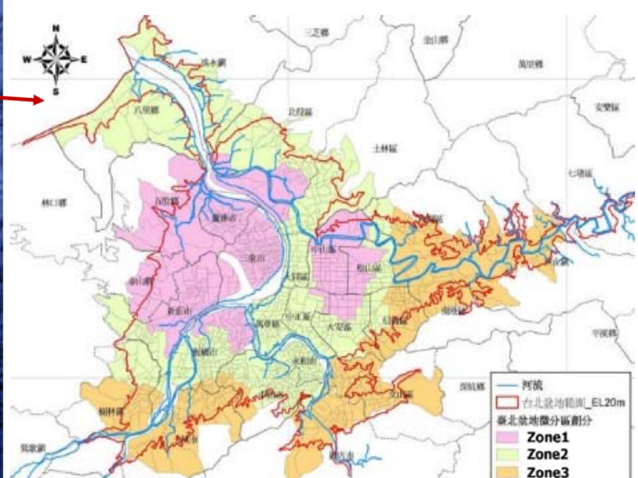
Mr. Liu is now a registered structural engineering of the Taipei Structure Engineering Association (TESA).

NSG was founded in 1976 by Dr. H.M.Liao. The company reputed with the two famous work in Taiwan, one is the first high-rise steel building in Taipei, introduced in 1981. And the other, Taipei Tzu Chi Hospital is the first large-scale earthquake-isolation hospital designed in 2000.

Energy Dissipation vs. Isolation Design of High-Rise Buildings in Taipei Basin

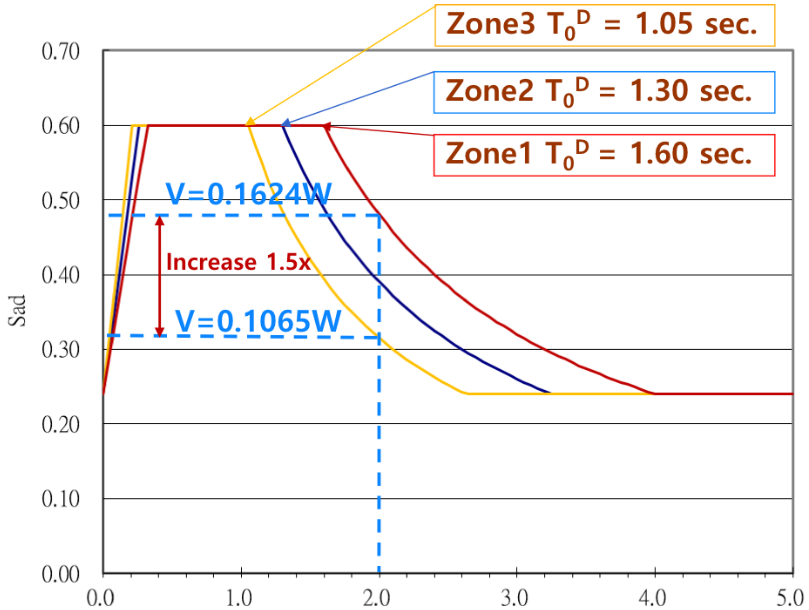
NEW STRUCTURE GROUP
Hsien-Kai Liu
Vice President

Introduction- Taipei Basin



Taipei Basin
Design acceleration response spectrum

NEW STRUCTURE



If the structure 1st model period=2sec

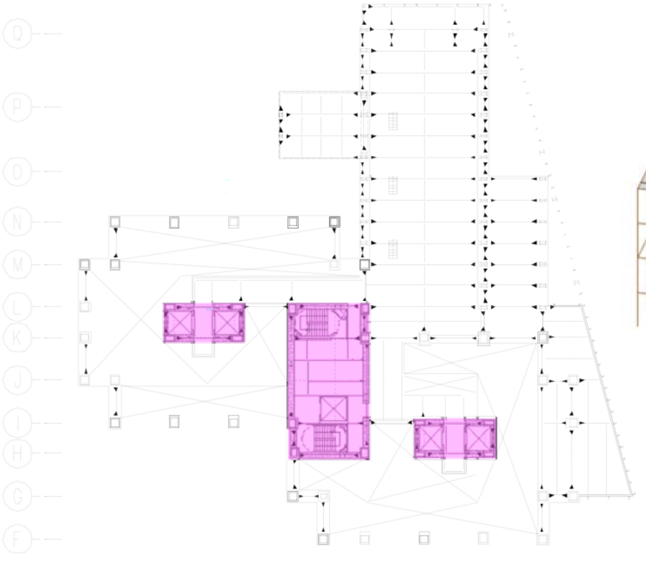
NEW STRUCTURE

CASE 1:Energy Dissipation

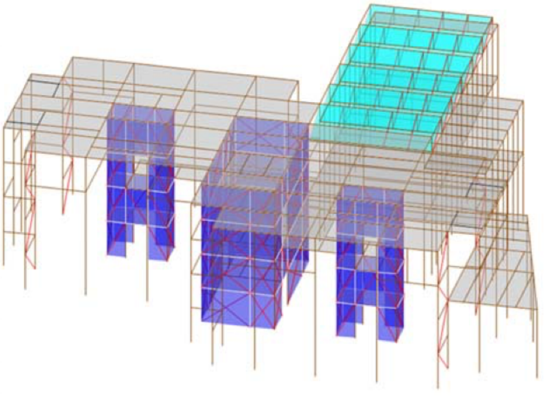
Case 1 Building Summary

- Area of construction base: 5,717.48 m^2,and the site is in Zone2.
- 38 stories aboveground, 4 stories underground
- 1st& 2nd floor height :7.2m , lobby height :14.4m
- Standard floor height:3.6m , Total height: 145m
- Dry-hang marble slab in outside column and beam
- Exterior wall is RC wall with sawed contraction joint or large window.
- Partition wall, separating wall and staircase wall are drywall.
- Central core wall is 15cm RC wall with sawed contraction joint.
- Elevator walls on both sides is use 45cm shear wall for the core wall.

Structure of 1st~2nd Floor



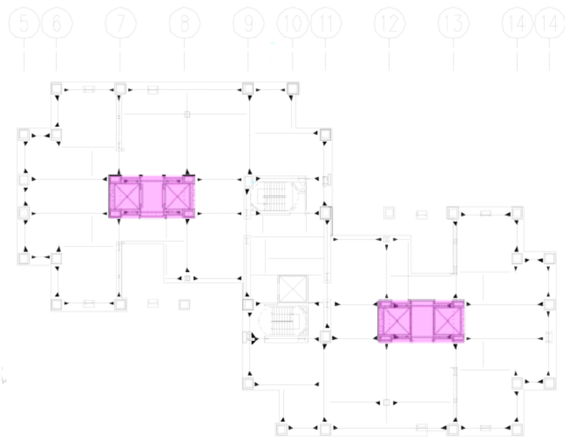
2nd Floor plane



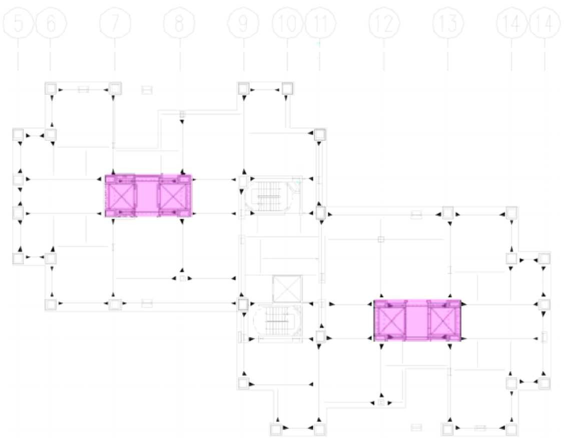
1st~2nd Floor

Structure Plane

NEW STRUCTURE



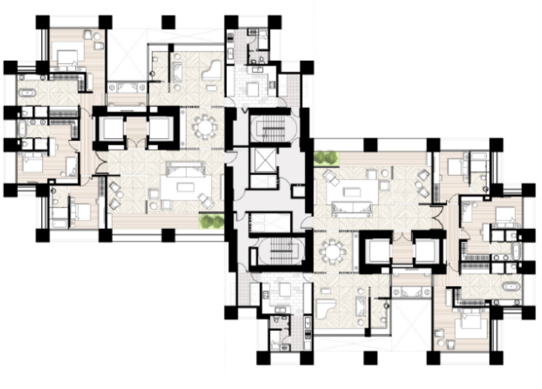
Even floor plane

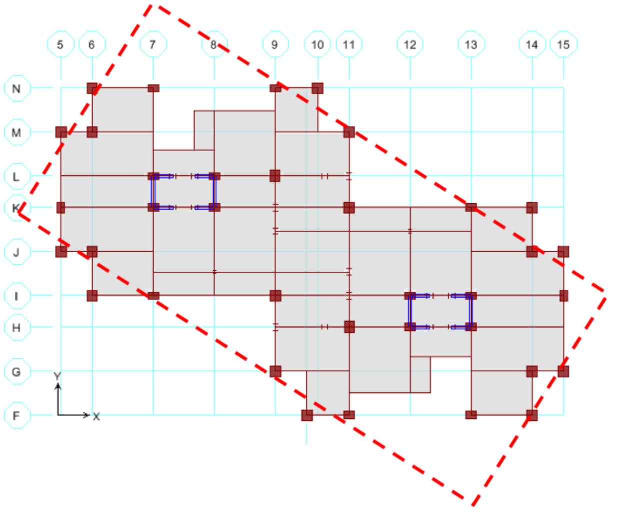


odd floor plane

Superstructure plane

NEW STRUCTURE





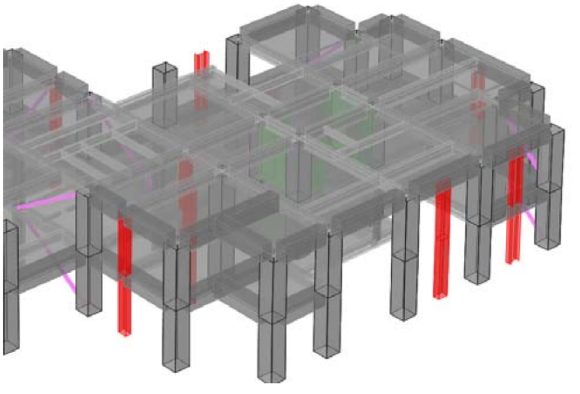
Plane Regularity

Dual Core Dislocation, Symmetry

Long side 55m,Short side 25m, Building height 145m

Stub column

NEW STRUCTURE



Design building facade of stud column matching structure requirements.

Structure summary

NEW STRUCTURE

- Steel Special Moment Resisting Frame+Buckling Restrained Brace(short side frame)+stub column(long side frame)
- 1F~2F central elevator core and elevator walls of both service core are 45cm shear wall.
- Above the 3F, the central elevator core is use VEM damper.
- Column size

  1F~2F: BOX-800×1000(CFT)+RC-1000×1200

  3F~20F: BOX-800×800(CFT)+RC-1000×1000

  above 21F: BOX-800×800+RC-1000×1000
- Beam size

  Exterior beam is Steel beam H850×(400~350) with covering 10cm RC

  Interior beam is Steel beam H700×(400~350)

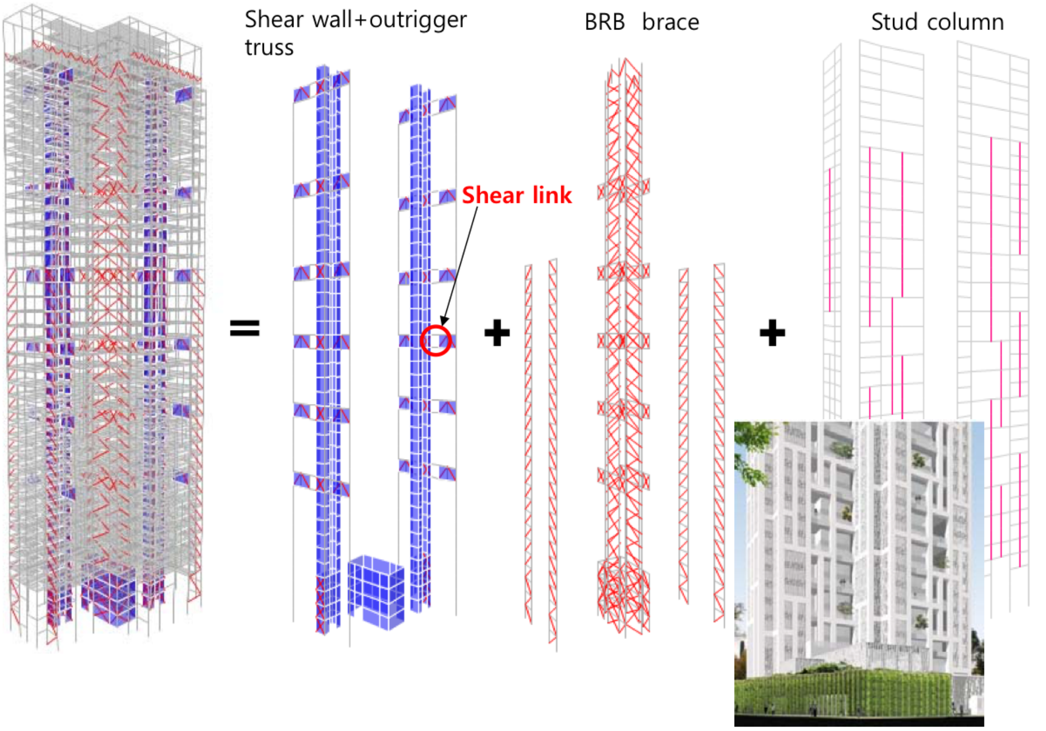
Structure system

NEW STRUCTURE

Problem / Correspond with	Soft Story of 1F	Stiffness (Torsion)	Strength	Toughness	Comfort performance
Central elevator core shear wall	●	●	●		
Service core shear wall	●	●	●		
VEM damper					●
Stub column		●	●		
Buckling Restrained Brace	●	●	●	●	
Outrigger truss		●	●		
Shear link				●	

Structure system

NEW STRUCTURE



Shear Link

NEW STRUCTURE

(a) Web Warping at $\gamma_{eff} = 0.18$ *rad* (b) Web Tearing Failure

Figure 6: Failure Mode of Link L225

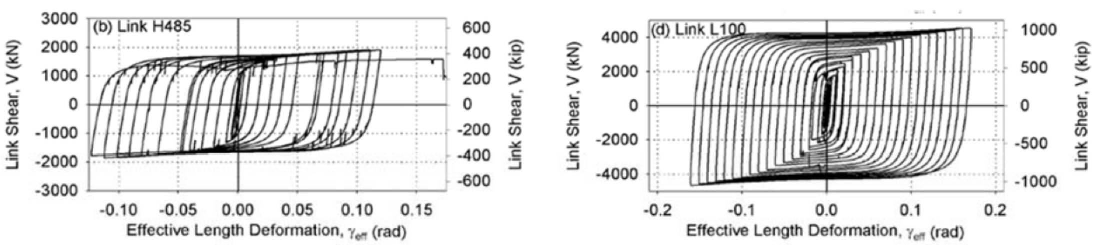
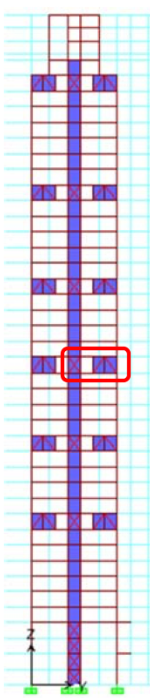
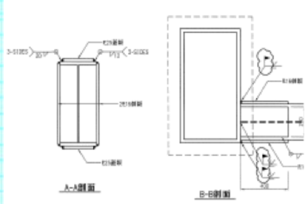


Figure 4: Hysteretic Response of Shear Links under Cyclic Loading

Shear link design

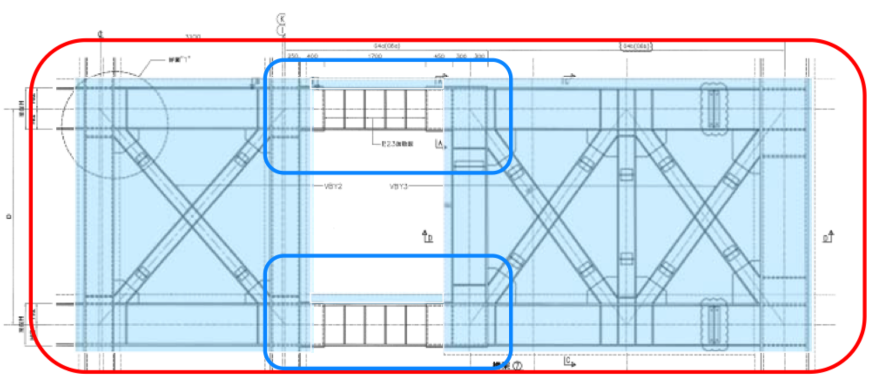
NEW STRUCTURE



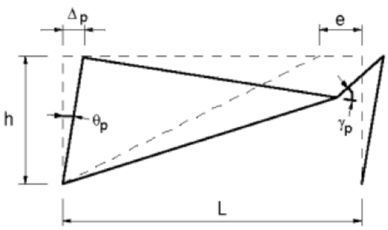


LINK DESIGN

1. Shear yield
2. Link rotation angle
3. Stiffeners
4. Connections
5. SRC shear wall design



Shear link plastic rotation



$$\gamma_p = \frac{L}{e}\theta_p$$

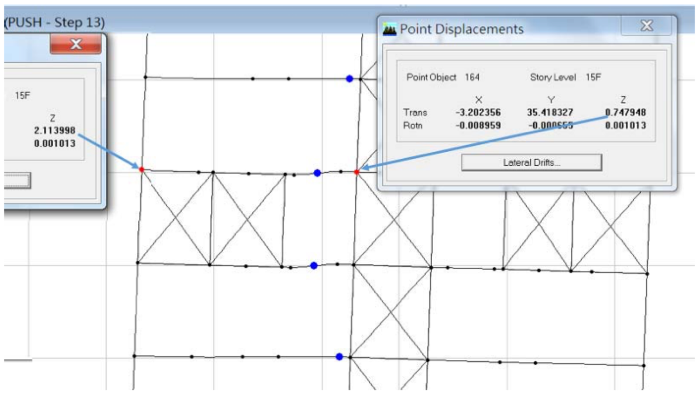
$$r_E = \theta_E \times \frac{L}{e}$$

$$r_P = r_E \times 1.4\alpha_y Fu$$ (Estimated value)

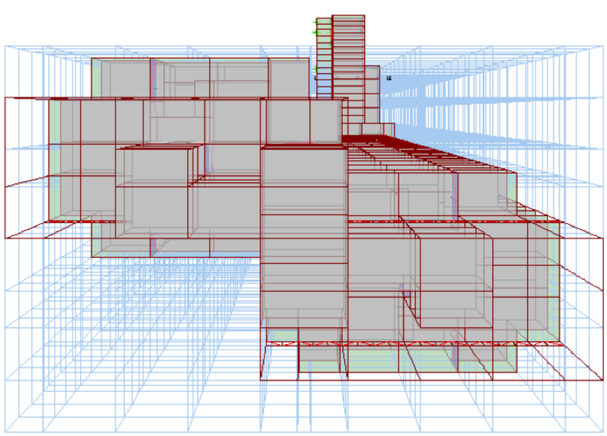
$$r_P = (\theta_{2500年} - \theta_{ROTATE}) \times \frac{L}{e}$$ (Pushover analysis value)

$$r_P = (0.01125 - (2.11 - 0.75)/8200) \times \frac{8200}{1700}$$
$$= 0.0535 < 0.08$$

Shear yield $e < 1.6 M_P / V_P$

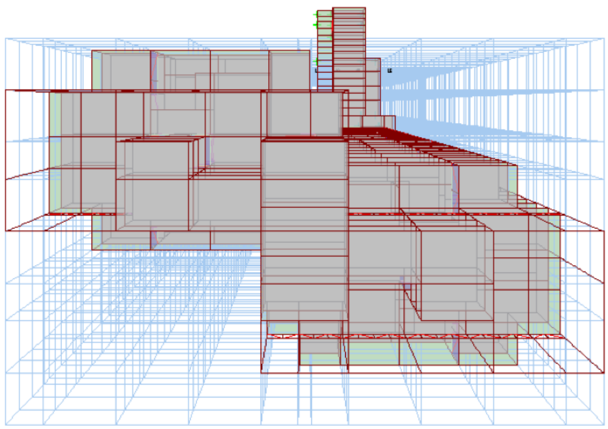


Mode 1 (T=2.9sec)



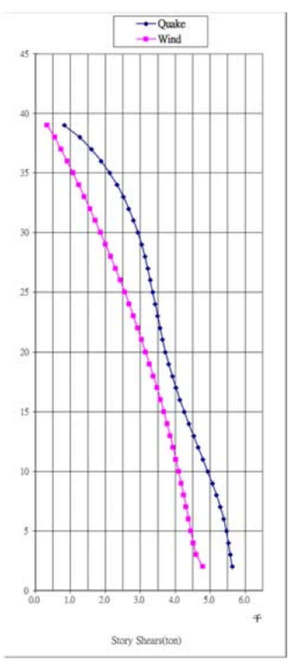
NEW STRUCTURE

Mode 2 (T=3.4sec)

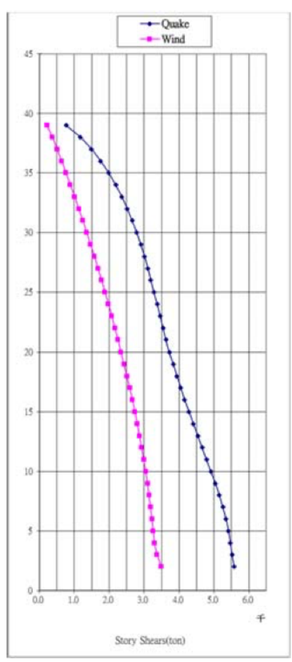


NEW STRUCTURE

Horizontal force



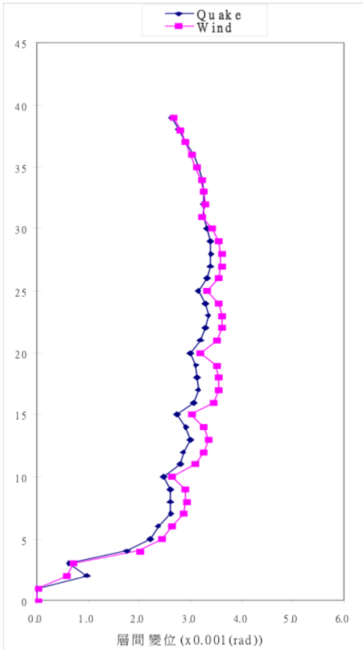
Short side



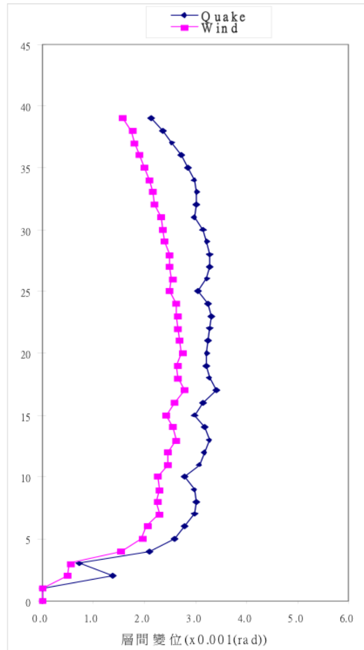
Long side

Compare earthquake and wind force (story drift)

NEW STRUCTURE



(short side)

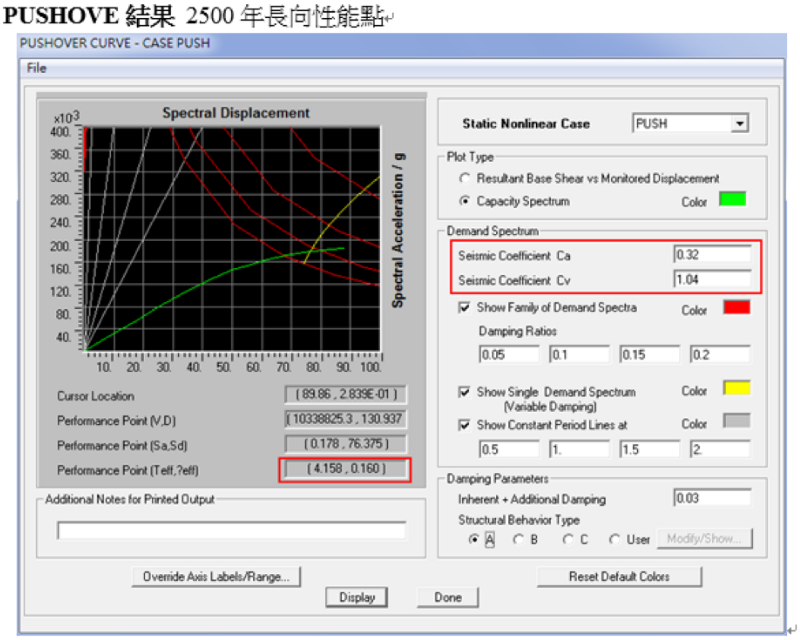


(long side)

Pushover analysis MCE performance point(long side)

NEW STRUCTURE

PUSHOVE 結果 2500 年長向性能點

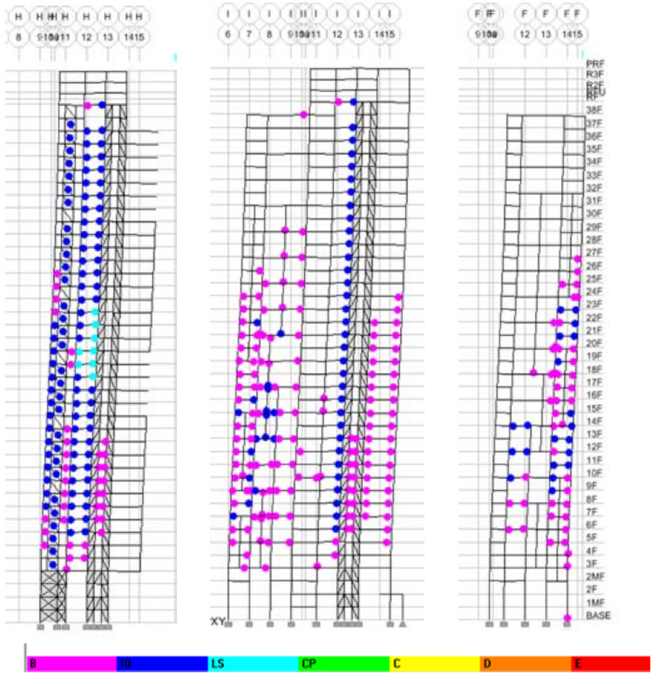


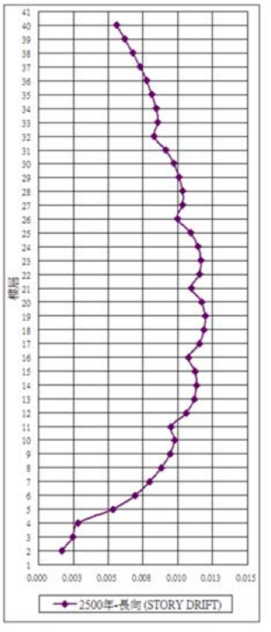
工址： $S_{DS}=0.8=2.5C_A$ $\therefore C_A=0.32$

$T_0^D=1.30=C_V/2.5C_A$ $\therefore C_V=1.04$

Pushover analysis(long side)

NEW STRUCTURE

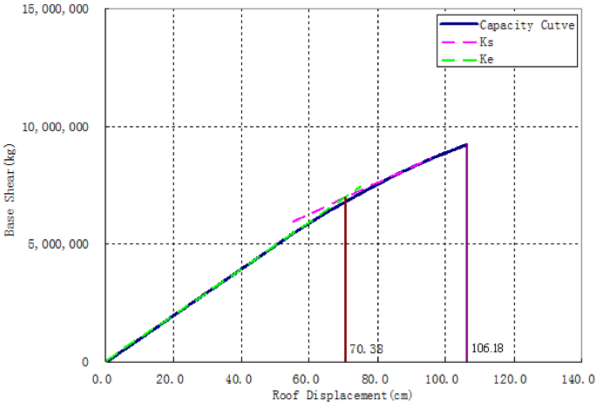




Pushover analysis

NEW STRUCTURE

長向 475 年

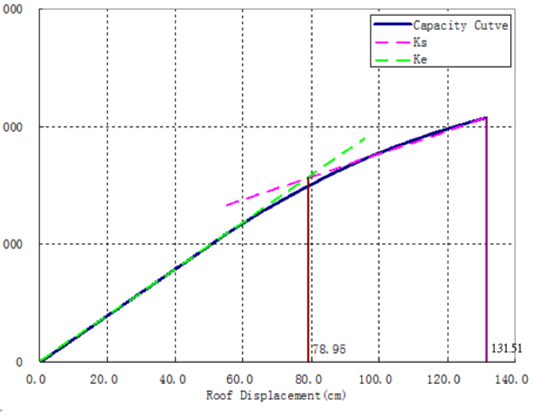


$\Delta u=106.18$

$\Delta y=70.38$

$R=\Delta u/\Delta y=106.18/70.38=1.5$

長向 2500 年



$\Delta u=131.51$

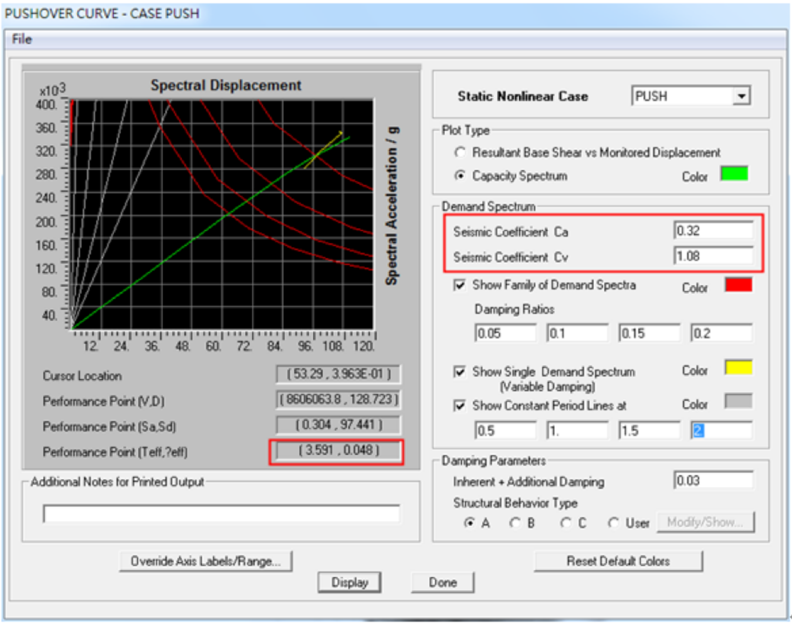
$\Delta y=78.95$

$R=\Delta u/\Delta y=131.51/78.95=1.67$

Pushover analysis
MCE performance point(short side)

NEW STRUCTURE

PUSHOVE 結果 2500 年短向性能點

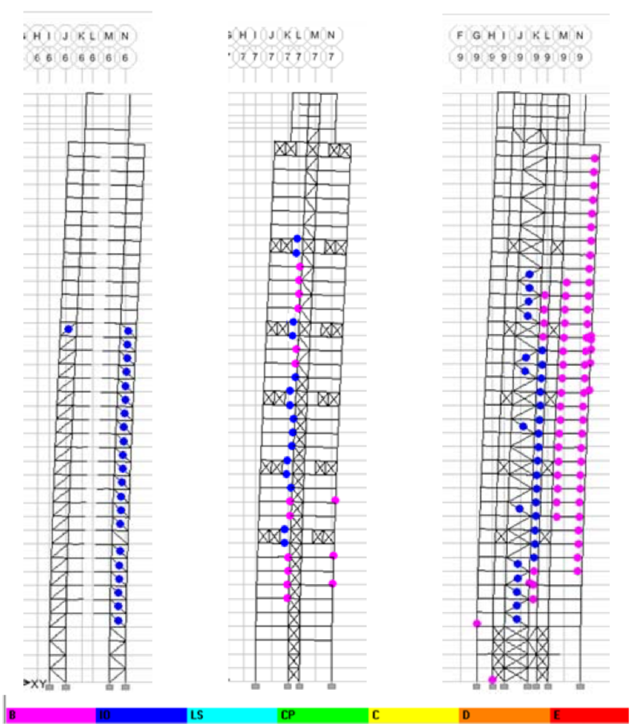


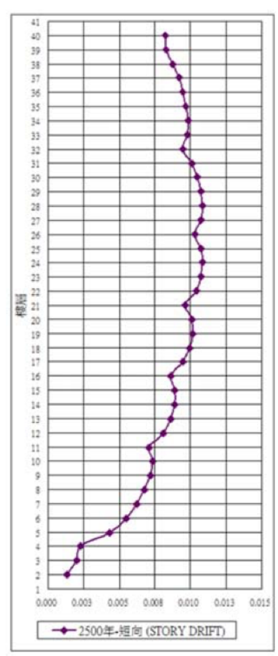
工址： $S_{DS}=0.8=2.5C_A$ $\therefore C_A=0.32$

$T_0^D=1.30=C_V/2.5C_A$ $\therefore C_V=1.04$

Pushover analysis(short side)

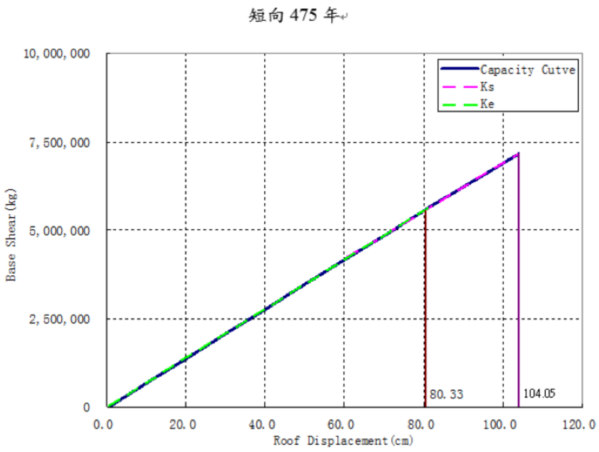
NEW STRUCTURE



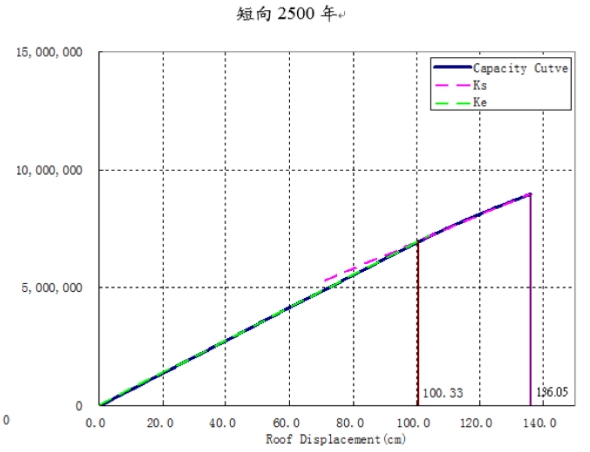


Pushover analysis

NEW STRUCTURE



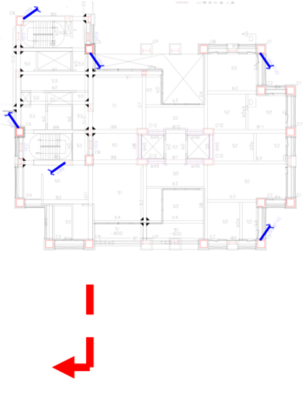
Δu=104.05
Δy=80.33
R=Δu/Δy=104.05/80.33=1.29

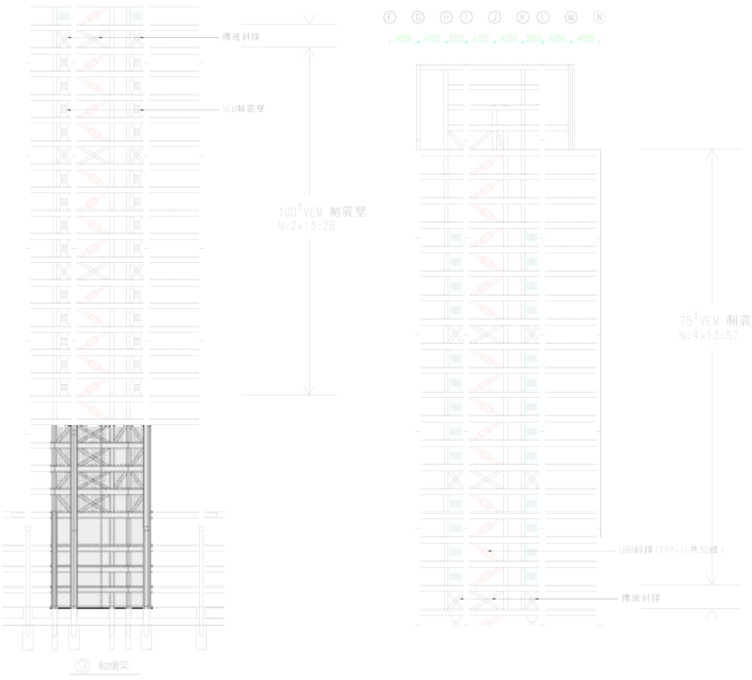


Δu=136.05
Δy=100.33
R=Δu/Δy=136.05/100.33=1.36

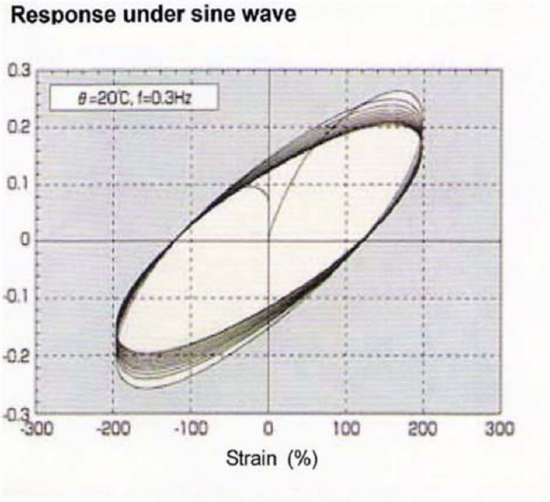
VEM damper arrange for wind

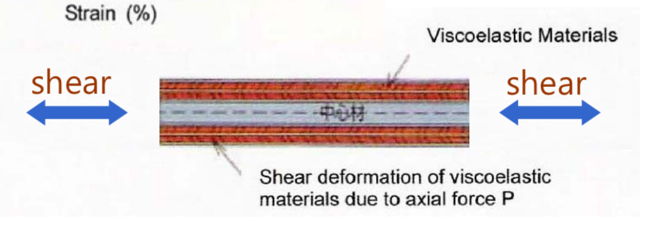
NEW STRUCTURE



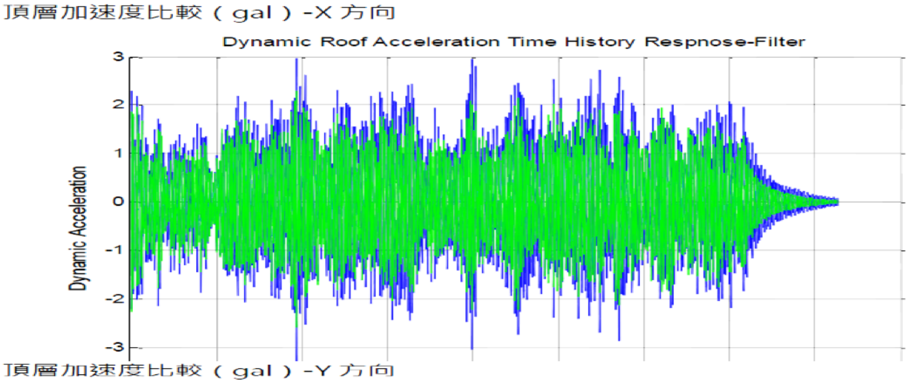


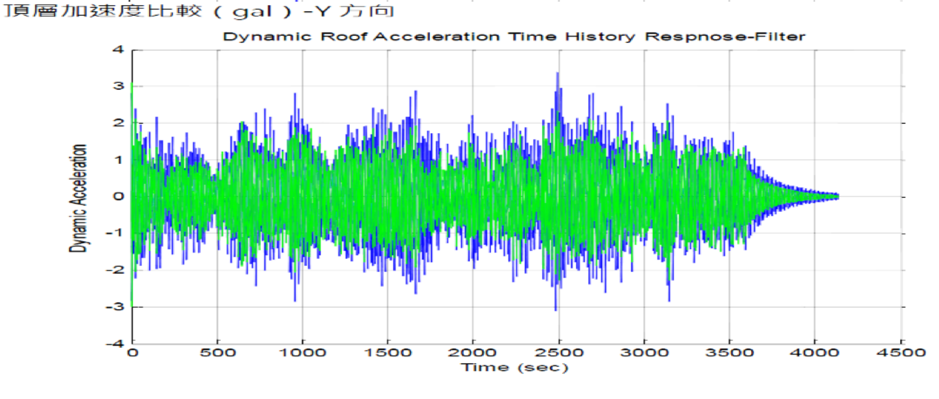
Velocity-displacement damper (NIPPON STEEL-VEM)





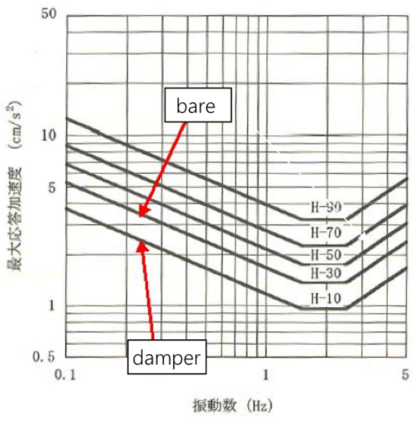
Result of wind load analysis

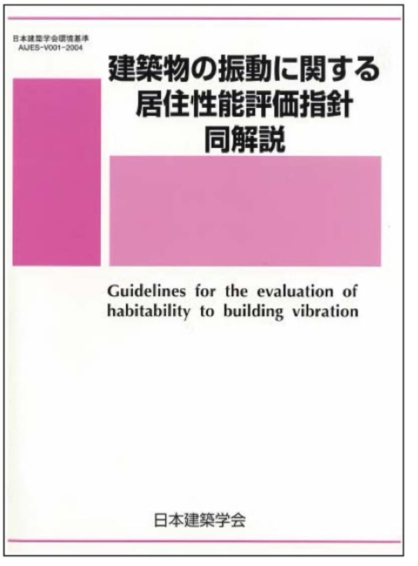




Result of wind load analysis

Damper quantity for wind load	75t VEM : 104 100t VEM : 52
Roof acceleration	bare frame:A=0.035m/sec^2
	damper frame:A=0.025m/sec^2





Conclusion of case1

1. The use of outrigger truss effectively increases the stiffness of slender structure and reduces the story drift.
2. Large earthquakes use BRB braces to (1) dissipate energy (2)combine rigidity and ductility (3) have good seismic resistance.
3. Designing the stud column of building façade is for matching structure requirements , increasing structural stiffness, and having aesthetics and mechanics.
4. Sufficient structural stiffness and velocity-displacement damper are for comfort performance of wind load.

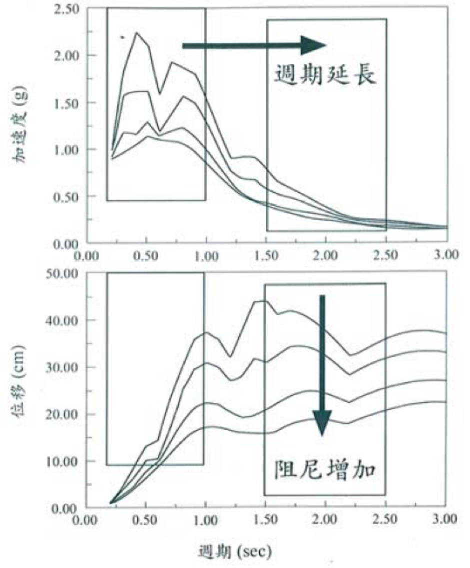
NEW STRUCTURE

CASE 2 : Isolation Design

NEW STRUCTURE

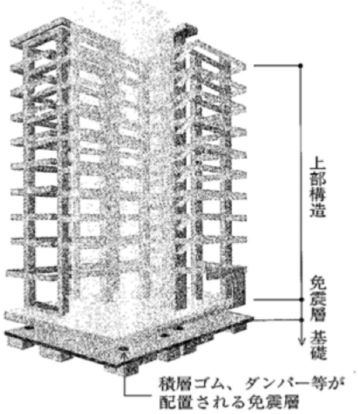
Basic concept of seismic base isolation

- The seismic design of the general building is based on the toughness which combine the structure strength and ductility.
- The seismic isolation structure is based on the isolation of the energy dissipation system to extend the structural period and increase the damping to decrease the seismic response of the structure.

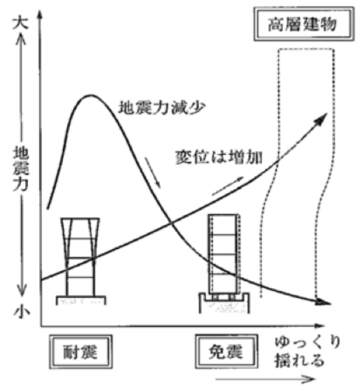


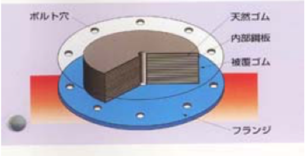
Seismic isolation principle (Long period effect)

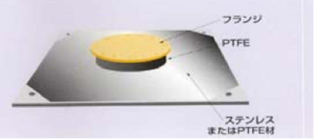
▼ 図１　基礎免震建築物



▼ 図２　建築物の受ける地震力と揺れ







Seismic isolation principle (damping effect)

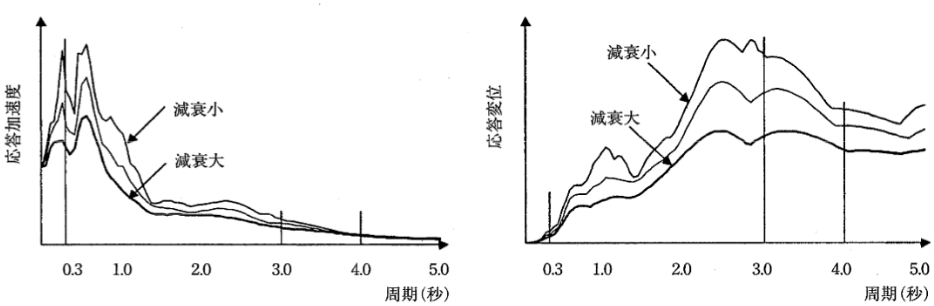
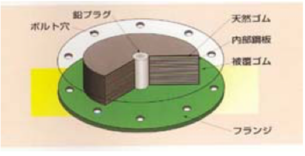


図1.3　地震応答スペクトルの例



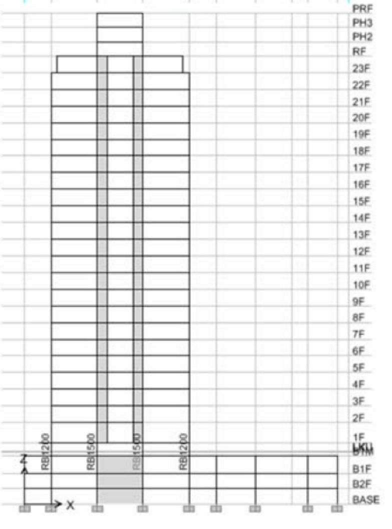
lead rubber bearing

Isolated structure design

- Performance target setting
- Isolation layer and expansion joint position selection
- Appropriate time history functions for site
- Damping of isolation estimation and static formula calculation
- Time history analysis confirms performance target
- Check the pressure of the rubber bearings
- Reconfirm upper and lower limits of bearing pressure

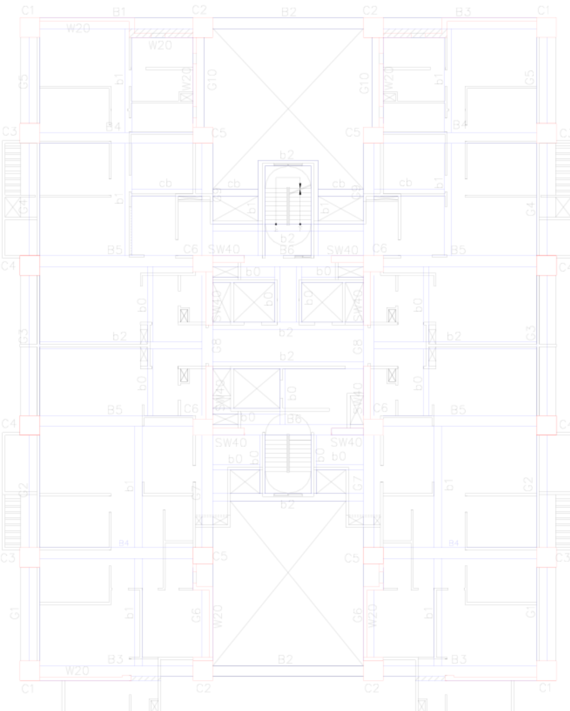
Case 2 Building Summary

- Area of construction base: 4,520 m2,and the site is in Zone3.
- 23 stories aboveground, 3 stories underground
- 1st floor height :4.2m , Isolation floor height:2.85m ,Standard floor height:3.5m , Total height: 81.2m



Superstructure plane

NEW STRUCTURE



MEMBER 編號		MEMBER SECTION 斷面尺寸
C1–C4	3F–23F	110x110
	1F–2F	130x110
C5,C6	8F–23F	100x100
	3F–6F	110x110
	1F–2F	130x110
B1–B3	19F–RF	60x80
	13F–18F	60x90
	2F–13F	60x100
B4–B5	19F–RF	60x70
	2F–18F	70x70
B6	2F–RF	60x120
G1–G10	14F–RF	60x80
	2F–13F	60x90
b0		30x55
b1,b2,cb		40x60
S1		t=15cm
S2		t=17cm

Structure summary

NEW STRUCTURE

- The building adopts seismic isolation design, the upper structure and the basement are RC moment resisting frame (MRF) and shear wall composite system to increase structural rigidity and improve isolation performance.
- Column size

  1F~2F: RC-1300×1100

  3F~23F:RC-1100×1100
- Beam size

  2F~13F:RC-600×900,RC-600×1000

  14F~RF:RC-600×800,RC-600×900

Target Performance of seismic design

NEW STRUCTURE

Earthquake scale	Isolated member		Upper structure	foundation
	Relative displacement (Bearing shear strain)	Base shear coefficient	State of structure	State of structure
30years Return period	D≦24㎝ (γ≦100%)	≦0.10	–	–
475years Return period (DBE)	D_{TD}≦48㎝ (γ≦200%)	≦0.10	–	–
2500years Return period (MCE)	D_{TM}≦70.0㎝ (γ≦290% For RB120)	≦0.12	Within the elastic limit	Within the elastic limit

Performance target for Comfort

NEW STRUCTURE

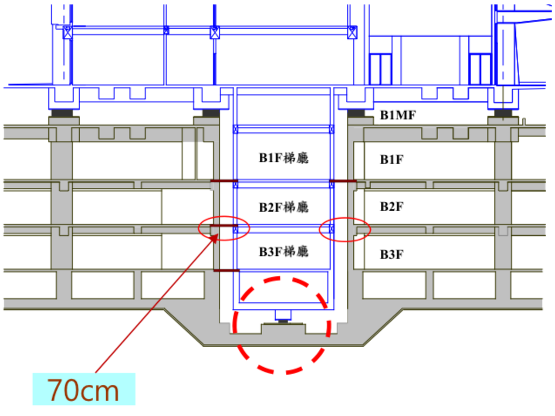
In order to increase the comfort during the earthquake, reduce the overturning of equipment in the building and maintain the function after the earthquake, set the upper structural response acceleration target value as follows

Earthquake scale	23floor Acceleration response
30years Return period	Under 80 cm/s2
475years Return period (DBE)	Under 250 cm/s2
2500years Return period (MCE)	Under 300 cm/s2

Isolation layer and expansion joint position selection

NEW STRUCTURE

- In this case, an isolation layer is installed between B1F and 1F。
- Reserve distance for moveable is 70cm

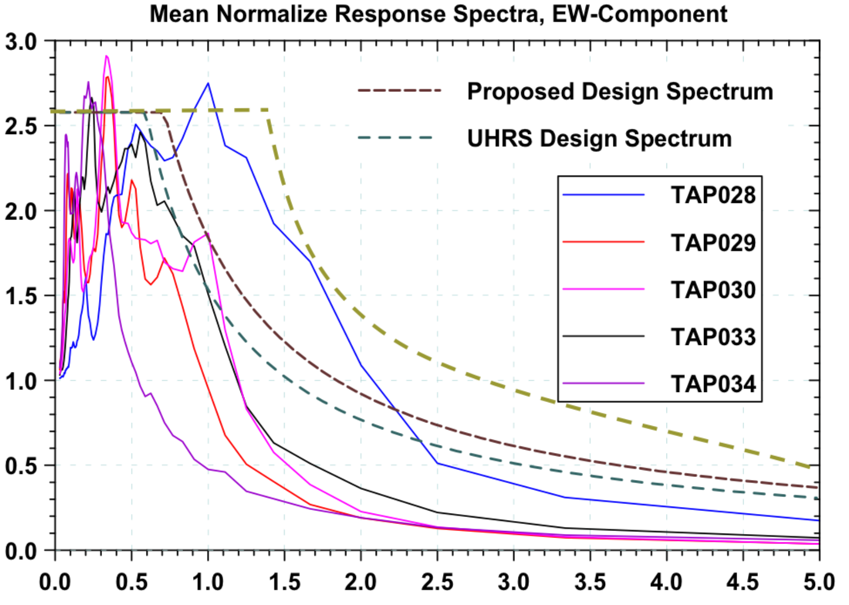


superstructure
foundation

Sliding bearing for elevator weight

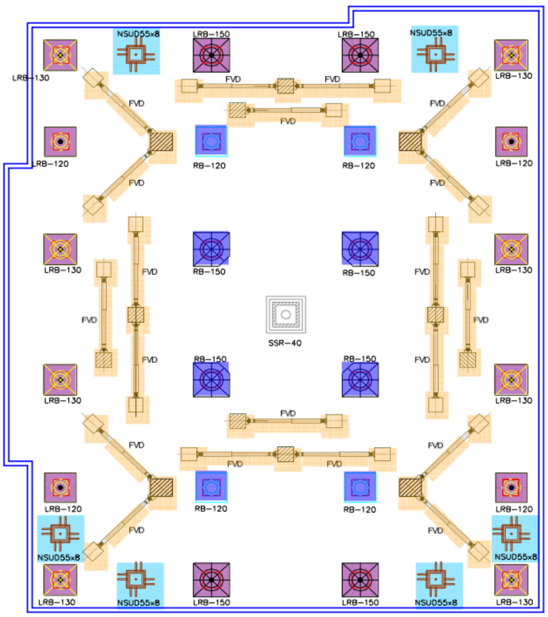
Appropriate Time-History functions for site

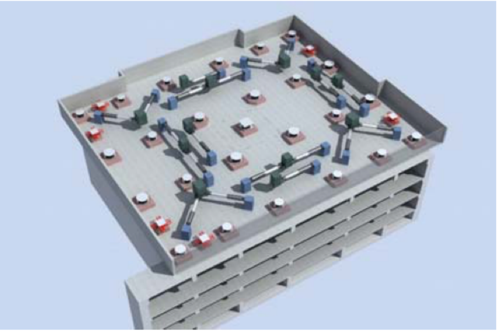
NEW STRUCTURE



Seismic isolation plan

NEW STRUCTURE





Isolation device

08 RB multilayer natural rubber

16 LRB multilayer natural rubber

Energy dissipating device

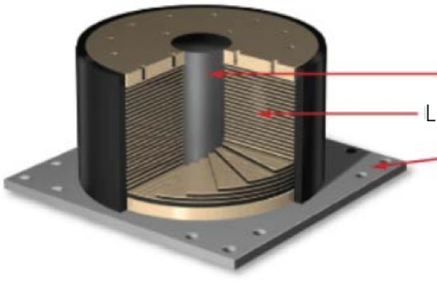
20 Oil damper

06 U-shaped steel damper

Isolation devices
LRB multilayer natural rubber

NEW STRUCTURE

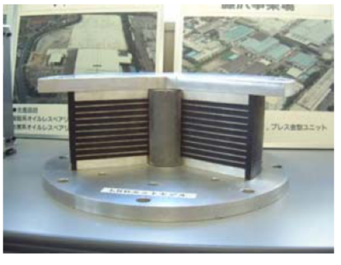
Isolator Diameter (cm)	Shear modulus (Kg/cm²)	Total rubber thickness(cm)	First shape factor S1	Second shape factor S2	Lead Diameter (cm)	Elastic Stiffness K1(t/cm)	Yielded Stiffness K2(t/cm)	Characteristic Strength Qd(t)	Compression Stiffness Kv(t/cm)
120	4.18	0.8x30 =24	37.5	5.0	24	25.536	2.04	36.22	6,112
130	4.18	0.8x31 =24.8	40.6	5.2	26	29.002	2.35	42.86	7,142
150	5.10	0.8x38 =30.4	46.9	4.9	30	37.330	3.06	57.14	8,673



Energy dissipation core

Layers of rubber and steel

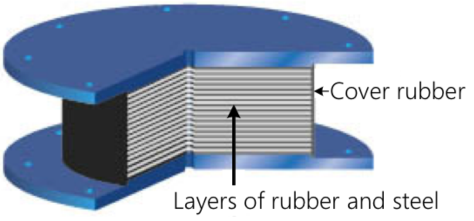
Steel mounting plate



Isolation devices
RB multilayer natural rubber

NEW STRUCTURE

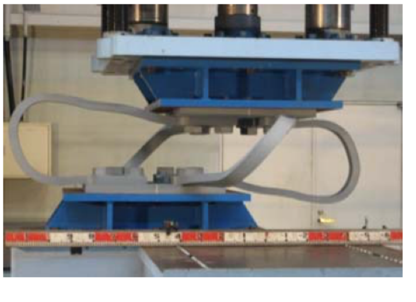
Isolator Diameter (cm)	Shear modulus (Kg/cm^2)	Total rubber thickness(cm)	First shape factor S1	Second shape factor S2	Shear stiffness (t/cm)	Compression Stiffness Kv(t/cm)
120	4.18	0.8x30 =24	35.3	5.0	2.04	5,102
150	5.10	0.8x38 =30.4	44.5	4.9	3.06	7,653



Energy dissipating device
U-shaped steel damper

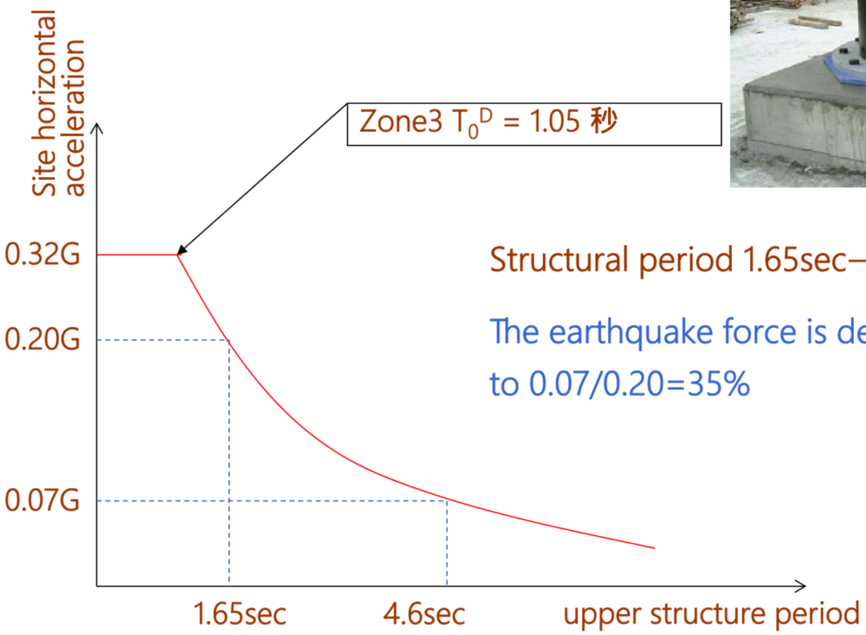
NEW STRUCTURE

	Initial Stiffness K1(t/cm)	2nd Stiffness K2(t/cm)	Yield Force Qy(t)	Yield Deformation δy(cm)	Ultimate Deformation (cm)
NSUD55X8	19.592	0.3265	62.041	3.17	>70



NEW STRUCTURE

Long period effect



Structural period 1.65sec→ 4.6sec

The earthquake force is decreased to 0.07/0.20=35%

NEW STRUCTURE

Damping effect

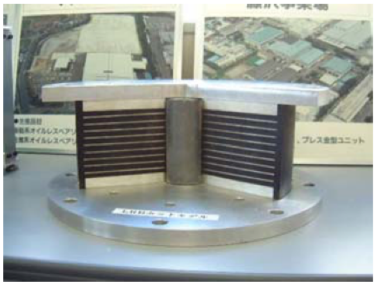
Provide damping

U-shaped steel damper : 6 units

LRB with Energy dissipation core : 16 units

The displacement of the isolation layer

is decreased from 1.80m to 0.722m



Energy dissipating device
Oil damper

NEW STRUCTURE

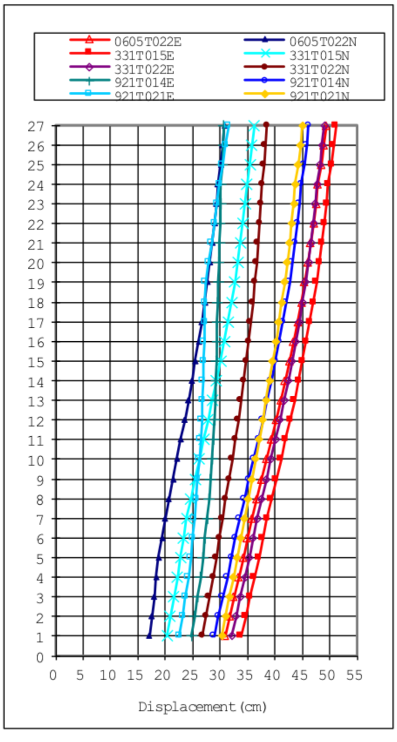
Use 20 units oil damper to decrease the displacement from 0.72m to 0.58m, and then the earthquake force decreased to 35%x0.631=22%

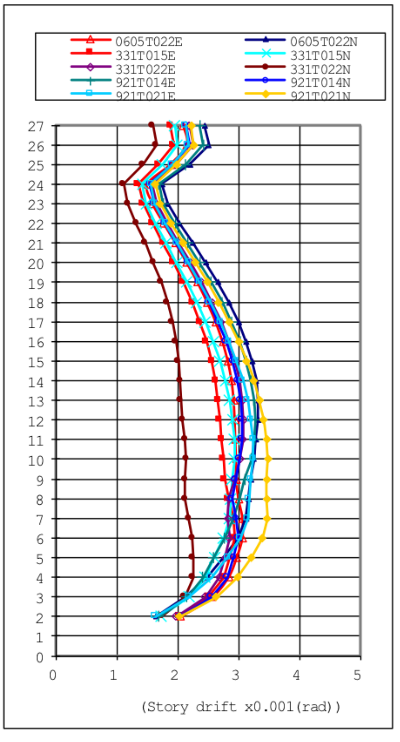
FVD Oil damper
F = 90 tf
$F=CV^{\alpha}$

C : the damping constant，$C=21.4\ tf^{*}(s/cm)^{0.3}$
V : end to end velocity across the element (cm/s)
α : 0.3

Result of vibration analysis
(DBE X-direction)

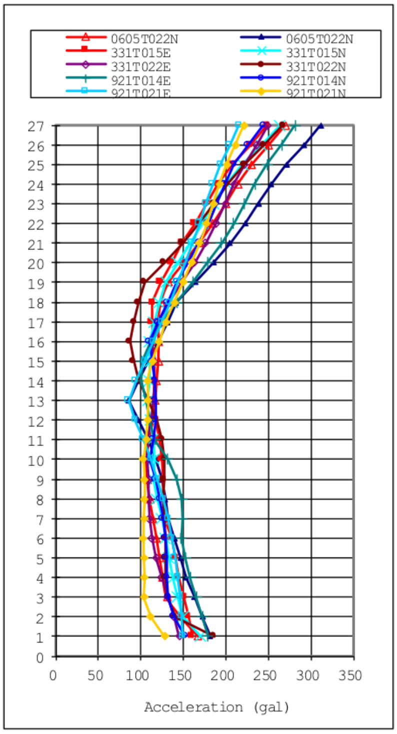
NEW STRUCTURE

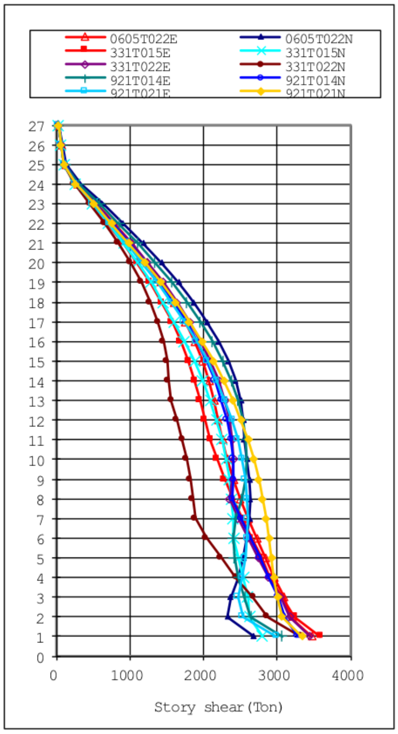




Result of vibration analysis (DBE X-direction)

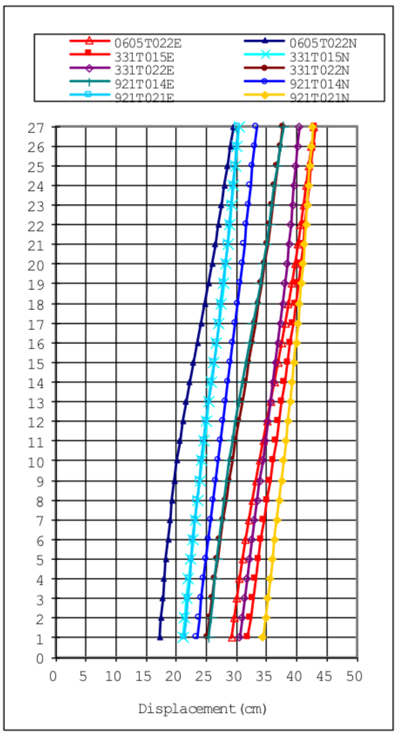
NEW STRUCTURE

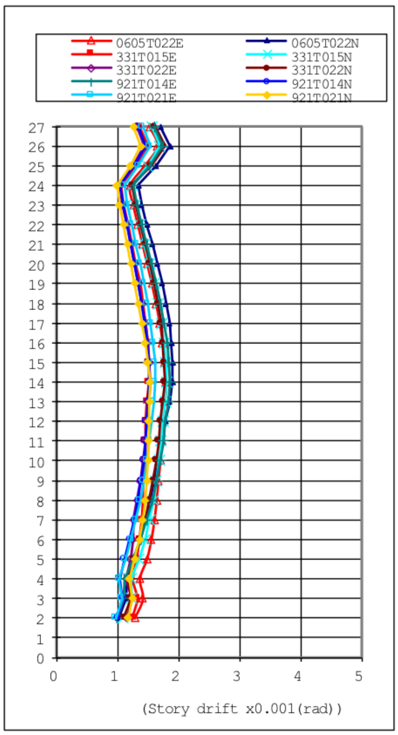




Result of vibration analysis (DBE Y-direction)

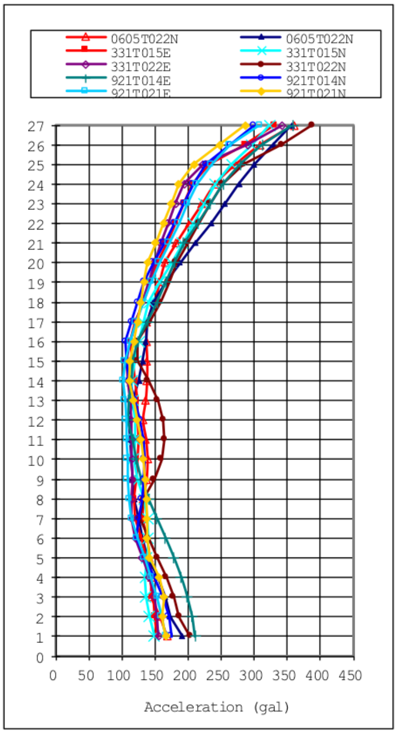
NEW STRUCTURE

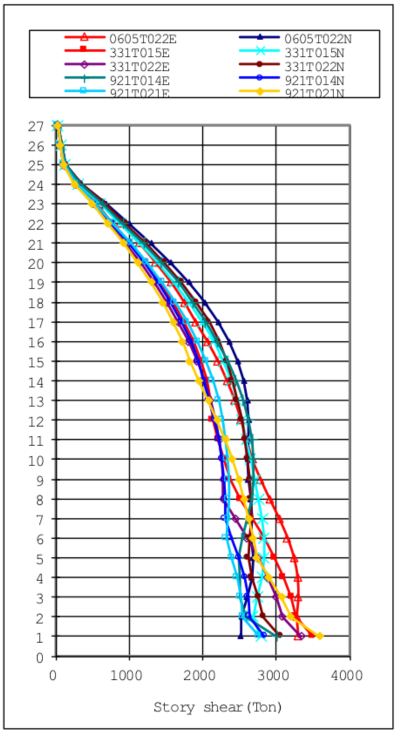




Result of vibration analysis (DBE Y-direction)

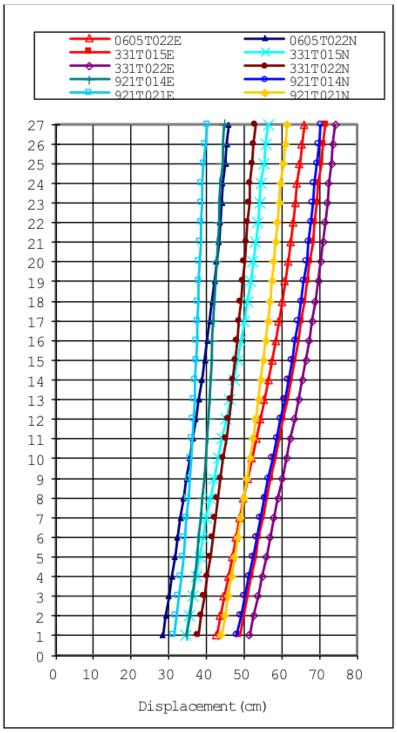
NEW STRUCTURE

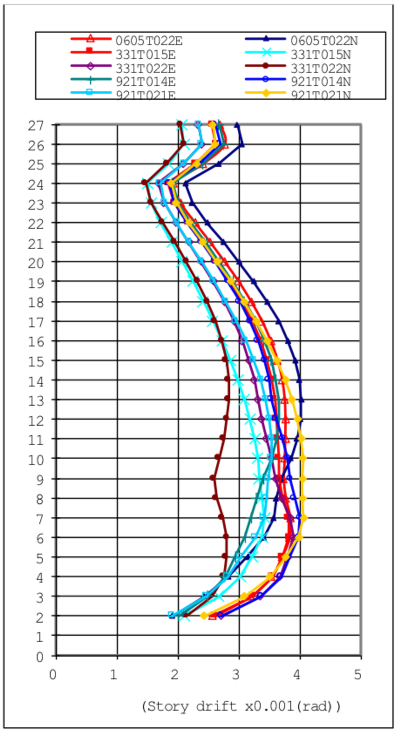




Result of vibration analysis (MCE X-direction)

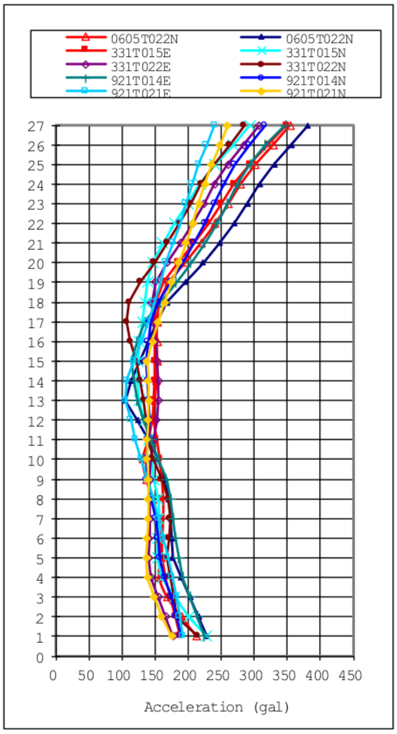
NEW STRUCTURE

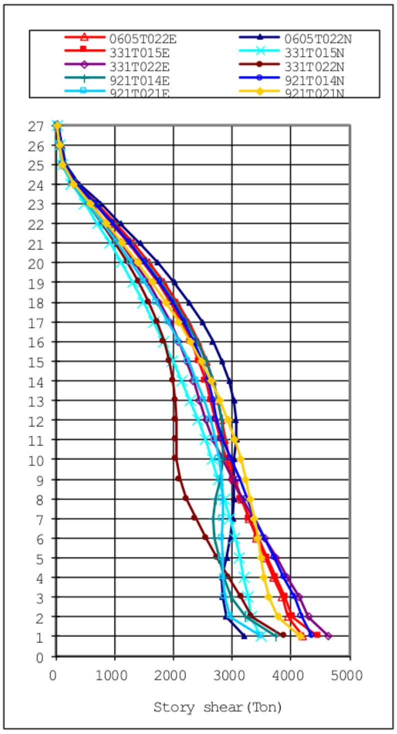




Result of vibration analysis (MCE X-direction)

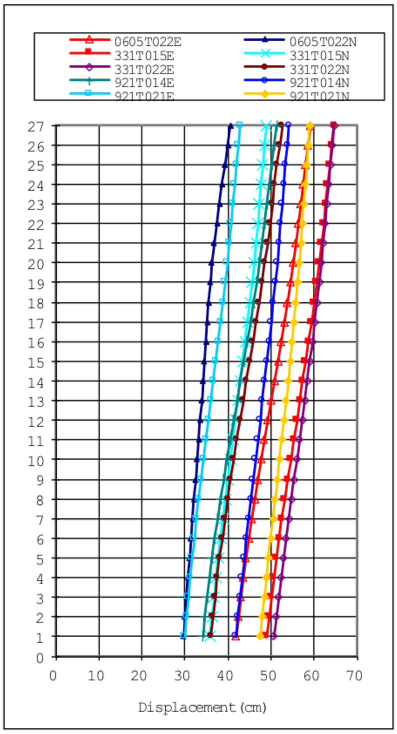
NEW STRUCTURE

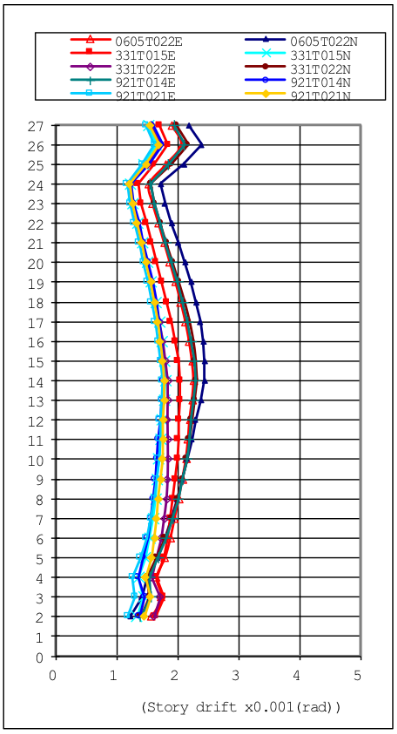




Result of vibration analysis (MCE Y-direction)

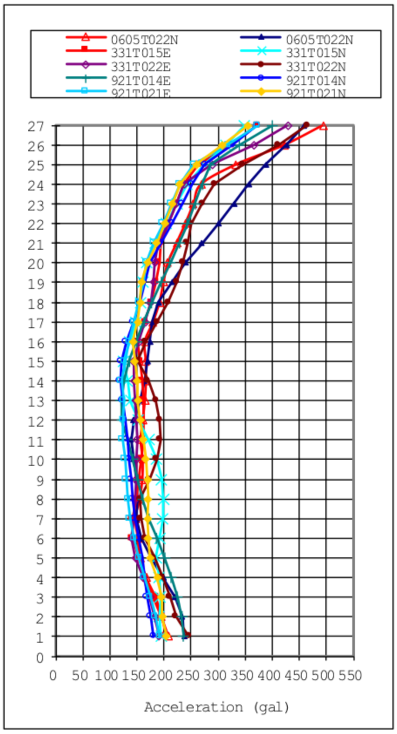
NEW STRUCTURE

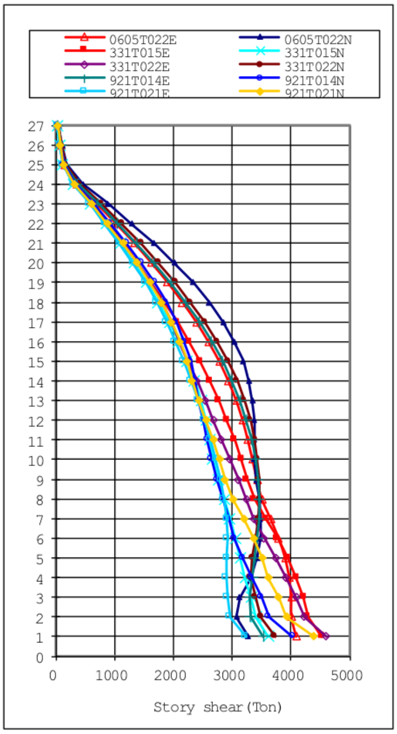




Result of vibration analysis (MCE Y-direction)

NEW STRUCTURE





Stress of the rubber bearings

NEW STRUCTURE

RB150

Long-term σ<200 kg/cm^2

short-term σ<375 kg/cm^2

せん断ひずみγにおける圧縮限界強度を次式で規定する。

(a) $\sigma_{cr}\left(1-\frac{4}{\alpha_c \cdot S_2}\right)<30$ のとき

$$\sigma=\sigma_{cr}\left(1-\frac{\gamma}{\alpha_c \cdot S_2}\right)$$ (σの上限値は 60)

(b) $\sigma_{cr}\left(1-\frac{4}{\alpha_c \cdot S_2}\right)\geq 30$ のとき

$$\sigma=\sigma_{cr}\left(1-\frac{\gamma}{4}\right)+\frac{30}{4}\gamma$$ (σの上限値は 60)

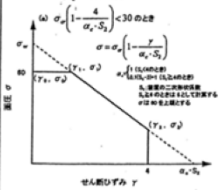
以下は (a), (b) 共通である。

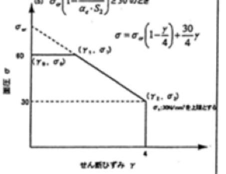
$\sigma_{cr} = \zeta \cdot G \cdot S_1 \cdot S_2$

$; \zeta = \begin{cases} 0.85 & (S_1 \geqq 30 のとき) \\ 0.90 & (S_1 < 30 のとき) \end{cases}$

$\alpha_c = \begin{cases} 1 & (S_2 < 4 のとき) \\ 0.1(S_2-3)+1 & (S_2 \geqq 4 のとき) \end{cases}$

$S_2 = \begin{cases} S_2 & (S_2 \leqq 6 のとき) \\ 6 & (S_2 > 6 のとき) \end{cases}$





	1	2	3	4	DL	1
G	90	128	123	93	LL	0.5
F	107	98	101	95	EX	0
E	123	148	147	120	EY	0
D	125	149	150	122		
C	114	104	110	101		
B	101	136	130	103	單位 Kg/cm^2	

	1	2	3	4
G	130	150	150	130
F	120	120	120	120
E	120	150	150	120
D	120	150	150	120
C	120	120	120	120
B	130	150	150	130

	1	2	3	4	DL	1
G	19	52	202	166	LL	0.5
F	42	48	153	152	EX	1
E	54	53	244	186	EY	0
D	54	57	245	191		
C	45	64	154	161		
B	39	95	173	167		

	1	2	3	4	DL	1
G	161	205	44	21	LL	0.5
F	173	149	50	38	EX	-1
E	193	242	50	54	EY	0
D	197	241	55	54		
C	183	144	65	41		
B	164	178	87	39		

	1	2	3	4	DL	1
G	154	243	227	156	LL	0.5
F	112	73	89	99	EX	0
E	122	206	208	119	EY	1
D	126	93	95	123		
C	107	133	120	97		
B	39	18	23	41		

	1	2	3	4	DL	1
G	26	13	20	31	LL	0.5
F	102	124	113	91	EX	0
E	124	89	87	121	EY	-1
D	124	206	205	121		
C	120	75	100	106		
B	164	255	237	165		

	1	2	3	4	DL	1
G	14	45	196	161	LL	0
F	35	43	147	147	EX	1
E	47	44	235	179	EY	0
D	46	48	236	184		
C	38	59	149	155		
B	33	87	165	161		

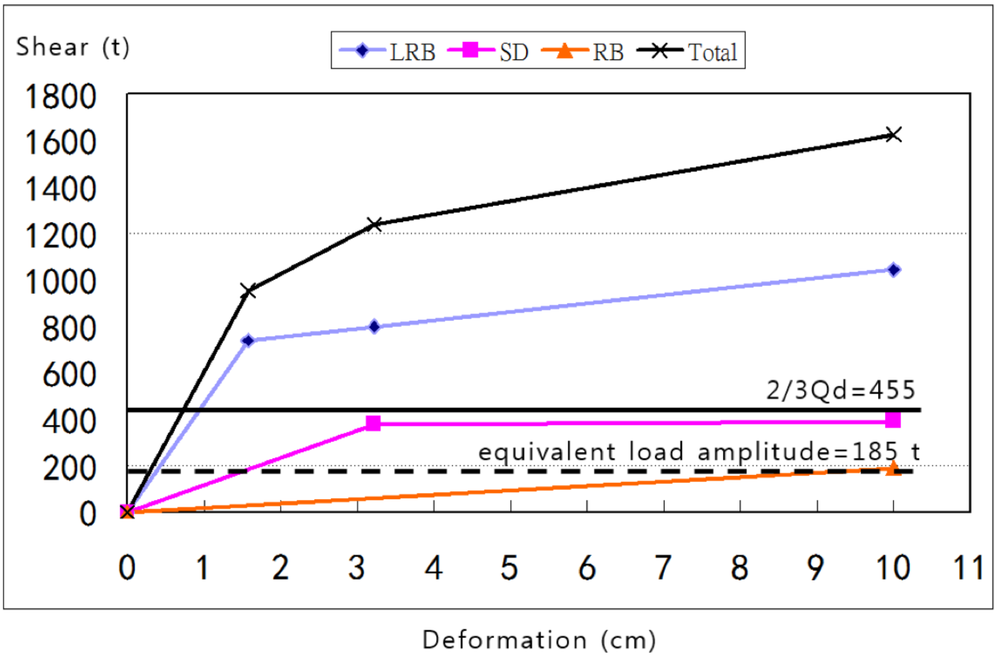
	1	2	3	4	DL	1
G	156	197	38	16	LL	0
F	167	144	45	33	EX	-1
E	185	232	40	47	EY	0
D	189	231	45	46		
C	176	139	59	35		
B	159	170	80	33		

	1	2	3	4	DL	1
G	149	236	220	151	LL	0
F	106	68	84	93	EX	0
E	115	197	198	112	EY	1
D	118	83	85	116		
C	100	128	114	91		
B	33	10	15	35		

	1	2	3	4	DL	1
G	21	6	13	26	LL	0
F	96	119	108	86	EX	0
E	117	80	77	114	EY	-1
D	117	196	195	114		
C	113	70	94	100		
B	159	247	230	159		

Wind load stability check

NEW STRUCTURE



Conclusion of case2

NEW STRUCTURE

1. It is insufficient to consider long period effects in Taipei basin if only displacement-dependent dampers are used.
2. The deformation decreased greatly by viscous damper .
3. Viscous damper can decrease the demand of deformation in displacement-dependent damper in high-rise buildings under the influence of wind force.

Sloped Rolling-Type Seismic Isolation Design For Critical Equipment in High-Tech Factories, Museums, and Emergency-Response Centers

Dr. Mu-sen Tsai

Vice General Manager of VIO

Experiences

- **Engineer, VIO Creation Technology Inc.**

Dr. Mu-sen Tsai is currently as an vice general manager of VIO Creation Technology Inc. in Taiwan.

Dr. Tsai is in charge of designing devices to protect machines applied in semi conductor industry from earthquake damage. He has also designed isolation systems for institute of history and philosophy, Academia Sinica.

Sloped rolling-type seismic isolation design for critical equipment in high-tech factories, museums, and emergency-response centers

Professional Innovative Service with Care

唯創光電精密科技股份有限公司
VIO Creation Technology Inc.

Outline

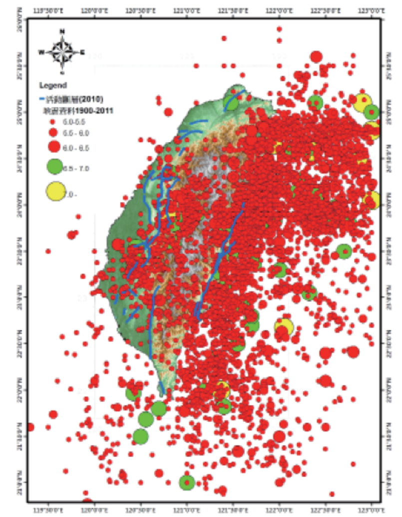
(1) Seismic Protection

(2) Design concept

(3) Shaking table tests

(4) Applications

Earthquake!! An inevitable fate!!



Lessons and experiences from the 921 Earthquake (Magnitude 7.3, 1999/09/21 1:47AM)!!

2,444 dead, 50 missing, 758 injured, 38,935 houses collapsed and 5,320 houses damaged.

Earthquakes are happening more frequently and with more intensity. When and where will the next one occur

Based on the statistics from the 1990s until now, an earthquake over Magnitude 6 will occur every 10 years in western Taiwan. From 2001 to 2013, five great earthquakes occurred in middle and southern Taiwan; such frequency is terrifying!

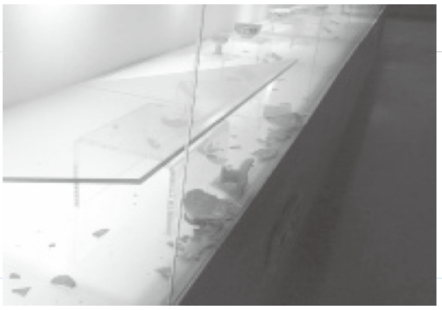
Seismic demand of Emergency Center

2008 Sichuan earthquake

System was shutdown for more the 17 hours due to the damage of the facilities in control tower.

Seismic demand of Museum



Even though many buildings that preserve valuable antiques and arts were not obviously damaged in the 1999 921Chi-Chi Earthquake, many antiques and arts were severely wrecked. The 2008 Wen-Chuan Earthquake caused 68 key units and 142 provincial units that preserve valuable antiques and arts to be wrecked in China.

Seismic demand of High-Tech Industry


The 1999 921 Chi-Chi Earthquake brought great damage to Taiwan Hsinchu Science Park. The maximum ground acceleration measured was 0.12g, which may not cause severe damage to equipment or facility structures. However, they may malfunction due to the damage on parts. After investigation, the economic loss is over NT$10 billion, and the indirect economic loss is even inestimable.

Brand & Model	Tolerated instantaneous acceleration
DEC - ALPHA SERVER - #8200	0.5 g
DEC–ALPHA SERVER- #4100	1 g
DEC– RZ 26 DRIVE UNIT	0.2 g
DEC– RZ 28 DRIVE UNIT	0.5 g
DEC– RZ 29 DRIVE UNIT	0.5 g
HP– MODEL 20 DRIVE UNIT	0.25 g
HP– ENTERPRISE 9000	0.5 g
SGI– ORIGIN FIBER VAULT	0.25 g
SUN CLASS III DRIVE	0.25 g

According to different brands and models of IT facilities, the shockproof ability is between 0.2g to 0.5g in short duration time.

Seismic Isolation Strategy

Transmitted acceleration responses

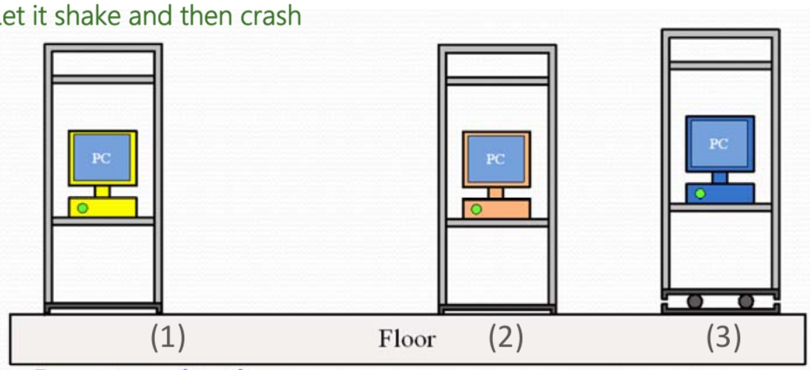
(1) No protection

(2) Reinforcement

(3) Isolation technology

Seismic energy is concentrated in equipment, enlarged acceleration (serious deformation)

Let it shake and then crash



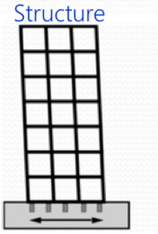
Input excitation

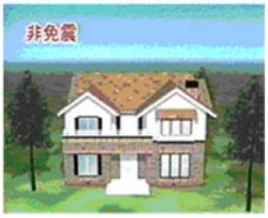
Isolate and dissipate most of horizontal earthquake input energy, control horizontal seismic responses of equipment

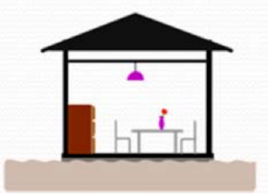
Effective seismic protection and function-maintenance strategy!!

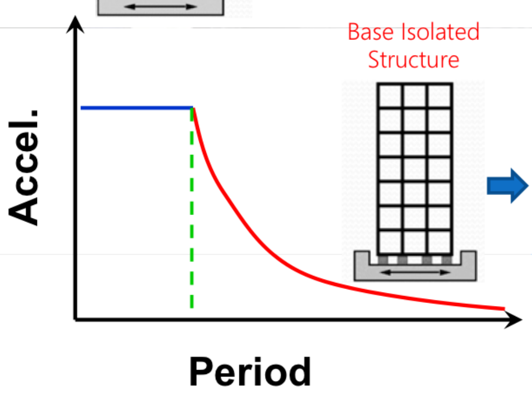
Seismic Isolation Introduction

Conventional Structure

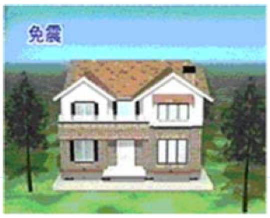




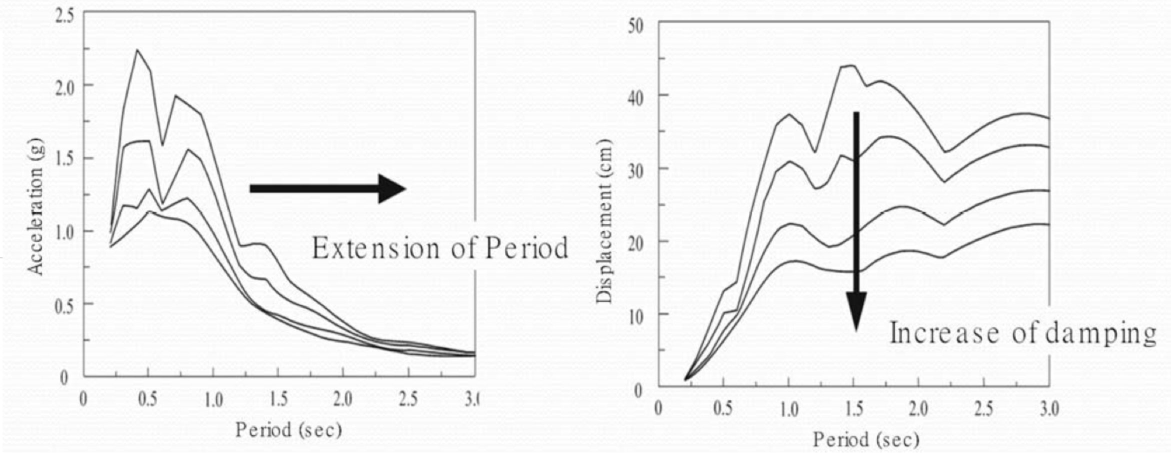




Base Isolated Structure

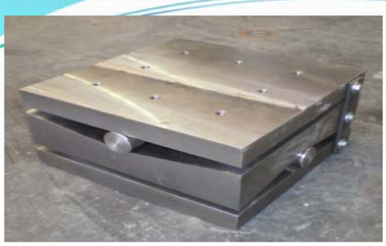


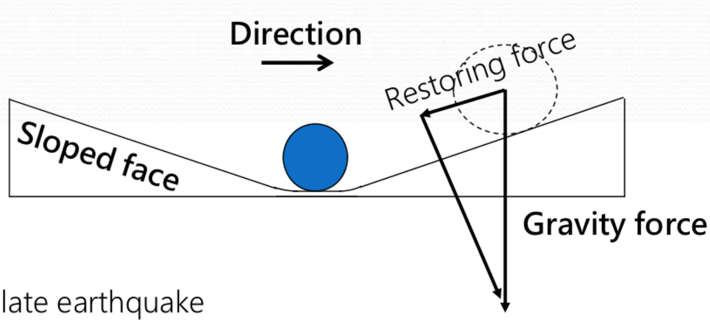
Seismic Isolation Strategy = Extension of Period + Increase of Damping



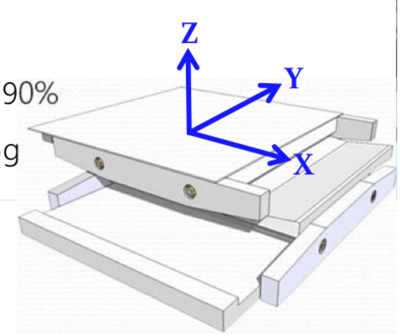
Isolation device **+** Damper

Design concept





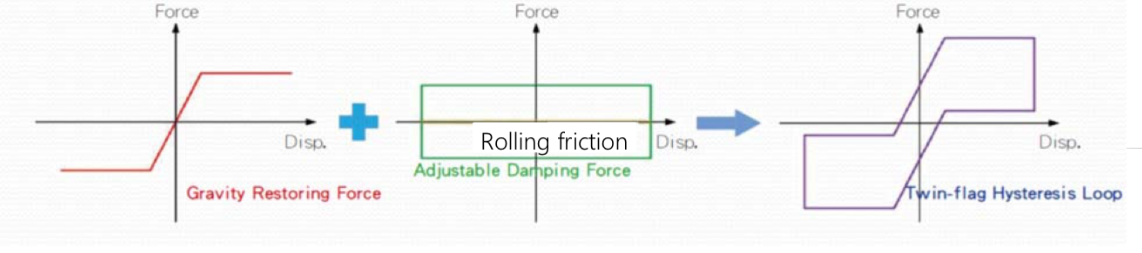
- ■Use the rolling mechanism to isolate earthquake
- ■Use the built-in adjustable damping to dissipate earthquake energy
- ■Use the gravity restoring force to re-center itself
- ■Response reduction under the 921 Chi-Chi Earthquake > 90%
- ■Maximum horizontal acceleration response output < 0.15g



Equation of Motion

Equation of Motion =

Gravity Restoring Force + Rolling Friction + Built-in Adjustable Damping



Optimum design ?

(1) Tolerated acceleration

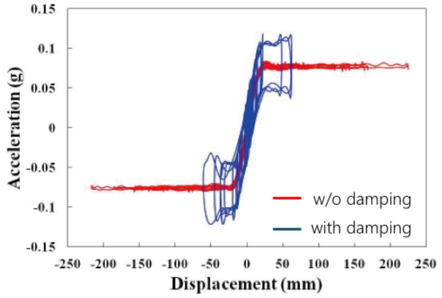
(2) Space (requirement of displacement)

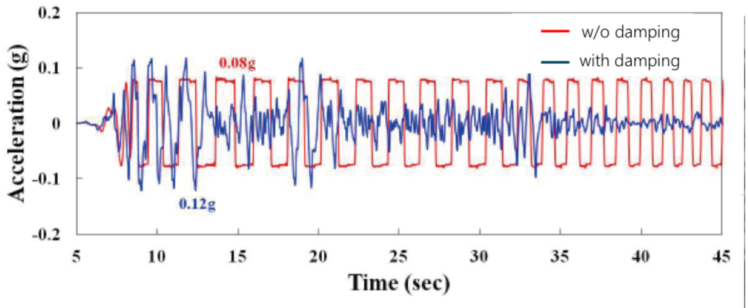
Product Features

- 360 degree horizontal protection
- Acceleration response is stable and controlled to be less than 0.15g.
- No fixed vibration frequency so that no resonance will occur with the to-be-protected object.
- The multi-roller design enables the isolation device to stay stable even if it's under eccentric load.
- The energy dissipation mechanism from the built-in damping can better control the displacement.
- Automatically re-centers itself after earthquakes.
- Unlimited installation and use to save investment costs.
- Easy to install, ready to use instantly and no need of extra holes to set it.

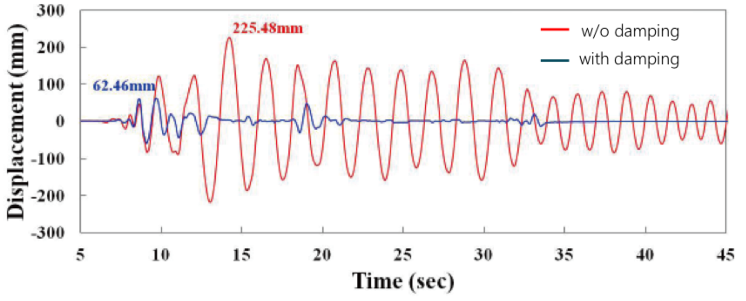
The Importance of Damping

The energy dissipation mechanism from the built-in damping effectively controls displacement caused by earthquakes and can re-center the isolation device immediately.



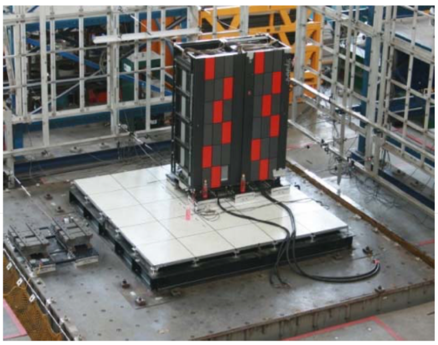


Displacement response
22.5 cm ➡6.2 cm
Space demand decreases effectively.

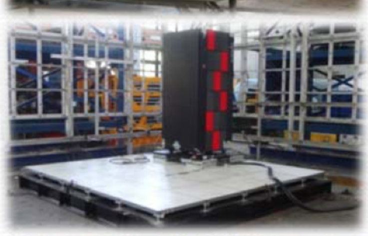


Shaking table tests

Shaking table tests



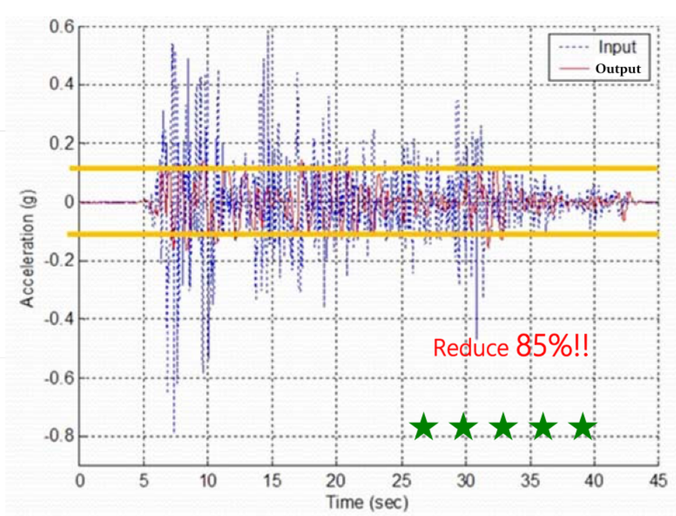
Test result



EL Centro earthquake

— Input= 0.8g

— Response=0.11g

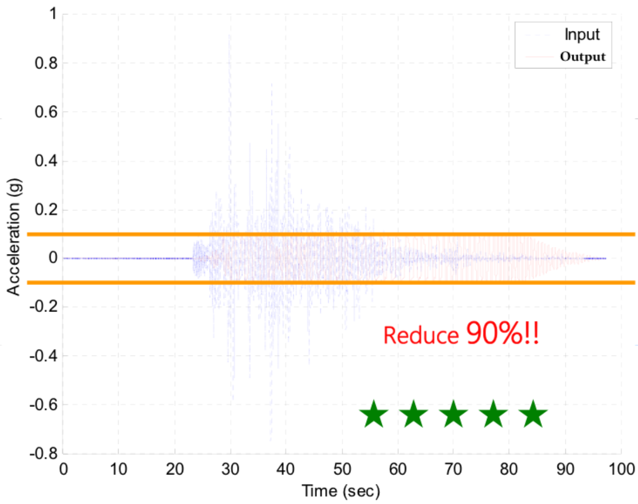


Test result

921 Chi-chi earthquake

— Input= 1g

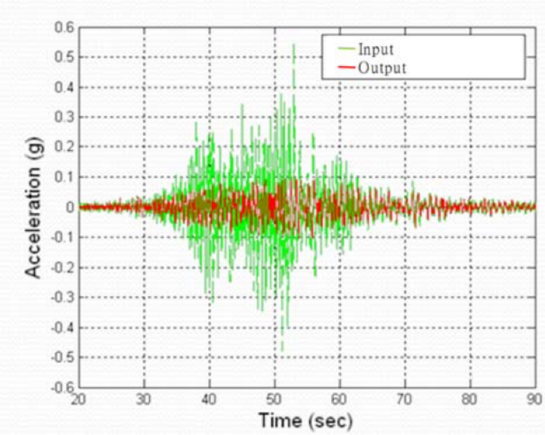
— Response=0.11g



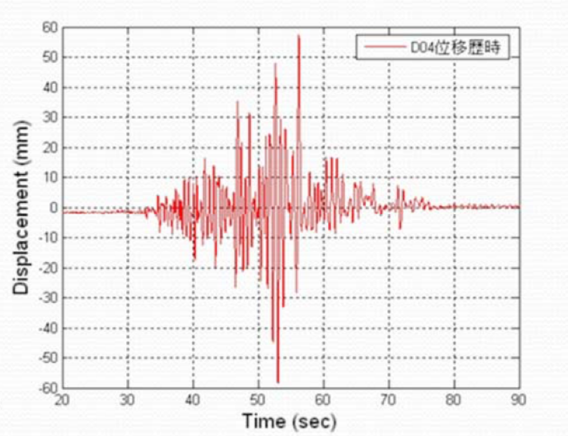
Test result

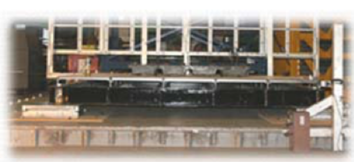
AC156 Peak accel. = 0.55g

Accel. Response



Displacement





Test on Isolated Reticle Stocker

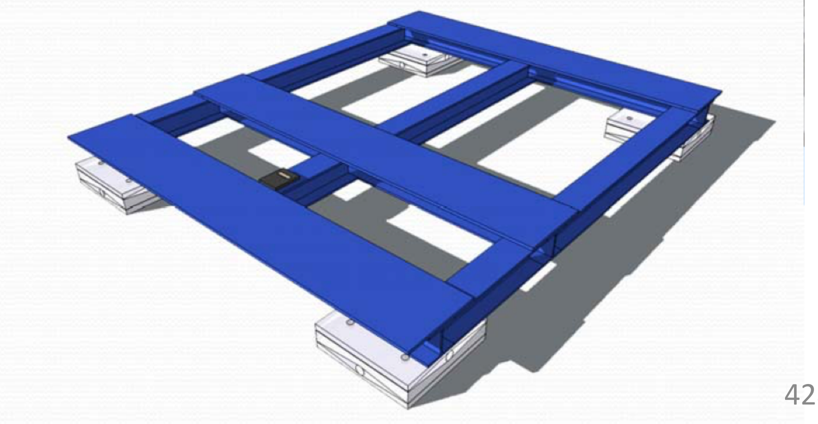
Seismic target

Target

1. Acceleration response < 150gal。

2. Maximum displacement < 20cm。

3. Residual displacement < 10mm。



Setup illustration

RST is fixed by 4 M10 screws.

Test result

No.	Intensity	Target	Accel. (X,Y,Z gal)			Residual Disp. (X,Y,Z mm)
			Shaking table	MRB	Facility	MRB
1	4	25	17, **45**, 31	15,44, 32	27, 45, 31	0.2 , 0.1
2	5	80	104, **138**, 38	34,54, 36	60, 57, 37	0.1 , 0.1
3	6	250	264, **325**, 91	50,65, 87	79, 76, 89	0.1 , 0.1
4	7	400	409, **522**,152	64,78,140	96, 92,144	0.3 , 0.1
5	7↑	600	531, **729**,236	73,79,271	121,101,267	1.1 , 0.1
6	7↑	850	654, **948**,314	81,83,305	115,106,315	0.6 , 2.0
ADDL'T	7↑	1000	696,**1036**,365	81,91,349	115,113,359	0.6 , 2.5

Test on Isolated Furnace tube facility

Seismic target

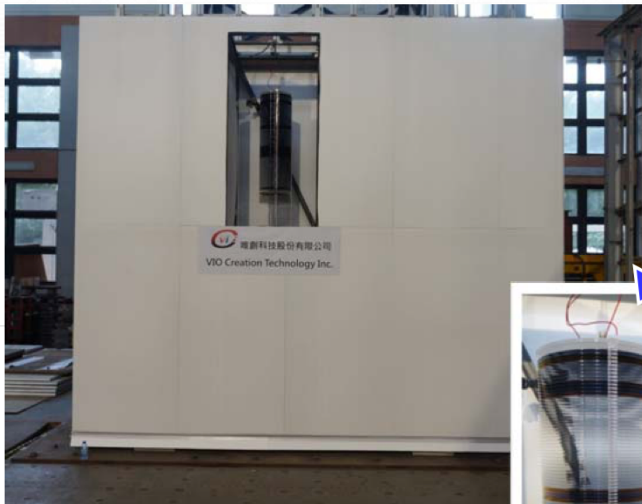
Target

1. Acceleration response < 40gal。

2. Maximum displacement < 14cm。

3. Residual displacement < 30mm。

Setup illustration



Acceleration gauge

Silicon boat and wafers

Comparison between facility W/O VS. With Isolator

X (Depth of facility)	20gal		40gal		80gal	
Top of Facility	48	15	97	17	156	21
Top of Boat	227	234	380	296	473	287
Bot. of Boat	42	10	83	11	131	13
VIO BASE	35	9	68	10	104	15
Y (Width of facility)	**13gal**		**25gal**		**51gal**	
Top of Facility	35	26	64	25	104	32
Top of Boat	360	236	521	215	608	257
Bot. of Boat	25	16	47	14	70	17
VIO BASE	12	7	23	7	36	10

According to experience, the wafers and silicon boats broken once the peak of acceleration exceeds 80 gal.

Actual Experience

Earthquake event	Project place	Distance to epicenter	Magnitude	Local intensity	Results
Jiaxian Earthquake 2010.03.04	Tainan (6F) IDC	25km	6.4	5	Safe
Nantou Earthquake 2013.03.27	Tainan (6F) IDC	120km	6.1	4	Safe
	Nantou (3F) IDC	**2km**		**6**	Safe
	Taipei (3F) antique storage room	150km		2	Safe
Hualien Earthquake 2013.10.31	Tainan (6F) IDC	100km	6.3	2	Safe
	Nantou (3F) IDC	50km		3	Safe
	Taipei (3F) antique storage room	180km		3	Safe

Note: Seismic intensity scale (Courtesy of CWB)
Seismic Intensity 4 (Moderate), ground acceleration: 25-80 gal
Seismic Intensity 5 (Strong), ground acceleration: 80-250 gal
Seismic Intensity 6 (Very strong), ground acceleration: 250-400 gal
Seismic Intensity 7 (Great), ground acceleration: 400 gal and above

Seismic Isolation for Art and Antique Exhibitions

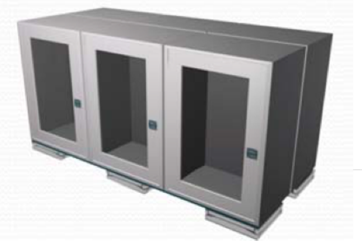
Application

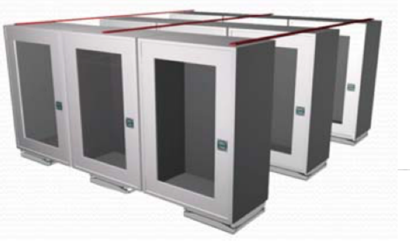
It is easy to install by positioning MRB directly under arts, antiques or display cabinets. MRB is aesthetically designed, light and ready to use instantly.

Seismic Isolation for Storage Cabinets

Application

MRB60WD model applied to the storage cabinets in the Institute of History and Philology, Academia Sinica.





STEP 1

STEP 2

STEP 3

Seismic Isolation for Information Facilities

Single cabinet with MRB

- ■Easy to install, no need of extra construction
- ■Reserved surrounding space for the isolation displacement
- ■Reserved cable lengths that can accommodate the isolation displacement

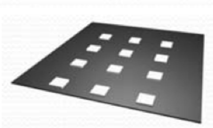
Multiple cabinets with MRB

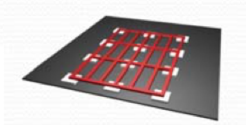
- ■Applicable to tandem cabinets
- ■Modular installation
- ■Good plane rotation control and good use of space
- ■Reserved surrounding space for the isolation displacement
- ■Reserved cable lengths that can accommodate the isolation displacement

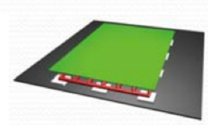
Seismic Isolation for Information Facilities

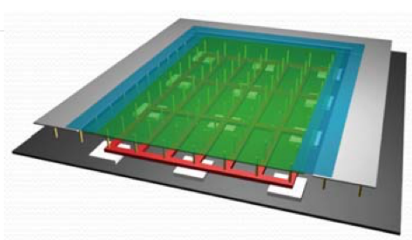
■ Easy to install, with immediate setting upon arriving and no need of complicated installation procedure.
■ Equipment could be set up with help of a ramp without disassembling interior drive units.
■ MRB is equipped with anti-slip pads to simplify the installation of equipment.

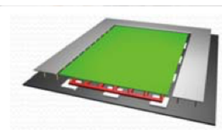
Seismic Isolation for Raised Floor Systems

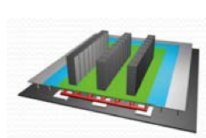

MRB installation

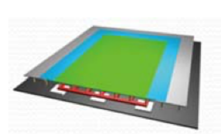

Modular frame installation


Isolated raised floor installation




Raised floor installation


Set up IT facilities

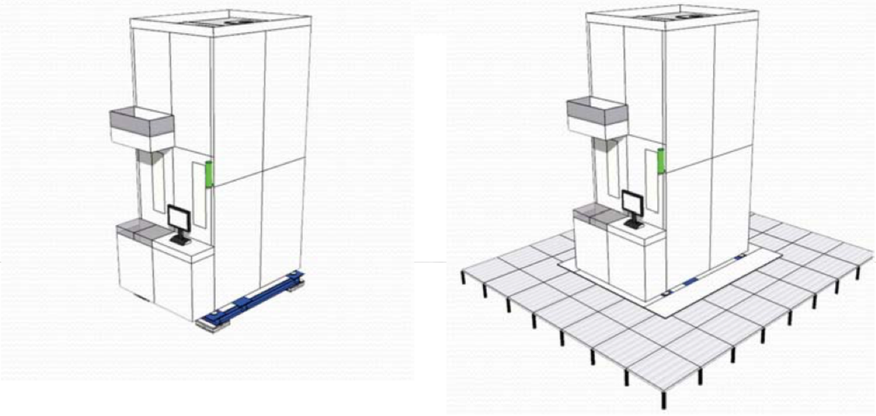

Buffer area installation

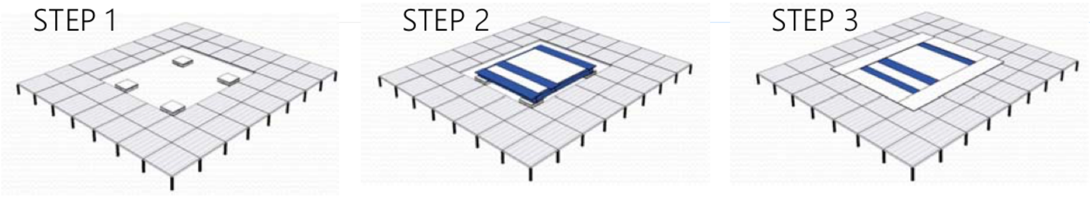
Seismic Isolation for Raised Floor Systems

Application

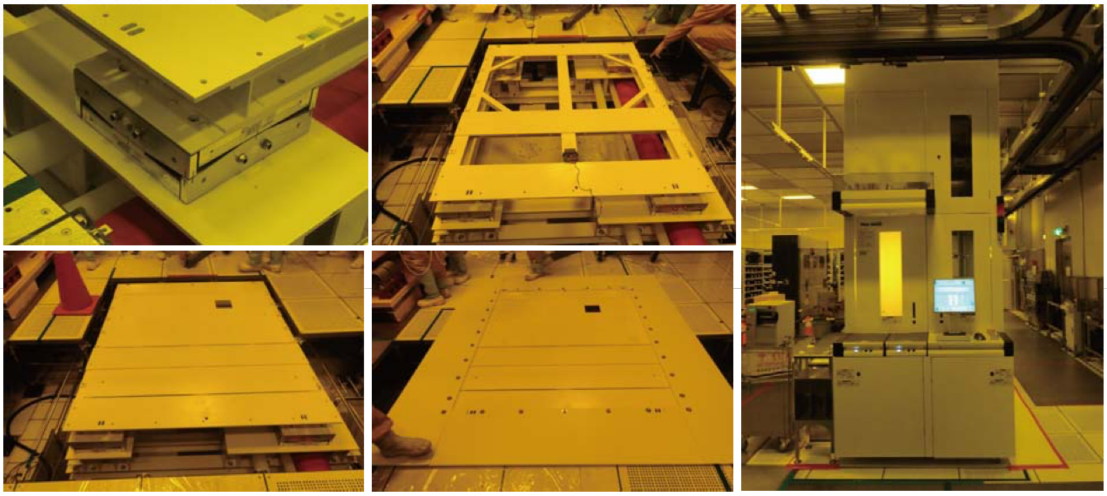
Seismic isolation area is 73.44m^2, constructed with a raised floor system, modular frame and 24 sets of MRB60WD. The maximum acceleration transmitted from MRB to raised floor system does not exceed 0.12g.

Seismic Isolation for High-Tech Industry





Seismic Isolation for High-Tech Industry



Application

As the semiconductor instruments in UMC were already installed with intricate cables under the raised floor, MRB could not be directly installed on the concrete floor. We designed another steel foundation to accommodate the existing cables and to install MRB.

Thank you

and

Questions?

Dr. Ir. Muslinang Moestopo

Associate Professor at Institut Teknologi Bandung (ITB)

Experiences

- Associate Professor at Institut Teknologi Bandung (ITB)

Dr. Muslinang Moestopo is a lecturer and researcher at civil engineering at Faculty of Civil and Environmental Engineering of Institut Teknologi Bandung (ITB). He received bachelor degree in civil engineering (1985) from ITB, then Master Degree (1989) and Ph.D degree (1994) from University of Wisconsin-Madison.

He specializes and has authored many papers in the area of seismic resistant steel structures.

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