Structural Engineers Association of Southern California

You're invited:	Tri-Counties Chapter Dinner Meeting; (*Webinar to be announced soon*)
Presentation:	Seismic Retrofit utilizing Damper Panels
Date:	Wed. July 11, 2012 (Dinner & Networking 5:30 - 7:30 p.m. - Presentation 7:30 - 8:30 p.m.)
Program:	Practical Approaches on Damper Panel System Design
Speaker:	***Fred Schott, SE***; SEAOSC Past President President of "Fred H Schott & Associates" in San Luis Obispo, CA
Venue:	Fourpoints Sheraton Hotel (Clipper Rooms) 1050 Schooner Dr. Ventura, CA 93001 Phone: (805) 658-1212
Abstract and Faculty:	The presentation examines the use of seismic dampers to retrofit buildings; in particular, soft, weak, open front (SWOF) buildings, typical of a large number of buildings in San Francisco and many other cities. This type of building either has garage doors or large shop windows on the bottom floor which makes them highly torsional. A two, three, four, and five story building was modeled and subject to three different earthquake time histories. The buildings were tested without dampers, then with dampers at the ground floor. When the results are compared, the size of earthquake the building with dampers could withstand was a factor of 3 to 4 times larger than a conventional system. A couple of damper panel systems are also examined, showing different approaches to attach the dampers and maximize their effectiveness.
Click to register; *or walk in*	http://seaosc.org/events_detail.cfm?pk_event=195 (SEOASC Member to Login first)
Host/Moderator:	SEOASC Director; Casey K. Hemmatyar, SE

Seismic Retrofit with Damper Panels

By Fred H. Schott S.E., P.E., SECB
& David Lee PhD

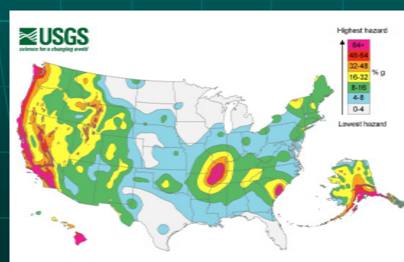
Earthquake Design Criteria

The 1989 Loma Prieta earthquake collapsed buildings in San Francisco's Marina

- For the past 80 years the minimum design criteria has been "life safety" which has recently been changed to collapse prevention.
- As a result of a significant earthquake, large numbers of people are without:
  - shelter
  - water
  - sanitary facilities
- Results in concerns about sustainability of existing housing

Typical Design of Residential Structures

- Base Shear = Sds x W÷R/I
  - Sds = design force coefficient acting on a short period (stiff) structure at a particular location subjected to an earthquake with a return frequency of 475 years.
    - Ground motion "contour" maps
    - Dependent upon the geology and proximity to known fault sources (USGS)
    - Modified by soil conditions at that particular site



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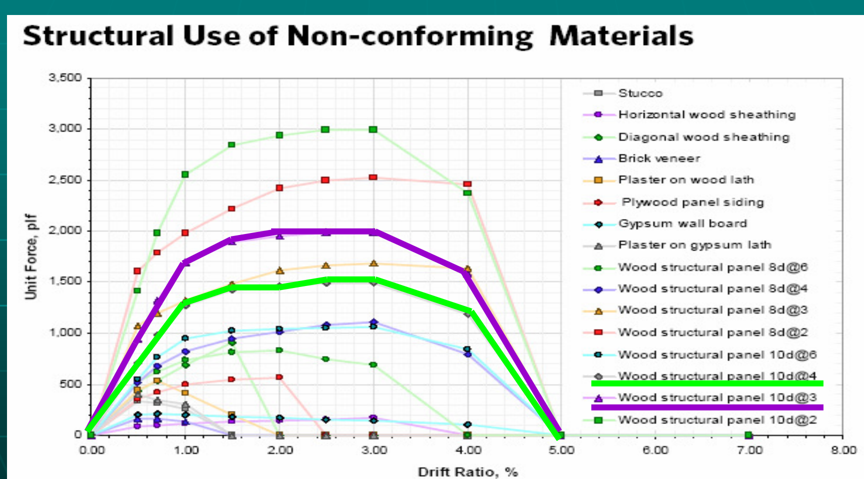
    - Modified by soil conditions at that particular site
  - W = weight of the structure
  - I = importance factor (generally 1.0 for residences)
  - R = response modification factor which is a measure of the over strength beyond yield stress and the energy dissipation of the system in the inelastic range.

Typical Design of Residential Structures

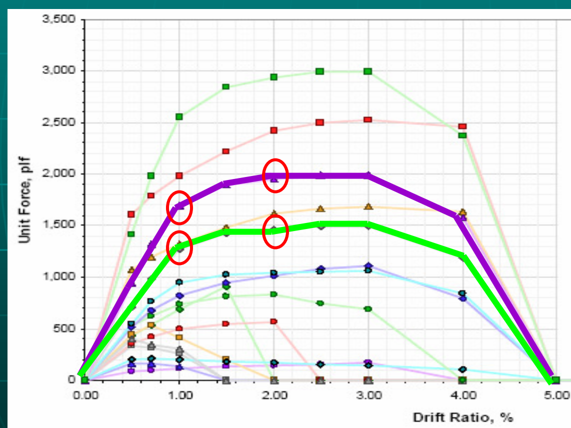
Home lost to the Loma Prieta Earthquake, 1989. Santa Cruz Mountains.

- The latest code value of R in light framed walls sheathed with wood structural panels or steel sheets is 6.5
- This means that a design earthquake could cause forces on the building which are 6.5 times the code design forces.

Force vs. Drift ATC 71-1 Curves



Force vs. Drift ATC 71-1 Curves



- The allowable stresses for 15/32 inch plywood
  - 10d at 4" = 510 lb/ft
  - 10d at 3" = 665 lb/ft
- With a drift ratio of 1%:
  - 1275 lb/ft
  - 1696 lb/ft
  - ~ 2.5 times the allowable values.
- With a drift ratio of 2%:
  - 1466 lb/ft
  - 1949 lb/ft
  - ~ 2.9 times the allowable values.

Building Drift

- 1% drift is the generally accepted value above which damages start to become severe.
- This means that base shear forces greater than 2.5 times the design forces will result in severe damage to the building and the building probably would not fall into the sustainability category.

Soft Weak Open Front Buildings


http://quake.abag.ca.gov/housing/softstory/

http://www.pwtsf.com/html/photo_storeFront.html

- Have not performed well in recent earthquakes
- Often occurs with wood frame structures:
  - "tuck-under" construction to accommodate street facing garages
  - commercial facilities requiring extensive open display windows
- Their poor performance, including total collapse, has resulted in code modifications that increase the requirements for these structures, and often prohibits these systems in new structures.

Methods of Improving Building Performance

1. Increase the capacity of the structure by designing for greater force levels
2. Reduce the loading imposed on the structure by incorporating an energy absorbing interface between the ground and the structure such as base isolation and/or some type of damper system.

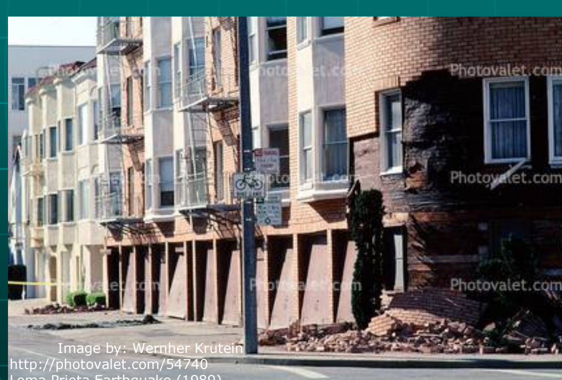


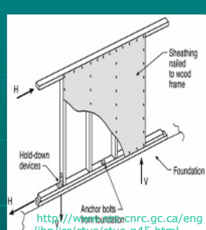
Image by: Wernher Krutein
http://photovalet.com/54740
Loma Prieta Earthquake (1989)

Alternatives for Building Owner

1. Tear down the structure and design and build a new structure which meets the designated design capacity.
2. Supplement the existing lateral force resisting system
   - Add new lateral force resisting elements
3. Upgrade the existing system
   - Strengthen the elements in the existing system
4. Install a base isolation or damping system

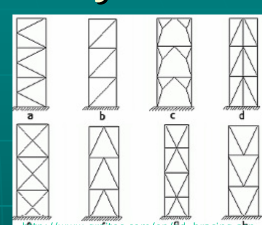
- Solutions 2 & 3 utilize a rigid lateral force resisting system with limited flexibility (including rigid frames, braced frames, shear walls, etc.) where the only significant difference between the systems is the response modification factor R.
- Solution 4 allows the building structure above the ground floor to move relative to the ground and absorb energy through the support system. The interface between the moving portion of the structure and the rigid support system absorbs energy using elastomeric bearing pads, friction pendulum systems, etc. and/or some type of dampers.

Conventional Retrofit System



Shear Wall

Rigid Frames

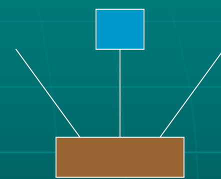


Braced Frames

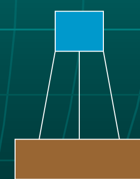
- Ground accelerations are amplified
- The mass at the second level is subjected to accelerations which are substantially greater than they would be if only the ground accelerations were applied to the mass.
  - F=Ma
  - (a_max 2^{nd} Level) = (F_max 2^{nd} Level)/(M_2^{nd} Level)
  - (a_max Ground) = (a_max 2^{nd} Level)/(Amplification Factor) = governing earthquake

Amplification Factor

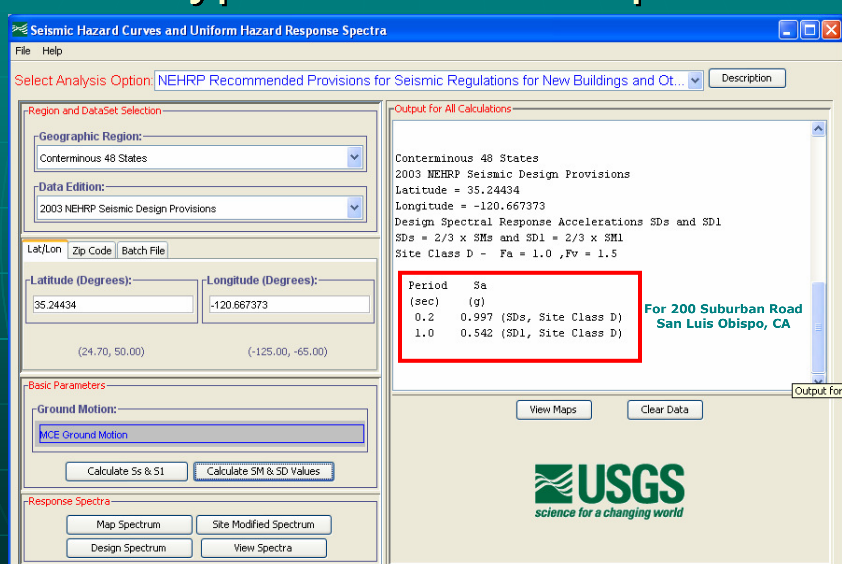
- Conventional System
  - Amplification Factor for El Centro
    - AF = 3 for 2 story building
      - F = M (3 A)
    - AF = 1.5 for a five story building
      - F = M (1.5 A)



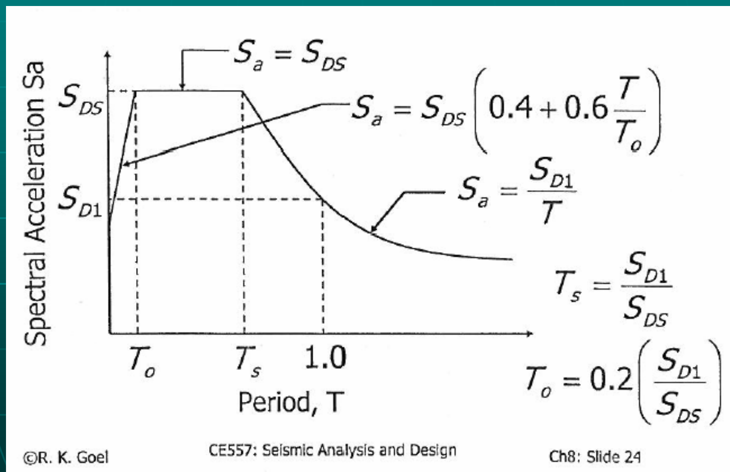
- Damper System
  - Amplification Factor for El Centro
    - AF = 0.77 for a two story building
      - F = M (0.77 A)
    - AF = 0.5 for a five story building
      - F = M (0.5 A)



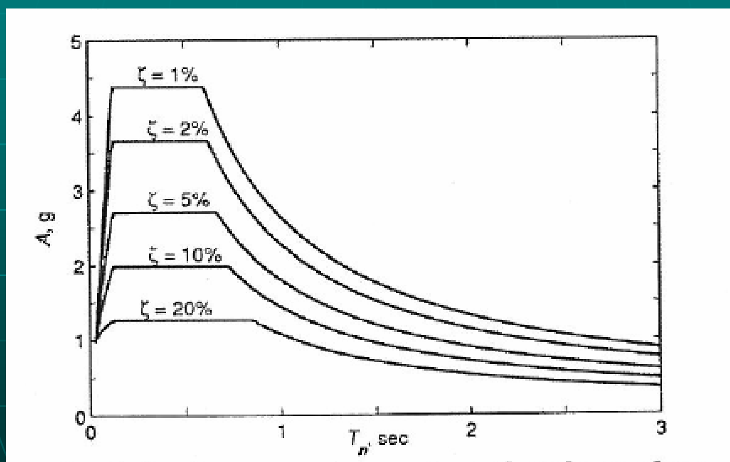
Typical USGS Output



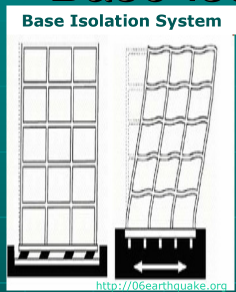
Design Response Spectrum

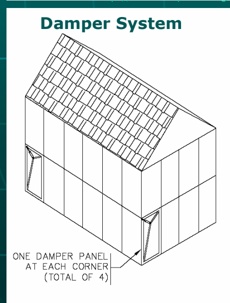


Effect of Damping on the Design Response Spectrum



Base Isolation vs Damper Solution





- Base Isolation System:
  - Two separate foundations
    - The bottom foundation moves with the ground
    - The upper supports the structure and is isolated from the lower
  - This alternative is generally far too expensive for use in a residential application.
  - Difficult to add to an existing building
- A damper system
  - Could require as few as 4 shear panels (one on each side of the building)
  - Limit the drift to 1% (or less if desired)
  - Reduce the earthquake forces acting on the structure
  - Absorb a significant portion of the energy which would otherwise be imposed on the structure
  - Dramatically reduce damage to the structure
- The cost of a damper system would be far less than a base isolation system and could allow a performance approaching that of a complete base isolation system.

Soft Weak Open Front Buildings

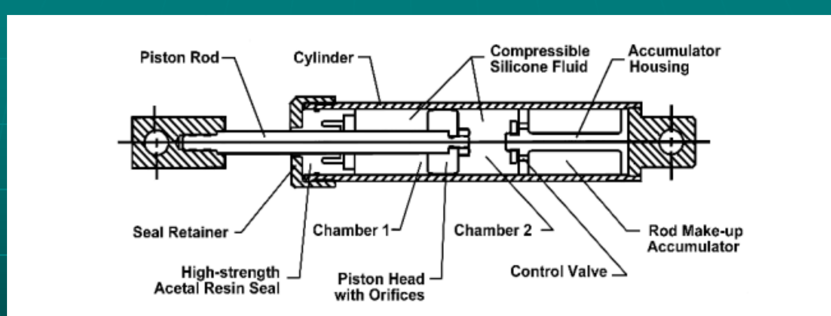
- Increase sustainability in soft, weak, open front buildings at minimal cost
  - Limiting work to the ground floor
  - Using energy absorbing elements

Damper Retrofit System

Seismic fluid viscous damper, 50,000 pounds output

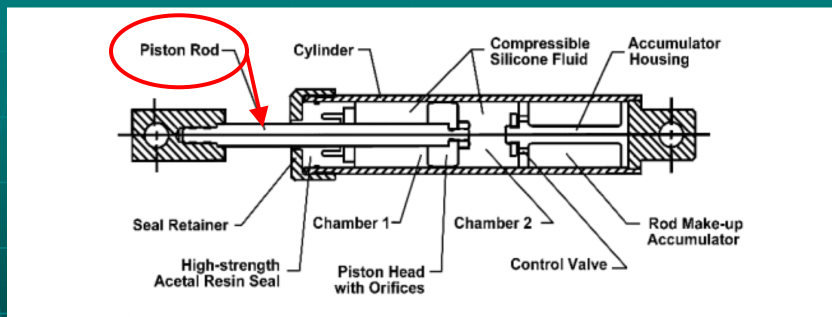
- Accelerations at the second floor are only slightly increased or decreased from the ground level accelerations
- Require much greater ground accelerations (larger earthquake) to reach the limiting strength of the lateral force resisting system at the second floor.
- The ground acceleration of a building can often be increased by a factor of 3 to 4 over a conventional retrofit system.

Fluid Viscous Dampers



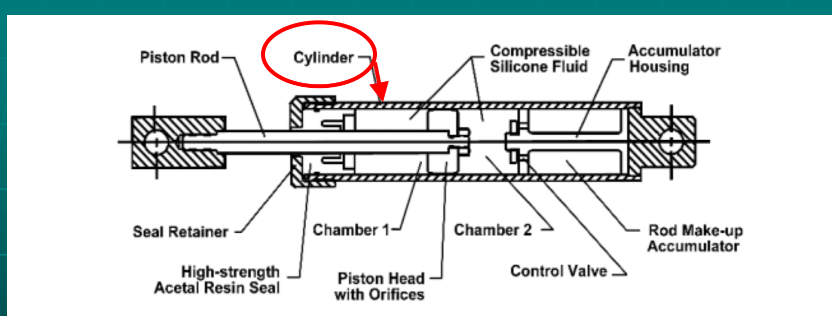
- Best performance
- Damper force is related to the velocity ($F=c*v^k$)
- 90 degrees out of phase
- Not additive to forces related to displacement

Fluid Viscous Dampers



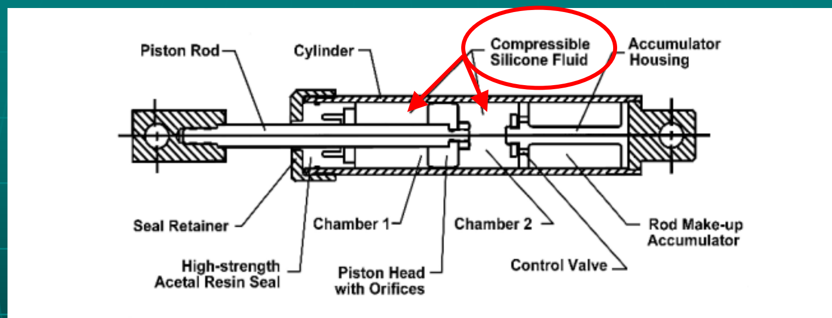
- Piston Rod
  - Typically Stainless Steel
  - External end connects to mounting clevis
  - Slides through the seal and seal retainer
  - Internal end connects to the piston head

Fluid Viscous Dampers



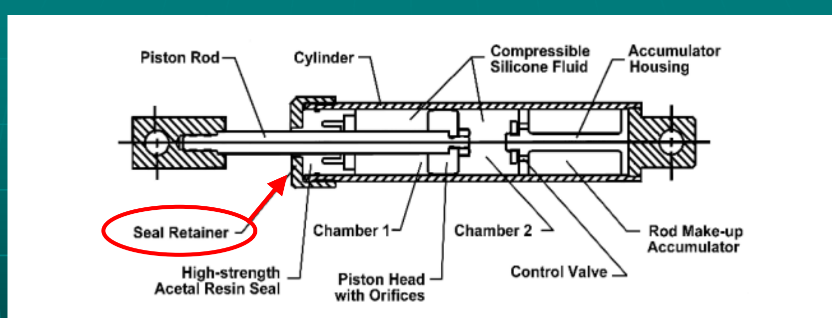
- Cylinder
  - Contains the fluid medium
  - Seamless steel tubing
    - Welded or cast construction is not permissible due to concerns about fatigue life and stress cracking
  - Designed for a minimum proof pressure loading equal 1.5 times the expected internal pressure

Fluid Viscous Dampers



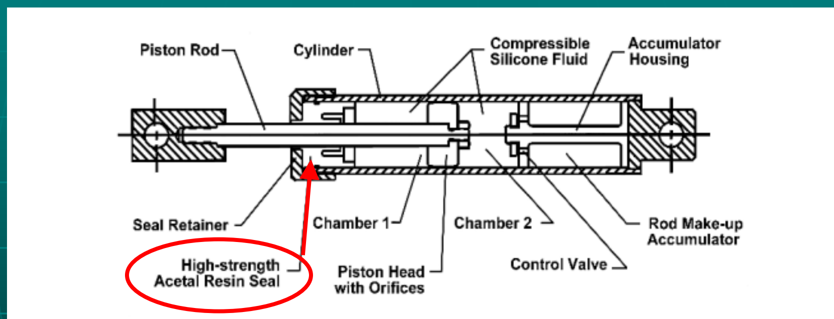
- Damper Fluid
  - Must be fire-resistant, non-toxic, thermally stable, and will not degrade with age
  - At present, only the silicon family meets these attributes
  - The fluid's properties effect the dampers c & k coefficients ($F=c*v^k$)

Fluid Viscous Dampers



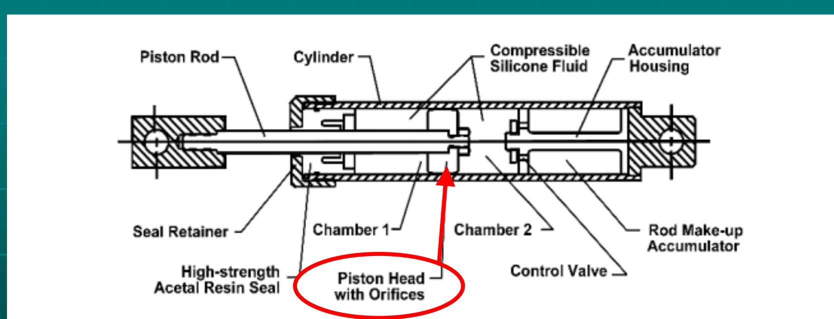
- Seal Retainer
  - Often called end cap, end plate, or stuffing box
  - Threaded directly to the cylinder bore
  - If this fails and the damping fluid escapes, the damper will no longer work

Fluid Viscous Dampers



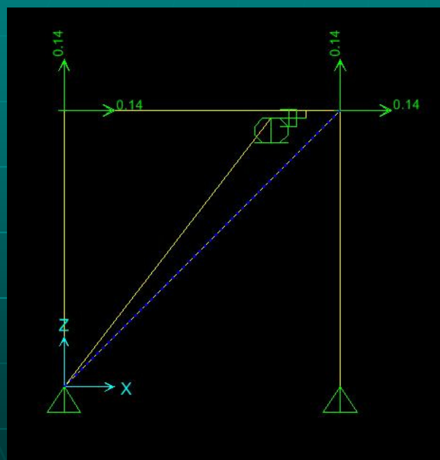
- Seal
  - Material chosen based on a minimum service life of 25 years and it's compatibility with the damper fluid
  - Must not exhibit long-term sticking or allow slow seepage of fluid

Fluid Viscous Dampers



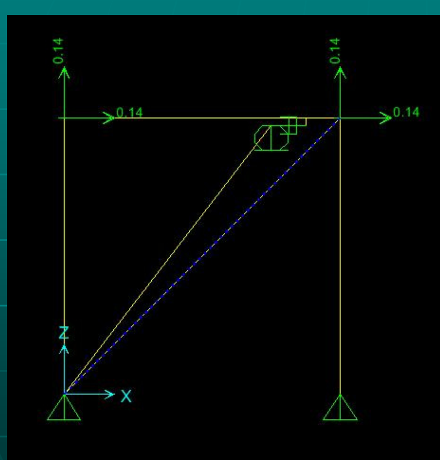
- Piston Head
  - Divides the cylinder into two pressure chambers
  - Orifices through the head to allow the fluid to travel between the two chambers and generate damping pressure
  - The size and number of holes effects the dampers c & k coefficients ($F=c*v^k$)

Designing a Damper System

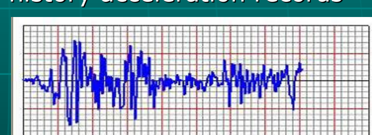


- Create a mathematical model of the structure
  - We used SAP2000v15
  - Lateral force resisting elements at the ground floor
  - Model the ground floor matching the dimensions of the building
  - Apply a mass to the top of the frame with a density equal to the weight of the floors and roof above

Designing a Damper System

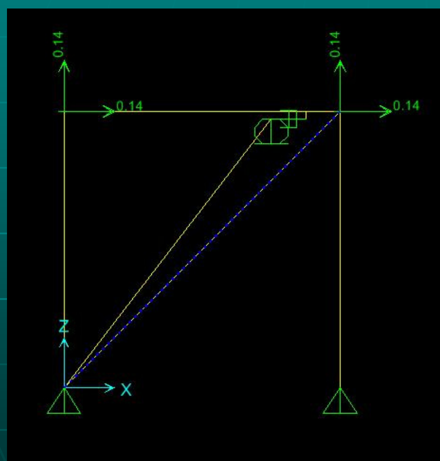


- Attach a Damper Link in the model with properties for a viscous elastic damper
- Subject it to a number of time history acceleration records



  - Time Histories induce accelerations on the structure from recorded earthquakes
  - When the mass at the top of the frame is accelerated, the frame and damper resist the movement. F = m A

Designing a Damper System



- Run Analysis
  - Nonlinear analysis
  - Modal-Ritz
  - 5% modal damping from the building
- Vary the values of c & k for the damper resisting force
  - $F = c^*v^K$

Damped vs Undamped Example

- Time History Responses:
  - 1940 El Centro earthquake
  - Loma Prieta earthquake
    - Treasure Island (T.I.)
    - Outer Harbor Wharf (OHW)
- Varied the effective weights of the buildings to simulate 2, 3, 4 & 5 story buildings (48.7k, 77.9k, 107.6k & 137.3k)
- Considered allowable 2nd floor drift ratios of 1% and 2.5%
- The selected strength value for the second floor was 34.4k

Damped vs Undamped Example

	1% Allowable Drift Ratio = 1.44in				2.5% Allowable Drift Ratio = 3.60in			
	Two Story	Three Story	Four Story	Five Story	Two Story	Three Story	Four Story	Five Story
Tributary Mass	48.2kips/g	77.9 kips/g	107.6 kips/g	138 kips/g	48.2kips/g	77.9 kips/g	107.6 kips/g	138 kips/g
2nd Floor Acceleration	0.71g	0.44g	0.32g	0.25g	0.71g	0.44g	0.32g	0.25g
El Centro Maximum Ground Accelerations								
Undamped	0.23g	0.16g	0.16g	0.17g	0.43g	0.26g	0.24g	0.29g
Damped	0.92g	0.71g	0.59g	0.50g	1.34g	0.98g	0.81g	0.68g
Loma Prieta (TI) Maximum Ground Accelerations								
Undamped	0.32g	0.14g	0.12g	0.09g	0.24g	0.13g	0.12g	0.13g
Damped	0.81g	0.52g	0.41g	0.32g	0.91g	0.63g	0.49g	0.40g
Loma Prieta (OHW) Maximum Ground Accelerations								
Undamped	0.37g	0.25g	0.12g	0.11g	0.32g	0.17g	0.17g	0.18g
Damped	0.85g	0.58g	0.45g	0.37g	1.00g	0.70g	0.56g	0.48g

Damped vs Undamped Example

Four Story Building		
	1% Drift	2.5% Drift
Tributary Mass	107.6 kips	107.6 kips
Allowable 2nd Floor Acceleration	0.32g	0.32g
El Centro **Maximum Ground Accelerations**		
Undamped	0.16g	0.24g
Damped	0.59g	0.81g
Loma Prieta (TI) **Maximum Ground Accelerations**		
Undamped	0.12g	0.12g
Damped	0.41g	0.49g
Loma Prieta (OHW) **Maximum Ground Accelerations**		
Undamped	0.12g	0.17g
Damped	0.45g	0.56g

Damped vs Undamped Example

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Undamped	0.12g	0.17g
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(a_max 2nd Level) = (F_max 2nd Level)/ (M_2nd Level)

Damped vs Undamped Example

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Undamped	0.12g	0.17g
Damped	0.45g	0.56g

(a_max 2nd Level) = (F_max 2nd Level)/ (M_2nd Level)

(a_max Ground) = (a_max 2nd Level)/ (Amplification Factor)

AF =2.67

Damped vs Undamped Example

Four Story Building		
	1% Drift	2.5% Drift
Tributary Mass	107.6 kips	107.6 kips
Allowable 2nd Floor Acceleration	0.32g	0.32g
El Centro **Maximum Ground Accelerations**		
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Undamped	0.12g	0.17g
Damped	0.45g	0.56g

(a_max 2nd Level) = (F_max 2nd Level)/ (M_2nd Level)

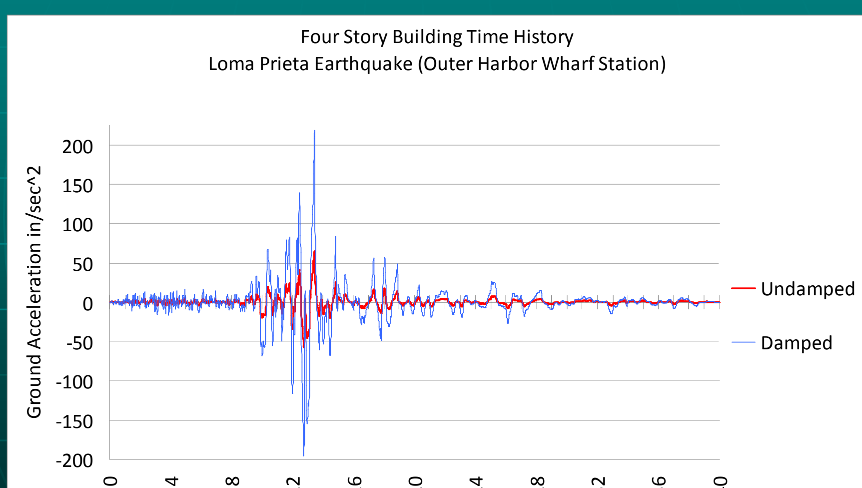
(a_max Ground) = (a_max 2nd Level)/ (Amplification Factor)

AF =2.67

AF =0.71

.45g/.12g = 3.75 x Larger Ground Acc.

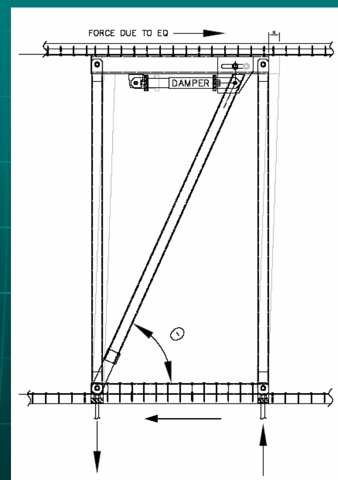
Damped vs Undamped Example



The damped building can resist much higher ground accelerations

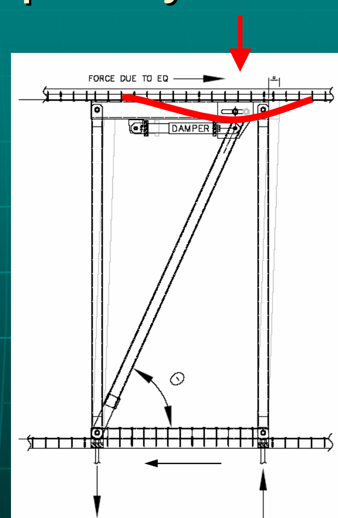
Designing a Damper System

- One can modify the tributary mass (vary the distance between braces) to limit the force and establish the strength available at the 2nd floor for any particular structure.
- There must be a proper load path:
  - Vertical (tie down) forces at each end
    - The upward vertical component must be resisted by the tributary weight of the building
    - The downward forces must be resisted by the bearing capacity of the foundation



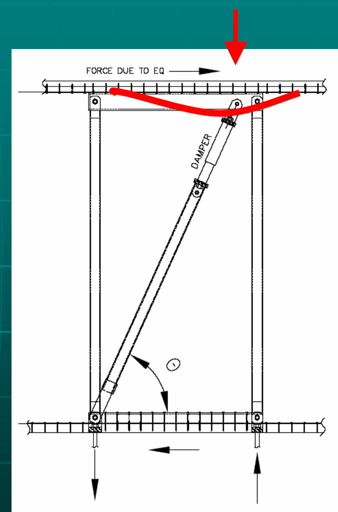
Designing a Damper System

- When the vertical component of the force in the damper system is resisted by a relatively flexible beam the effective stroke of the horizontally installed damper is reduced by the vertical deflection of the beam times the co-tangent of the angle of the brace (relative to the horizontal).



Designing a Damper System

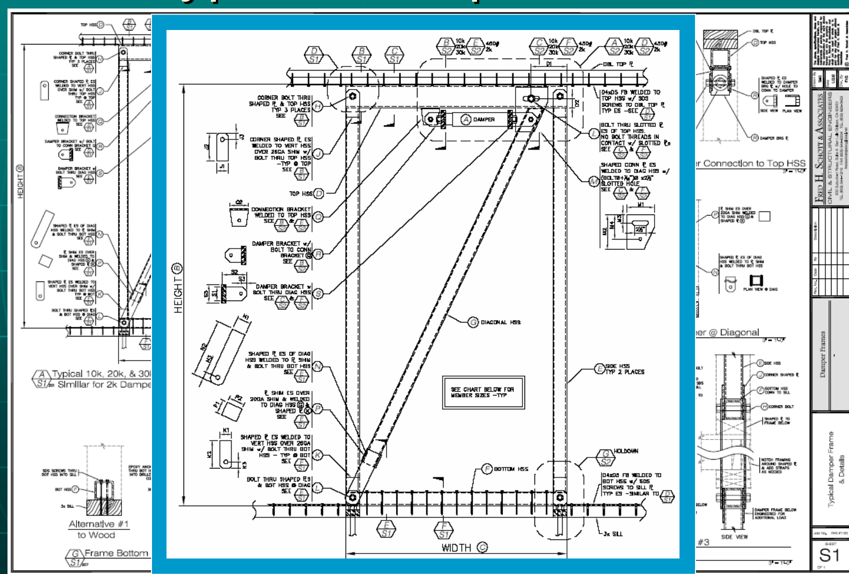
- When the damper is installed in the diagonal brace, the effective stroke of the damper is decreased by the vertical beam deflection divided by the sin of Θ.



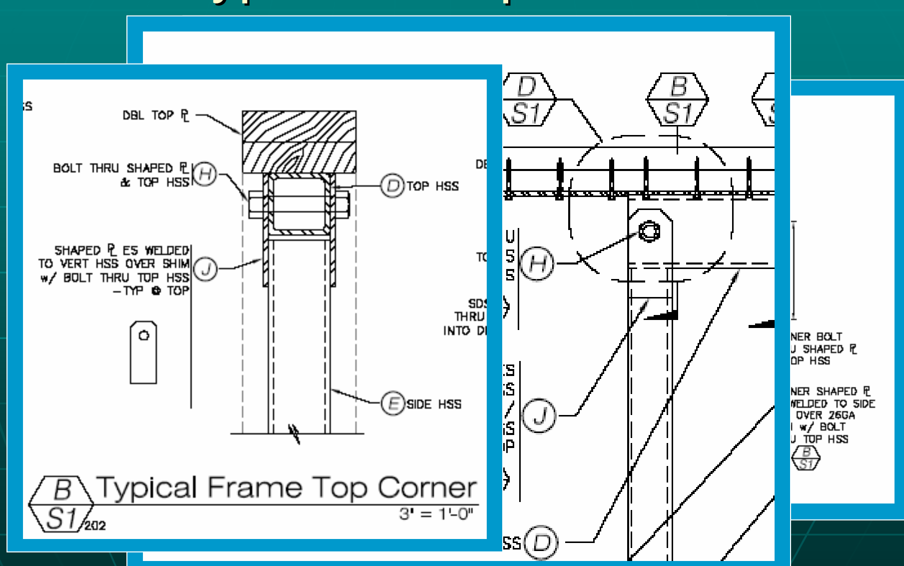
Designing a Damper System

- This issue can be addressed by:
  - Use a chevron brace system where there is no net vertical force on the beam.
  - Make your diagonal brace intersect at beam-column connections.
  - Make the beam stiff enough such that the vertical deflection is insignificant.
  - Increase the stroke of the damper to allow for the horizontal displacement due to the vertical deflection of the beam caused by the vertical component of the diagonal force.
  - Use a shear panel framed with metal incorporating a viscous damper to absorb energy

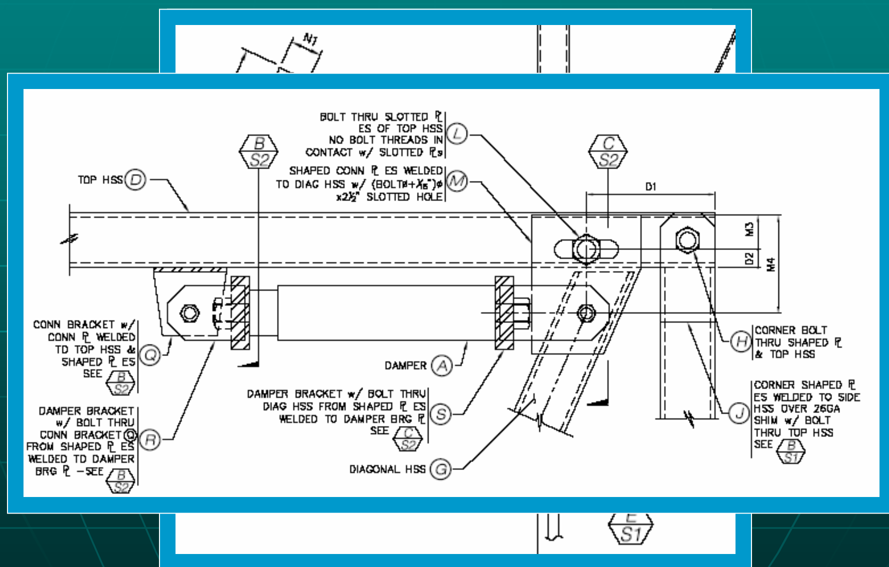
Typical Damper Panel



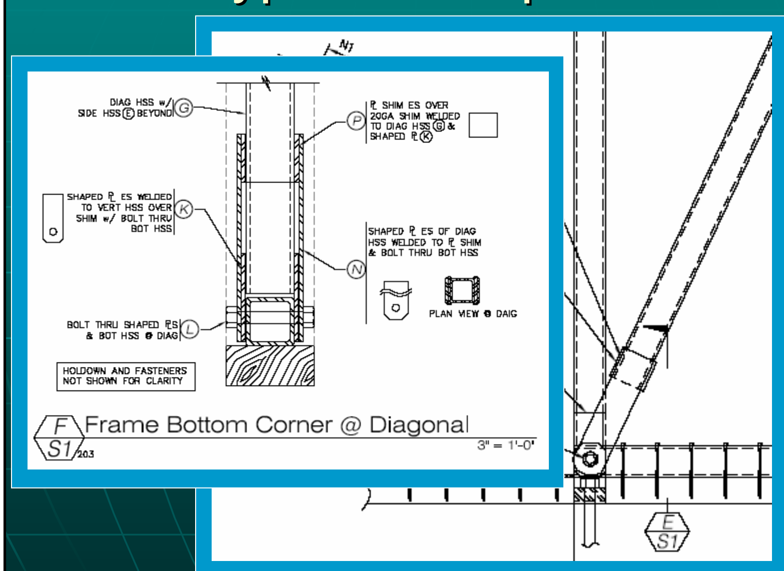
Typical Damper Panel



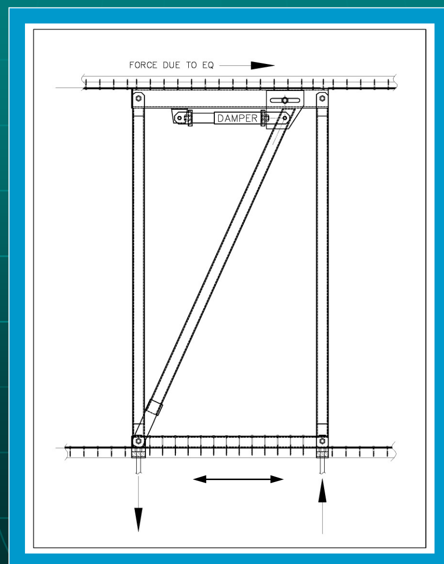
Typical Damper Panel



Typical Damper Panel



Typical Damper Panel



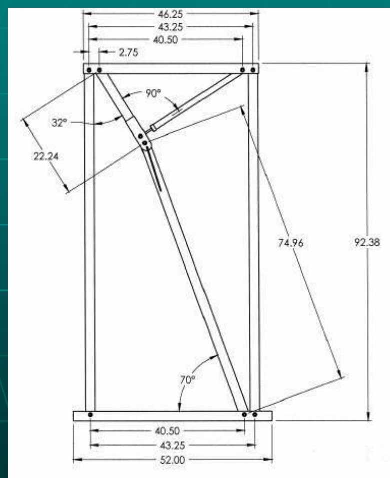
Designing a Damper System

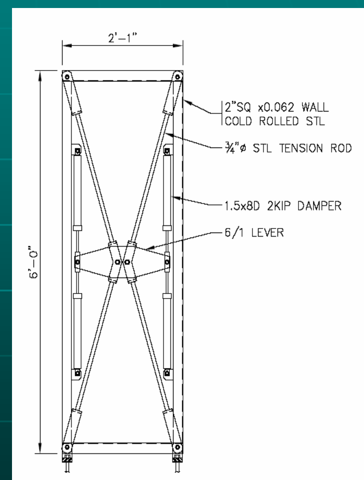
- For a damper installed in a diagonal brace:
  - As the angle Θ of the damper (relative to the horizontal) increases:
    - The force in the damper increases
    - The displacement in the damper decreases
    - The vertical component of the force increases
    - Increases the required capacity and cost of the dampers
    - May require more dampers to limit the vertical "tie down" force to that which the building weight and/or foundation capacity can provide.
- At some point (with increased values of Θ) it will be necessary to use a toggle or scissor system to amplify the displacement in the damper to optimize the effect and minimize the cost of the dampers

Smaller Theta

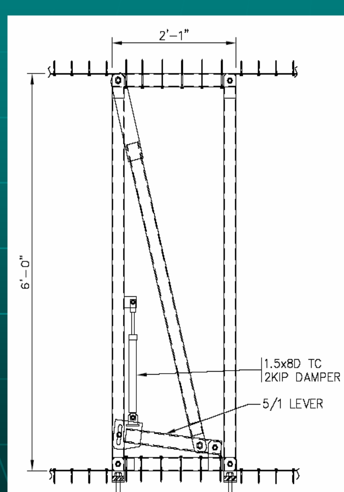
Larger Theta

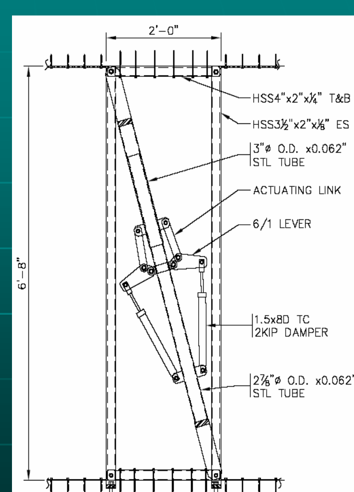
Damper Systems





Damper Systems





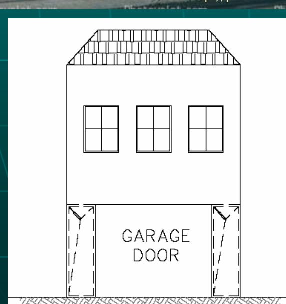
SWOF Buildings

http://opinexperts.com/journal/2012/03/20/case-study-soft-story-building-retrofit-in-san-fra/

San Francisco has a huge number of tall, thin residential structures which have a street facing garage, making them highly torsional. The two side walls and the back wall of the building are generally stiff. The ground level wall with the garage doors has almost no stiffness.

SWOF Buildings

Wernher Krutein http://photovalet.com/54728



- This can be compensated by adding damper panels
  - The logical place for these dampers is within the two narrow panels, one on each side of the door.
  - Commonly only 24 inches wide by 80 inches tall
  - Difficult for the standard toggle brace to work.
    - The angle Θ is too large.
- There are two things that need to be done for this case:
  - Increase the stiffness of the columns either side of the damper panel
    - Add steel reinforcements to the wood columns
    - Add a light gage steel moment frame.
  - Provide greater multiplication in the linkage

SWOF Buildings

Loma Prieta, San Francisco, CA 1989 Earthquake

- Another solution could be installing garage width damper panels at the back of the car spaces parallel to the open side which is capable of supporting lateral loads from the front of the building to midway between the new panels and the next lateral force resisting element toward or at the rear wall along with panels between car spaces at appropriate spacing to resist torsion.

Conclusion

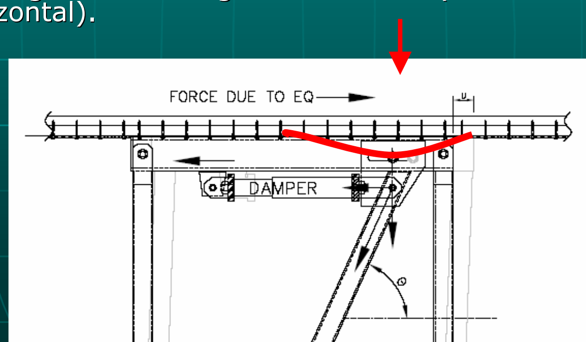
- Based on the previous examples it is obvious that installing a bracing system in the ground floor of a soft, weak, open front building which incorporates viscous dampers in the bracing system can dramatically increase the ground acceleration necessary to reach the limiting force capacity of the second floor over a bracing system which does not include dampers.

Questions ???

San Francisco after the 1989 Loma Prieta Earthquake.

Designing a Damper System

- When the vertical component of the force in the damper system is resisted by a relatively flexible beam the effective stroke of the horizontally installed damper is reduced by the vertical deflection of the beam times the co-tangent of the angle of the brace (relative to the horizontal).



Designing a Damper System

- When the damper is installed in the diagonal brace, the effective stroke of the damper is decreased by the vertical beam deflection divided by the sin of Θ.