Framework for Performance-Based Earthquake Engineering

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Where were we 10 years ago?

SEAOC Vision 2000, FEMA 273, ATC-40

- Descriptive performance levels (IO, LS, CP, etc.)
- Associated with specific hazard levels → Performance Objectives
- Qualitative (and a few quantitative) damage measures
- Limited consideration of uncertainties
- Implementation in terms of **FORCES and DEFORMATIONS**

<table>
<thead>
<tr>
<th>Earthquake Performance Level</th>
<th>Fully Operational</th>
<th>Operational</th>
<th>Life Safe</th>
<th>Near Collapse</th>
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<tr>
<td>Frequent (43 year)</td>
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<td>Occasional (72 year)</td>
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<td>Unacceptable <strong>Performance</strong> (for New Construction)</td>
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<td>Rare (475 year)</td>
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<td>Very Rare (970 year)</td>
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**Earthquake Design Level**

- Safety Critical Objective
- Essential/Hazardous Objective
- Basic Objective
Measures of Performance - PBEE

 Forces and deformation?
- Yes, but only for engineering calculations
- Intermediate variables
- Not for communication with clients and community

 Communication in terms of the three D’s:
- Dollars (direct economic loss)
- Downtime (loss of operation/occupancy)
- Death (injuries, fatalities, collapse)

 Quantification
- Losses for a given shaking intensity
- Losses for a specific scenario (M & R)
- Annualized losses
- With or without rigorous consideration of uncertainties
Vision of PBEE

1. Complete simulation
2. Defined performance objectives
   - Quantifiable performance targets
   - Annual probabilities of achieving them
3. Informed owners

Sources: G. Deierlein, R. Hamburger
The Peer Framework Equation - 1999

\[ v(DV) = \int \int \int G(DV | DM) \cdot dG(DM | EDP) \cdot dG(EDP | IM) \cdot d\lambda(IM) \]

Impact  Performance (Loss) Models and Simulation  Hazard

Curse?  Blessing
Performance-Based Methodology – Bldgs.

Measures of Performance

- Collapse & Casualties
- Direct Financial Loss
- Downtime

Decision Variable

Damage Measure

Engineering Demand Parameter

Intensity Measure

Drift as an EDP

NSF-PEER Summative Meeting
Performance-Based Methodology
Incremental Dynamic Analysis

\[ \lambda_{\text{EDP}} (y) = \int P[\text{EDP} \geq y \mid \text{IM} = x] \, d\lambda_{\text{IM}} (x) \]
Performance-Based Methodology

Decision Variable

Damage Measure

Engineering Demand Parameter

Intensity Measure

Performance Assessment types (ATC-58 definitions):

Intensity-based: Prob. facility perf., given intensity of ground motion
Scenario-based: Prob. facility perf., given a specific earthquake scenario
Time-based: Prob. facility perf. In a specific period of time

Damage Fragility Curves:

Cost Functions:

Mean Loss Curve:

Cost of Repair / Cost New

Tape, Paste & Repaint
Replacement of gypsum boards
Partition replacement

Mean Loss Curve - 9-STORY MRF

Mean Spectral Acc. Hazard Curve -- T = 1.8 sec.
Van Nuys, CA, Horizontal Component

Mean Annual Freq. of Exceedance, \( \lambda \)

Spectral Acceleration \( S_a(g) \)

Median & Krawinkler

Aslani & Miranda
Deaggregation of Expected Annual Loss

Example: Van Nuys Testbed Building

Non-collapse: 71%
Collapse: 29%
Non-structural: 88%
Structural: 12%

Source: E. Miranda
Design Decision Support

Hazard Domain
Mean Hazard Curve

Structural System Domain
Mean IM-EDP Curves
EDP = Max. Interstory Drift
EDP = Max. Floor Acceleration

Loss Domain
Mean Subsystem Loss Curves
Expected $Loss
EDP = Max. Interstory Drift
EDP = Max. Floor Acceleration

Zareian & Krawinkler (2005)
Assessment of Collapse Potential

NORM. STRENGTH VS. MAX. STORY DUCT.
N=9, T₁=0.9, ξ=0.05, α=0.03, θ=0.015, H₃, BH, K₁, S₁, NR94nya

\[ \gamma = \frac{V_y}{W} \]

\[ \frac{[S_a(T_1)/g]}{\gamma} \]

- Non-degrading system
- Degrading system

Collapse Capacity
Modeling of Deterioration

UCI G12 OSB

$F_y = 8.2 \text{ kips}$, $\delta_y = 0.45 \text{ in}$, $\alpha_s = 0.047$, $\alpha_c = -0.081$, $\alpha_u = 1.94$, $\delta_c/\delta_y = 5.44$

UCI G12 OSB

Pinching Model, $\kappa = 0.5$, $F_y = 8.2 \text{ kips}$, $\delta_y = 0.45 \text{ in}$

$\alpha_s = 0.047$, $\alpha_c = -0.081$, $\alpha_u = 1.94$, $\delta_c/\delta_y = 5.44$, $\gamma_s = 270$, $\gamma_c = 270$, $\gamma_k = \infty$, $\gamma_a = 270$
Collapse Capacity for a Set of Ground Motions

MAX. STORY DUCTILITY vs. NORM. STRENGTH
N=9, T₁=0.9, ξ=0.05, K₁, S₁, BH, θ=0.015, Peak-Oriented Model,
αₛ=0.05, δₑ/δᵧ=4, αₑ=-0.10, γₛ=8, γₑ=8, γₖ=8, γₐ=8, λ=0, LMSR

Individual responses
Obtaining the collapse fragility curve (MRF)

N = 8, T₁ = 1.2, γ = 0.17, Stiff & Str = Shear, SCB = 2.4-2.4, ξ = 0.05
θₚ = 0.03, θₚc/θₚ = 5, λ = 20, Mc/My = 1.1

Zareian & Krawinkler (2004)
Probability of Collapse at MCE, for MRFs with $R = 8$

$P(\text{Collapse})$ at MCE given $R = 8$ & $\Omega = 2.5$ (MRF)

Siff. & Str. = Shear, SCB = 2.4-1.2, $\zeta = 0.05$, $\theta_{pc}/\theta_p = 15.0$, $\lambda = 50$, $M_c/M_y = 1.1$

Design Spectrum:
$Sa(T_1)/g = 0.32 \leq 0.6/T < 1.0$

$\theta_p = 0.06$

$\theta_p = 0.03$

Zareian & Krawinkler (2007)
Implementation of Framework

- **ATC-58** – Guidelines for Seismic Performance Assessment of Buildings
- **ATC-63** – Recommended Methodology for Quantification of Building System Performance
- **TBI** – Tall Building Initiative
- **LRFD** for bridge design
Concluding Remarks - 1999

- Performance based engineering is here to stay
- It enforces a transparent design/assessment approach
- Much more emphasis must be placed on $ losses and loss of function (downtime)
- Performance based design should be reliability based
- We have a long road ahead of us