A Brief Overview Of Seismic Isolation Bridge Projects

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Presented by:

Sylvain Montminy, P. Eng., ing.

Structures Division Manager and Senior Principal with Delcan

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Seismically Evaluated Bridges

Multi-modal Spectral Analysis and Time Histories

Multi-modal Spectral Analysis (Lifeline and Emergency Route Bridges)

- Macdonald Cartier Bridge
- Lower Liard Suspension Bridge
- Bytown Bridges
- Heron Road Bridges
- Pretoria Avenue Lift Bridge
- Lemieux Island Bridges
- Madawaska River Bridge
- King Edward Avenue Redpath Road Overpass
- Bainsville Road Highway 401 Underpass
- Township Road Highway 401 Underpass
- Sutherland Creek Highway 401 Bridge
- Westley Road Highway 401 Underpass
- County Road 2 Highway 401 Underpass

Time History Analysis (Lifeline and Emergency Route Bridges)

- Heron Road Bridges
- A25 Main Cable Stayed Bridge

New Bridge Designs using Seismic Isolation

- Regional Road 22 Highway 417 Underpass
- Strandherd Armstrong Bridge
- King Edward Overpasses
- Bytown Bridges
- A25 Main Cable Stayed Bridge

Seismic Retrofitting of Existing Bridges using Isolation

- Heron Road Bridges
- Lemieux Island Road and Pipeline Bridges

BYTOWN BRIDGES

ORIGINAL BYTOWN BRIDGES

General Info

Year Built: 1954

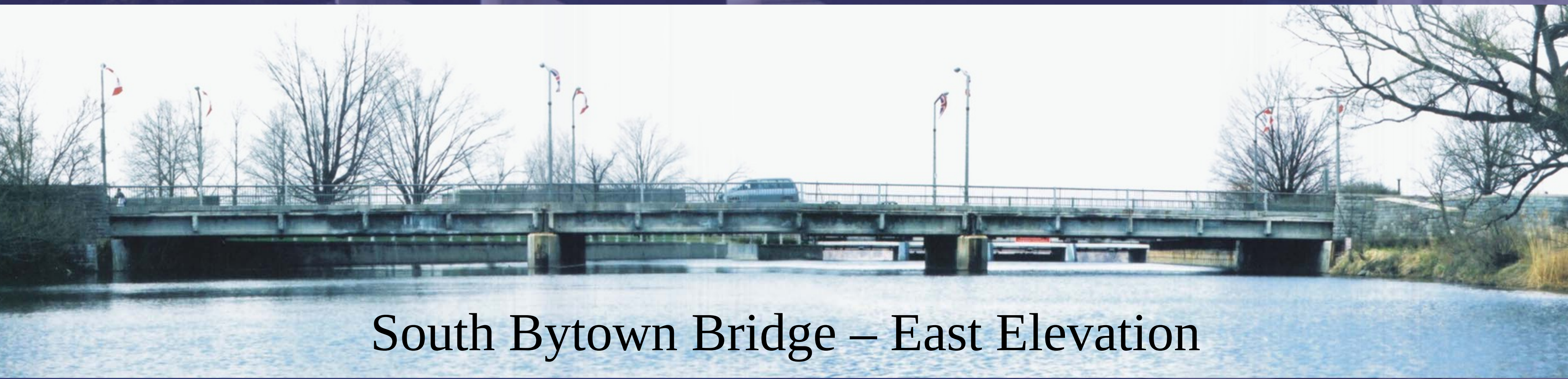
Spans: 3 spans each

Total Length: North Bridge - 81 m (266 ft)
South Bridge – 69 m (226 ft)

Total Width: 19.9 m (65 ft)

Superstructure: 18 lines of pre-cast prestressed "T" Girders

Substructure: - Wall type concrete piers on bedrock
- Concrete facing over old 1885 masonry abutments



South Bytown Bridge – East Elevation

BRIDGE CONDITION

Repair History

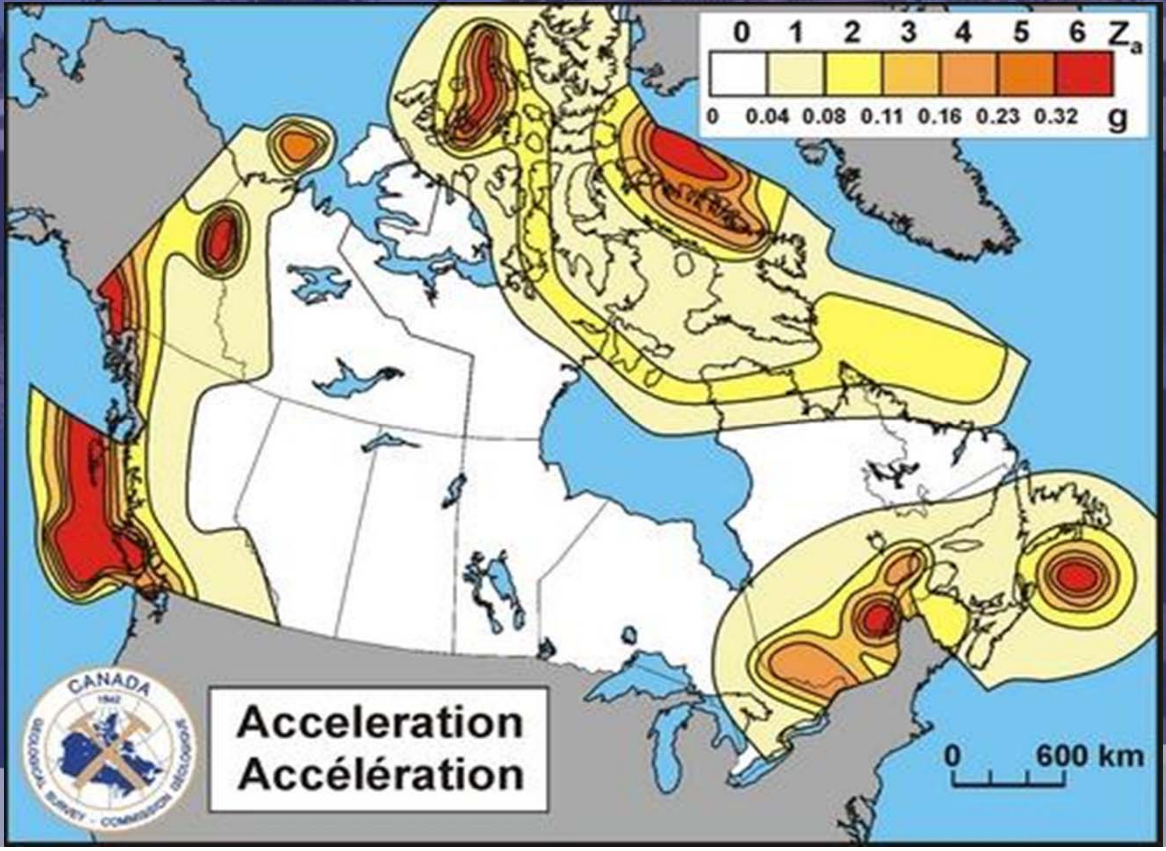
- 1975 Major Rehab (repairs to girders & addition of new concrete topping)
- 1990 Evaluation recommends to load post the bridges and replace them within 5 years
- 1997 & 2001 Emergency removal of failing exterior girders

Observed Deteriorations

- Widespread concrete scaling, delamination & spalling;
- Corrosion of reinforcing steel & prestressing tendons;
- Failed bearings & exp. joints;
- Damaged railing (not to code)
- Impending failure of several girders on South Bridge.

GENERAL SITE SEISMICITY

- Zonal Acceleration Ratio, A of 0.20
- Seismic Performance Zone 3
- Peak ground acceleration 0.16 to 0.23 g
- Site Coefficient, S of 1.0



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DESIGN SEISMIC LOAD

Emergency-Route Bridge

- Emergency vehicles access; Moderate Damage
- 10% probability of exceedance in 50 years (return period of 475 years)
- Importance Factor, I of 1.5

Seismic Design Spectrum

$$C_{sm} = \frac{1.2 \cdot A \cdot I \cdot S}{T_m^{2/3}} \leq 2.5 \cdot A \cdot I$$

- C_{sm} is the Seismic Response Coefficient (g)
- T_m is the Period of Vibration (s)

WHY REPLACE & NOT REHAB

Why Full Replacement of Pier

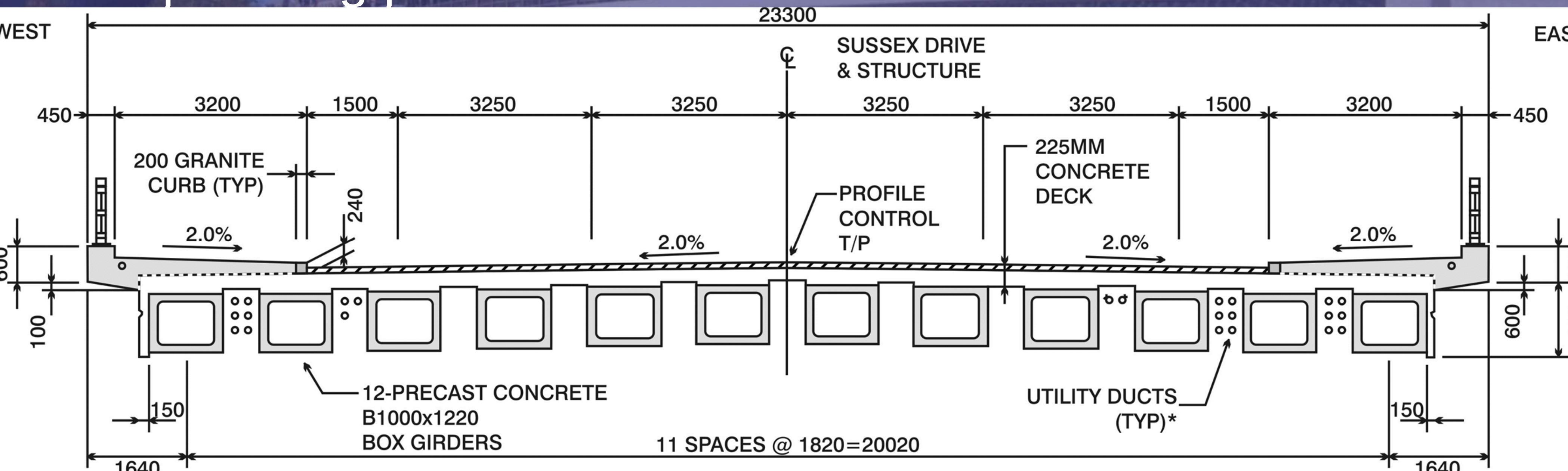
- Preliminary costing revealed the full replacement of the piers to be slightly less costly than the previously described rehabilitation;
- The time required to undertake the required chloride extraction was not feasible due to schedule constraints, and;
- Full replacement allowed for some flexibility with the span layout and pier widths in order to optimize the design.

PREFERRED DESIGN CONCEPT

Preferred Superstructure - Pre-cast Box Girders

Selected as it best satisfied all of the evaluation criteria:

- No requirements for falsework for construction;
- Shorter construction period due to pre-cast;
- No reduction in freeboard, and;
- No perching provision for birds.



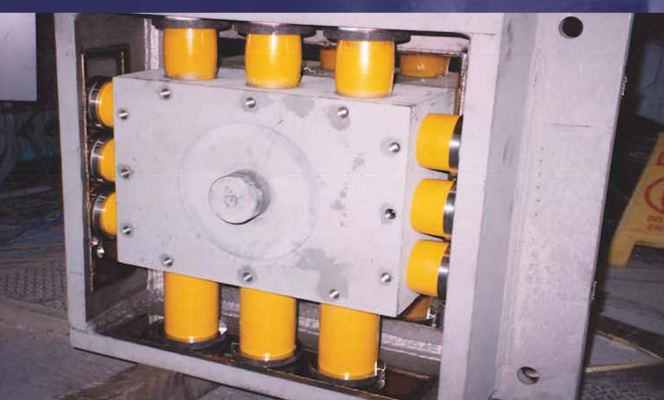
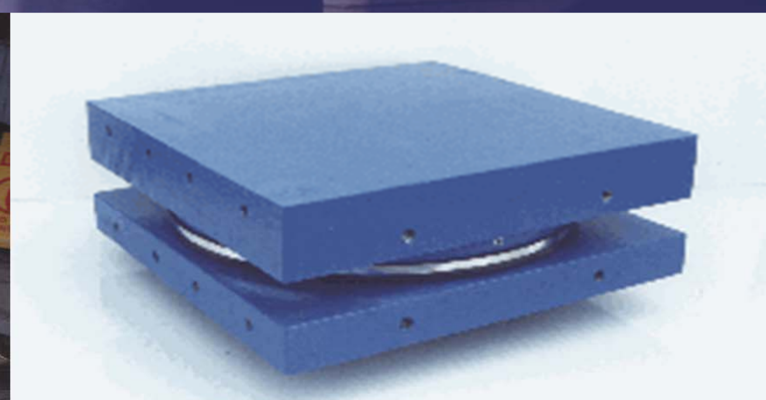
SUBSTRUCTURE SEISMIC DESIGN

Issues with Conventional Seismic Design

- Very short, wide and stiff piers (no ductility);
- Need 82 rock anchors at fixed pier (8 m deep).

Using Seismic Isolation Bearings

- Share the load to all substructure elements;
- Dampen seismic loading & minimize demand on structural members.


BASE ISOLATION ADVANTAGE

Changes to Seismic Response Coefficient (C_{sm})

- Loose the Importance Factor (I)
  - CHBDC indicated : "*design philosophy for isolated bridges already ensures a level of performance for all bridges which is comparable to that required for conventional Lifeline and emergency-route bridges for the design earthquake*."
- Gain Damping Coefficient (B)

$$C_{sm} = \frac{1.2 \cdot A \cdot I \cdot S}{T_m^{2/3}} \leq 2.5 \cdot A \cdot I \quad \text{(CHBDC 4.4.7.1)}$$

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- Gain Damping Coefficient (B)

$$C_{sm} = \frac{A \bullet S_i}{B \bullet T_e} \leq 2.5 \bullet \frac{A}{B}$$

(CHBDC 4.10.6.1)

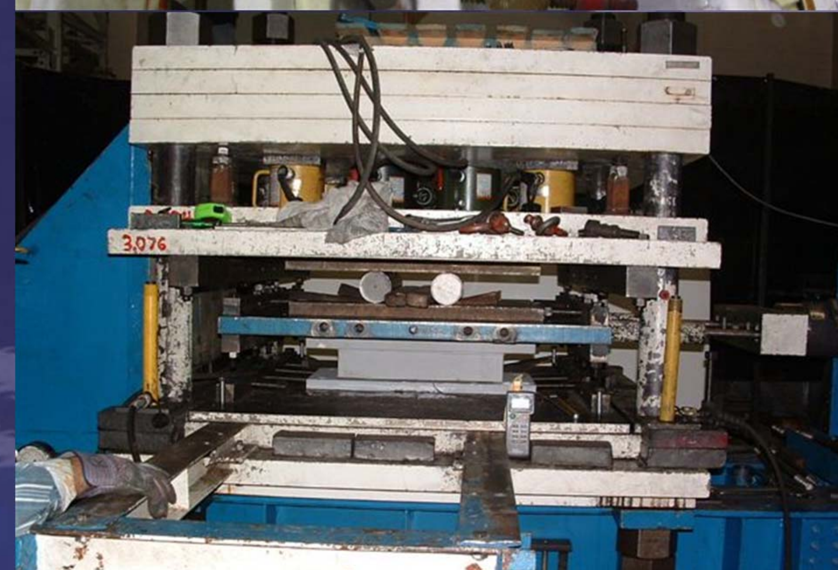
COLD TEMPERATURE TESTING OF SEISMIC ISOLATION BEARINGS

Performance Requirements

- Seismic loading transferred to substructure at -34°C must not exceed 130% the load at 15°C.

Testing of Seismic Bearings

- Seismic performance test on full size production bearings;
- Conditioning bearings to -34°C in freezer for 14 days;
- Subjected to design dead loads with 70% of the design seismic displacements.



HYBRID PRECAST / CAST IN PLACE

What is this Design Concept?

- 1 Isolation Bearing per line of girders per pier;
- Girders initially on blocks;
- Final support through pier diaphragms cast monolithic w/ deck & integral w/ girders.

Why this Innovative Concept?

- Reduce the total quantity of expensive isolation bearings;
- Reduce the required width of piers.

CONSTRUCTION TIMELINE

July 2003 to August 2005

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Seismic Rehabilitation of the Heron Road Bridge

Bridge Location

Workshop on the Seismic Isolation and Damping of Bridge Structures

Seismic Rehabilitation of the Heron Road Bridge

Structure Description

- **Year Built:** 1966/1967
- **Spans:** Twin structures – seven spans each
- **Traffic:** Three lanes in each direction
- **Length:** 267 m (North Structure) / 276 m (South Structure)
- **Superstructure:** Cast-in-place Post-Tensioned voided concrete deck cantilevered to support three suspended spans
- **Substructure:** Six intermediate piers and abutments at ends

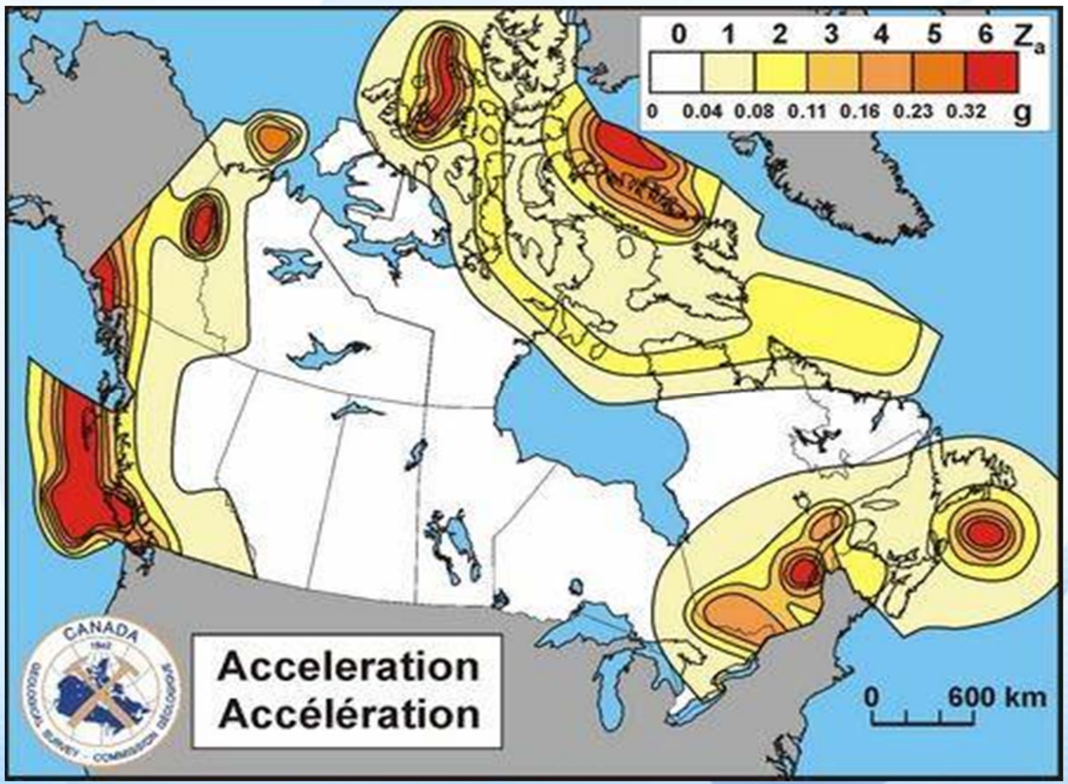
Seismic Rehabilitation of the Heron Road Bridge

Structure Description

Seismic Rehabilitation of the Heron Road Bridge

General Site Seismicity

- Zonal Acceleration Ratio, A of 0.20
- Seismic Performance Zone 3
- Peak ground acceleration 0.16 to 0.23 g
- Emergency-route Bridge, Importance Factor, I =1.5



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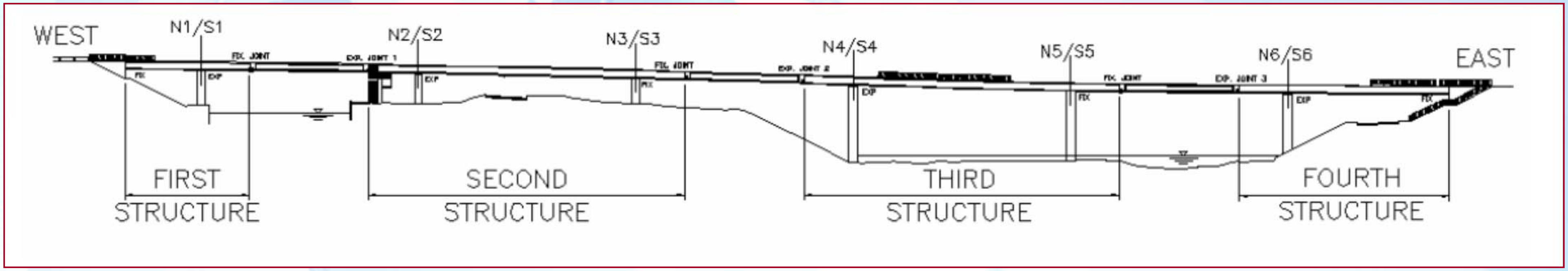
Seismic Rehabilitation of the Heron Road Bridge

Site Conditions



Structure No.	Support	Soil Profile Type / Support	Analytical Model Soil Profile Type	Site Coefficient, S	Site Coefficient for Seismic Isolation ,Si
SOUTH STRUCTURE - East Bound Lane					
1	West Abutment	III	III	1.5	2.0
	Pier S1	III			
2	Pier S2	III	III	1.5	2.0
	Pier S3	II			
3	Pier S4	I	I	1.0	1.0
	Pier S5	I			
4	Pier S6	II	II	1.2	1.5
	East Abutment	II			
NORTH BRIDGE - West Bound Lane					
1	West Abutment	III	III	1.5	2.0
	Pier N1	III			
2	Pier N2	III	III	1.5	2.0
	Pier N3	III			
3	Pier N4	I	II	1.2	1.5
	Pier N5	II			
4	Pier N6	II	II	1.2	1.5
	East Abutment	II			

Seismic Evaluation - Analysis

- Multi-modal analysis
- Simple Spine Model
- Special consideration for multi-gap bridge

  Dual-model tension / compression elastic modal analysis procedure

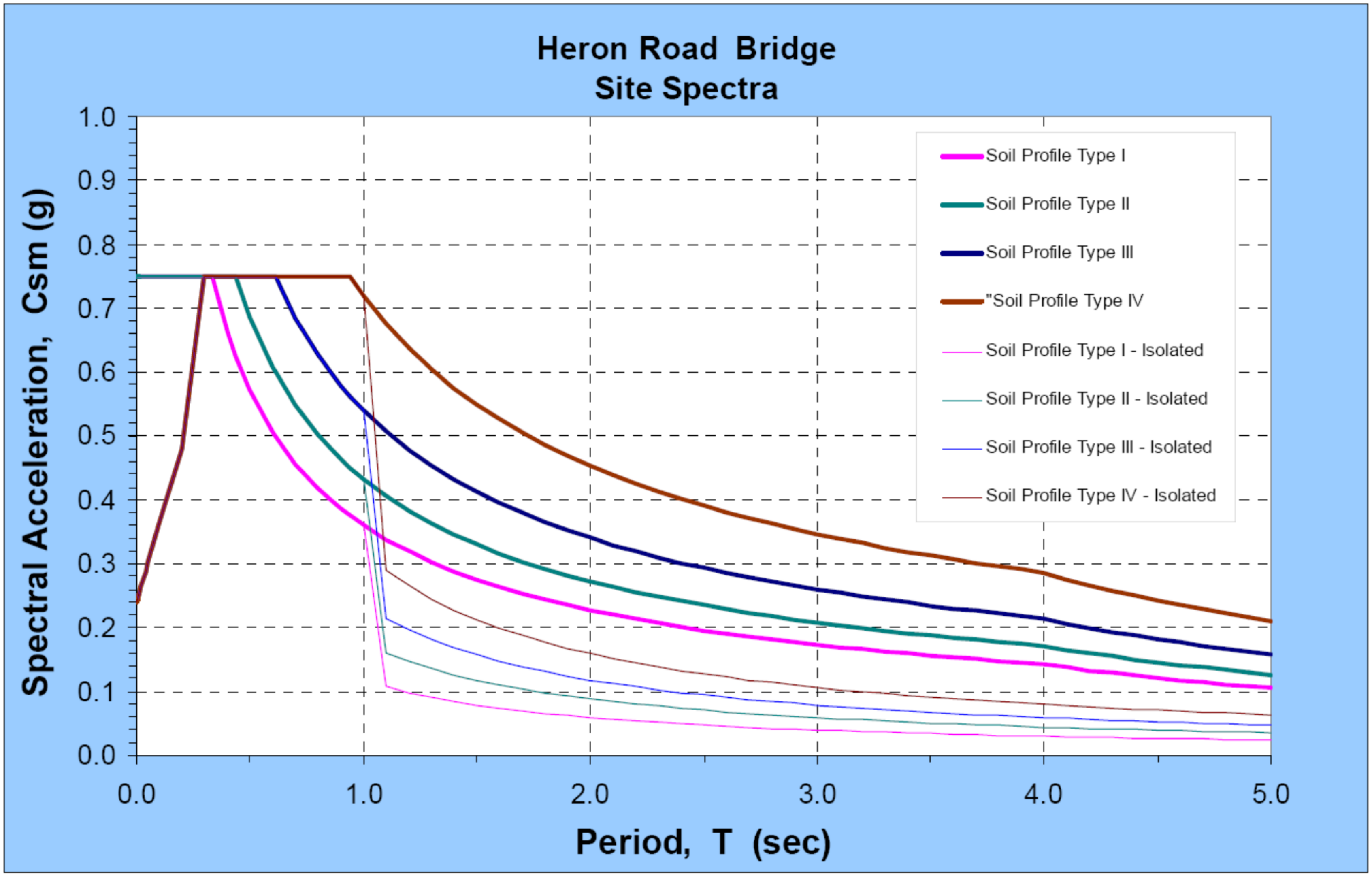
  – Tension model: joints are provided with linear elastic springs that model the opening of the gap
  – Compression model: superstructure segments are rigidly connected, modeling the closing of the gap

- Special Considerations for different Soil Profile Types

  – Soil Type III was used to model the entire structure
  – Each bridge is considered as a series of four individual structures with suspended spans in between and using the specific soil profile types.

Seismic Rehabilitation of the Heron Road Bridge

Seismic Evaluation – Response Spectra



Seismic Evaluation - Results

Sub-structure

- Piers and abutments are overstressed under seismic loading
- Piers are expected to rock under seismic loading
- Piled foundation and spread footings do not provide sufficient resistance to overturning moments associated with seismic forces

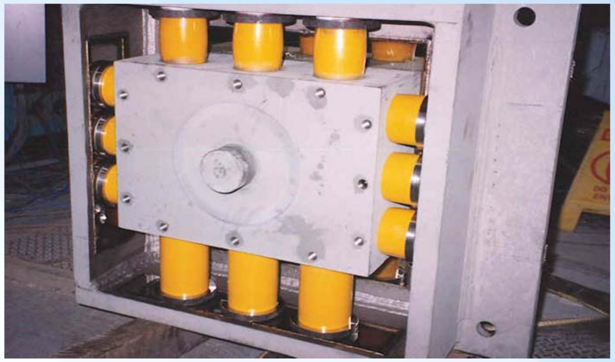
Suspended Spans

- Significant risk of unseating and full collapse of suspended spans.

Seismic Rehabilitation Options

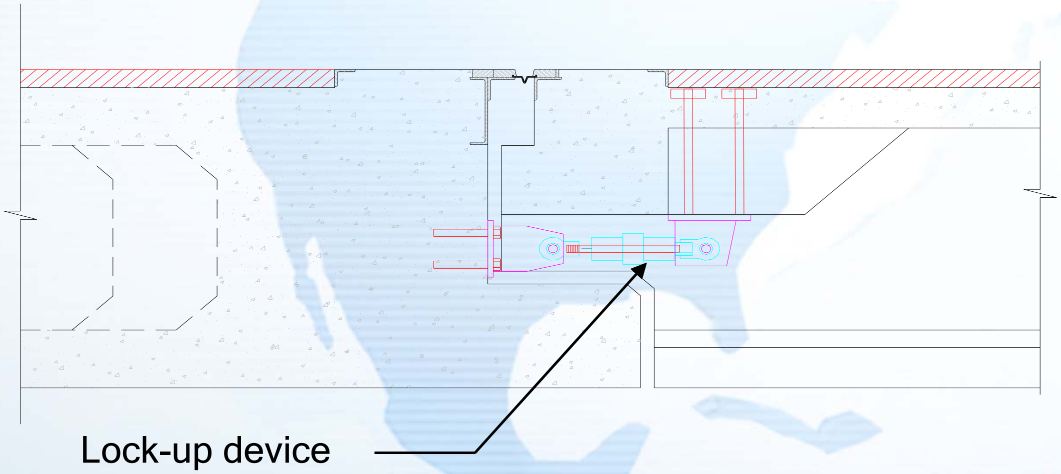
Piers & Abutments

- Strengthening vs. Seismic Isolation



Suspended Spans

- Flex slab system vs. Restrainers / Lock-up Devices (LUD's)



Retrofit was designed using multi-modal response spectrum analysis

Seismic Rehabilitation of the Heron Road Bridge

Seismic Retrofit Validation

- Nonlinear time history analysis using site specific excitations was used to validate the preliminary design for the following reasons:
  - Hysteretic isolators and lockup devices are highly nonlinear devices not always accurately modeled using linear methods such as response spectrum analysis
  - Site conditions ranged from Soil Type I (rock) to Soil Type III (soft soil), suggesting the need for different excitations for each substructure

Seismic Rehabilitation of the Heron Road Bridge

Site-specific time-history analysis

- Site-specific ground motions developed using the 4th generation seismic hazard maps developed by Geological Survey of Canada (GSC)
- Standard design earthquake having a probability of exceedance of 10% in 50 years i.e. 475 return period.
- A target site-specific spectrum, as developed based on 2005 NBCC for Site class B was used to develop five sets of spectrum compatible ground motions.
- The spectrum compatible ground motions for Class B rock were modified using the software "Proshake" to account for the overburden effects and resulted in the time histories used as an input for the structural analysis.

Seismic Analysis *continued*

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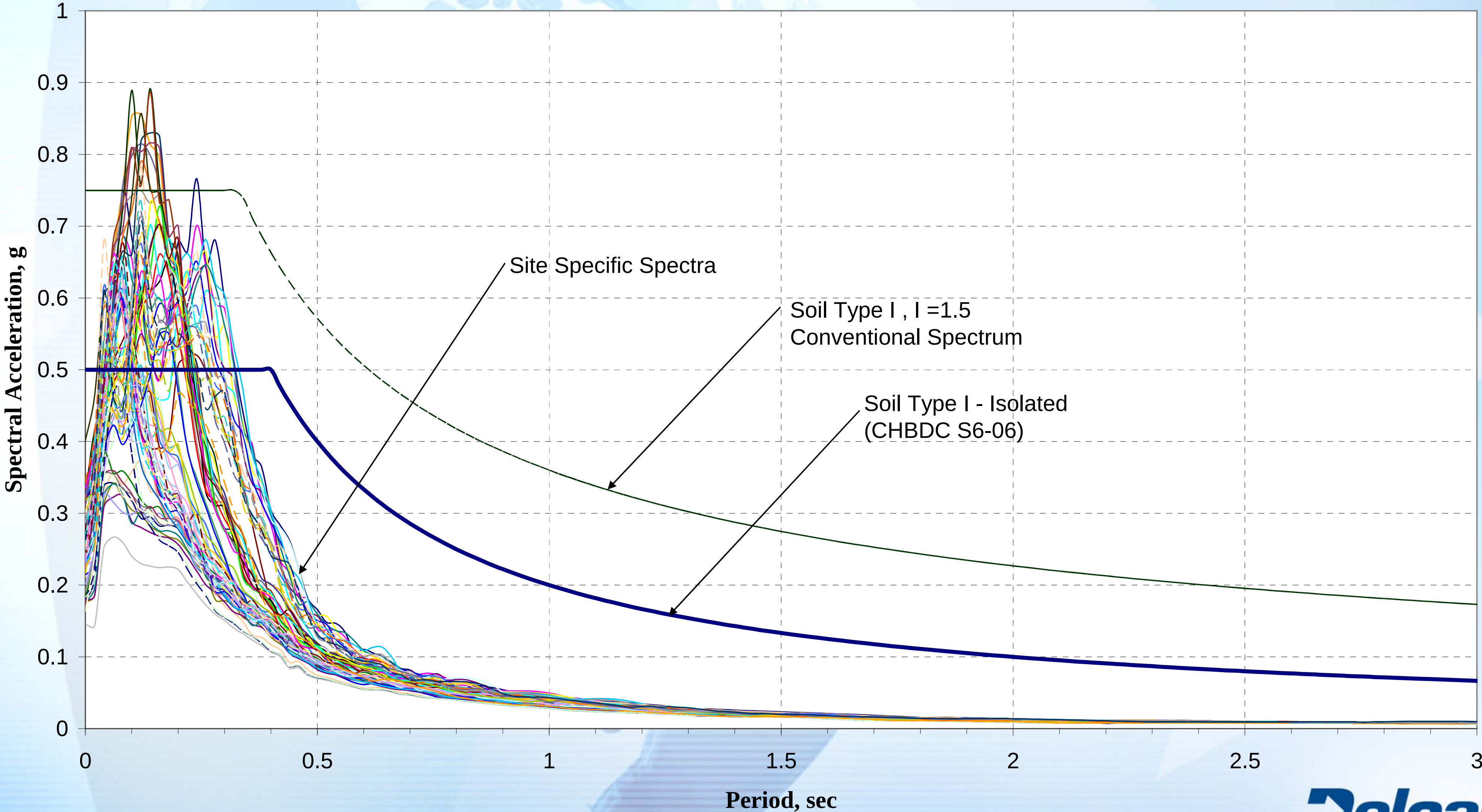

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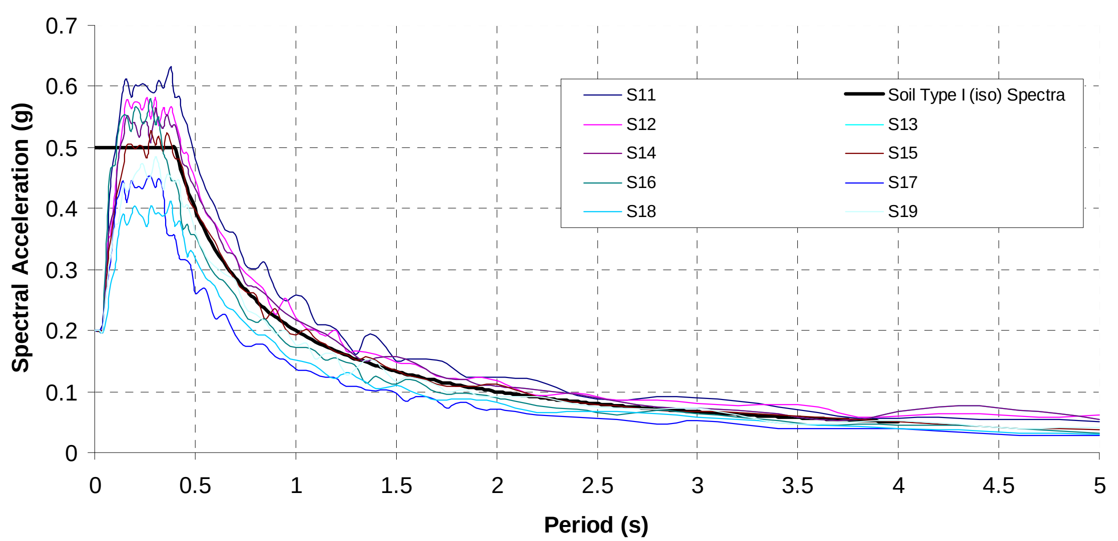
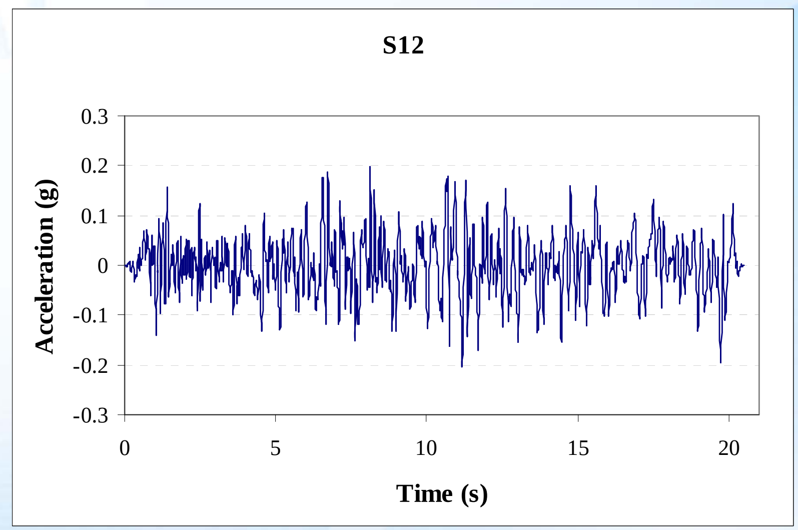
Seismic Rehabilitation of the Heron Road Bridge

Time-History Analysis

- Non-linear time history analysis using OPENSEES
- Seismic isolation bearings modeled as a bilinear hysteretic element
- Bumper restrainers modeled using elastic perfectly plastic gap material
- Time histories scaled to CHBDC Soil Type I Seismic isolation spectrum

Time History of Accelerations Scaled to 0.2 g using SHAKE Program





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Conclusions

- Seismic isolation reduced the seismic demand significantly.
- Nonlinear site specific time history analysis resulted in the optimization of the seismic isolation / restrainer system.
- Current CHBDC time history analysis requirements call for usage of excitations compatible with conventionally fixed response spectra. This presents a problem with isolated structures.
- Response spectrum and time history analyses complement each other well, and a design process using both has many advantages.

Thank you

Sylvain Montminy, P. Eng., ing. - Delcan

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