Seismic retrofitting of buildings using energy dissipation devices

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Aim of the talk

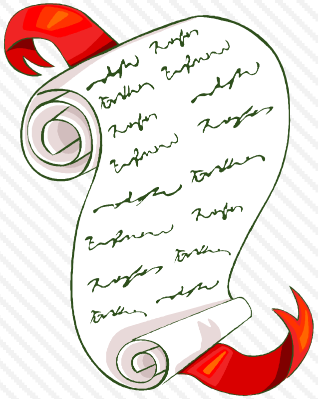
- Present ongoing research in which the presenter has been involved.
- Various types of energy dissipation devices will be discussed.
- Various structural systems (e.g. frames, walls etc.) are considered.
- How (and if) to use such devices in cultural heritage buildings? ⇨ discussion with the audience (future collaboration?).

Acknowledgement

- Prof. G.P. Cimellaro.
- Dr. Y. Daniel.
- Prof. G.F. Dargush.
- Dr. S. Dogruel.
- Prof. R. Levy.
- Prof. A.M. Reinhorn.
- Prof. A. Rutenberg.

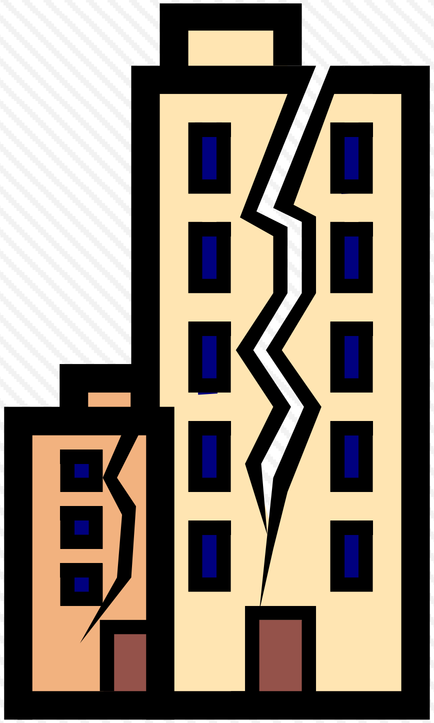
Presentation layout

- Motivation and introduction
- Various energy dissipation devices.
- Various design approaches (as time allows).
- Conclusions



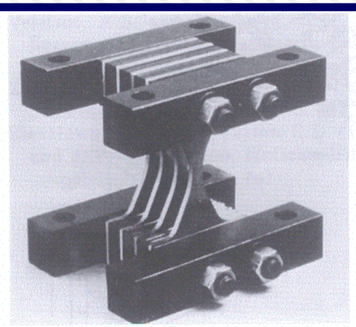
Motivation

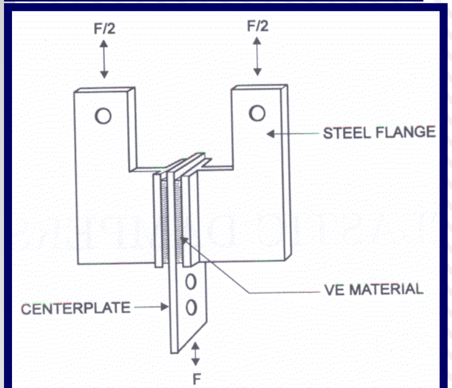
- Codes were aimed at preventing loss of human life while **permitting a heavy damage** to structures and property under strong earthquakes
- Heavy damage was caused by the 1994 Northridge and the 1995 Kobe earthquakes.
- Performance-Based-Design.
- Retrofitting of existing structures:
  - Passive control devices

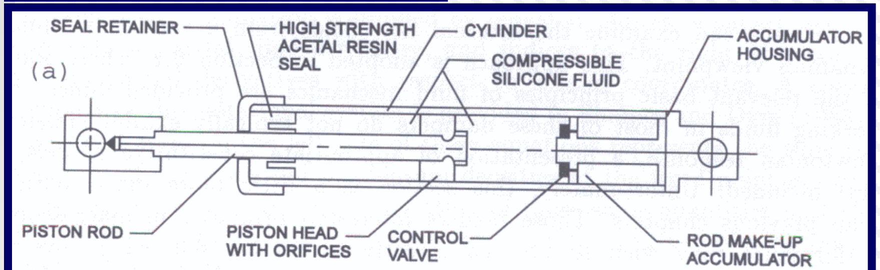


- **Goal: develop optimal design methodologies**

Energy dissipation devices







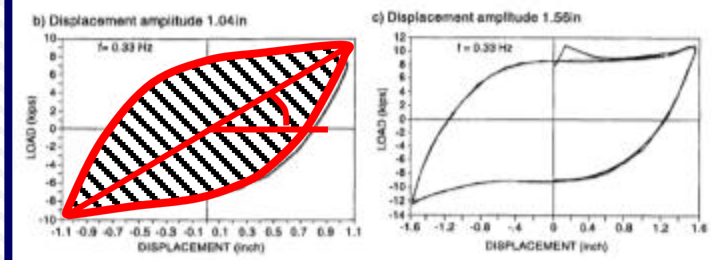


Figure 3.20 Force-Displacement Response of X-shaped Device (Bergman and Goel, 1987): Displacement Amplitude a) 0.42in, b) 1.04in, c) 1.56in

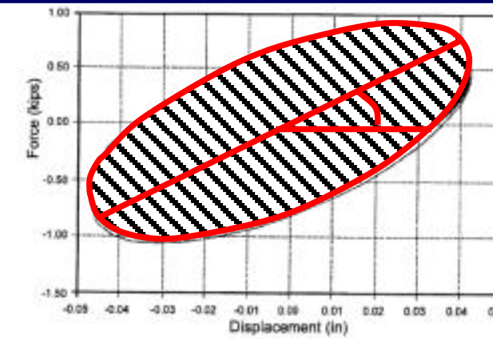


Figure 5.6 Typical Hysteresis Loop Results from a Sinusoidal Test

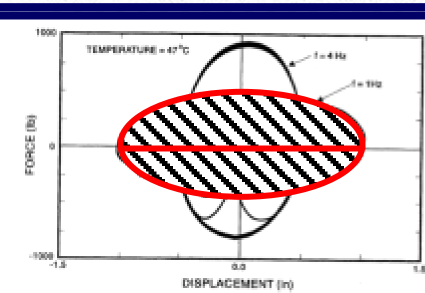
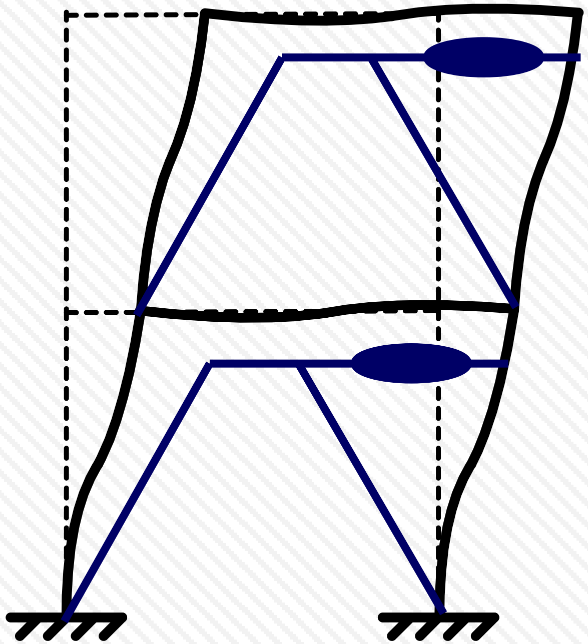
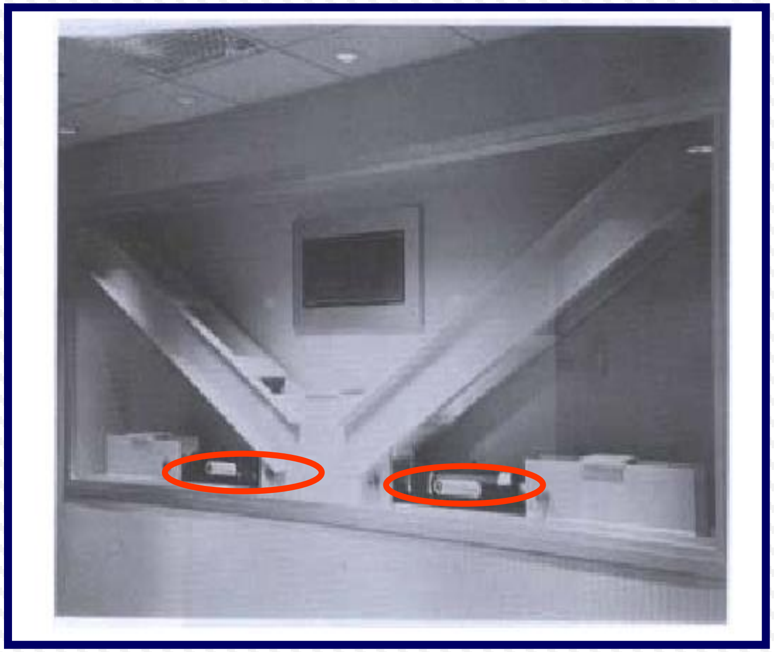


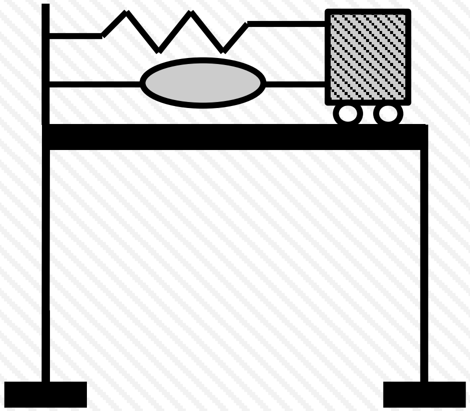
Figure 6.15 Orificed Fluid Damper Force-Displacement Response (Constantinou and Symans, 1993b)

Energy dissipation devices





Tuned Mass Dampers - TMDs



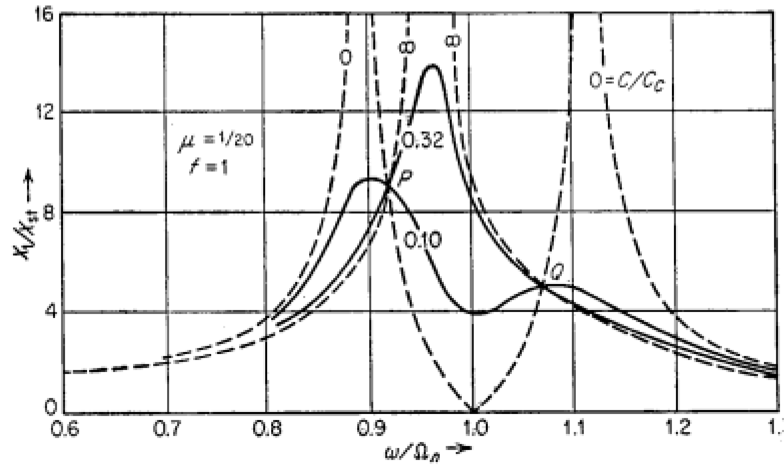


FIG. 3.12. Amplitudes of the main mass of Fig. 3.6 for various values of absorber damping. The absorber is twenty times as small as the main machine and is tuned to the same frequency. All curves pass through the fixed points P and Q.

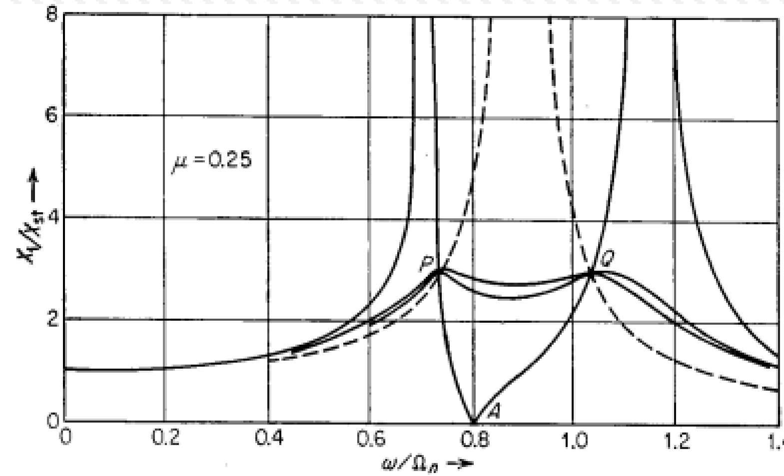
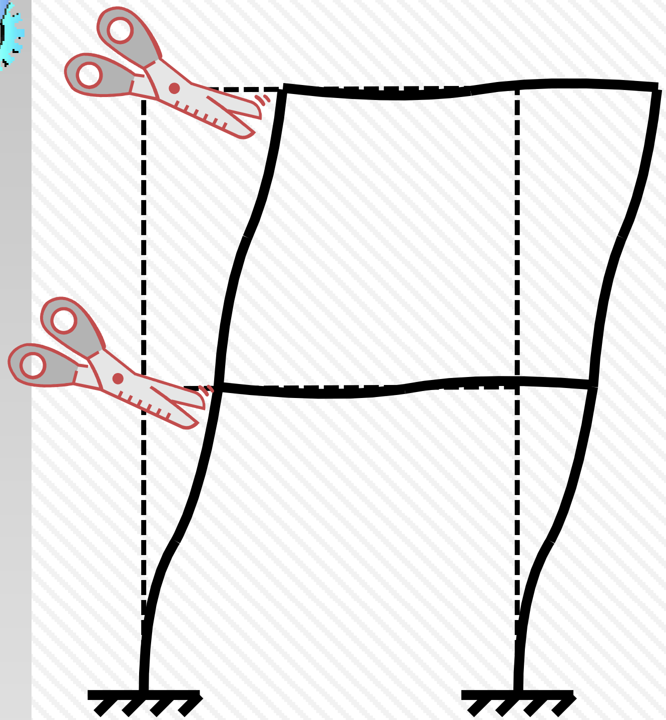
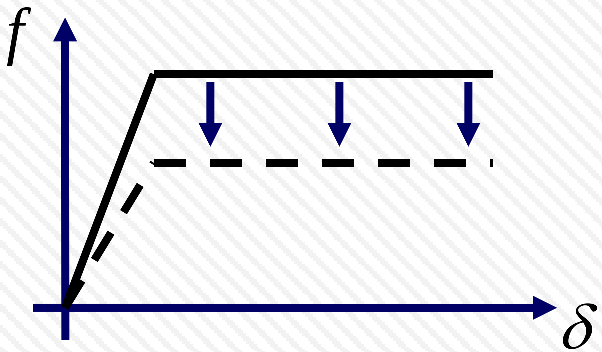
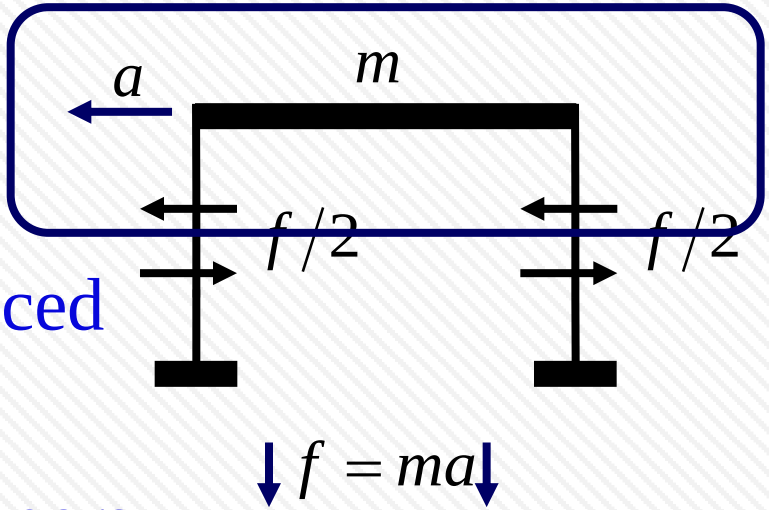


FIG. 3.13. Resonance curves for the motion of the main mass fitted with the most favorably tuned vibration-absorber system of one-fourth of the size of the main machine.

Weakening







- Accelerations (forces) are reduced
- Inter-story drifts are increased
- Combination with viscous dampers

Gap and objective

- The design process has become increasingly complex.
  - What type of damper is good for what purpose (hazard, type of damage to be controlled, type of structural system)?
  - Once a type of damper is chosen, how can one come up with an efficient design?
- Most design methodologies lead to "expensive" designs.
- Optimal design methodologies require understanding of concepts and tools from optimization theory.
- **Develop practical optimal design methodologies**.

Requirements from the design methodology

- Assist in choosing the right type of device
- General for all types of devices and objectives
- Lead to an efficient (optimal?) performance-based solution
- Small computational effort
- Simple and transparent to practicing engineers: Make use of tools familiar to the engineering community
- Lead to understanding of the behavior of the optimal designs
- **Unfortunately, there is no single method that can satisfy all requirements.**

Strategy – levels of optimization

- Identify what retrofitting technique is advantageous for what purpose and what characteristics optimal designs have.
  - ⇨ **Experience.**
  - III ⇨ **Multi-objective zero order optimization scheme (GA).**

- Identify what characteristics optimal designs of specific problems have.
  - I ⇨ **Gradient based approach**
  - ⇨ **Multi-objective zero order optimization scheme (GA).**

- Taylor simple design methods for specific problems considering insight from the results attained.
  - II ⇨ **Simple iterative approach**

Single objective gradient based approach

Lavan, O., and Levy, R. (2005). "Optimal design of supplemental viscous dampers for irregular shear-frames in the presence of yielding." Earthquake Engineering & Structural Dynamics, 34(8), 889-907.

Lavan, O., and Levy, R. (2006). "Optimal peripheral drift control of 3D irregular framed structures using supplemental viscous dampers." Journal of Earthquake Engineering, 10(6), 903-923.

Lavan, O., and Levy, R. (2006). "Optimal design of supplemental viscous dampers for linear framed structures." Earthquake Engineering & Structural Dynamics, 35(3), 337-356.

Lavan, O. and Levy, R. (2010) "Performance based optimal seismic retrofitting of yielding plane frames using added viscous damping." Earthquakes and Structures 1(3): 307-326.

Problem Formulation

Minimize the total added damping

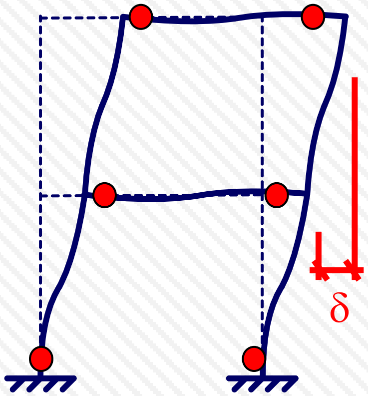
subject to :

Various inter-story performance indices at each story

Equations of motion

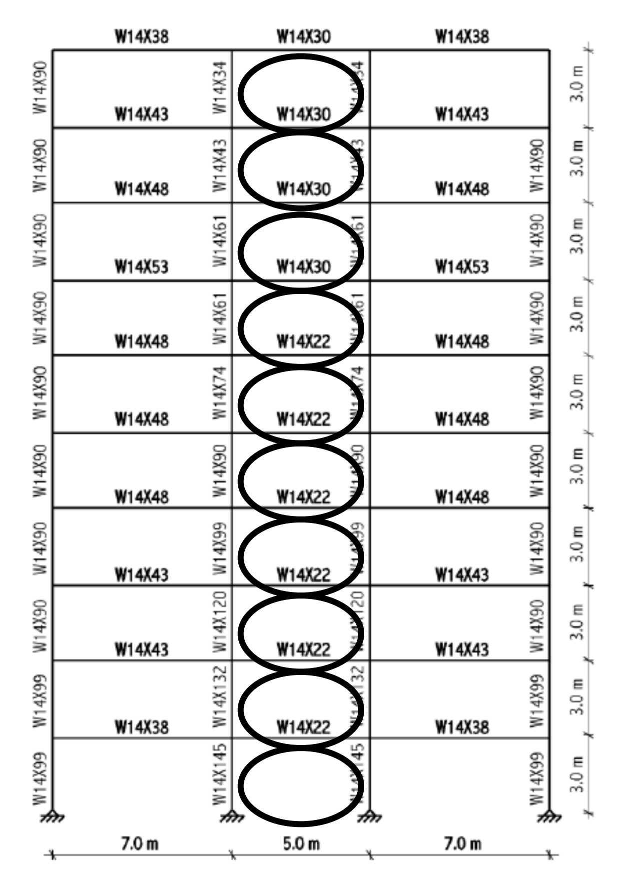
Size limitations

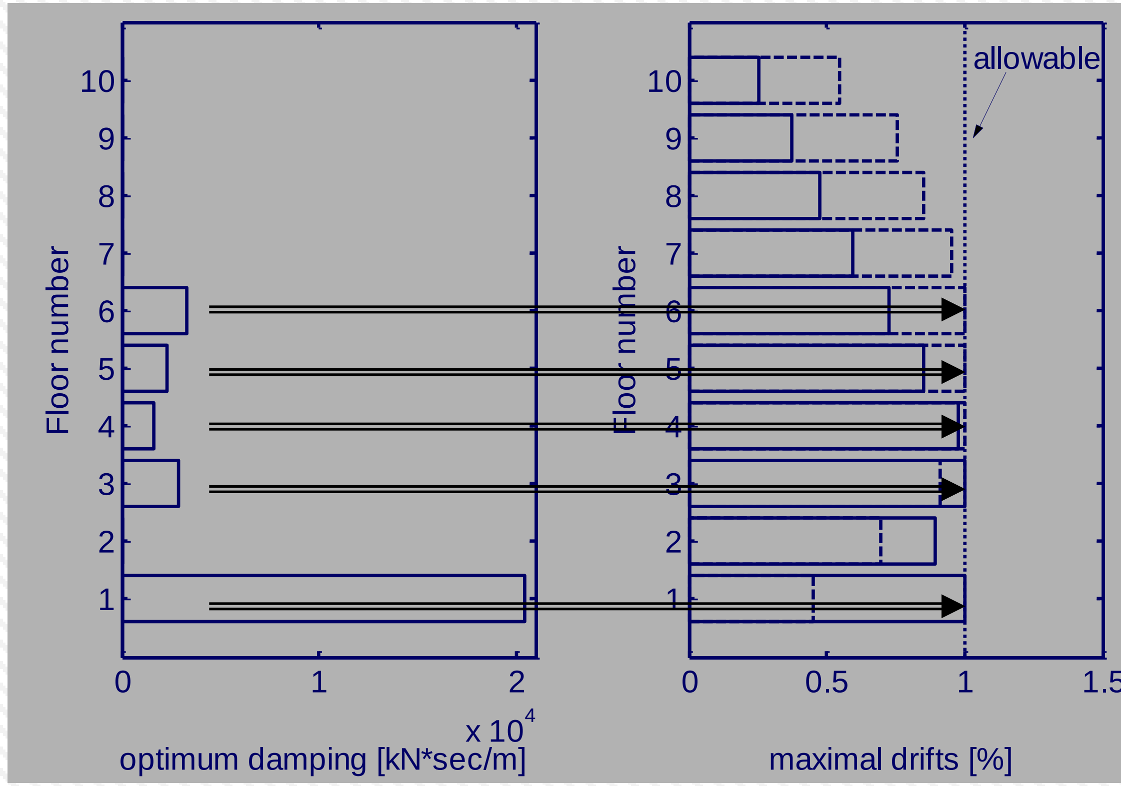
Whole ensemble



- **Gradient Based Opt**

Characteristic results





dampers are assigned only where the performance index is full

Single objective simple iterative approach

Viscous dampers

Lavan, O., and Levy, R., (2005), "Optimal seismic retrofit of irregular 3D framed structures using supplemental viscous dampers", Proceedings of the 4th European Workshop on the Seismic Behavior of Irregular and Complex Structures, Aug. 26-27, Thessalonica, Greece, Paper no. 52.

Levy, R., and Lavan, O. (2006). "Fully stressed design of passive controllers in framed structures for seismic loadings." Structural and Multidisciplinary Optimization, 32(6), 485-498.

Lavan, O., and Levy, R., (2009) "Simple iterative use of Lyapunov's solution for the linear optimal seismic design of passive devices in framed buildings." Journal of Earthquake Engineering, 13(5), 650–666.

Hysteretic dampers

Daniel, Y., Lavan, O, Levy, R. (2011) "A simple methodology for the seismic passive control of irregular 3D frames using friction dampers." 6WEICS – 6th European Workshop on the seismic behavior of Irregular and Complex Structures, Haifa, Israel.

Single objective simple iterative approach

Multiple Tuned Mass dampers

Daniel, Y., Lavan, O. (2011) "Seismic design methodology for control of 3D buildings by means of multiple Tuned-Mass-Dampers." COMPDYN 2011 - 3rd International Conference in Computational Methods in Structural Dynamics and Earthquake Engineering, Corfu`, Greece.

Lavan, O., Daniel, Y. (2013) "Full resources utilization seismic design of irregular structures using multiple tuned mass dampers." Structural and Multidisciplinary Optimization, 48(3), 517-532

Weakening and damping

Lavan, O. (2010) "Seismic design procedure for total accelerations and inter-story drifts reduction of existing and new buildings with protective systems." Structures Congress 2010, Orlando, Florida.

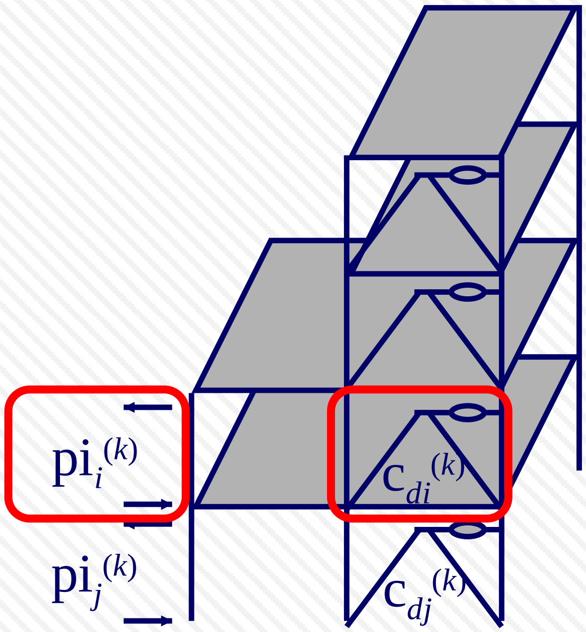
Analysis/Redesign

dampers are assigned only where the performance index is full

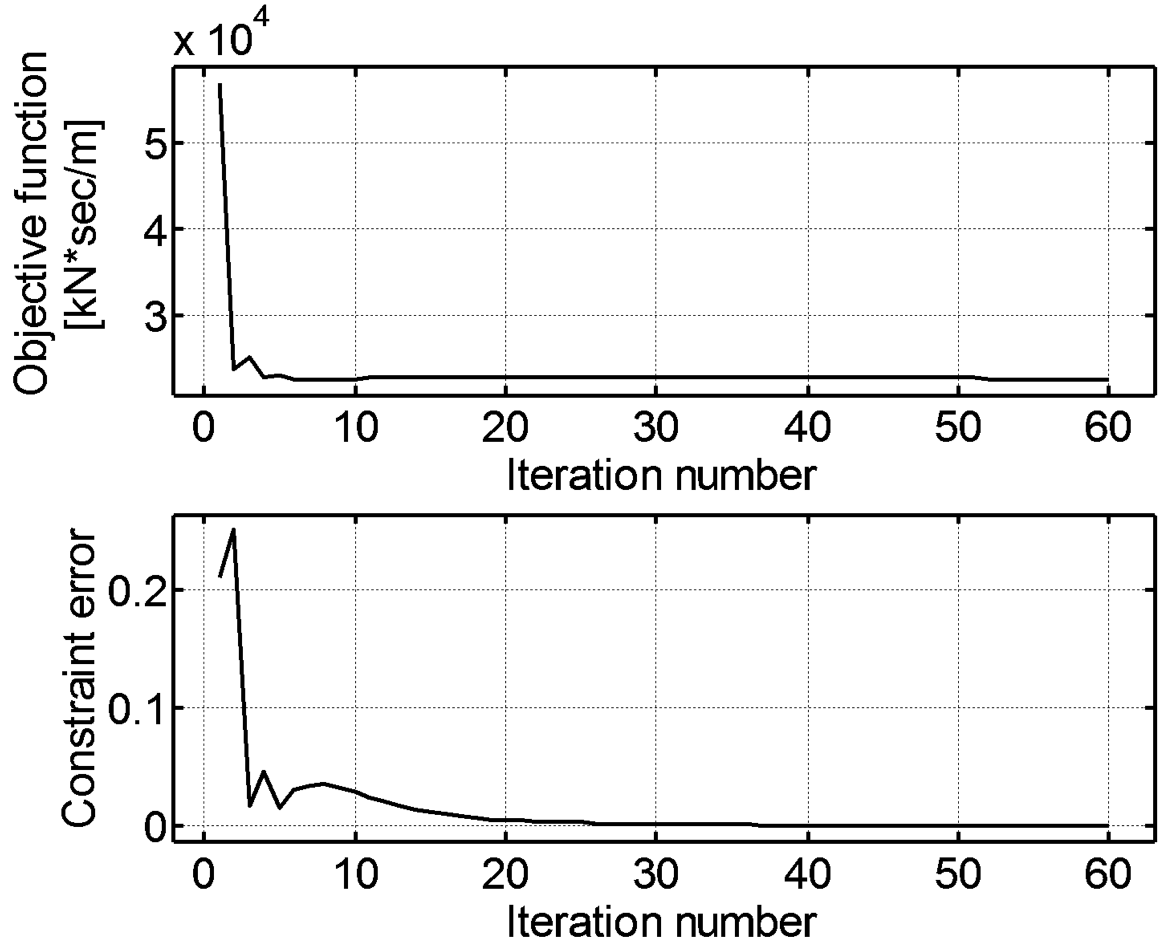
1. Perform time-history analysis.
2. Design new damping using the recurrence formula.

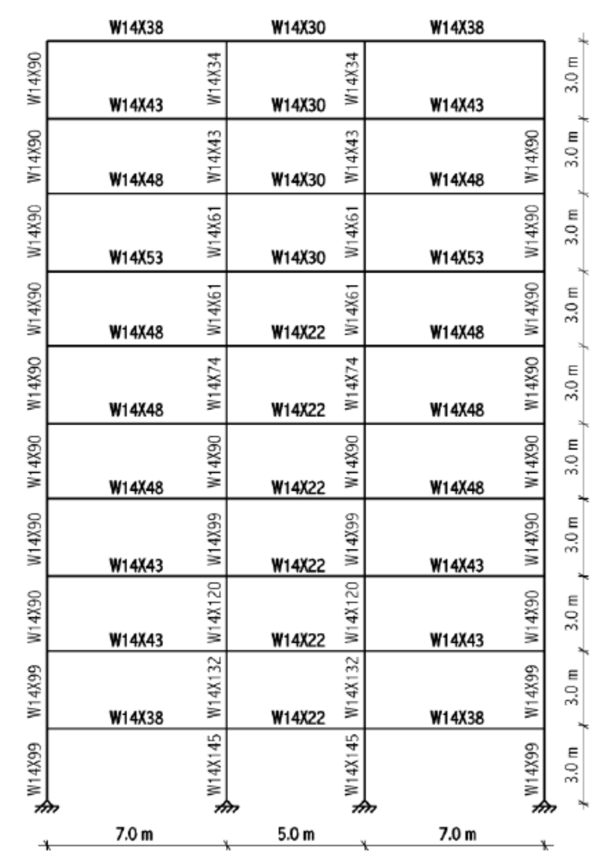
$$c_{d\,i}^{(k+1)} = c_{d\,i}^{(k)} \left(pi_i^{(k)} \right)^{\frac{1}{q}}$$

3. Return to *stage 1* if the results are not satisfying.

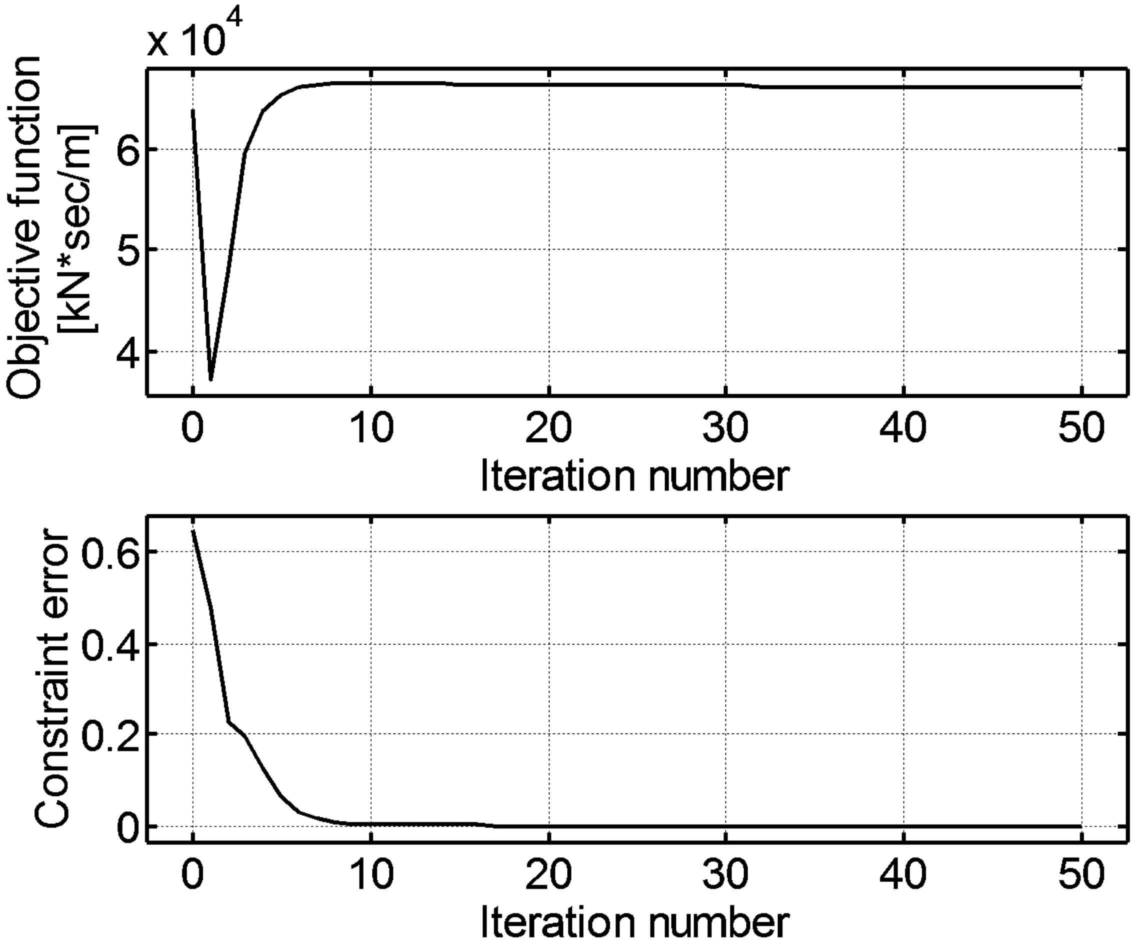


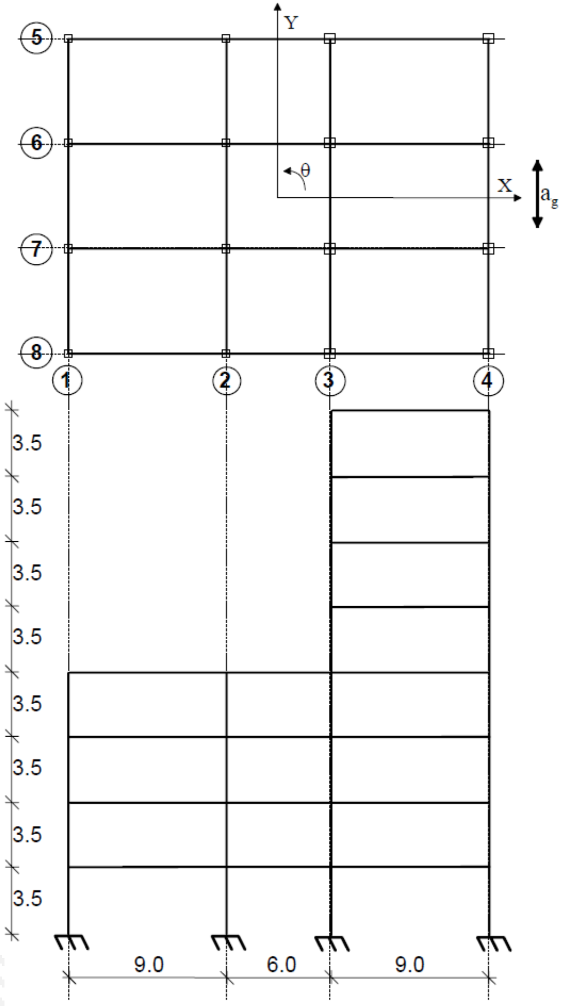
Convergence



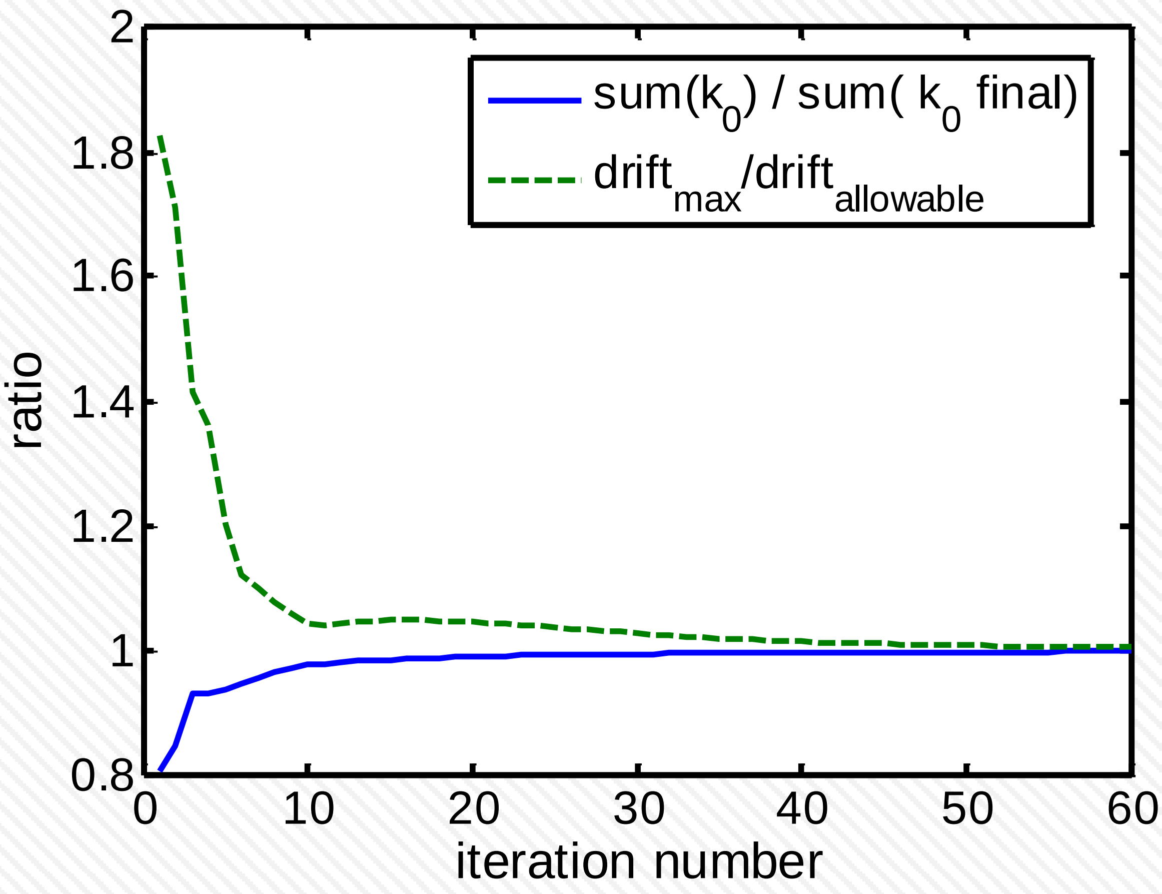


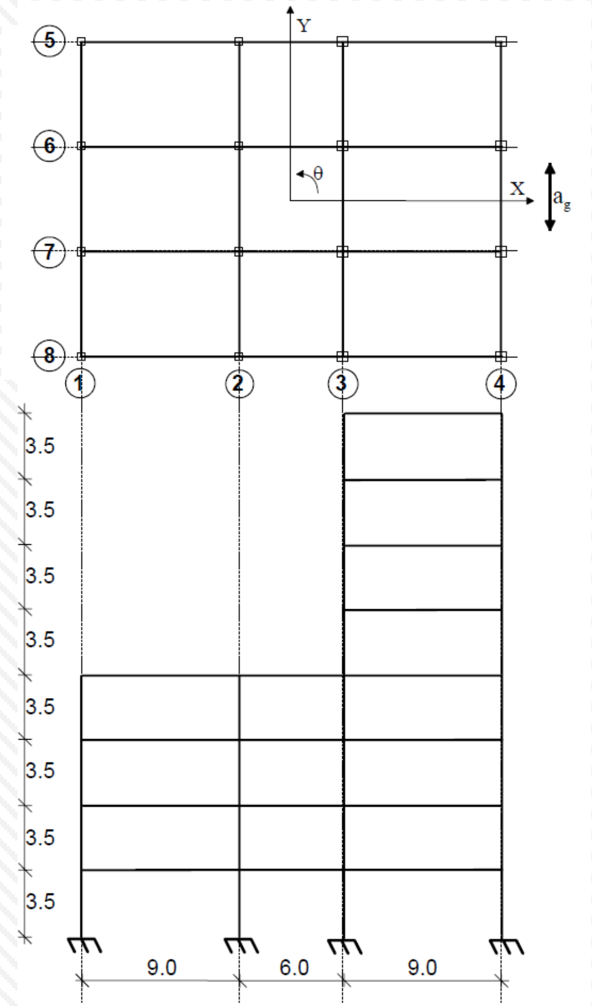
Convergence





Convergence – hysteretic dampers



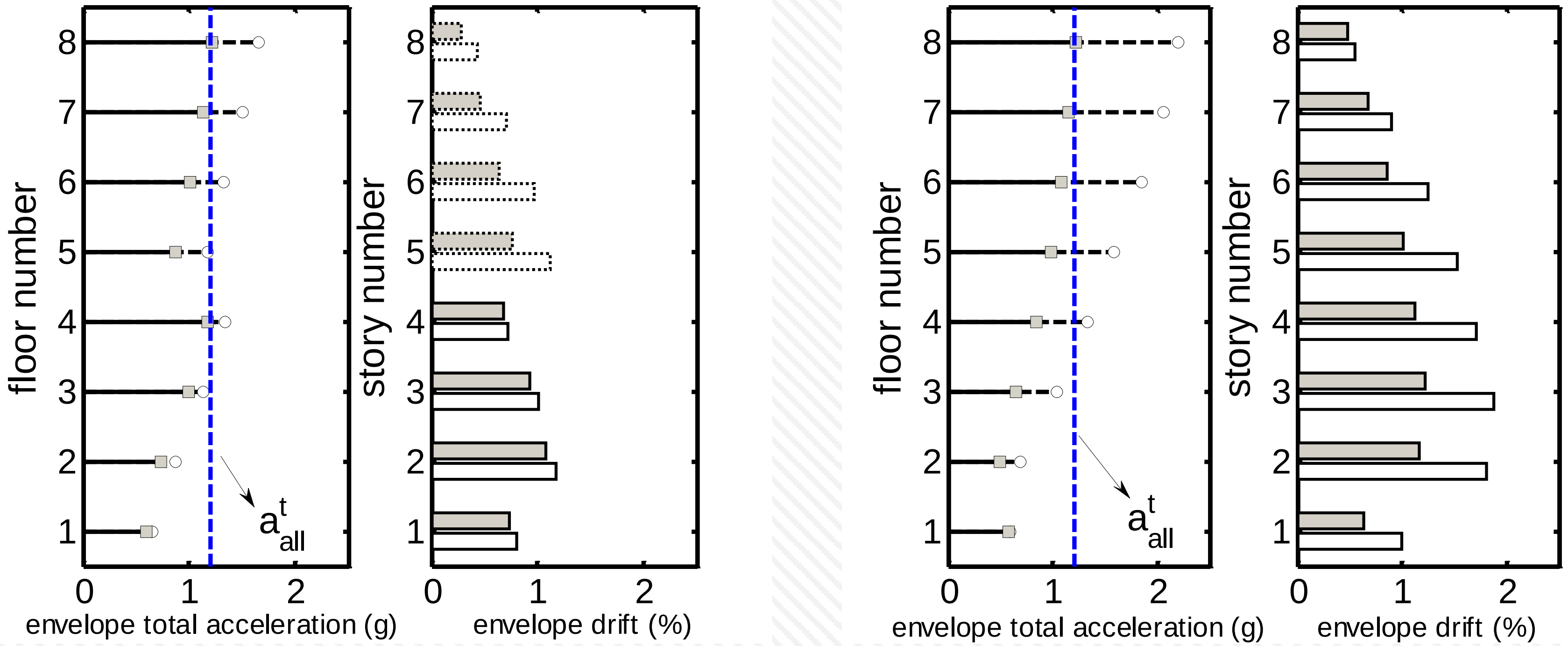


Convergence - MTMDs

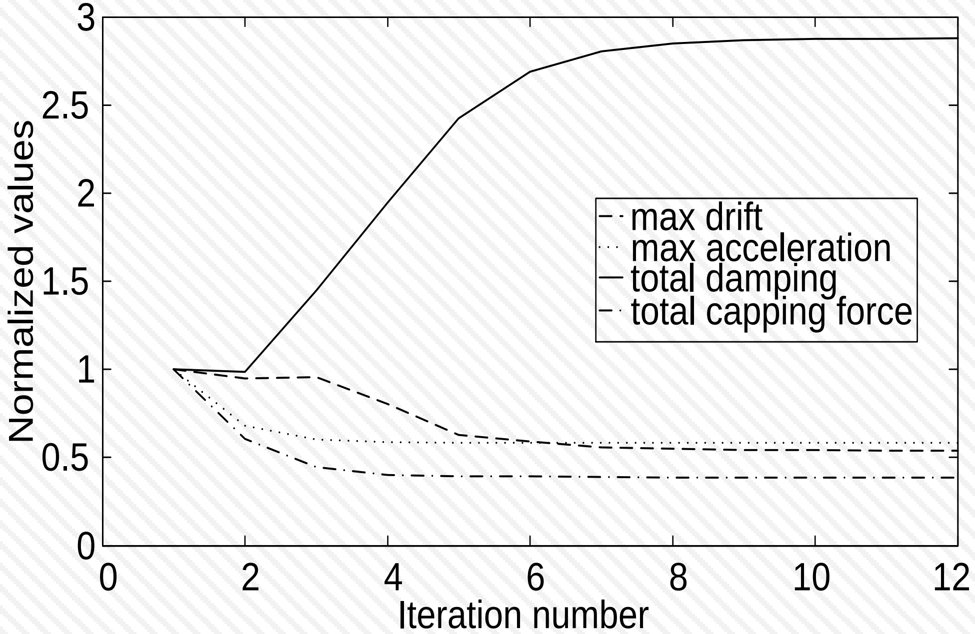
After the third modification, the added mass of TMDs increased to 4.6%. Upon convergence, the properties of each TMD were:

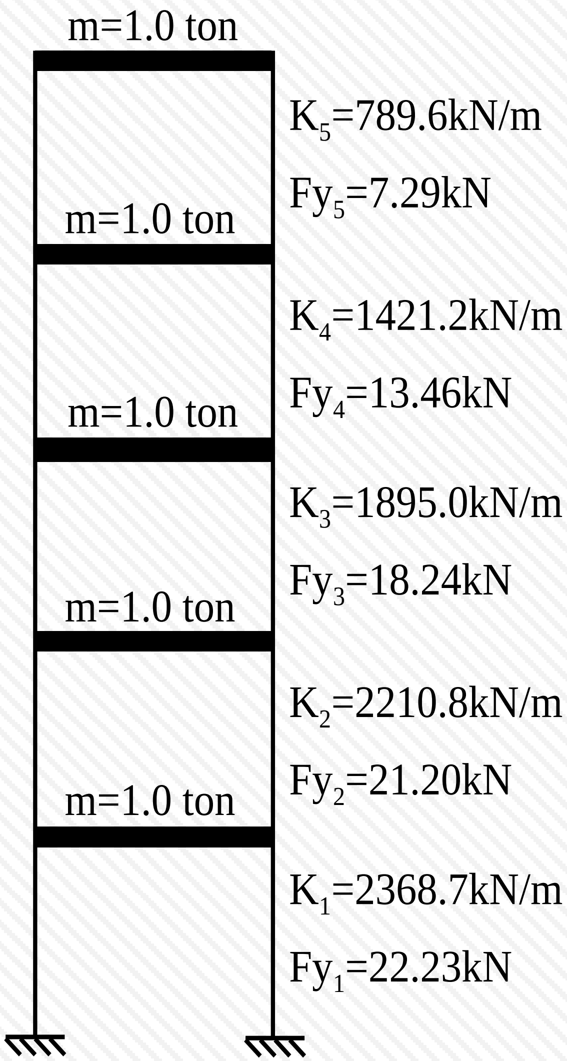
Frame	Floor	Mode to dampen	Final mass (ton)	Final stiffness (kN/m)	Final damping ratio
1	4	3	3.96	416.10	0.0655
3	8	5	0.44	139.13	0.0267
4	8	2	78.08	2974.8	0.2062

TIME domain



Convergence W+D





Multi-objective optimal seismic retrofitting of buildings

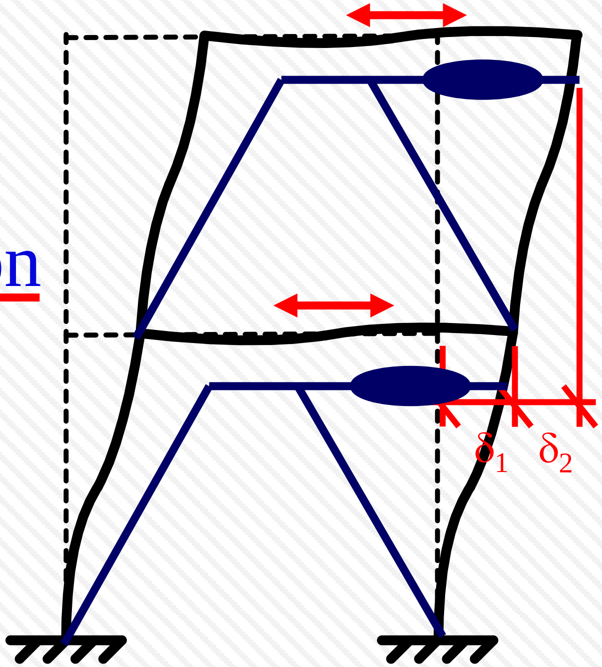
Lavan, O., and Dargush, G. F., (2009) "Multi-objective optimal seismic retrofitting of structures." Journal of Earthquake Engineering, 13, 758–790.

Dogruel, S., Lavan, O. (2010) "A comparative study of the seismic retrofitting of structures using various innovative technologies." 14th European Conference on Earthquake Engineering. Ohrid, Republic of Macedonia.

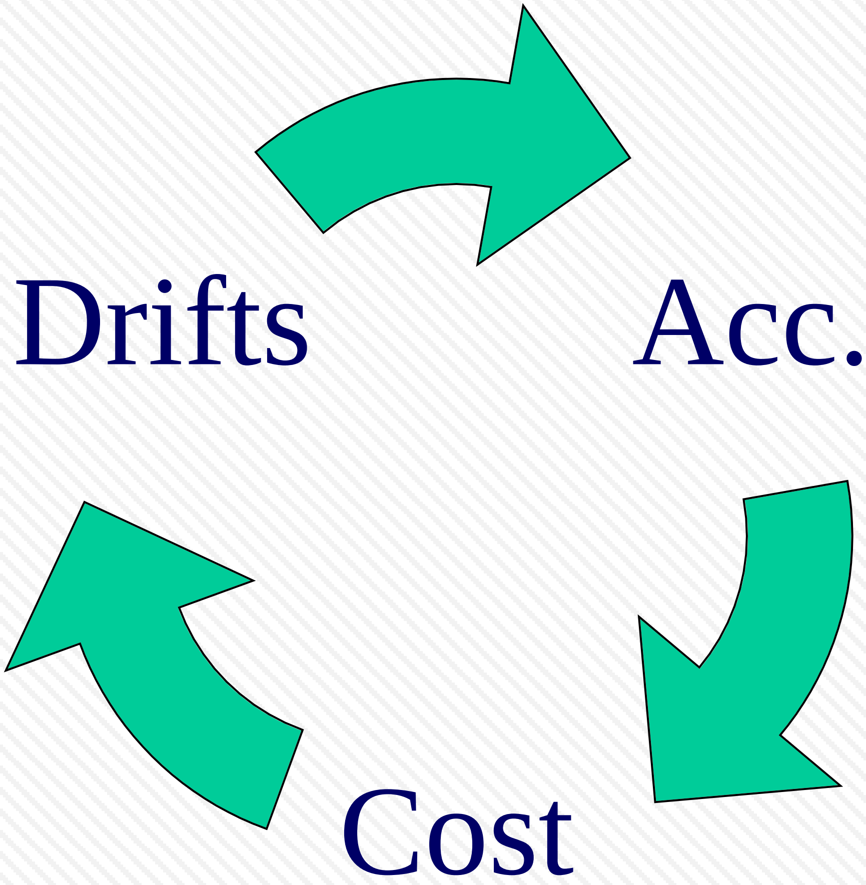
Dogruel, S., Lavan, O. (2012) "A comparative study of seismic retrofitting of a steel benchmark structure using various types of passive controllers." Structures Congress 2012, Chicago, Illinois

Optimization objectives

- Maximal normalized inter-story drift of all selected locations.
- Maximal normalized total acceleration of all selected locations.
- Cost

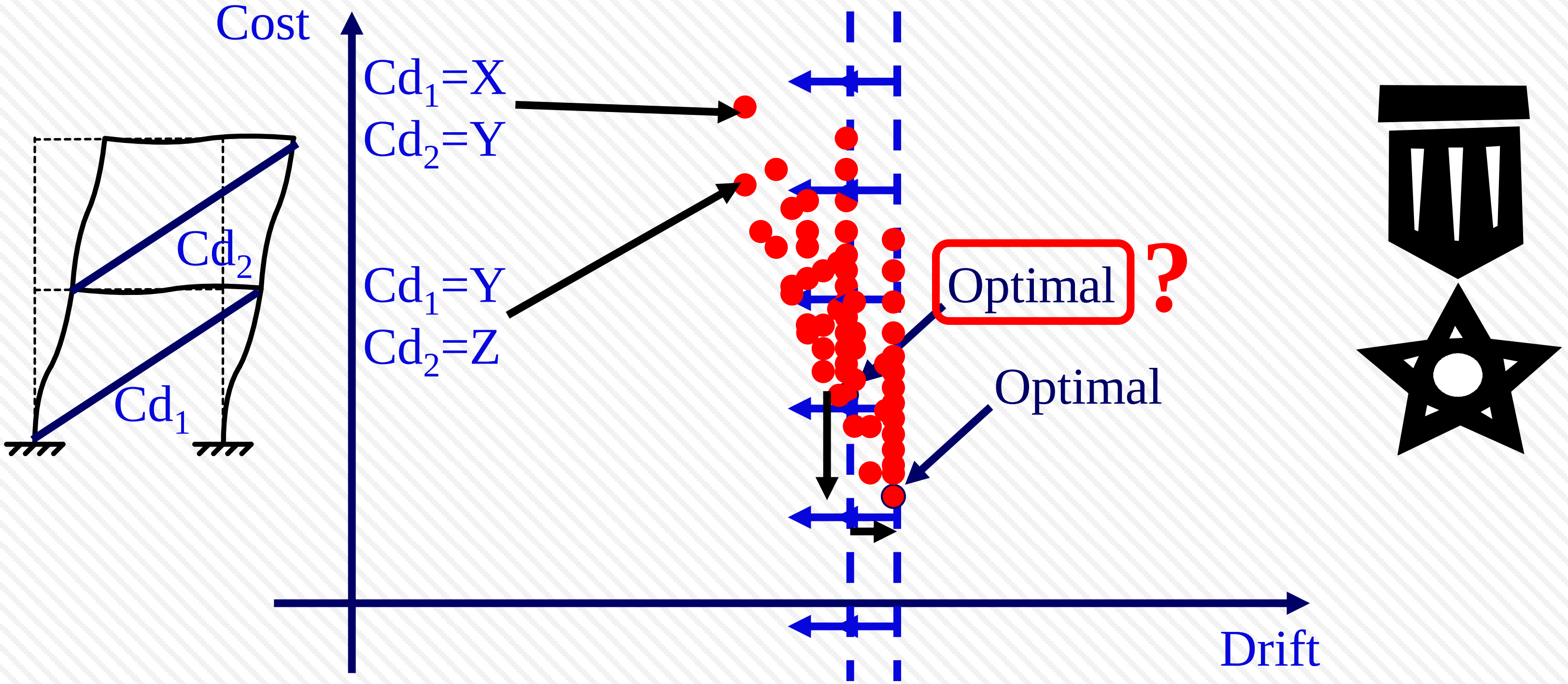


Multi-objective opt. – why?



Multi-objective opt. – why?

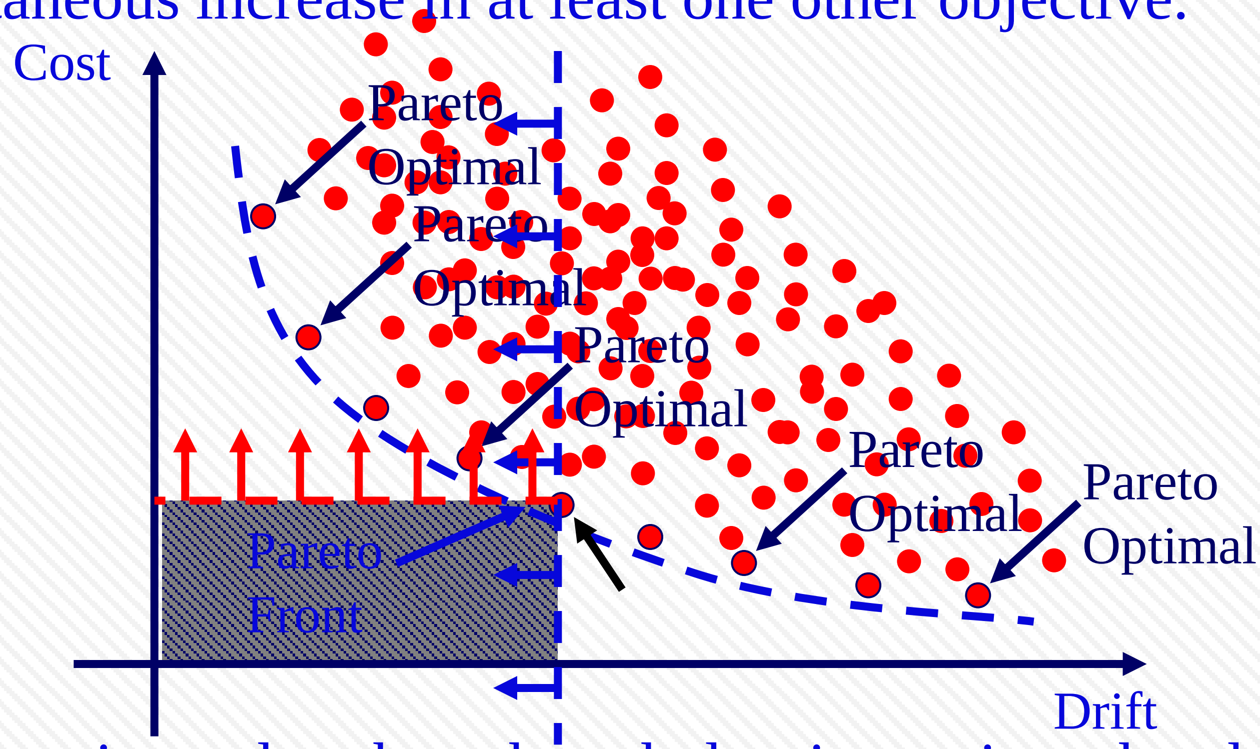
- Traditional optimization



- A small compromise on the performance may lead to a much cheaper solution.

Pareto front

- A design is Pareto optimal if there exists no feasible design which would decrease some objective without causing a simultaneous increase in at least one other objective.



- Decision is made when the whole picture is at hand (choose best compromise).
- Large computational effort

Example

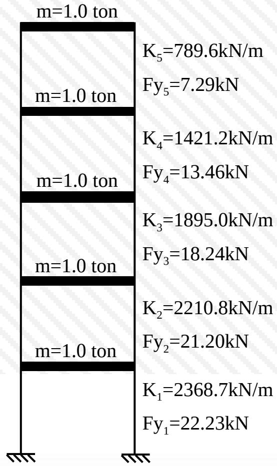
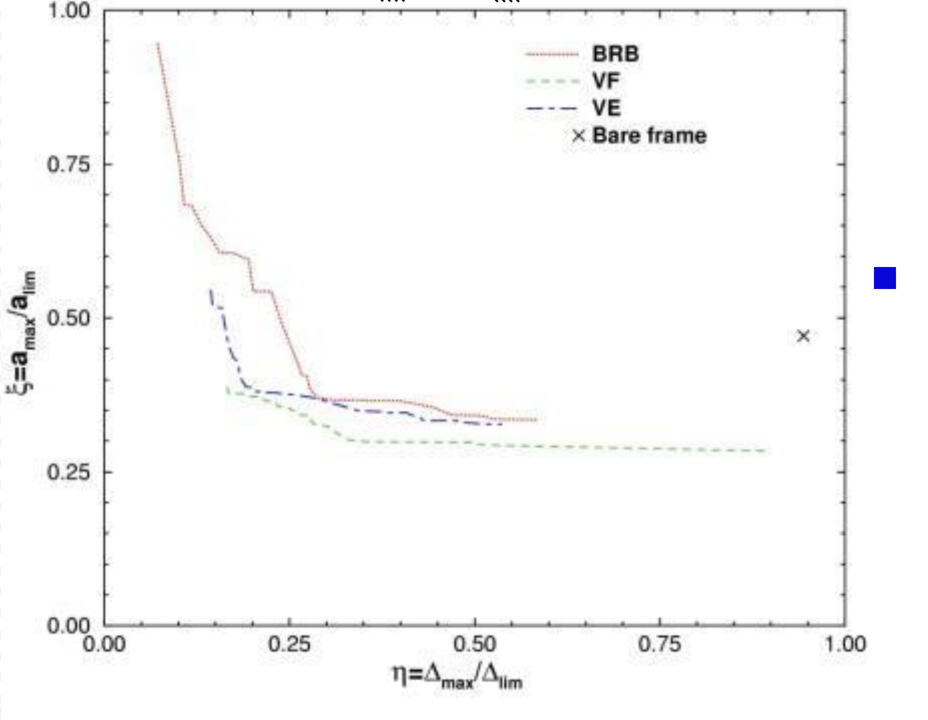
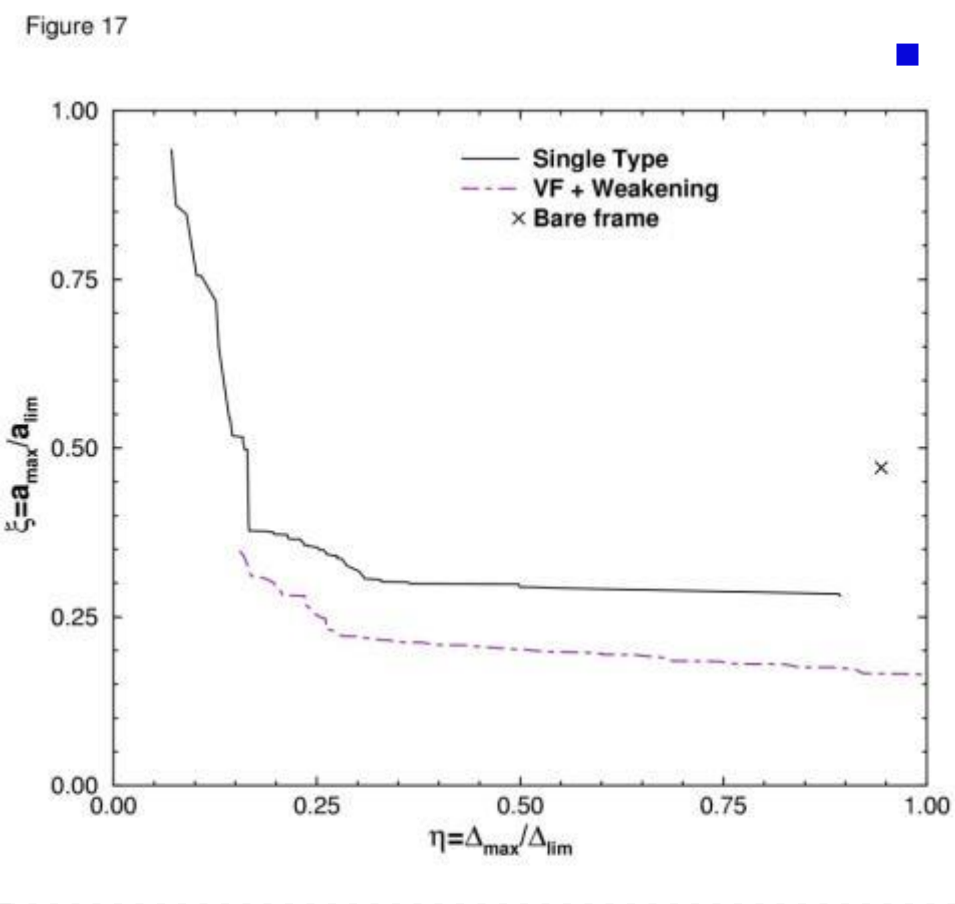


Figure 16



- With the right design all types of dampers can reduce both objectives.
- Viscous dampers are more efficient in reducing both objectives simultaneously.
- There is a wide region where a large reduction of drifts is accompanied with only a small increase in accelerations

Example

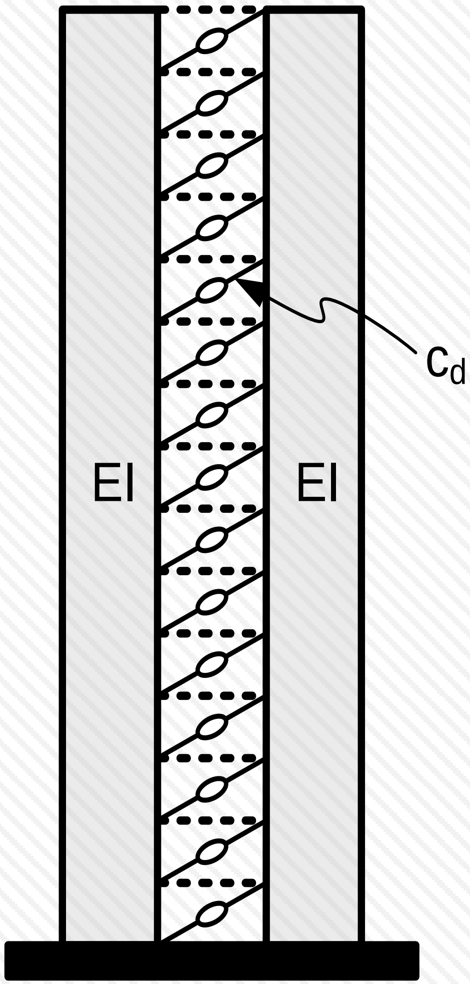


- The weakening and damping approach is more efficient in reducing both objectives simultaneously.

EDDs in wall structures

Lavan, O. (2012). "On the efficiency of viscous dampers in reducing various seismic responses of wall structures." *Earthquake Engineering and Structural Dynamics* 41:1673–1692.

- A single parameter controls the response of VCSW.
- It does not depend on the height of the structure. Hence, this system is also efficient for low rise buildings.
- Based on the example, such a reduction is feasible using "off-the-shelf" dampers.



Open questions

- The research done by the author so far focuses on “modern” buildings.
- How to use such devices in cultural heritage buildings?
- Some research on that has been done by others.
- (Maybe) There is more room for research on that topic.

Thank you!