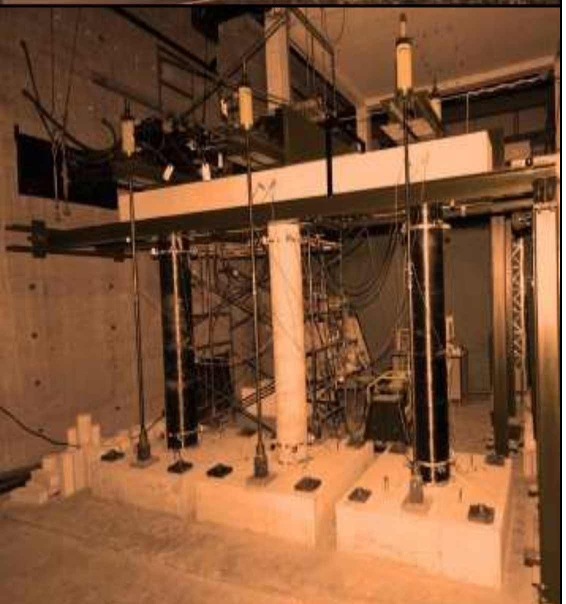

Development of Fragility Curves to Evaluate the Retrofit of a Highway Bridge in Quebec

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Presentation Plan

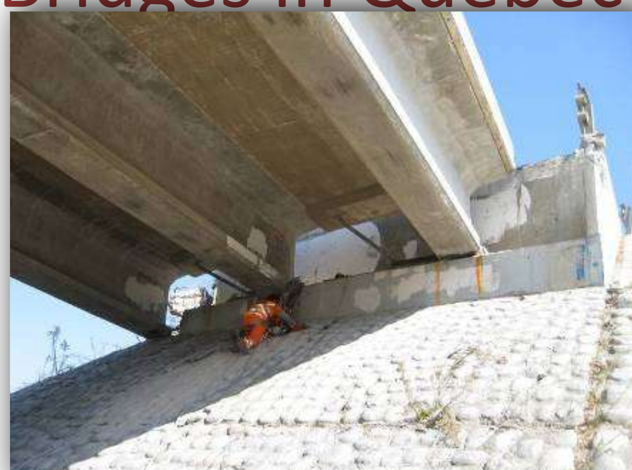
- ✓ Introduction
- ✓ Retrofit using seismic isolation
- ✓ Methodology
- ✓ Deterministic Analysis
- ✓ Analytical Fragility Curves

Introduction

Bridges

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

Bridges in Quebec



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Introduction

Fragility Curves

- ✓ *Statistical Tool*

  Define the probability of damage

  - ✓ *Beyond a given level*

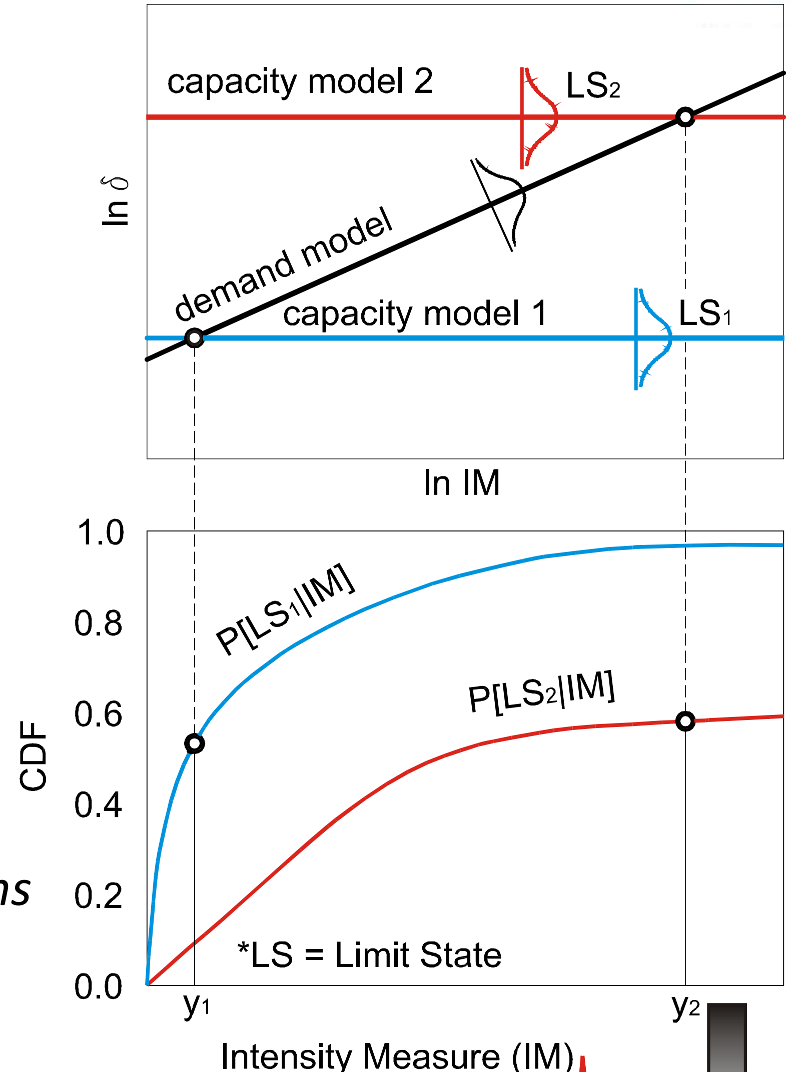
    damage states

    physical meaning – functionality

  - ✓ *According to an intensity measure*

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

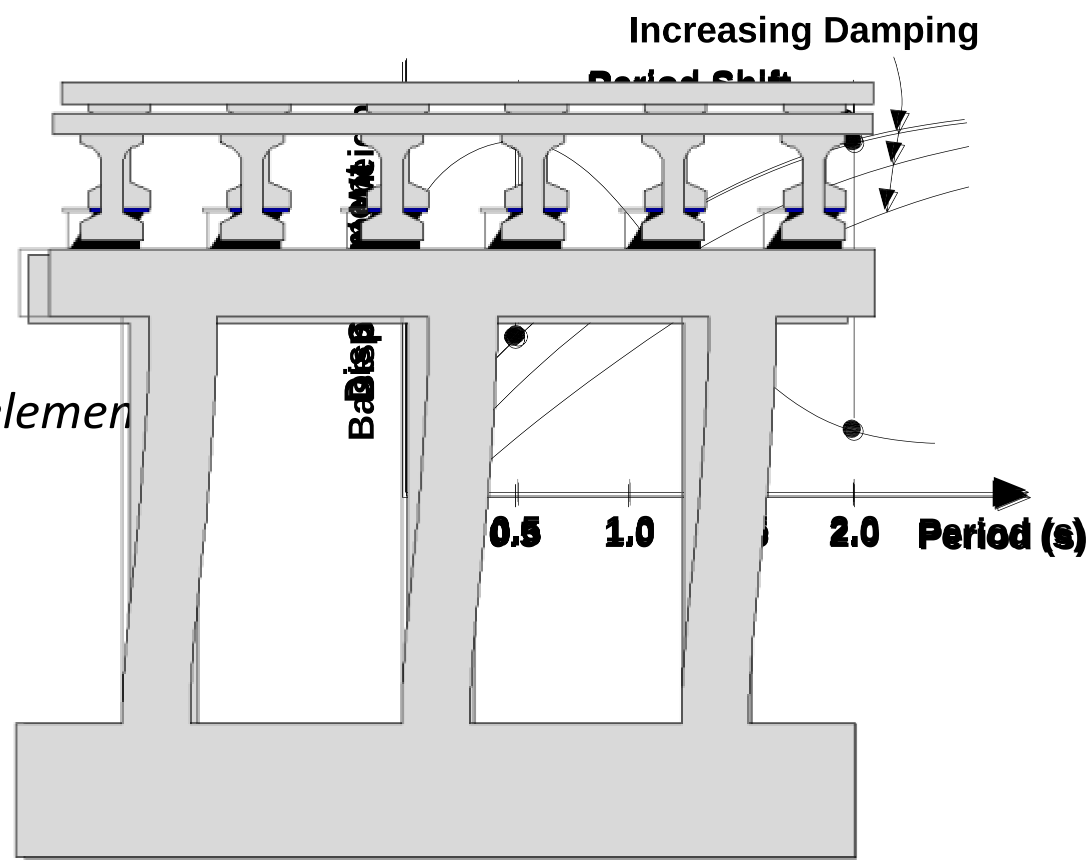
- ✓ *Seismic Vulnerability Assessment*
- ✓ *Uncertainties Demand/Capacity*
- ✓ *Strategical Post-Earthquake decisions*
- ✓ *Effectiveness of Retrofit Measure*



Seismic Isolation Retrofit

Seismic Isolation

- ✓ *Effective Methode :*
  - ✓ *Protection*
  - ✓ *Rehabilitation*
- ✓ *Periode Shift*
- ✓ *Protection of foundation elemen*
  - ✓ *Remain in elastic range*
- ✓ *Increase displacement*
- ✓ *Alternative: damping*

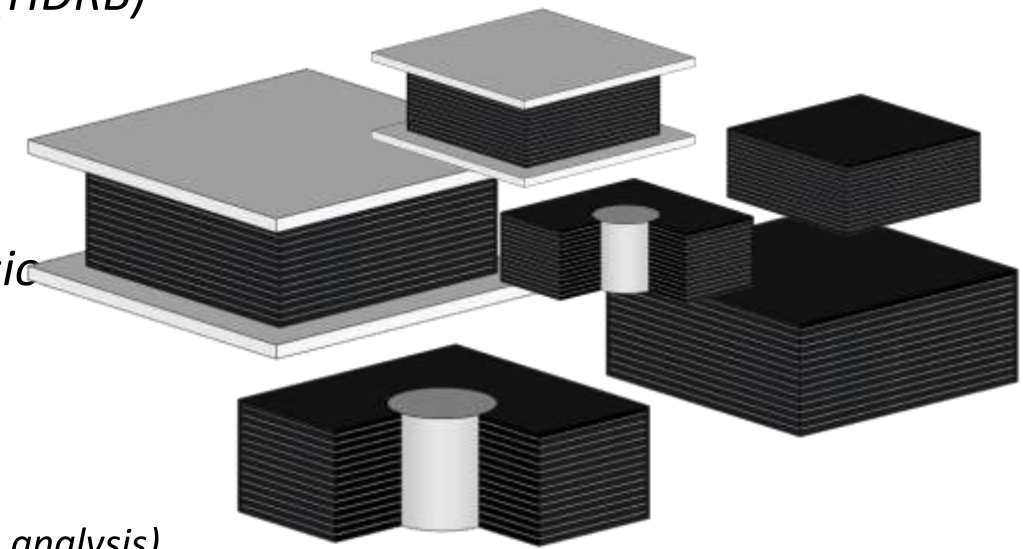


Seismic Isolation Retrofit

Seismic Isolation Retrofit

Elastomeric Devices

- ✓ *Natural Rubber Bearings (NRB)*
- ✓ *High Damping Rubber Bearings (HDRB)*
- ✓ *Lead-Rubber Bearings (LRB)*



Properties

- ✓ *Moduli : shear (G) and compressic*
  - ✓ *G → 0.4 to 1.4MPa*
- ✓ *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 (E_c)*
  - ✓ *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

$$K_V = \frac{E_c \times A_r}{T_r}$$

$$E_c = 6.0 \times G \times S^2$$

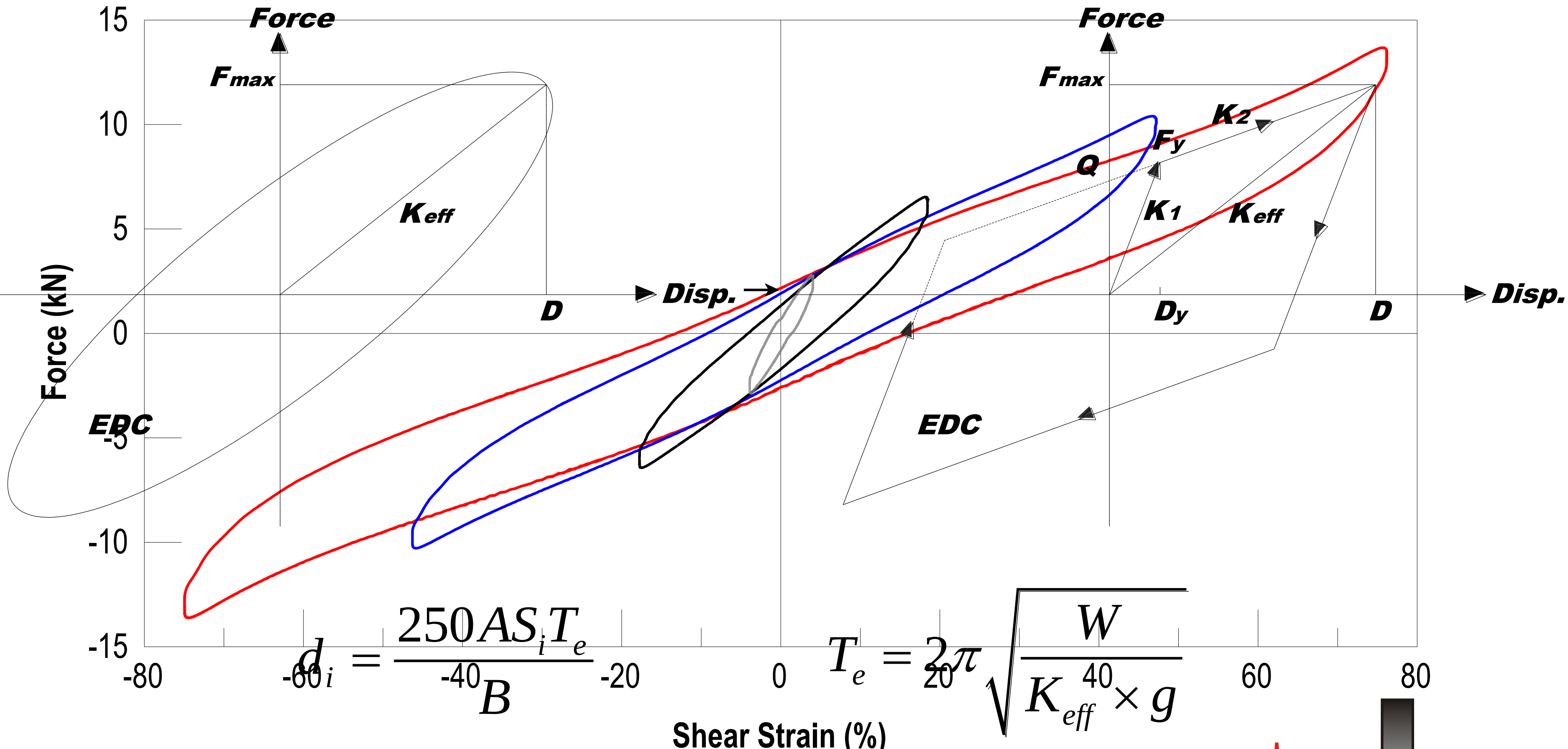
- ✓ S – Shape Factor
  - ✓ 10 to 20

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

$$S = \frac{D}{4 \times t}$$

Seismic Isolation Retrofit

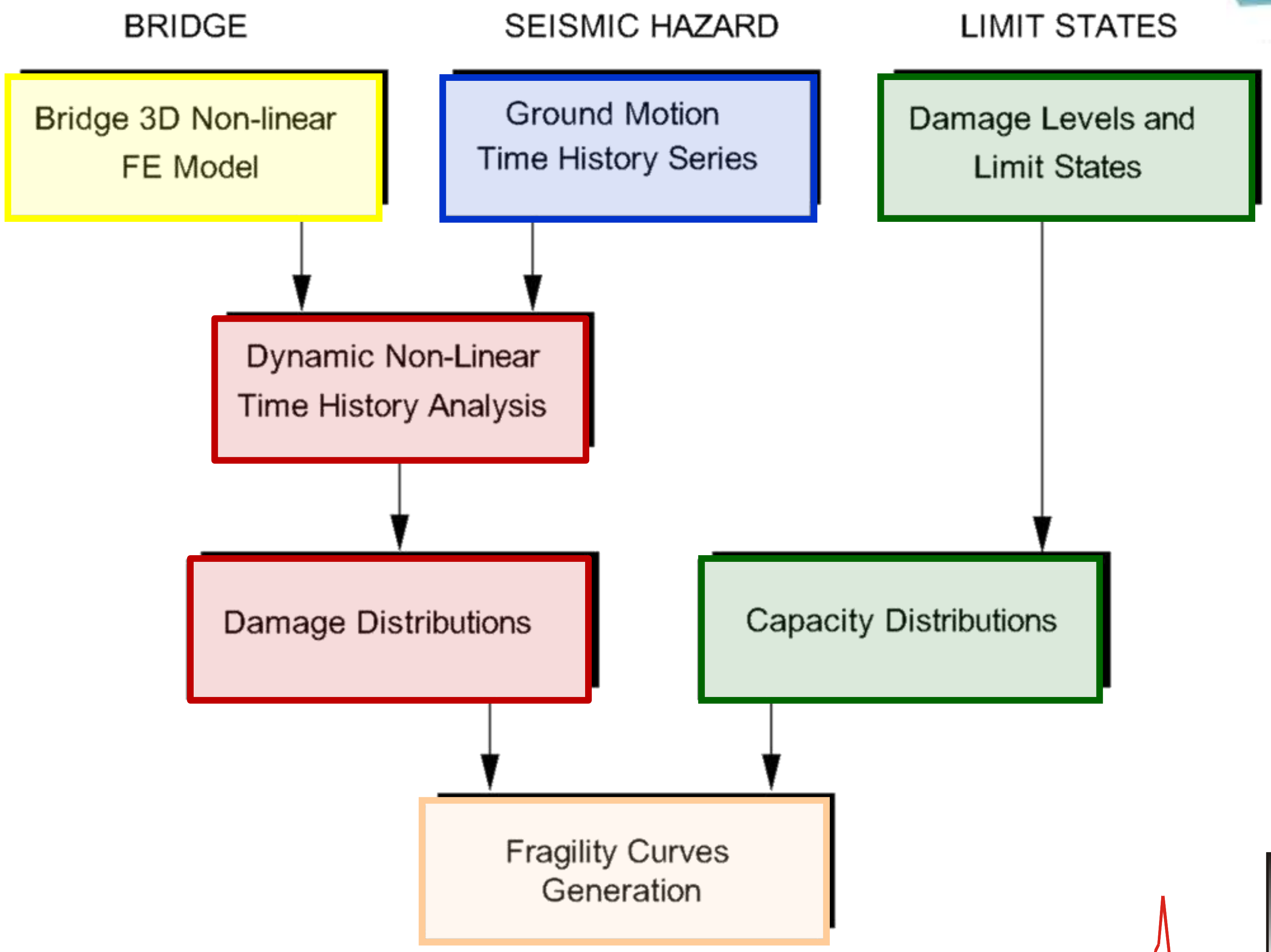
Behavior



$$d_i = \frac{250 A S_i T_e}{B}$$

$$T_e = 2\pi \sqrt{\frac{W}{K_{eff} \times g}}$$

Methodology



Methodology

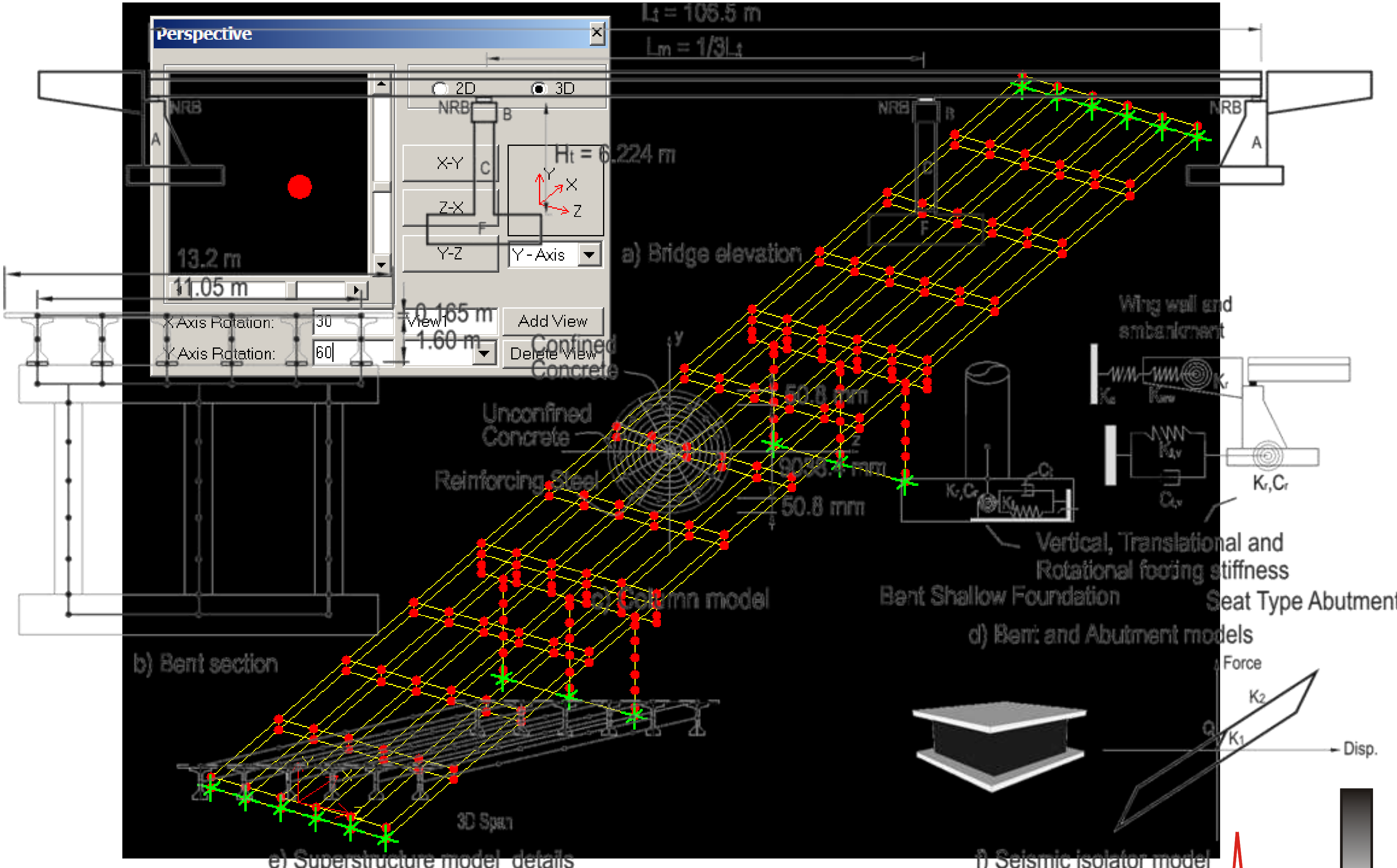
Bridge Simulation – Chemin des Dalles Bridge

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

Length = 106.5m | **Width = 13.2m**
Deck Slab = 0.17m | **Dist. Bents = 35.5m**
H columns = 6.2m | **Diam. columns = 0.914m**
2 Transverse Beams = conventional concrete 31.0MPa
6 Longitudinal Girders = Prestressed concrete
Bents – Shallow Foundations
Abutments – Wing Walls

Methodology

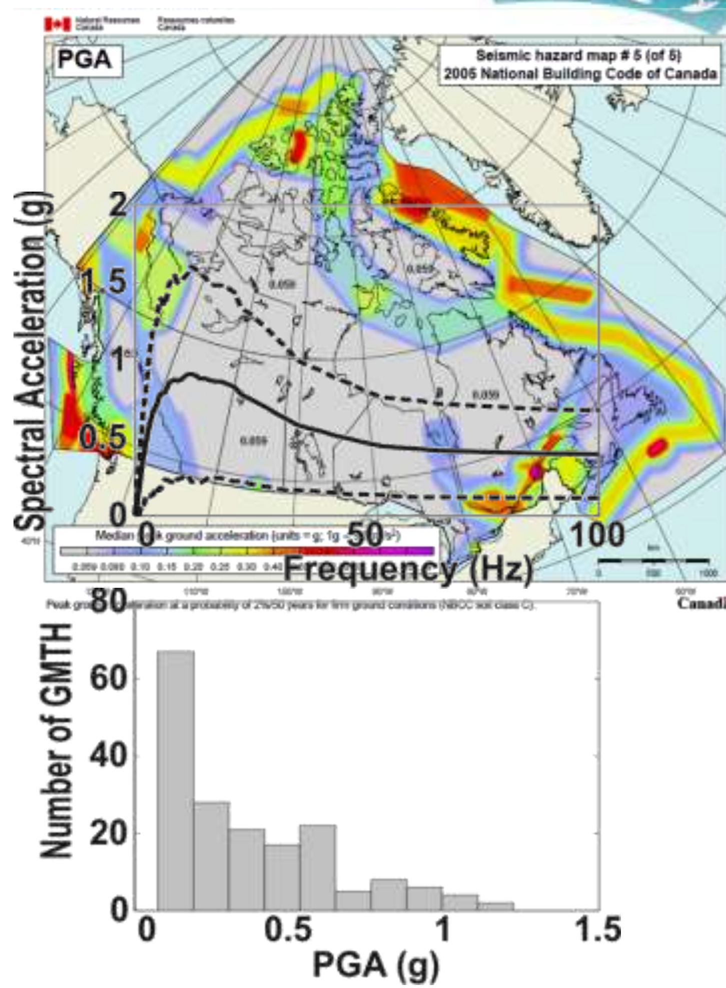
Bridge Simulation – Chemin des Dalles Bridge



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 faillure – structurally unsafe);*
  - *Complete: column collapsing.*

- *Quantitative measures*
  - *Most used – Column ductility*
    - *Displacement ductility*
    - *Curvature ductility*
  - *Column Drift*

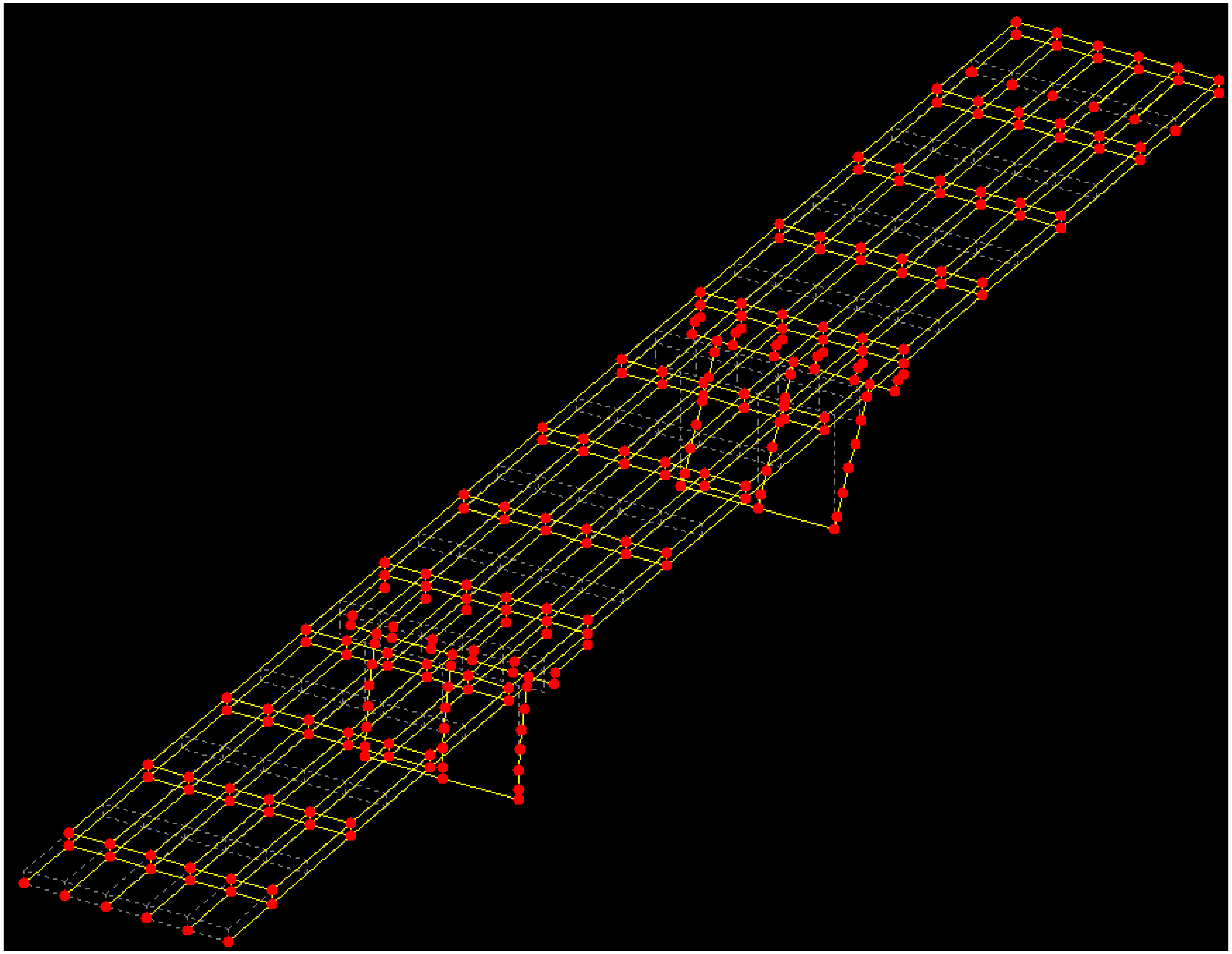
S	M	E	C
1.0	1.2	1.76	3.0

Sectional analysis - MNPHi

28.5mm	34.2mm	50.2mm	85.0mm

Deterministic Analysis

Modal Analysis



As-Built

Mode 1 – Long

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Deterministic Analysis

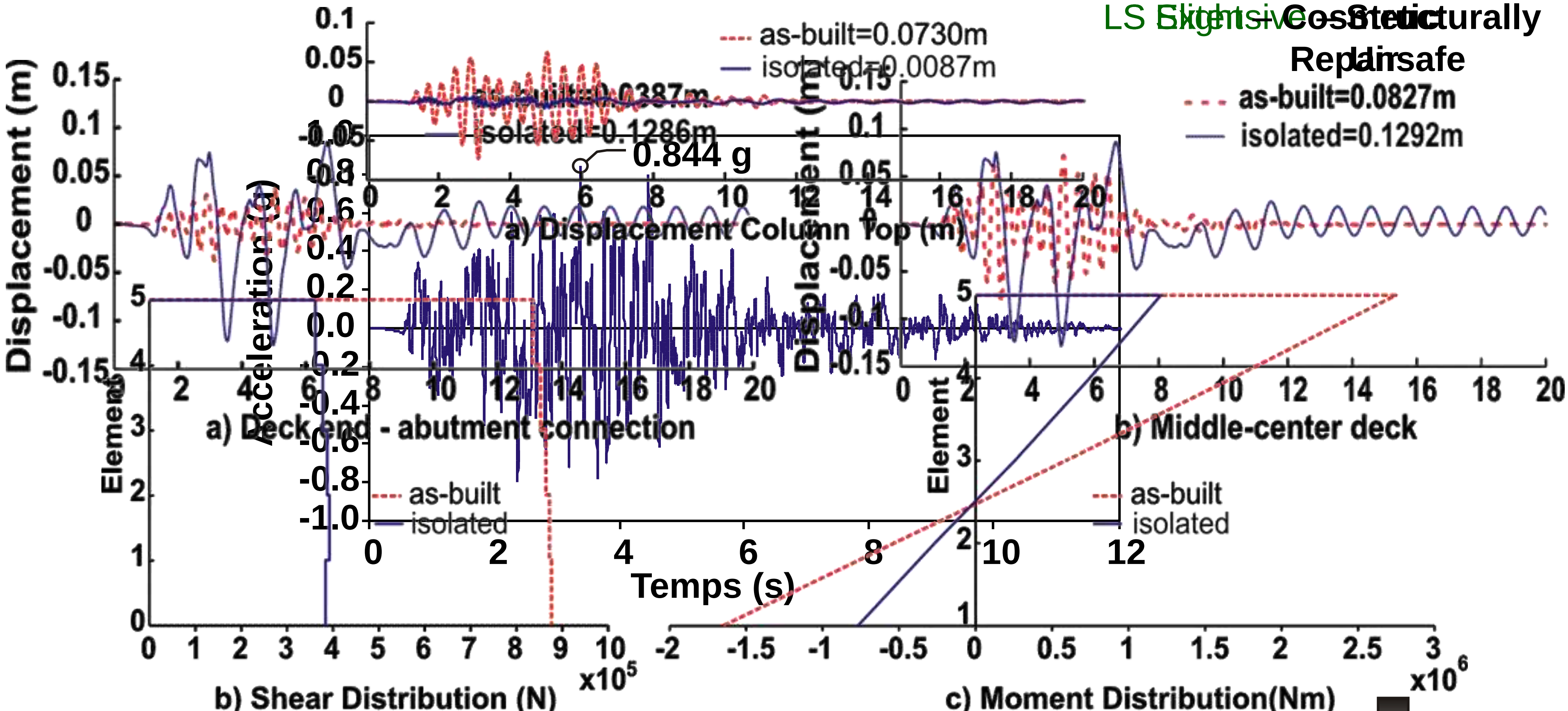
Time-History Analysis

- ✓ *Magnitude 7 (distance 15.0 Km)*

Top Column Disp. 28.2mm

LS Slight – Cosmetic Repair

LS Extensive – Structurally Unsafe



Analytical Fragility Curves

Seismic Fragility

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

→ *Represented as Lognormal Distributions*

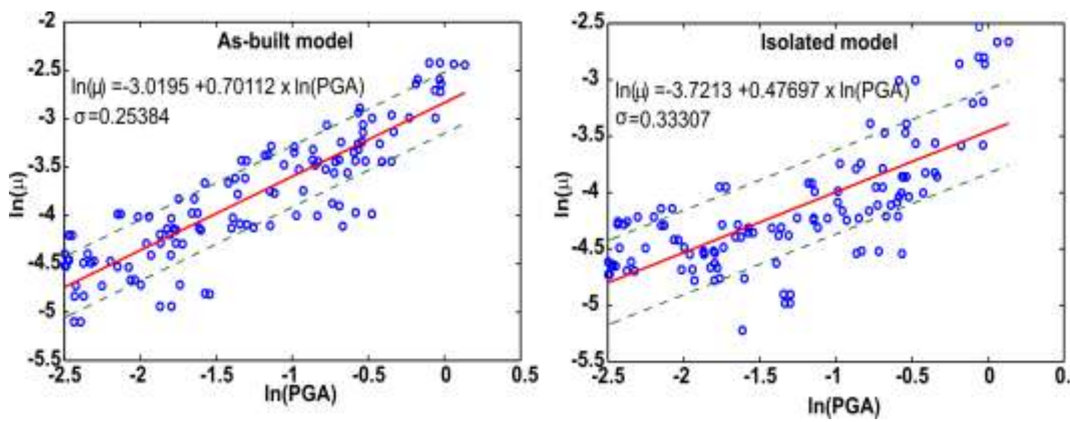
$$P_f = \Phi\left[\frac{\ln(S_d / S_c)}{\sqrt{\beta_d^2 + \beta_c^2}}\right]$$

$\Phi[\cdot]$ – *standard normal distribution function*

S_d, S_c – *mean structural demand and capacity*

β_d, β_c – *logarithmic standard deviation*

180 pairs bridge/GMTH



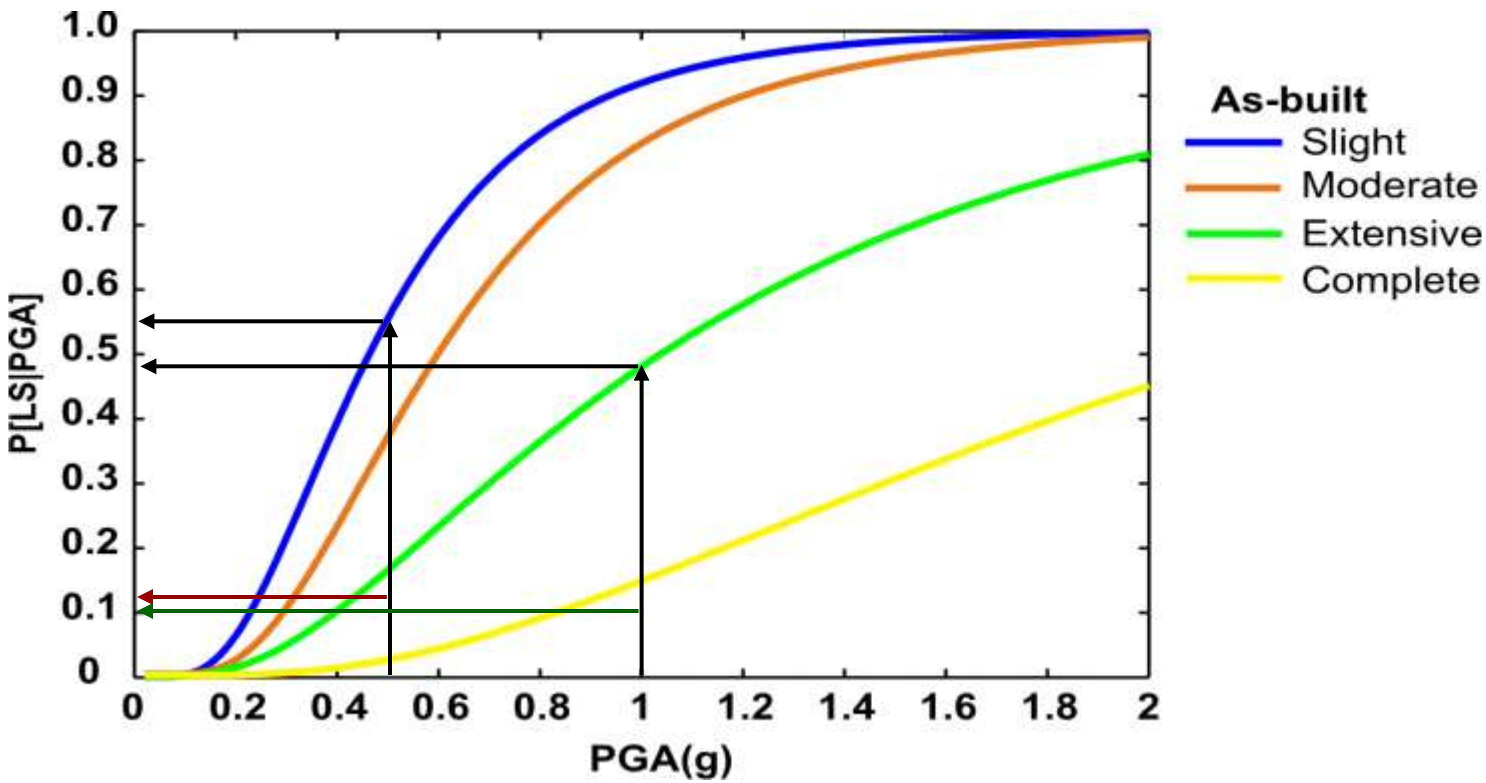
Peak Responses Projected Into a Lognormal Space

$$\ln(S_d) = \ln(a) + b.\ln(IM)$$

Analytical Fragility Curves

Fragility Curves

*With **C**/**D***



Obrigado!!!

Thank You!!!

Questions?!

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