Retrofit Measures for Superstructures, Bearings and Seats
Purpose

- To describe typical retrofit measures for:
  - Bridge decks and girders
  - Bearings, anchorages and pedestals
  - At expansion joints
    - Increase displacement capacity
    - Reduce displacement demand
Retrofit of bridge decks and girders

- Lateral load path enhancement
  - Deck to girder connection
  - Diaphragm strengthening/stiffening
  - Girder strengthening

- Provide longitudinal continuity
  - Web and flange plates
  - Superstructure joint strengthening

- Reduction of dead load

- Strengthening of continuous superstructures
Girder bracing retrofit

- High transverse bending at bearings
- Most critical when:
  - Beam type diaphragm
  - No diaphragm
Bearing stiffener retrofit

- High transverse bending at bearings
- Bearing stiffeners may be overstressed
Provide superstructure continuity

- Remove portion of deck
- Connect flanges
- Reconstruct continuous deck
- Verify girder can carry $M_{\text{neg}}$
Web splice retrofit

- Provide transverse restraint to prevent web tear
- Provides vertical support for unseated girder
- Slotted holes for expansion

Elevation of Girders

Splice plate - place bolts through holes drilled in girders - use slotted holes to accommodate thermal movement
Web splice details

- Shims may be required
- Use slotted holes at expansion joints
- Transverse restraint is required to prevent web tearing

Methods for accommodating girder misalignment
Reduction of dead load

- Remove heavy barriers, overlay
- Replace deck with lightweight concrete

- Decreases natural period
  - Higher spectrum accelerations
  - Displacements reduced
  - Ductility demand reduced
Elements to be retrofitted

- Bridge decks and girders
- Bearings, anchorages and pedestals
Retrofit of bearings, anchorages and pedestals

- Strengthening of existing bearings
- Bearing replacement
- Strengthening superstructure to substructure connections
Strengthening of existing bearings

- Do not retrofit if:
  - Collapse mechanism is avoided...ie
    - Cap support is wide
    - Superstructure will drop only short distance
  - Common bearing failure locations (steel)
    - Connection between girder and bearing
    - Connection between masonry plate and bearing
    - Anchor bolts
Strengthening of existing bearings

- Connections
  - Fixed bearings
    - Sole plate to girder
    - Bearing to masonry plate
    - Masonry plate to substructure
  - Expansion bearings
    - Sole plate to girder
    - Masonry plate to substructure
Bearing sole plate connection

- Use high strength bolts
- Consider double shear
- Check forces in flange

Bearing sole plate to girder retrofit
Anchor plate retrofit

- Masonry plates typically connected to substructure with anchor bolts
- Bolts must resist EQ shear
- Increase capacity with more HS bolts
Vulnerable tall bearing (fixed)

- Resists long & transverse forces
- Failure may shift to sole pl/girder connection
Bearing encasement retrofit

- Prevents transv. failure and toppling of bearings
- Limits vertical drop
Vulnerable tall bearing (tall)

- \( F_b = (DL) \tan \alpha \)
Bearing replacement

- Preferred bearing retrofit method
- Use same bearing at exp and fixed end to allow same rotation and preserve symmetry
- Increase “t” of pad-EQ forces are reduced
Bearing replacement

- Isolation
Bearing replacement

- Not suited for isolation
  - Bridges on soft soil (acc increases)
  - Long period structures (little is gained)
  - Extreme seismicity (large deflections)

![Diagram of period shift and acceleration (acc) with points labeled as S_p, S_2, and S_3]
Bearing seat extensions

- Seat extensions and catcher blocks
  - Use to reduce number of restrainer cables required
  - Use when too many restrainer cables are required to limit deflection to 67% available seat length
Abutment seat extenders

- Design 2 load cases
  - 2 x DL (account for impact)
  - DL + EQ (assumes structure falls and still under EQ force) Lesser of:
    - DL x Acc
    - DL x friction
Abutment seat extenders

\[ N(d) = \left[ 4.0 + 0.02L + 0.08H + 1.1\sqrt{H}\sqrt{1+\left(\frac{2B}{L}\right)^2}\right] \frac{(1+1.25F_vS_1)}{\cos \alpha} \]

N = recommended support length (in)
L = length of bridge from seat to adjacent expansion joint (ft)
H = height (ft)
B = width (ft)
\( \alpha \) = skew angle
Abutment seat extenders

Abutment

Column or Pier

Hinge Within a Span
Cable Restrainers
Caltrans cable restrainer detail

- 3/4” cable (same as used for guardrail)
- Failure about 4.5”-5” elongation w/ 9.5’ cable
- Axial forces will be applied to superstructure
Precast girder anchorage

- Minimize damage to reinforcing steel
Restrainer at pier

- Provide positive connection at pier
- When joint closes, restrainer must resist mass from both spans
Restrainer orientation

- Place in direction of movement
  - Rigid supports
  - Flexible supports
EXAMPLE
Cable restrainer design (non iterative procedure)

- Single step method
  - 1) Calculate maximum allowable expansion joint displ.
  - 2) Compute unrestrained relative expansion joint displ.
  - 3) Find required restrainer stiffness
  - 4) Calculate number of required restrainers

- Valid if:
  - Ratio of structural periods > 0.6 \( \left( \frac{T_{\text{small}}}{T_{\text{large}}} \right) \)
  - Ratio of restrainer capacity/unrestrained capacity is between 0.2 and 0.5
Structural configuration

$W_1 = 5000 \text{ kip}$

$W_2 = 5000 \text{ kip}$

$K_1 = 2040 \text{ k/in}$

$K_2 = 914 \text{ k/in}$
Seat length (N) = 10”
Concrete cover (dc) = 2”
Restrainer yield stress (fy) = 176 ksi
Restrainer mod of elast (E) = 10000 ksi (pre tension)
Restrainer length (Lr) = 9.8 ft
Restrainer slack (Drs) = 1”
Displacement ductility (μ) = 4
Frame stiffness (k1 & k2) = 2040 k/in and 914 k/in
Frame weight (w1=w2) = 5000 kip
Acceleration coefficients

Response spectral acceleration, $S_a$

$S_{DS} = F_a \quad S_a = 1.75 \text{ g}$

$S_a = S_{D1}/T$

$S_{D1} = F_v \quad S_1 = 0.7 \text{ g}$

Period, $T$ seconds
1) Maximum expansion joint displacement

- Step 1) Restrainer elongation at yield
  \[ D_y := f_y \cdot \frac{L_r \cdot 12}{E} \]
  \[ = 176 \times (9.8\times12)/10000 \]
  \[ = 2.07 \text{ in} \]

- Displacement capacity of restrainer
  \[ D_r := D_y + D_{rs} \]
  \[ = 2.07 + 1 = 3.07 \text{ in} \]

- Available seat length
  \[ D_{as} := N - \text{gap} - 2 \cdot d_c \]
  \[ = 10 - 1 - (2 \times 2) = 5 \text{ in} \]

- Check if restrainer elongation is ok
  (is restrainer capacity << seat length)
  \[ \frac{2}{3} \cdot D_{as} = 3.33 \text{ in} \]

OK – continue with design
2) Unrestrained relative expansion joint displacement

- Joint displacement without restrainers
- pier 1

\[ k_{\text{eff}_1} := \frac{k_1}{\mu} \quad 2040/4 = k_{\text{eff}_1} = 510 \frac{\text{kip}}{\text{in}} \]

- pier 2

\[ k_{\text{eff}_2} := \frac{k_2}{\mu} \quad 914/4 = k_{\text{eff}_2} = 228.5 \frac{\text{kip}}{\text{in}} \]
2) Unrestrained relative expansion joint displacement

- Natural period
  - frame 1
    \[ \omega_1 := \sqrt{\frac{k_{\text{eff}_1}}{W_1 \cdot \frac{1}{g \cdot 12}}} \]
    \[ \omega_1 = 6.28 \text{ rad/sec} \]
  - frame 2
    \[ \omega_2 := \sqrt{\frac{k_{\text{eff}_2}}{W_2 \cdot \frac{1}{g \cdot 12}}} \]
    \[ \omega_2 = 4.2 \text{ rad/sec} \]

Teff_1 := \frac{2 \cdot \pi}{\omega_1}

Teff_1 = 1 \text{ sec}

Teff_2 := \frac{2 \cdot \pi}{\omega_2}

Teff_2 = 1.5 \text{ sec}
3) Required restrainer stiffness

- Damping coefficient

\[
\xi_{\text{eff}} := .05 + \frac{.95}{\sqrt{\mu}} - .05 \cdot \sqrt{\mu}
\]

\[
\xi_{\text{eff}} = 0.19
\]

- Correct 5% damping in response spectrum

\[
c_d := \frac{1.5}{40 \cdot \xi_{\text{eff}} + 1} + .5
\]

\[
c_d = 0.68
\]
3) Required restrainer stiffness

Response spectrum accelerations (5% damping)

- $S_{DS} = F_a \quad S_a = 1.75 \, g$
- $S_a = S_{D1}/T$
- $S_{D1} = F_v \quad S_1 = 0.7 \, g$

<table>
<thead>
<tr>
<th>Period, $T$ seconds</th>
<th>$S_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 sec</td>
<td>0.7</td>
</tr>
<tr>
<td>1.5 sec</td>
<td>0.47</td>
</tr>
</tbody>
</table>

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3) Required restrainer stiffness

- Unrestrained deflections

- Span 1

\[ F_1 := \frac{W_1}{g \cdot 12} \cdot \left[ \frac{FvS1}{Teff_1} \cdot (12g) \cdot c \cdot d \right] \]

\[ F_1 = 2372.19 \text{ kip} \]

- Span 2

\[ F_2 := \frac{W_2}{g \cdot 12} \cdot \left[ \frac{FvS1}{Teff_2} \cdot (12g) \cdot c \cdot d \right] \]

\[ F_2 = 1587.84 \text{ kip} \]

\[ D_1 := \frac{F_1}{k_{eff_1}} \]

\[ D_1 = 4.65 \text{ in} \]

\[ D_2 := \frac{F_2}{k_{eff_2}} \]

\[ D_2 = 6.95 \text{ in} \]
3) Required restrainer stiffness

- Relative displacement demand (SRSS or CQC)
  \[ D_{eq0} := \sqrt{D_1^2 + D_2^2} \quad D_{eq0} = 8.36 \text{ in} \]

- Check displacement with available seat
  \[ D_{eq0} = 8.36 \text{ in} \quad \frac{2}{3}D_{as} = 3.33 \text{ in} \]

  \text{NG}

  Restrainers required
3) Required restrainer stiffness

- Check if non-iterative procedure is valid
  - Ratio of periods
    \[
    \frac{T_{\text{eff.1}}}{T_{\text{eff.2}}} = 0.67 - >?? 0.6 \quad \text{OK}
    \]
  - (Restrained displacement capacity/unrestrained displacement demand) ratio
    \[
    \eta := \frac{D_r}{D_{\text{eq0}}} = \frac{3.07}{8.36} = \eta = 0.37\quad \text{Between 0.2 and 0.5 OK}
    \]
Structural Model

Frame stiffness and mass-(stiffness is in series)

Restrainer stiffness $k_r$

Frame 1- mass $m_1$

Frame 2- mass $m_2$

Frame 1 stiffness $k_1$

Frame 2 stiffness $k_2$
4) Number of restrainers required

- Area of restrainer
  \[ A_r := .222 \text{ in}^2 \]

- Number required
  \[ N_r := \frac{K_r \cdot D_r}{f_y \cdot A_r} \]

\[ K_r := K_{\text{eff}_{\text{mod}}} \left( .5 + \frac{.5 - \eta^2}{\eta} \right) \]

\[ 1/k_{\text{eff}_{\text{mod}}} = 1/k_1 + 1/k_2 \]
4) Number of restrainers

- Required restrainer stiffness

\[ Kr := K_{\text{eff_mod}} \left( 0.5 + \frac{0.5 - \eta^2}{\eta} \right) \]

\[ Kr = 235.89 \text{ kip/in} \]

- Required number of restrainers

\[ f_y \cdot A_r \cdot N_r = Kr \cdot Dr \]

\[ Nr = \frac{235.89 \times 3.07}{176 \times 0.22} \]

\[ N_r = 18.53 \]

Say 20 to be symmetrical
## Comparison with “CQC” method

<table>
<thead>
<tr>
<th>Item</th>
<th>SRSS</th>
<th>CQC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative displacement</td>
<td>8.36”</td>
<td>9.8”</td>
</tr>
<tr>
<td>Displacement ratio</td>
<td>0.37</td>
<td>0.48</td>
</tr>
<tr>
<td>Restrainer stiffness</td>
<td>256 k/in</td>
<td>165 k/in</td>
</tr>
<tr>
<td># of restrainers</td>
<td>19</td>
<td>14</td>
</tr>
</tbody>
</table>
Transverse restrainers

- Vulnerable conditions
  - High concrete pedestals
  - Narrow bearing seats
  - Highly skewed seats
  - Steel rockers
  - Transverse edge distance
Transverse shear keys

- Design to remain elastic
- Diaphragms must transfer the force
Vertical motion restrainers

- Prevent uplift when DL < EQ (vertical)
- Not economical unless additional retrofit is performed
# Vertical motion restrainers

<table>
<thead>
<tr>
<th>Member Force / Moment</th>
<th>Distance from Fault (km), D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 ≤ D &lt; 10</td>
</tr>
<tr>
<td>Pier axial force</td>
<td>0.7</td>
</tr>
<tr>
<td>Superstructure shear force at pier</td>
<td>0.7</td>
</tr>
<tr>
<td>Superstructure bending moment at pier</td>
<td>0.6</td>
</tr>
<tr>
<td>Superstructure shear force at mid-span</td>
<td>0.1</td>
</tr>
<tr>
<td>Superstructure bending moment at mid-span</td>
<td>1.4</td>
</tr>
</tbody>
</table>

**Note:**
The dead load multipliers given above are in addition to the dead load. Thus the actual ‘load factor’ is 1.0 plus/minus the tabulated values.

Vertical Load = (1 ± Cv) DL
Summary

- Describe typical retrofit measures for:
  - Bridge decks and girders
  - Bearings, anchorages and pedestals
  - Expansion joints
What questions do you have?