COSMOS Annual Meeting

Example of Current Code Procedure Applied to Ground Motion Scaling at a Northern California Site

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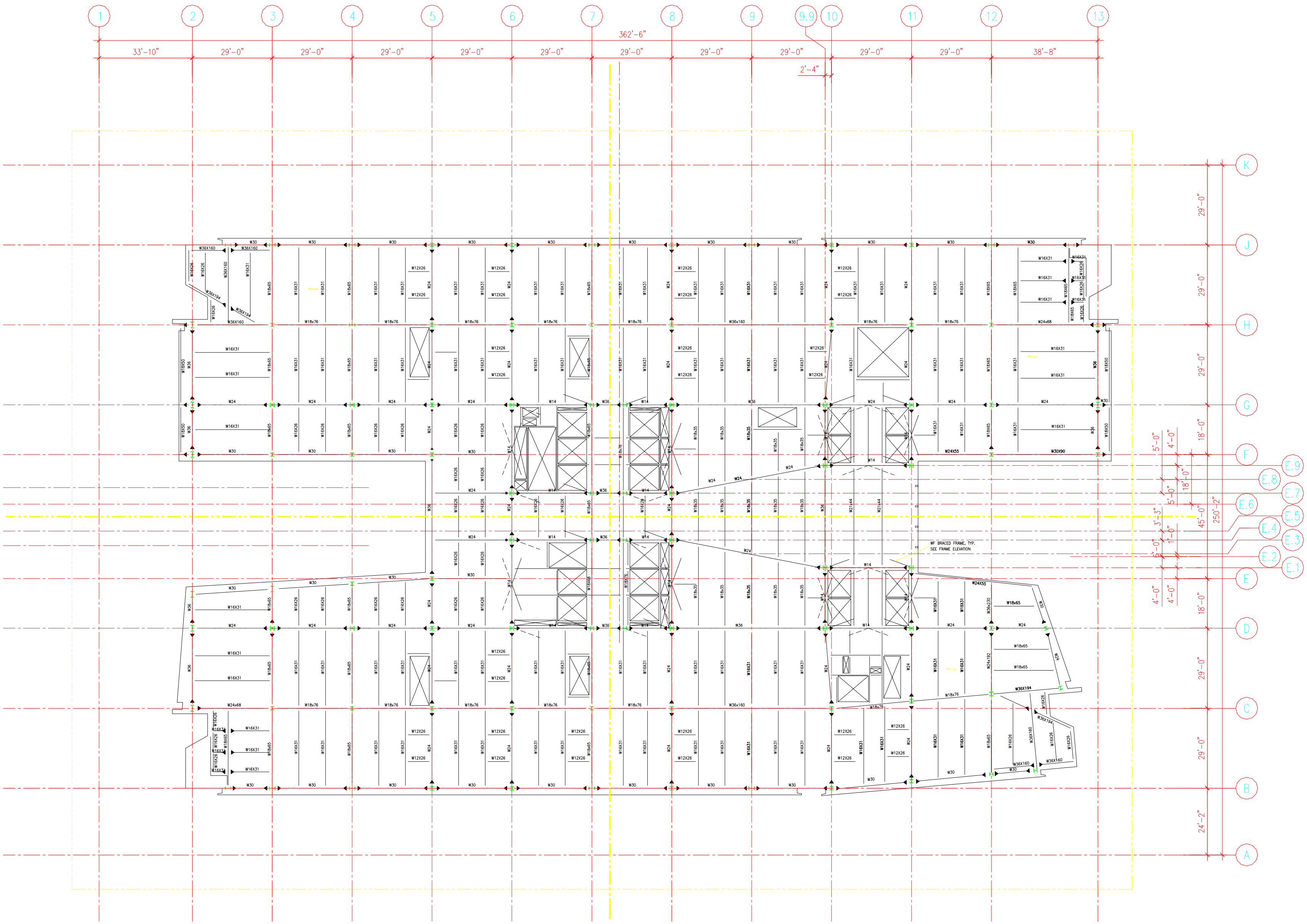
Outline

> Project Summary
> Seismic Hazard
> California Building Code Ground Motion Scaling Requirements (Appendix Chapter 16A)
> Site Specific Response Spectra
> Time History Scaling Procedures
> Directivity & Problem Areas
> Soil Structure Interaction
> Observations
> Close

Project Summary

- New seismically isolated hospital to be located in downtown San Francisco
- 22 stories, 350 feet
- approximately 1.5M square-feet
- Dual system - braced frames in the cores, with outrigger braced frames at mechanical levels and a moment frame system at the building perimeter.
- Sloping site, two stories.
- Five below grade levels with mat foundation.
- Split-level base isolation system at 1st Floor, 3rd floor and at foundation mat

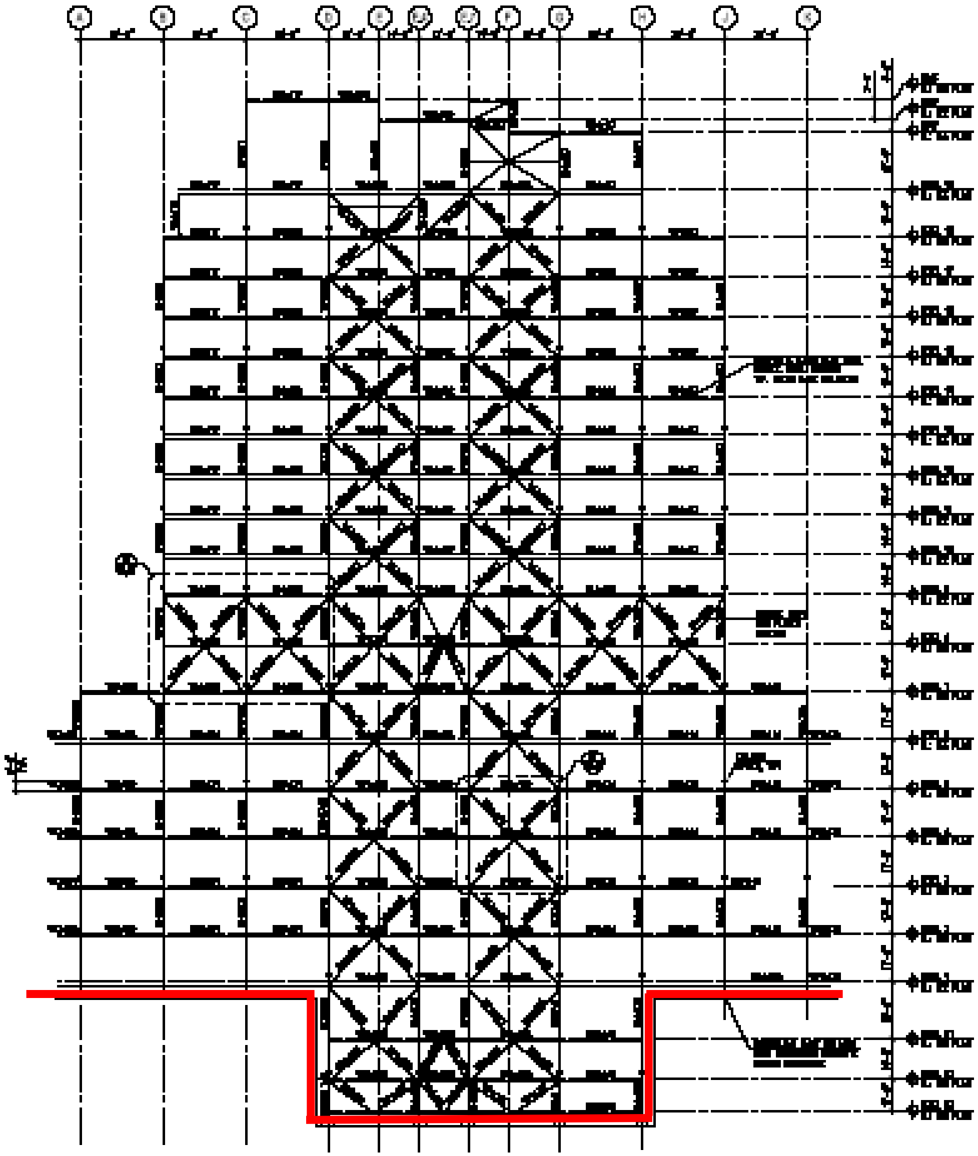


Typical Tower Plan


1
2
3
4
5
6
7
8
9
9.9
10
11
12
13
362'-6"
33'-10"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
29'-0"
38'-8"
2'-4"
K
J
H
G
F
E.9
E.8
E.7
E.6
E.5
E.4
E.3
E.2
E.1
E
D
C
B
A
250'-2"
29'-0"
29'-0"
29'-0"
18'-0"
45'-0"
18'-0"
29'-0"
29'-0"
24'-2"

Level 5 Plan

Line 8 Elevation



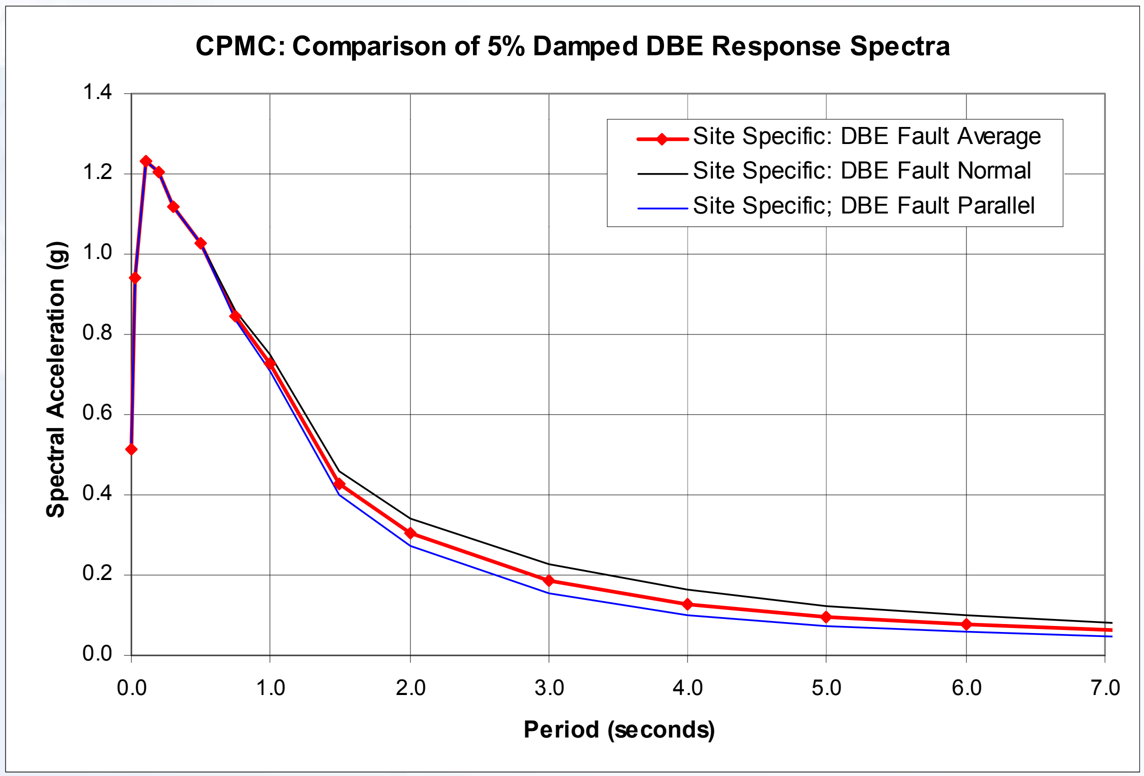
Line D Elevation

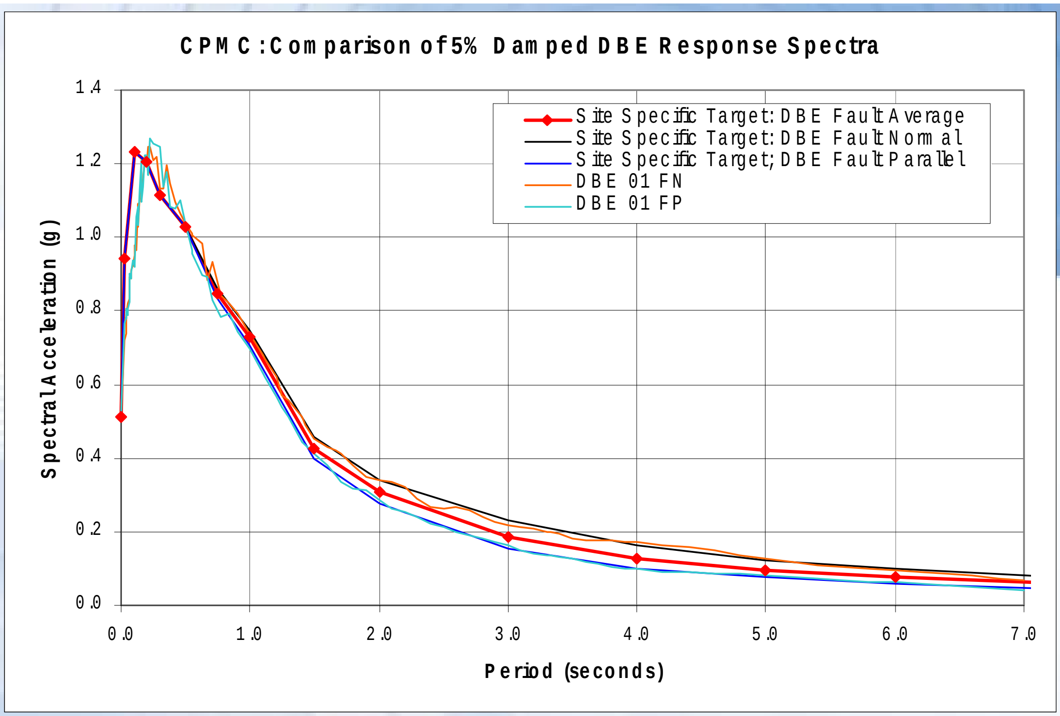
Geotechnical /Geohazard Report

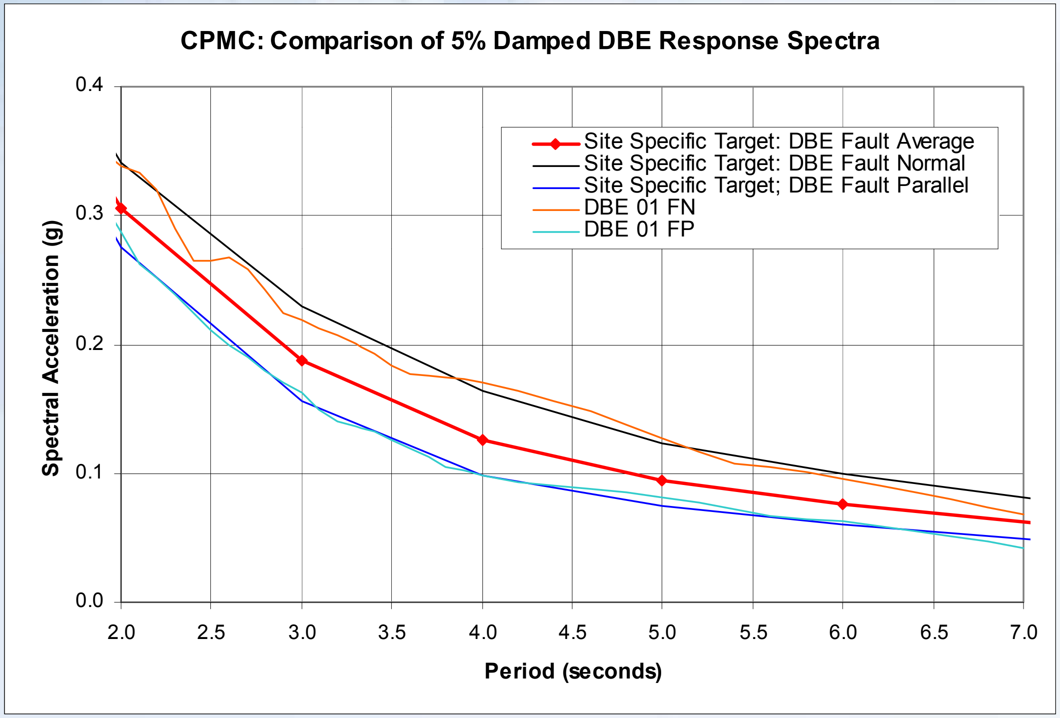
- Seismic Hazard Evaluation performed by Treadwell and Rollo.
- Free field ground motions. No cap.
- Peer Review team accepted ground motions
- Ground motions reviewed and approved by CGS

TABLE 2
Time Histories for Scaling

Earthquake	Magnitude	Time History	Directions of Recorded Components	Epicentral Distance (km)	Closest Distance to Rupture (km)
Imperial Valley	6.6	Differential Array	270 deg., 360 deg.	26	5
Loma Prieta	6.9	Los Gatos PC	0 deg., 90 deg.	23	6
Erzincan	6.9	Erzincan	NS, EW	15	2
Landers	7.4	Yermo	270 deg., 360 deg.	84	25
Landers	7.4	Joshua Tree	0 deg., 90 deg.	15	15
Kocaeli	7.4	Duzce	180 deg., 270 deg.	90	13
Kocaeli	7.4	Gebze	0 deg., 270 deg.	50	14







CPMC Ground Motions – Record Pair #1

CBC: Site Specific Response Spectra Requirements

1659A.4 Ground Motion.

1659A.4.1 Design spectra. Properly substantiated, site-specific spectra are required for design of all structures.

A design spectrum shall be constructed for the design-basis earthquake. This design spectrum shall not be taken as less than the response spectrum given in Figure 16A-3 of Chapter 16, Division III, where the values of C_a shall be taken as equal to C_{AD} and C_v shall be taken as equal to C_{VD}.

> **EXCEPTION:** If a site-specific spectrum is calculated for the design-basis earthquake, then the design spectrum may be taken as less than 100 percent, but not less than 80 percent of the response spectrum given in Figure 16A-3 of Chapter 16, Division III, where the values of C_a shall be taken as equal to C_{AD} and C_v shall be taken as equal to C_{VD}.

A design spectrum shall be constructed for the maximum capable earthquake. This spectrum shall not be taken as less than the spectrum given in Figure 16A-3 of Chapter 16, Division III where the values of C_a shall be taken as equal to C_{AM} and C_v shall be taken as equal to C_{VM}. This spectrum shall be used to determine the total maximum displacement and overturning forces for design and testing of the isolation system.

> **EXCEPTION:** If a site-specific spectrum is calculated for the maximum capable earthquake, then the design spectrum may be taken as less than 100 percent, but not less than 80 percent of the response spectrum given in Figure 16A-3 of Chapter 16, Division III, where the values of C_a shall be taken as equal to C_{AM} and C_v shall be taken as equal to C_{VM}.

CBC: Time History Scaling Requirements

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1659A.4.2 Time histories. Pairs of appropriate horizontal ground-motion time-history components shall be selected and scaled from not less than three recorded events. Appropriate time histories shall have magnitudes, fault distances and source mechanisms that are consistent with those that control the design-basis earthquake (or maximum capable earthquake). Where three appropriate recorded ground motion time history pairs are not available, appropriate simulated ground motion time history pairs may be used to make up the total number required. For each pair of horizontal ground-motion components, the square root sum of the squares (SRSS) of the 5 percent-damped spectrum of the scaled horizontal components shall be constructed. The motions shall be scaled such that the average value of the SRSS spectra does not fall below 1.3 times the 5 percent-damped spectrum of the design-basis earthquake (or maximum capable earthquake) by more than 10 percent for periods from $0.5T_D$ seconds to $1.25T_M$ seconds. *The SRSS of the time history components shall be equal to or greater than the 5 percent damped spectra at the isolated period T_I, either T_d or T_m.*

The duration of the time histories shall be consistent with the magnitude and source characteristics of the design-basis earthquake (or maximum capable earthquake).

Time histories developed for sites with a Near-Source Factor, N_a, greater than 1.0 shall incorporate near-source phenomena.

Typical Procedure

> Receive Site Specific Response Spectra

> Check 80% Minimum Requirements

> Receive Suite of Site Specific Ground Motions (Seven Pairs)

(1) Compute the SRSS spectrum for each record pair
(2) Compute the average response spectrum using the seven SRSS spectra
(3) Compute 1.3 x 0.9 x CBC design spectrum for the site
(4) Plot and check that (2) exceeds (3) at all computed period points over required period range (0.5Td to 1.25Tm)
(5) If not, calculate single amplitude scale factor for entire suite
(6) Perform process for DBE and MCE separately

> Set up analyses in computer model (No FN/FP)

(1) Run analyses with records applied at 0° and 90°, and then at 180° and 270° (both components reversed)
(2) Run analyses with records applied at 90° and 180°, and then at 270° and 0° (both components reversed)
(3) Envelope response quantities over each pair of analysis in (1) and (2) – giving fourteen combinations. Envelop used to ensure similar peak responses in each direction of loading.
(4) Compute average responses over the fourteen combinations

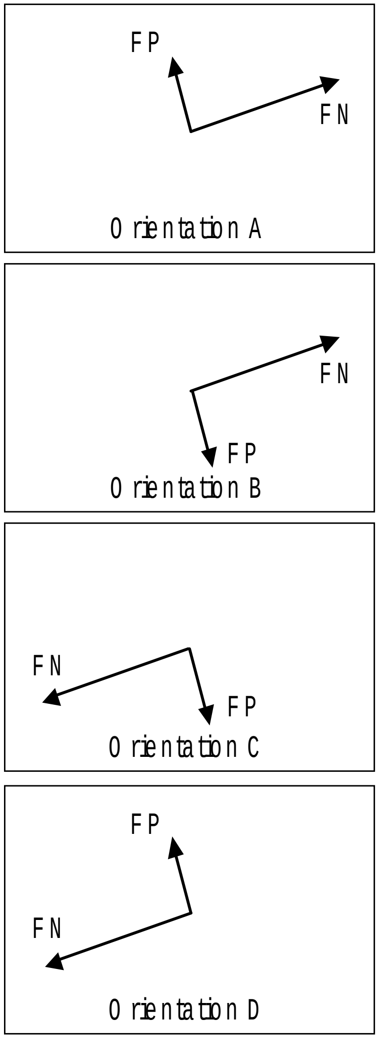
> Other direction options

(1) If average of spectra in each horizontal direction are similar, then may be able to skip (2) and compute response over average of seven combinations.
(2) May also elect, or may be required, to envelope over all four directional options in (1) and (2), then average over seven combinations.
(3) Can also average over 28 analyses.

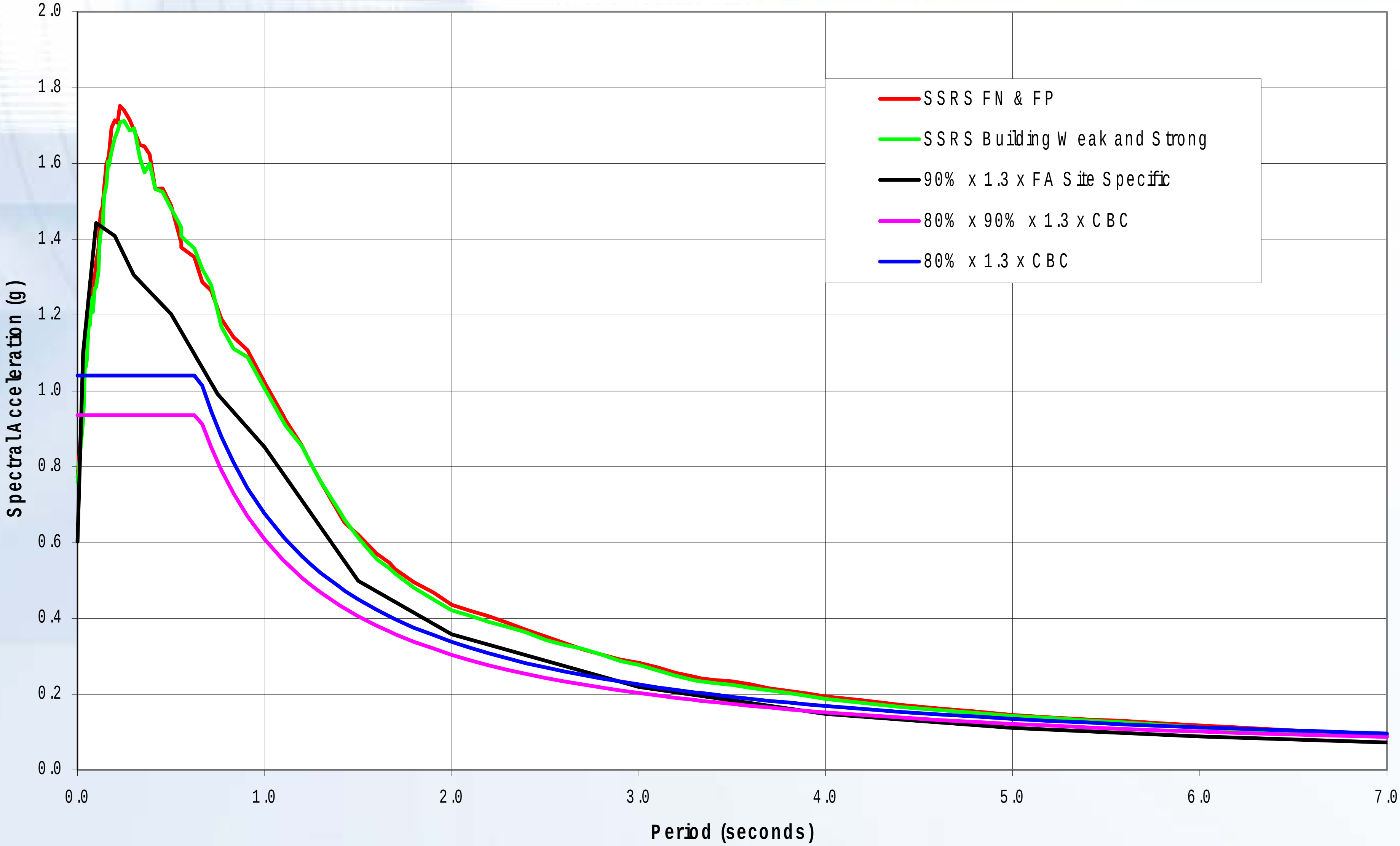
Time History Analysis

- Seven ground records with fault normal and parallel effects
- Rotate to match orientation of building to primary fault – San Andreas
- Rotate records for negative and positive

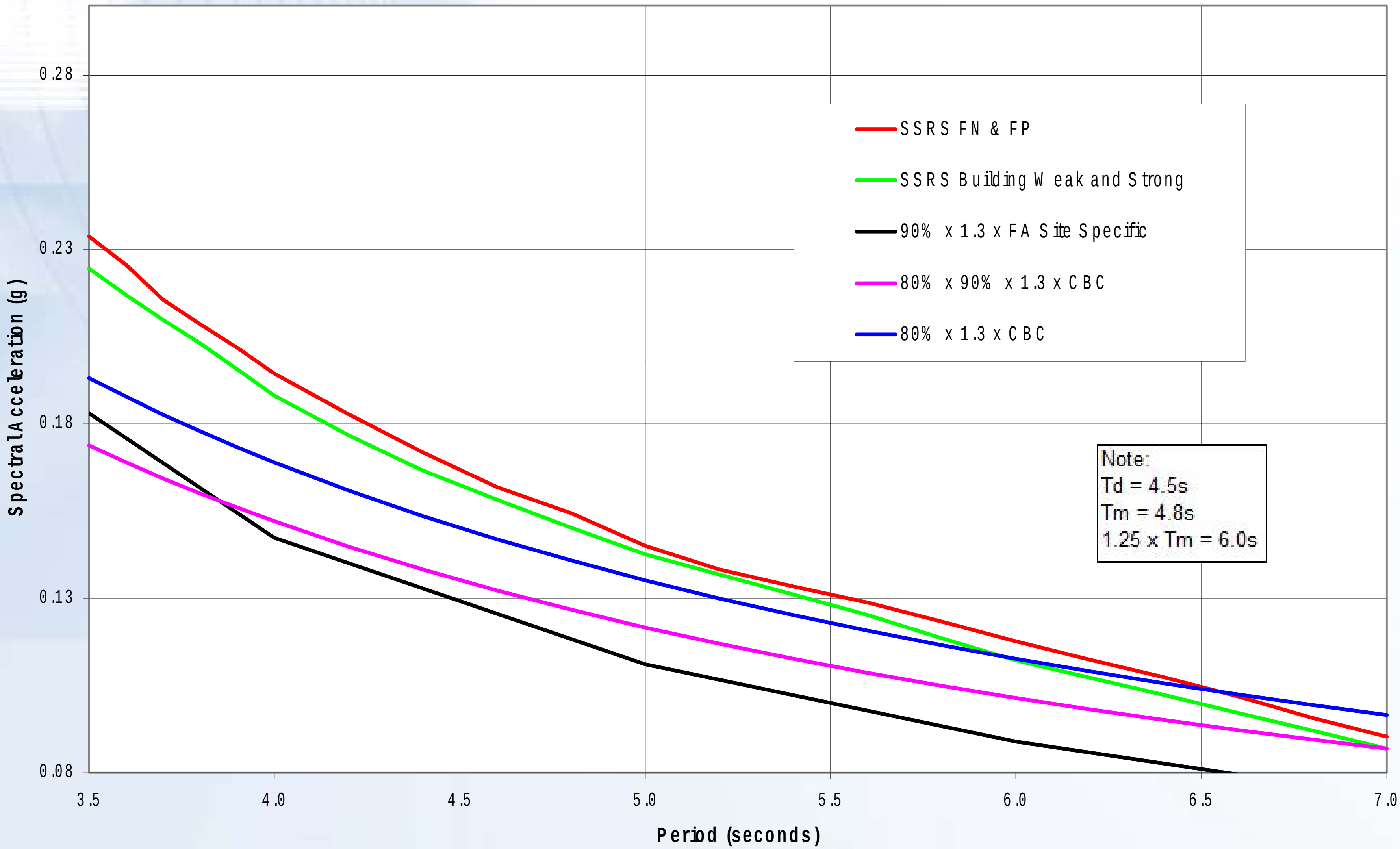
  4 x 7 = 28 DBE records,
  28 MCE records
- All design and testing parameters may be taken as the average of the maximum values from 28 records.



CPMC: Comparison of 5% Damped DBE Spectra



CPMC: Comparison of 5% Damped DBE Spectra



Problem Areas

- CBC out of step with latest mapped ground motions
  - CBC values higher in long period.
- Scaling parameter can be dependent on structural analysis
  - Scale over period range 0.5Td to 1.25Tm
  - Scale over period range 0.2T to 1.5T in fixed base structure (should be period dependent?).
- The 1.3 and 10% numbers vary by code document
  - 10% number intended to permit one part of spectra to “dip below” target spectrum.
  - Open to potential abuse if ground motions are frequency scaled.
  - The more spectral points you compute the worse off you generally are.
- Response spectrum usually performed using 100% and 30% in the two horizontal directions
  - Amounts to a 1.04 factor – a penalty for using time-history analysis.
- ASCE-7 appears to require the SRSS each record to be scaled independently
  - May result in the average SSRS spectra substantially exceeding the target spectra
- Minimum base shear scaling requirements often govern anyway

Directivity Complications

- Different spectra and records for fault normal and parallel
  - Receive fault normal, parallel and fault average spectra, and fault normal and fault parallel records.
- Ground motions components may need to be rotated to match axis of nearest fault
  - Either take components outside the analysis program, or apply at an angle inside the program
  - All code scaling requirements are checked along building axes, not ground motion axes
- Fault parallel may underestimate minimum code spectra (80%)
  - Interpret requirement to refer to fault average
- Time-history records compared to site specific spectra, not code
  - Site specific spectra not used for design
  - Two step process is confusing and unnecessary – can compare spectrum from time-history direct to code minimum spectra (80%)
- Cannot rotate both components 90°
  - This would apply the FP component in the FN direction
  - Elected to reverse sign on FP, then apply (-1) to both components
- Responses may be scaled up to satisfy minimum base shear
  - Use different scaling factors in each direction, for components so aligned – e.g. beams, braces.
  - Biaxially loaded columns get the larger scale factor since portion of demand due to earthquake in each direction cannot be separated out.

Soil Structure Interaction

> Purpose

Reduce amplification of input motion in low periods,
0 to 0.9 seconds

Introduce soil damping in low period response

Mitigates unrealistic response at certain isolator locations

> Methodology – FEMA 440 – Chapter 8

Flexibility of soil-foundation system – soil springs

Kinematic effects – applied at mat base with dampers

Foundation damping effects – applied at upper levels

> Preferred Procedure

Establish site specific response spectra

Check code compliance

Establish short period reduction factors and modify spectra

Scale ground motions to match response spectra

Spectra from time-history records will fall below code spectra

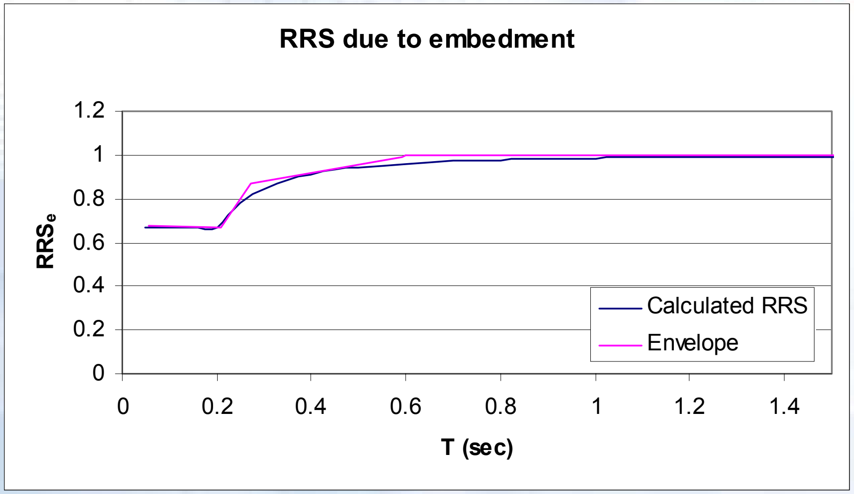
> Key Results

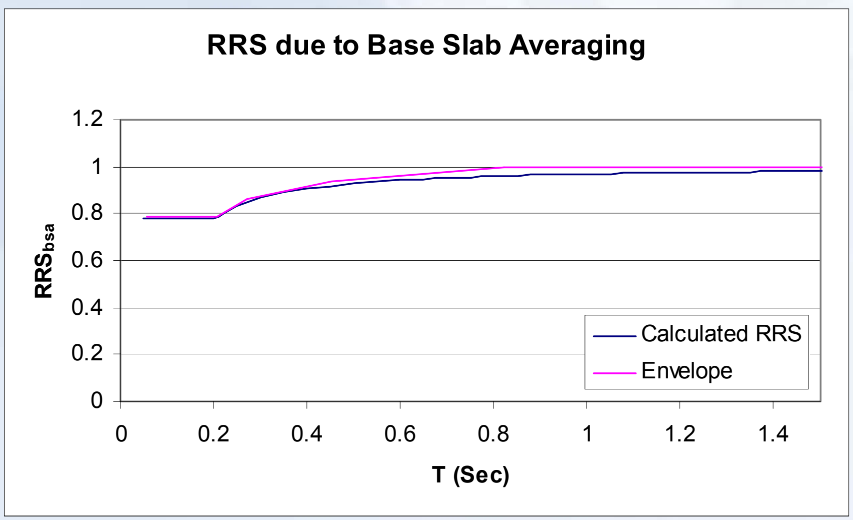
Reduces inertial forces in substructure

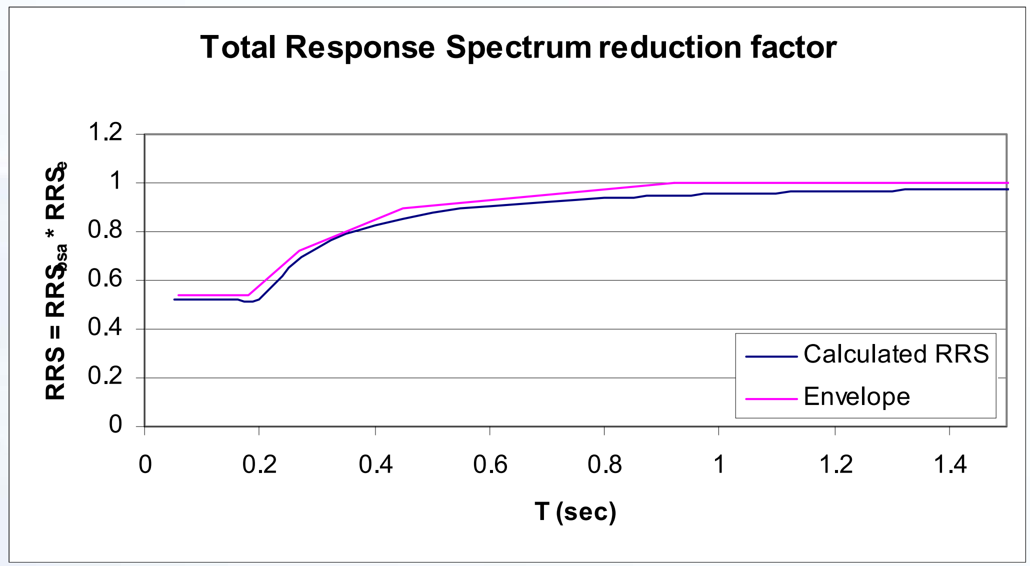
Does not affect superstructure forces, displacements

Reduces ground motion amplification at top of embedded substructure

Short Period Spectra Reduction







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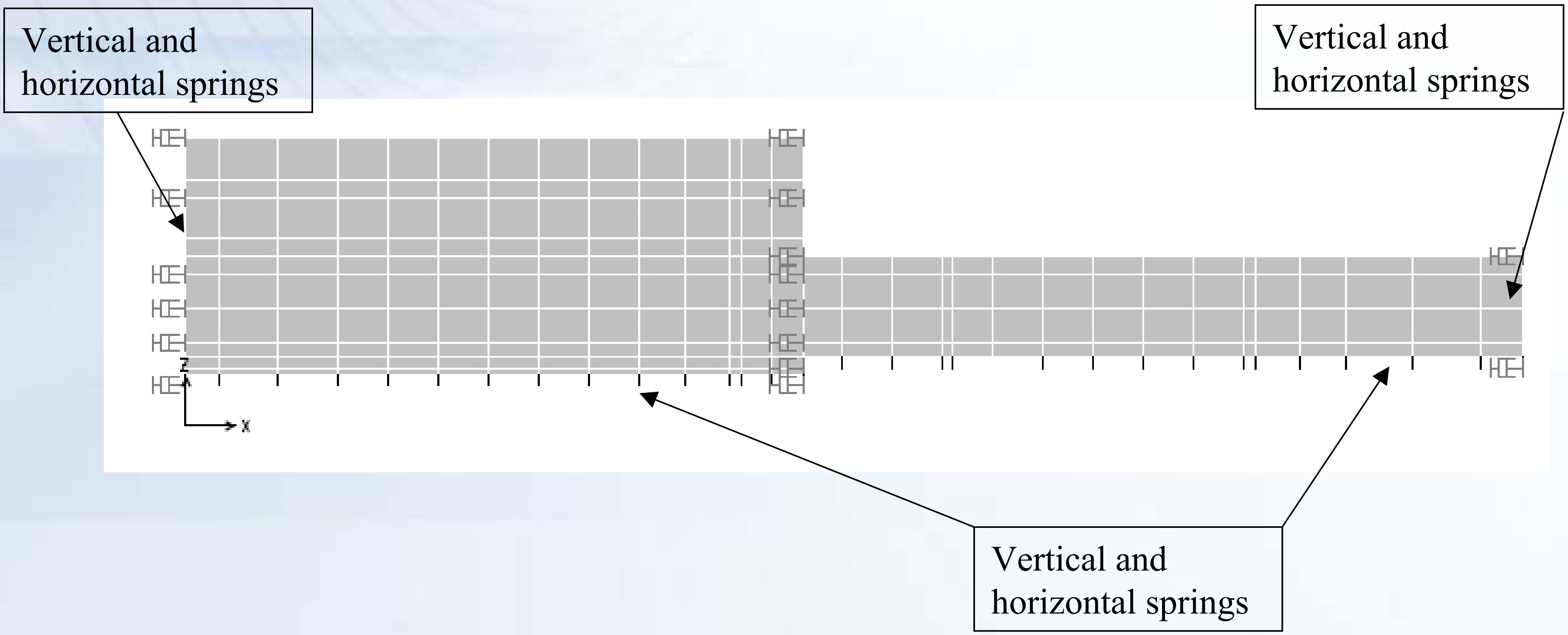
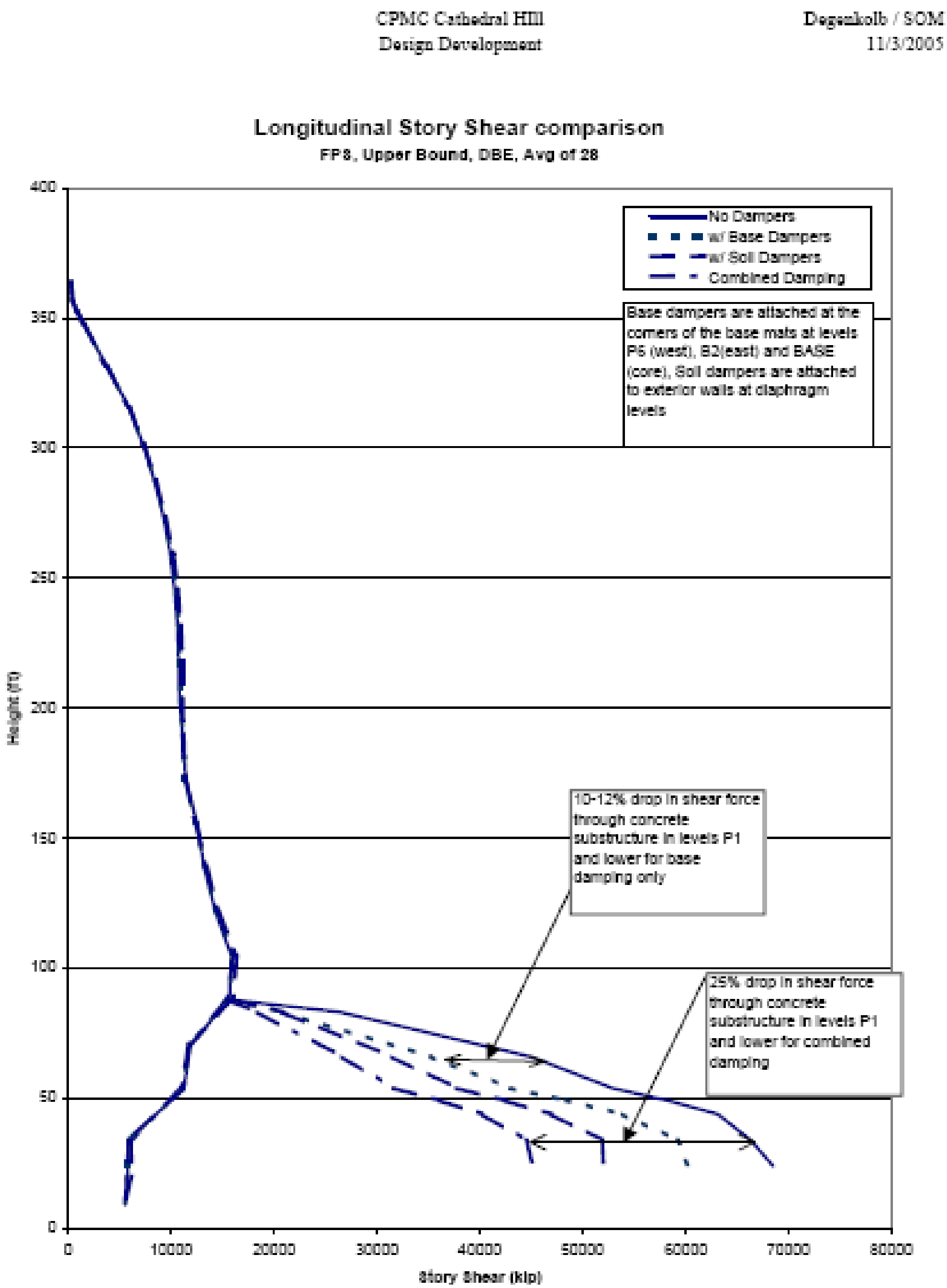
Substructure Spring and Damper Configuration



Story Shear Comparison - with and without dampers



Observations / Close

- Correct method of enveloping/averaging.
- How to address fault parallel / fault normal conditions
- Compare time-history direct to 80% minimums
  - Spectra from the time history records generally slightly exceed the site specific response spectra.
- Disconnect with response spectrum analysis requirements
- FEMA 440 Soil Structure Interaction
- Number of runs – seven versus three not a big deal
  - Seven record pairs x Four directions x Five mass eccentricities x Two (or more) seismic isolation systems x (2) Upper and lower bound isolator properties x (2) Upper and lower bound soil stiffness properties
  - = 1120 runs
- Capped versus Uncapped Response Spectra
- FEMA 351 Probabilistic Procedures – Appendix A
- Structural analysis programs all designed to compute mean response, not median.

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