Challenges of Communicating Earthquake Design In the Pacific Northwest

EERI Session 8A
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Panelists:
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Robert Braddock, Jordan Cove LNG
The Pacific Northwest is unique in the United States, as it is affected by multiple seismic sources with large variations in earthquake magnitude.

Large infrastructure projects may require consideration of multiple design codes with varying hazard levels.

This session will include a panel of speakers to discuss:

- challenges of designing in accordance with various design codes
- effectively communicating the hazards/risks to owners, agencies, and public
- utilizing experience to outline strategies to reduce common pitfalls
Session Overview

- Design Overview – Codes and Owners
- Seismicity/Hazard Overview – Uniquely PNW
- Geotechnical & Tsunami Hazards
- Projects with Multiple Codes
- Hypothetical Example Projects
  - Hi-Rise Hotel Assessment/Retrofit
  - Bulk Handling Facility on River
- Discussion and Questions
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### Seismic Design Code Development and Growth

<table>
<thead>
<tr>
<th>Seminal Event</th>
<th>Year</th>
<th>UBC / ASCE 7</th>
<th>Year</th>
<th>AASHTO</th>
<th>ASCE 41</th>
<th>ASCE 61</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>House Code</td>
<td>Bridge Code</td>
<td>Rehab</td>
<td>Marine</td>
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<tr>
<td>1972 San Fernando Earthquake</td>
<td>1970</td>
<td>10 pp</td>
<td>1969</td>
<td>1/3 pg</td>
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<tr>
<td></td>
<td>1976</td>
<td>14 pp</td>
<td>1977</td>
<td>6 pp</td>
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<td></td>
<td>2010</td>
<td>174 pp</td>
<td>2015</td>
<td>120 pp</td>
<td>2006</td>
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</table>
Challenges of Seismic Design and Communication

- Technical methodologies increasingly more complex.
- Owner’s expectations becoming more refined.
- Code challenges:
  - Meeting one code is generally easy.
  - Reconciling multiple codes on one project is more difficult.
- Helping Owners make informed decisions requires explaining complex concepts in simple terms, and requires carefully selected metrics.
Performance-Based Seismic Design – What’s Under the Hood of Design Codes ...In One Form or Another

Rational process to link decision making to seismic input, facility response and potential damage

Seismic Hazard (Spectral Acceleration, Acceleration Histories)

Geotechnical Analysis (Ground response, surface accelerations)

Structural Analysis (Strains, Displacements)

Damage Analysis (Immediate Use, No Collapse)

Loss Analysis ($, Downtime)

NCHRP Synthesis 440
Relationship of Seismic Response to Outcome - Bridges

NCHRP 440 / Moehle & Deierlein, 2004
### Damage Descriptors

<table>
<thead>
<tr>
<th>Classification</th>
<th>None</th>
<th>Minor</th>
<th>Moderate</th>
<th>Life Safety</th>
<th>Near Collapse</th>
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</thead>
<tbody>
<tr>
<td>Damage Description</td>
<td>None</td>
<td>Minimal</td>
<td>Repairable</td>
<td>Significant</td>
<td>Near Collapse</td>
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<tr>
<td>Physical Description (RC Elements)</td>
<td>Hairline cracks</td>
<td>First yield of tensile reinforcement</td>
<td>Onset of spalling</td>
<td>Wide cracks extended spalling</td>
<td>Bar buckling bar fracture confined concrete crushing</td>
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<tr>
<td>Displacement Ductility</td>
<td>$\mu_\Delta \leq 1$</td>
<td>$\mu_\Delta = 2$</td>
<td>$\mu_\Delta = 4$ to 6</td>
<td>$\mu_\Delta = 8$ to 12</td>
<td></td>
</tr>
</tbody>
</table>

| Repair | Reparability | None/no interruption | Minor repair/no closure | Repair/limited closure | Repair/weeks to months closure | Replacement |

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<table>
<thead>
<tr>
<th>Performance Descriptors</th>
<th>Availability</th>
<th>Immediate Open to All Traffic</th>
<th>Open to Emergency Vehicles Only</th>
<th>Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance Level</td>
<td>Fully Operational</td>
<td>Operational</td>
<td>Life Safety</td>
<td>Collapse</td>
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<tr>
<td>Retrofit Manual</td>
<td>PL3</td>
<td>PL2</td>
<td>PL1</td>
<td>N/A</td>
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</tbody>
</table>

NCHRP 440
Non-Structural Displacement Capacity

Utility Articulation On Bridge

24-in. Sanitary Sewer Joint at Abutment

Abutment Shear Keys Designed to Break Away (Fuse) In Design EQ

Ball Joints
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Seismicity Overview

- **Juan de Fuca Plate**
- **Pacific Plate**
- **Subduction zone earthquakes (1700)**
- **Crustal earthquakes (900AD, 1872)**

Locations:
- Vancouver
- Seattle
- Seattle Fault

Map showing the tectonic plates and seismic activity in the region.
Seismicity Overview

Personius 2003
Seismic Hazard Characterization

- **Deterministic** = Scenario...most easily understood
  - Specific source (fault), defined earthquake magnitude, at a specific location relative to site.
  - M9 at x distance produces y acceleration at my site. (e.g., Cascadia Subduction Zone)

- **Probabilistic** = “Odds-based”...more comprehensive, handles uncertainty, variability; not easily understood
  - Similar to deterministic, but adds:
    - all sources are included
    - includes uncertainty (spatial, temporal, model, ...)
  - e.g., there is a 2% chance in 50 years that y acceleration will be exceeded at my site (includes Cascadia Subduction Zone, but also local faults and deep earthquakes)
Seismic Hazard Metaphor - Dropping Rocks into a Pond (Must Consider All EQ Sources)

Magnitude 9
Far Away

Magnitude 6
Nearby

What do I feel?
(M6 vs M9)
Not uncommon for different seismic sources to control different aspects of the design: geotechnical, short buildings, tall buildings, etc.
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Geotechnical Hazards – Liquefaction-Induced, Lateral Spreading, Slope Instability, etc

- Codes establish hazard level
- Liquefaction challenges
  - Change from DE to MCE level
  - Liquefaction behavior is not linear, threshold level of shaking “switches” soil from non-liquefiable to liquefiable
  - Performance of non-standard soils; low to moderate plasticity silts
- Combination of Inertial Loading (EQ) and Soil Movement (S)
  - How to combine, timing?
- PSHA results need to be de-aggregated to events with a Magnitude assumption
- Owner must be involved in decisions for many projects
  - Many codes don’t define the acceptable deformations and performance criteria --- More on this later...
Liquefaction-Induced Lateral-Spreading Damage

Damage to Showa Bridge Due to Lateral Spreading
Niigata Earthquake, Japan, 1964
Accommodating Liquefaction-Induced Lateral Spreading

Superstructure

Plastic Hinges

Soil Movement

New Zealand, 2011 Cal ITIT
Tsunami Hazards: Damage Mitigation - Emerging Practice

Great East Japan Earthquake 2011
Damage in Utatsu, Japan
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Projects with Multiple Codes

- Piers or Wharves with Occupied Structures on Top
- Transit Guideways and Stations
- Industrial Facilities
  - Marine Terminals with Upland Facilities
  - Facilities with Storage Tanks and Conveyance Equipment
- Buildings with Cranes
Pier with Structures on Top – Ferry Terminal

- View platform
- Elevated walkway
- Terminal building
- Slip 3 movable bridges
- Elevated pedestrian connector
- Passenger-only ferry facility
- Existing toll booths
- Entry building
- Bicycle entry
- Retail space
- Marion Street pedestrian bridge (by City of Seattle)

WSDOT
Transit Guideway with Station

Sound Transit
Facilities with Storage and Conveyance Equipment – LNG Storage, Vessel Mooring, Transfer, and Loading Arms
Example Code Comparison
Military Facility with Enhanced Performance

UFC – Unified Facilities Criteria
OC – Occupancy Category (now RC – Risk Cat.)
LS – Life Safety
IO – Immediate Occupancy
MCE – Maximum Considered Event (2,475-yr)
Complex Projects Combining Codes

- IBC for many structures
  - ASCE 7 for structure seismic – 2/3 MCE (MCE=2,475 yr)
  - Geotechnical Hazards – Full MCEg
- ASCE 61-14 for marine
  - OLE (72 yr), CLE (475 yr), DE (life-safety)
- AASHTO
  - 1,000 yr
- UFC 3-301-01 and 3-310-04 for DoD facilities
- Force-based (R-factor), Displacement-based, and Performance-based Design Methodologies In Use
  - Increased rigor and rationale from force-based to PBSD
Satisfy All-Requirements Approach

- Recognize different return periods/prob of exceedance
- Consider enveloping
- Consider code-based prescriptive measure conflicts
- Often satisfying every requirement is not possible

Performance-Based Approach (Project-Specific Criteria)

- First-principle engineering is needed to assess actual performance (Performance-Based Seismic Design)
- Owners must be involved in this process
- Early decisions help projects proceed in a rational manner
- Process can be iterative
Rational process to link decision making to seismic input, facility response and potential damage:

- **Seismic Hazard**
  - Spectral Acceleration, Acceleration Histories

- **Geotechnical Analysis**
  - Ground response, surface accelerations

- **Structural Analysis**
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NCHRP Synthesis 440
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Hypothetical Hotel Seismic Evaluation

- Hotel decision maker reads the New Yorker Article, Oregon Resilience Plan, etc.
  - What is going to happen to my building if one of these Magnitude 9 earthquakes occur?
  - Contacts a structural/geotechnical team to help evaluate their risks
Commonly an ASCE 41 or IBC evaluation

Assume quick evaluation relative to current IBC to limit multiple hazard level discussions.

Current IBC is based on ASCE 7-10.

- Structural analysis will be defined by the DE which is 2/3 of the MCE_R or approximately 2/3 of a 2,475 year hazard level with risk coefficients
- Geotechnical hazards are based on the full MCEg values which are approximately a 2,475 year hazard level (regardless of building risk category)

Answer client’s question about M9?
Hypothetical Columbia River Bulk Handling Facility

- Existing Dock Renovation or New Dock
  - ASCE 61
- New Highway/Rail Bridge
  - AASHTO, possibly AREMA
- Upland Storage Structures, Office Buildings,
  - IBC and ASCE 7-10
- Petroleum Storage
  - API
Hypothetical Columbia River Bulk Handling Facility

- Assume no rail or petroleum component for “simplicity”
- Already have eight (8) probabilistic/deterministic hazard levels or definitions to evaluate

<table>
<thead>
<tr>
<th>Code</th>
<th>Seismic Hazard Level Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASCE 61</td>
<td>OLE (75 yr prob.)</td>
</tr>
<tr>
<td></td>
<td>CLE (475 yr prob.)</td>
</tr>
<tr>
<td></td>
<td>DE (2/3 MCE)</td>
</tr>
<tr>
<td>IBC</td>
<td>DE (2/3 MCE)</td>
</tr>
<tr>
<td></td>
<td>MCEr, (about 2,475 year prob. w/risk coef.)</td>
</tr>
<tr>
<td></td>
<td>MCEg 2,475 year prob.</td>
</tr>
<tr>
<td>ODOT/AASHTO</td>
<td>M9 deterministic</td>
</tr>
<tr>
<td></td>
<td>1000 year prob.</td>
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</table>
The Pacific Northwest and the I-5 corridor in particular are unique in the range of contributing seismic sources and implications to seismic design. Evolution of seismic design and built environment also create unique challenges.

The seismic hazard variability within and between codes and design criteria can make communicating the risks to owners, design team, and the public challenging.

Evolutionary changes within design code cycles is a significant challenge for projects, particularly for owners/designers close to a code cycle change.

Use of multiple design codes requires development of project specific design criteria.

Design team is responsible for helping owner develop performance criteria. Owner must be involved in the process early and the entire design team must understand and scope the process as each site is unique!
Discussion and Questions?