Probabilistic Seismic Demand Models for Multi-Span Highway Bridges

Kevin Mackie
Bozidar Stojadinovic

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Seismic Response of Bridges

University of California, Berkeley
Department of Civil and Environmental Engineering &
Pacific Earthquake Engineering Research Center

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What is a PSDM?

PSDM = Probabilistic Seismic Demand Model

Relationship of seismic Intensity Measures (IM) to structural Engineering Demand Parameters (EDP)
Why a demand model?

1.) Quantitative Performance Based Earthquake Engineering tool for designers of bridges

What is probability of $y$, given $x$?
Why a demand model?

2.) How do design parameters affect performance?

- Shorter (stiffer)
- Taller (flexible)
Why a demand model?

3.) Module in Pacific Earthquake Engineering Research Center (PEER) probabilistic framework

PEER Performance based earthquake engineering framework
Probabilistic Seismic Demand Analysis

- Define motions (IM)
- Define class of structures (EDP)
- Define analysis model
- Nonlinear analysis

- Design parameter sensitivity
- Ground motion bin sensitivity
- Residual dependence (M, R)
Seismicity: Ground Motions & IMs

• Period Independent Intensity Measures
  • Magnitude, Distance, Strong motion duration
  • Cumulative absolute velocity
  • Cumulative absolute displacement
  • Arias intensity
  • Frequency ratios
  • RMS acceleration
  • Characteristic intensity
  • PGA, PGV, PGD

• Period Dependent Intensity Measures
  • Sa, Sv, Sd
  • Spectral combinations
  • Sd_{inelastic}
Demand: Bridges

- Single bent
- 2-bent
- 3-bent

Single-column bents

3-bent stand-alone
Demand: EDPs

- Local EDPs
  - Steel stress & strain
  - Concrete stress & strain
- Intermediate EDPs
  - Column curvature ductility
  - Maximum column moment
  - Plastic rotation
  - Hysteretic energy

- Global EDPs
  - Displacement ductility
  - Drift ratio
  - Residual displacement index

Single column/bent highway overpasses in California
OpenSees Bridge Model

- Elastic deck
- Fiber RC column
- Abutment springs and gaps
- Ground level
- Soil springs

Modes:
- Mode 1 - Longitudinal
- Mode 2 - Transverse
- Mode 3 - Vertical
Bridge Design Parameters

- **L**: span length \(60-180\) ft
- **L/H**: span to column height ratio \(1.2-3.5\)
- **\(\bar{d}_{s,\text{long}}\)**: column longitudinal reinforcement \(1-4\%\)
- **Dc/Ds**: column to superstructure dimensions \(0.67-1.33\)
- **Abut**: abutment mass/stiffness models various
Extending Optimal PSDM to Multi-bent bridges

Period-dependent IM with Global response parameter

Intensity Measure vs Demand Measure (Parameters)

Stiffness

Practical, effective, efficient

2-bent bridge with abutments
Extending Optimal PSDM to Multi-bent bridges

Period-independent IM with Global response parameter

Practical, effective, efficient in short period range

2-bent bridge with abutments
Sufficiency

Magnitude dependence

Distance dependence

Residual Dependence (semilog scale)

\[ c(\text{E}^{-2}) = 0.04, -0.11, 0.15, 0.63 \]

\[ l_2 = 1080, 1440, 2160, 2520 \]

Residual Dependence (semilog scale)

\[ c(\text{E}^{-2}) = 7.46, 11.54, 0.19, -36.89 \]

\[ l_2 = 1080, 1440, 2160, 2520 \]
Bent Configuration Comparison

- Longitudinal demand ↓ as bents ↑
- Transverse demand approx. same
Design Parameter Sensitivity

Intermediate Span length (L2)

Increasing stiffness lowers demand slightly

3-bent bridge no abutments

Intensity Measure vs Demand Measure (Parameters)

Stiffness

Sa T, longitudinal (cm/s²)

Maximum Displacement Longitudinal

L2 small

L2 large

L2=0.26, 0.25, 0.19, 0.30
Seismicity

- Parameter sensitivity to bins
- All lines of same color should have same slope at given intensity
- Higher demand for higher magnitude bins

Column diameter to superstructure ratio (DcDs)
Transverse Irregularity $RI^*$

$RI^* = \frac{1}{L} \int_0^L \hat{f}(x) dx \times 100\%$

1st transverse mode shape

vs pure transverse translation

No loss of efficiency with period independent IM
PSDM Extensions

Structural Demand Hazard Curves

![Graph showing average structural demand hazard curves with different drift ratios: Dr/Ds=0.67, Dr/Ds=0.75, Dr/Ds=1.0, Dr/Ds=1.3. The y-axis represents MAF/EDP and the x-axis represents Drift Ratio Longitudinal.](image)
PSDM Extensions

Functional EDPs

- Maximum post-earthquake functionality (traffic load, eg)
- Probability of exceeding a given damage state (fragility)
Conclusions

- PSDMs allow designers to see the effects of:
  - seismicity
  - design parameters
  - on seismic performance of a bridge
- PSDMs fit into PEER performance-based design framework, $\text{Sa}(T_1)$-optimal PSDM reduces demand model dispersion
- Optimal single-bent models remain optimal for multi-bent
- Transverse irregularity ($\text{RI}^*$) adequately predicted by $\text{Sa}(T_1)$
Thank You!

✿ Questions?

✿ For more information contact:
  ✿ Kevin Mackie: mackie@ce.berkeley.edu
  ✿ Boza Stojadinovic: boza@ce.berkeley.edu

✿ Visit
http://millerbird.ce.berkeley.edu