General Assembly of
the Japan Association for Earthquake engineering

SEISMIC PERFORMANCE EVALUATIONS

Joseph Penzien

International Civil Engineering Consultants, Inc.

Berkeley, CA 94704

CEC

LECTURE TOPICS

- Technological developments
- Dual strategy of design
- Seismic design criteria
- Site-specific response spectra
- Design of time histories of ground motion
- Spectrum-compatible time histories
- Recorded time histories in near-field
- Multiple support time histories
- Performance evaluation
- Future improvements
- Aesthetics

Technological Advances (1950-2000)

- Digital Computers
- Numerical Methods
- Role of Inelastic Deformations
- Free-Field Ground Motions
- Design Detailing
- Modeling and Analysis
- Role of Statistical and Probabilistic Methods

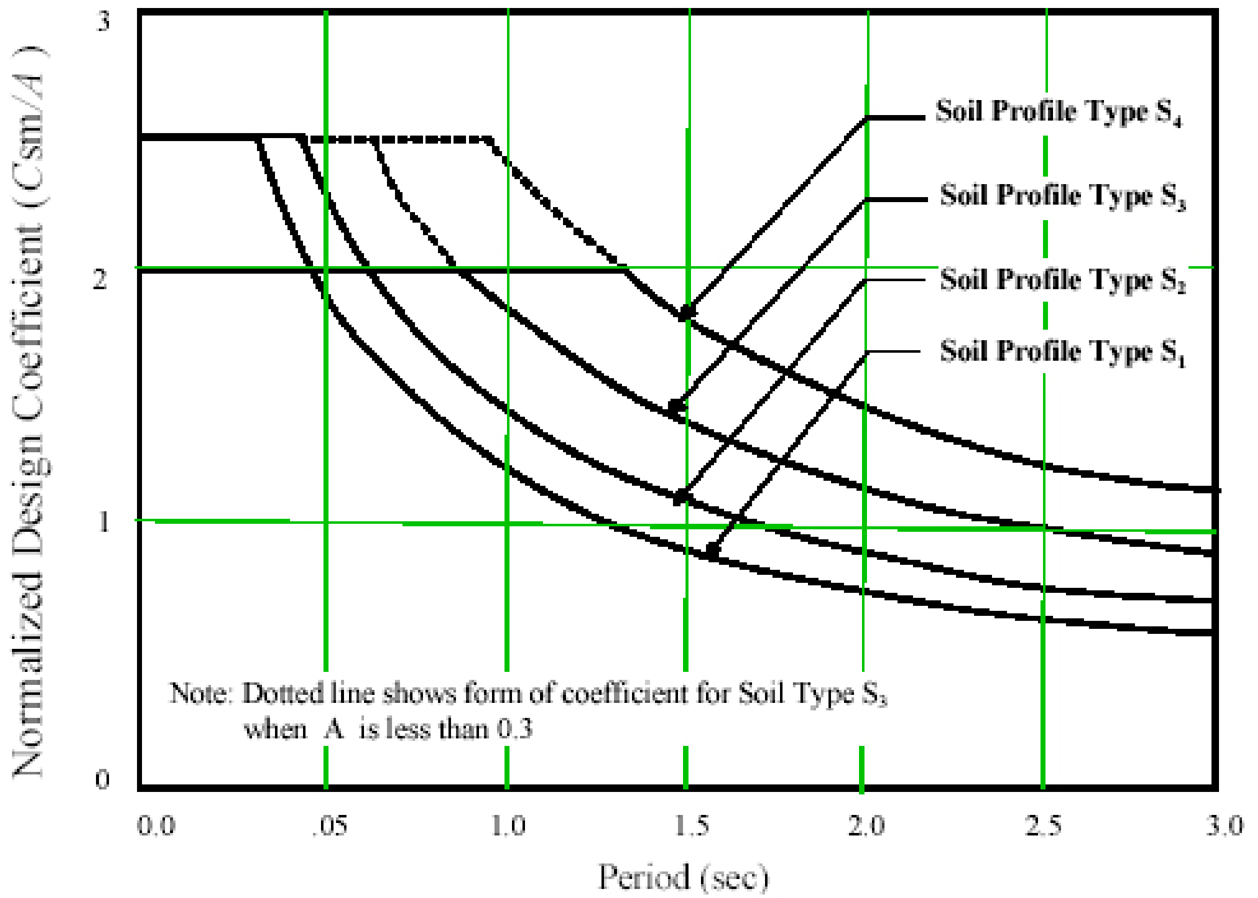
Dual Strategy of Design

- Functional Evaluation Earthquake (FEE)
  - High probability of occurrence during lifetime
  - Perform without significant damage
- Safety Evaluation Earthquake (SEE)
  - Most sever event
  - Significant structural damage, no collapse
- Classifications
  - Important
  - Essential
  - Critical (Lifeline)

SEISMIC DESIGN CRITERIA

1. **Design Ground Motions**
   - Response Spectra
   - Time Histories
2. **Structural Performance**
   - Global Response
   - Local Response

CODE RESPONSE SPECTRA



Seismic response coefficients for various soil profiles, normalized with respect to acceleration coefficient "A" (Source: AASHTO LRFD, 1994)

SITE-SPECIFIC "ROCK-OUTCROP" MCE RESPONSE SPECTRA

1. **Deterministic Approach**
   - Seismic sources
   - Upper-bound magnitudes
   - Source-to-site distances
   - "Rock-outcrop" attenuation relations (B/C)
     - Abrahamson and Silva (1997)
     - Boore et al. (1997)
     - Campbell (1997, 2000)
     - Sadigh et al. (1993, 1997)
     - Idriss (1991, 1994, 1995)

SITE-SPECIFIC "ROCK-OUTCROP" MCE RESPONSE-SPECTRA (Cont'd)

- Directivity effects
  - Somerville et al.
- Target design response spectra
  - Median
  - Median + 1σ

SITE-SPECIFIC "ROCK-OUTCROP" MCE RESPONSE-SPECTRA (Cont'd)

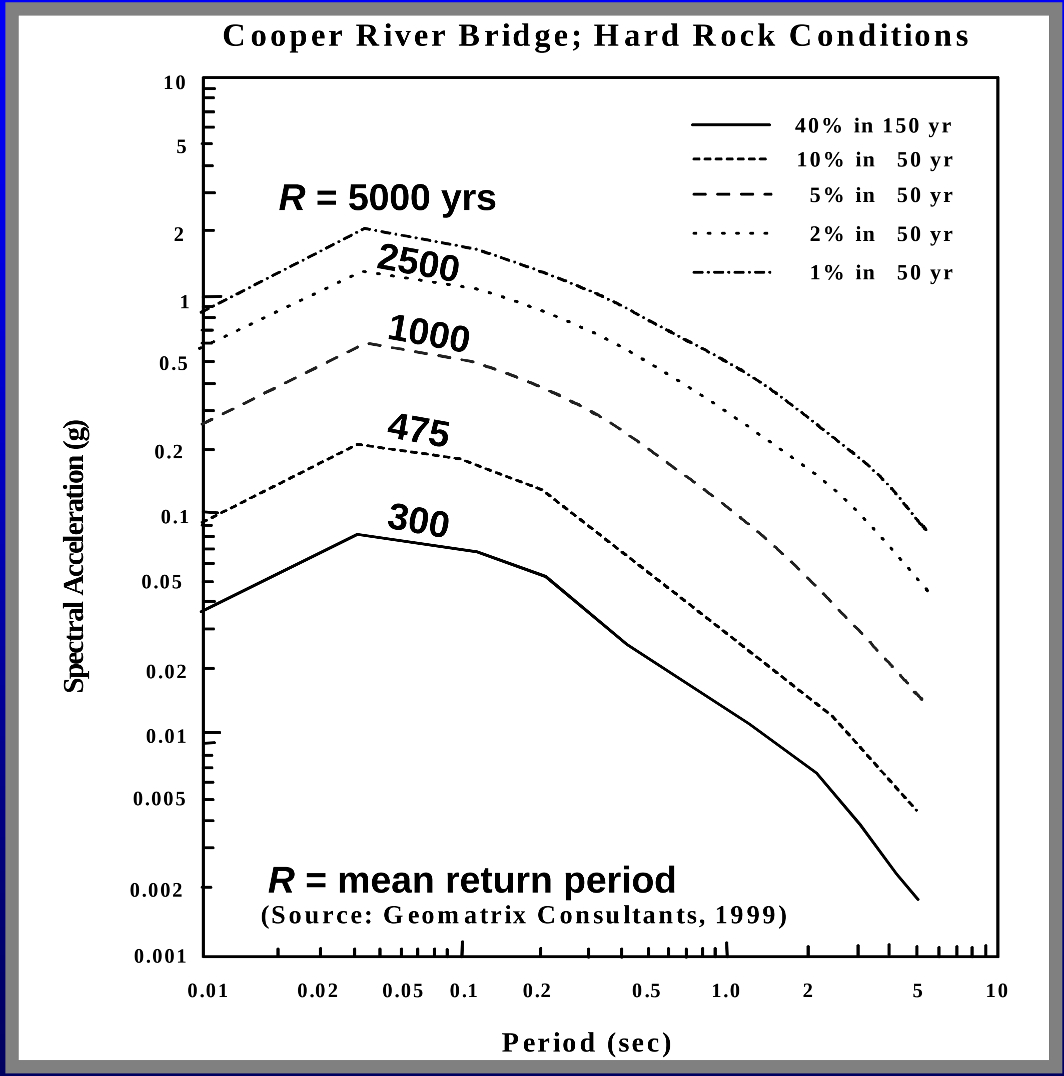
2. Probabilistic Approach (PSHA, SRA)

- Seismic sources
  - Fault specific
  - Areal sources
- Magnitude/recurrence relations
- Upper-bound magnitudes
- Source-to-site distances
- Attenuation relations (B/C)
  - Lognormal distribution
  - Median
  - Variance (σ^2)

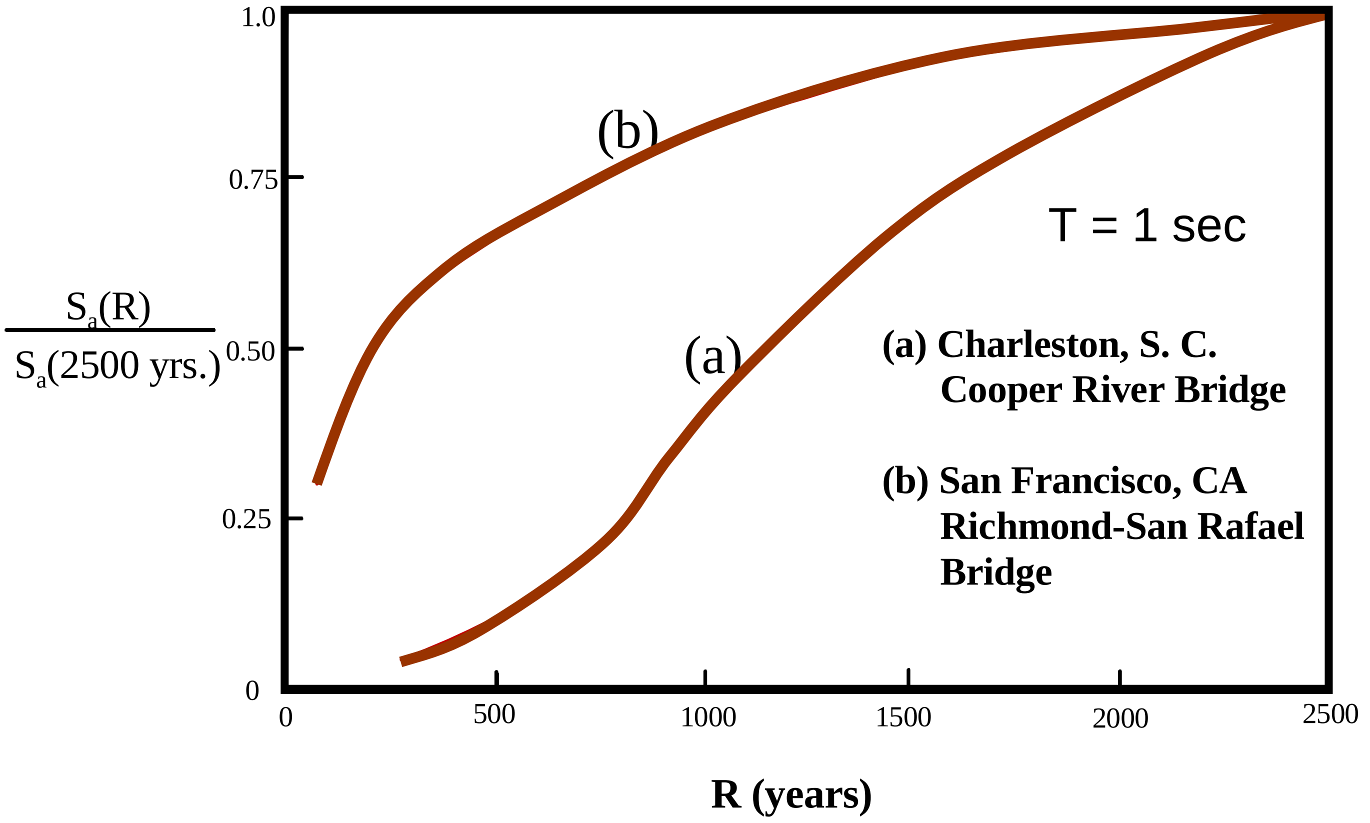
SITE-SPECIFIC "ROCK-OUTCROP" MCE RESPONSE-SPECTRA (Cont'd)

- Directivity effects
- Fault normal vs. fault parallel
- Uncertainties

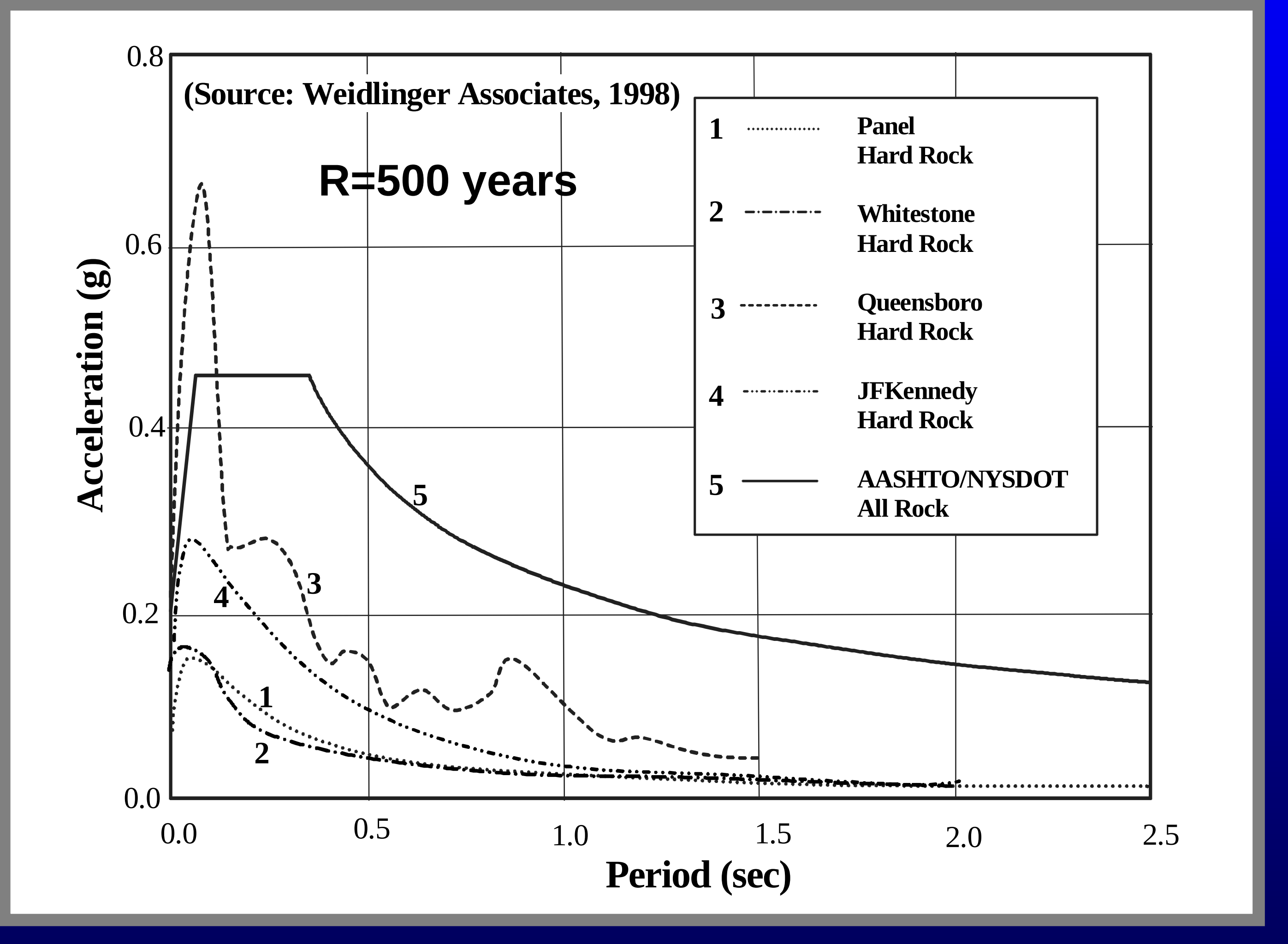
SITE-SPECIFIC RESPONSE SPECTRA BY PSHA



REGIONAL VARIATION OF PSHA RESPONSE SPECTRA



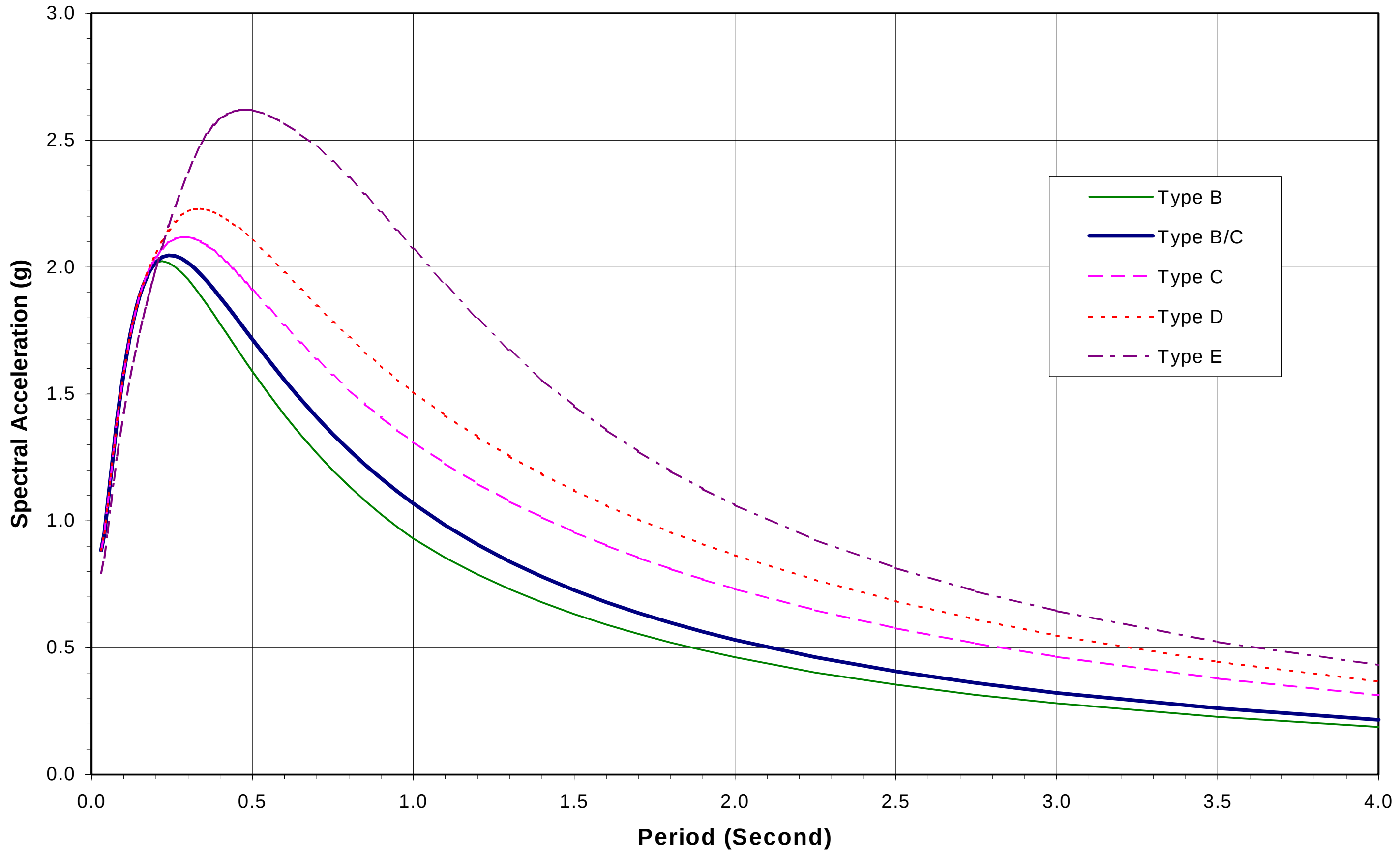
EPISTEMIC UNCERTAINTIES OF RESPONSE SPECTRA



SITE-SPECIFIC GROUND-SURFACE DESIGN SPECTRA

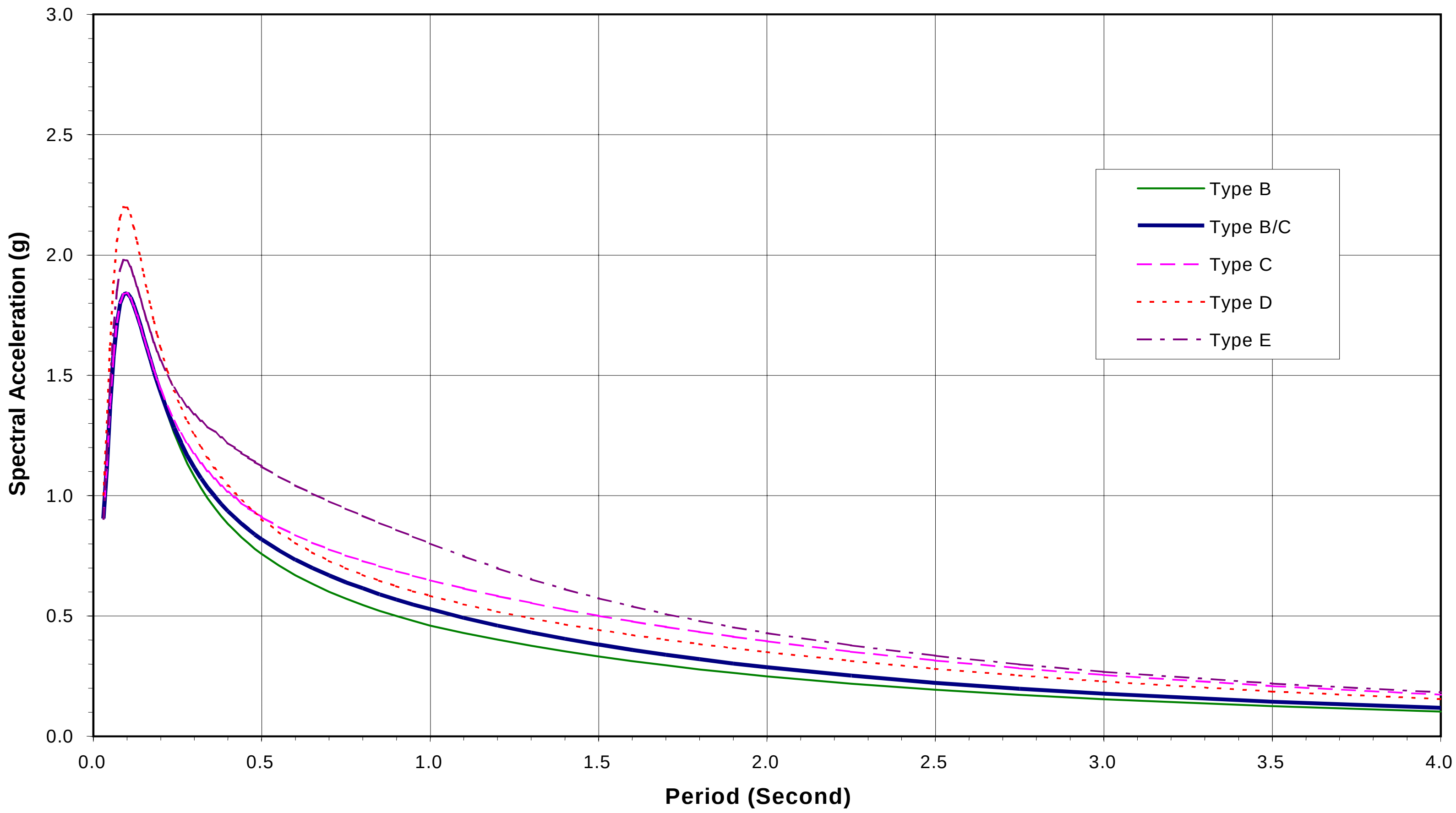
- Generate using soil attenuation relations directly
- Multiply “rock-outcrop” spectra by published site amplification factors
- Conduct site response analyses

Site-dependent Response Spectra
Horizontal



Site-dependent Response Spectra

Vertical



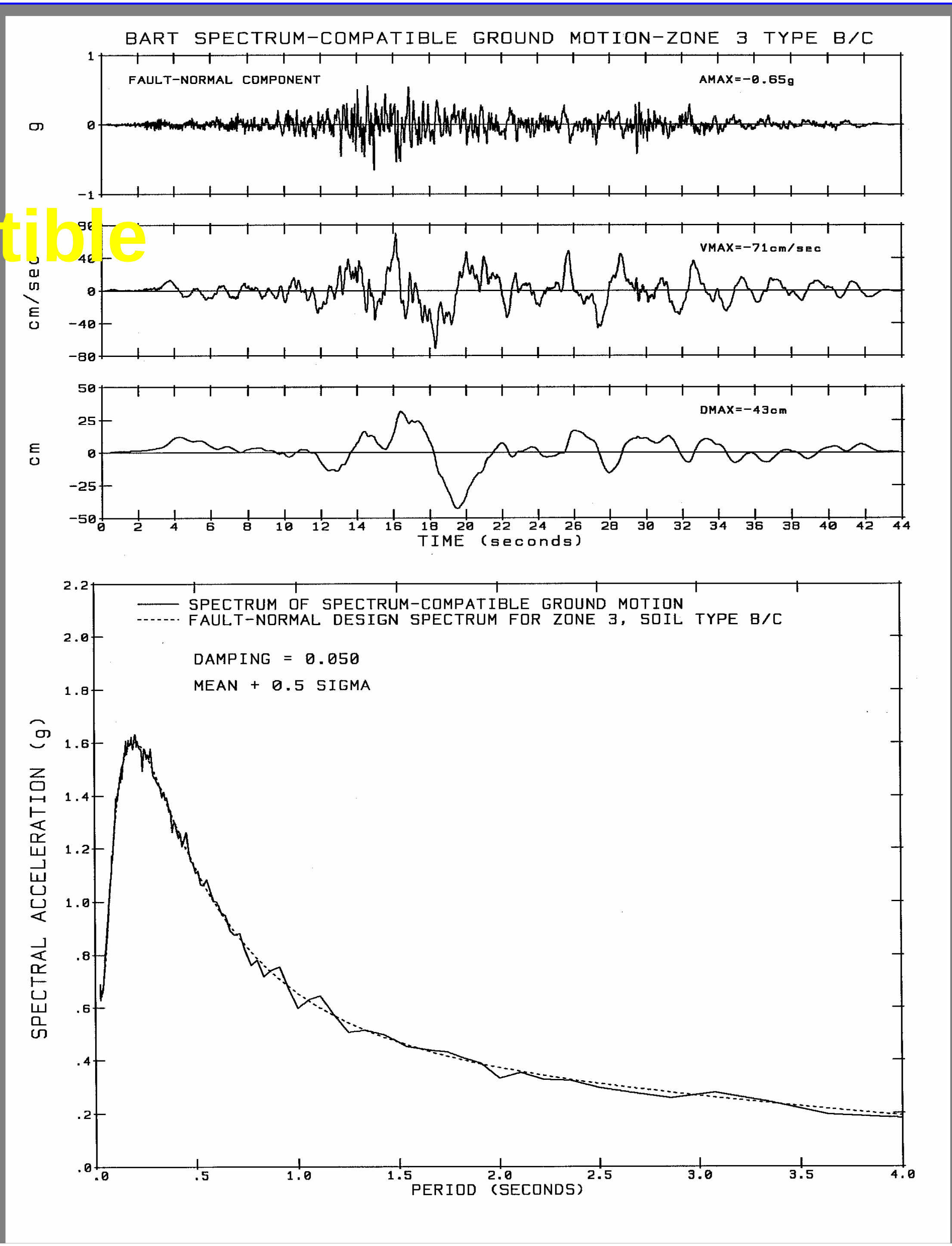
DESIGN TIME-HISTORIES OF GROUND MOTION

- Specify **SEE UHRS**; x, y, z
- Select recorded “rock-outcrop” motions
- Modify to be response-spectrum-compatible

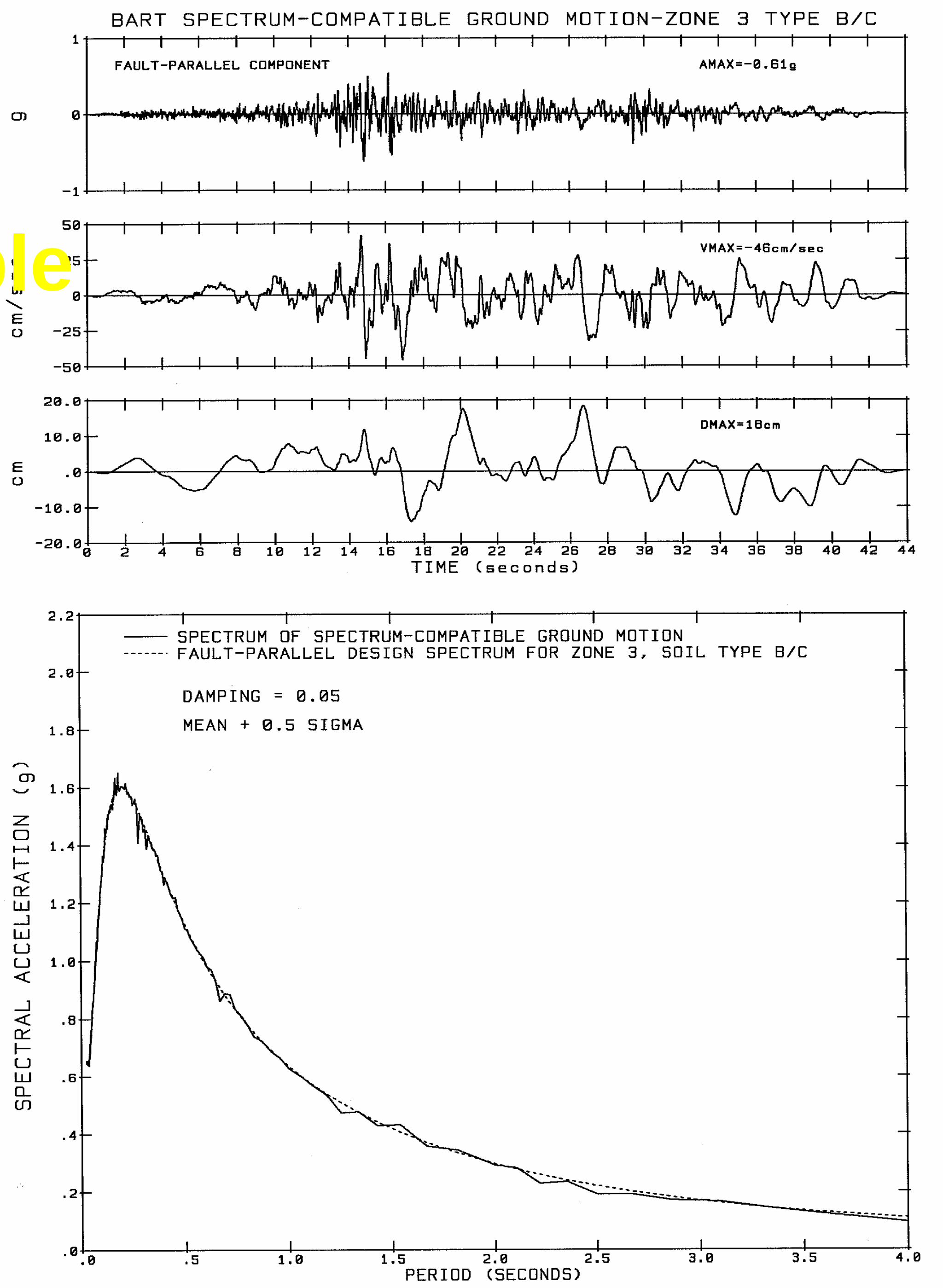
SPECTRUM-COMPATIBLE TIME HISTORIES

1. **Frequency Domain**
   - Modify amplitudes
   - Retain phase angles
2. **Time Domain**
   - Add local time-history adjustments at times of maximum response of oscillators of different frequencies
   - Calculate changes in acceleration response spectral values
   - Iterate to convergence

BART Design Spectrum-Compatible Motion



BART Design Spectrum-Compatible Motion

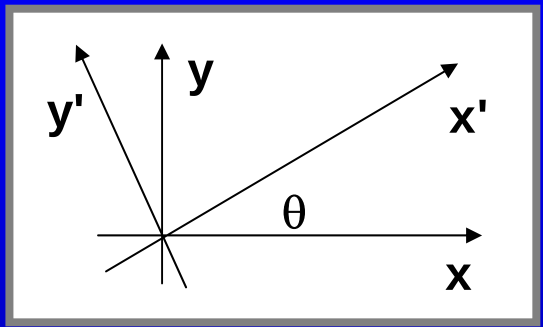


RECORDED TIME-HISTORIES IN NEAR FIELD

D < 10 km.

Recording Station	Earthquake
El Centro #6	Imperial Valley - 1979
Capitola	Loma Prieta - 1989
Joshua Tree	Landers - 1992
Yermo	Landers - 1992
Lucerne Valley	Landers - 1992

Transformation of 2-D Ground Motion



$$a_{x'}(t) = a_x(t)\cos\theta + a_y(t)\sin\theta$$

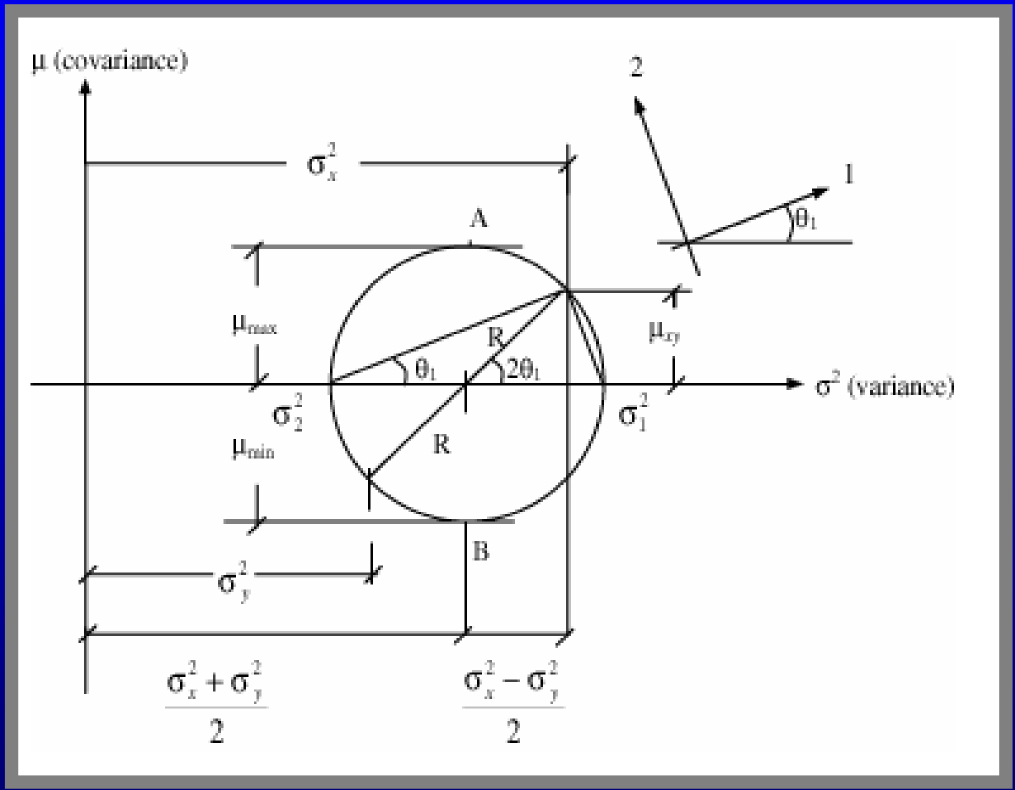
$$a_{y'}(t) = -a_x(t)\sin\theta + a_y(t)\cos\theta$$

$$\sigma_x{}^2 \equiv \frac{1}{t_d}\int_0^{t_d}\left[a_x(t) - \overline{a_x(t)}\right]^2 dt$$

$$\sigma_y{}^2 \equiv \frac{1}{t_d}\int_0^{t_d}\left[a_y(t) - \overline{a_y(t)}\right]^2 dt$$

$$\mu_{xy} \equiv \frac{1}{t_d}\int_0^{t_d}\left[a_x(t) - \bar{a}_x(t)\right]\left[a_y(t) - \bar{a}_y(t)\right]dt$$

Principal Components of Motion



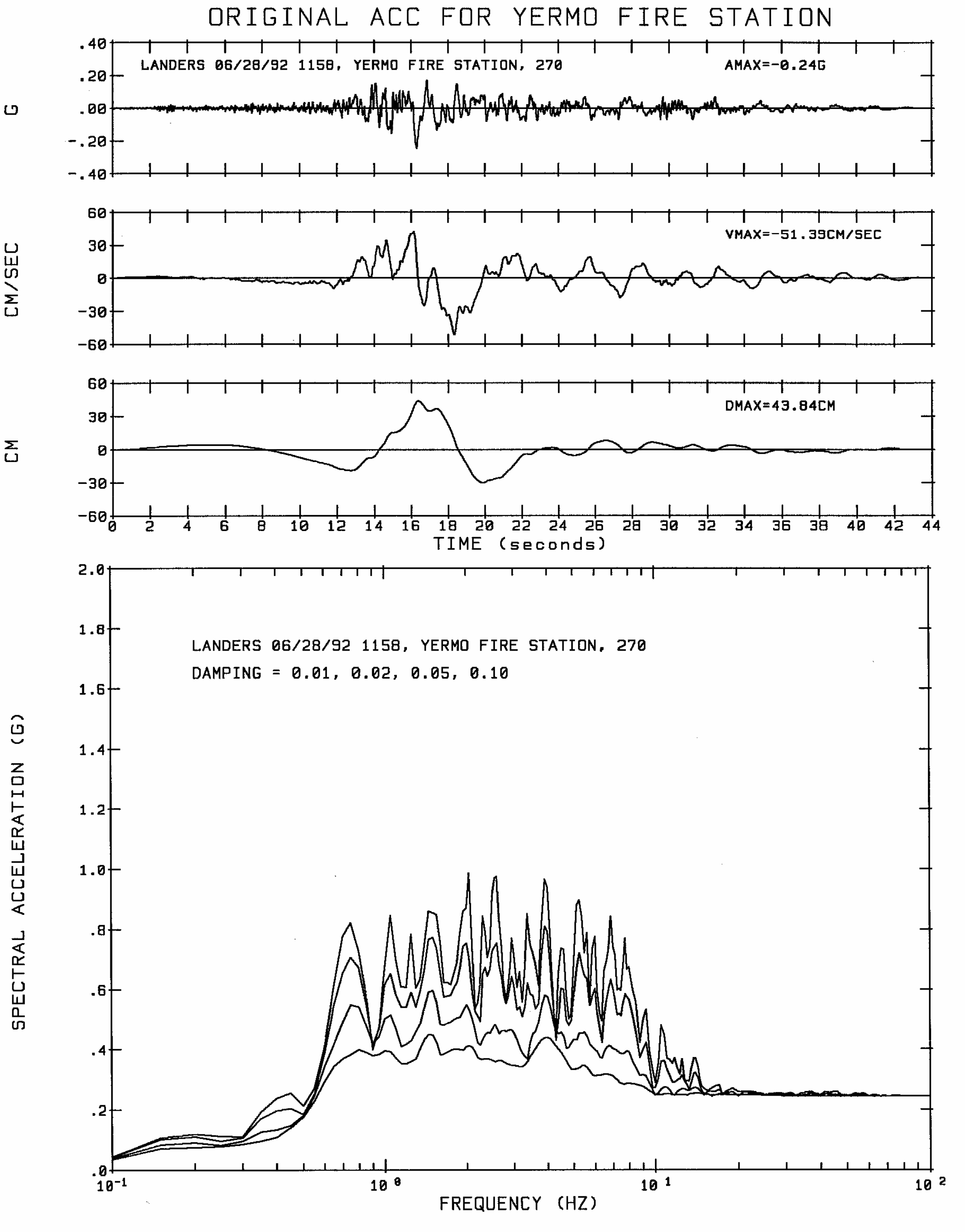
$$R = \left[\left(\frac{\sigma_x^2 - \sigma_y^2}{2}\right)^2 + \mu_{xy}^2\right]^{1/2}$$

$$\mu_{max} = \pm\left[\left(\frac{\sigma_x^2 - \sigma_y^2}{2}\right)^2 + \mu_{xy}^2\right]^{1/2}$$

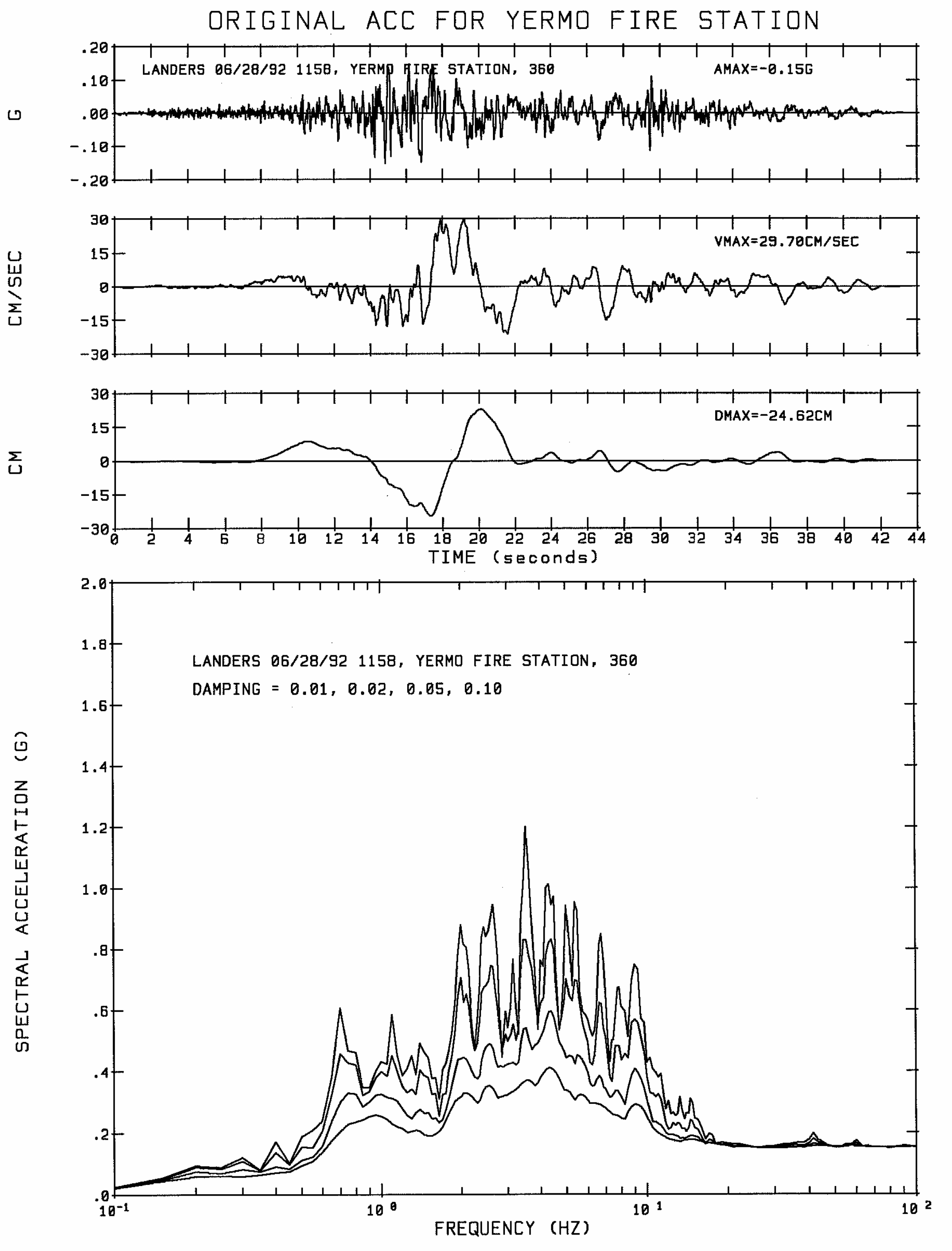
$$\sigma_{1,2}^2 = \left(\frac{\sigma_x^2 + \sigma_y^2}{2}\right) \pm \left[\left(\frac{\sigma_x^2 - \sigma_y^2}{2}\right)^2 + \mu_{xy}^2\right]^{1/2}$$

Original Record Yermo Fire Station 270

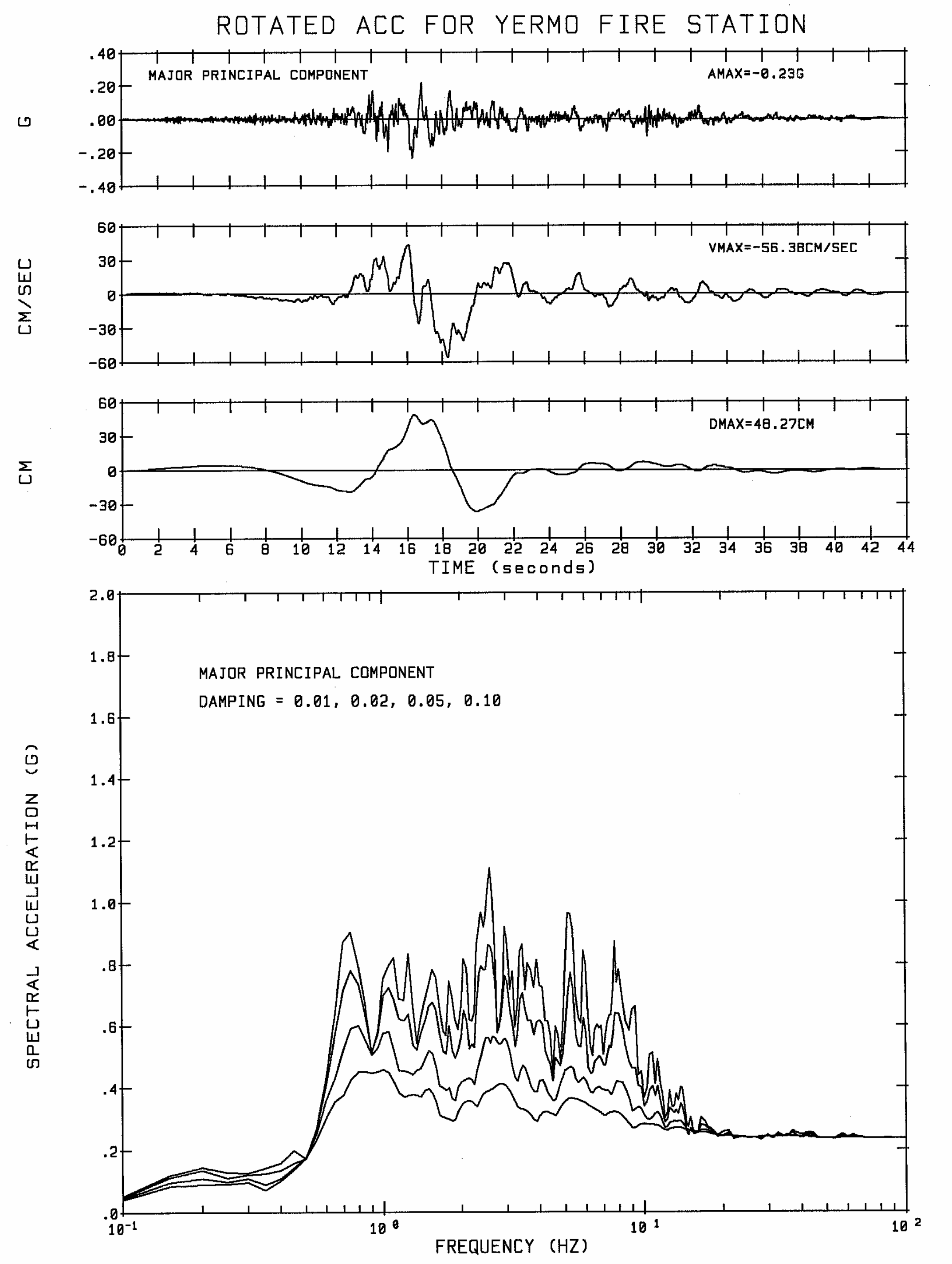
1992 Landers EQ



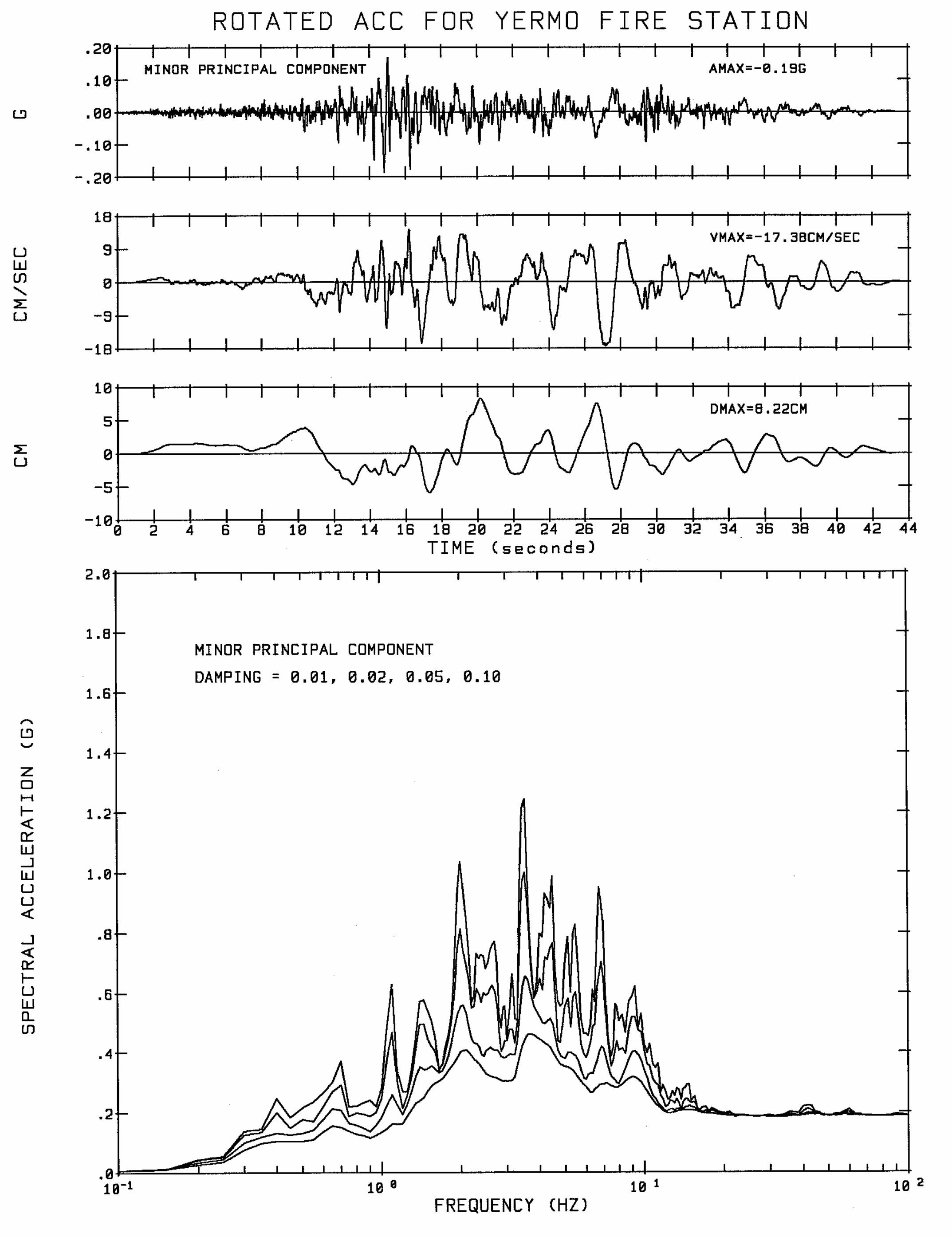
Original Record
Yermo Fire Station
360
1992 Landers EQ



Major Principal Component



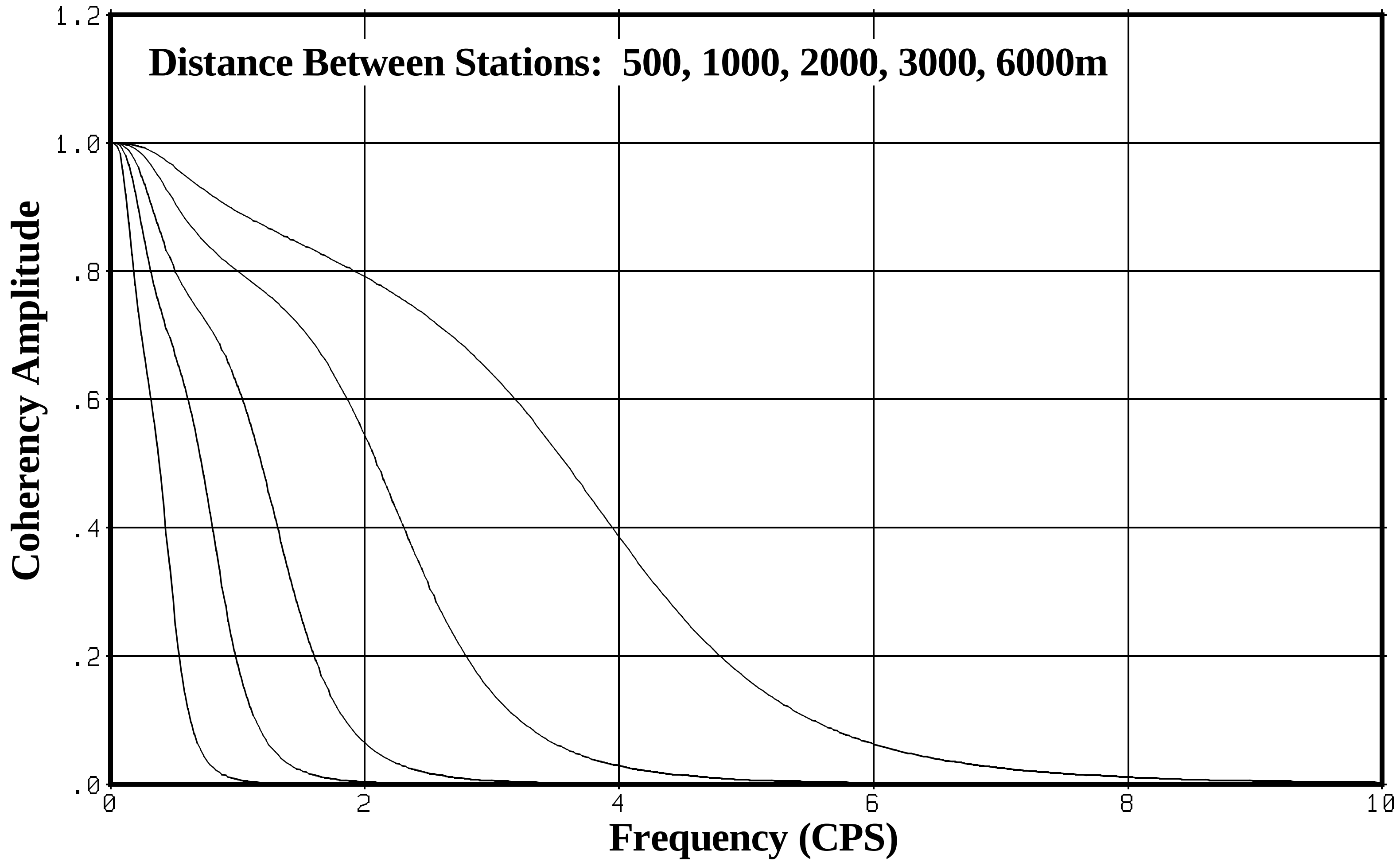
Minor Principal Component



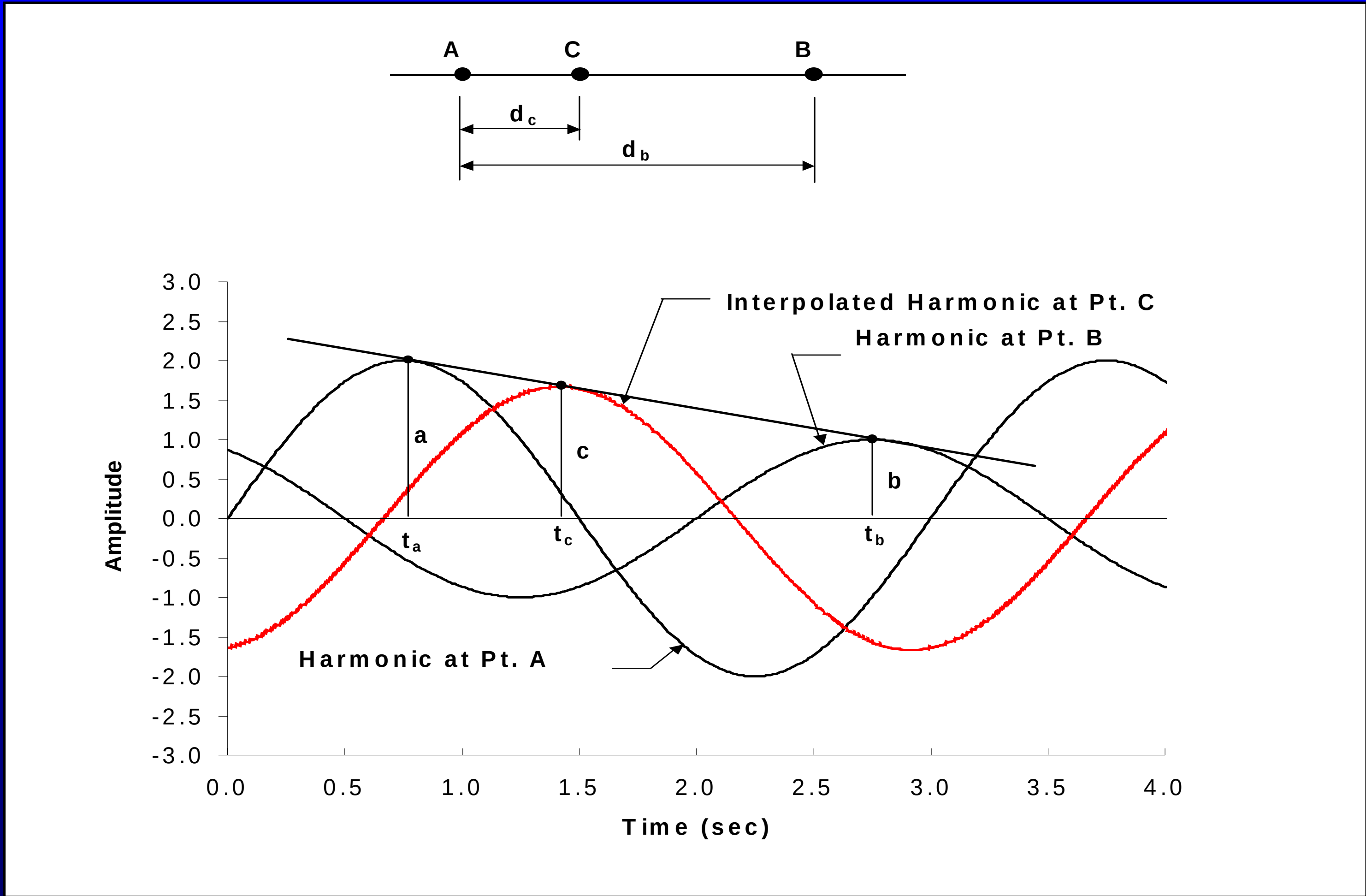
MULTIPLE-SUPPORT DESIGN TIME HISTORIES OF GROUND MOTION

- Specify **SEE UHRS**; x, y, z
- Select recorded “rock-outcrop” motions
- Modify to be response-spectrum compatible
- Coherency- and response-spectrum compatible
- Wave Passage (V_a = 2500 m/sec)
- Site response analyses
- Frequency-domain interpolation

Coherency Functions for Spatial Variation of Ground Motion



Interpolation in the Frequency Domain



Performance Evaluations

1. Response-Spectrum Demand Analysis

- Linear model
- Rigid boundary input (x, y, z)
- Force reduction factors (R_w, R, Z)
  - Global response
  - Member response
- Equal displacement rule $T \geq T^*$

Performance Evaluations (Cont'd)

- Global ductility demand (Δ_d)
- Global ductility capacity (Δ_c)
- Demand / capacity ratio
  - Global $\mu_{\mathbf{d}}/\mu_c$
  - Local $\varepsilon_{\mathbf{d}}/\varepsilon_c$

Performance Evaluations (Cont'd)

2. Nonlinear Time-History Analyses

- Nonlinear model
- Multiple 3-D boundary time-history inputs
- Use time histories with velocity pulses,

  $D \leq 10$ km
- Time-history responses
- Local maximum ductility demands (strains)
- Performance assessment

Future Improvements

- **Ground-Motion Characteristics**
  - Seismic Sources
  - Energy Release Mech.
  - Directivity Effects
  - Energy Transmission
  - Attenuation Relations
  - Recurrence Rates
  - Spatial Variations
  - Local Site Effects

Future Improvements (Cont'd)

- **Dual Strategy of Seismic Design**
  - FEE Mean Return Period
  - SEE Mean Return Period
  - Cost-Benefit Analysis
- **Modeling and Analysis**
  - Demand
  - Capacity

Future Improvements (Cont'd)

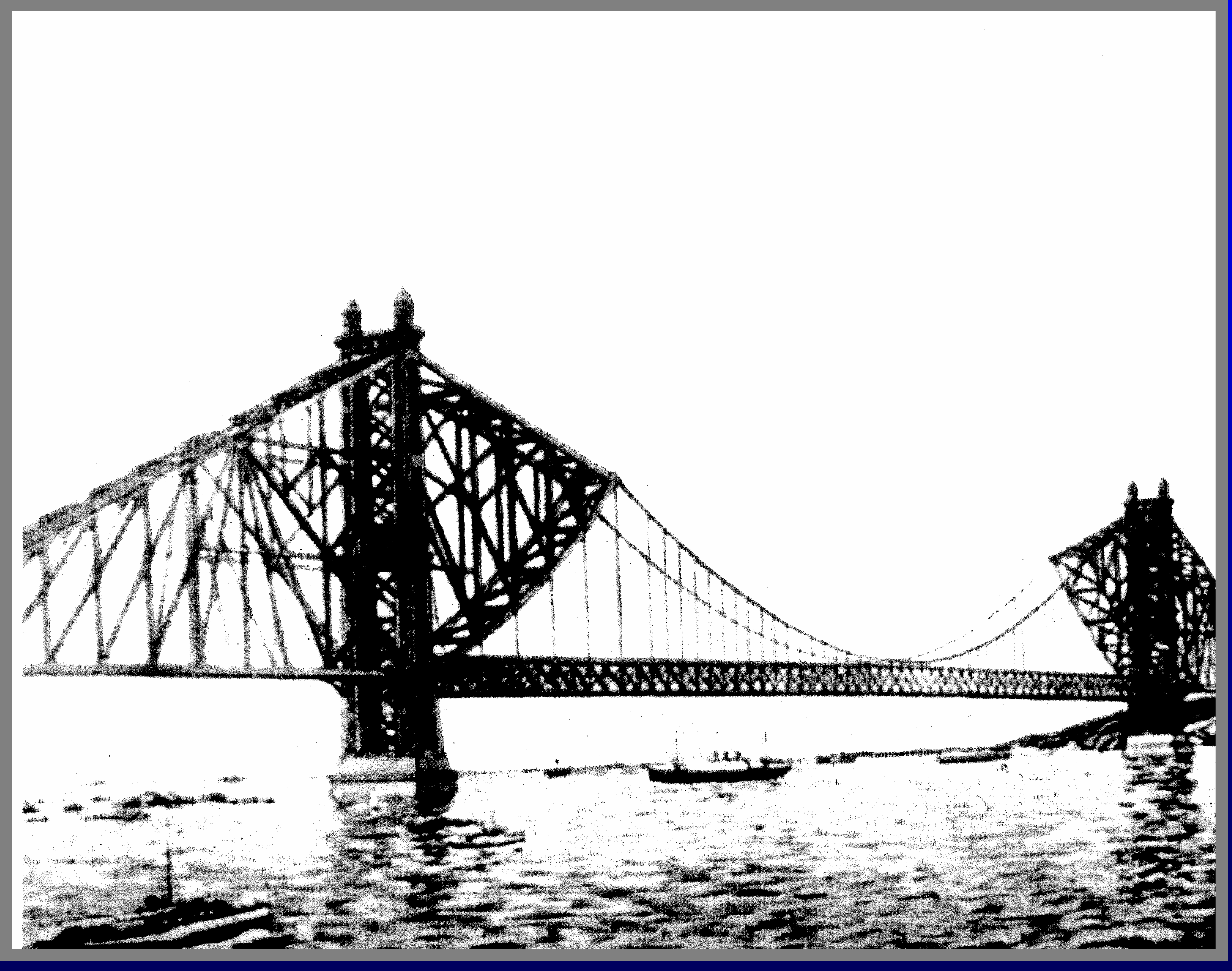
- **Laboratory Tests**
  - Quasi-static
  - Dynamic
- **Field Tests**
  - Recording Response
  - Correlation Studies
- **Code Changes**
  - Performance Focused
  - Deformation Based

Aesthetics

- Public Involvement
- Role of the Architect

Golden Gate Bridge

Original Design Concept



Final Design

Golden Gate Bridge