Preliminary Sizing of Viscous Damping Devices

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General Comments about Modal Damping

- **Specified by**
  - **modal damping ratios**
  - **mass and stiffness multipliers**
- **Do you really get something for nothing?**
- **Violates dynamic equilibrium**
  - **inertia forces don't equal reactions!**
  - **modal damping introduces fictitious external loads**
- **5% damping in free vibration**
  - **about 25% displacement reduction per cycle**
  - **nearly 50% energy loss per cycle**

Effectiveness of Additional Damping depends on Where You Start

Effective Damping	Response Ratio
2%	1.25
5%	1.00
7%	0.93
10%	0.83
20%	0.67
30%	0.56

- 2% plus supplemental 5% gives 26% response reduction
- 5% plus supplemental 5% gives 17% response reduction

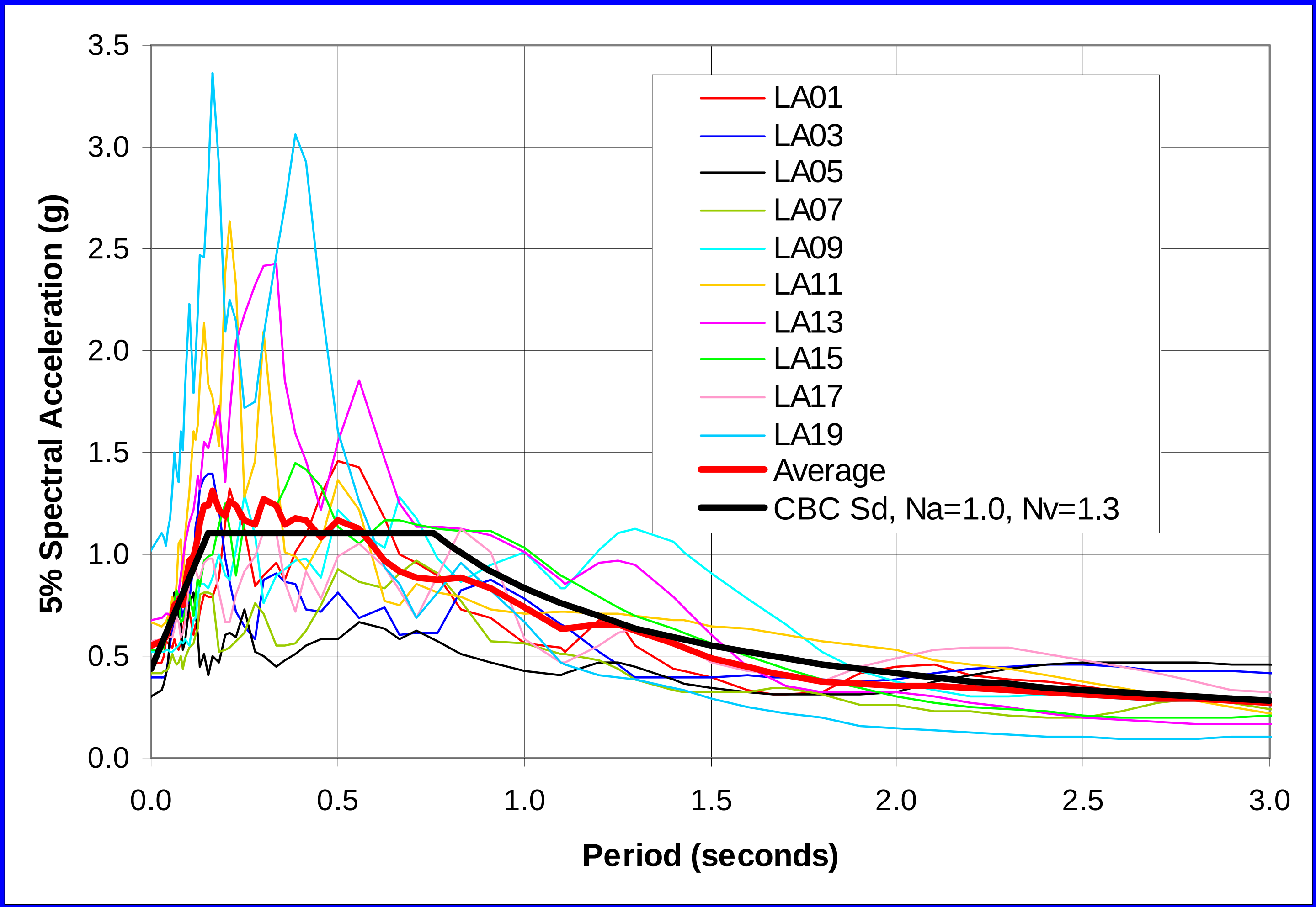
EQ Ground Motion Records

- Many records now available via the internet
- SAC EQ records, for example

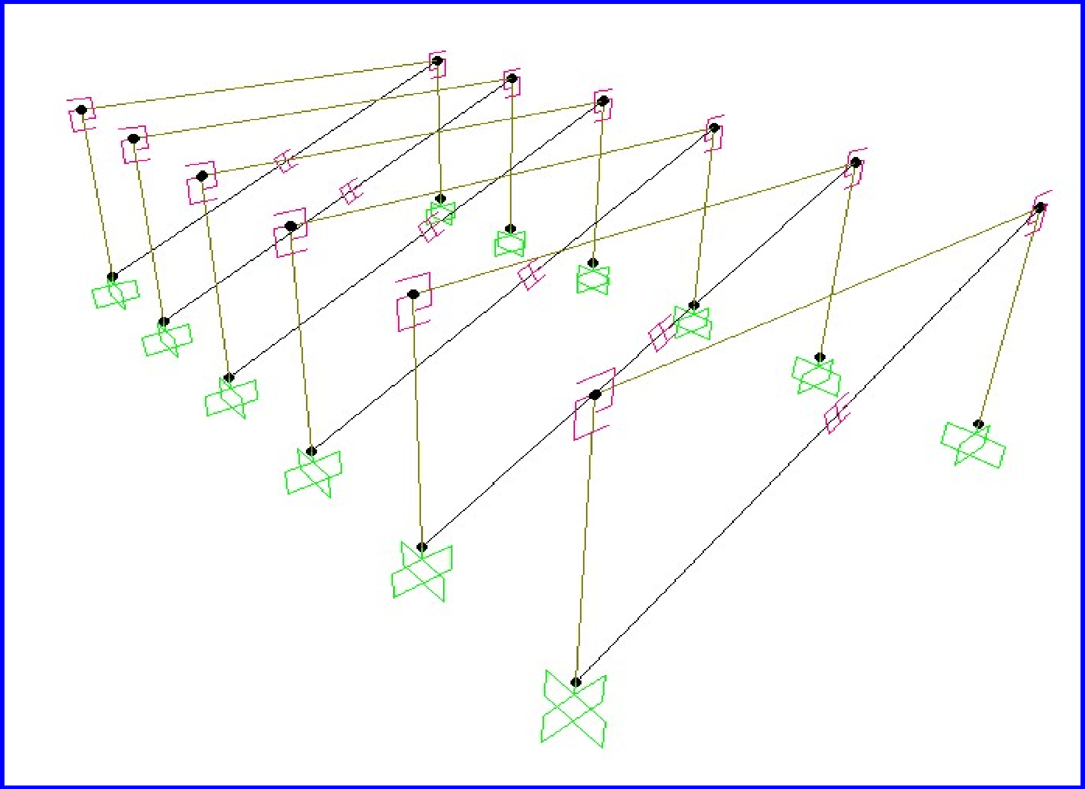
  http://nisee.berkeley.edu/data/strong_motion/sacsteel/ground_motions.html

  - motions for 50%, 10% and 2% PE in 50 years
  - motions for Los Angeles, Seattle, Boston
  - motions for soft sites and near field conditions
- 10 pairs of records in each category
- Soil Type S_D
- Average response spectra match 1997 NEHRP
- Records may need scaling for your site

LA Records: 10% PE in 50 Years



Response of Single Degree of Freedom Systems



- Six **SDOF systems, elastic periods of 0.5 seconds to 3.0 seconds**
- **Elastic or inelastic behavior in beams**
- **With or without viscous devices, $F = Cv$ or $F = Cv^{0.4}$**

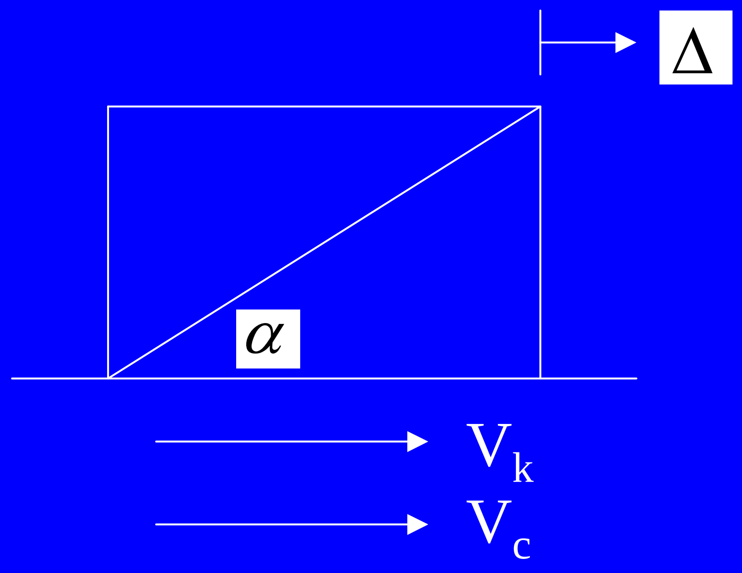
Calculation of Effective Device Damping
(F = Cv)

$$\beta = \frac{1}{4\pi}\frac{EDC}{SE}$$

$$EDC = \pi \frac{V_c}{\cos\alpha}\Delta\cos\alpha$$

$$SE = \frac{1}{2}V_k\Delta$$

$$\therefore \beta = \frac{1}{2}\frac{V_c}{V_k}$$



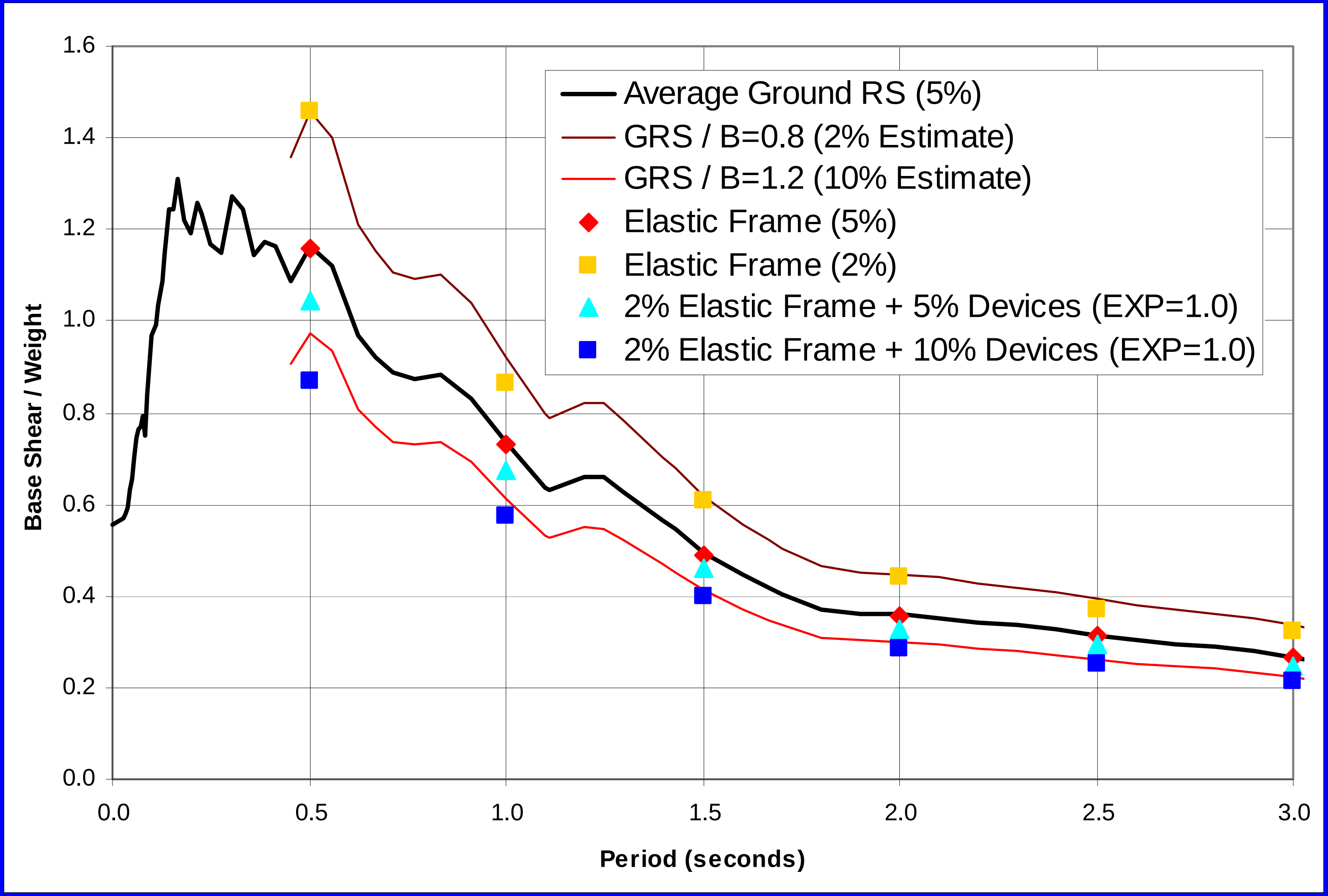
V_k: stiffness-related base shear

V_c: damping-related base shear

Estimate Damper Properties (F=Cv)

- Know response without dampers: V_k, velocity
- Set target effective damping from damping devices
  - could determine approximate target from B factors
- Set target $V_c / V_k = 2\beta$
  - note V_c and V_k are both linear functions of response
- Compute $V_c = 2\beta V_k$ and hence F_{damper}
- Determine damper $C = F_{damper} / v_{damper}$
- Note F_{damper} and v_{damper} will not be achieved
  - but C will achieve β in the damped SDOF system!

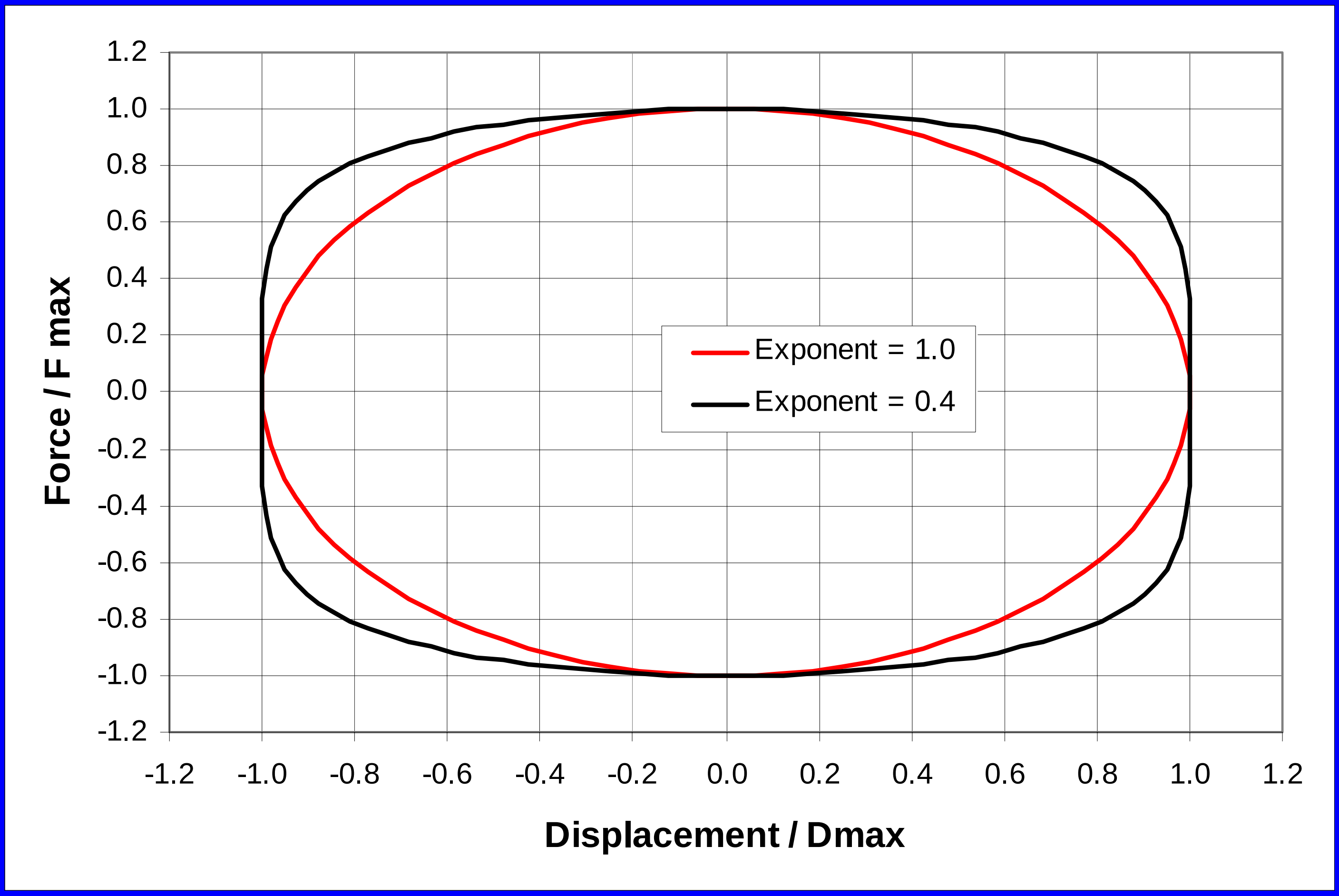
Elastic Structure, F=Cv Dampers



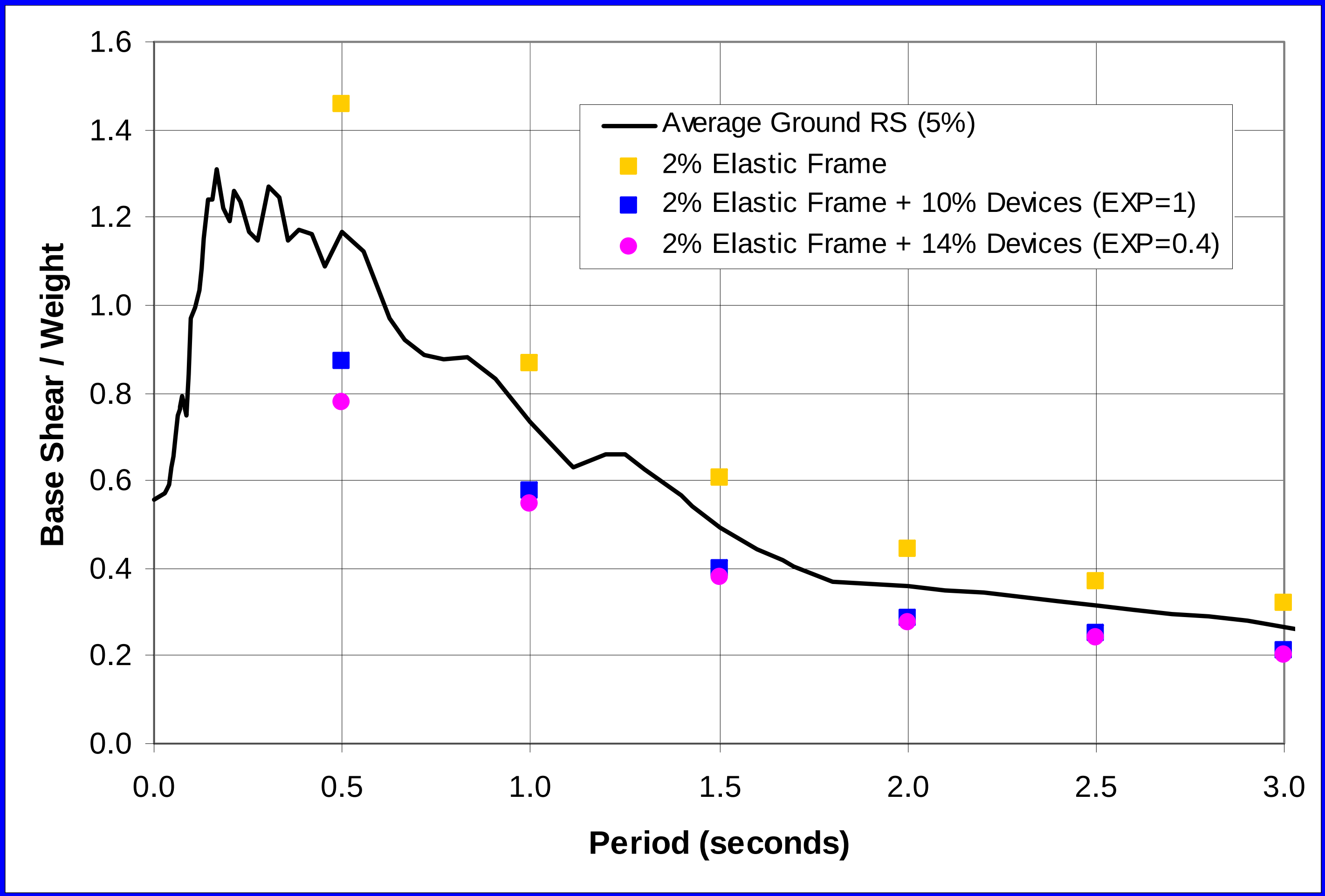
Estimate Damper Properties ($F=Cv^{0.4}$)

- $V_c = 2\ \beta\ V_k$ is no longer strictly true
  - hysteresis area from $F=Cv^{0.4}$ is 14% larger than from F=Cv
  - damper force is not linearly related to structure Δs
- Previous approach (for F=Cv) results in a larger β:
  - targeting 5% resulted in 7% added damping
  - targeting 10% resulted in 17% added damping
- Method provides a good starting point for design

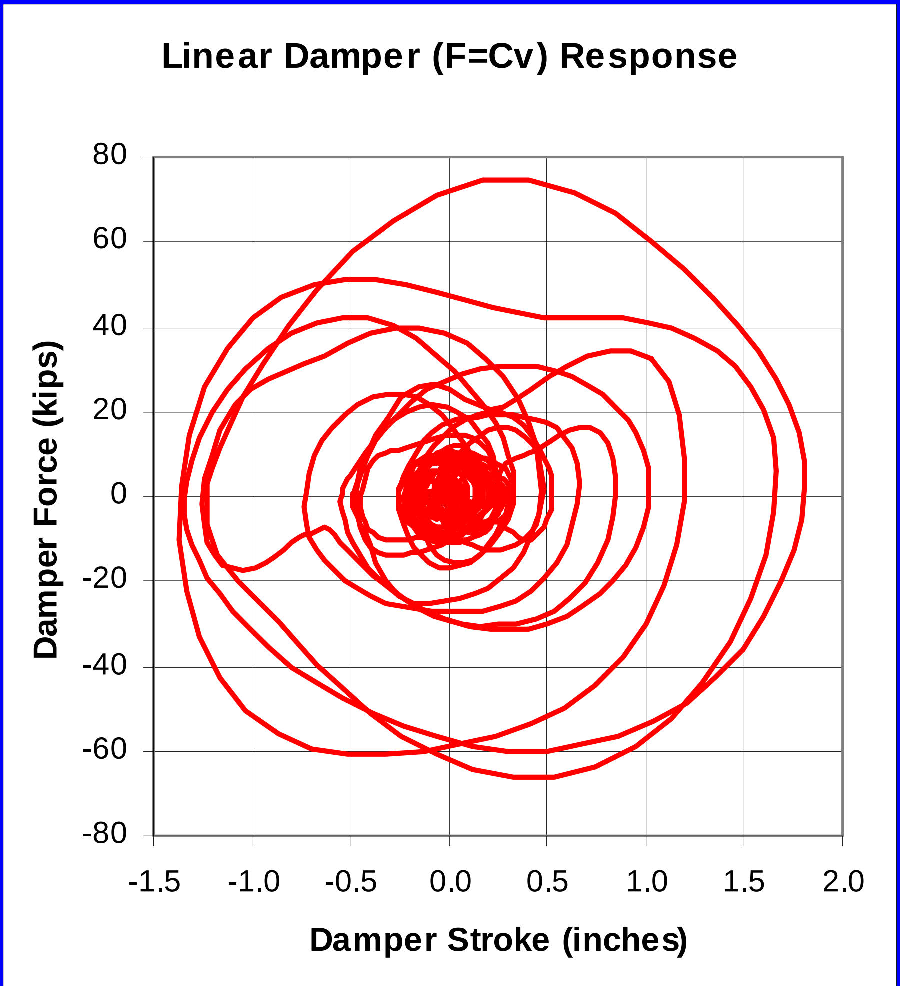
Comparison of Idealized Hysteresis Loops

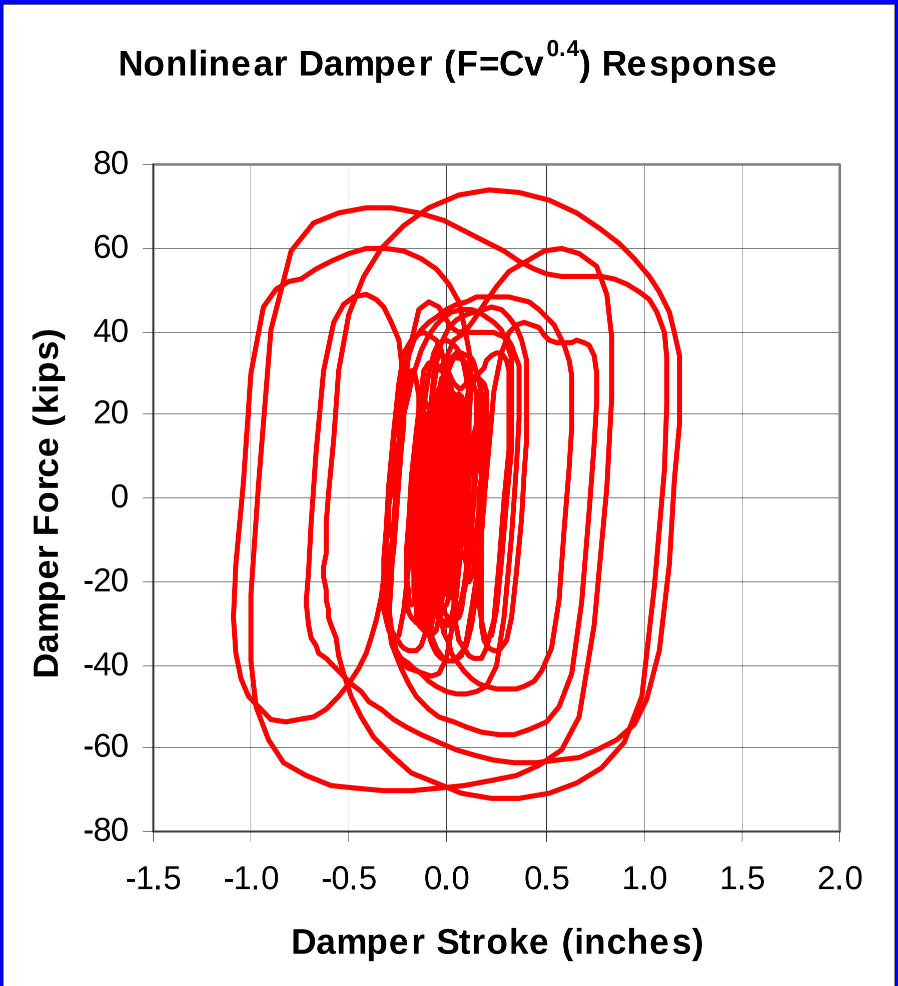


Comparison of System Response for Equal Damper Force



Comparison of Damper EQ Loops

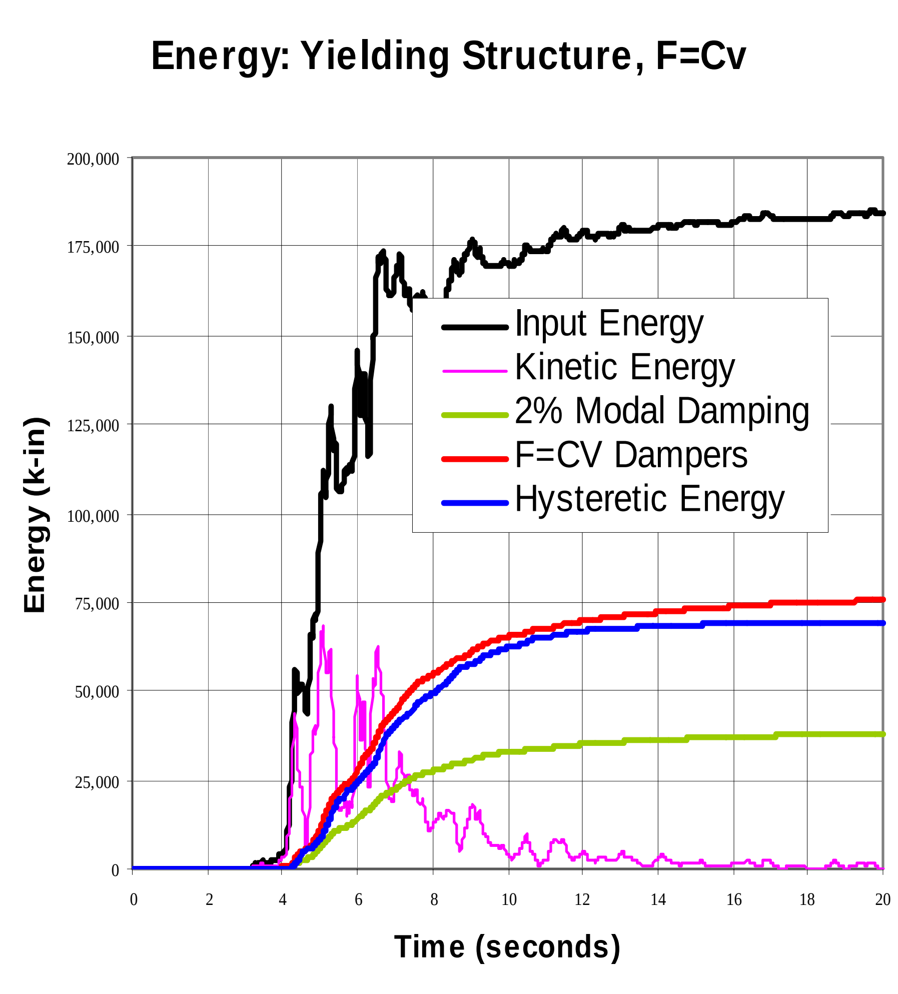


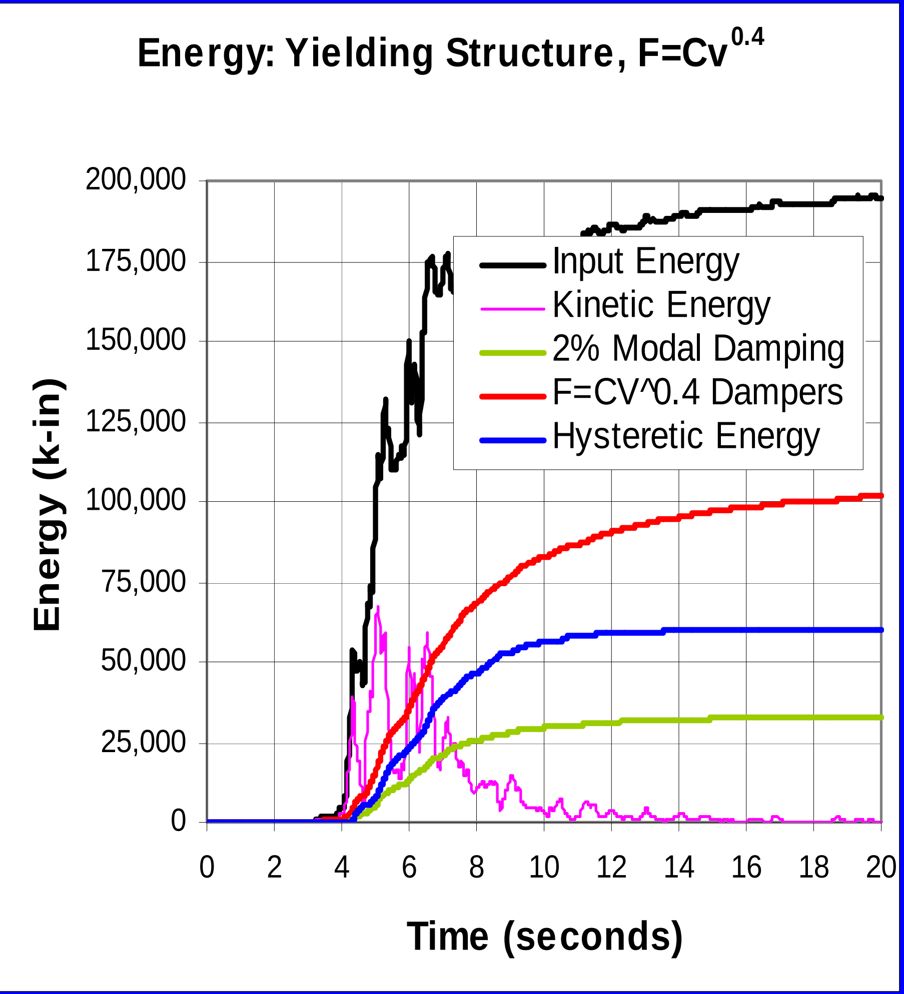


Response of SDOF Inelastic Systems

- For the same amount of added device damping
  - energy dissipation in an inelastic structure effectively increases the "starting" damping
  - response reduction is less than in an elastic system
  - difference is a function of the yield level and strain hardening properties of the yielding system
- For 10% damping from F=Cv devices:
  - about 35% response reduction in an elastic system
  - about 25% response reduction in an inelastic system where beams yield at approximately 15% of the elastic demand, with beam hinge strain hardening of 3%.

Energy Balance Comparison



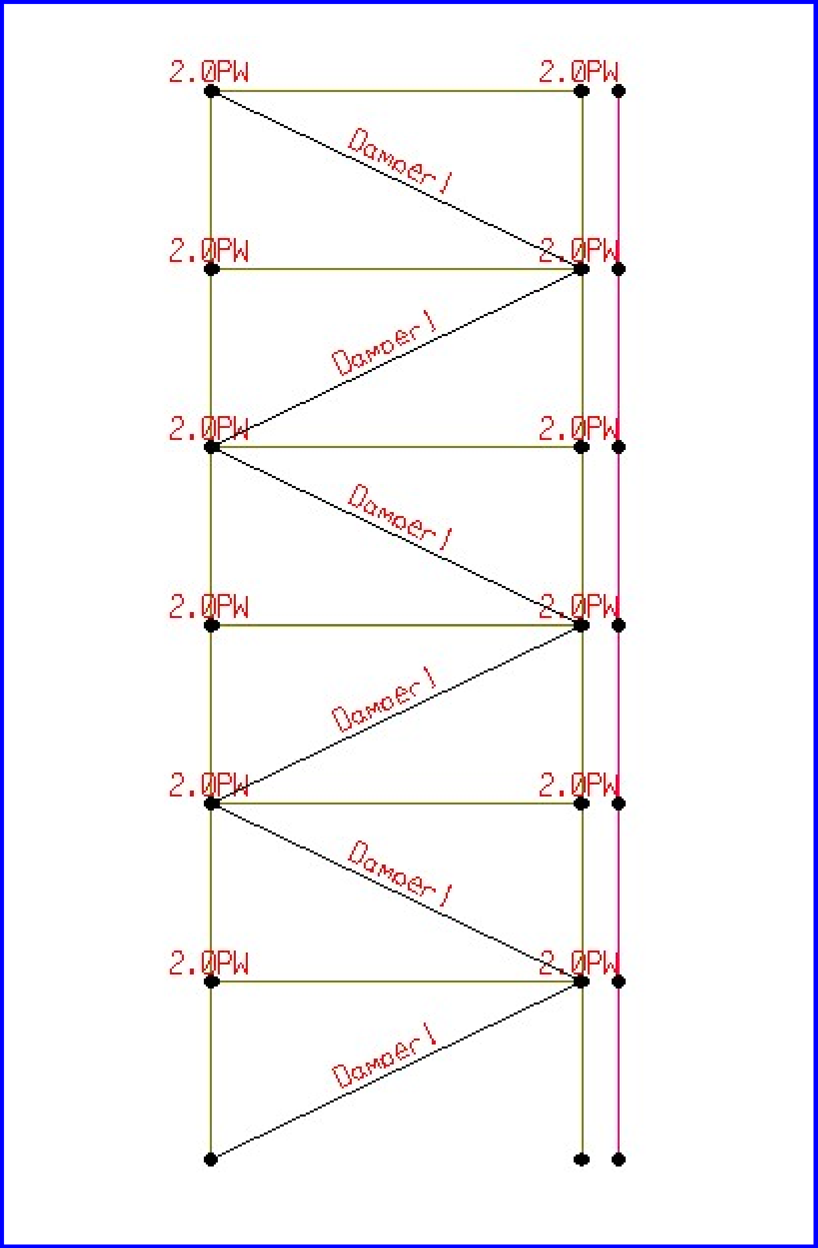


Six Story Inelastic Frame

- Elastic period is 2.0 seconds
- 70% mass in mode 1; 25% mass in mode 2
- Beam yielding at 20% of elastic demand
- Response without damping devices:

Story	Drift	Plastic θ
6	2.6%	1.8%
5	2.8%	2.0%
4	2.9%	2.1%
3	2.8%	2.2%
2	2.3%	1.9%
1	1.1%	1.2%

Six Story Inelastic Frame Model



Six Story Frame: Trial Dampers

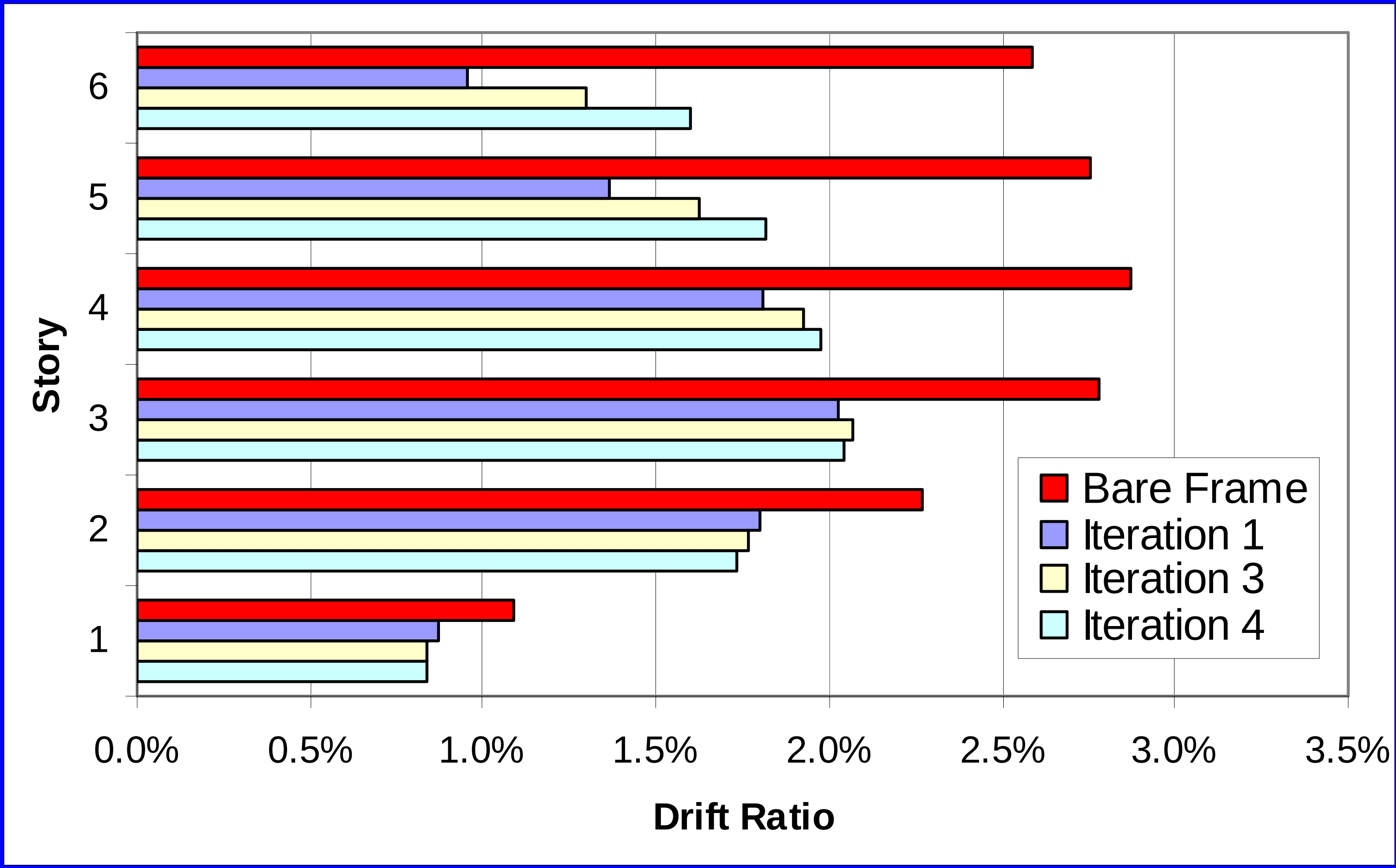
- **Performance goals:**
  - target maximum drift: 2.0%
  - target maximum hinge rotation: 1.5%
  - deformation reduction: approximately 30%
- **Use $F=Cv^{0.4}$ devices**
- **Use SDOF inelastic system results:**
  - for 30% deformation reduction, try $V_c / V_k = 0.2$
- **From six story bare frame, $v_1 = 10$ in/sec**
- **Compute $C = 12.5$ k-(s/in)$^{0.4}$, $F=12.5v^{0.4}$**
  - use this value at all floors for first iteration

Evolution of Damper Design

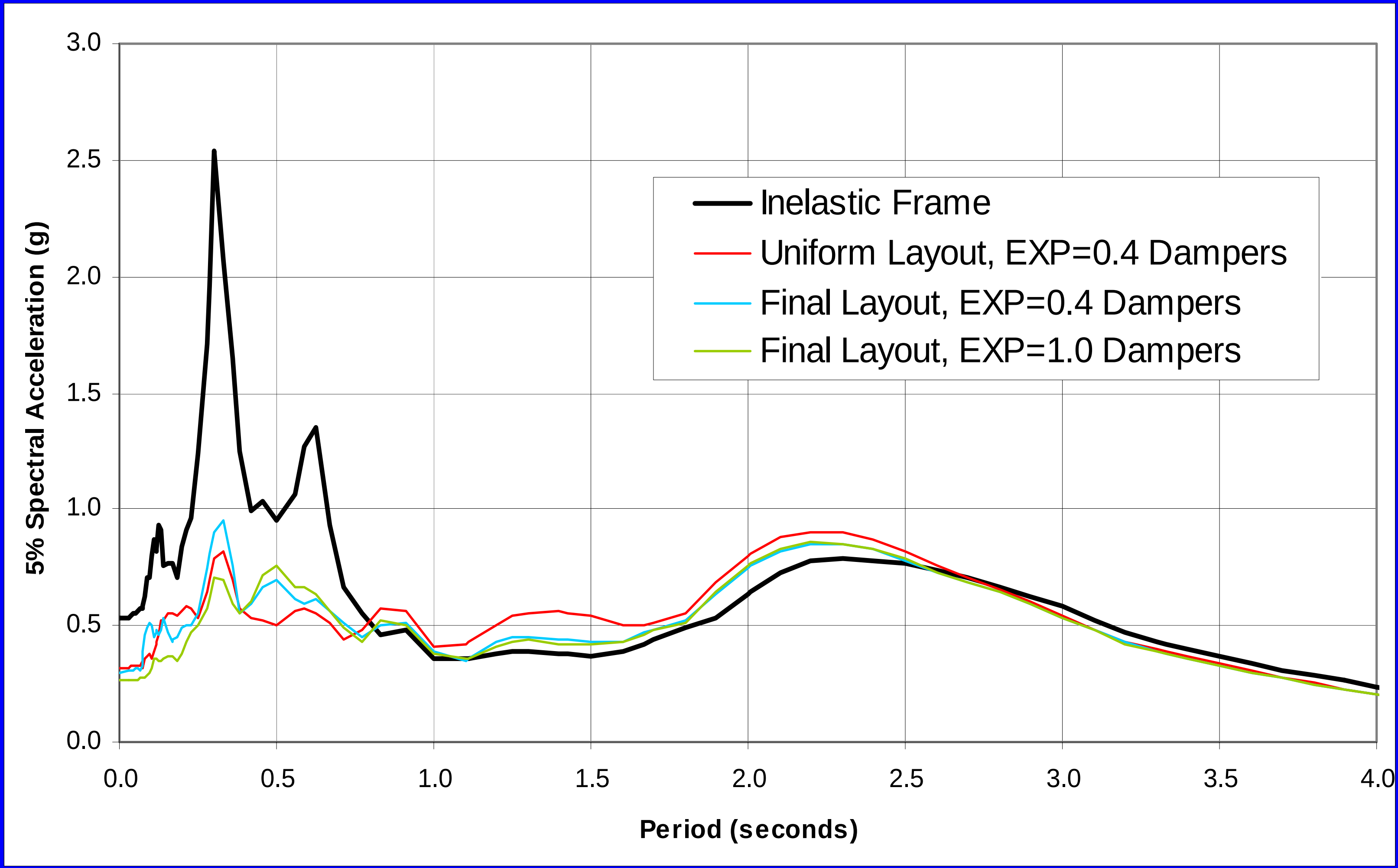
- Suite of 10 EQ motions runs in a few minutes
- Using computed response, update damper C and layout
  - – iterate to achieve close to target performance at many floors
- Summary of damper C characteristics:

Story	Iteration 1	Iteration 4
6	12.5	no damper
5	12.5	no damper
4	12.5	7.5
3	12.5	15.0
2	12.5	15.0
1	12.5	15.0

Summary of Frame Drift Response



In-Structure Motions: Fourth Floor Spectra



Concluding Remarks

• **Preliminary sizing of a supplemental damper system to achieve target performance can be readily achieved by:**

- **understanding the behavior of very simple systems incorporating explicit damping devices**
- **recognizing that a very powerful analysis tool exists on many desk tops**
- **iterating towards optimization using computer analysis**

• **The iterative process converges quickly**

• **In the region of a solution, structural response is only weakly sensitive to changes in the damping system**