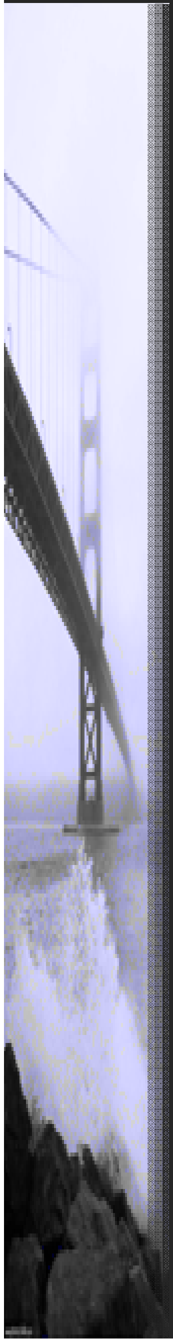
Groupe de recherche en GÉNIE DES STRUCTURES

ÉCOLE POLYTECHNIQUE MONTRÉAL
Affiliée à l'Université de Montréal



HYBRID SUMILATIONS ON ISOLATED AND DAMPED BRIDGES

Workshop on the Seismic Isolation and Damping of Bridge Structures

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May 26th 2011

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Collaborators :
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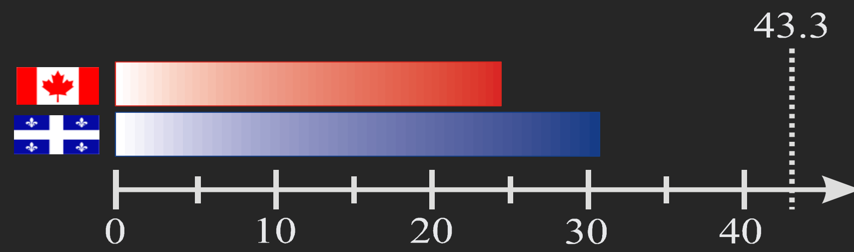
Martin Leclerc

Granville Street Bridge, Vancouver, seismic retrofit : 1996

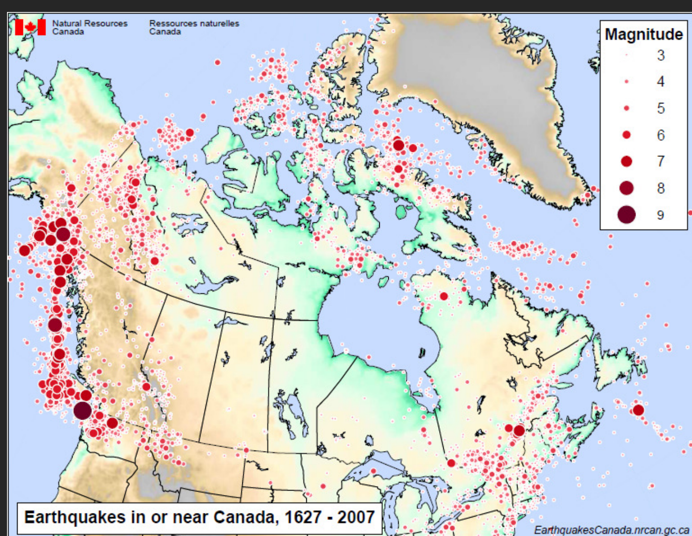
INTRODUCTION

PROBLEM

- **Aging** of bridge structures



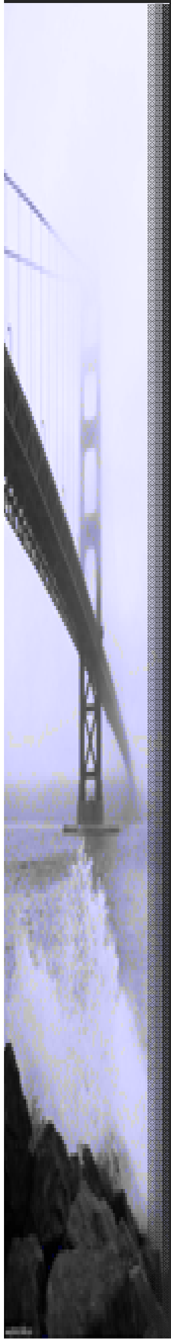
- **Seismic design requirements** were first introduced in the Canadian bridge design code (S6) in 1966, but became progressively more severe with every new edition of the S6.



➢ Many bridges of the transportation network in Quebec were built either before seismic design provisions were introduced in our code or with much less severe requirements than the ones prescribed in the present code.

➢ There is an increased need for innovative techniques to achieve **time and cost effective seismic retrofit and construction of bridges**.

INTRODUCTION

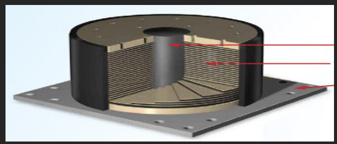


SOLUTION STUDIED

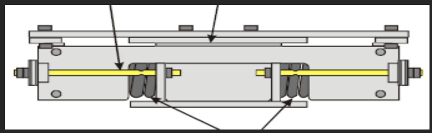
Seismic protection devices :

- Isolators
- Dampers
- Shock transmission devices

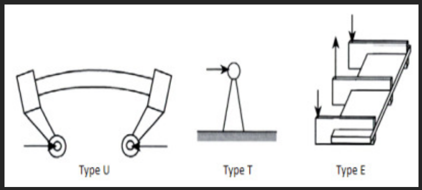
Laminated Rubber Isolator



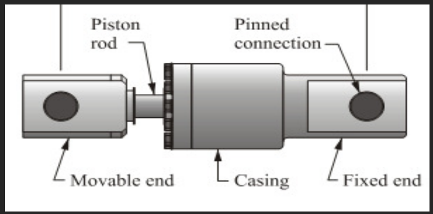
Friction Isolator



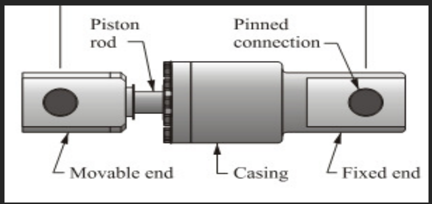
Metallic Damper



Viscous Damper



Viscous Shock Transmission Unit



RESEARCH OBJECTIVES

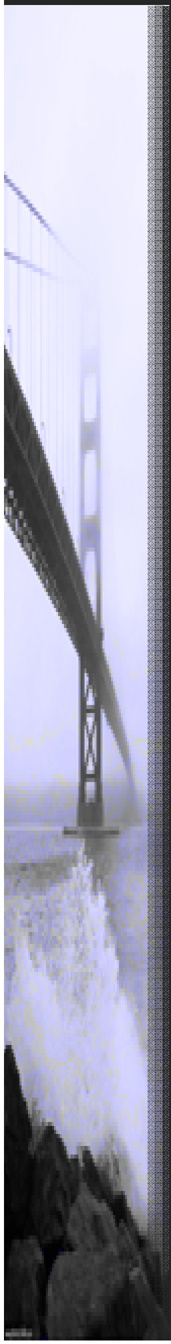
Study the performance of simple numerical models in reproducing the dynamic behaviour of bridges equipped with seismic protective devices :

- Run **non-linear time history analyses** of purely numerical models with **SAP2000**.
- Run **real-time hybrid tests** of the same bridges and **compare** the numerical results to the experimental results.

PRESENTATION OVERVIEW

1. Experimental method
2. 1st case study : Isolated bridge
3. 2nd case study : Bridge equipped with viscous dampers
4. Conclusions

PRESENTATION OVERVIEW



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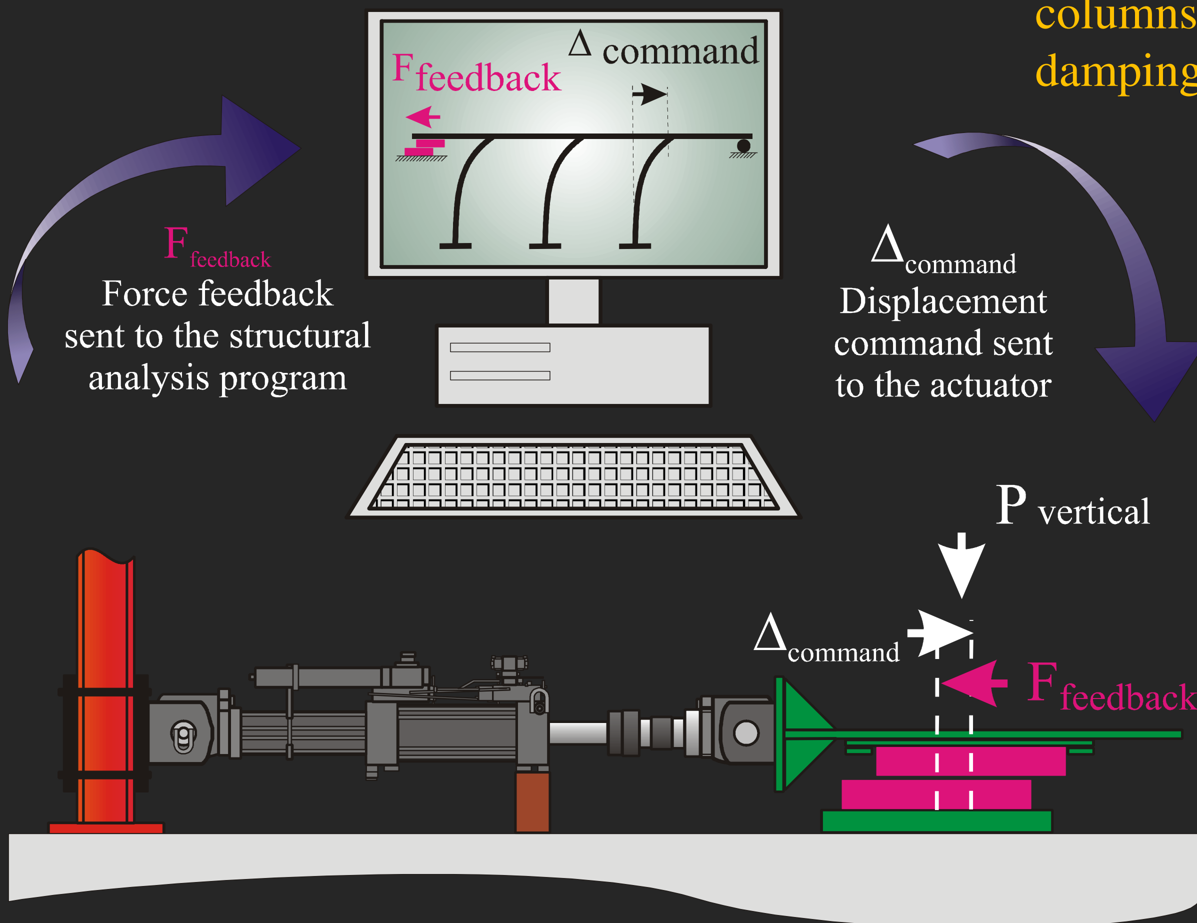
REAL TIME HYBRID SIMULATIONS

Also referred to as ...

"Real Time Dynamic Substructuring (**RTDS**) "

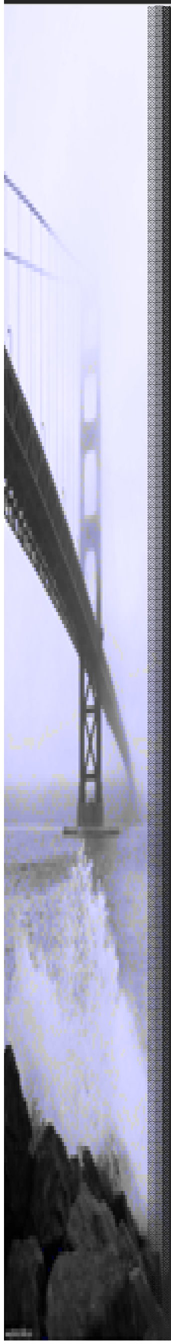
PHYSICAL substructure:
Seismic protective device

NUMERICAL substructure:
columns, deck mass, numerical damping, other bearings, etc.



Algorithm used for structural analysis : Rosenbrock-W (Lamarche et al. 2009) implemented in Simulink (Matlab).

PRESENTATION OVERVIEW



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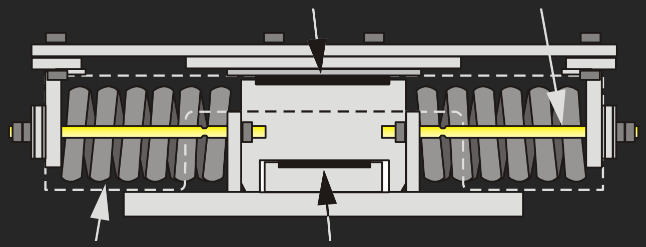
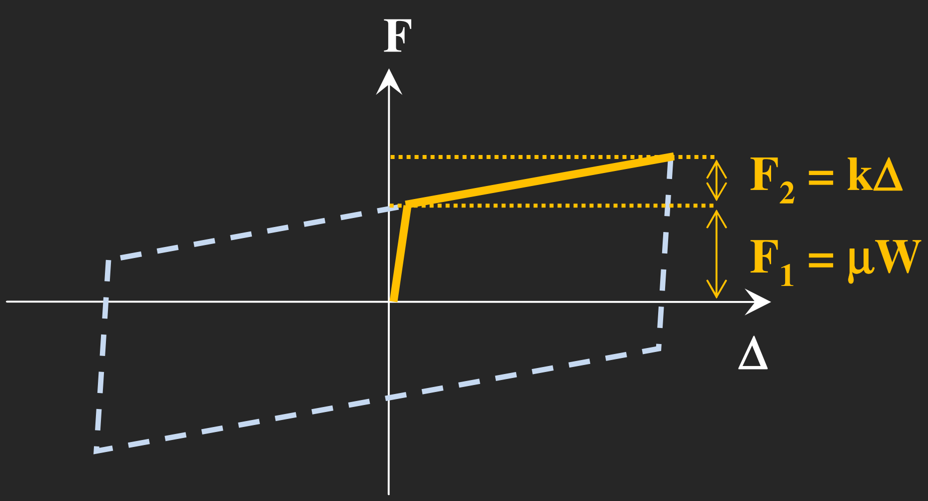
FRICTION ISOLATOR

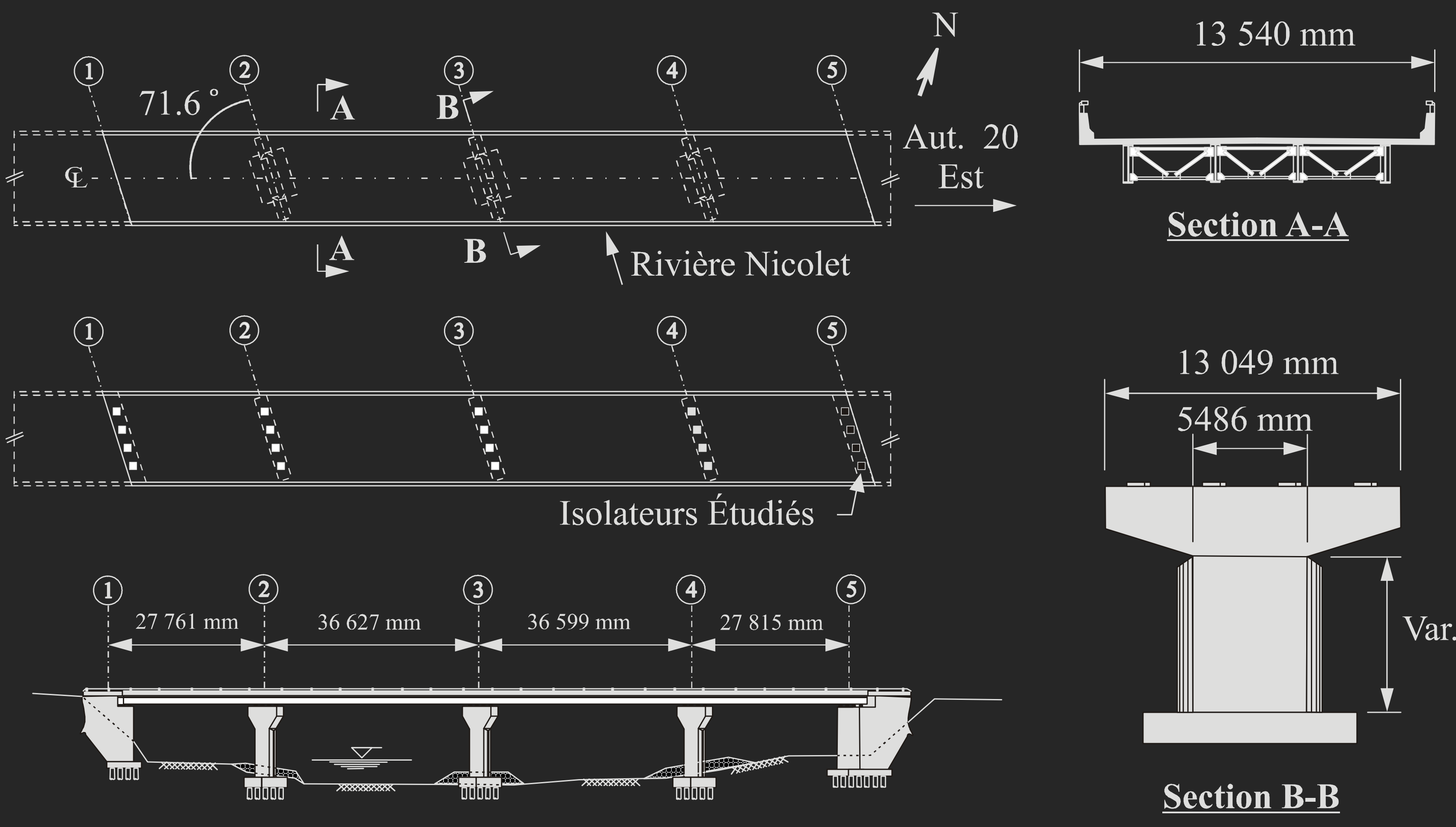


Goodco Z-Tech device :

- Stainlesse-steel / teflon interface : $F_1 = \mu W$
- Metallic coil springs : $F_2 = k\Delta$



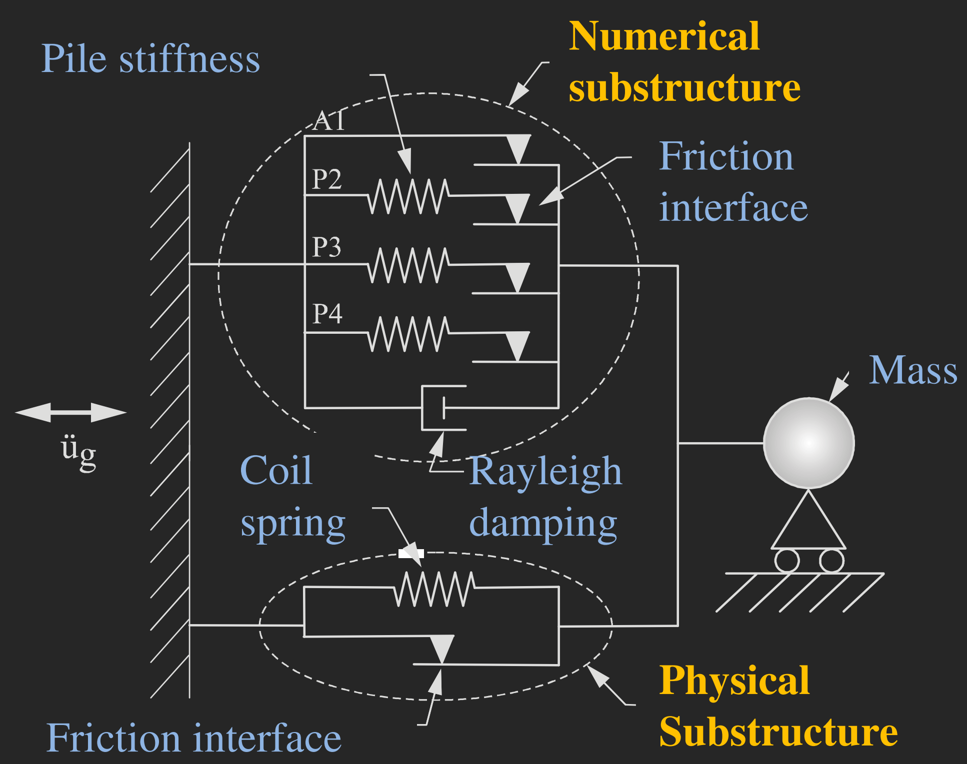
ISOLATED BRIDGE

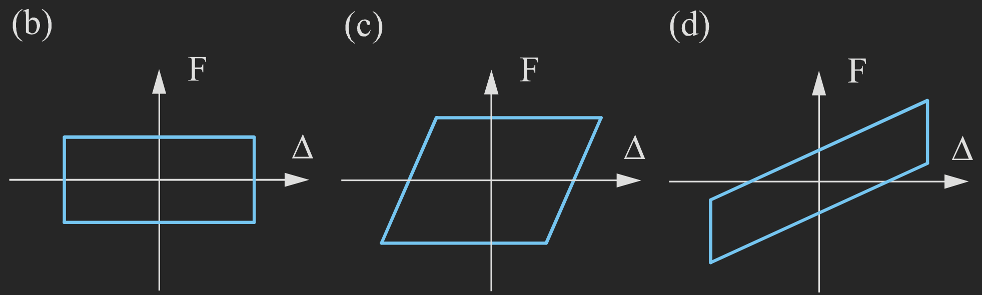


- 4 isolators at abutment 5.
- Dynamic behaviour is studied along the longitudinal direction on the bridge
- Hypothesis : Deck is axially infinitely stiff
- Hypothesis : Abutments are longitudinally infinitely stiff

ISOLATED BRIDGE

SDOF NUMERICAL MODEL

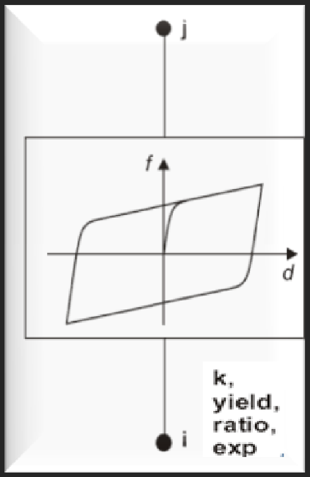




Abutment 1 **Piles 2, 3 and 4** **Abutment 5**

SAP2000

« **Plastic (Wen)** » link/support type for all supports

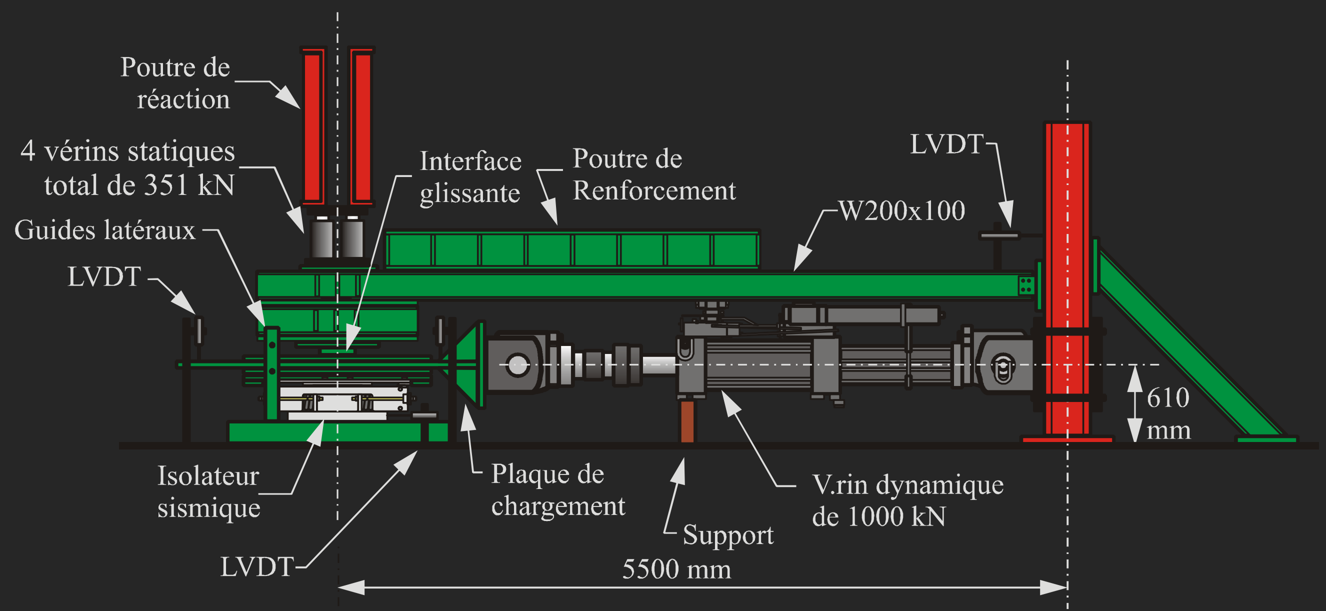


Mass proportional Rayleigh numerical damping

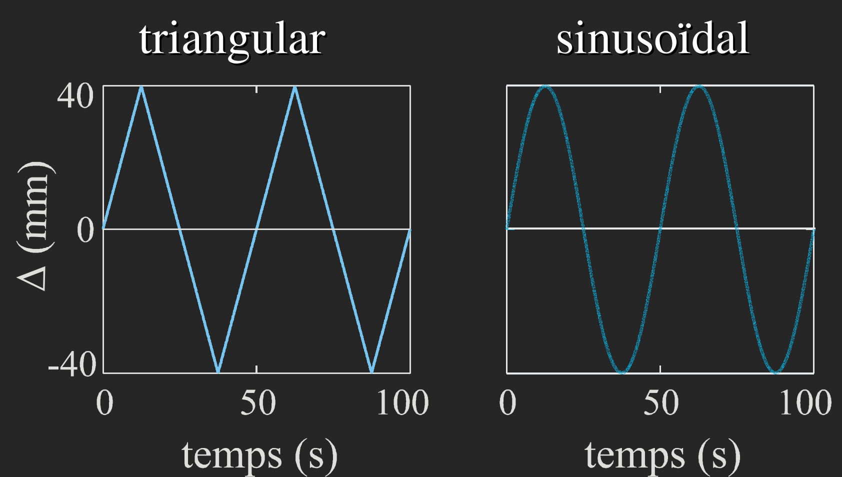
$\xi = 5\%$

ISOLATED BRIDGE

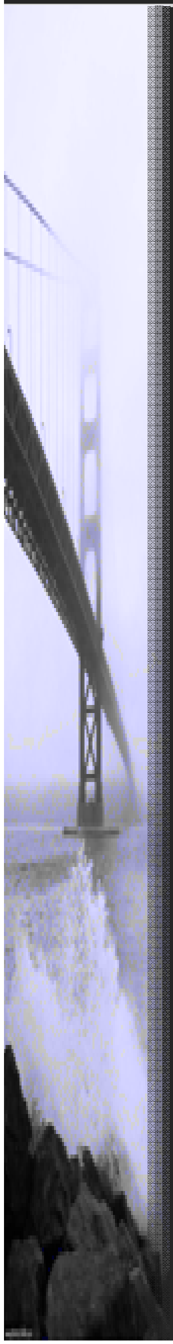
Setup :



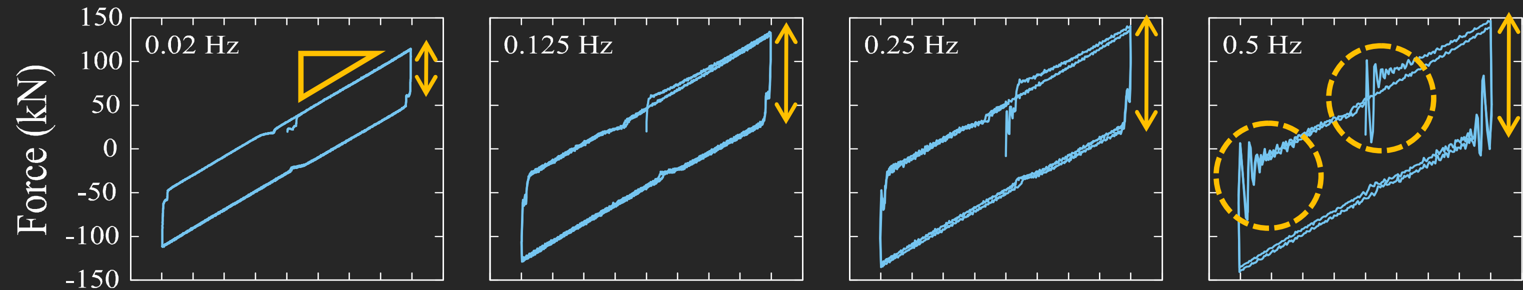
Cyclic tests for device characterization:



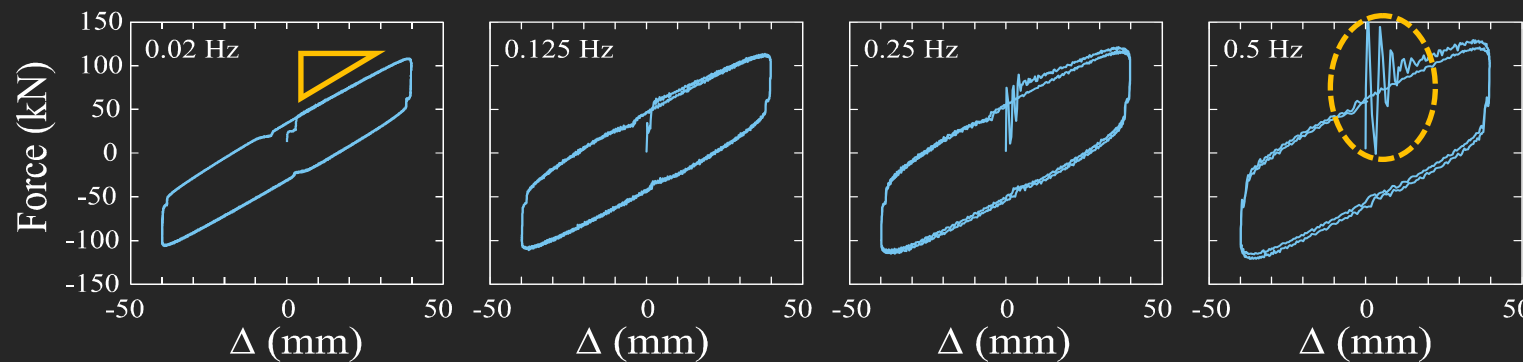
ISOLATED BRIDGE



- triangular :



- sinusoidal :

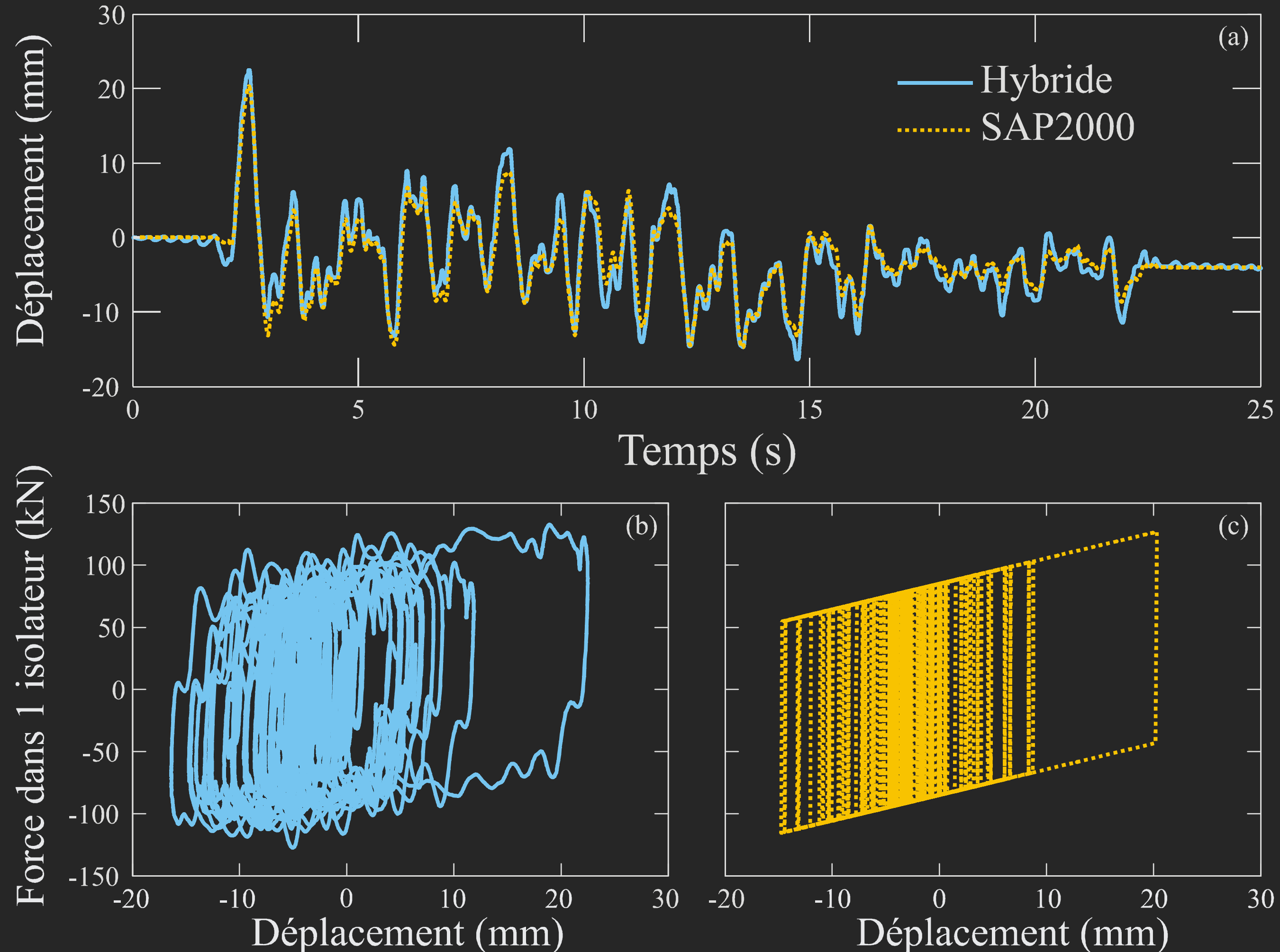


- ➢ Stiffness **K**
- ➢ Friction coefficient μ varies with velocity
- ➢ Dynamic amplification due to stick-clip action and sudden velocity change

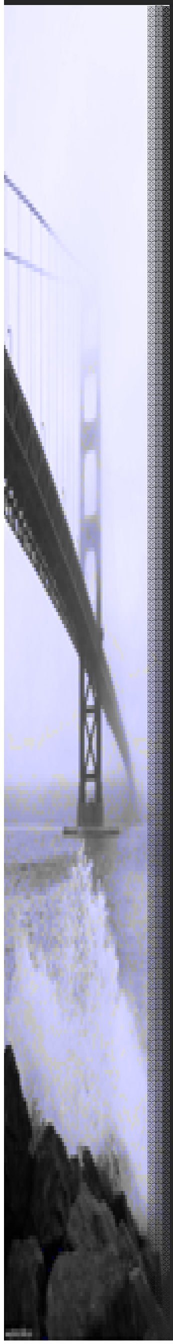
ISOLATED BRIDGE

COMPARISON : EXPERIMENTAL VS NUMERICAL

Result example with a magnitude 7.0 synthetic accelerogram (Atkinson)



PRESENTATION OVERVIEW



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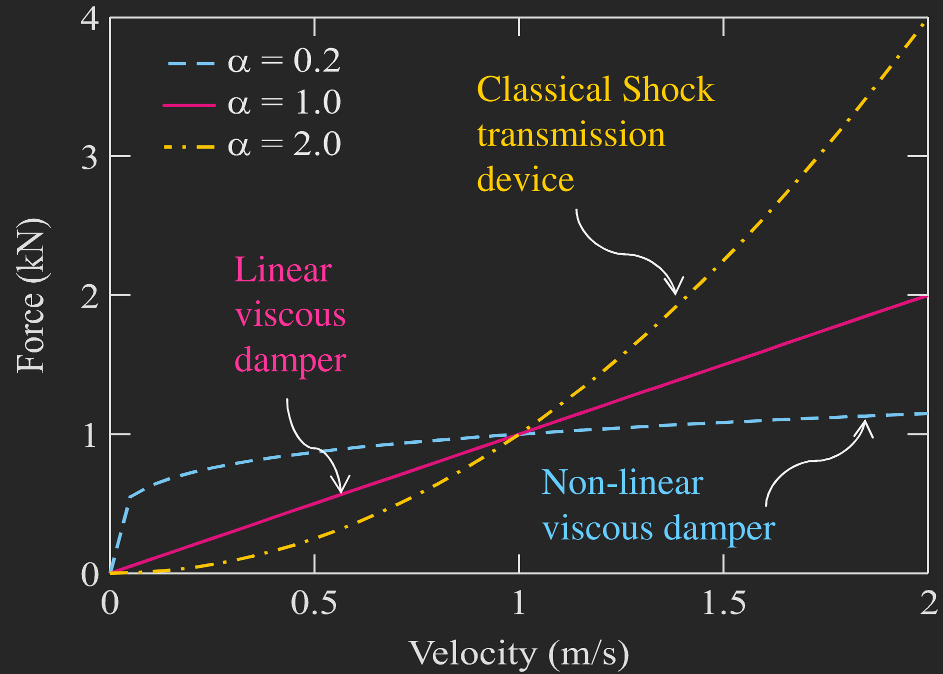
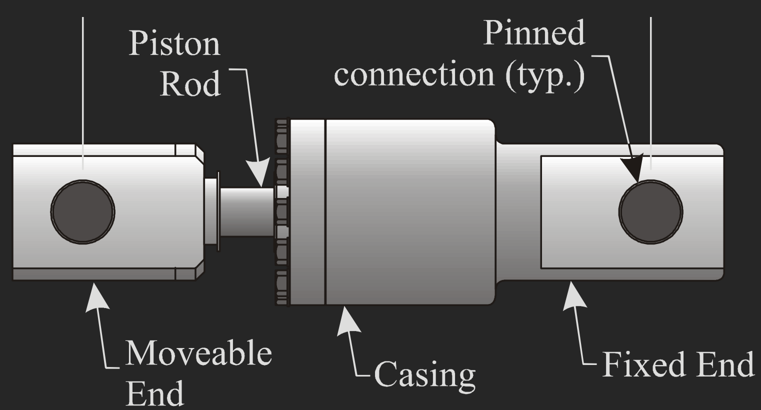
DAMPER AND SHOCK TRANSMISSION UNIT

- **Force-velocity fonction:** $F = CV^{\alpha}$

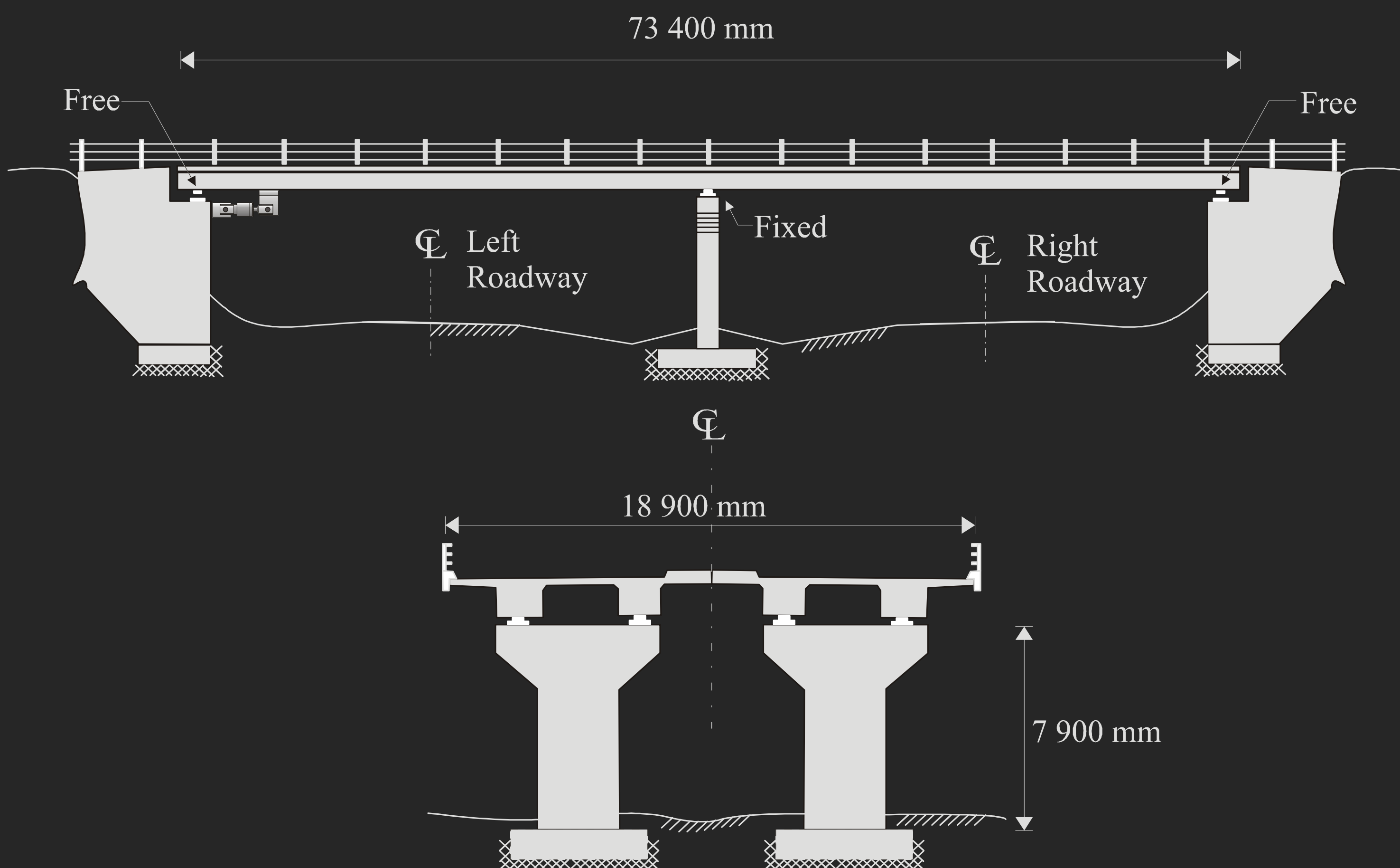




- Seismic Damping Unit (SDU) from *LCL-Bridge Products Technology*
- Double action piston
- Allowable movement 100 mm
- Resisting force created by fluid shear

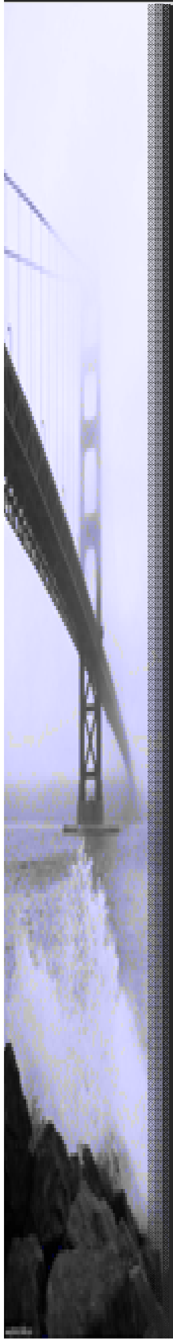
VISCOUS DAMPER

BRIDGE STRUCTURE STUDIED



- Fictitious bridge located in Montreal, QC
- W = 25 100 kN
- Dynamic behaviour is studied along the longitudinal direction on the bridge
- Hypothesis : Deck is axially infinitely stiff
- Hypothesis : Abutments are longitudinally infinitely stiff

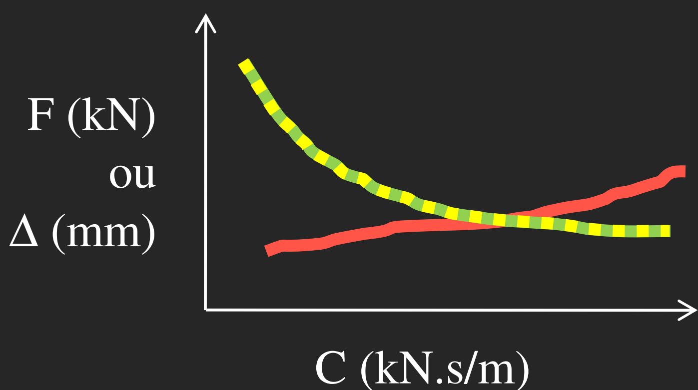
VISCOUS DAMPER



DESIGN : CHOICE OF DAMPER VISCOUS PARAMETERS

•Design Objectives : obtain linear-elastic behaviour in columns, minimize displacements, distribute forces equally between columns and abutment

➢ Parametric study on C and α :

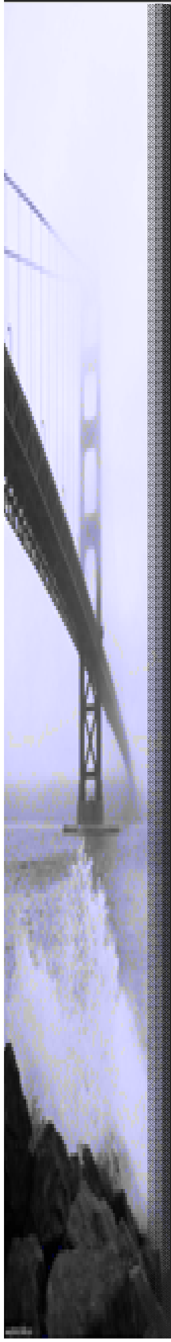


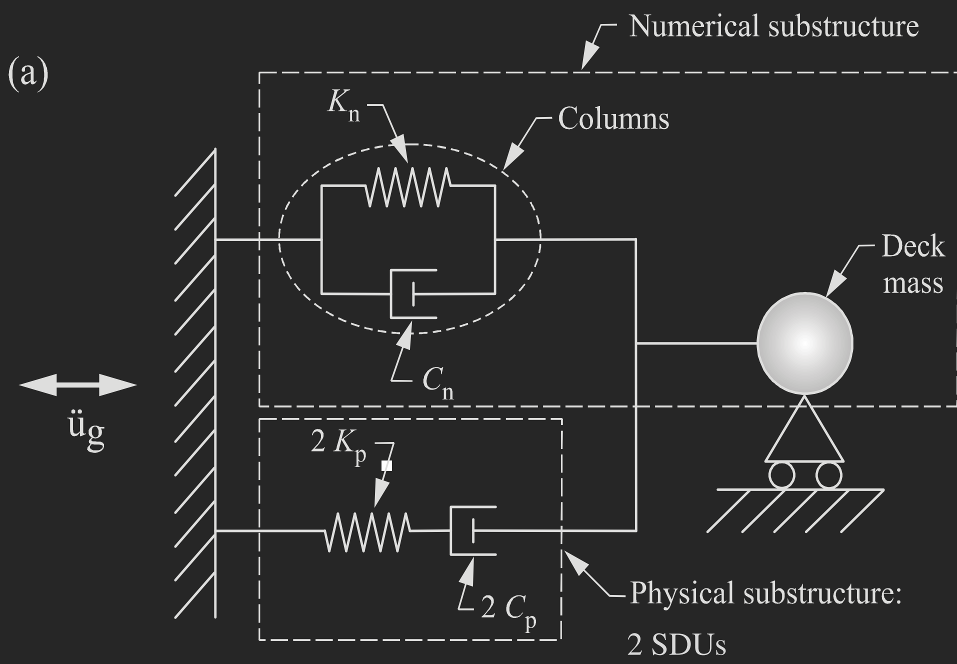
- **Force in 2 SDUs (= abutment) F = CV$^{\alpha}$**
- **Force in columns**
- **Displacement (deck)**

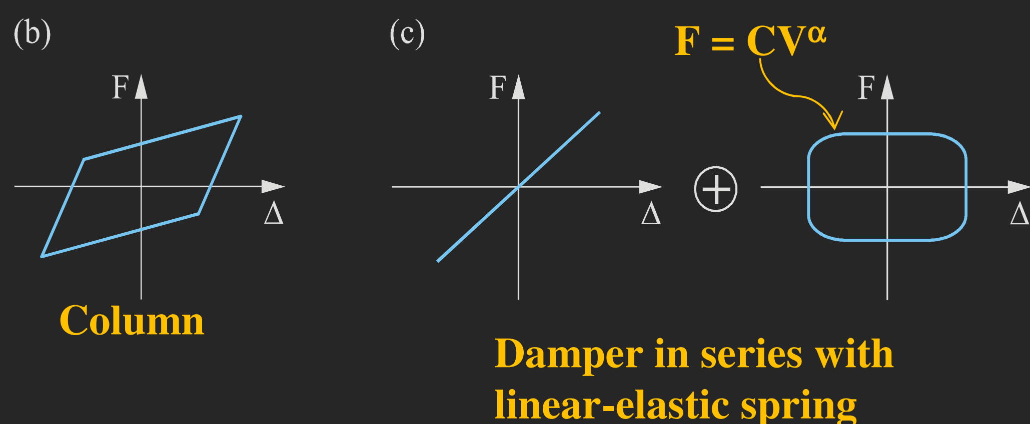
➢ **Choice** : **C = 600 - 900 kN.s /m**, **α = 0.14 - 0.22** -> limit the forces in abutment and columns to **1200 kN**, and displacement to **25 mm**.

VISCOUS DAMPER

SDOF NUMERICAL MODEL

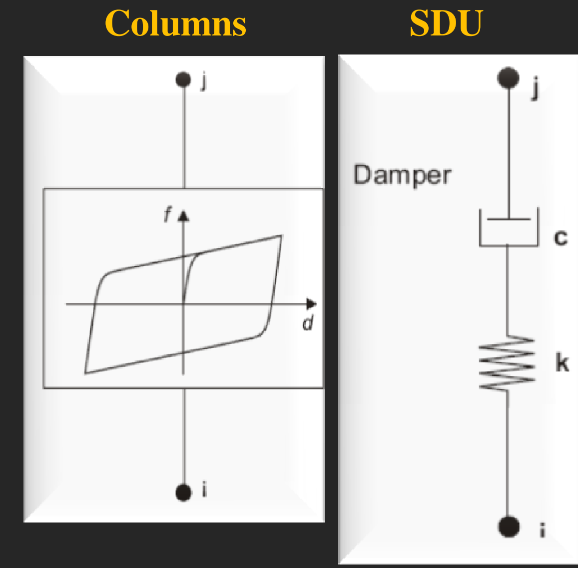






SAP2000

« **Plastic (Wen)** » link/support type for the columns and « **Damper** » for the SDU.



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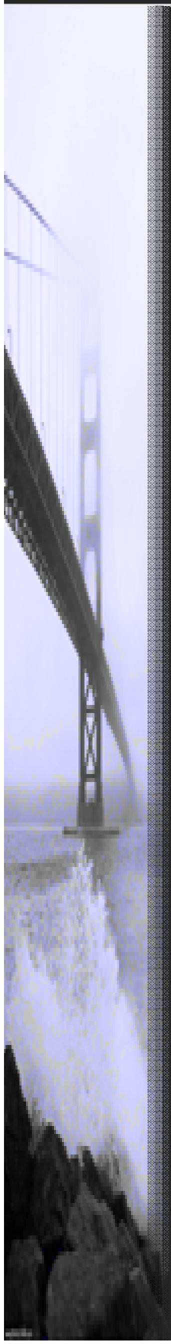
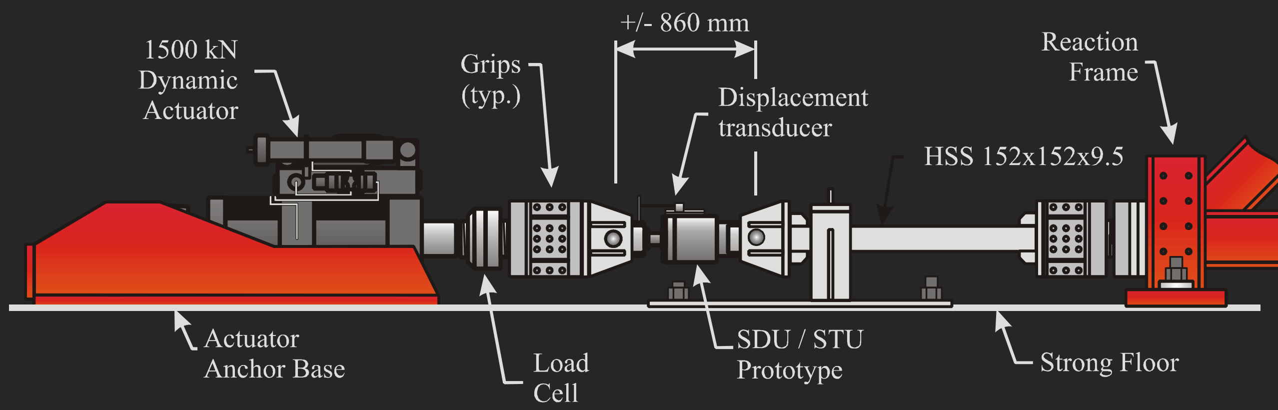


VISCOUS DAMPER CHARACTERIZATION TESTS

Setup :



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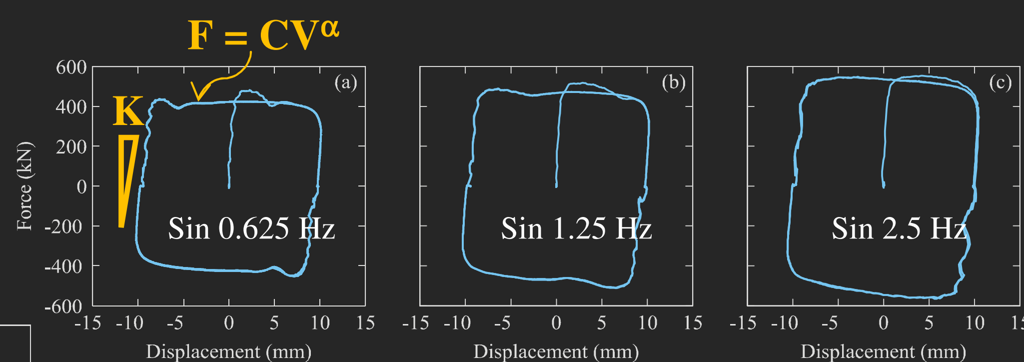

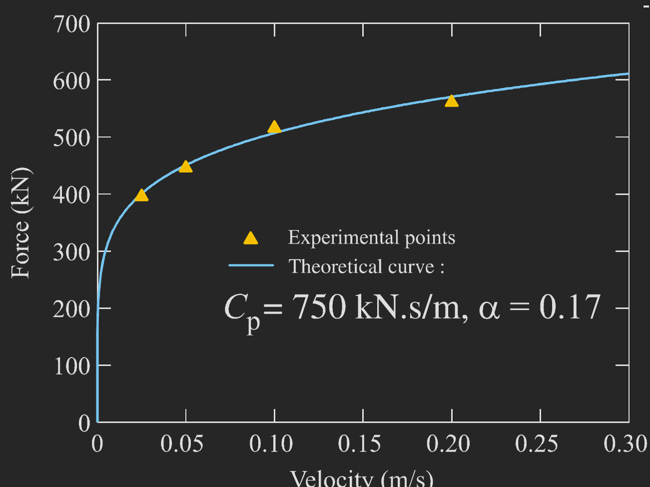

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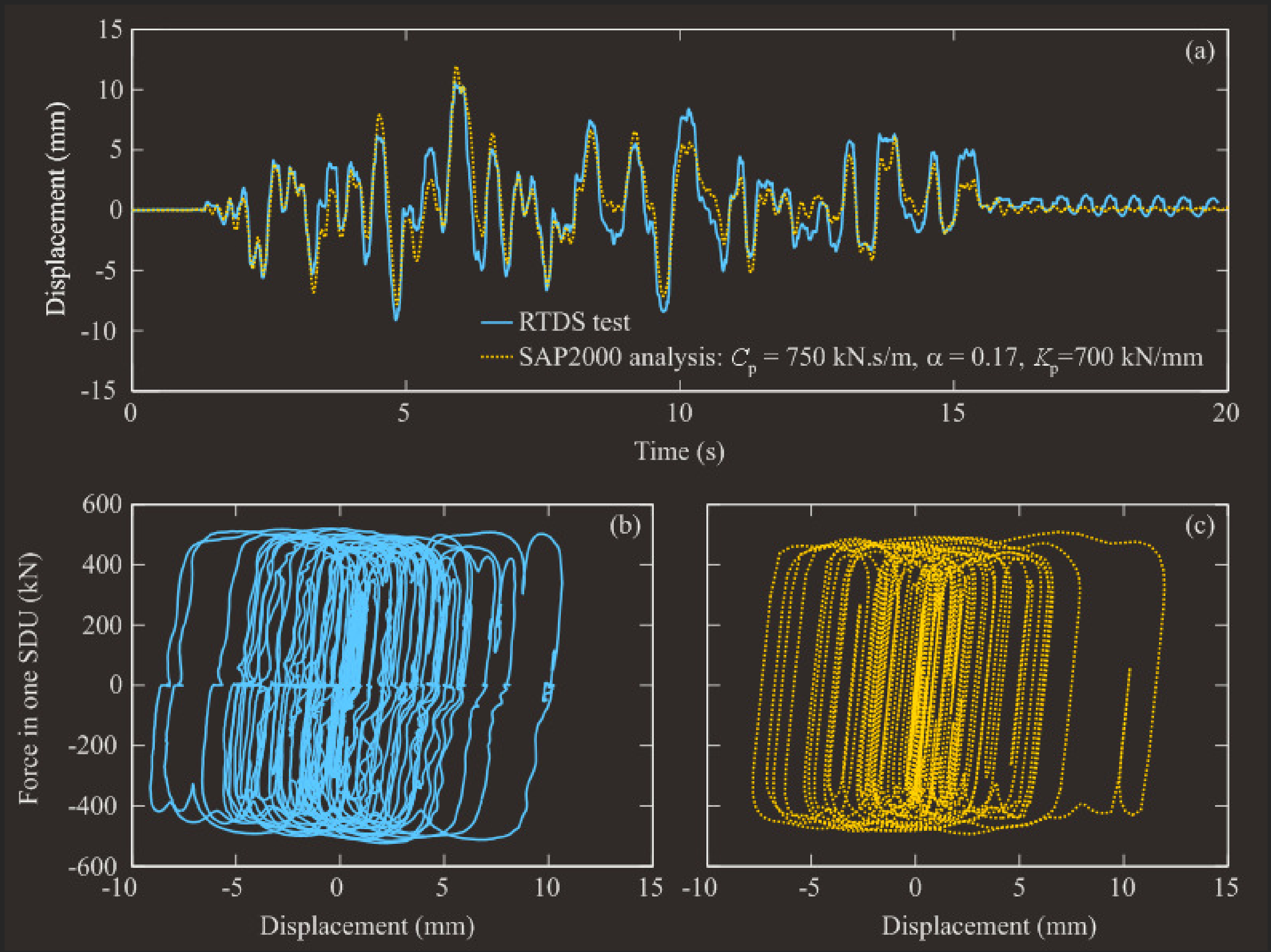
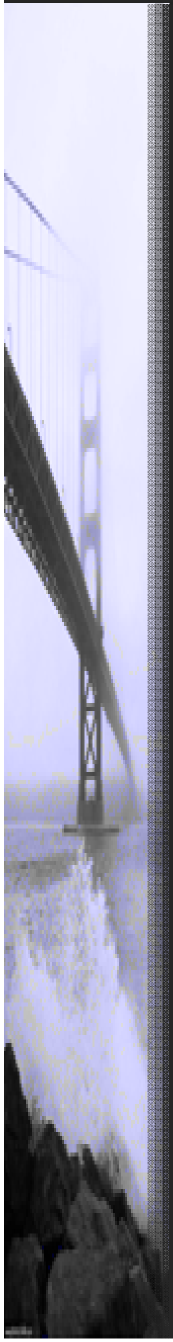


PRESENTATION OVERVIEW



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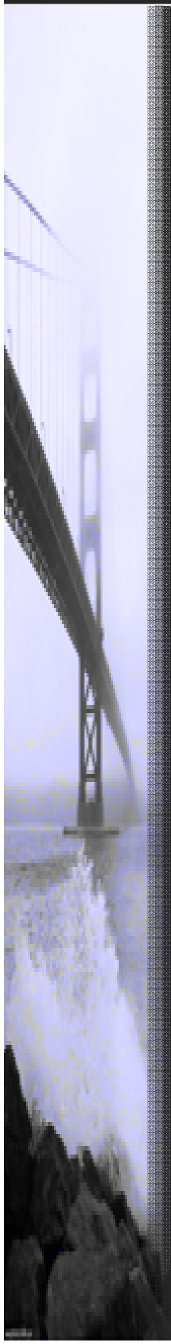
4. **Conclusions**

CONCLUSIONS



1. The **hybrid testing program** was successfully completed.
2. **Simplified numerical models capable** of adequately predicting the displacement response of seismically protected bridges.
3. It is imperative to **accurately characterize the devices** in order to properly predict their behaviour.
4. No simplified **design method** for bridges equipped with supplemental damping devices is available in CSA S6-06.

Note :

$B = \Delta_0/\Delta_{damped}$
or
$B = F_0/F_{damped}$

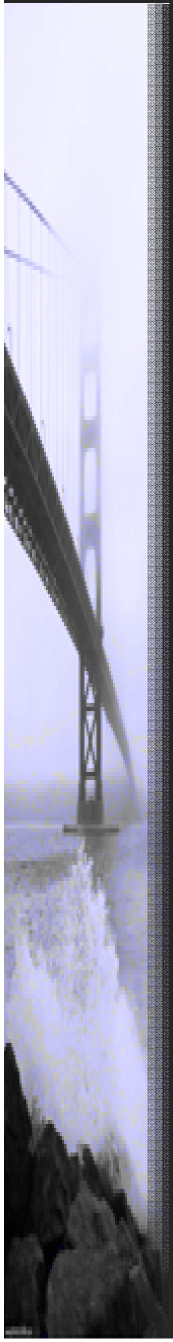
→

Tableau 4.8
Coefficient d'amortissement B
(voir les articles 4.10.6.2.1 et 4.10.11.2)

Amortissement visqueux équivalent, β (% de l'amortissement critique)	Coefficient d'amortissement, B
≤ 2	0,8
5	1
10	1,2
20	1,5
30	1,7
40	1,9
50	2

→ $C = \beta * 2\sqrt{(km)}$ →

$$\frac{C_{NL}}{C} \cong \frac{\sqrt{\pi}}{2}(\omega X_0)^{1-\alpha}$$



Merci!

Robert Tremblay
Najib Bouaanani
Charles-Philippe Lamarche
Martin Leclerc

Goodco Z-Tech

LCL – Bridge Products Technology

NSERC

MTQ

Dessau