Development of Fragility Curves to Evaluate the Retrofit of a Highway Bridge in Quebec

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Presentation Plan

- Introduction
- Retrofit using seismic isolation
- Methodology
- Deterministic Analysis
- Analytical Fragility Curves
Introduction

Bridges

- Structural Simplicity
- Behavior Easy to Predict
- Recent Earthquake Damage
- Transportation system
  Most vulnerable component

Bridges in Quebec

- The most vulnerable component
- Most recent earthquakes in Quebec
- Seismic Design Standards
  Early stage of development
  Changes
    - NBCC 2005
    - Increase in earthquake hazard for some regions
  Seismically deficient
    - vulnerability assessment
    - Challenges: upgrading, rehabilitation
Fragility Curves

✓ **Statistical Tool**

*Define the probability of damage*

✓ **Beyond a given level**

*damage states*

*physical meaning – functionality*

✓ **According to an intensity measure**

*(PGA, PGV, Sa(0.1), Sa(tm))*

✓ **Seismic Vulnerability Assessment**

✓ **Uncertainties Demand/Capacity**

✓ **Strategical Post-Earthquake decisions**

✓ **Effectiveness of Retrofit Measure**
Seismic Isolation Retrofit

Seismic Isolation

- Effective Method:
  - Protection
  - Rehabilitation
- Periodic Shift
- Protection of foundation elements:
  - Remain in elastic range
- Increase displacement
- Alternative: damping

Increasing Damping

Base Shear / Weight

Period (s)

Displacement

Increasing Damping
Seismic Isolation Retrofit
Seismic Isolation Retrofit

Elastomeric Devices
- Natural Rubber Bearings (NRB)
- High Damping Rubber Bearings (HDRB)
- Lead-Rubber Bearings (LRB)

Properties
- Moduli: shear (G) and compression
  - $G \rightarrow 0.4$ to $1.4$ MPa
- Damping rate
  - 5 to 10% (NRB)
  - 10 to 25% (LRB/HDRB)
  - Up to 30% (Special attention - analysis)
- Hardness (Shore “A”)
  - Related to Shear (G) and Compression (Ec)
  - 50 to 70 (EUA)/ 55 ± 5 (CAN)
- Rupture Tensile Strain
- Tensile Strength
- Scragging
- Crystallization stiffening (Temperature and Strain)
Seismic Isolation Retrofit

Mecanical Properties Calculation

✓ Shear Stiffness

\[ K_H = \frac{G \times A_r}{T_r} \]

✓ Compression Stiffness

\[ K_V = \frac{E_c \times A_r}{T_r} \]

\[ E_c = 6.0 \times G \times S^2 \]

✓ S – Shape Factor

✓ 10 to 20

\[ S = \frac{l_1 \times l_2}{2 \times t \times (l_1 + l_2)} \]

\[ S = \frac{D}{4 \times t} \]
Seismic Isolation Retrofit

Behavior

\[ d_i = \frac{250AS_iT_e}{B} \]

\[ T_e = \frac{2\pi}{20} \sqrt{\frac{W}{K_{eff}^40 \times g}} \]
Methodology

BRIDGE

Bridge 3D Non-linear FE Model

SEISMIC HAZARD

Ground Motion Time History Series

LIMIT STATES

Damage Levels and Limit States

Dynamic Non-Linear Time History Analysis

Damage Distributions

Capacity Distributions

Fragility Curves Generation
Methodology

Bridge Simulation – Chemin des Dalles Bridge

✓ CRGP Studies
  ✓ Dynamic In-situ Tests
  ✓ Roy 2006 – CFRP Reinforcement

Length = 106.5m
Deck Slab = 0.17m
H columns = 6.2m
2 Transverse Beams = conventional concrete 31.0MPa
6 Longitudinal Girders = Prestressed concrete

Width = 13.2m
Dist. Bents = 35.5m
Diam. columns = 0.914m
Bents – Shallow Foundations
Abutments – Wing Walls
Methodology

Bridge Simulation – Chemin des Dalles Bridge

- Perspective model
- 2D and 3D views
- Bridge elevation
- Bent section
- Superstructure model details
- Seismic isolator model
Methodology

Seismic Hazard

✓ NBCC 2005 – UHS 2% - 50 years

✓ Atkinson 2009 - Compatible Ground Motion Time-Histories (GMTH)

✓ Different Soil Conditions
  ✓ Very dense soil and soft rock (Soil C)

✓ Eastern Canada
  ✓ Magnitude 6 (45 x 2)
    ✓ M6 Set 1 – Fault-distances 10-15 km
    ✓ M6 Set 2 – Fault-distances 20-30 km
  ✓ Magnitude 7 (45 x 2)
    ✓ M7 Set 1 – Fault-distances 15-25 km
    ✓ M7 Set 2 – Fault-distances 50-100 km
Methodology

Characterization of Damage

✓ Essential - Not Trivial Task
  ✓ Limit States Definition
  ✓ Qualitative or Functional Interpretations – Damage level after an Earthquake

✓ In this Study Columns - HAZUS 2003
  ✓ Slight: minor spalling (cosmetic repair);
  ✓ Moderate: moderate cracking (shear cracks) and spalling;
  ✓ Extensive: column degrading without collapse (shear failure – structurally unsafe);
  ✓ Complete: column collapsing.

✓ Quantitative measures
  ✓ Most used – Column ductility
    ✓ Displacement ductility
    ✓ Curvature ductility
  ✓ Column Drift

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Sectional analysis - MNPHi
28.5mm 34.2mm 50.2mm 85.0mm
Modal Analysis

As-Built

Mode 1 – Tran 0.379s

As-Built

Mode 2 – Vert 0.315s

Isolated

Mode 1 – Long 1.86s

Deterministic Analysis

Isolated

Mode 2 – Tran 1.626s
Deterministic Analysis

Time-History Analysis

✓ Magnitude 7 (distance 15.0 Km)

Top Column Disp. 28.8mm

LS Extensive - Structurally Unsafe
Cosmetic Repair

-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
0 2 4 6 8 10 12
Acceleration (g)
Temps (s)

0.844 g

b) Middle-center deck
Analytical Fragility Curves

Seismic Fragility

\( C \) (capacity) – related to LS  
\( D \) (demand) – related to the response GMTH

\[
P_f = \Phi \left[ \frac{\ln(\frac{S_d}{S_c})}{\sqrt{\beta_d^2 + \beta_c^2}} \right]
\]

\( \Phi[\cdot] \) – standard normal distribution function  
\( S_d, S_c \) – mean structural demand and capacity  
\( \beta_d, \beta_c \) – logarithmic standard deviation

180 pairs bridge/GMTH

Peak Responses Projected Into a Lognormal Space

\[ \ln(S_d) = \ln(a) + b \cdot \ln(IM) \]
Analytical Fragility Curves

Fragility Curves

With $C/D$
Obrigado!!!
Thank You!!!
Questions?!

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