Day 1 Summary

Presented by Ian Buckle
Civil and Environmental Engineering
University of Nevada Reno

Day 1:

- Philosophy and Process
  - Performance-based retrofit: upper and lower level earthquakes
  - Seismic Retrofit Categories
  - Screening, Evaluation and Retrofit (Strategies, Approaches and Measures)

- Category A and B bridges
  - Screening
  - Evaluation
  - Retrofit measures
    - Seats, bearings, superstructures
Days 2 and 3:

Category C and D bridges:
- Requirements
- Screening
- Evaluation
  - Structural modeling, demand & capacity assessment
  - Geotechnical modeling and capacity assessment
- Substructure retrofit measures (columns, abutments, footings, and foundations)
- Site remediation, hazardous sites
Screening Bridges in Categories C and D

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MULTIDISCIPLINARY CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

Diagram:
- Is Bridge Exempt?
  - Yes: Pass
  - No: Screen / prioritize

Screen / prioritize:
- Evaluate
  - Pass: Next bridge
  - Fail: Fail

Fail:
- Retrofit
- Review
Information required to determine *seismic retrofit category*

- Anticipated Service Life
- Performance Objectives
- Bridge Inventory
- Seismic Hazard
  - Ground motions
  - Site effects

Seismic retrofit category

| Seismic retrofit category |

<table>
<thead>
<tr>
<th>HAZARD LEVEL</th>
<th>PERFORMANCE LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PL0: No min.</td>
</tr>
<tr>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>II</td>
<td>A</td>
</tr>
<tr>
<td>III</td>
<td>A</td>
</tr>
<tr>
<td>IV</td>
<td>A</td>
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</table>
## Minimum requirements

<table>
<thead>
<tr>
<th>ACTION</th>
<th>SEISMIC RETROFIT CATEGORY</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Screening/ Retrofitting</td>
<td>NR</td>
</tr>
</tbody>
</table>

### Screening and prioritization

- **Purpose** is to screen an existing inventory of bridges for seismic deficiencies and prioritize the inventory for seismic retrofitting based on vulnerability, hazard, and other factors.

- **Screening methods** are expected to be quick and thus conservative; bridges that ‘fail’ are passed to a second level of screening i.e. ‘detailed evaluation’.
Seismic Retrofit Category

Seismic Retrofit Category, A

Seismic Retrofit Categories B, C, D

Compile bridge and hazard data. Calculate Bridge Rank, R, based on vulnerability and seismic hazard

Compile Other Issues, O e.g. bridge importance, network redundancy, nonseismic rehab needs...

Retrofitting Not Required

Calculate Priority index

\[ P = f(R,O) \]

Screening requirements for C & D

- Seismic retrofit category C:
  - seats
  - connections
  - Columns
  - footings
  - liquefaction

- Seismic retrofit category D:
  as for SRC C plus abutments
Bridge seismic inventory data form (T1-8)

GENERAL
Bridge Name ____________________________________________ BIN Number________________________
Location ______________________________________________________________________________________
Year Built ________________ ADT____________________________  Detour Length_________________
Total Length __________ Feature Carried____________________________________________________
Overall Width __________ Feature Crossed___________________________________________________
Importance: essential / standard Alignment: straight / skewed/ curved Geometry: regular / irregular
Seismic Hazard (100-year event): Ss =________ g   S1 = _______ g Soil Site Class: A / B / C / D / E _____
(1000-year event): Ss =________ g   S1 = _______ g Soil Site Class: A / B / C / D / E _____

SUPERSTRUCTURE
Material and Type ______________________________________________________________________________
Number of spans __________ Continuous: yes / no  Number of expansion joints________

BEARINGS
Type ____________________   Condition: functioning / not functioning ____________________________________
Type of restraint: Longitudinal: ____________________________ Transverse:______________________________
Actual support length____________________________________Minimum required length____________________

COLUMNS AND PIERS
Material and Type ______________________________________________________________________________
Cross-section: Min. transverse dimension__________________ Min. longitudinal dimension ___________________
Height range (low – high): ____________________________ Fixity: Top _____________ Bottom_______________
Longitudinal reinforcement (%), __________ Splices in end zones ?  yes / no_________________
Transverse confinement steel_____________________________________________________________________

FOUNDATIONS AND ABUTMENTS
Pier foundation type: spread footings / pile footings / pile bent / single shaft / other
Abutment type: seat / integral / other ___________ On Piles: yes / no other__________________
Abutment height__________ Approach slabs: yes / no  Slab length ______
Location: cut / fill  Wingwalls: yes / no  Liquefaction: susceptibility low / moderate / high___________

REMARKS
___________________________________________________________________________________

Inventory form continued
Factors considered

- Structural vulnerability
- Seismic and geotechnical hazards
- Other
  - Importance
  - Network redundancy
  - Age and physical condition

Screening and prioritization

\[ P = f(R, \text{importance, non-seismic and socioeconomic factors}) \]

where:  
- \( P \) = assigned priority
- \( R \) = bridge rating (or rank) based on hazard and vulnerability
Screening and prioritization

- Three methods:
  - *Expected Damage Method* (new, uses bridge fragility functions, rank is based on direct losses due to damage)
  - *Seismic Risk Assessment Method* (new, uses network models and fragility functions, rank is based on direct and indirect losses, uses REDARS software)

**Indices method**

- Assign vulnerability index to bridge, \( V \), in range 0-10
- Calculate seismic and geotechnical hazard index for site, \( E \), in range 0-10
- Calculate Bridge Rating, \( R \)
  
  \[
  R = V \times E \quad \text{(will be in range 0 - 100)}
  \]
- Assign priority, \( P \)
  
  \[
  P = f(R, \text{importance, non-seismic and socioeconomic factors})
  \]
Structural vulnerability for bridges in categories C and D

- **Structure vulnerability, V**
  - Connections, bearings and seats (i.e. support lengths) => V1 (0-10)
  - Substructure => V2 (0-10)
    - Column vulnerability, CVR
    - Abutment vulnerability, AVR
    - Liquefaction vulnerability, LVR

- V = maximum of V1 and V2

\[ V = \text{Maximum of } V_1, V_2 \]
Column vulnerability, CVR

- CVR = 0 when
  - SRC = B
  - Bearing restraints can be relied upon to fail
  - Column transverse steel meets all requirements of current AASHTO Specification

Column vulnerability continued

- Vulnerability to shear failure:
  - CVR1 = Q – PR
  - Q and P_R depend on column length, percentage and grade main reinforcing steel, end-fixity, width, and bridge skew, continuity

- Vulnerability to flexural failure when splices occur in plastic hinge zone:
  - CVR2 = 7 for SD1 < 0.5
  - CVR2 = 10 for SD1 ≥ 0.5
Column vulnerability continued

- Vulnerability due pile footings not reinforced for uplift or poorly confined foundation shafts:
  - $CVR_3 = 5$ for $0.5 < SD1 < 0.6$
  - $CVR_3 = 10$ for $0.6 < SD1$

- Overall column rating:
  - $CVR = \text{maximum } \{CVR_1, CVR_2, CVR_3\}$

Abutment vulnerability rating, AVR

- $AVR = 0$ if SRC B
- $AVR = 5$ if fill settlement exceeds 6 ins
  where settlement is estimated as follows

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Settlement as % fill height</th>
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<tbody>
<tr>
<td>$SD1 \leq 0.24$</td>
<td>0%</td>
</tr>
<tr>
<td>$0.24 &lt; SD1 \leq 0.39$</td>
<td>1%</td>
</tr>
<tr>
<td>$0.39 &lt; SD1 \leq 0.49$</td>
<td>2%</td>
</tr>
<tr>
<td>$0.49 &lt; SD1$</td>
<td>3%</td>
</tr>
</tbody>
</table>
Abutment vulnerability rating, AVR

- AVR = 5 if SRC = D and either fill settlement exceeds 6 ins, or any of the following conditions occur:
  - cantilevered abutment
  - skew angle > 40°
  - distance from abutment seat to underside of footing > 10 ft

Structure vulnerability

- Substructure vulnerability
  \[ V_2 = CVR + AVR + LVR \leq 10 \]
- Seats, connections, bearings vulnerability, V1
- Structure vulnerability
  \[ V = \text{maximum} \ [V_1, V_2] \]
Hazard rating for SRC C and D bridges

\[ \text{Hazard, } E = 10.F_v S_1 \]
\[ = 10.S_{D1} \leq 10.0 \]

where \( F_v \) = soil factor in long period range, and
\( S_1 \) = spectral acceleration at 1.0 sec period

Bridge rating (rank)

\[ \text{Bridge Rating, } R = V.E \]
EXAMPLE 4.1: PRESTRESSED CONCRETE BRIDGE WITH SIMPLE SPANS – INDICES METHOD

A four-beam, prestressed concrete bridge is located on very dense soil and soft rock (site class C).

Constructed in 1968, it has three simply-supported spans, each seated on elastomeric pads directly on the cap beams (no pedestals); seat widths are 450 mm (17 ¾”).

EXAMPLE 4.1 continued

The total length of the bridge is 56 m (183’- 8 ¾”), with an overall width of 10 m (32’- 9 ¾”) and a skew of 32°.

Abutment fill height is 7.6 m (24’- 11 ¼”).

The bridge carries 65,000 ADT and is considered to be ‘essential.’

Calculate the bridge rank R, for this bridge using the indices method.
EXAMPLE 4.1 - Step A

Step A. Determine seismic retrofit category, SRC, and minimum screening requirements

The anticipated service life, performance level, and seismic hazard level are required to find the SRC, as follows:

**Anticipated service life (ASL):**
Age of bridge = 2004-1968 = 36 years
Assumed service life = 75 years
Anticipated service life = 39 years
Service life category = ASL 2 (table 1-1)

**Performance level (PL):**
Bridge importance is 'essential'
Therefore the performance level for the upper level earthquake is PL1 (table 1-2).

**Seismic hazard level (SHL):**
Obtain Ss and S1 from USGS CD-ROM (section 2.3) for upper level earthquake.
Take Ss and S1 = 1.40 and 0.28.
Obtain Fa and Fv from table 1-4 for site class C.
Calculate SDS and SD1 and obtain SHL from table 1-5.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Ss</th>
<th>S1</th>
<th>Fa</th>
<th>Fv</th>
<th>SDS</th>
<th>SD1</th>
<th>SHL</th>
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</thead>
<tbody>
<tr>
<td>Upper</td>
<td>1.40</td>
<td>0.28</td>
<td>1.0</td>
<td>1.52</td>
<td>1.4</td>
<td>0.43</td>
<td>IV</td>
</tr>
</tbody>
</table>
EXAMPLE 4.1 - Step A

Seismic retrofit category (SRC):
Obtain SRC from table 1-6.

Earthquake | PL | SHL | SRC
--- | --- | --- | ---
Upper | PL1 | IV | C

Minimum screening requirements for SRC = C are given in table 1-7.
• seat widths, connections
• columns, walls, footings, and
• liquefaction.

EXAMPLE 4.1 - Step B

Step B. Calculate vulnerability, V

Use the procedure in section 4.2.1.1 to find vulnerability rating, V.

Step B.1 Bearing and seat width vulnerability, V1:
Simple spans, elastomeric bearings, no pedestals,
beaminentures are not vulnerable to toppling,
Four-beam bridge, gives VT = 0
Required longitudinal support, N = 545 (21½") mm
(equation 4-3a)
EXAMPLE 4.1 - Step B

Available support, \(L = 450\) mm (17 ¾”); hence \(0.5 \, N < L < N\) and \(VL = 5\).

\[ V1 = \text{greater of } VT \text{ and } VL = \text{greater of } 0 \text{ and } 5 = 5. \]

Use procedure in section 4.2.1.1(b).

EXAMPLE 4.1 - Step B

Step B.2 Column, abutment, and liquefaction vulnerability,

\[ V2 = CVR + AVR + LVR < 10 \]

Assume elastomeric bearings do not fail and seismic loads are transferred to columns; assume columns are not vulnerable to shear failure but longitudinal steel is spliced in potential plastic hinge region.

Superstructure has expansion joints (three simple spans) and \(SD1 = 0.43 < 0.5\); hence \(CVR = 7\) (section 4.2.1.1(b)).
EXAMPLE 4.1 - Step B

Fill settlement behind abutment estimated at two percent x 7600 = 152 mm (6’); hence AVR = 5 (section 4.2.1.1 (b))

The susceptibility of soils in site class C to liquefaction is low, and from table 4-2, the potential for liquefaction-related damage is ‘low’; hence LVR = 0.

Therefore $V_2 = CVR + AVR + LVR \leq 10$ (equation 4-4)

$= 7 + 5 + 0 = 12 > 10$

Hence $V_2 = 10$

EXAMPLE 4.1 - Step B

Step B.3 Overall bridge vulnerability, $V$

Bridge vulnerability calculated as:
$V = \text{greater of } V_1 \text{ and } V_2$

$= \text{greater of } 5 \text{ and } 10.$

$V = 10$
EXAMPLE 4.1 – Steps C and D

**Step C. Seismic hazard rating, E**

Calculate \( E = 10 \ SD1 \leq 10.0 \) (equation 4-8)

\[
= 10 \times 0.43 \\
= 4.3 \quad \text{for} \ SD1 = 0.43.
\]

**Step D. Bridge rank, R**

Calculate \( R = V.E \) (equation 4-2)

\[
= 10 \times 4.3 \\
= 43 \quad \text{Answer}
\]

**Expected damage method**

\[ P = f(R, \ \text{importance}, \ \text{non-seismic and socioeconomic factors}) \]

where: \( P = \) assigned priority

\( R = \) bridge rating (or rank)

based on expected damage and repair costs
Expected damage method cont’d

- Expected damage and repair costs are estimated from bridge fragility curves which give probabilities of given bridge subject to given hazard, sustaining certain levels of damage from which repair costs may be calculated.
- Bridge with the likely highest repair cost is ranked first, and second highest second, and so on.

Seismic risk assessment method

- Most sophisticated of all methods
- Explicit analysis conducted of highway network, system redundancy captured, and importance quantified
- Bridge vulnerabilities modeled by fragility functions; also site hazards are specifically assessed
- Rank is based on impact of bridge damage on traffic congestion and restoration time of network
- Still a research tool
REDARS: Memphis test bed