Combination of Seismic and Thermal Displacements for the Design of Bridge Seismic Isolators

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Outline

1 – Introduction

2 – to present different types of seismic isolation systems available for bridges in Canada

3 – to demonstrate through the CHBDC CSA-S6-06 how to calculate $\Delta_{seismic}$ and $\Delta_{thermal}$

4 – to illustrate how international bridge design provisions combine $\Delta_{seismic}$ and $\Delta_{thermal}$

5 – to analyze a typical bridge in Montreal equipped with a base isolation system

6 – to produce a $\Delta_{seismic}$ and $\Delta_{thermal}$ combination with the total probability theorem

7 – Conclusions and recommendations

1 - Introduction

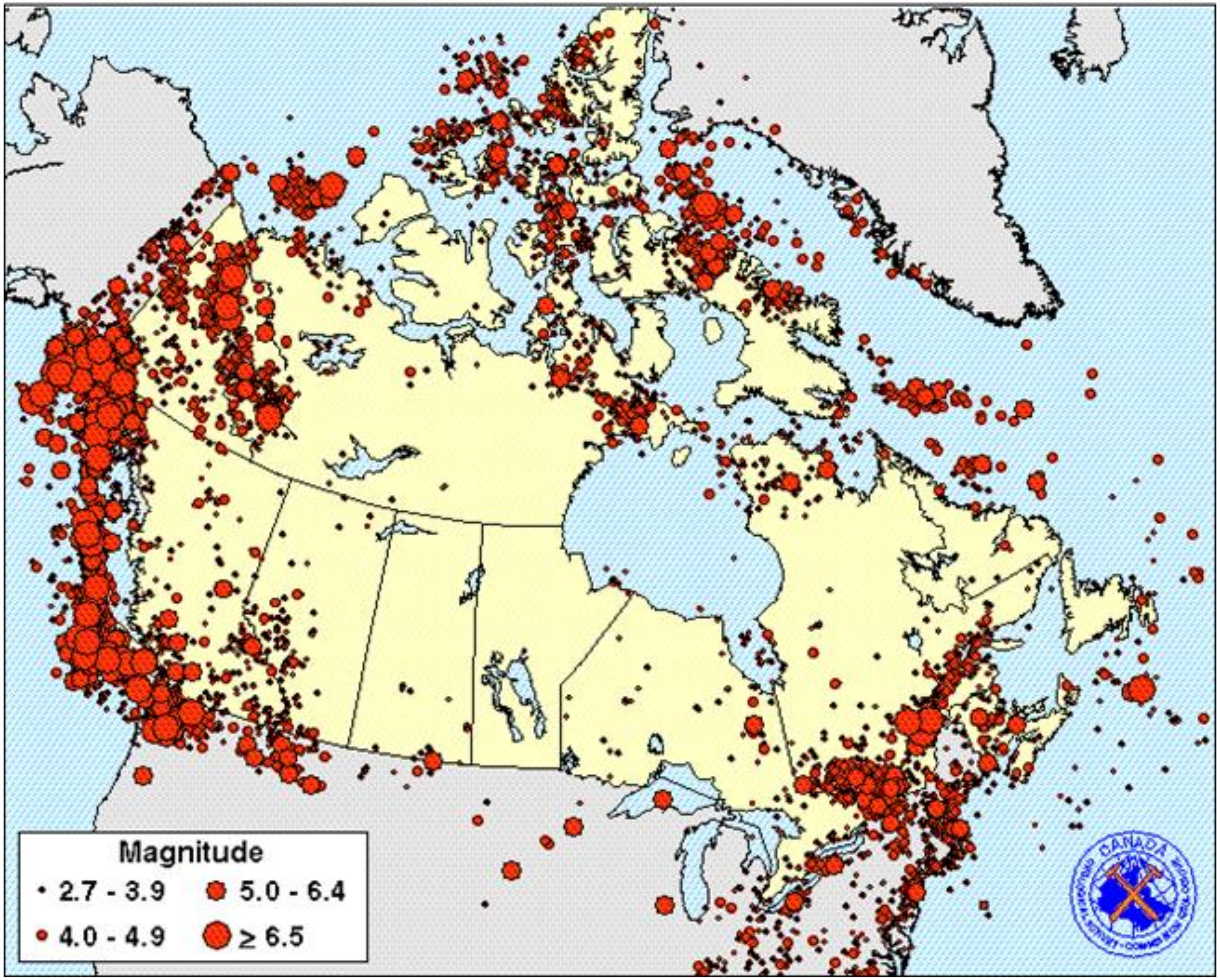
- Seismic Design Requirements were first introduced in the CHBDC in 1966

- Over the past 20 years, seismic loads have increased significantly in the CSA-S6 and NBCC

- Only since 2000, a section is reserved for Seismic Base Isolation in the CSA-S6(Clause 4.10)

- Nowhere in the CSA-S6-06 do they suggest or recommend a procedure to combine $\Delta_{seismic}$ and $\Delta_{thermal}$ for base isolation systems

1 - Introduction



2 - Base Isolation Systems for Bridges

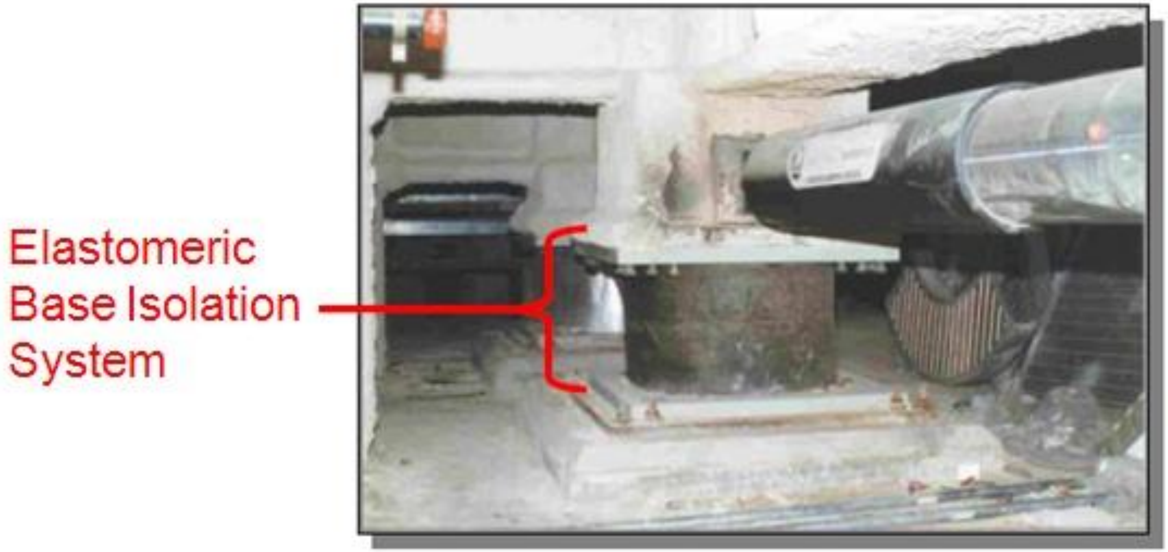
Elastomeric Base Isolation Systems

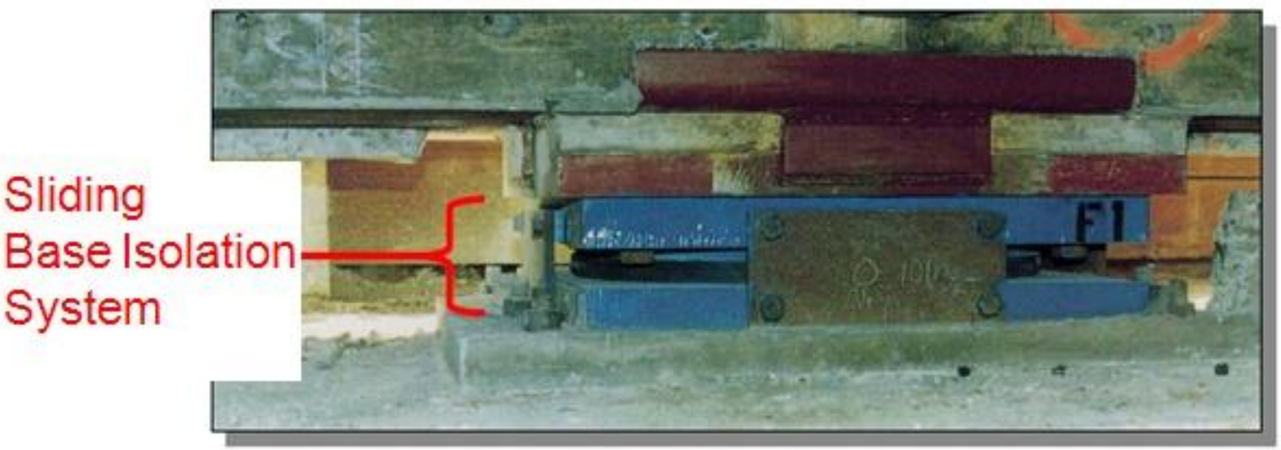
- Low-Damping Natural or Synthetic Rubber Isolator
- High-Damping Natural Rubber Isolator
- Lead-Rubber Isolator

Sliding Base Isolation Systems

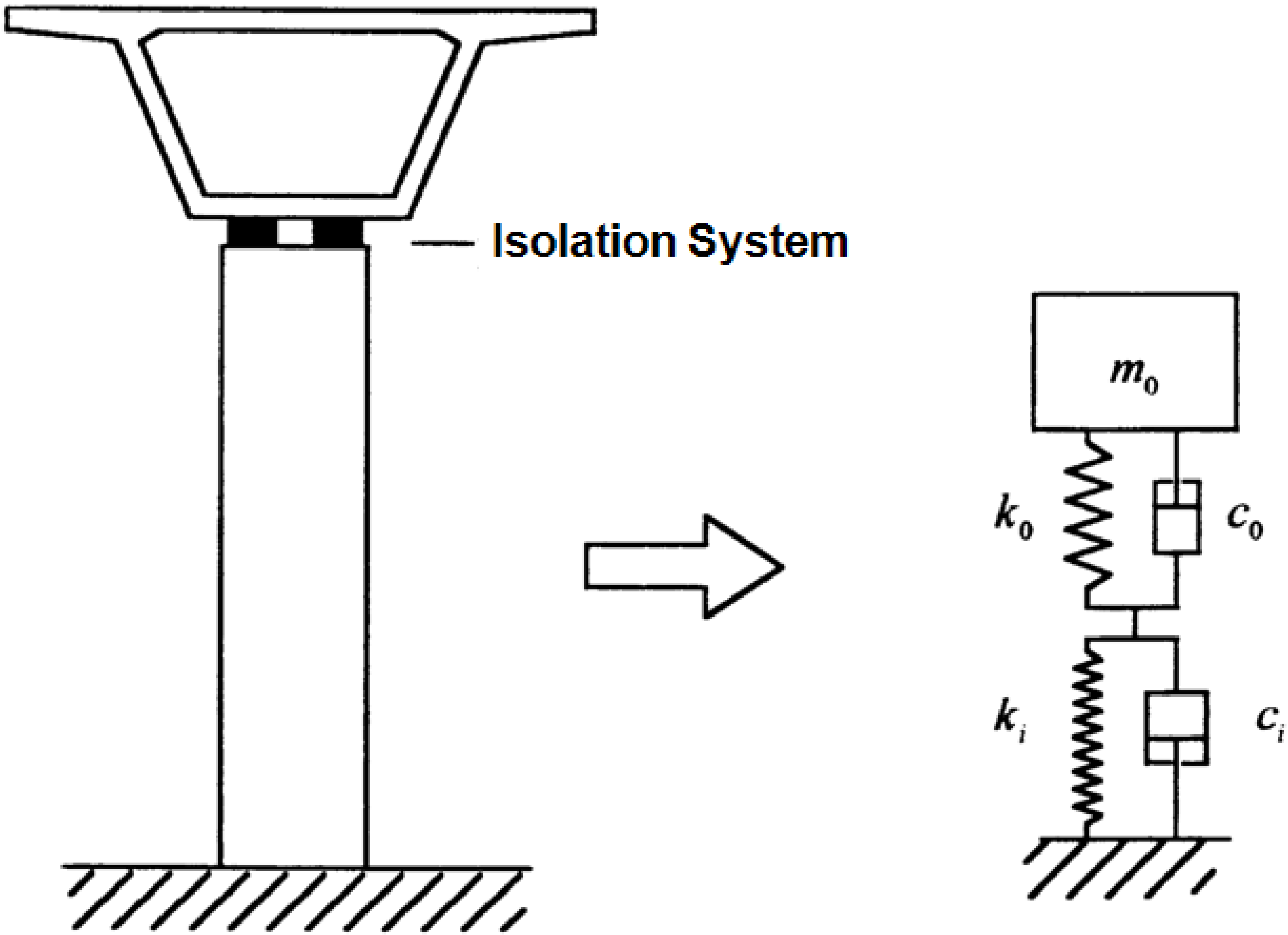
- Flat Sliding Isolator
- Spherical Sliding Isolator or Friction Pendulum System

2 - Base Isolation Systems for Bridges





2 - Base Isolation Systems for Bridges



2 - Base Isolation Systems for Bridges

- Decouple the superstructure from its substructure resting on ground-motion

- Increase the period of vibration to consequently reduce the transferred ground accelerations

- Energy dissipation to control the isolation system's displacements

- Rigidity under low load levels, such as wind and minor earthquakes

- Protect the bridge's integrity

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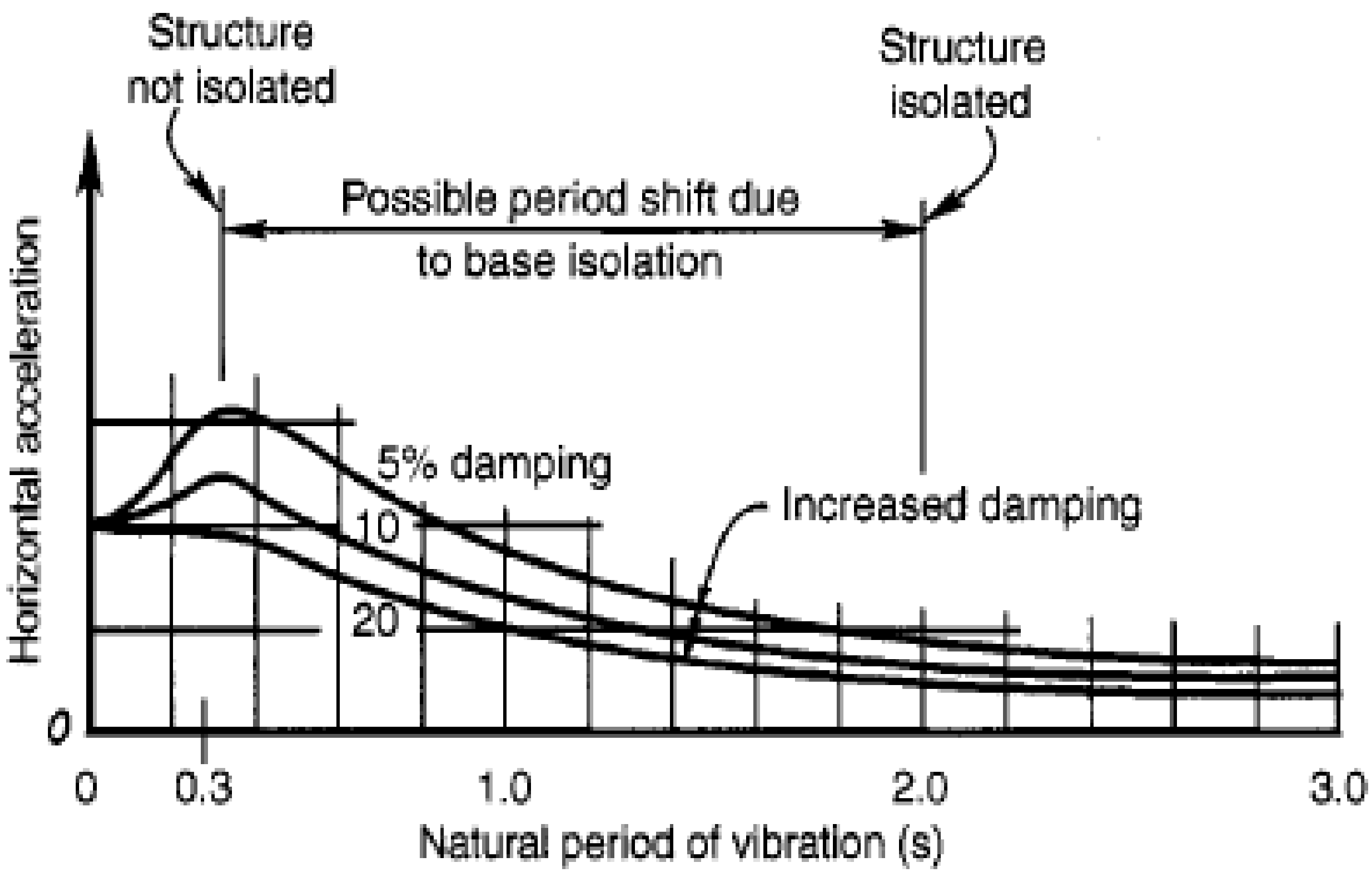
2 - Base Isolation Systems for Bridges



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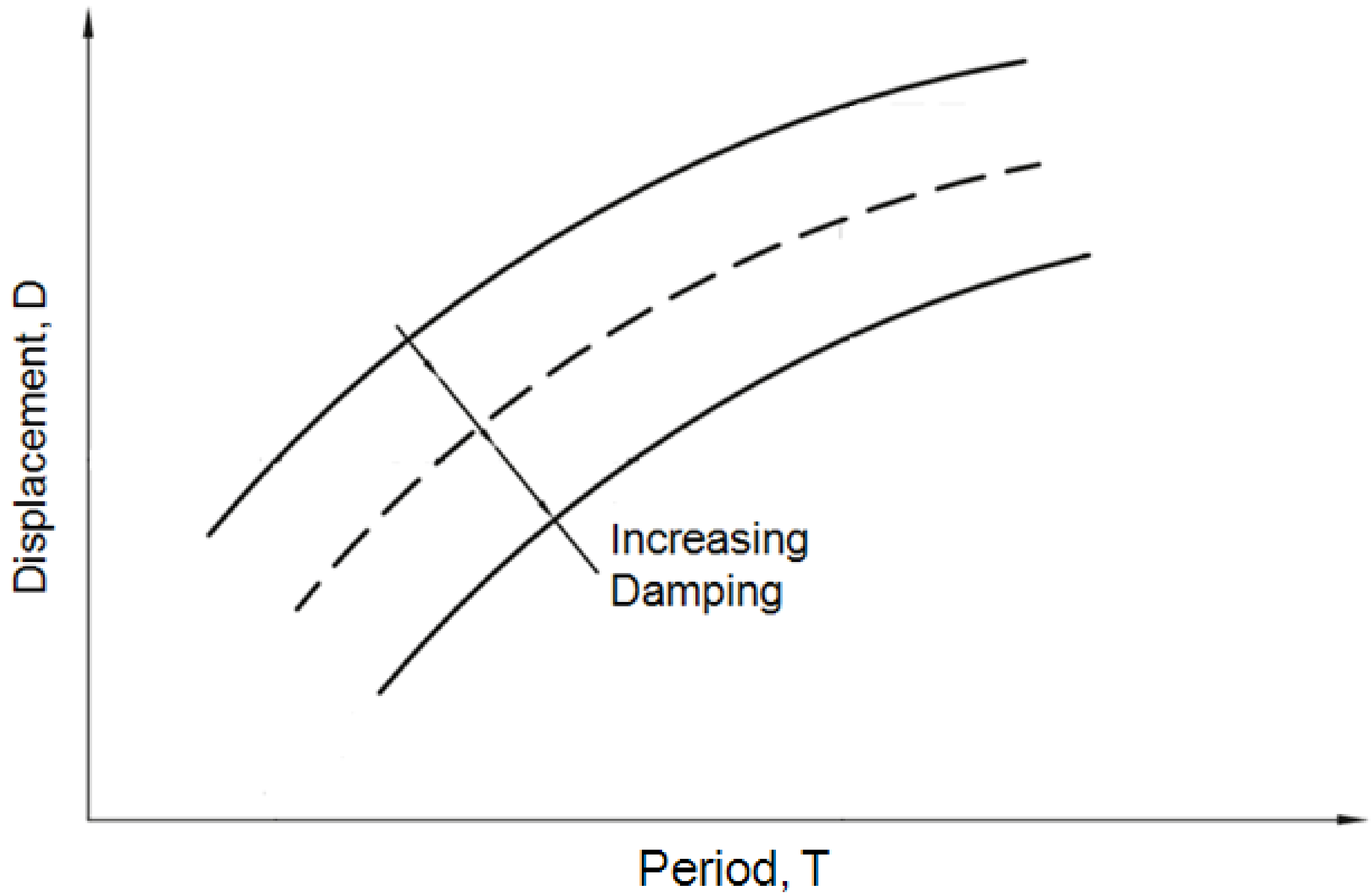

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3 - How to Calculate $\Delta_{seismic}$ and $\Delta_{thermal}$ CHBDC CSA-S6-06

$\Delta_{seismic} = 250*A*S_i*T_e/B$

$\Delta_{thermal} = \alpha*L*\Delta T_{max}$

where

A = zonal acceleration ratio

S_i = site coefficient

T_e = period of seismically of the isolated structure

B = numerical coefficient related to the effective damping of the isolation system

α = material thermal coefficient

L = length of the member

ΔT_{max} = temperature difference after onsite installation

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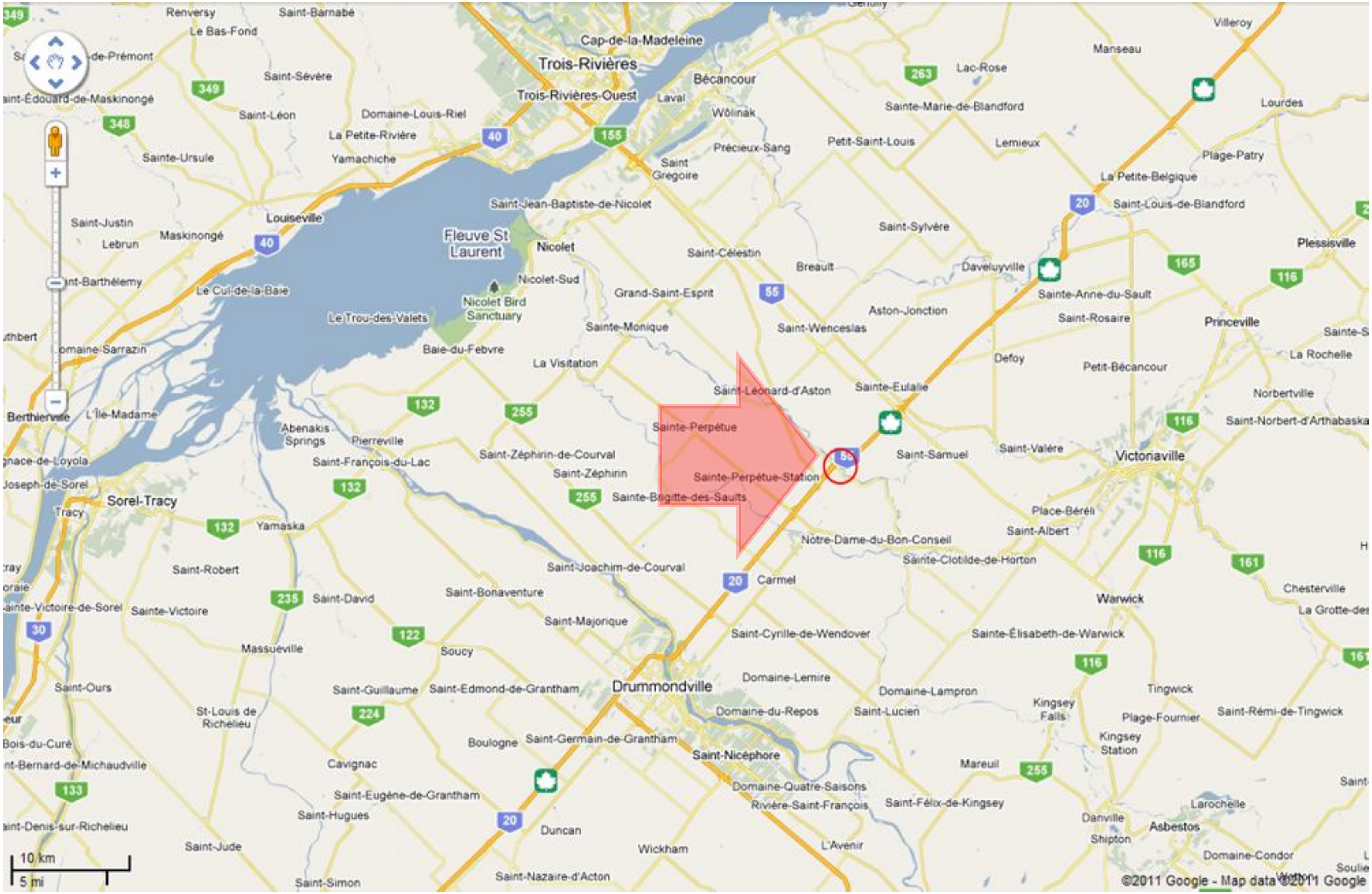
4 - International Seismic Base Isolation Design Combination of $\Delta_{seismic}$ and $\Delta_{thermal}$

National Bridge Design Code	Combination Formula of $\Delta_{seismic}$ and $\Delta_{thermal}$
CSA-S6-06, AASHTO-2004 and Chile-2002	None
British Columbia Ministry of Transportation Bridge Standards and Procedures Manual (2007)	$\Delta_{seismic} + 40\%\Delta_{thermal}$ (Clause 4.10.7)
New Zealand Transportation Agency Bridge Manual (2004)	$\Delta_{seismic} + 33.3\%\Delta_{thermal}$ (Clause 5.6.1)
Eurocode 8 Part 2: Bridges (2003)	$\Delta_{seismic} + 50\%\Delta_{thermal}$ (Clause 7.6.2)

5 – Base Isolation System Analysis – Madrid Bridge (Qc)



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5 – Base Isolation System Analysis – Madrid Bridge (Qc)

- Lifeline Bridge, I = 3.0 (MTQ)

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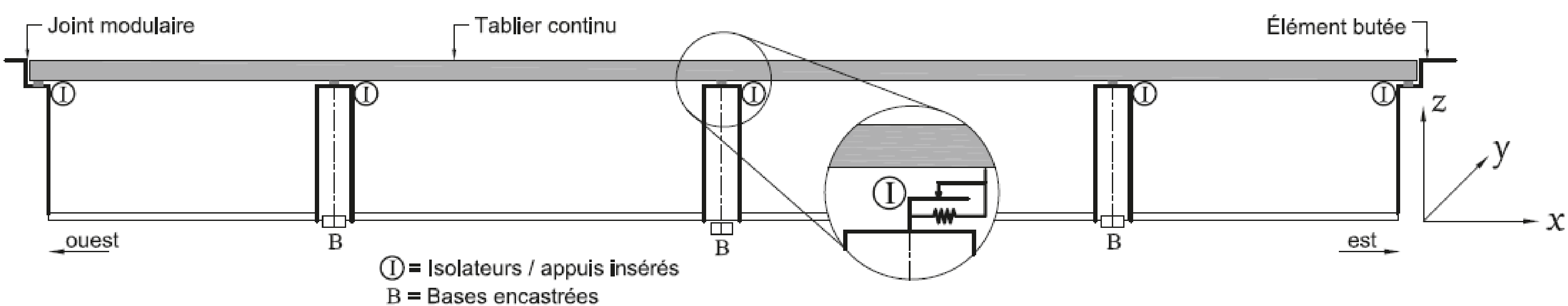
5 – Base Isolation System Analysis – Madrid Bridge (Qc)

- 4 spans
- 2 expansion joints at abutments
- Total length = 128.8 m
- Steal beams with reinforced concrete deck
- Depth of superstructure = 1903 mm

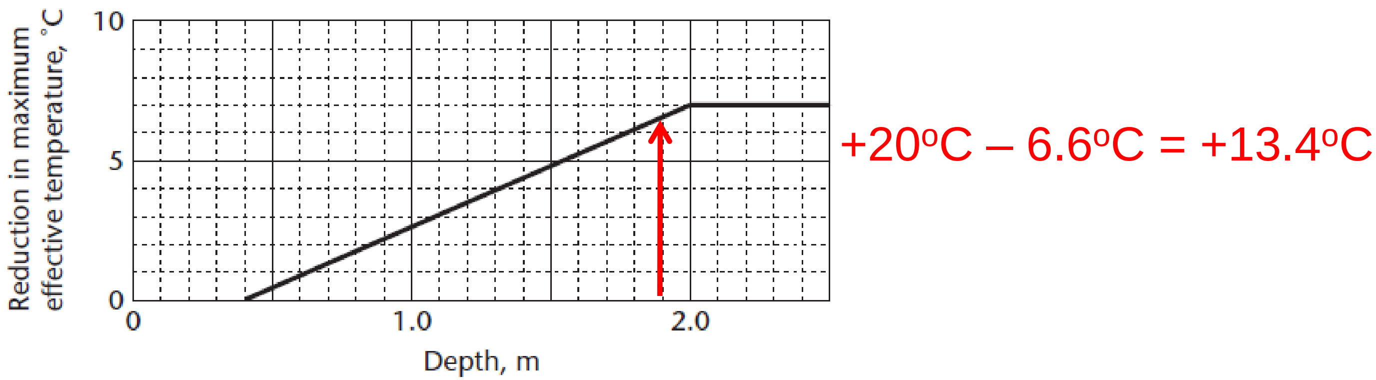


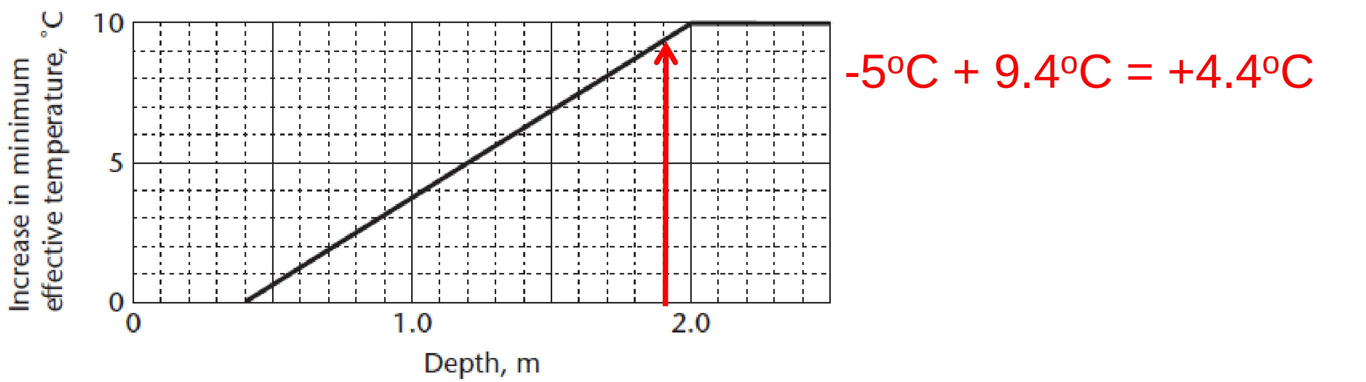
5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc)

- Effective temperatures
- Takes into consideration:
  - daily temperature changes
  - thermal gradient effects
  - material thermal coefficient
  - geometry of the superstructure
  - effective construction temperature (T_o = 15°C)

5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc)

Superstructure type (see Clause 3.9.3.)	Maximum effective temperature	Minimum effective temperature
A	25 °C above maximum mean daily temperature	15 °C below minimum mean daily temperature
B	20 °C above maximum mean daily temperature	5 °C below minimum mean daily temperature
C	10 °C above maximum mean daily temperature	5 °C below minimum mean daily temperature





5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc)

- Methodology

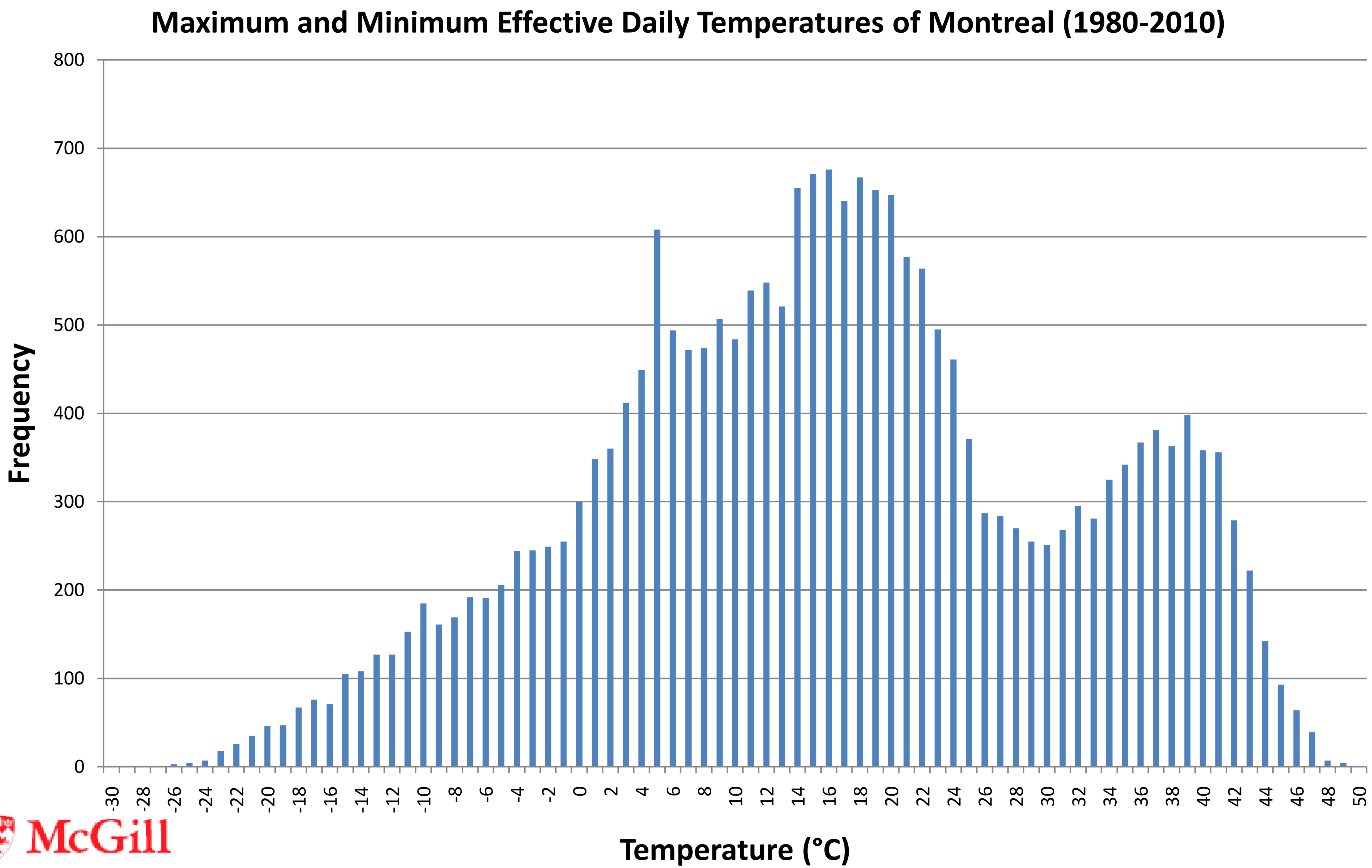
Distribution:

Maximum and Minimum Effective Daily Temperatures of Montreal (1980-2010) (-30°C à 50°C)

Compare to the CSA-S6-06:

Maximum and Minimum Mean Daily Temperatures (-31.6°C à 41.4°C)

5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc) - Distribution



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5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc) - Distribution

$\Delta_{thermal}$ (mm) = $\alpha * L * \Delta T_{max}$

where

α = 11 x 10^{-6}/ °C for steal beams and reinforced concrete deck
L = 128.8/2 = 64.4 m = 64 400 mm

(-30°C à 50°C) and T_o = 15°C
@ -30 °C: ΔT = 45°C
@ +50 °C: ΔT = 35°C

$\Delta_{thermal}$ max = (11 x 10^{-6}/ °C)*(64 400 mm)*(45°C) = **31.9 mm**

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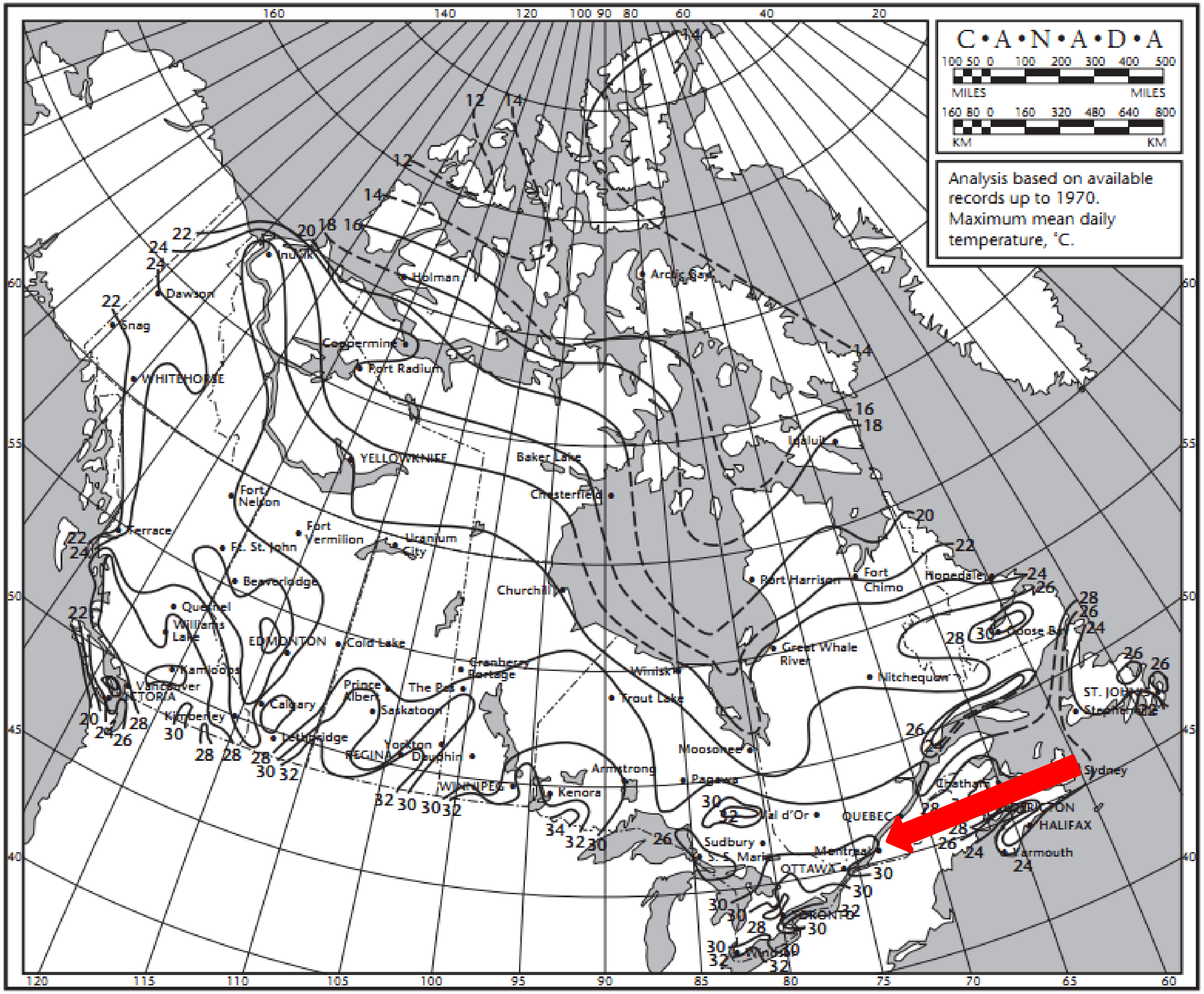
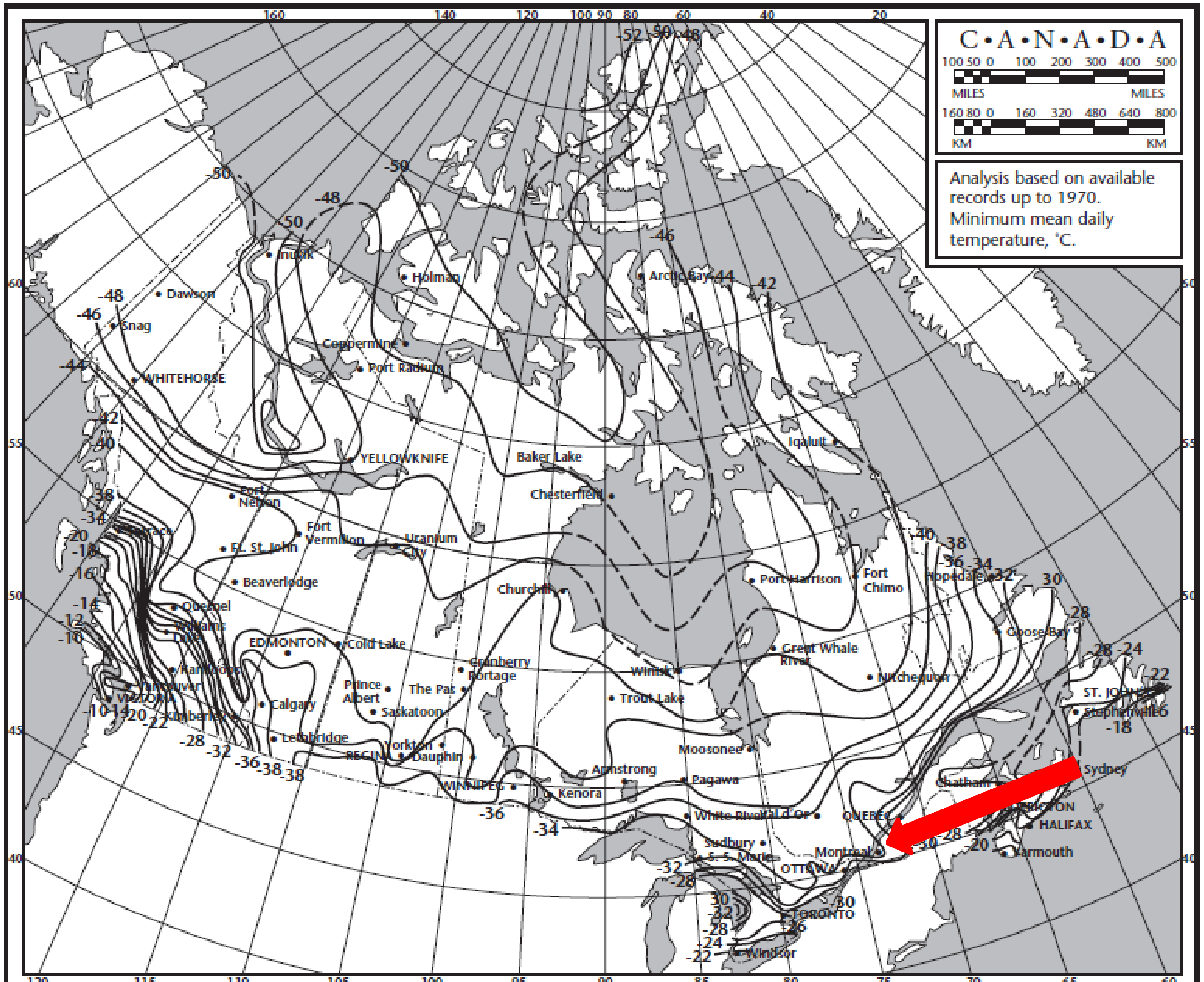
5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc) - CSA-S6-06

Maximum Mean Daily Temperatures



5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc) - CSA-S6-06

Minimum Mean Daily Temperatures



5.1 – $\Delta_{thermal}$ of the Madrid Bridge (Qc) - CSA-S6-06

- Maximum Mean Daily Temperatures = 28°C
- Minimum Mean Daily Temperatures = -36°C

- Superstructure Type = B

28°C + 20°C = 48°C et -36°C - 5°C = -41°C

- Depth of superstructure = 1903 mm

48°C – 6.6°C = 41.4°C et -41°C + 9.4 = -31.6°C

(-31.6°C à 41.4°C) et T_o = 15°C

@ -31.6 °C: ΔT = 46.6°C

@ +41.4 °C: ΔT = 26.4°C

$\Delta_{thermal}$ max = $(11 \times 10^{-6}/ °C)$*(64 400 mm)*(46.6°C) = **33.0 mm**

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5.2 – $\Delta_{seismic}$ of the Madrid Bridge (Qc) - CSA-S6-06

- To calculate $\Delta_{seismic}$, new earthquake ground-motion relations were used from Gail M. Atkinson and David M. Boore (2006)

- seismic events with 2% probability of exceedance in 50 years, which is equivalent to a return period of 2475 years (CNBC 2005)

$\Delta_{seismic}$ = 250*A*S_i*T_e/B

S_i = site coefficient = 1.0

T_e = period of seismically of the isolated structure = 1.87s

B = numerical coefficient related to the effective damping of the isolation system = 1.431

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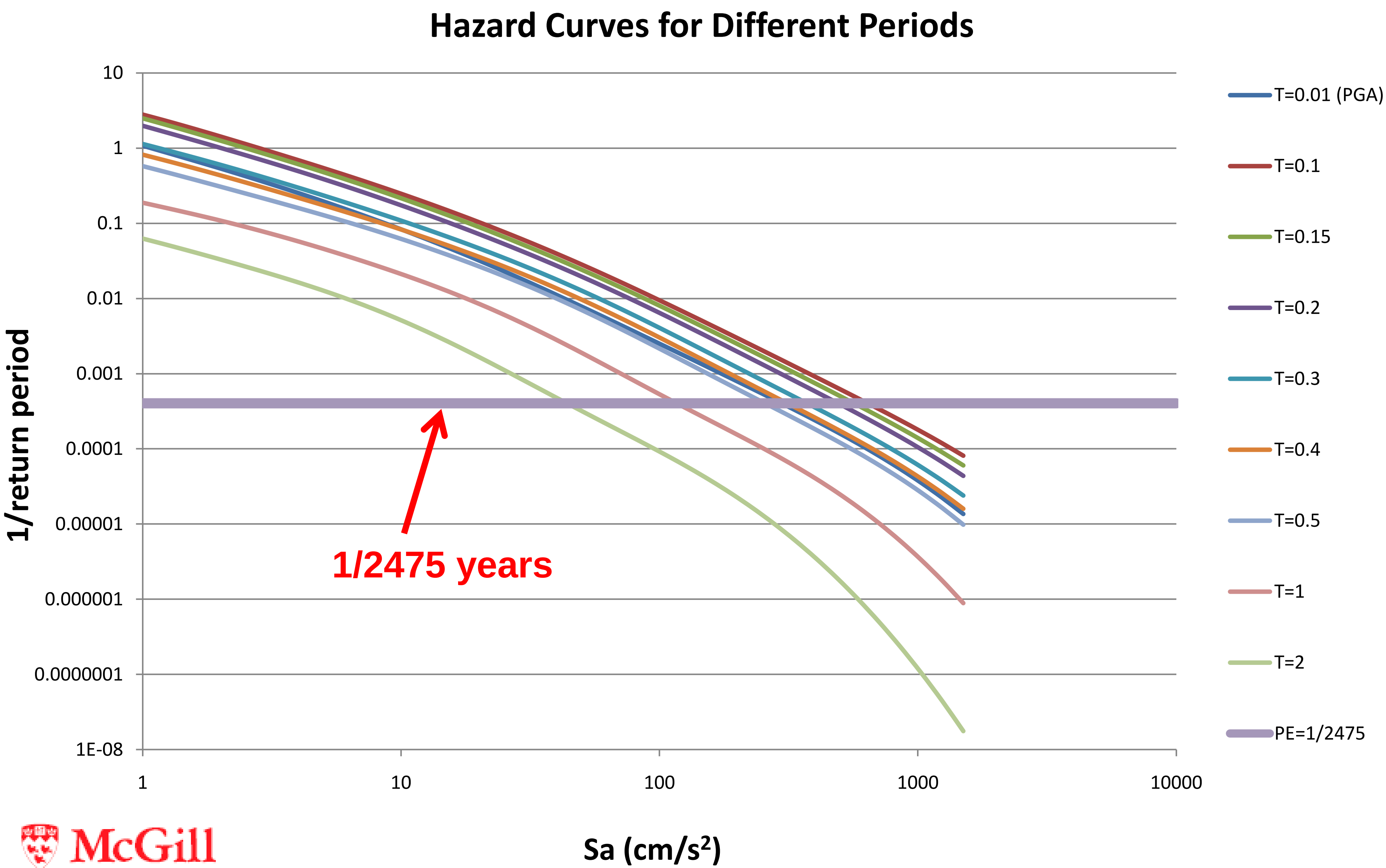
5.2 – $\Delta_{seismic}$ of the Madrid Bridge (Qc) - CSA-S6-06



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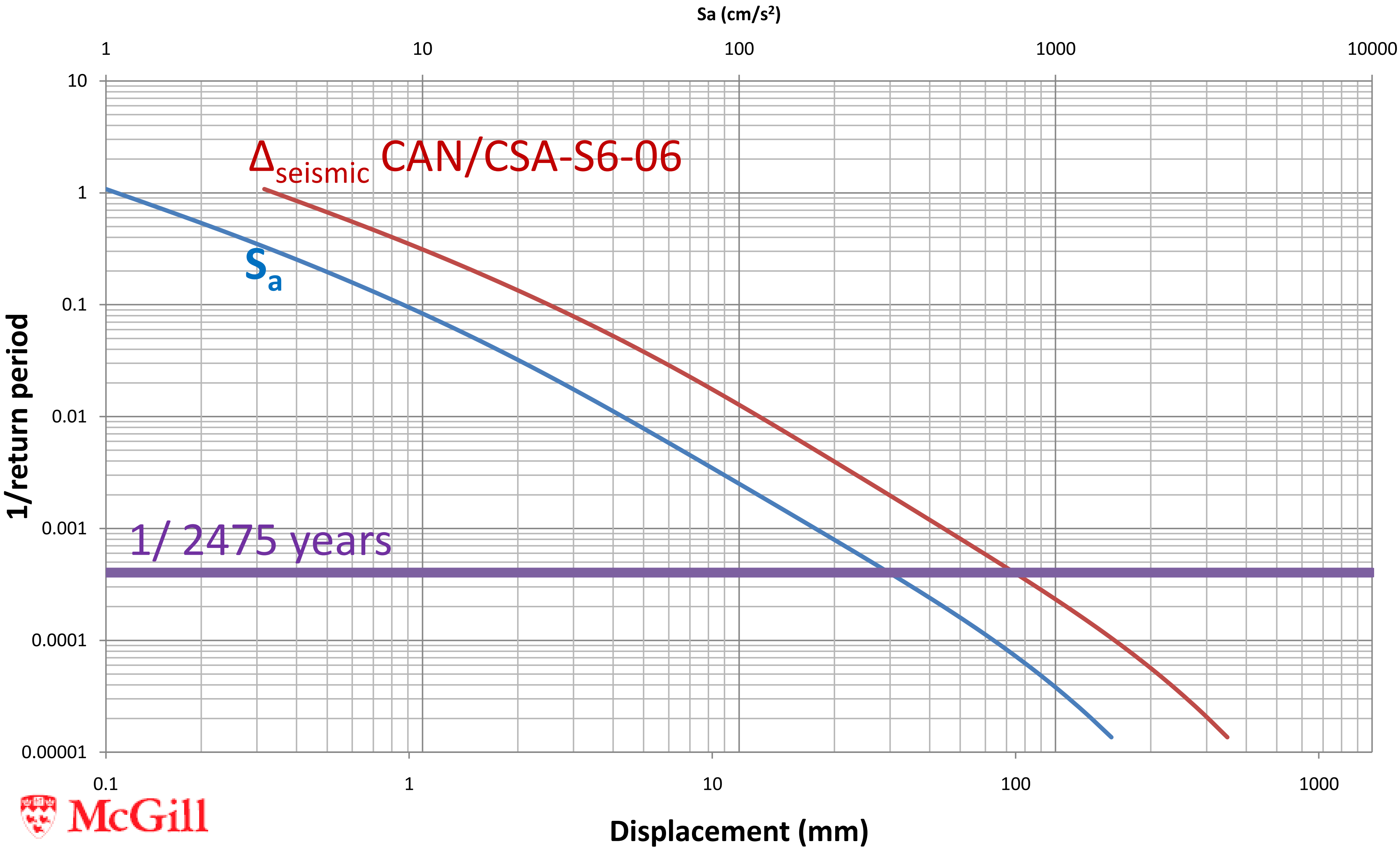

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5.2 – $\Delta_{seismic}$ of the Madrid Bridge (Qc) - CSA-S6-06

- From the S_a vs 1/RP curve, S_a = 300.4 cm/s^2 at 1/2475

- A = Sa/(100*g) = 300.4/(100*9.81) = 0.306g

- $\Delta_{seismic}$ = 250*A*S_i*T_e/B

- $\Delta_{seismic}$ = (250*0.306*1.0*1.87)/1.431 = 100.0 mm

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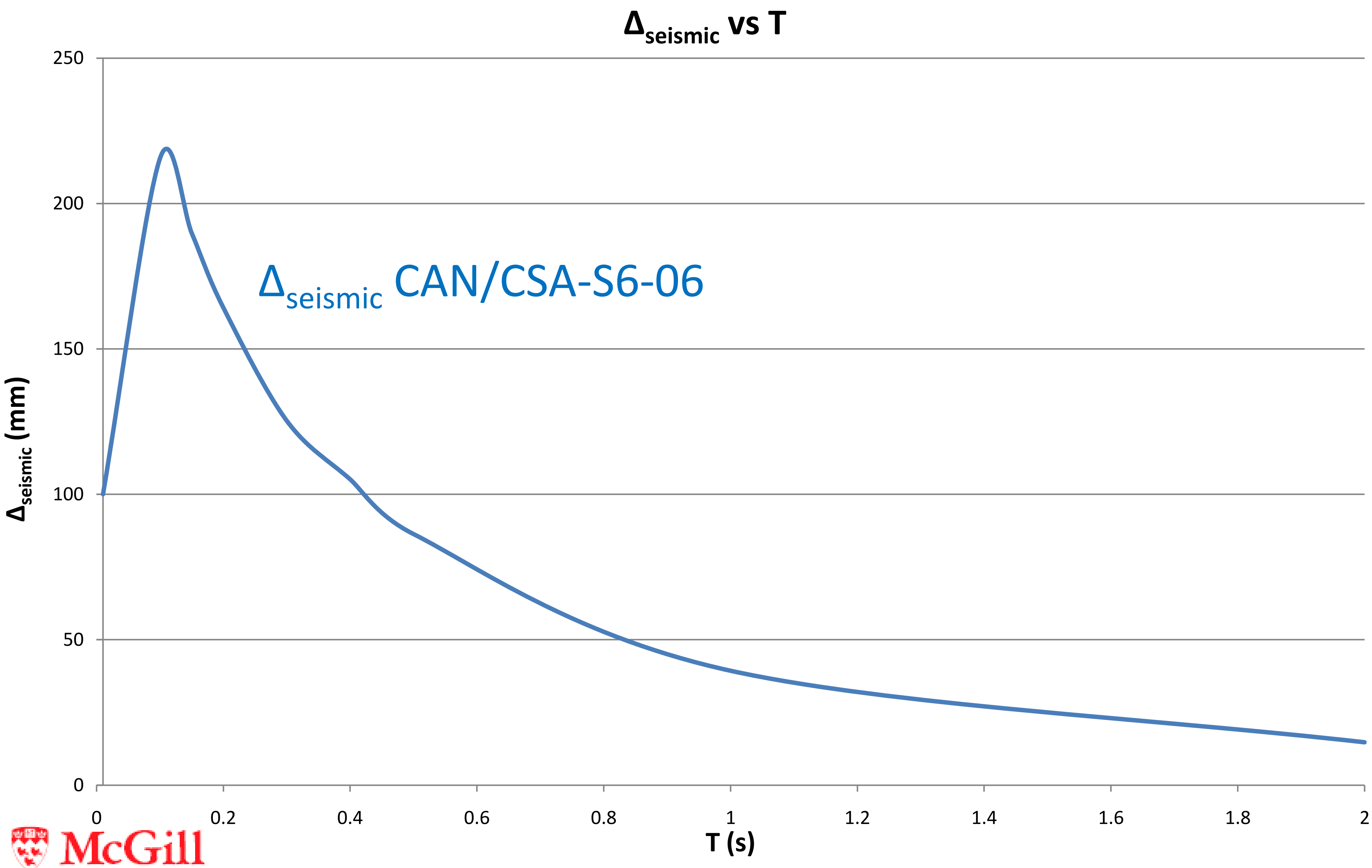
5.2 – $\Delta_{seismic}$ of the Madrid Bridge (Qc) - CSA-S6-06



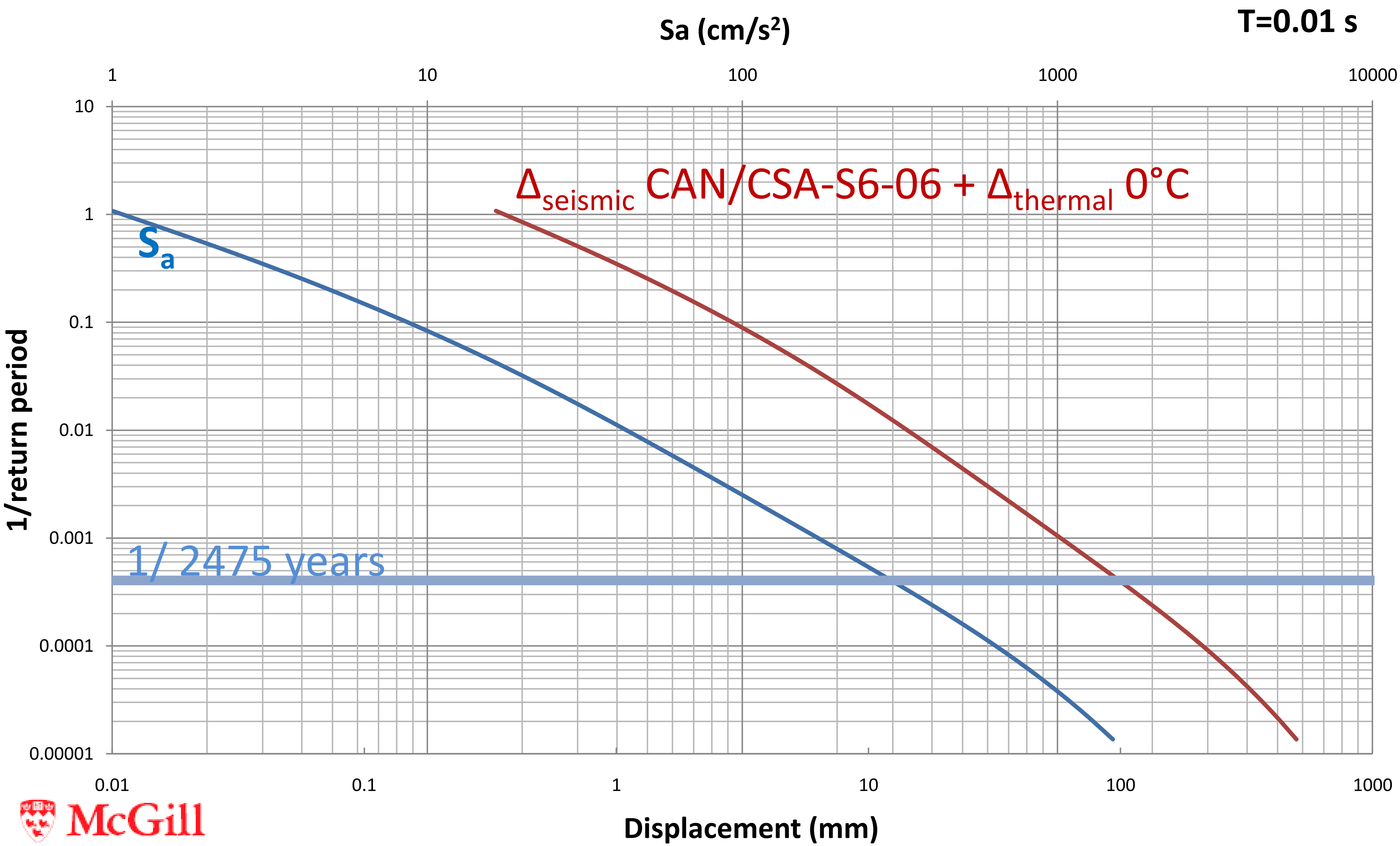
6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)

- 2 independent random variables

- Methodology:

  Use the hazard curves S_a vs 1/RP and the combined calculated $\Delta_{seismic}$ and $\Delta_{thermal}$ curves

6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)



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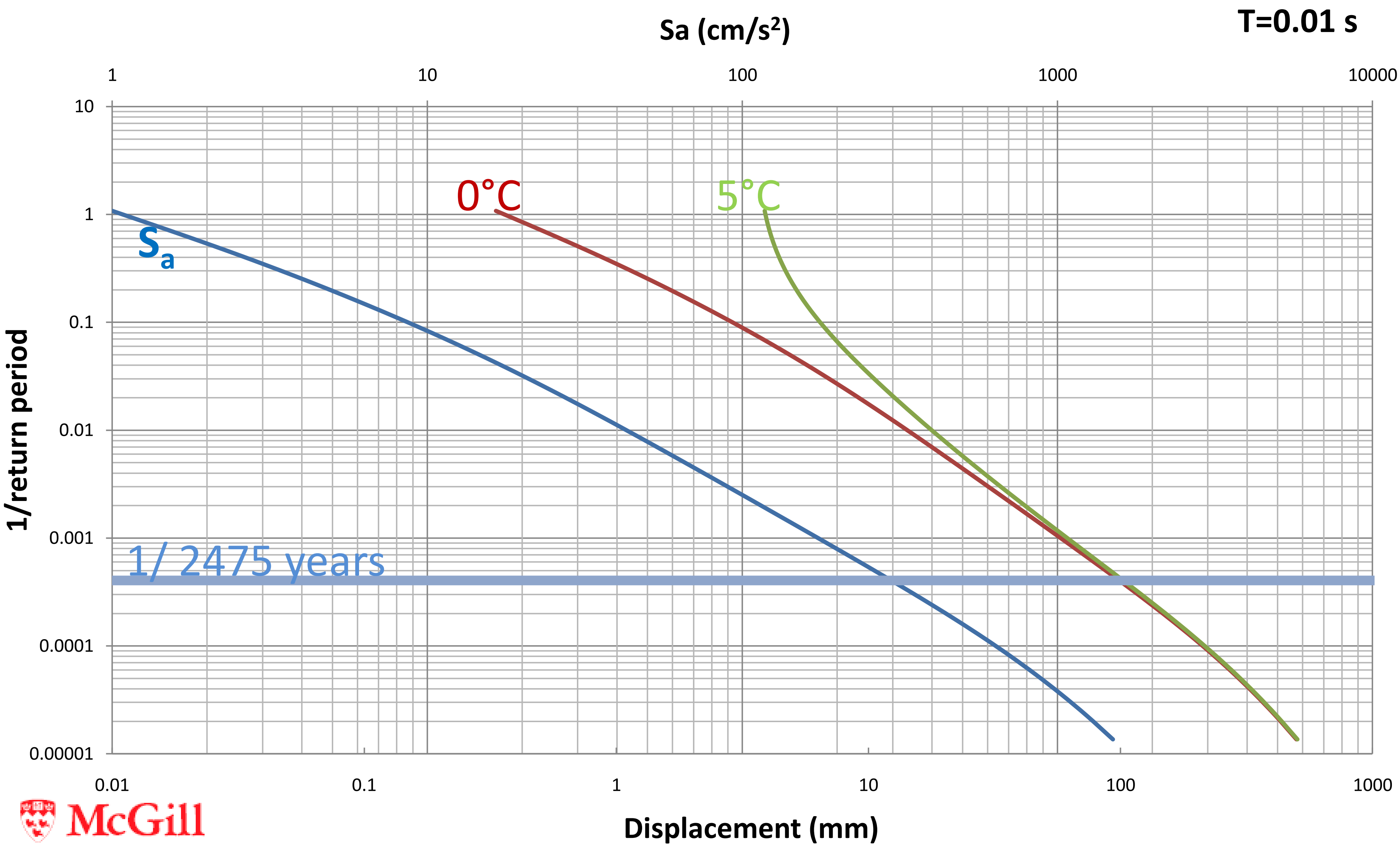

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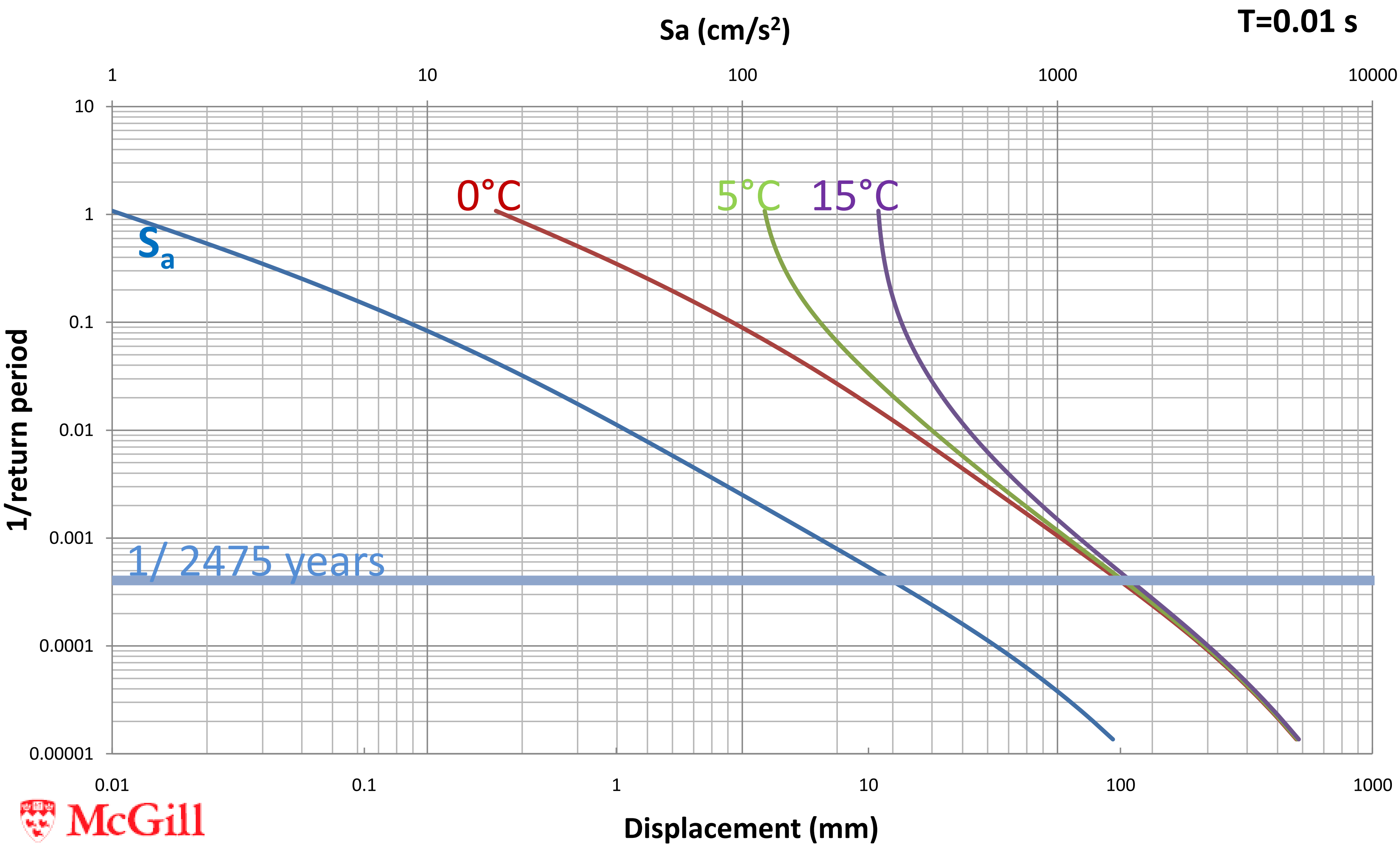

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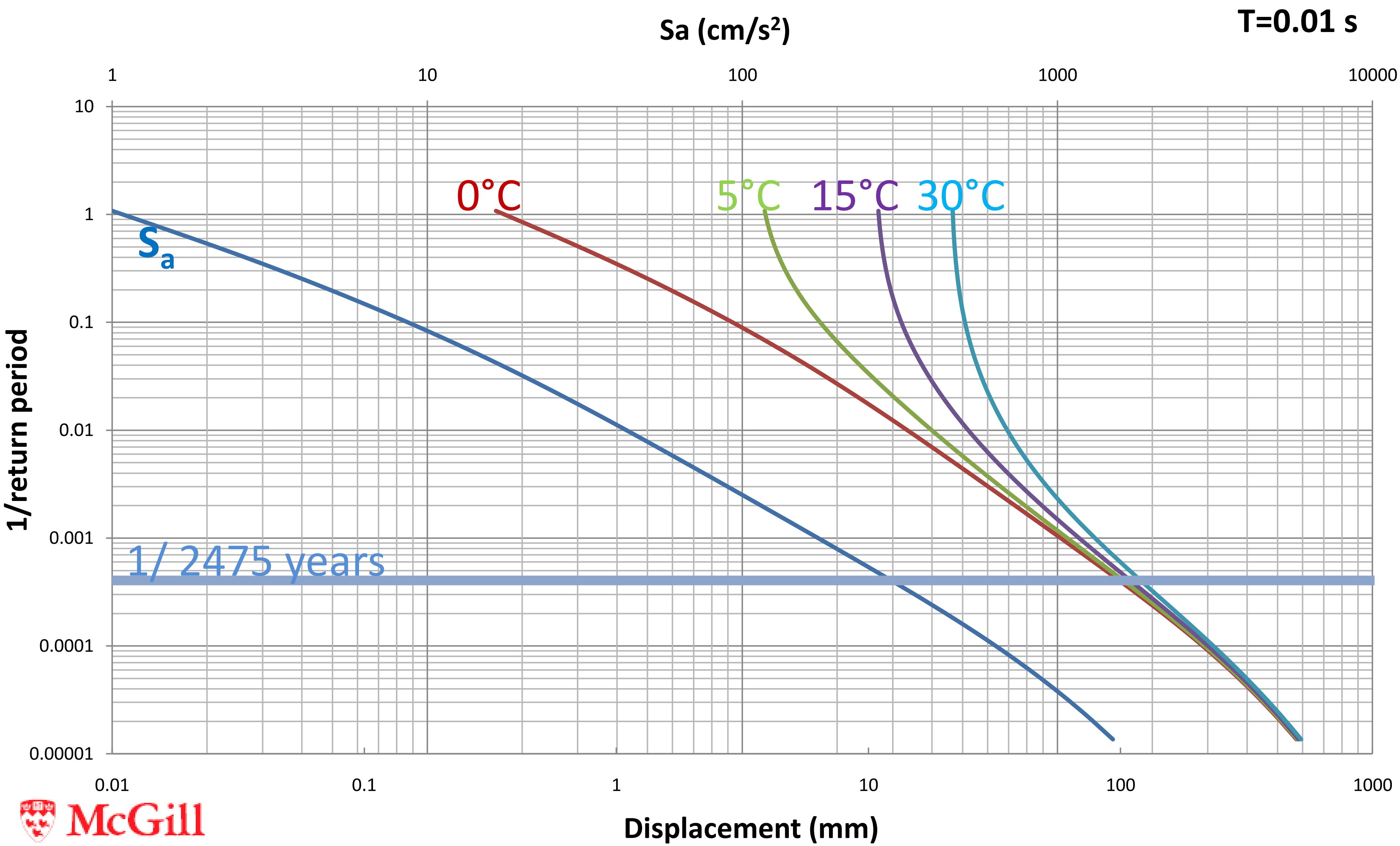

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6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)

0°C

5°C 15°C 30°C

45°C

S_a

1/ 2475 years

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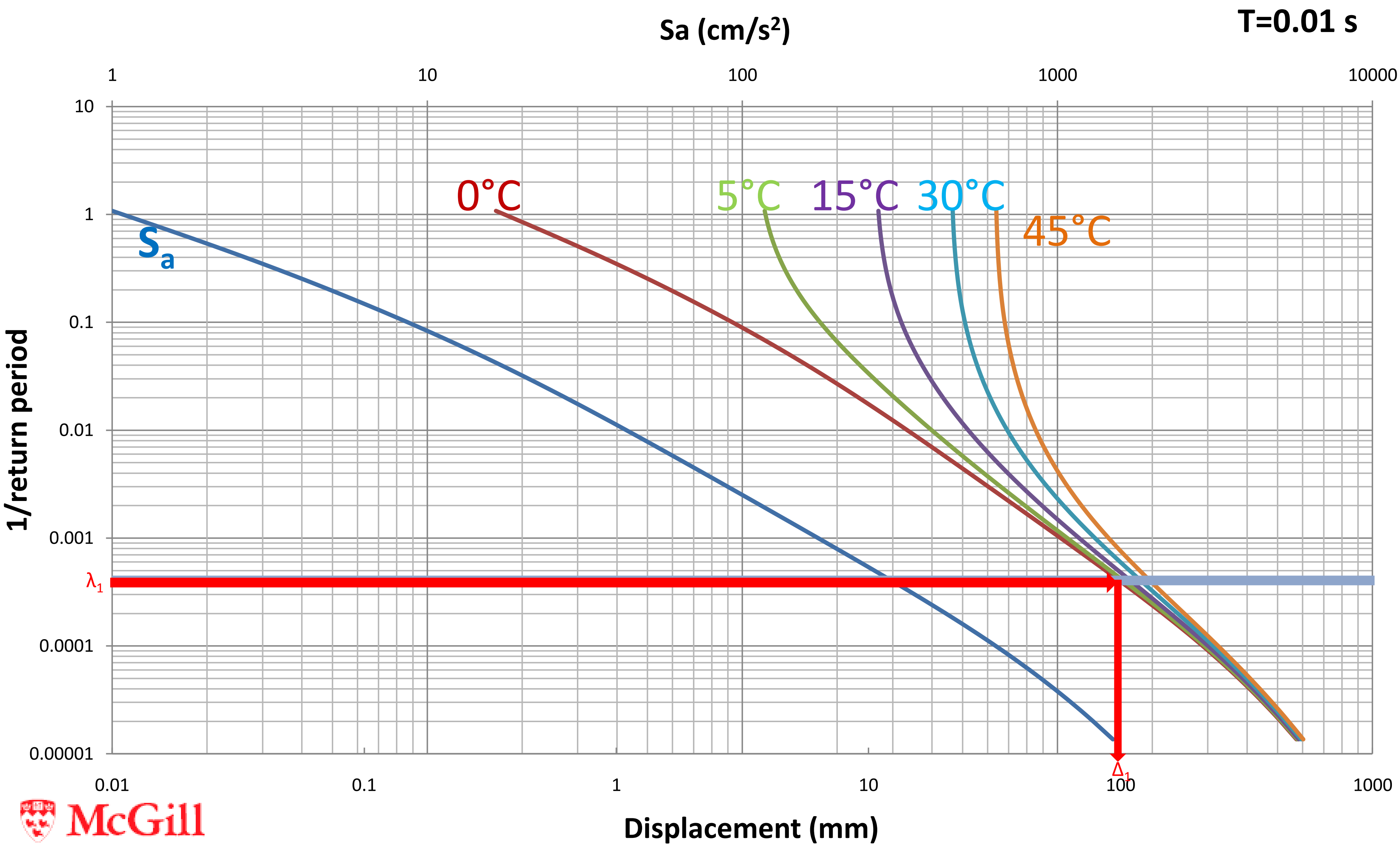
6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)



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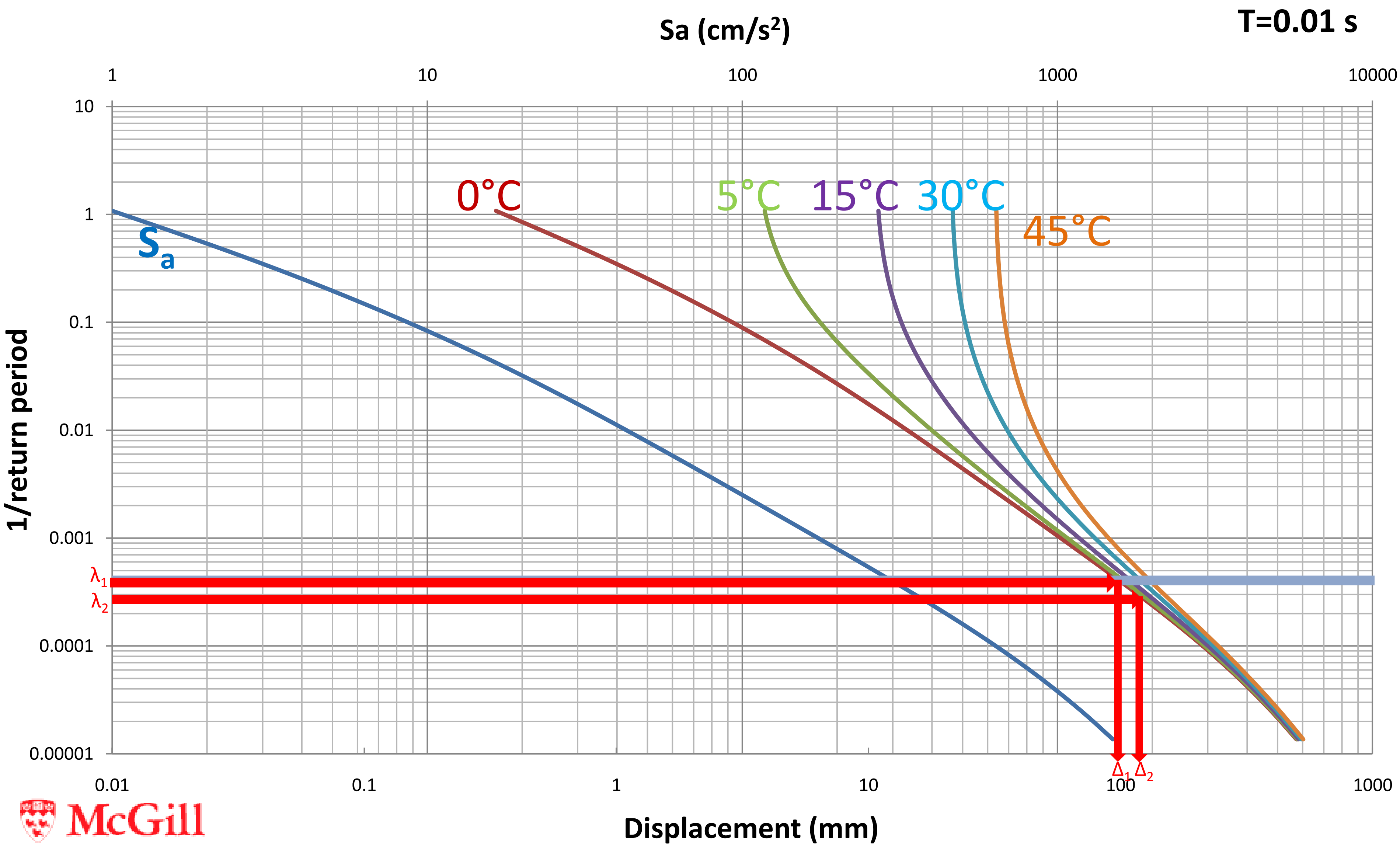

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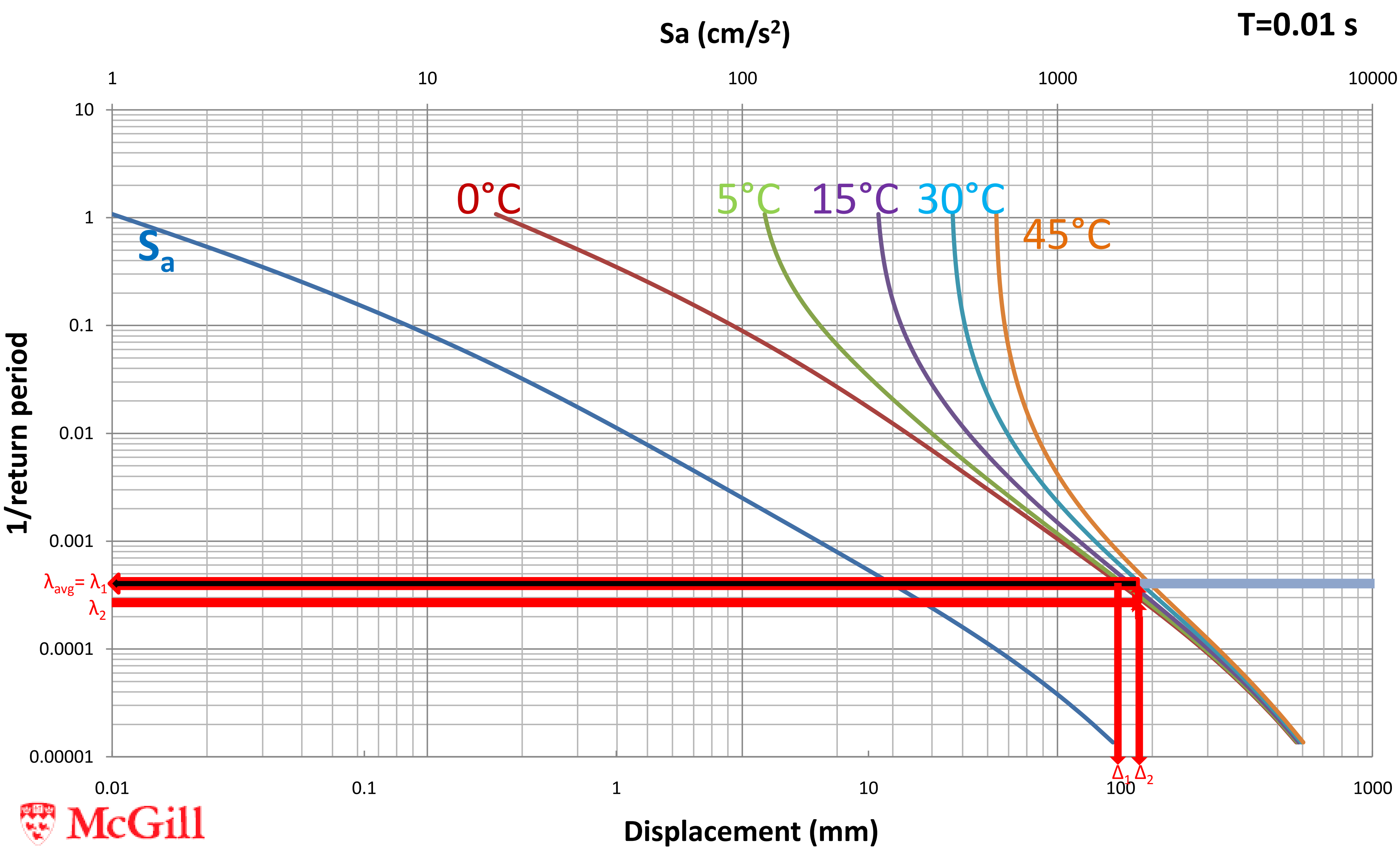

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6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)

- Results:

$\Delta_{seismic\ @\ \lambda 1=1/2475} = 100.0$ mm

$\Delta_{seismic\ @\ \lambda 2=1/2868} = 108.9$ mm

$\lambda_{avg} = \sum(\lambda_{\Delta thermal} * f_{\Delta thermal}) = 1/2475 = 0.000404 = \lambda_1$

$\Delta_{thermal\ avg}/\Delta_{thermal\ max} = \%\Delta_{thermal}$

$\Delta_{thermal\ avg} = 8.9$ mm

$\Delta_{thermal\ max}$ → 31.9 mm (Distribution)
→ 33.0 mm (CSA-S6-06)

Distribution: 8.9/31.9 = 27.9%
CSA-S6-06: 8.9/33.0 = 27.0%

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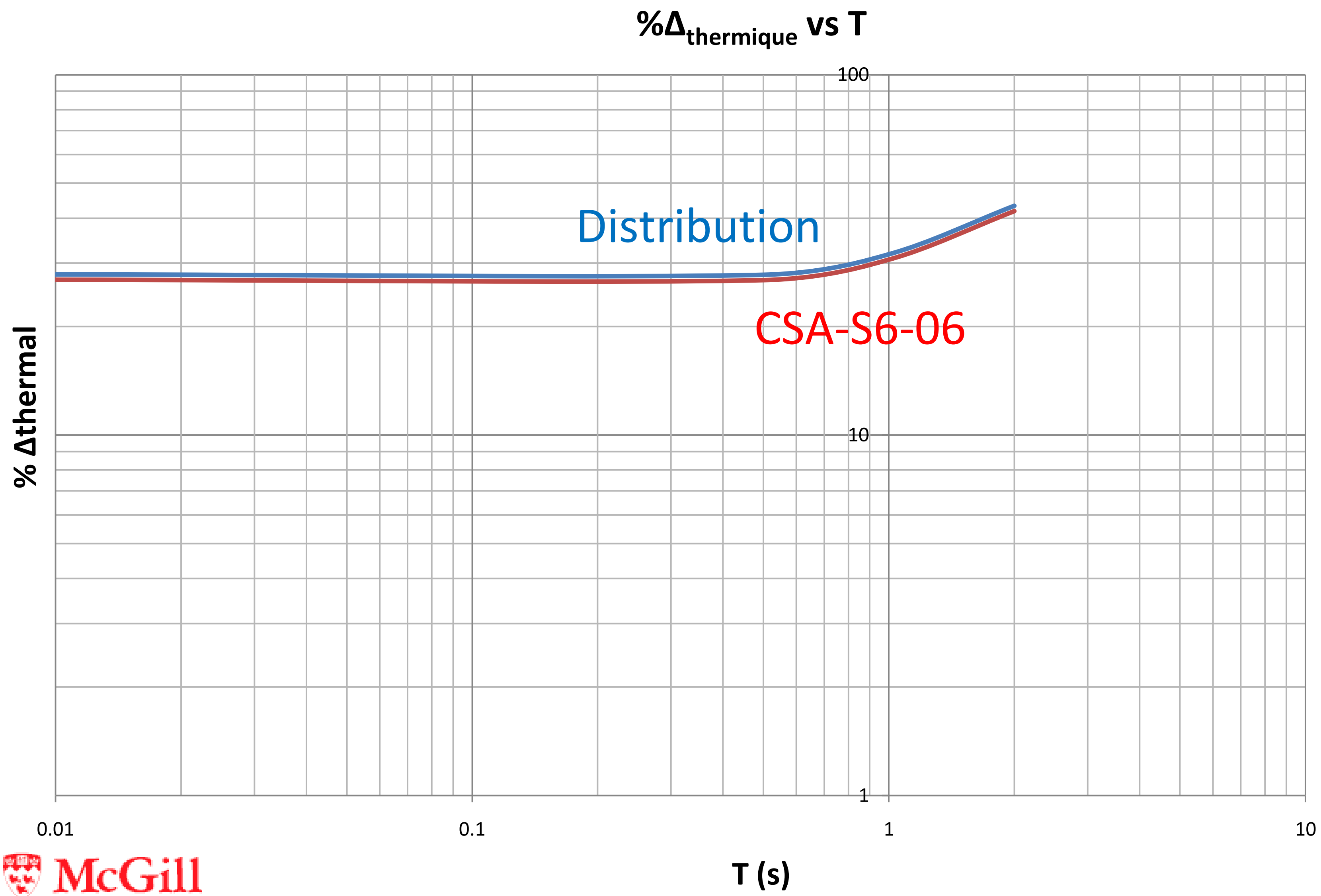
6 – Total Probability Theorem Analysis of the Madrid Bridge (Qc)



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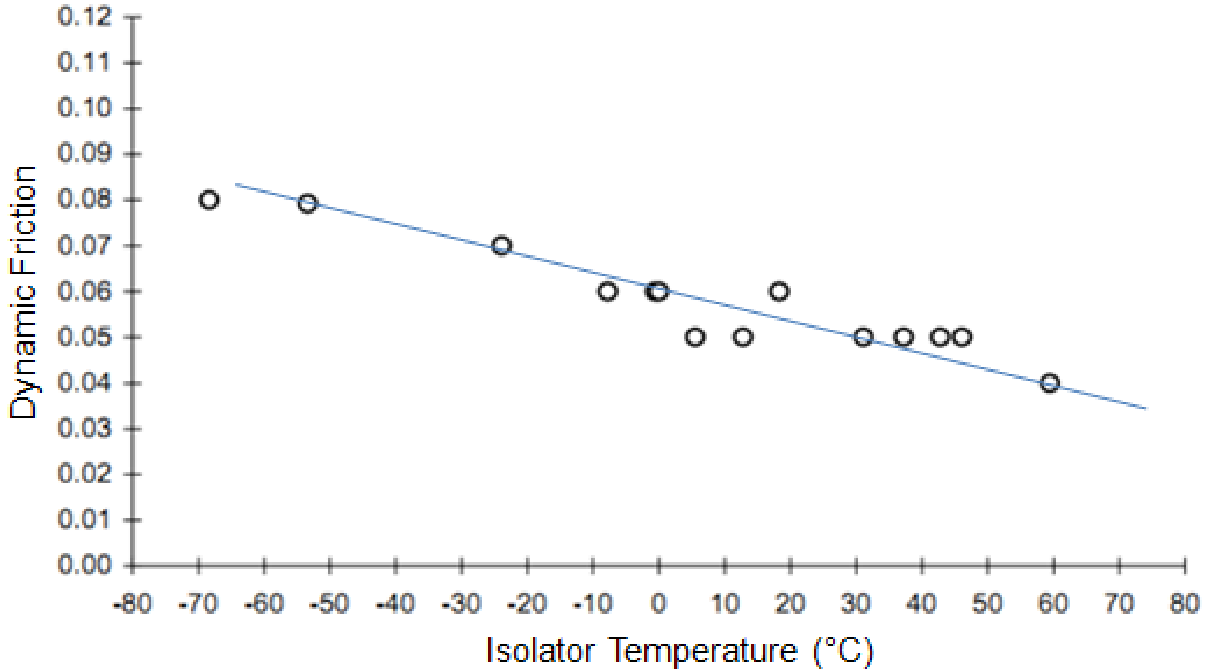
Conclusion

- Upcoming work:
  - différents cities/regions
  - performance vs temperature



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THANK YOU

QUESTIONS?