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Leader in innovative shock control

Design of Fluid Viscous Dampers as per ASCE 7-16

Presented by:

Sandeep Shah
TAYLOR DEVICES INDIA

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What are Fluid Viscous Dampers?

- Originally developed as shock absorbers for aerospace and defense industry.
- Main components Silicon fluid filled steel cylinder, piston and orifices.
- When activated the fluid flows from one chamber to other through orifices.
- During seismic events the damper activates and dissipates seismic energy to heat energy.
- Used in many thousands of structures worldwide and preferred by many building codes.

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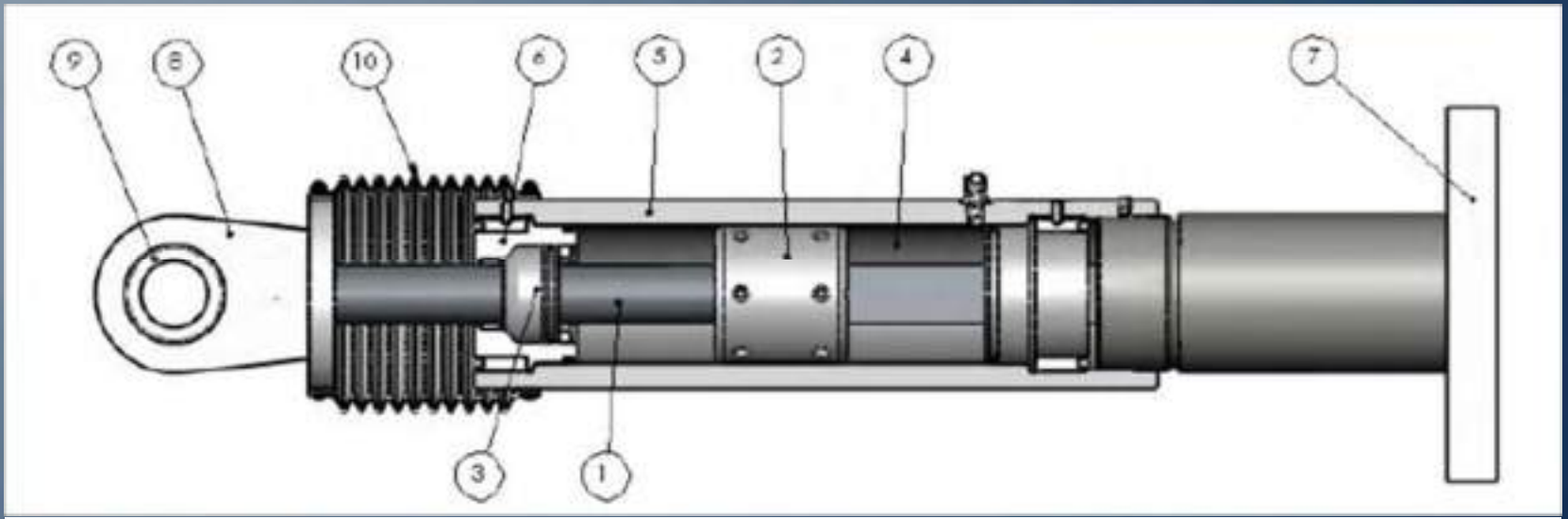
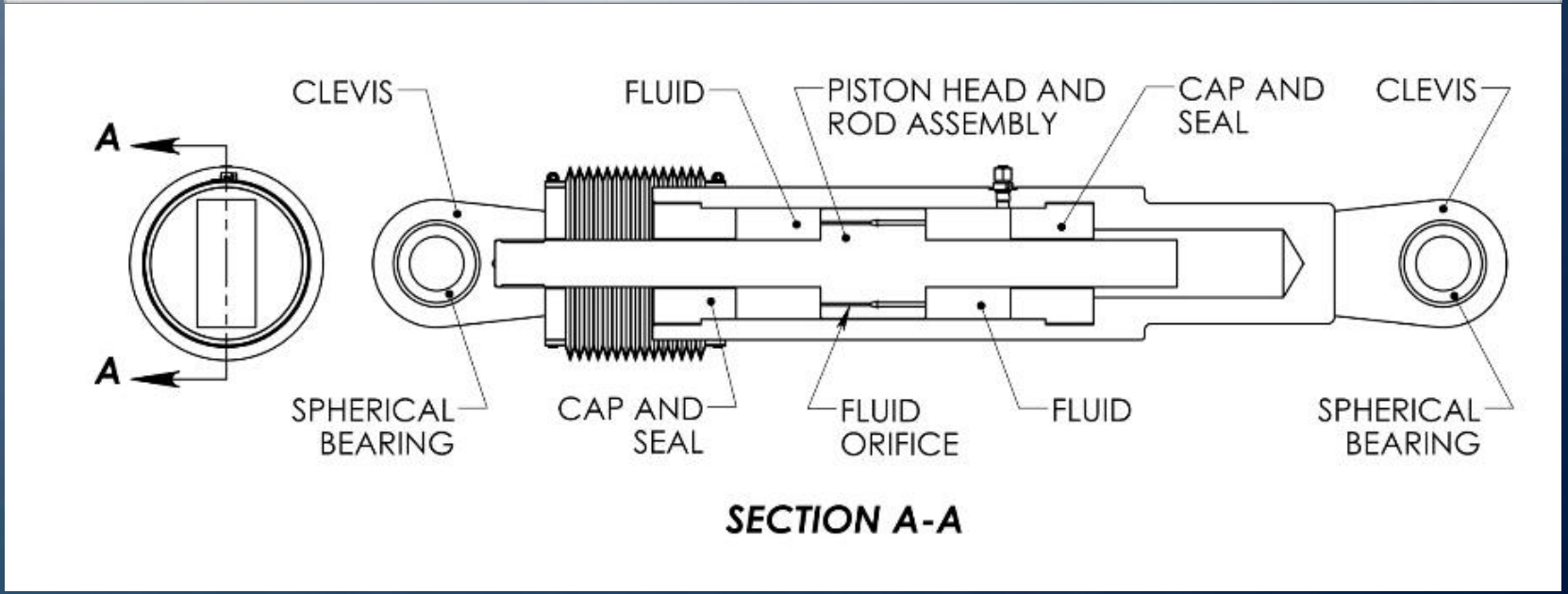
Fluid Viscous Damper





Clevis - Clevis type and Clevis – Base Plate type.

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USP of Fluid Viscous Dampers

- Reduction in structural costs by savings in material (concrete and steel), time and labour.
- No Maintenance after installation.
- Warranty of 35 years
- Life of 100 years and beyond
- Aerospace Quality certified factory production.
- Increased structural performance.
- Remain in as-new condition even after repeated earthquakes.

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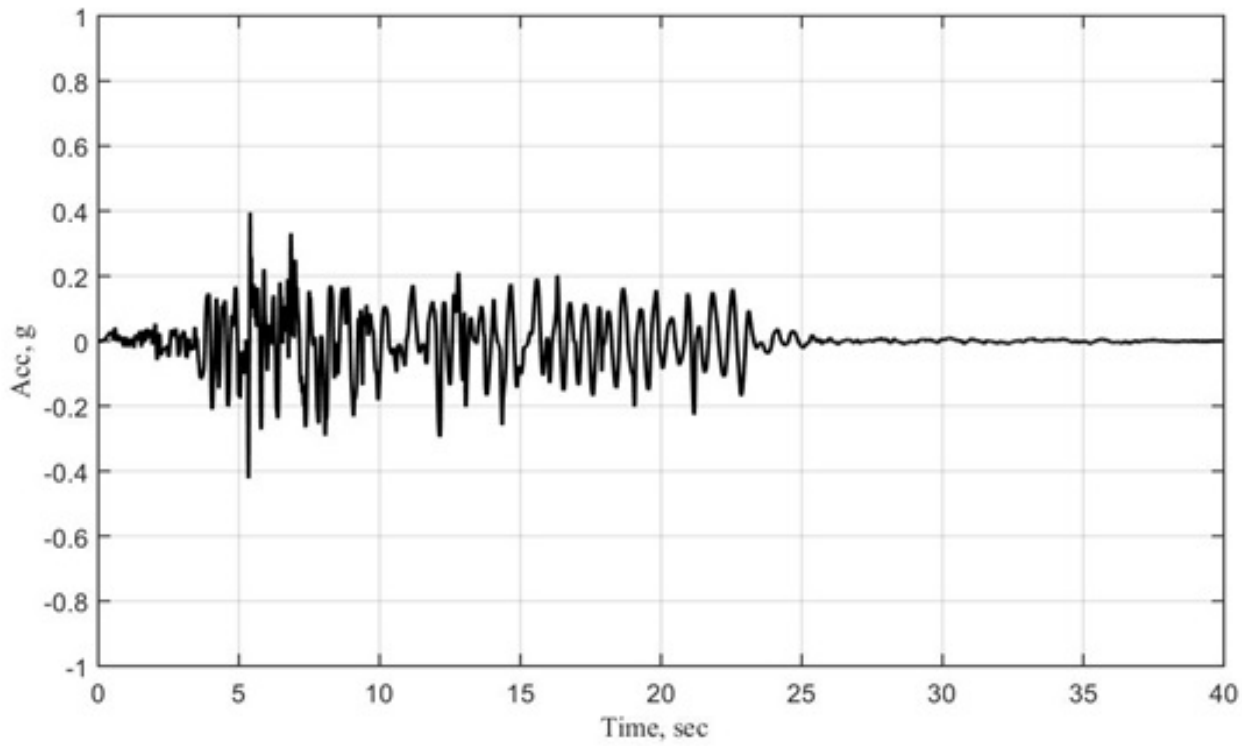
Sample Earthquake Time History



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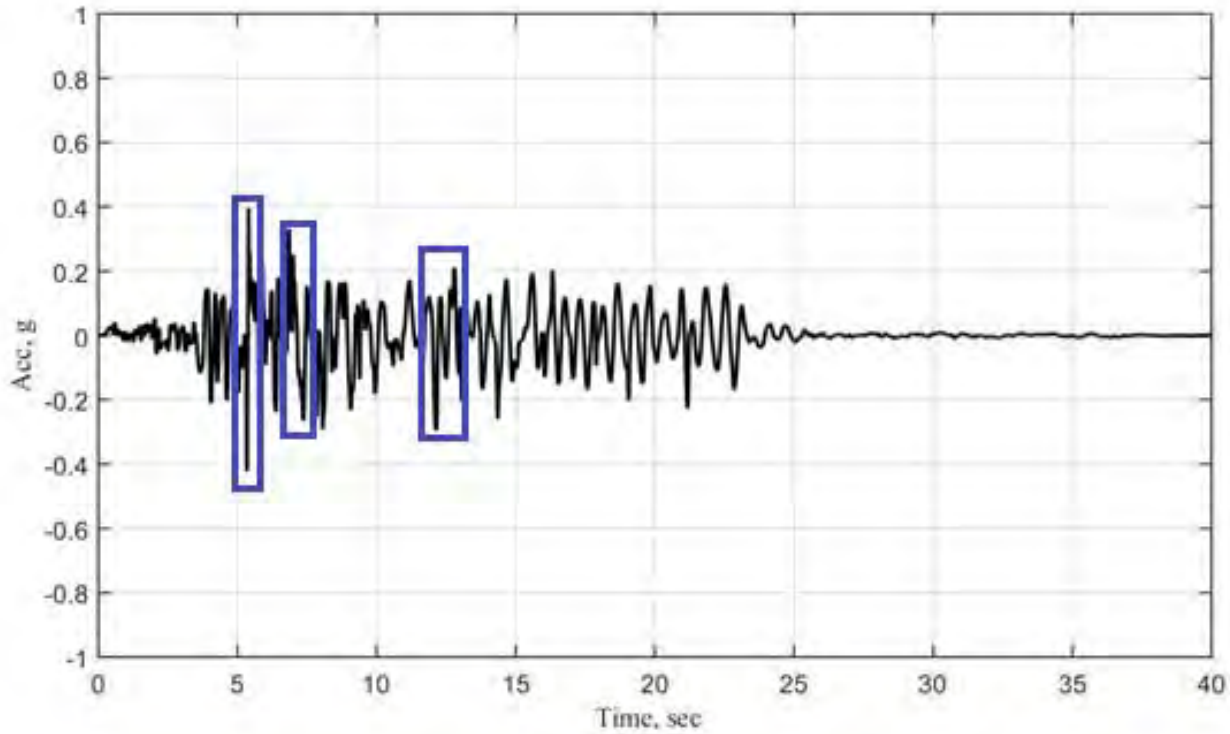
Our Competitors Devices Work for 15-20% of the Time



TIME WINDOWS WHEN YIELDING DEPENDENT DEVICES ARE ACTIVE, THESE TIME WINDOWS COMPRISE ONLY 15 TO 20 % OF THE FULL TIME HISTORY TIME

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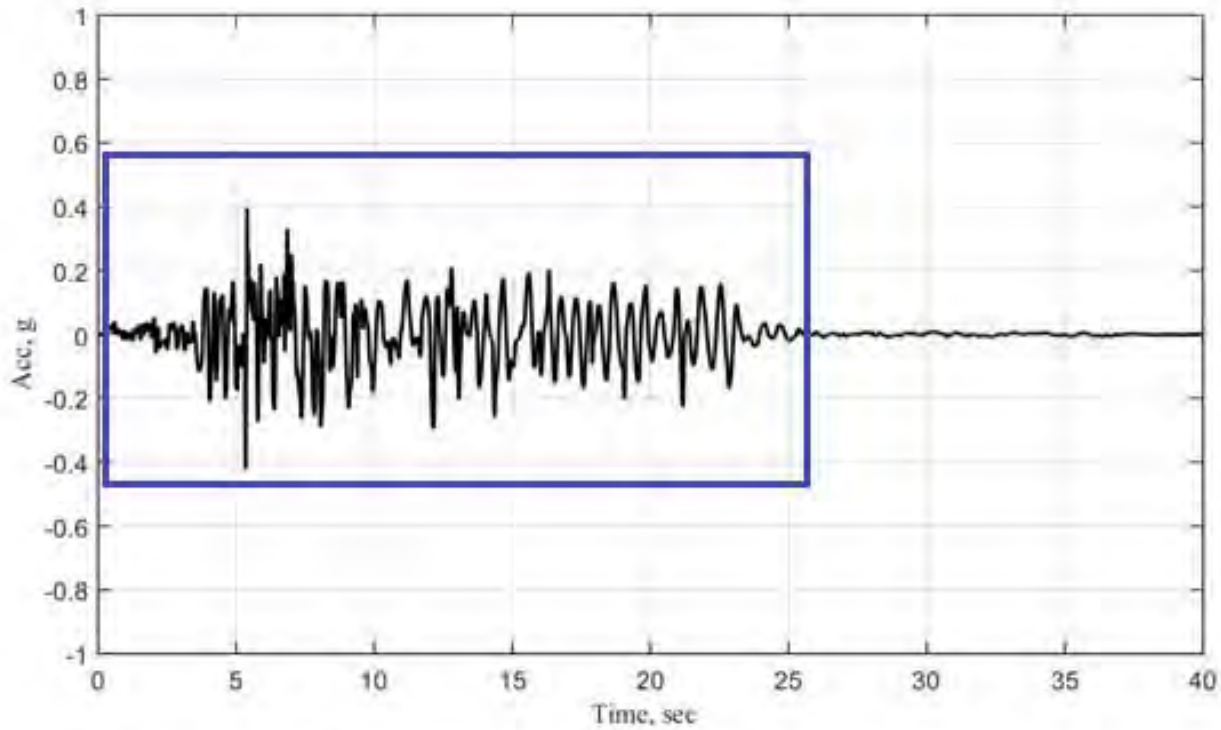
Our Devices Work for 100% of the Time and that too More Efficiently



TIME WINDOW WHEN FLUID VISCOUS DAMPERS ARE FUNCTIONAL AND DISSIPATING ENERGY ON A CONTINUOUS BASIS THEREBY REDUCING DISPLACEMENTS, ACCELERATIONS AND STRESSES.

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Code Compliant Cost Efficient Design - 1

- MRF with FVDs provides greatest cost savings
- Zone-2 - OMRF or SMRF
- Zones 3 to 5 - SMRF
- Moment Resisting Frames are designed to the strength requirements of the design code after taking into account the benefit of reduced base shear due to increased damping.
- However the MRF will fail in code requirement of Story Drift Ratio (SDR).
- Compliance to SDR using Dampers.
- **$F=CV^{\alpha}$**

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Code Compliant Cost Efficient Design - 2

- FVD response is out of phase with the inertial forces so no additional forces on the structural elements or foundations, this makes FVD favorable for retrofits and upgrades also.
- Velocity exponents of 0.3 and 0.5 are most popular Non-Linear dampers.
- ASCE 7-16 has introduced ‘Bounding Analysis’ for FVDs the C-value range is +/- 15%
- Upper Bound C-value governs FVD size (Force capacity) to be used in the structure.
- Lower Bound C-value governs Story Drift Ratios.

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Code Compliant Cost Efficient Design - 3

- As per ASCE 7-16 when using FVD it is permissible to reduce the base shear demand to 75% of computed demand.
- Linear Dampers when installed Horizontally are more efficient in stroke, however non-linear diagonal dampers are as efficient.
- Usually the inter story velocities in a building during an earthquake can vary from 0.05 M/sec to 0.5 M/sec .
- A single non-linear damper can be configured to work for this complete range.
- Usually damper stroke in earthquakes can range from +/- 5 MM to +/- 75 MM

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Code Compliant Cost Efficient Design - 4

- Step 1 – Create/Use the Etabs model.
- Step 2 – using story drifts identify if you require dampers in X or Y or both directions.
- Step 3 – Define Link Property

Link Property Data

General

Link Property Name	FVD-Non Linear	Link Type	Damper - Exponential
Link Property Notes	Modify/Show Notes...	P-Delta Parameters	Modify/Show...

Total Mass and Weight

Mass	0.01	kg	Rotational Inertia 1	1E-05	ton-m²
Weight	1E-05	kN	Rotational Inertia 2	1E-05	ton-m²
			Rotational Inertia 3	1E-05	ton-m²

Factors for Line and Area Springs

Link/Support Property is Defined for This Length When Used in a Line Spring Property	1	m
Link/Support Property is Defined for This Area When Used in an Area Spring Property	1	m²

Directional Properties

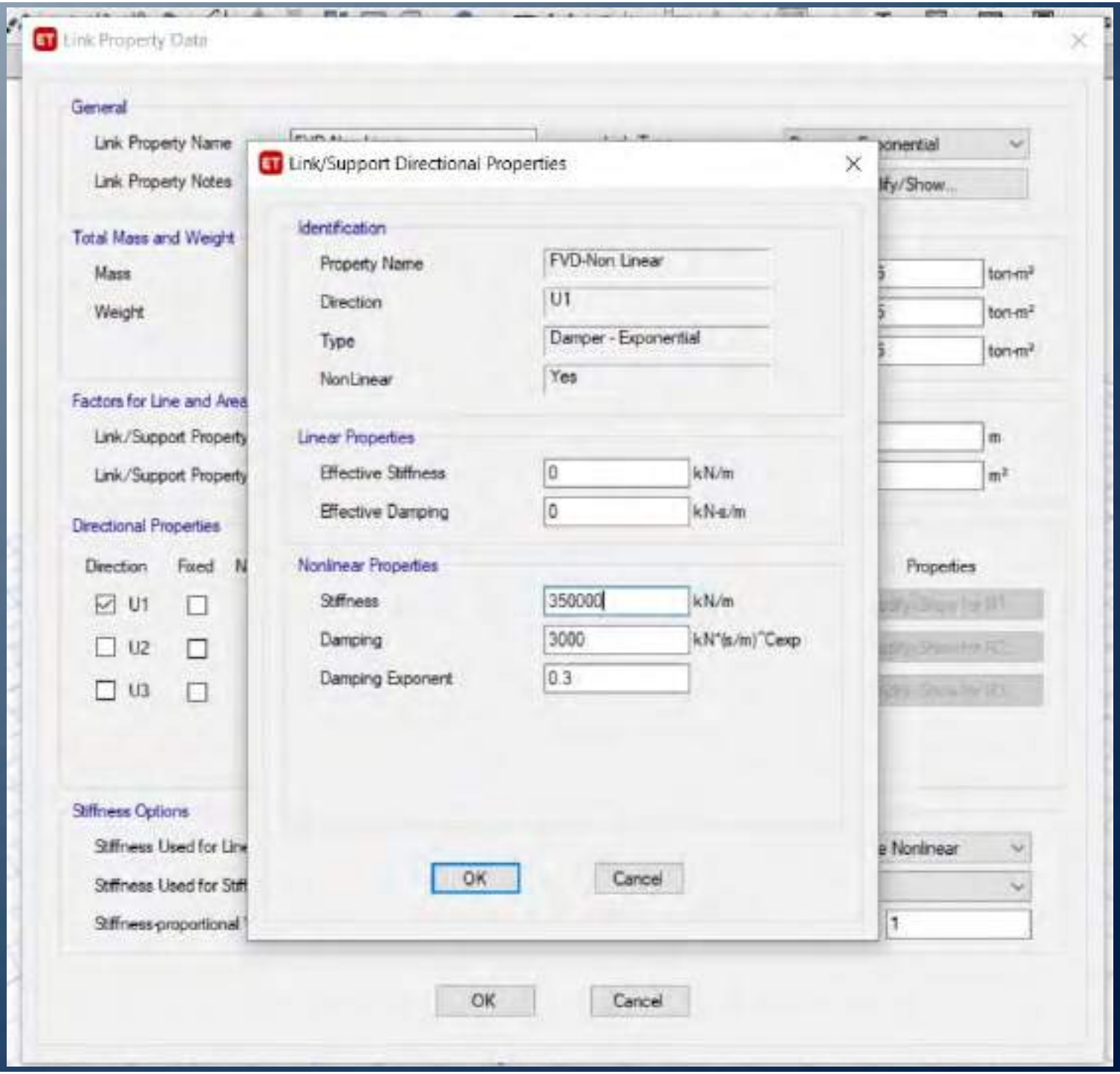
Direction	Fixed	NonLinear	Properties	Direction	Fixed	NonLinear	Properties
☑ U1	☐	☑	Modify/Show for U1...	☐ R1	☐		
☐ U2	☐			☐ R2	☐		
☐ U3	☐			☐ R3	☐		

Fix All Clear All

Stiffness Options

Stiffness Used for Linear and Modal Load Cases	Effective Stiffness from Zero, Else Nonlinear
Stiffness Used for Stiffness-proportional Viscous Damping	Initial Stiffness (K0)
Stiffness-proportional Viscous Damping Coefficient Modification Factor	1

OK Cancel


Link Property Data
General
Link Property Name
Link Property Notes
Total Mass and Weight
Mass
Weight
Factors for Line and Area
Link/Support Property
Link/Support Property
Directional Properties
Direction
Fixed
U1
U2
U3
Stiffness Options
Stiffness Used for Line
Stiffness Used for Stiff
Stiffness-proportional
OK
Cancel
Link/Support Directional Properties
Identification
Property Name
FVD-Non Linear
Direction
U1
Type
Damper - Exponential
NonLinear
Yes
Linear Properties
Effective Stiffness
0
kN/m
Effective Damping
0
kN-s/m
Nonlinear Properties
Stiffness
350000
kN/m
Damping
3000
kN*(s/m)^Cexp
Damping Exponent
0.3
OK
Cancel

Code Compliant Cost Efficient Design - 4

- Step 1 – Create/Use the Etabs model.
- Step 2 – using story drifts identify if you require dampers in X or Y or both directions.
- Step 3 – Define Link Property
- Step 4 – Draw Links (Dampers) Either use draw links or draw any null line, select it and use assign-> link property command.
- Depending on the strength and stiffness of the columns and beams for initial damper analysis you can decide to use 750/1000/1500/2000 KN damper.

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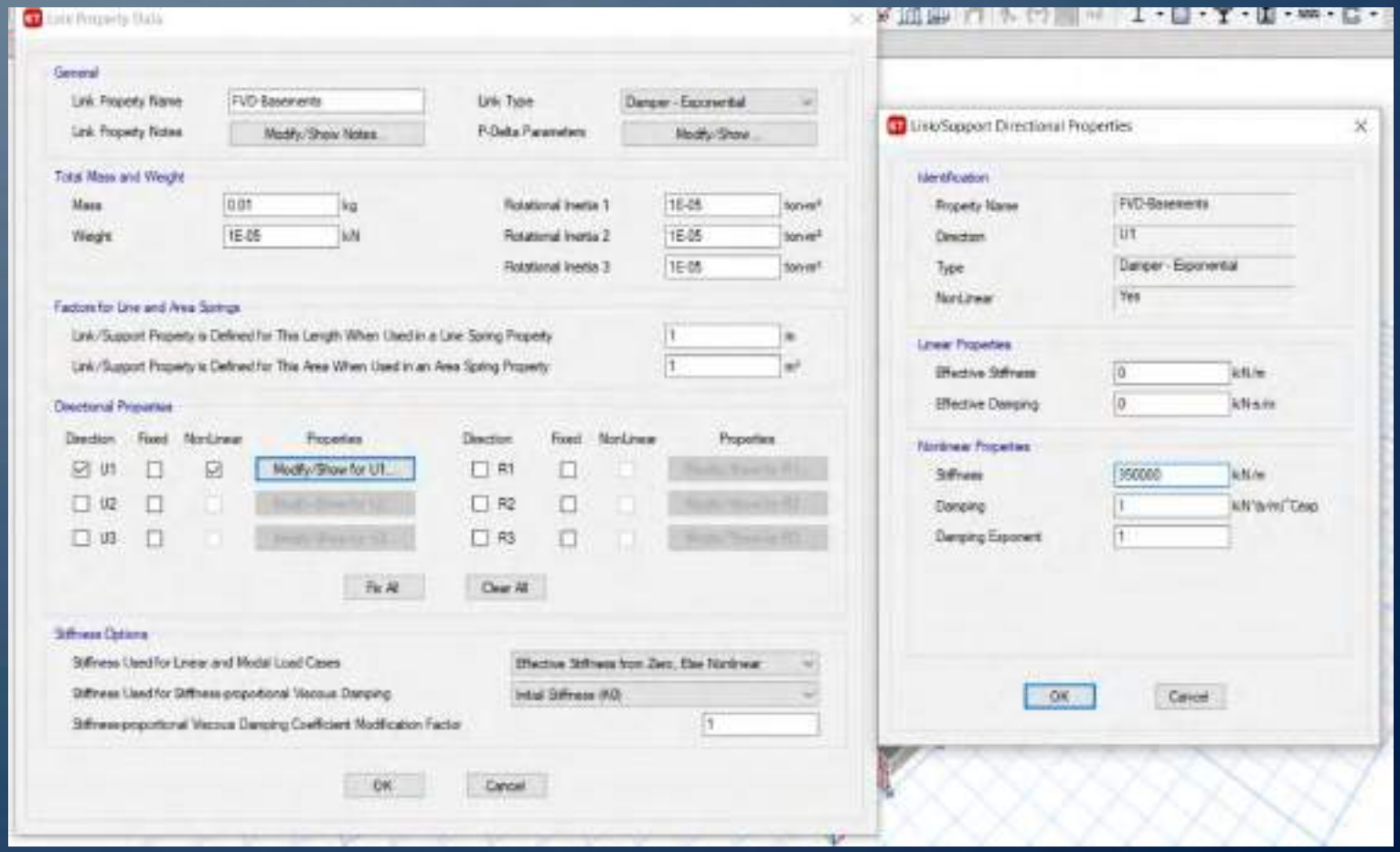
Code Compliant Cost Efficient Design - 5

- Use equation **$F=CV^{\alpha}$** to calculate C-value for first analysis
- If structure is very flexible use 0.1 M/sec velocity, if very stiff then use 0.4 M/sec velocity to calculate the C value. How to compute inter story velocities in Etabs.

- Model Unity Damper and Run Time History Analysis
- In Output Tables select Link-Forces
- See maximum force, that will be the inter story velocity



Code Compliant Cost Efficient Design - 5

- Use equation **$F=CV^{\alpha}$** to calculate C-value for first analysis
- If structure is very flexible use 0.1 M/sec velocity, if very stiff then use 0.4 M/sec velocity to calculate the C value. How to compute inter story velocities in Etabs.
- Using Code Response Spectrum calculate short period and 1 second acceleration (for zone-4 S_s= 2.5 x 0.24 = 0.6 and S_1= 0.24 x 1.36/1 = 0.3264)
- Use ASCE Table 7.6-1 and 7.6-2 to establish Seismic Design category of building.
- Design the Moment Resisting Frames to Code Compliance for strength.

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Code Compliant Cost Efficient Design - 6

- As Non Linear dampers are being configured so Non Linear Response History Analysis (NLRHA)

Load Case Data

General

Load Case Name: Zone2_Case1_UnScaled

Load Case Type/Subtype: Time History | Nonlinear Modal (FNA)

Exclude Objects in this Group: Not Applicable

Mass Source: Previous (MsSrc1)

Design... | Notes...

Initial Conditions

- ○ Zero Initial Conditions - Start from Unstressed State
- ◉ Continue from State at End of Nonlinear Case (Loads at End of Case ARE Included)

Nonlinear Case: Gravity_Non-Linear

Loads Applied

Load Type	Load Name	Function	Scale Factor
Acceleration	U1	Zone2_TH1	9810
Acceleration	U2	Zone2_TH2	9810

Add | Delete

☐ Advanced

Other Parameters

Modal Load Case: Modal

Number of Output Time Steps: 2500

Output Time Step Size: 0.01 sec

Modal Damping: Constant at 0.05 — Modify/Show...

Nonlinear Parameters: Default — Modify/Show...

OK | Cancel

Code Compliant Cost Efficient Design - 6

- As Non Linear dampers are being configured so Non Linear Response History Analysis (NLRHA)
- Choose 7 sets of time histories from database (PEER)
- Scaling or Spectrum matching both are permitted. Etabs can do Spectrum Matching of Time Histories very efficiently.

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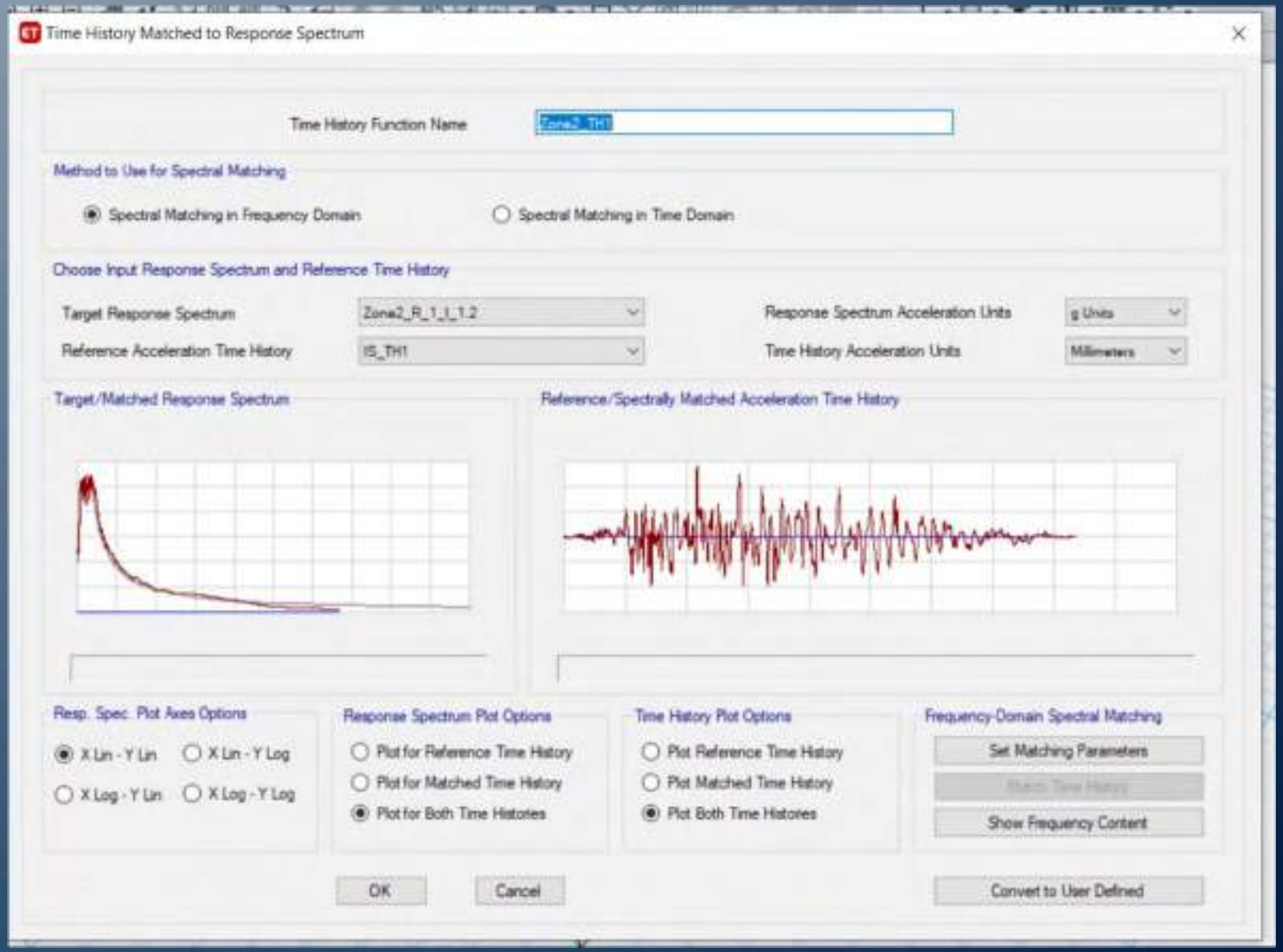
Time History Matched to Response Spectrum
Time History Function Name
Zone2_TH1
Method to Use for Spectral Matching
Spectral Matching in Frequency Domain
Spectral Matching in Time Domain
Choose Input Response Spectrum and Reference Time History
Target Response Spectrum
Zone2_R_1_I_1.2
Reference Acceleration Time History
IS_TH1
Response Spectrum Acceleration Units
g Units
Time History Acceleration Units
Millimeters
Target/Matched Response Spectrum
Reference/Spectrally Matched Acceleration Time History
Resp. Spec. Plot Axes Options
X Lin - Y Lin
X Lin - Y Log
X Log - Y Lin
X Log - Y Log
Response Spectrum Plot Options
Plot for Reference Time History
Plot for Matched Time History
Plot for Both Time Histories
Time History Plot Options
Plot Reference Time History
Plot Matched Time History
Plot Both Time Histories
Frequency-Domain Spectral Matching
Set Matching Parameters
Show Frequency Content
OK
Cancel
Convert to User Defined

Code Compliant Cost Efficient Design - 6

- As Non Linear dampers are being configured so Non Linear Response History Analysis (NLRHA)
- Choose 7 sets of time histories from database (PEER)
- Scaling or Spectrum matching both are permitted. Etabs can do Spectrum Matching of Time Histories very efficiently.
- Code permitted Story Drift Ratio for SMRF
- = 0.04 x 5 = 2%
- Finalise, number of dampers in each direction and their C-value
- Keep looking at energy graph, it's a useful tool as to what the dampers are doing.

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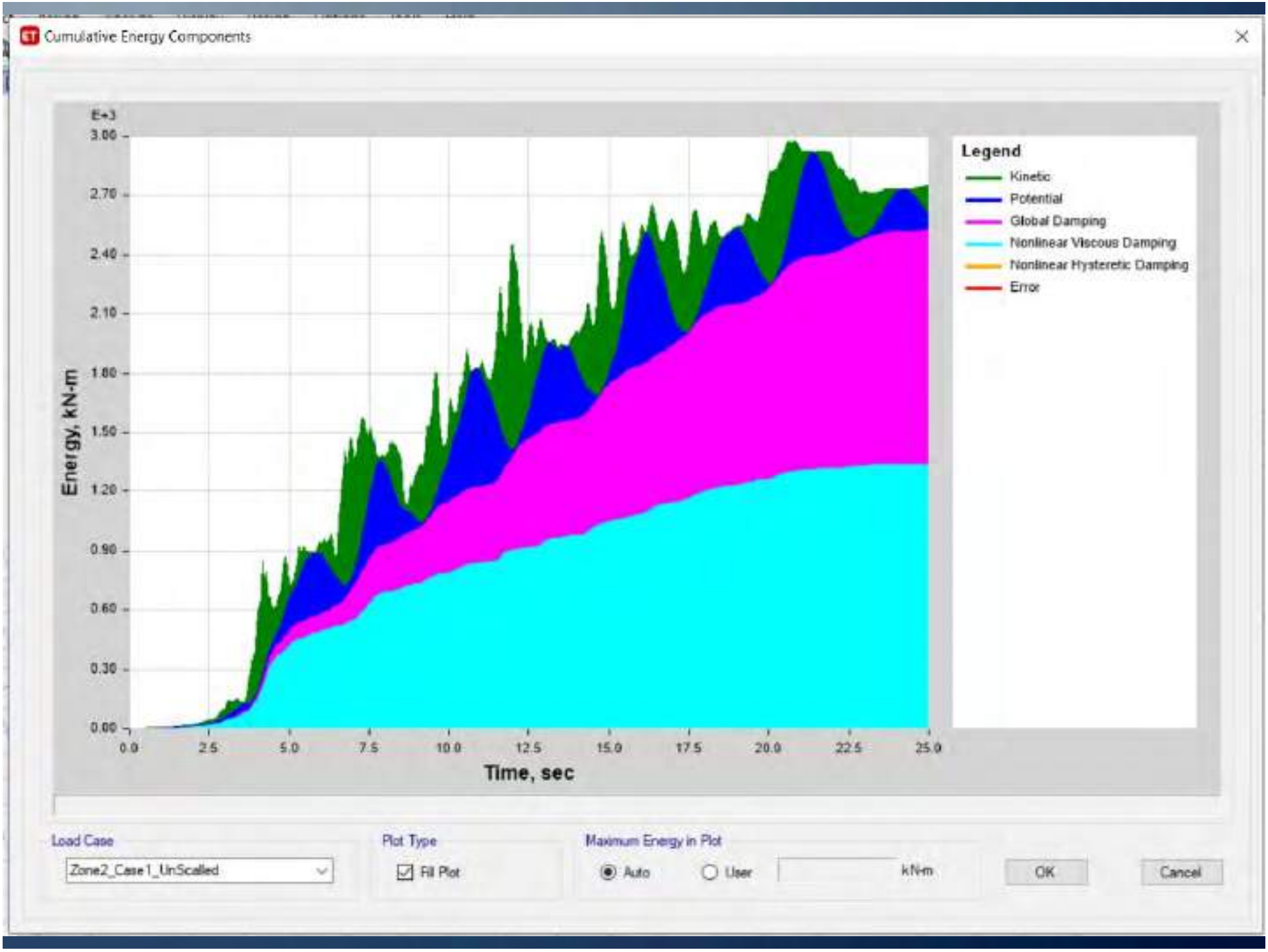
Cumulative Energy Components
E+3
3.00
2.70
2.40
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0.00
Energy, kN-m
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Time, sec
Legend
Kinetic
Potential
Global Damping
Nonlinear Viscous Damping
Nonlinear Hysteretic Damping
Error
Load Case
Zone2_Case1_UnScalled
Plot Type
Fill Plot
Maximum Energy in Plot
Auto
User
kN-m
OK
Cancel

Code Compliant Cost Efficient Design - 7

- Once dampers are finalised then compute the Damper Force Capacity and Story Drift Ratios for lower bound, nominal and upper bound C-values using +/- 15%
- The Damper Force capacity to be configured to MCE conditions. The best part is that same Non-Linear dampers are equally efficient for DBE and MCE and beyond.
- Taylor Devices uses a factor of 2 in the Force Capacity of the damper before the damper starts to yield.

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Code Compliant Cost Efficient Design - 8

- In many cases you can configure dampers to achieve Immediate Occupancy and also save on structural cost. See table below.

Type of EQ	V in m/sec	C – constant (KN-sec/m)	∞ - constant	Force Capacity (KN)	Damper Design Capacity (KN)	Damper Yield Capacity (KN)
DBE	0.20	1100	0.3	678	1000	2000
100% MCE	0.40	1100	0.3	834	1000	2000
200% MCE	0.80	1100	0.3	1028	1000	2000
300% MCE	1.20	1100	0.3	1161	1000	2000
400% MCE	1.60	1100	0.3	1266	1000	2000

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Code Compliant Cost Efficient Design - 9

- How to minimise the cost of dampers:
  - Use same dampers C, α and Force capacity
  - This can be done easily in non linear dampers
  - Minimise the total number of dampers by using more of 1500 KN and 2000 KN dampers
  - Try to configure dampers so that with upper-bound C-value the force capacity is as close as possible to 750/1000/1500/2000 KN which are standard sizes
  - Try and configure dampers in such a way that the same damper can be used for both DBE and MCE.
  - Use FNA feature of Etabs to save time.

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What Sets Taylor Devices Apart?

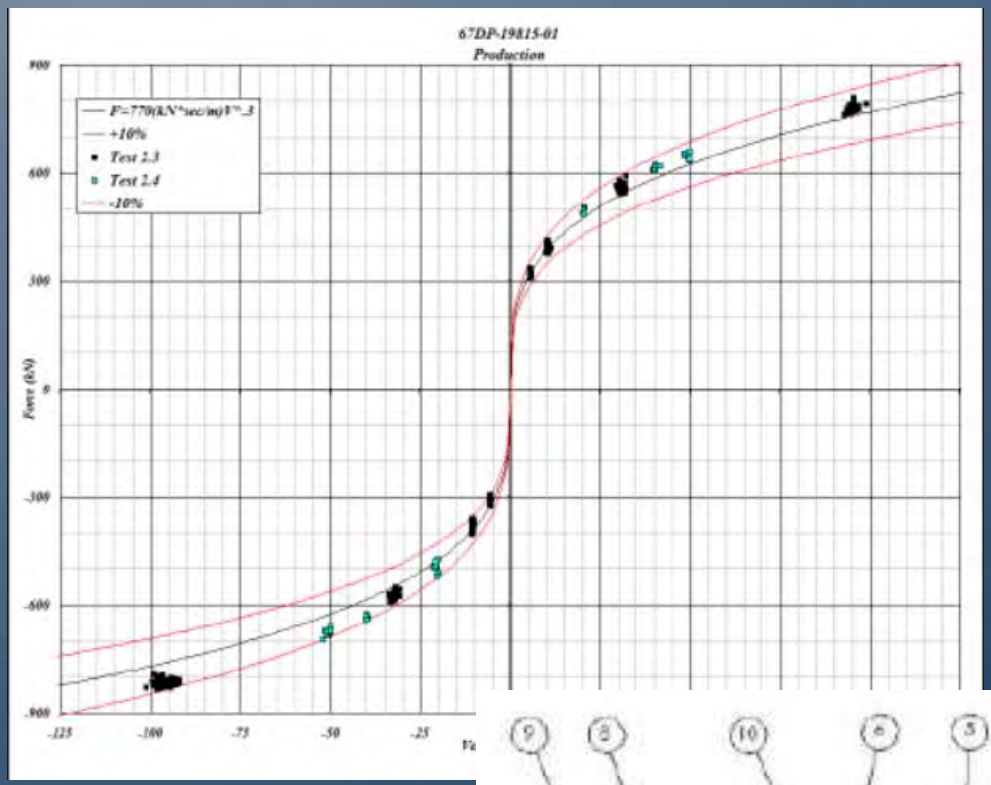
1. Velocity Dependent and Not Displacement Dependent, work efficiently even with minimum displacements, can be installed in rigid areas.

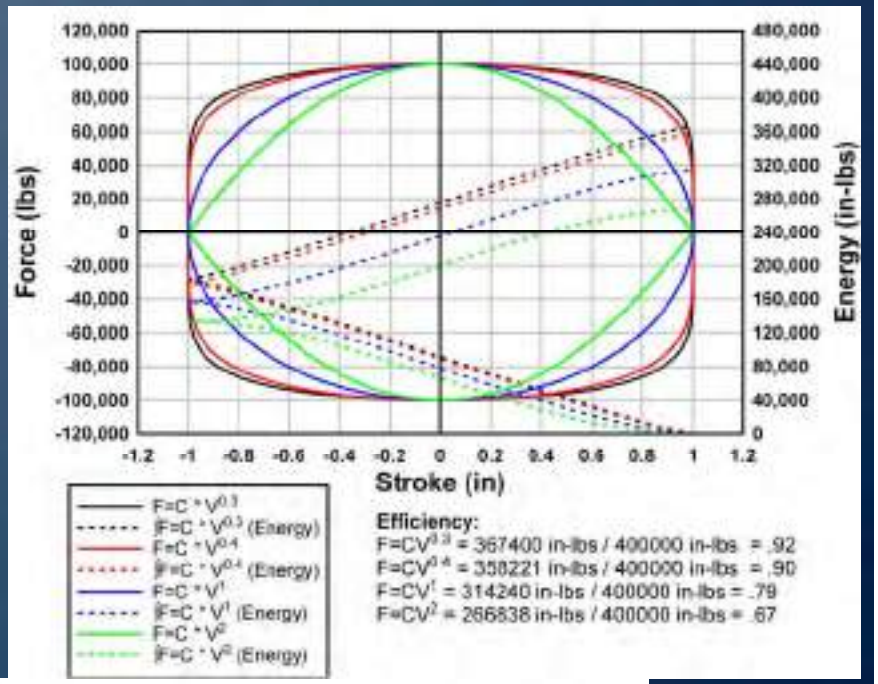
What Sets Taylor Devices Apart?

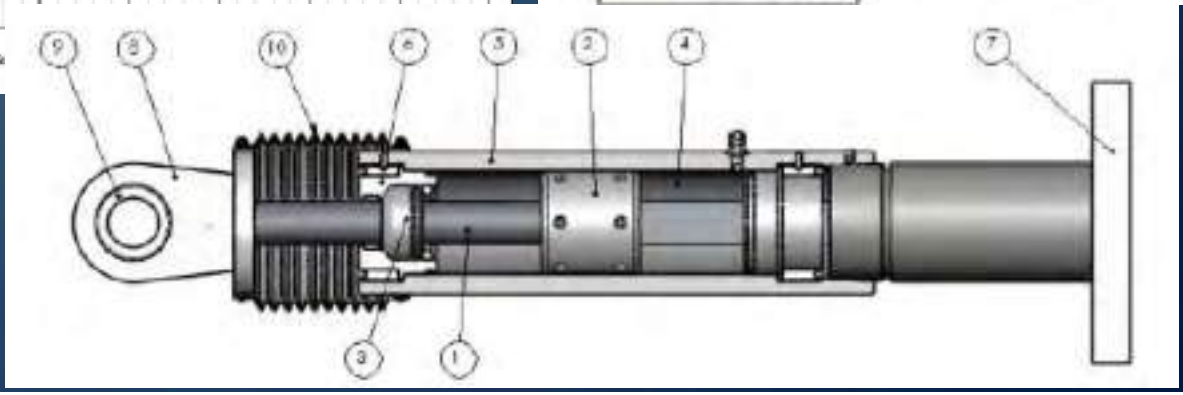
2. No Upper Bound either for Maximum Force or for Maximum Velocity

What Sets Taylor Devices Apart?

3. Same Damper can be Configured to Work Equally Efficiently for Small Earthquakes, Long Distance Earthquakes and Strong Near Distant Earthquakes.







Benefits of Dampers:

- Reduce cost of structure.
- Reduced displacements / inter-story drifts / plastic rotations
- Decrease base shear and story shear
- Decrease floor accelerations thereby preventing damage to non structural components
- Reduce stresses as damper response is out-of-phase with forces induced due to structural response
- A special type of damper called “Metal Bellow” can be configured for both Wind and Seismic. Metal bellow dampers costs more than seismic damper

Viscous Damping Equation:

$F=CV^{\alpha}$

where

F = Force in KN

C = Damping coefficient, a constant KN-sec/M

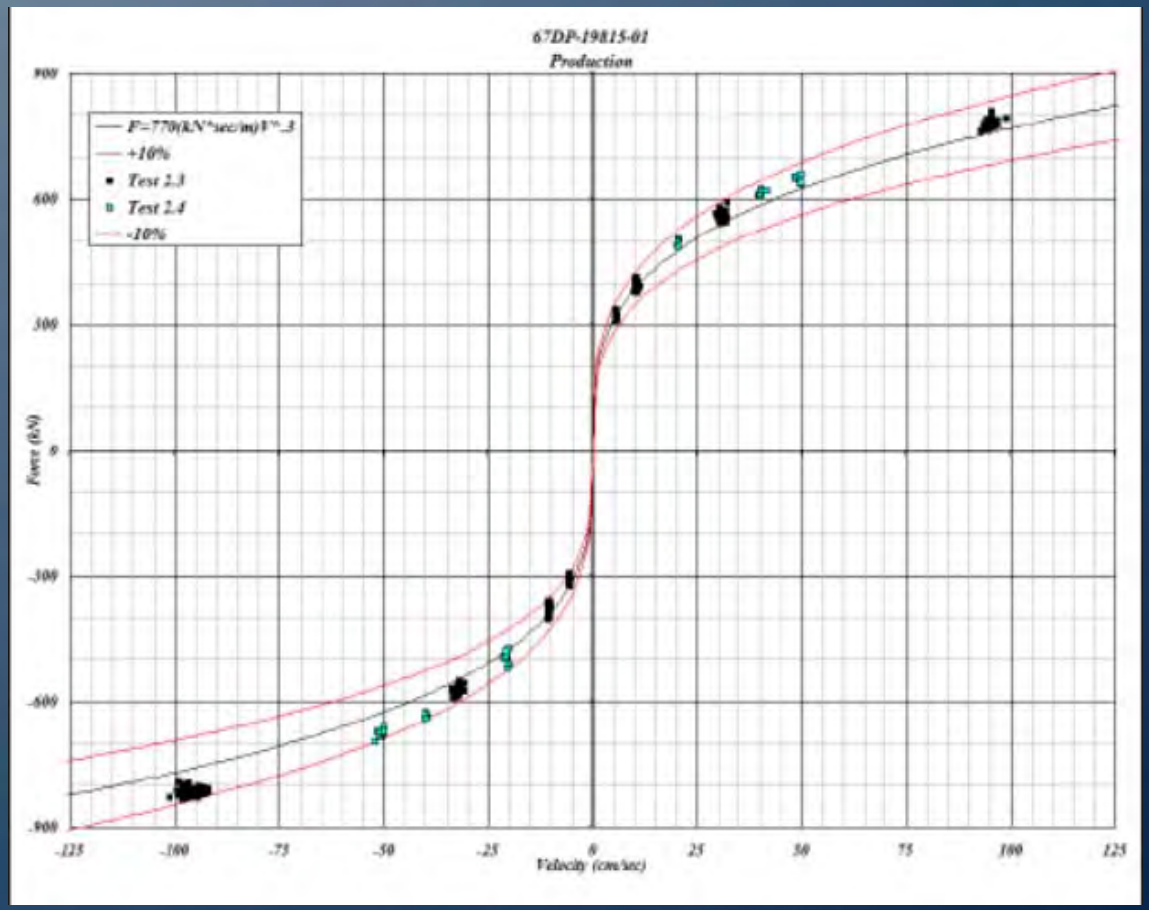
V = Velocity in M/sec

α = Damping exponent, a constant

"α" can be set to any value from $.3 < a < 2.0$ In general, the lower this value, the greater the energy dissipation per cycle for a given maximum stress in the structure. α = 1 (linear damper) is easiest to analyze. Many optimized structures use α = .3

Non-Linear Force Vs Velocity Curve +/- 10%

We test 100% of our Dampers and they remain as-new even after repeatedly experiencing earthquakes, other type of devices test only the prototype as they deteriorate after each cycle of operation.



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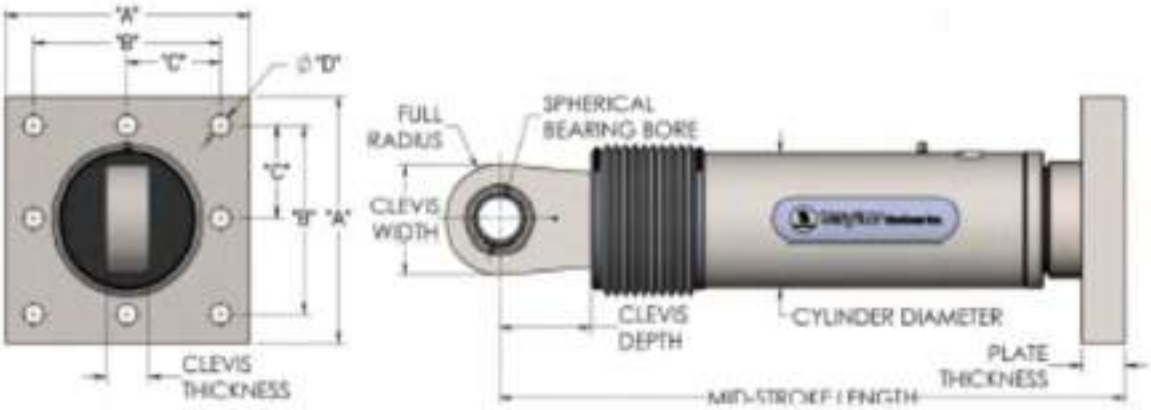
FLUID VISCOUS DAMPERS & LOCK-UP DEVICES
CLEVIS – BASE PLATE CONFIGURATION, METRIC UNITS



NOTE:
VARIOUS STROKES ARE AVAILABLE, FROM ±50 TO ±900 mm. FORCE CAPACITY MAY BE REDUCED FOR STROKE LONGER THAN STROKE LISTED IN THE TABLE. ANY STROKE CHANGE FROM THE STANDARD STROKE VERSION DEPICTED CHANGES THE MIDSTROKE LENGTH BY 5 mm PER ±1 mm OF STROKE.

EXAMPLE:1000kN±100mm STROKE, MID-STROKE LG IS 1048mm
1000 kN ± 150 mm STROKE, 150÷100= 50, 50*5=250
1048+250 = 1298 mm MID-STROKE LENGTH

BELLOWS MAY BE REPLACED WITH A STEEL SLEEVE AS DESIRED STROKE LENGTHS INCREASE. CONSULT TAYLOR DEVICES FOR STROKE OVER ±300 mm AND/OR FOR FORCE CAPACITIES FOR STROKE LONGER THAN LISTED IN TABLE.

FORCE (kN)	TAYLOR DEVICES MODEL NUMBER	SPHERICAL BEARING BORE DIAMETER (mm)	MID-STROKE LENGTH (mm)	STROKE (mm)	CLEVIS THICKNESS (mm)	MAXIMUM CLEVIS WIDTH (mm)	CLEVIS DEPTH (mm)	BEARING THICKNESS (mm)	MAXIMUM CYLINDER DIAMETER (mm)	WEIGHT (kg)	"A" (mm)	"B" (mm)	"C" (mm)	"D" (mm)	PLATE THICKNESS (mm)
250	17120	38.10	787	±75	43	102	83	33	114	44	178±3	127±.25	†	20.6±.25	38±.76
500	17130	50.80	997	±100	55	127	102	44	146	98	262±3	203±.25	†	31.8±.25	38±.76
750	17140	57.15	1016	±100	59	152	129	50	184	168	343±3	254±.25	127±.25	28.7±.25	51±.76
1000	17150	69.85	1048	±100	71	184	150	61	210	254	419±3	318±.25	159±.25	31.8±.25	76±1.5
1500	17160	76.20	1105	±100	77	203	162	67	241	306	432±3	330±.25	165±.25	34.9±.25	76±1.5
2000	17170	88.90	1346	±125	91	235	191	78	292	503	457±3	343±.25	171.5±.25	38.1±.25	102±1.5
3000	17180	101.60	1441	±125	117	286	203	89	350	805	508±3	406±.25	203±.25	41.4±.25	102±1.5
4000	17190	127.00	1645	±125	142	324	273	111	425	1088	**	**	**	**	**
6500	17200	152.40	1752	±125	152	360	306	121	515	1930	**	**	**	**	**
8000	17210	177.80	1867	±125	178	415	343	135	565	2625	**	**	**	**	**

† DENOTES 4 HOLE PATTERN, MEANING NO CENTER HOLES.
** CONSULT FACTORY FOR DIMENSIONS.

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CLEVIS – CLEVIS CONFIGURATION, METRIC UNITS

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250	17120	38.10	867	±75	43	33	102	83	114	41
500	17130	50.80	1067	±100	55	44	127	102	150	82
750	17140	57.15	1194	±100	59	50	152	129	184	136
1000	17150	69.85	1238	±100	71	61	184	160	210	193
1500	17160	76.20	1314	±100	77	67	203	162	241	250
2000	17170	88.90	1575	±125	91	78	235	191	295	408
3000	17180	101.60	1575	±125	117/111*	89	286/324*	228/210*	350	701
4000	17190	127.00	1880	±125	142	111	324	210	425	1225
6500	17200	152.40	2134	±125	152	121	350	305	515	1810
8000	17210	177.80	2293	±125	178	136	415	343	565	2495

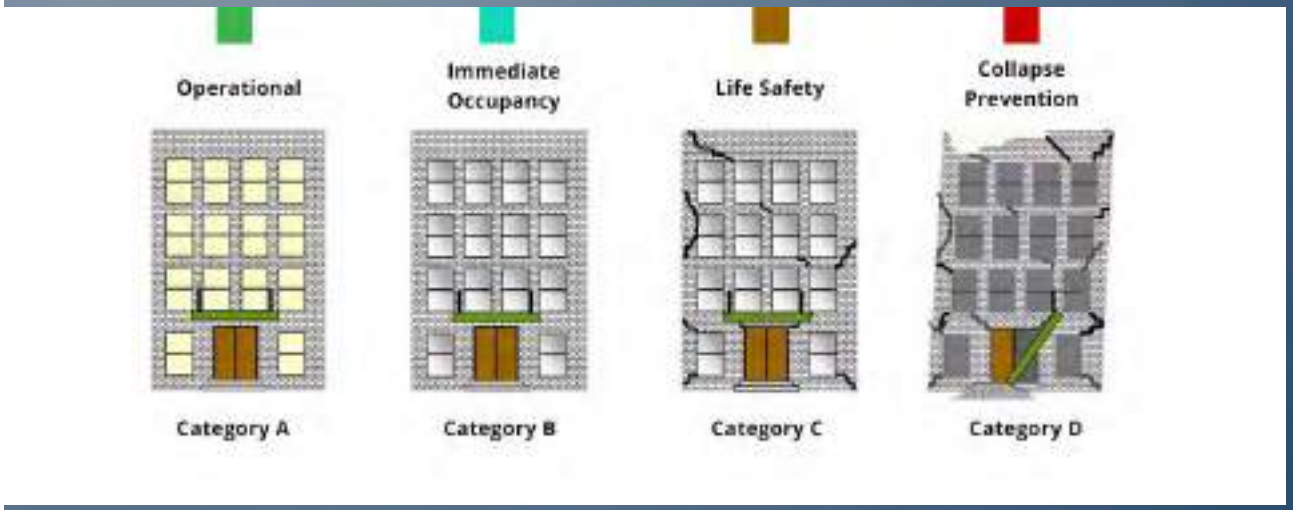
* DENOTES MODEL WITH DIFFERENT CLEVIS SIZES ON EACH END.

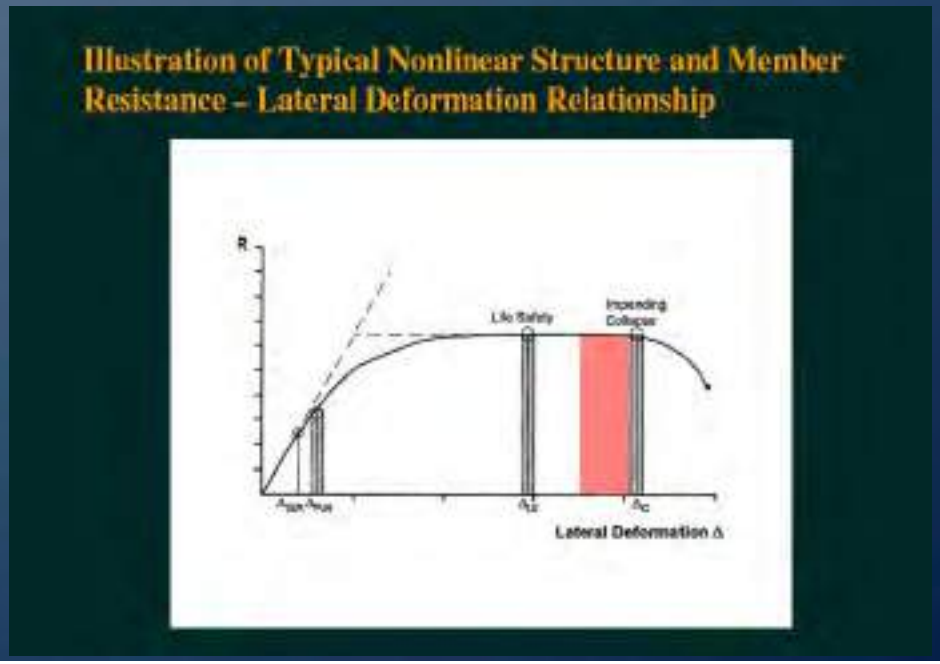
MADE IN USA

How We Work

- Taylor Devices in India are contractors undertaking design and build projects for installation of supplementary damping systems and base isolation in buildings.
- We work along with structural engineers (engineer-of-record), architects, developers and building owners to upgrade existing and new buildings to Code standards and Immediate Occupancy standards.
- Comes on-board as a specialist contractor to undertake the detailed design and installation of the damping system. We also work with Client deputed contractors and supervise their work.
- Design reports and analysis results are submitted to the structural engineer (engineer-of-record) and building owners before actual execution.
- Offering ready-to-use technology for seismic protection that was previously not present in the country. Buildings designed for resilience will also be able to use the trademark “Taylor Protected”.

Performance Levels





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Typical Performance Based Design Seismic Upgrade

New Udaan Bhawan – Delhi Airport

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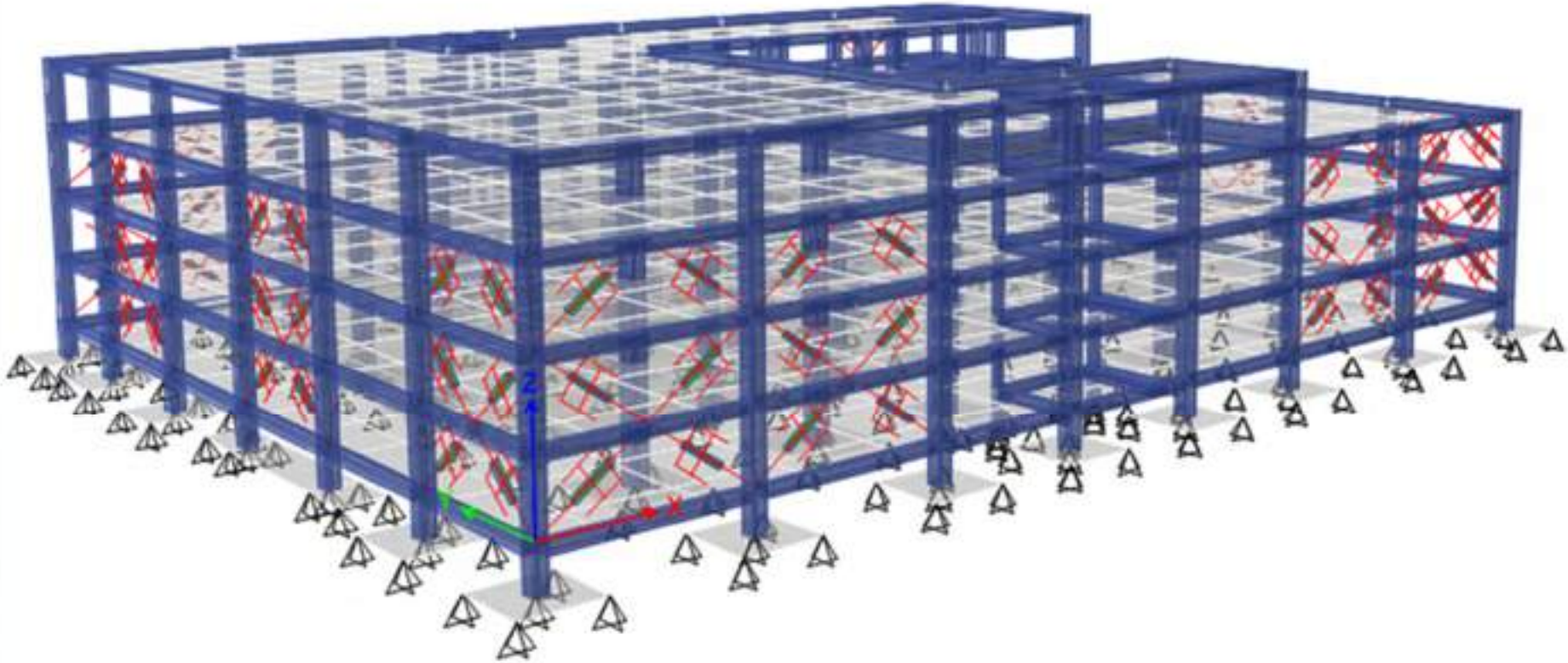
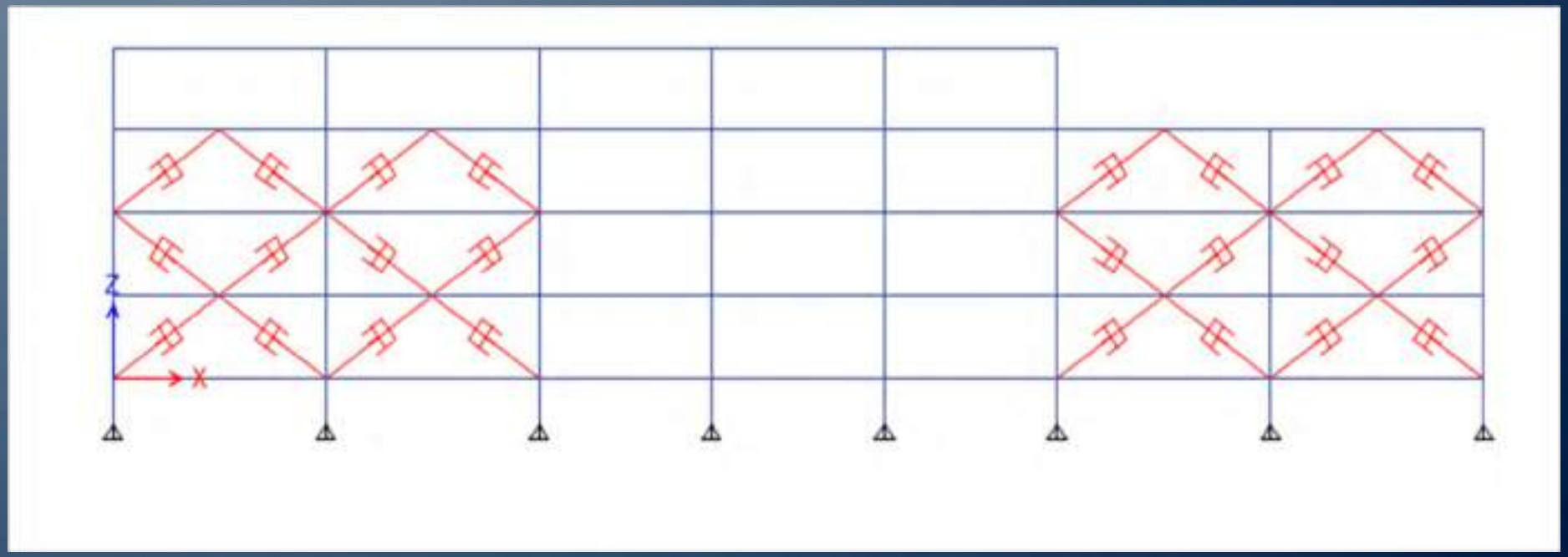
KRA by the Client

1. Should be the most cost effective seismic upgrade solution
2. Buildings need to be operational at all times.
3. Buildings will not be vacated.
4. Least disruptions to interiors
5. No disruption to office working
6. Quality – best standards
7. Maintaining completion timeline
8. Warranty of 35 years

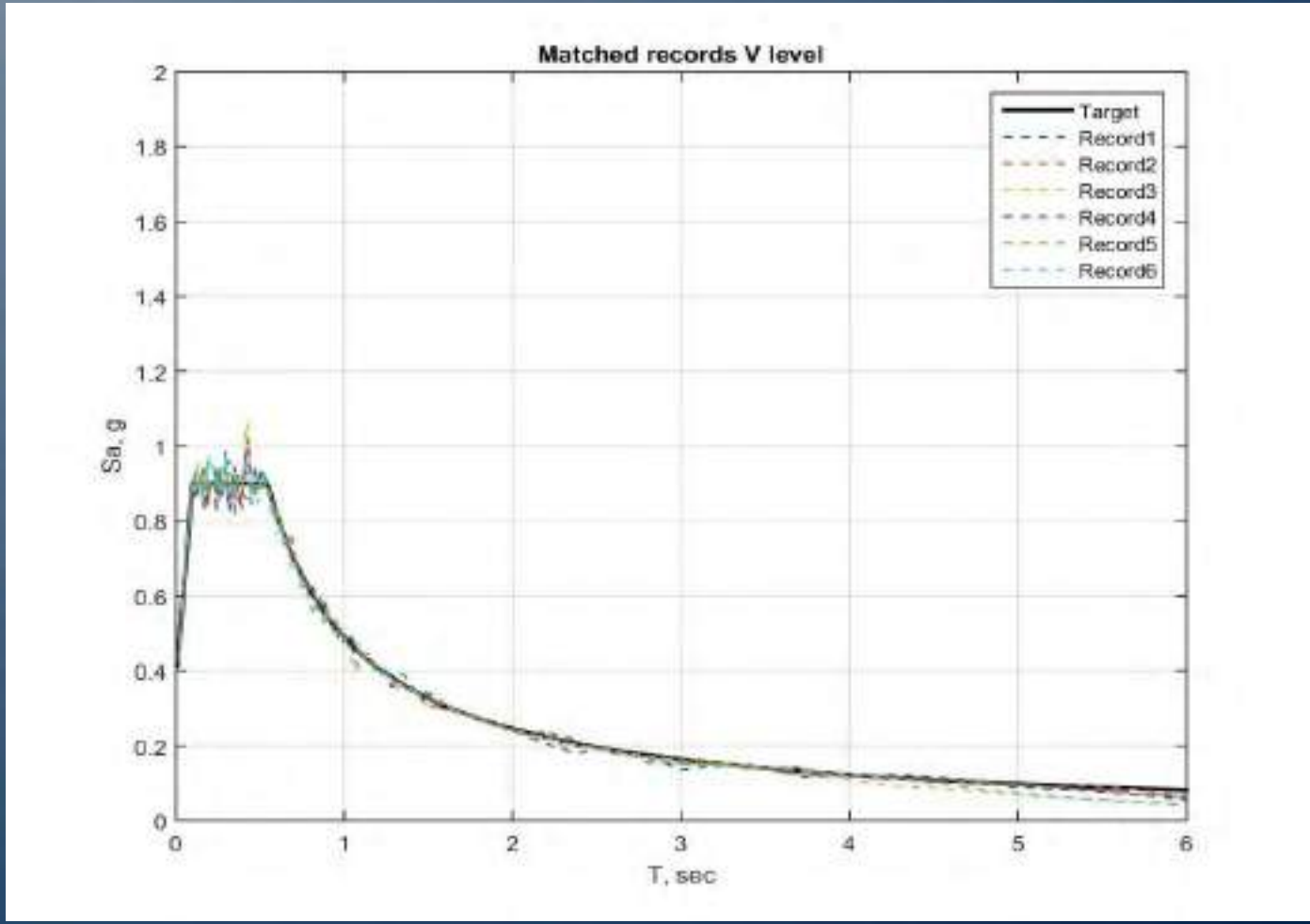
Building modelled in Etabs



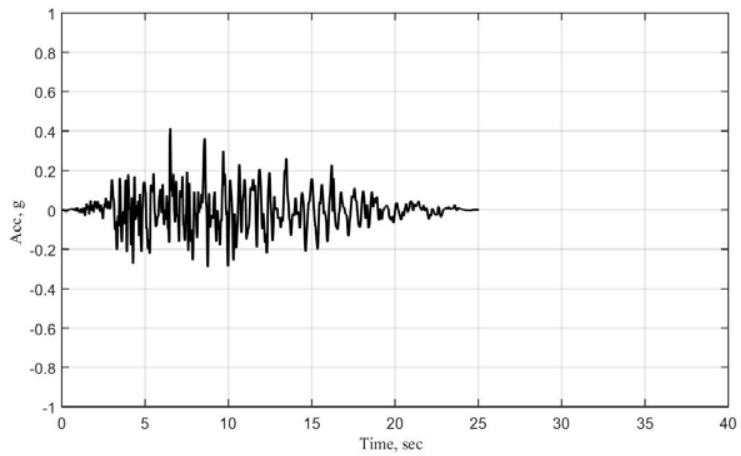
Analytical Modeling of the Buildings

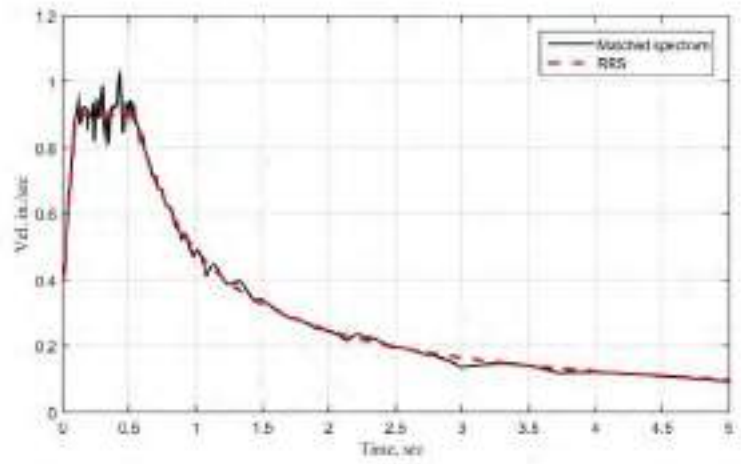


Seismic Hazard – Generation of Time Histories

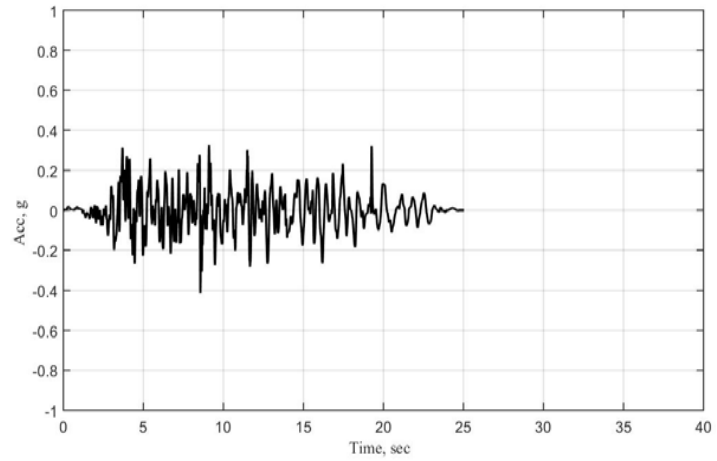


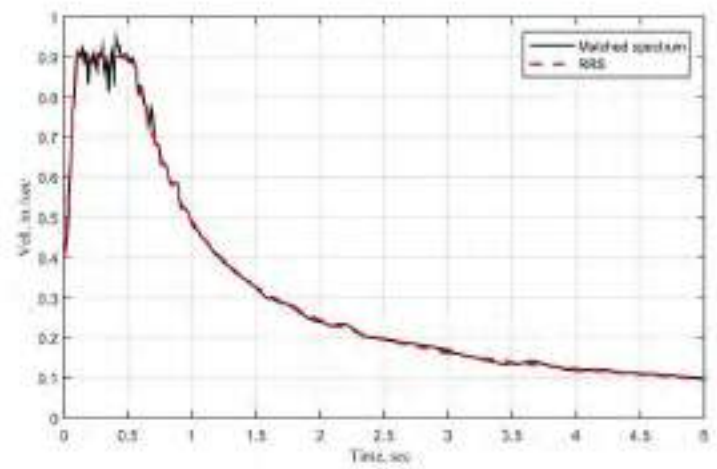
Record 1: component 1



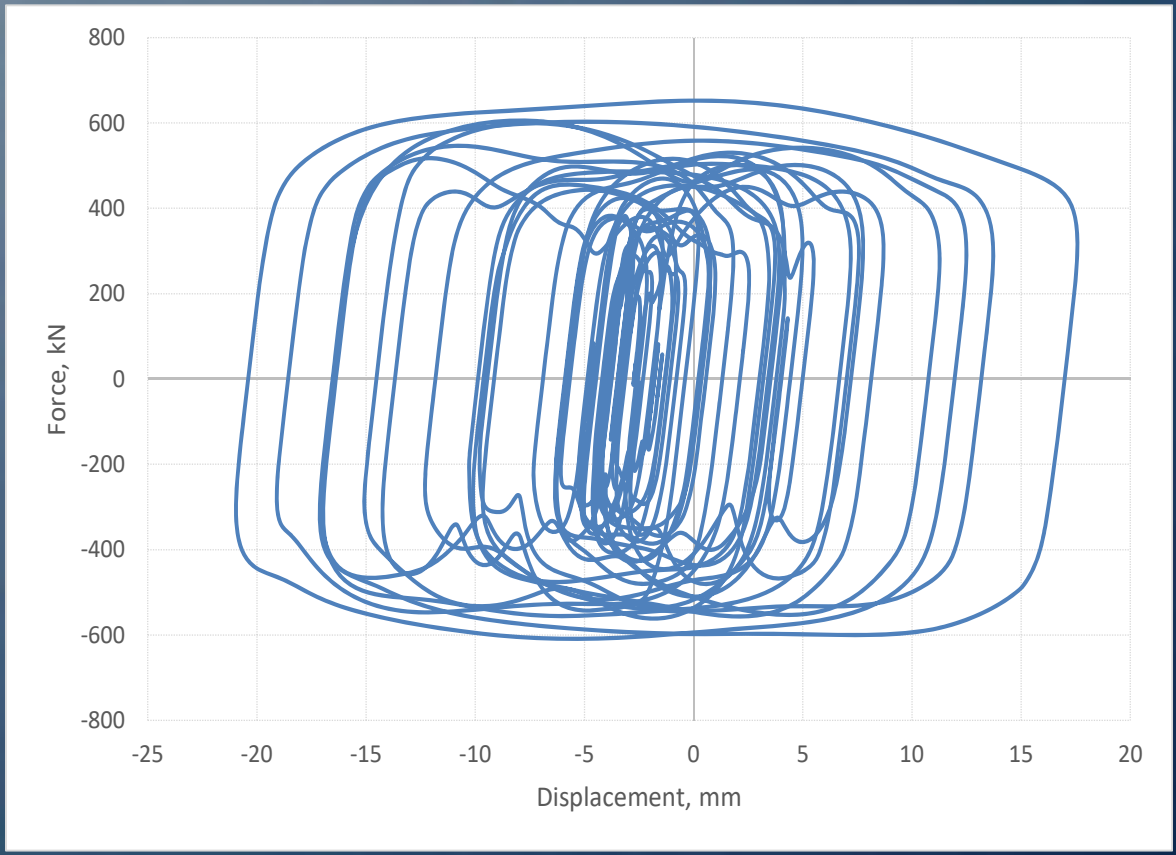


Record 1 : Component 2

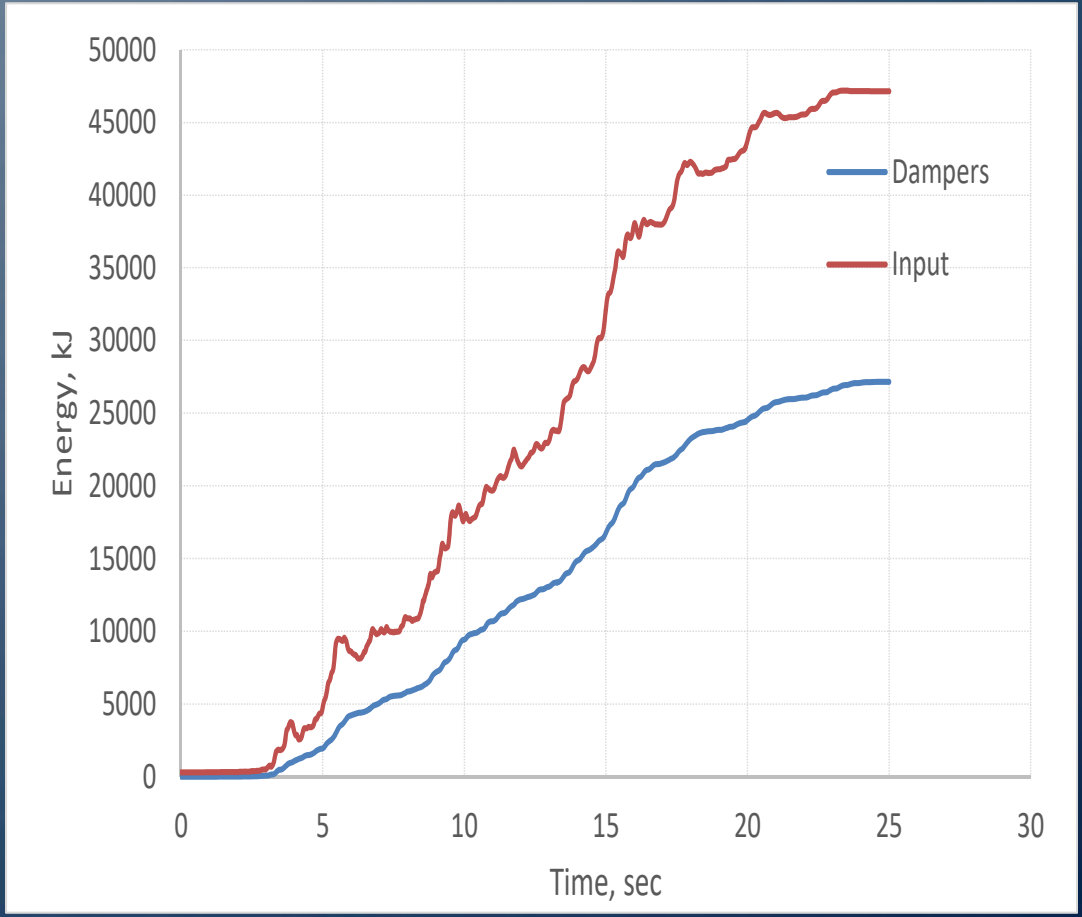




Energy dissipation by seismic dampers



Energy components for an example acceleration record



Analysis Objectives and Results

Structure to remain Elastic

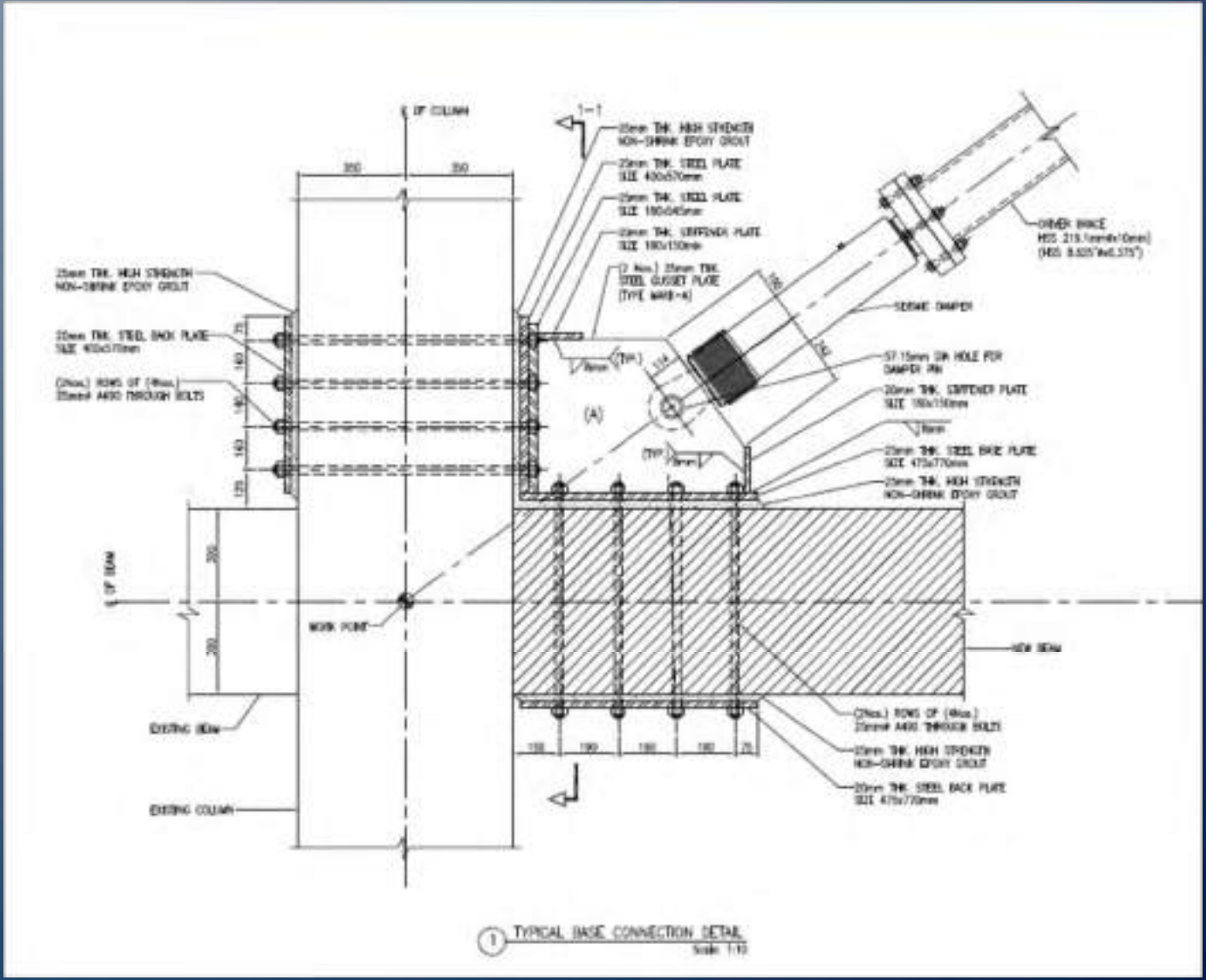
After the seismic dampers are added to the model, the maximum drift ratio measured at any story is approximately 0.8%.

Level	Damped	
	X	Y
ROOF	0.33%	0.41%
THIRD	0.53%	0.57%
SECOND	0.76%	0.79%
FIRST	0.86%	0.85%
GROUND	0.74%	0.67%

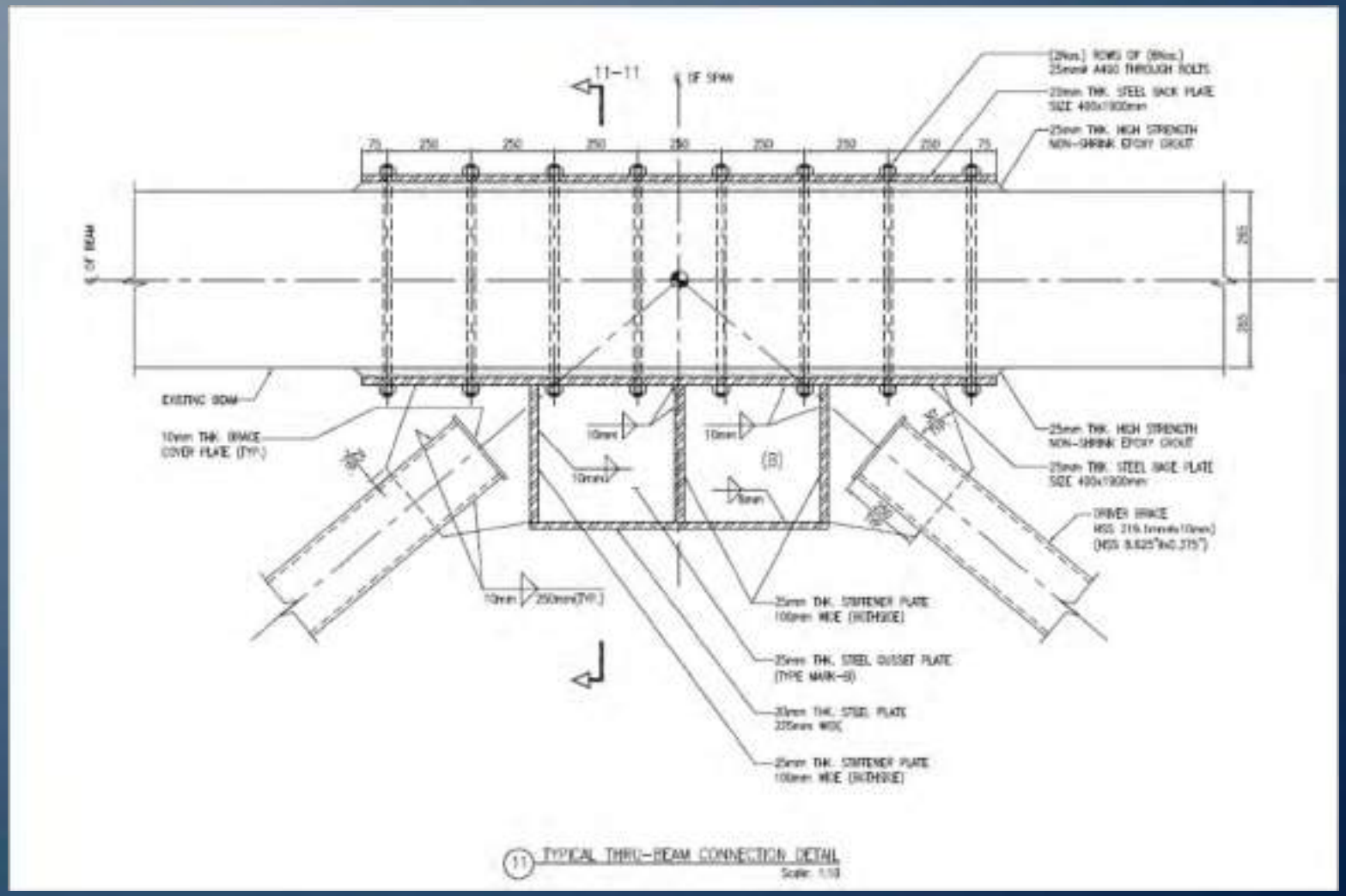
Base Shear Reduction

Base Shear Case	Direction X	Direction Y
Existing	103,200	104,700
Damped	76,200	89,800

Typical Damper Attachment



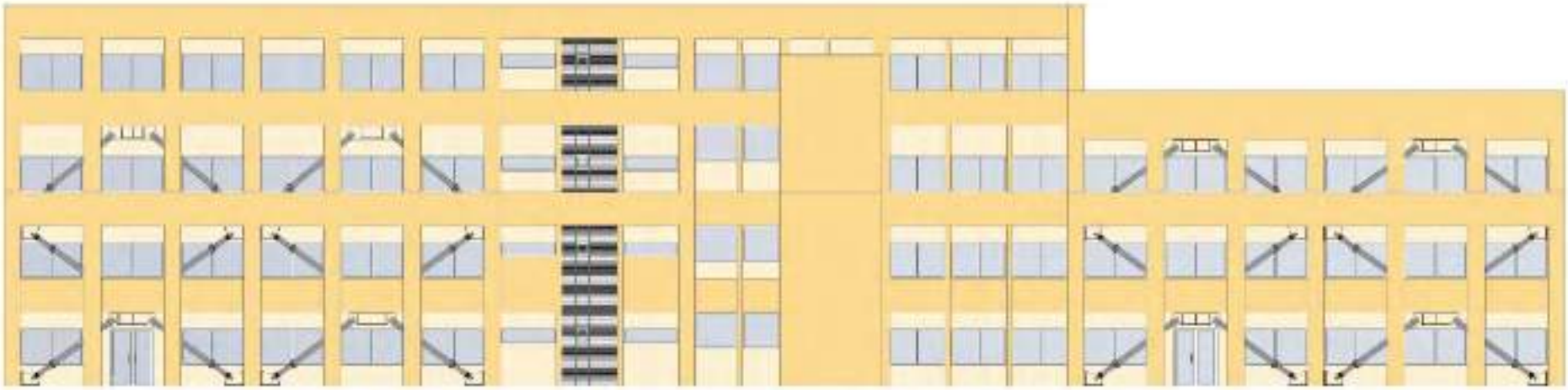
Typical Damper Attachment



Structural Steel - Quality and Fabrication

S	Member	Grade and Specifications
a	HSS Brace	ASTM A500 Grade-B (Fy = 42 ksi)
b	Gusset Plates	ASTM A572 Grade-50 (Fy = 50 ksi)
c	Base/ Brace Plates	ASTM A572 Grade-50 (Fy = 50 ksi)
d	Stiffener and all steel plates	ASTM A572 Grade-50 (Fy = 50 ksi)
e	Through Bolts	ASTM A490 (Fub = 150 ksi)
f	Weld electrodes	E70 (Fexx =70 ksi) AWS
g	Bolts for Damper to Brace connection	1and1/8 inch diameter ASTM A490 (Fy = 130 ksi and Fub = 150 ksi)

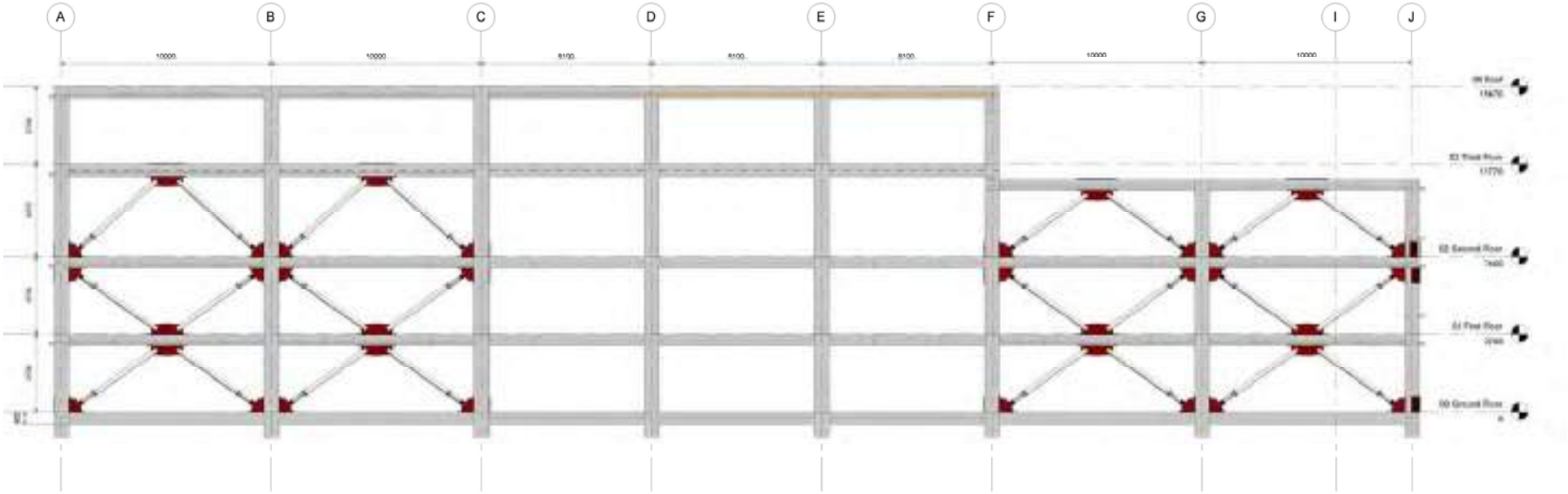
Rear Elevation

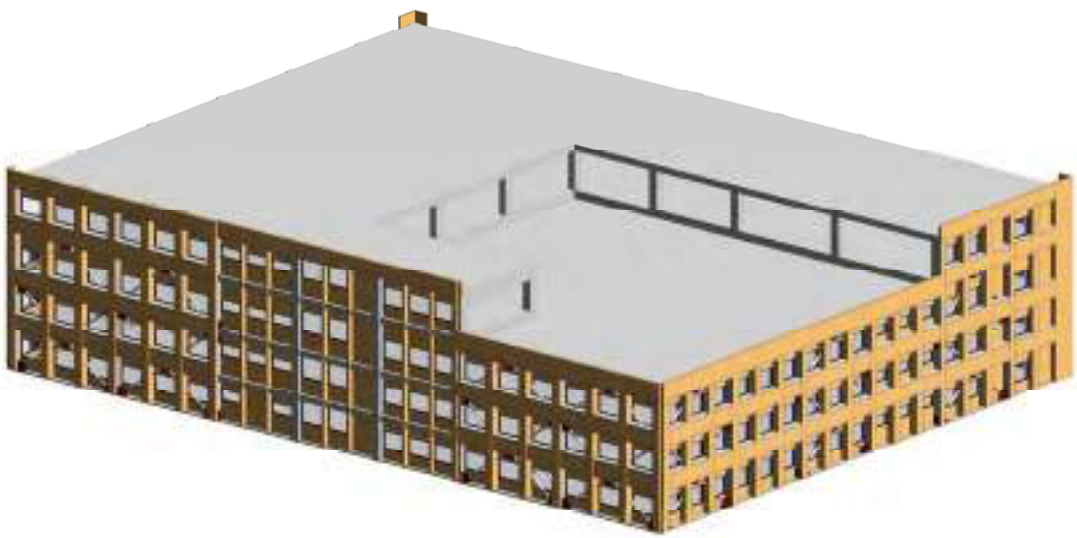


BACK SIDE ELEVATION

BACK SIDE ELEVATION

Damper Installation





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Damper Testing

Damper Testing

Installation

Installation

Installation

Sequence of Damper Installation

1. Damper Arrive on Site

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Sequence of Damper Installation

2. Damper Brackets with Anchor Bolts

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Sequence of Damper Installation

3. Damper Top Attachement

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Sequence of Damper Installation

4. Damper Anchor Bolts

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Sequence of Damper Installation

5. Formwork for Bottom Attachment

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Sequence of Damper Installation – Project 2

6. Pouring of Concrete

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Sequence of Damper Installation – Project 2

7. Completed Damper Attachment

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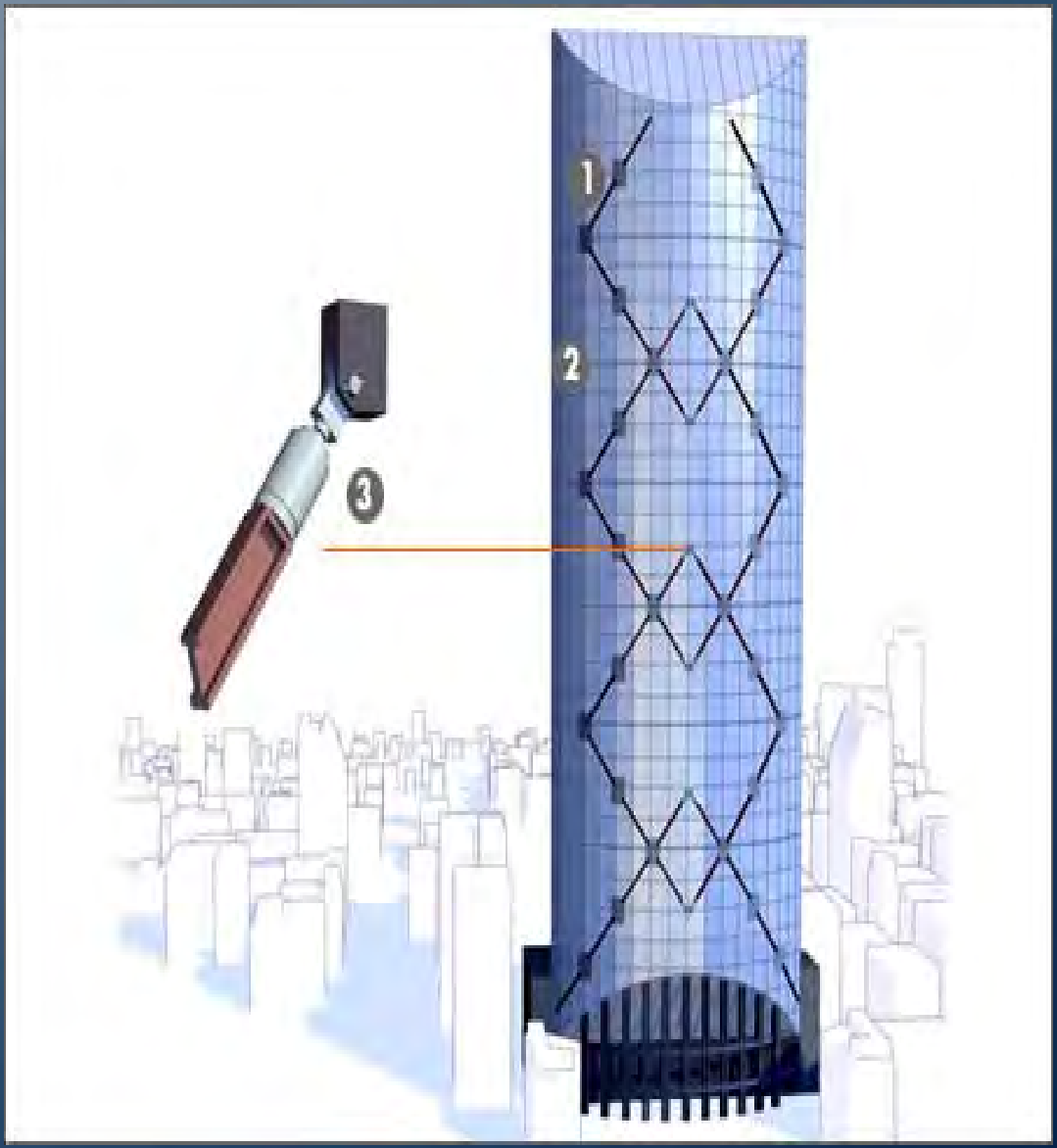
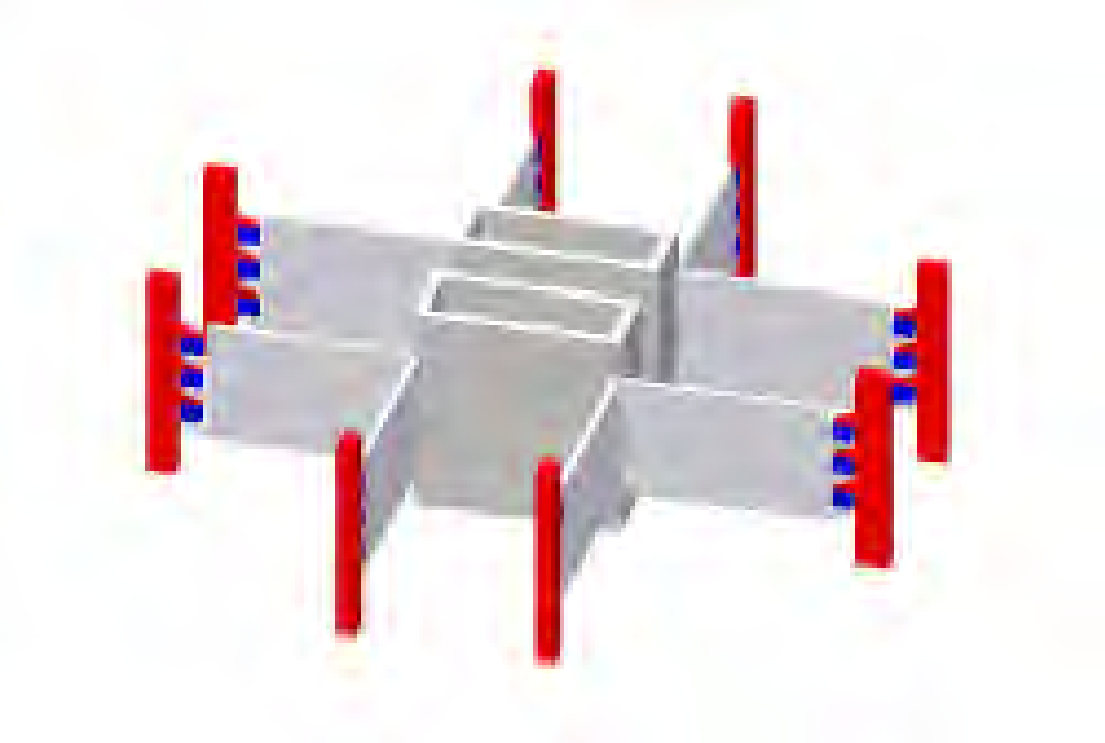
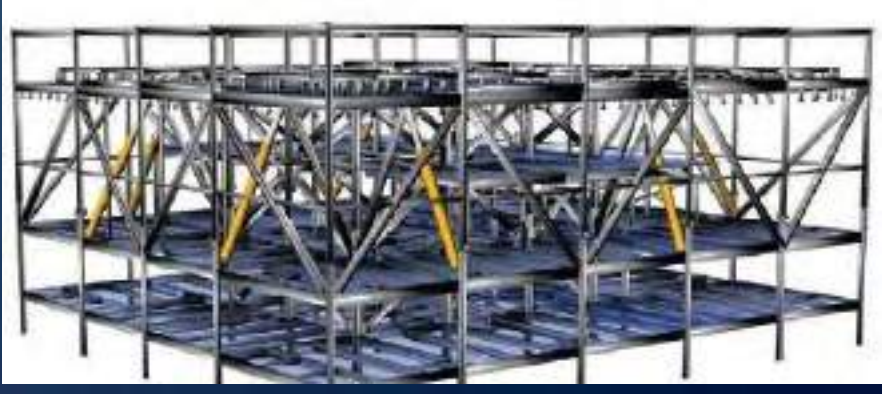
Mega Brace

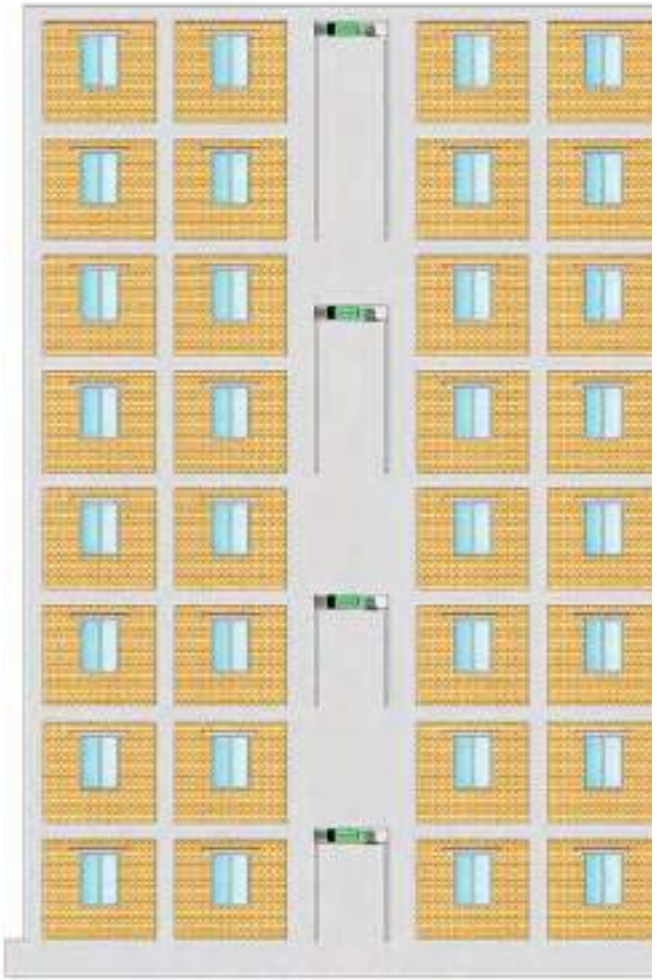


OUTTRIGGER WALLS AS BRACE

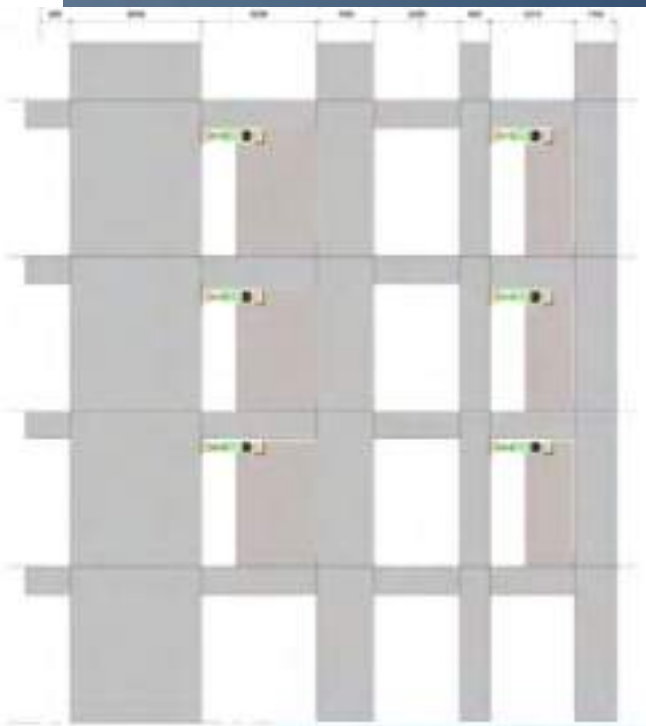




Shear Wall Damper



DAMPED SHEAR WALL



3

2 3D View - Amenity Inside Wall Damper

Diagonal Brace

Inverted Brace

Toggle Brace

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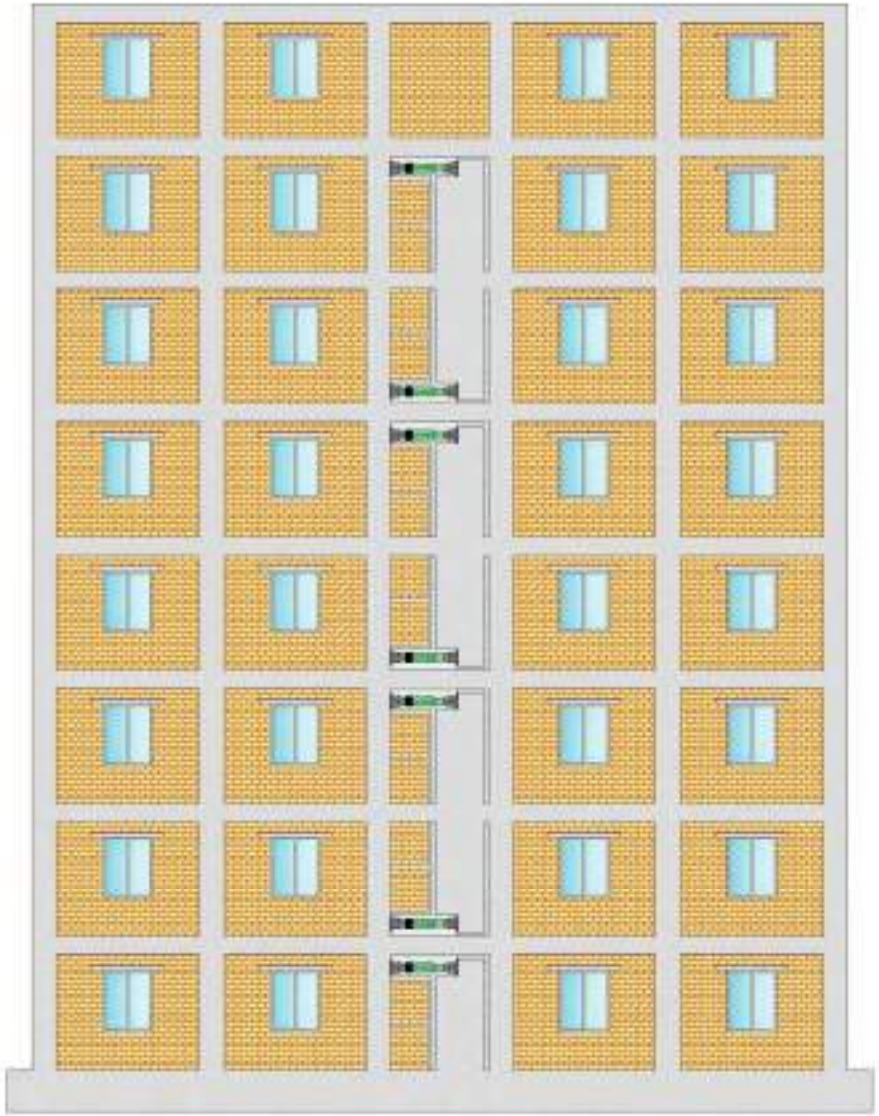
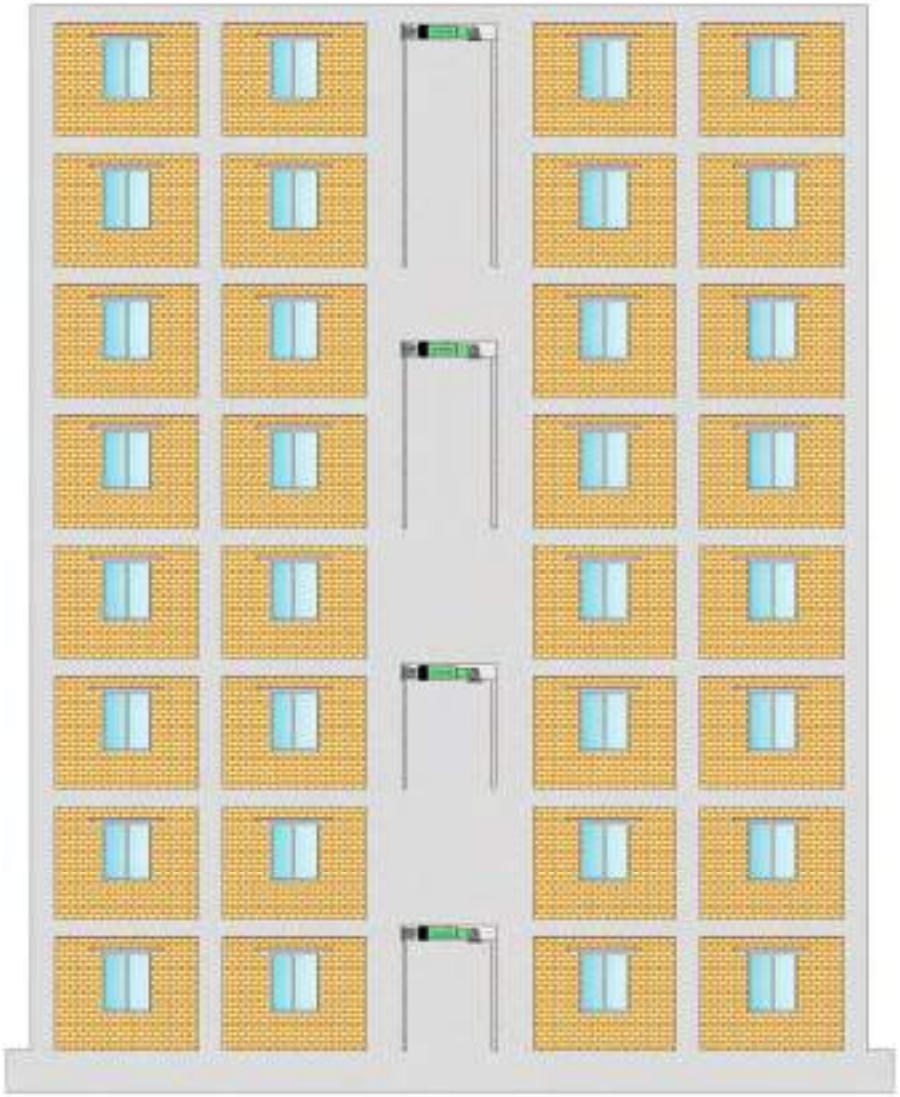
Damper Installation



CONCRETE WALL ACTING AS DAMPER BRACE

Damper Installation

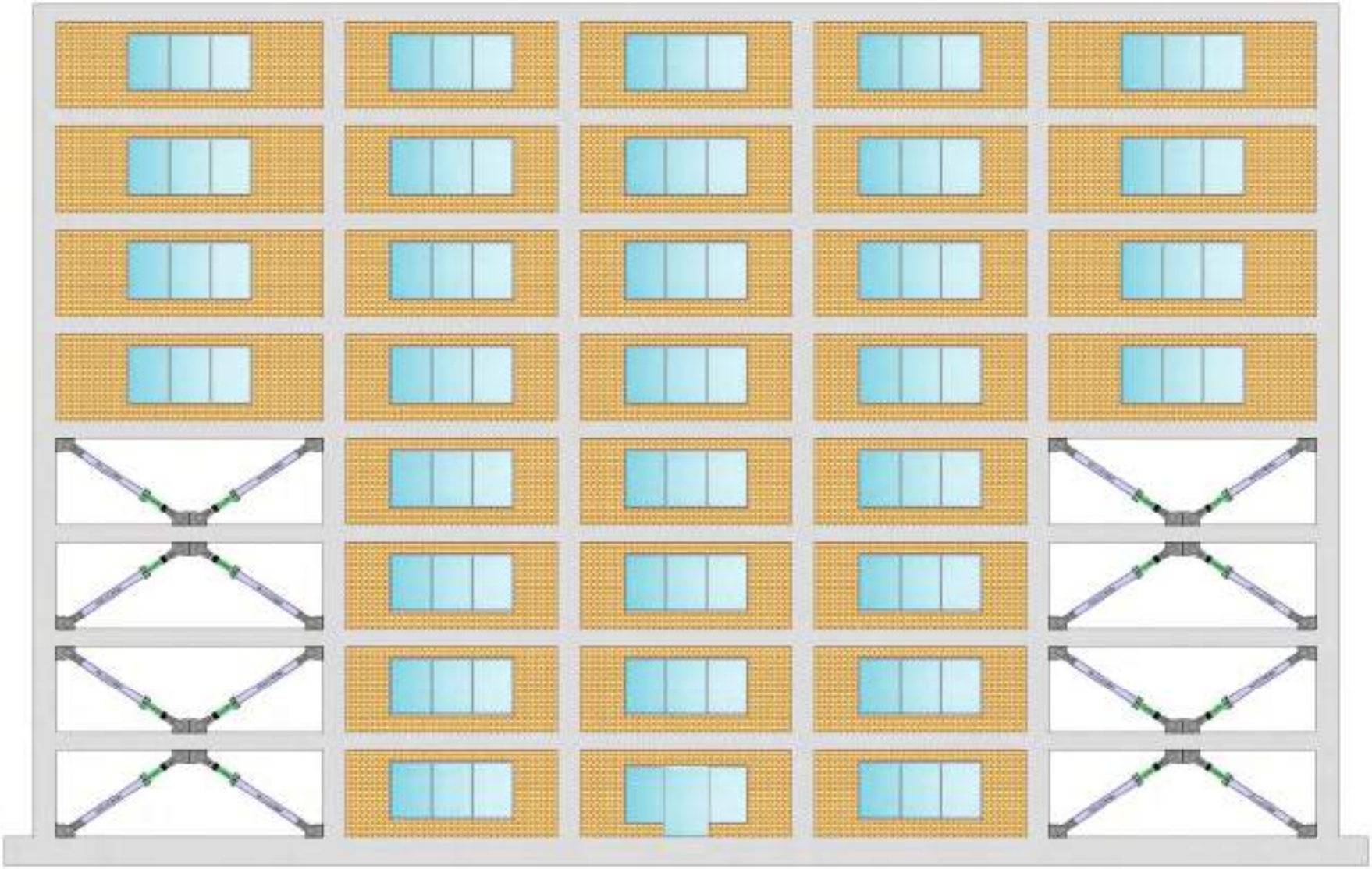


DAMPED SHEAR WALL

Damper Installation

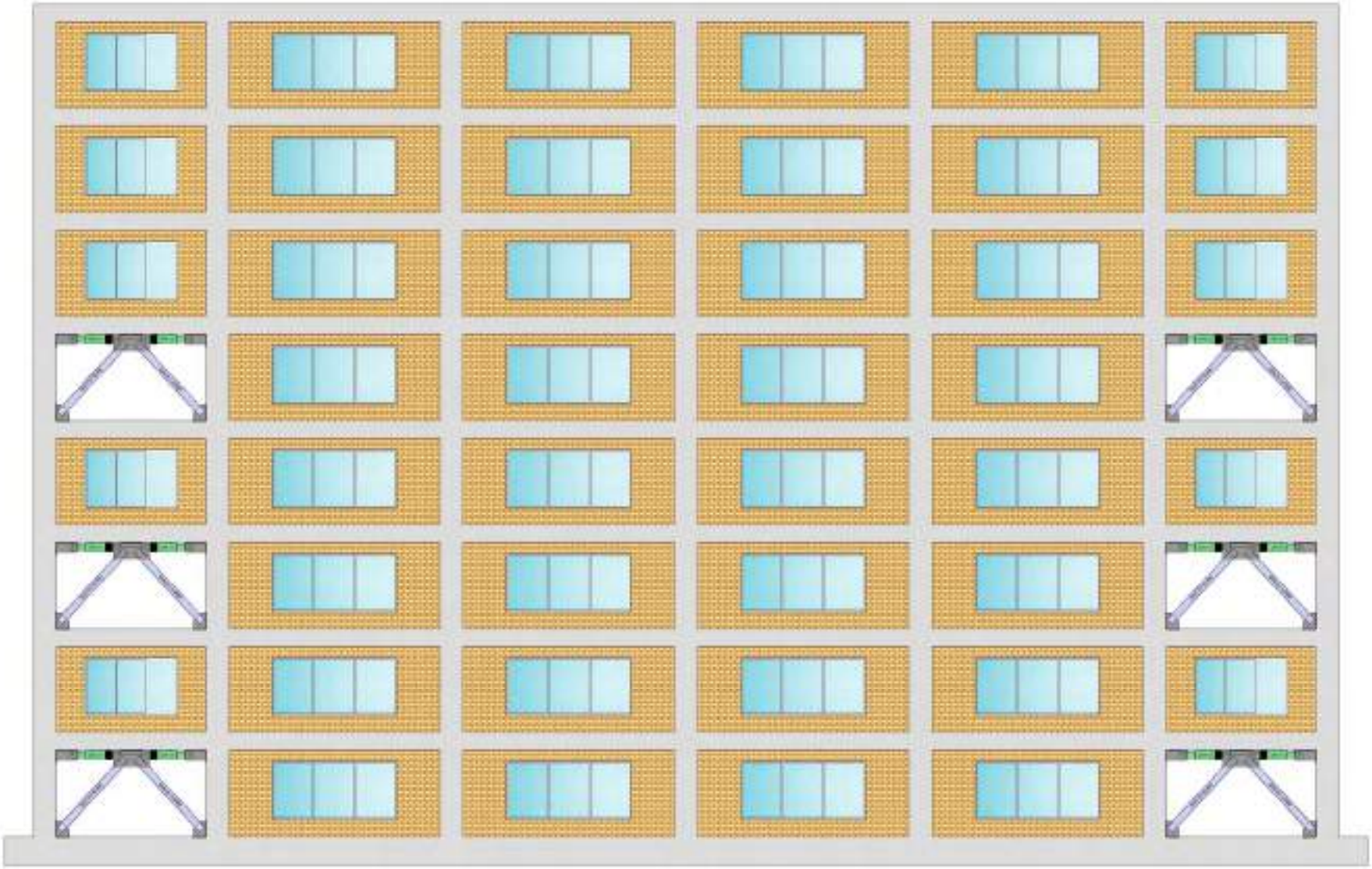
DAMPERS IN CHEVRON BRACE

Damper Installation



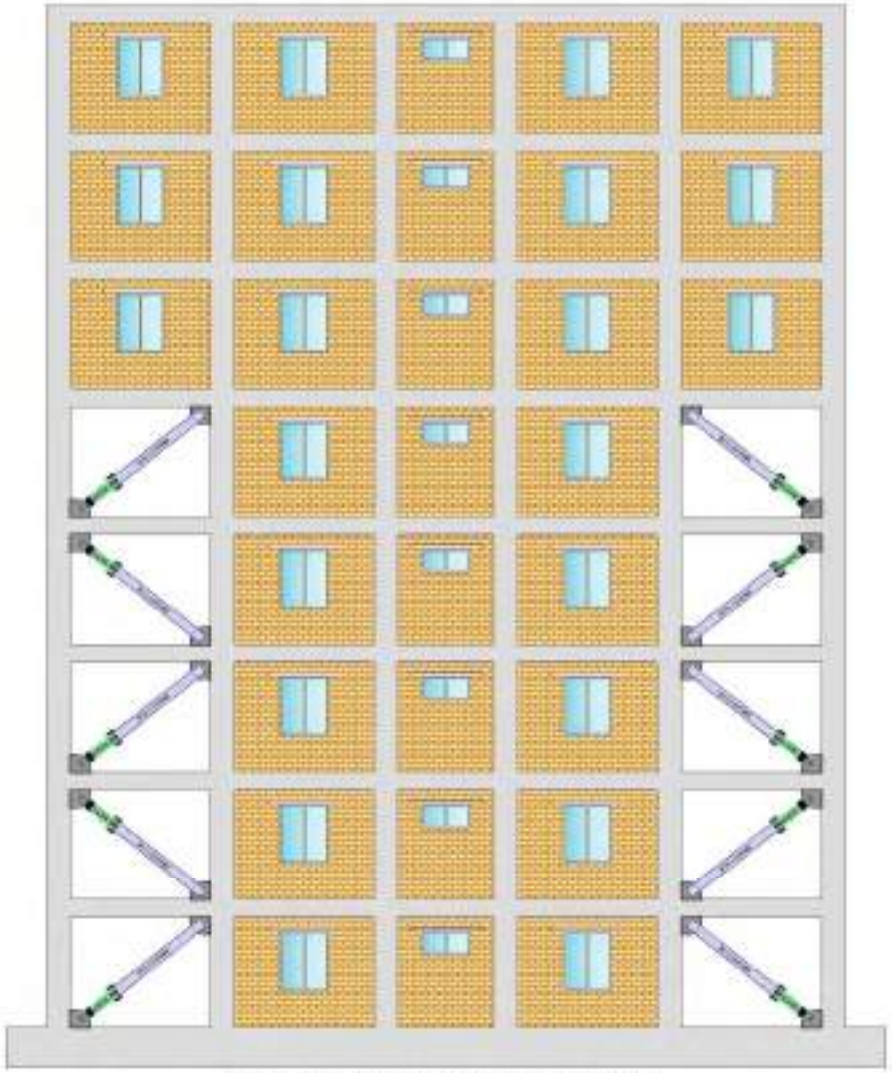
DAMPERS IN CHEVRON BRACE

Damper Installation



DAMPERS IN CHEVRON BRACE

Damper Installation



DAMPERS IN DIAGONAL BRACE

THANK YOU