Design of Fluid Viscous Dampers as per ASCE 7-16

Presented by:
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TAYLOR DEVICES INDIA
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.
Fluid Viscous Damper

Clevis - Clevis type and Clevis – Base Plate type.
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.
Sample Earthquake Time History
Our Competitors Devices Work for 15-20% of the Time

TIME WINDOWS WHEN YIELDING DEPENDENT DEVICES ARE ACTIVE, THESE TIME WINDOWS COM普RICE ONLY 15 TO 20% OF THE FULL TIME HISTORY TIME
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.
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.

\[ F = CV^\alpha \]
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.
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
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
## General
- **Link Property Name**: FVD-Non Linear
- **Link Type**: Damper - Exponential
- **Link Property Notes**:
- **P-Delta Parameters**:

## Total Mass and Weight
- **Mass**: 0.01 kg
- **Weight**: 1E-05 kN
- **Rotational Inertia 1**: 1E-05 ton-m²
- **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
<table>
<thead>
<tr>
<th>Direction</th>
<th>Fixed</th>
<th>NonLinear</th>
<th>Properties</th>
<th>Direction</th>
<th>Fixed</th>
<th>NonLinear</th>
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<tbody>
<tr>
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<td>R3</td>
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<td>Modify/Show for R3...</td>
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</table>

## 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 (X0)
- **Stiffness-proportional Viscous Damping Coefficient Modification Factor**: 1
**Identification**
- **Property Name**: FVD-Non Linear
- **Direction**: U1
- **Type**: Damper - Exponential
- **NonLinear**: Yes

**Linear Properties**
- **Effective Stiffness**: 0 kN/m
- **Effective Damping**: 0 kN-m/s/m

**Nonlinear Properties**
- **Stiffness**: 350000 kN/m
- **Damping**: 3000 kN*(s/m)^Cexp
- **Damping Exponent**: 0.3

[OK] [Cancel]
- 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.
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
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 $S_s = 2.5 \times 0.24 = 0.6$ and $S_1 = 0.24 \times 1.36/1 = 0.3264$)

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.
As Non Linear dampers are being configured so Non Linear Response History Analysis (NLRHA)
Load Case Data

General
- Load Case Name: Zone2_Case1_Uncalced
- Load Case Type/Subtype: Time History, Nonlinear Modal (FNA)
- Exclude Objects in this Group: Not Applicable
- Mass Source: Previous (MsSrc1)

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

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Load Name</th>
<th>Function</th>
<th>Scale Factor</th>
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<tbody>
<tr>
<td>Acceleration</td>
<td>U1</td>
<td>Zone2_TH1</td>
<td>9810</td>
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<tr>
<td>Acceleration</td>
<td>U2</td>
<td>Zone2_TH2</td>
<td>9810</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type of EQ</th>
<th>V in m/sec</th>
<th>C – constant (KN-sec/m)</th>
<th>∞ – constant</th>
<th>Force Capacity (KN)</th>
<th>Damper Design Capacity (KN)</th>
<th>Damper Yield Capacity (KN)</th>
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<tbody>
<tr>
<td>DBE</td>
<td>0.20</td>
<td>1100</td>
<td>0.3</td>
<td>678</td>
<td>1000</td>
<td>2000</td>
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<tr>
<td>100% MCE</td>
<td>0.40</td>
<td>1100</td>
<td>0.3</td>
<td>834</td>
<td>1000</td>
<td>2000</td>
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<tr>
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<td>1100</td>
<td>0.3</td>
<td>1028</td>
<td>1000</td>
<td>2000</td>
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<tr>
<td>300% MCE</td>
<td>1.20</td>
<td>1100</td>
<td>0.3</td>
<td>1161</td>
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<td>400% MCE</td>
<td>1.60</td>
<td>1100</td>
<td>0.3</td>
<td>1266</td>
<td>1000</td>
<td>2000</td>
</tr>
</tbody>
</table>
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.
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
\( \alpha \) = Damping exponent, a constant

“\( \alpha \)” can be set to any value from \( .3 < \alpha < 2.0 \). In general, the lower this value, the greater the energy dissipation per cycle for a given maximum stress in the structure. \( \alpha = 1 \) (linear damper) is easiest to analyze. Many optimized structures use \( \alpha = .3 \)
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.
**FLUID VISCOS 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:** 1000 kN, 100 mm STROKE, MID-STROKE LG 10148 mm. 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. For stroke lengths over ±300 mm and/or for force capacities for stroke longer than listed in table, consult Taylor Devices Inc.

<table>
<thead>
<tr>
<th>FORCE (kN)</th>
<th>TAYLOR DEVICES MODEL NUMBER</th>
<th>SPHERICAL BEARING BORE DIAMETER (mm)</th>
<th>MID-STROKE LENGTH (mm)</th>
<th>STROKE (mm)</th>
<th>CLEVIS THICKNESS (mm)</th>
<th>MAXIMUM CLEVIS WIDTH (mm)</th>
<th>CLEVIS DEPTH (mm)</th>
<th>BEARING THICKNESS (mm)</th>
<th>MAXIMUM CYLINDER DIAMETER (mm)</th>
<th>WEIGHT (kN)</th>
<th>&quot;A&quot; (mm)</th>
<th>&quot;B&quot; (mm)</th>
<th>&quot;C&quot; (mm)</th>
<th>&quot;D&quot; (mm)</th>
<th>PLATE THICKNESS (mm)</th>
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<td>44</td>
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<td>102</td>
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<td>784.25</td>
<td>259.1</td>
<td>295.1</td>
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</tr>
</tbody>
</table>

† DENOTES 4 HOLE PATTERN, MEANING NO CENTER HOLE.
** DENOTES 2 HOLE PATTERN, MEANING NO CENTER HOLE.

**MADE IN USA**
FLUID VISCOS DAMPERS & LOCK-UP DEVICES
CLEVIS – CLEVIS CONFIGURATION, METRIC UNITS

NOTE:
VARIous STROKES ARE AVAILABLE FROM ±50 TO ±900mm
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: 1000 KN x 100mm STROKE, MID-STROKE L0 = 1048mm
1000 KN x 150mm STROKE, 150 = 100 ± 50, 50°5 ± 250
1048 ± 250 ± 1298mm MID-STROKE LENGTH

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

<table>
<thead>
<tr>
<th>FORCE</th>
<th>TAYLOR DEVICES MODEL NUMBER</th>
<th>SPHERICAL BEARING BORE DIAMETER (mm)</th>
<th>MID-STROKE LENGTH (mm)</th>
<th>STROKE</th>
<th>CLEVIS THICKNESS (mm)</th>
<th>BEARING THICKNESS (mm)</th>
<th>MAXIMUM CLEVIS WIDTH (mm)</th>
<th>CLEVIS DEPTH (mm)</th>
<th>MAXIMUM CYLINDER DIAMETER (mm)</th>
<th>WEIGHT (kg)</th>
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<td>250</td>
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</tbody>
</table>

* DENOTES MODEL WITH DIFFERENT CLEVIS SIZES ON EACH END.

MADE IN USA
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”.

How We Work
Performance Levels

Illustration of Typical Nonlinear Structure and Member Resistance – Lateral Deformation Relationship
Typical Performance Based Design Seismic Upgrade
New Udaan Bhawan – Delhi Airport
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
After the seismic dampers are added to the model, the maximum drift ratio measured at any story is approximately 0.8%.

<table>
<thead>
<tr>
<th>Level</th>
<th>Damped</th>
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<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>ROOF</td>
<td>0.33%</td>
</tr>
<tr>
<td>THIRD</td>
<td>0.53%</td>
</tr>
<tr>
<td>SECOND</td>
<td>0.76%</td>
</tr>
<tr>
<td>FIRST</td>
<td>0.86%</td>
</tr>
<tr>
<td>GROUND</td>
<td>0.74%</td>
</tr>
</tbody>
</table>
# Base Shear Reduction

<table>
<thead>
<tr>
<th>Base Shear Case</th>
<th>Direction X</th>
<th>Direction Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>103,200</td>
<td>104,700</td>
</tr>
<tr>
<td>Damped</td>
<td>76,200</td>
<td>89,800</td>
</tr>
</tbody>
</table>
Typical Damper Attachment
Typical Damper Attachment
## Structural Steel - Quality and Fabrication

<table>
<thead>
<tr>
<th>S</th>
<th>Member</th>
<th>Grade and Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>HSS Brace</td>
<td>ASTM A500 Grade-B (Fy = 42 ksi)</td>
</tr>
<tr>
<td>b</td>
<td>Gusset Plates</td>
<td>ASTM A572 Grade-50 (Fy = 50 ksi)</td>
</tr>
<tr>
<td>c</td>
<td>Base/ Brace Plates</td>
<td>ASTM A572 Grade-50 (Fy = 50 ksi)</td>
</tr>
<tr>
<td>d</td>
<td>Stiffener and all steel plates</td>
<td>ASTM A572 Grade-50 (Fy = 50 ksi)</td>
</tr>
<tr>
<td>e</td>
<td>Through Bolts</td>
<td>ASTM A490 (Fub = 150 ksi)</td>
</tr>
<tr>
<td>f</td>
<td>Weld electrodes</td>
<td>E70 (Fexx = 70 ksi) AWS</td>
</tr>
<tr>
<td>g</td>
<td>Bolts for Damper to Brace connection</td>
<td>1 and 1/8 inch diameter ASTM A490 (Fy = 130 ksi and Fub = 150 ksi)</td>
</tr>
</tbody>
</table>
Rear Elevation
Damper Testing
Damper Testing
Installation
Installation
Installation
Sequence of Damper Installation

1. Damper Arrive on Site
Sequence of Damper Installation

2. Damper Brackets with Anchor Bolts
Sequence of Damper Installation

3. Damper Top Attachment
Sequence of Damper Installation

4. Damper Anchor Bolts
Sequence of Damper Installation

5. Formwork for Bottom Attachment
Sequence of Damper Installation – Project 2

6. Pouring of Concrete
Sequence of Damper Installation – Project 2

7. Completed Damper Attachment
Mega Brace
OUTTRIGGER WALLS AS BRACE
Shear Wall Damper
Diagonal Brace
Inverted Brace
Toggle Brace
CONCRETE WALL ACTING AS DAMPER BRACE
Damper Installation

DAMPERS IN CHEVRON BRACE
Damper Installation
Damper Installation
Damper Installation
THANK YOU