Selection, Scaling And Simulation Of Input Ground Motion For Time History Analysis Of Structures

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OUTLINES OF THE SEMINER

- Seismic Analyses of Structures
- Source of Accelerograms
- Selection of Time History Records
- Methods of Ground Motion Scaling of Earthquake Time Histories
- Criteria for Evaluation of Resulted Accelerograms
INPUT MOTIONS FOR EARTHQUAKE STRUCTURAL ANALYSES

Classical Earthquake Resistant Designs

- **Static Equivalent Method**

  \( \text{Spectral Acceleration at First Natural Period of Structure} \)

\[ V_{te} = M S_{ae}(T_1) \]
\[ M = \frac{W}{g} \]
\[ W = \sum_{i=1}^{N} w_i \]

\[ A(T) = A_0 I S(T) \]
\[ S_{ae}(T) = A(T) g \]

\[ S(T) = 2.5 \left( \frac{T_B}{T} \right)^{0.8} \]
INPUT MOTIONS FOR EARTHQUAKE STRUCTURAL ANALYSES

Classical Earthquake Resistant Designs

- Modal Combination Method

(Spectral Acceleration at all Effective Natural Periods of Structure)
HOW TO GET DESIGN SPECTRUM?

- Earthquake Design Codes (*NEHRP 1997, IBC2003, EuroCode 8*)
- Deterministic and Probabilistic Hazard Analysis

![Diagram showing Sa, S_{MS}, S_{M1}, and S_{MS} at different periods T_0, T_S, and 1.0 on the x-axis and Sa on the y-axis. The equation Sa = S_{M1} / T is also shown.]
INPUT MOTIONS FOR EARTHQUAKE STRUTUREAL ANALYSES

Time Domain Analyses

- Linear Dynamic (Acceleration Time History)
INPUT MOTIONS FOR EARTHQUAKE STRUCTURAL ANALYSES

Time Domain Analyses

- Nonlinear Dynamic (*Acceleration Time History*)
SOURCE OF ACCELEROGRAMS

- Real Accelerograms
- Artificial Accelerograms
- Synthetic Accelerograms
FACTORs INFLUENCING REAL ACCELEROMGRAMS

- **Source**
  - Magnitude
  - Rupture Mechanism
  - Directivity
  - Focal Depth

- **Path**
  - Crustal Structure

- **Site**
  - Surface Geology
  - Topography
  - Structures
RULES FOR SCALING TIME HISTORIES ACCORDING TO FIT DESIGN CODE SPECTURM

Guidance On How To Actually Select Appropriate Real Records Is Usually Focused On Compatibility With The Response Spectrum Rather Than Seismological Parameters

UBC 1997 And IBC 2000

- Maximum Structural Response If Three Records Used
- Average Structural Response If Seven Records Used
- (SRSS) Of The Two Horizontal Components – Should Not Be Less Than 1.4 The Design Spectrum Ordinates In The Range From 0.2T To 1.5T (UBC 1997)
RULES FOR SCALING TIME HISTORIES ACCORDING TO FIT DESIGN CODE SPECTURM

- Scaled Spectrum Should Not Be Less Than 0.9 The Design Spectrum Ordinates In The Range From 0.2T1 To 2T1 (DBYBHY 2007); T1 is the first fundamental Period of the Structure
- Earthquake Record duration > 5 T1 and > 15 sec
Processing Of Ground Motion To Fit Response Spectra (Real and Artificial Accelerograms)

- Ground Motion Scaling in Time Domain
- Spectral Matching in Frequency Domain
- Spectral Matching by Wavlets
- Spectrum Compatible Artificial Record Generation

Bommer & Acevedo 2004
REAL ACCELEROMETERS

**Advantages**
- Ground-motion Characteristics (Amplitude, Frequency And Energy Content, Duration And Phase Characteristics)
- Characteristics Of The Source, Path And Site

**Disadvantages**
- Not All Magnitude-Distance-Soil Combinations Are Covered
- Response Spectra Are Generally Not Smoothed.
PEER Strong Motion Database

1: Search earthquake or station characteristics and peak values

- Earthquake: Coalinga 1983/05/02 23:42
- Mechanism: Any
- Magnitude (Range): -
- Distance (km): -
- Site Classification: USGS
  - Any
  - (Compare to NEHRP classifications)
- Mapped Local Geology: Any
- Instrument Housing: Any
- Data Source: Any

PGA (g): Range 0.001 ... 20.86
PGV (cm/sec): Range 0.1 ... 269.1

http://peer.berkeley.edu/smcat
PEER STRONG MOTION DATABASE

- **Focal Mechanism**
  - Strike slip, Normal, Reverse normal, Reverse-oblique, Normal-oblique

- **Magnitude (ML, M, MS)**

- **Distance to Fault**
  - Closest, Hypocentral, Projection of fault plane

- **Site Classification and Mapped Local Geology**

- **Instrument Housing**
  - Free-field, shelter Type
## Query Results

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<th>PGA (g)</th>
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GROUND MOTION SCALING IN TIME DOMAIN

\[ \text{Difference} = \int_{T_A}^{T_B} \left[ \alpha S_a^{\text{actual}}(T) - S_a^{\text{target}}(T) \right]^2 dT \]

Nikolaou, 1998
DEVELOPMENT OF DISPLACEMENT RESPONSE SPECTRUM

El Centro Earthquake Record

T=0.6 Seconds

T=2.0 Seconds

Maximum Displacement Response Spectrum
GROUND MOTION SCALING
IN TIME DOMAIN (SCALING ON AMPLITUDE)

Match to Peak Ground Acceleration (PGA)

Match Spectral Acceleration at Specific Period

Cimellaro 2007
SCALING ON AMplitude

Match Spectral Acceleration At Period Range using least square Method

Match Multiple Motions match the median using Least Square Method

Cimellaro 2007
TIME SCALED EARTHQUAKE RECORDS

![Graph of Time Scaled Earthquake Records]

<table>
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<tr>
<th>RECORD ID</th>
<th>EARTHQUAKE</th>
<th>DATE</th>
<th>STATION</th>
<th>RECORD</th>
<th>COMPONENT</th>
<th>RECORDED TIME</th>
<th>DISTANCE to FAULT RUPTURE</th>
<th>MECHANISM</th>
<th>SCALE FACTOR (X)</th>
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<td>W15</td>
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SCALE IN FREQUENCY DOMAIN

Nikolaou, 1998
SCALE IN FREQUENCY DOMAIN (cont.)

STEP 2
Fourier Transform

STEP 6
Fourier Spectrum of \( TH_{\text{actual}}(t) \)

STEP 7
Filtered Fourier Spectrum

STEP 5
Filtering

STEP 8
Generate New Time History

STOP procedure
use \( TH(t) \) from Step 8

Repeat Steps 3-8
using \( TH(t) \) from Step 8

Nikolaou, 1998
SCALE IN FREQUENCY DOMAIN

<table>
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<tr>
<th>Record No</th>
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<th>Record</th>
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<td>P0828</td>
<td>Landers</td>
<td>28.06.1992</td>
<td>90052 Calabasas - N Las Virg</td>
<td>VIR290</td>
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</table>

![Seismic Waveforms](image1.png)
SCALE IN FREQUENCY DOMAIN

- **Scale in Frequency Domain**
  - Graphs showing spectral level, SA (g) vs. period, T (s) for different iterations.
  - Frequency spectra for different iterations, showing changes in frequency distribution.

**Graph Details:**
- **Spectral Level** vs. **Period**
- **Frequency Spectra** for **Original**, **3rd Iteration**, and **20th Iteration**.

**Legend:**
- **Z2; Deprem Böl.:1; i-1**
- **ARQ90 (Orijinal)**
- **ARQ90 (3. Iter)**
- **ARQ90 (20. Iter)**
SPECTRAL MATCHING USING WAVELETS

- Adjust the original record iteratively in the time domain to achieve compatibility with a specified target acceleration response spectrum by adding wavelets having specified period ranges and limited durations to the input time history.

- RSPMATCH software developed by Abrahamson (1992)
List of candidate earthquake records used for RSPMatch

<table>
<thead>
<tr>
<th>RECORD ID</th>
<th>EARTHQUAKE</th>
<th>DATE</th>
<th>STATION</th>
<th>RECORD</th>
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Acceleration, Velocity And Displacement Spectra For RSPMATCH Generated Records
DISCUSSIONS and CONCLUSIONS

- **RSPMatch** program requires a set of earthquake records that initially have considerable compatibility with the target spectrum. The matching procedure is not robust and program requests a lot of parameters related to additional wavelet iterations. The convergence is not guaranteed for many candidate records.

- The average of, acceleration velocity and displacement spectra for the matched records using RSPMatch have excellent fit with the design spectra.
ARTIFICIAL ACCELEROMETERS

- Generated To Match A Target Response Spectrum
- Earthquake Motion As The Output From Filters And Use Of System Response For A White Noise Input
- Disadvantages
  Records Generally Have An Excessive Number Of Cycles Of Strong Motion, And Consequently Have Unrealistically High Energy Content
**SPECTRUM COMPATIBLE ARTIFICIAL RECORD GENERATION (SIMQKE)**

- **SIMQKE** (Gasparini and Vanmarcke, 1976) computes a power spectral density function from a specified smooth response spectrum and uses this function to derive the amplitudes of sinusoidal signals which have random phase angles uniformly distributed between 0 and $2\pi$. The sinusoidal motions are summed to generate a time history record.

- In order to get other characteristics of artificial spectrum-compatible record, such as duration, it is necessary to obtain supplementary information about the expected earthquake motion apart from the response spectrum.
The code TARSCTHS (Papageorgiou et al., 2002) uses non-stationary stochastic vector processes to generate artificial time histories from a user defined elastic response spectrum. The iterative scheme is applied in frequency domain where the phase angles of the desired motion are randomly generated.
Acceleration, Velocity And Displacement Spectra And Ductility Demand For SIMQKE Generated Records

Trapezoidal intensity envelope with earthquake rise time = 2.5 sec, earthquake level time = 12 sec, desired duration of acceleration = 35 sec and desired maximum ground acceleration = 0.3 g

Filtered (0.1-20 Hz) and baseline corrected.
SPECTRUM COMPATIBLE ARTIFICIAL RECORD GENERATION

- Using either TARSCTHS or SIMQKE, the average of generated records acceleration, velocity and displacement spectra have inadequate fitting for longer periods.

- For option with no envelope in SIMQKE, non-realistic records that do not represent the general characteristics of real earthquakes are generated.

- Even though the unfiltered time histories have the same fit for the design spectrum as filtered time histories, unrealistic nonlinear behavior can be observed for the valid period range (0.1s-10s).
SYNTHETIC ACCELEROMETERS

- Stochastic Point Source and Finite Source ((Boore, 2003; Atkinson and Boore, 1997)
- Synthesize Earthquake Motion Using A Fault Dislocation Model Or Empirical Green’s Function Model
- Definition Of A Specific Earthquake Scenario
- Most Widely used EMPSYN Program L. Hutchings (1976)
- Geophysical Parameters
  - Hypocenter
  - Seismic Moment
  - Slip Vector
  - Asperities
  - Rupture Velocity
  - Rise Time
  - Stress Drop

Resulting accelerograms must have realistic characteristics of earthquakes in terms of amplitude, frequency content and duration.

A baseline correction and filtering should be performed to the generated or matched acceleration time histories.

The acceleration, velocity and displacement time histories should be examined to ensure that they are reasonably close to the target values in terms of peak values, wave form, strong shaking duration and other critical features such as the near-fault velocity pulse.
The resulting accelerograms

- **Power spectral density** function should be examined to ensure a broad distribution of energy in the final spectrum-compatible motion as a function of Fourier period and there are no significant deficiencies in the energy at periods important to the structure.

- In real earthquake records, the average of the ductility factor is expected to be equal to the structural behavior factor at longer periods (equal displacement rule) especially for velocity and displacement sensitive spectral regions (Chopra, 2000).
Realistic Acceleration, Velocity and Displacement

- **Acc (g)**
- **Vel (m/s)**
- **Disp (m)**

Graphs showing time (sec) against acceleration, velocity, and displacement over different time periods.
Acceleration, Velocity And Displacement Spectra And Ductility Demand For Time Scaled Records
Acceleration, Velocity And Displacement Spectra And Ductility Demand For SIMQKE Generated Records

Trapezoidal intensity envelope with earthquake rise time = 2.5 sec, earthquake level time = 12 sec, desired duration of acceleration = 35 sec and desired maximum ground acceleration = 0.3 g
Acceleration, Velocity And Displacement Spectra And Ductility Demand For TARSCTH Generated Records

TARSCTHS program requires moment magnitude and epicentral distance of scenario earthquake to compute duration.
Acceleration, Velocity And Displacement Spectra And Ductility Demand For RSPMATCH Generated Records
THANK YOU