2005 National Building Code of Canada

Seismic Design Changes

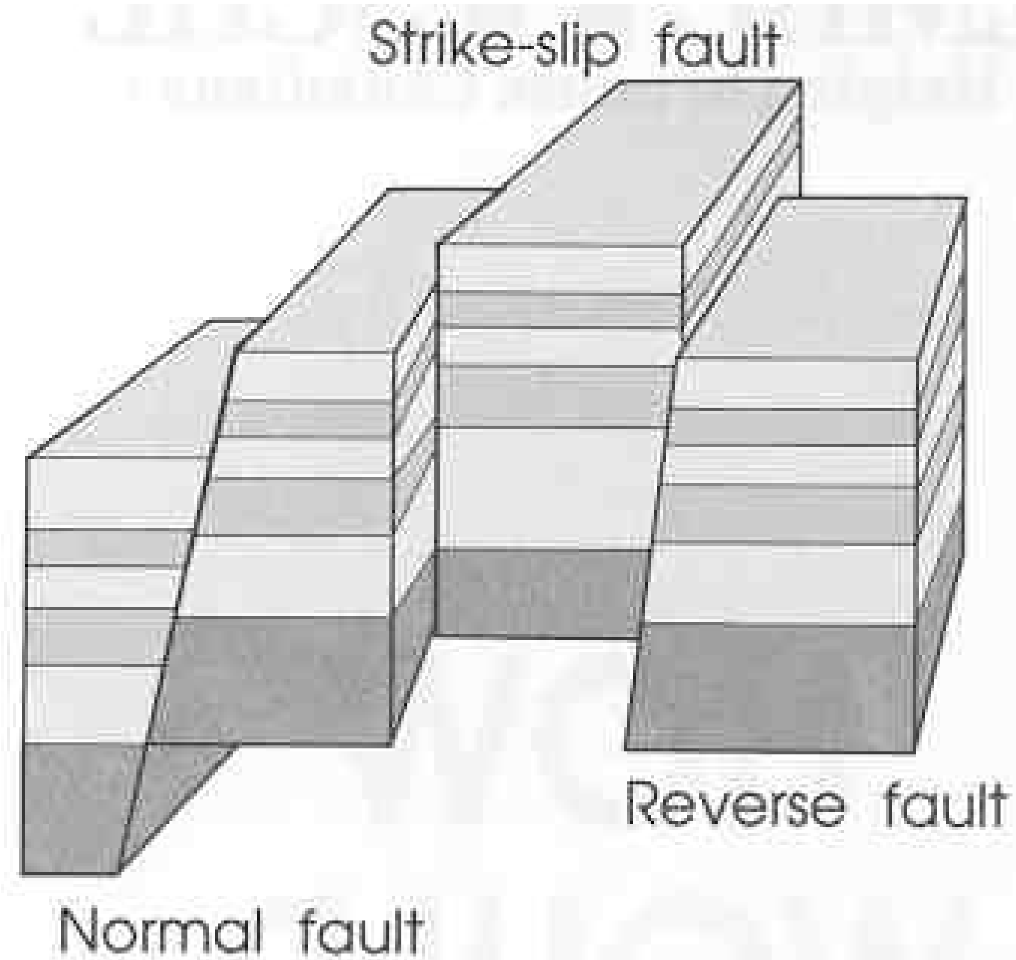
Impact on Insurance Industry

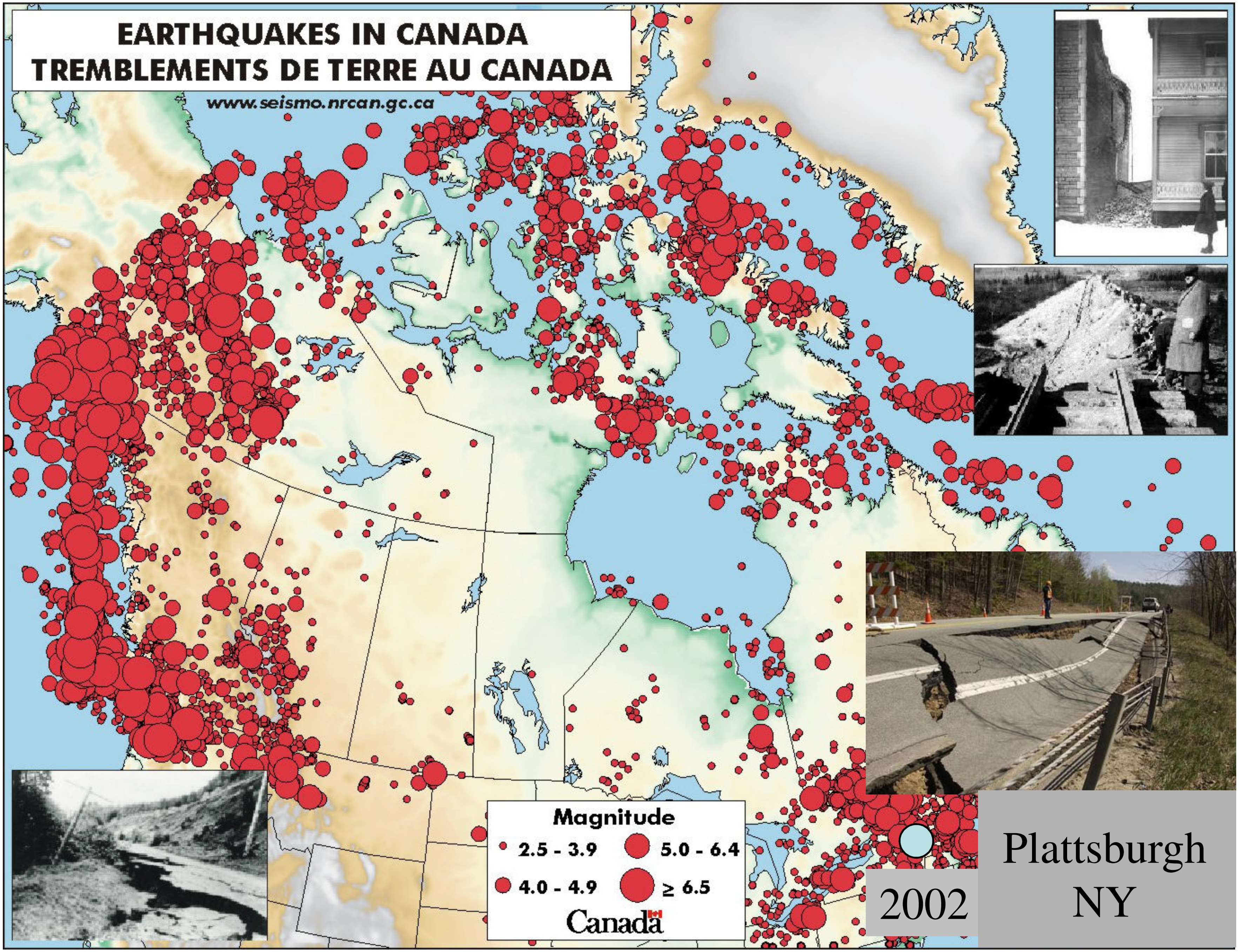
NBCC 2005 Seismic Design Changes

Gravity Element Failures

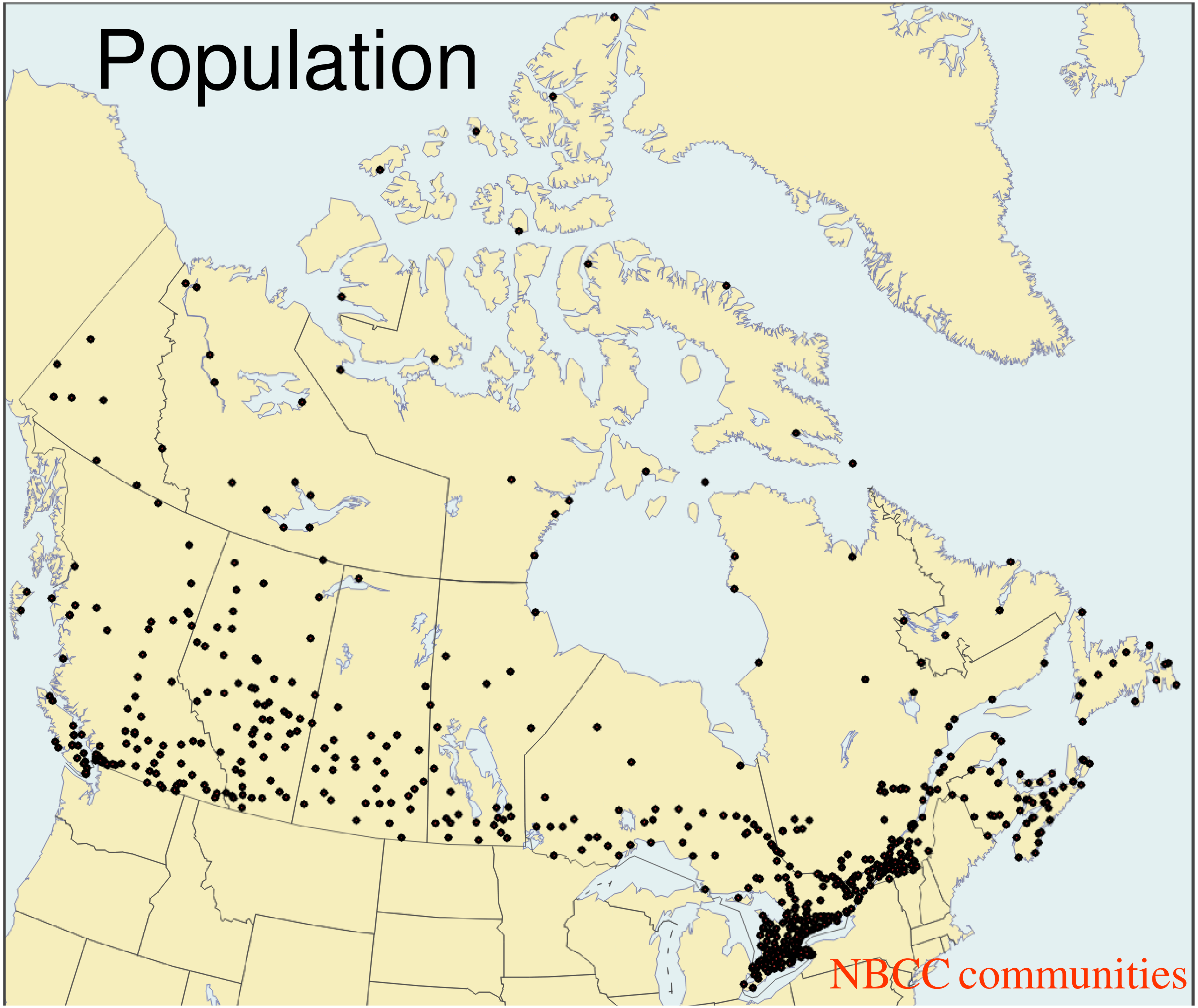
Reinforced Concrete Column Confinement

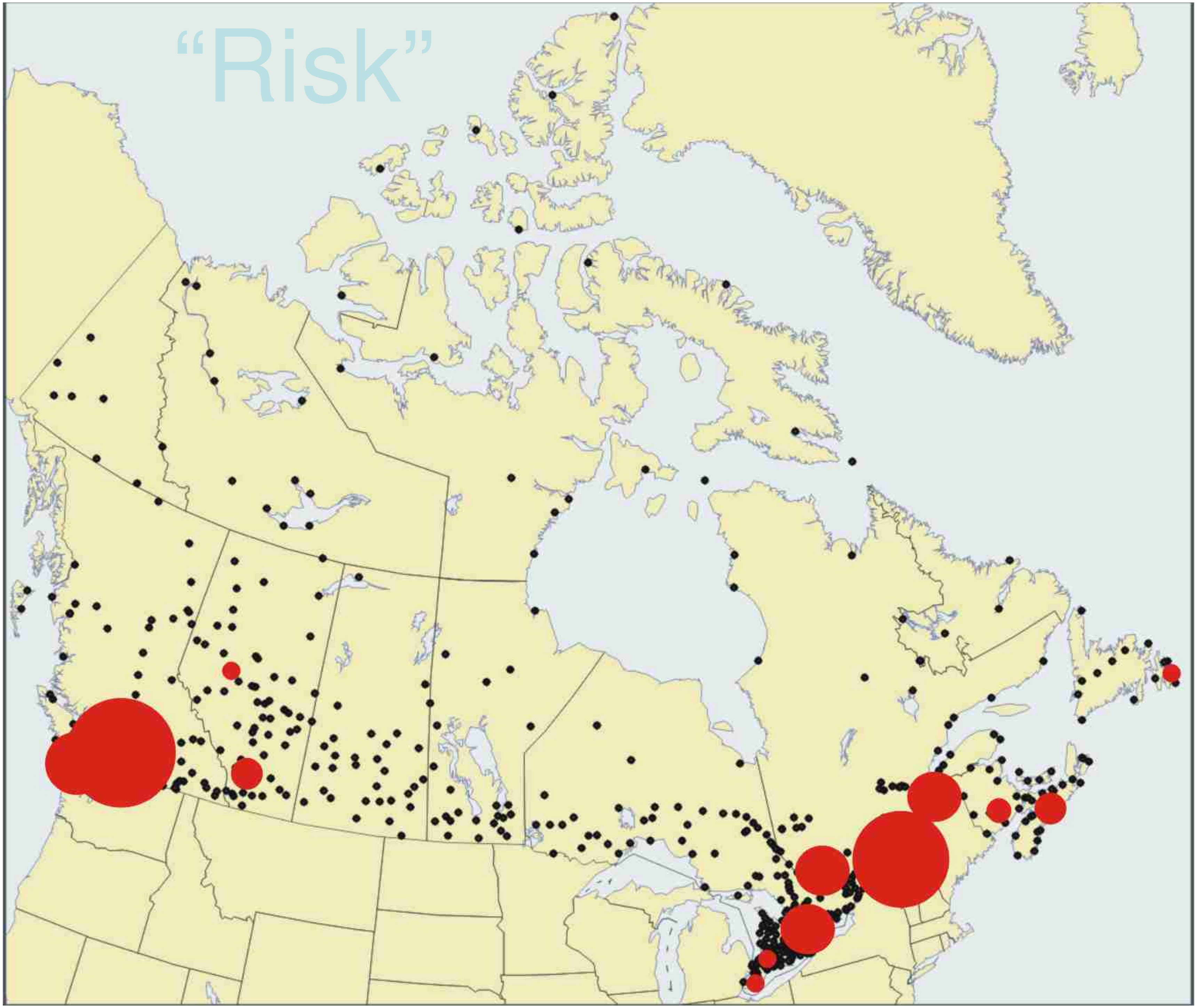
What Causes Earthquakes



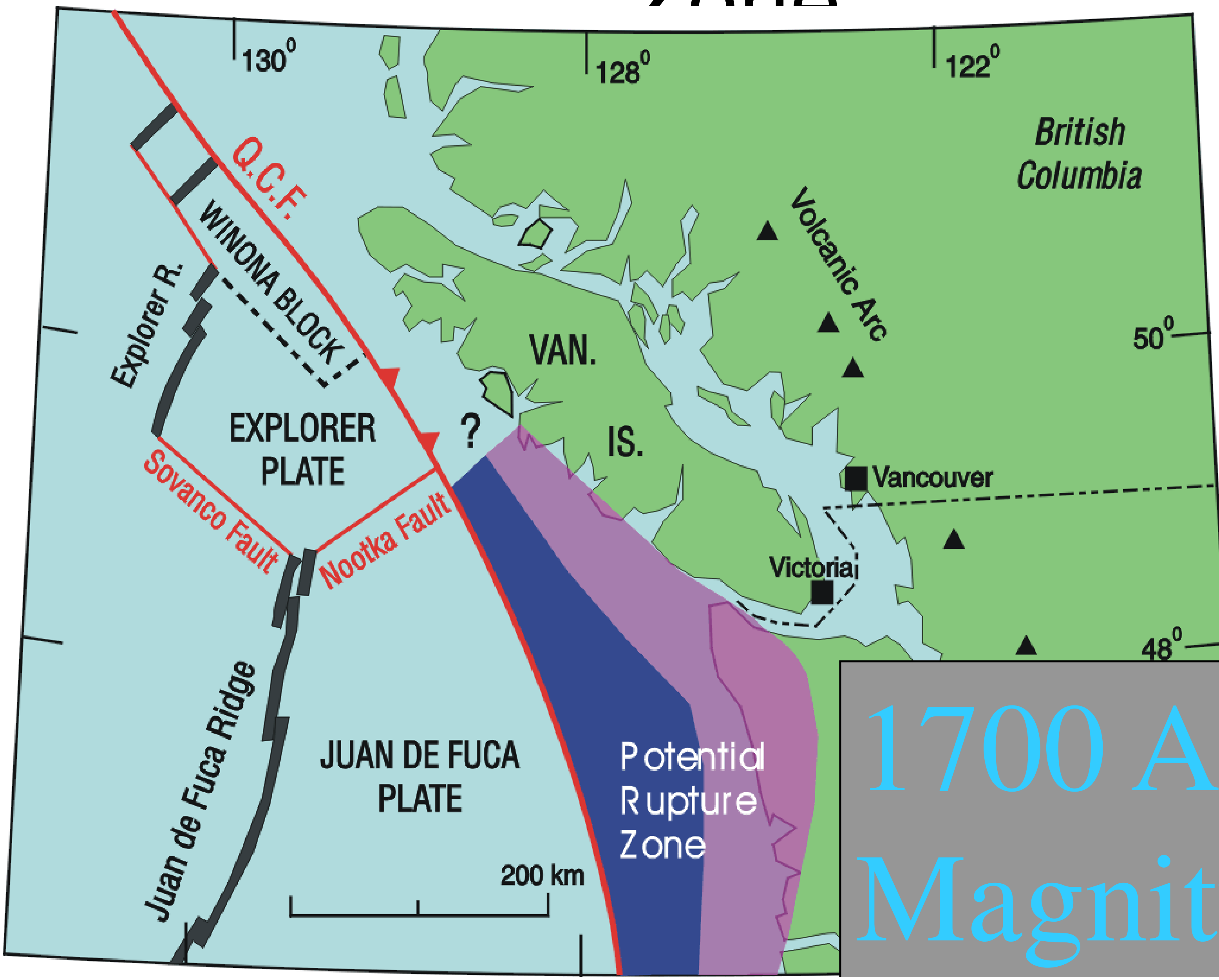

EARTHQUAKES IN CANADA
TREMBLEMENTS DE TERRE AU CANADA
www.seismo.nrcan.gc.ca
Magnitude
2.5 - 3.9
5.0 - 6.4
4.0 - 4.9
≥ 6.5
Canada
Plattsburgh
NY
2002

Population



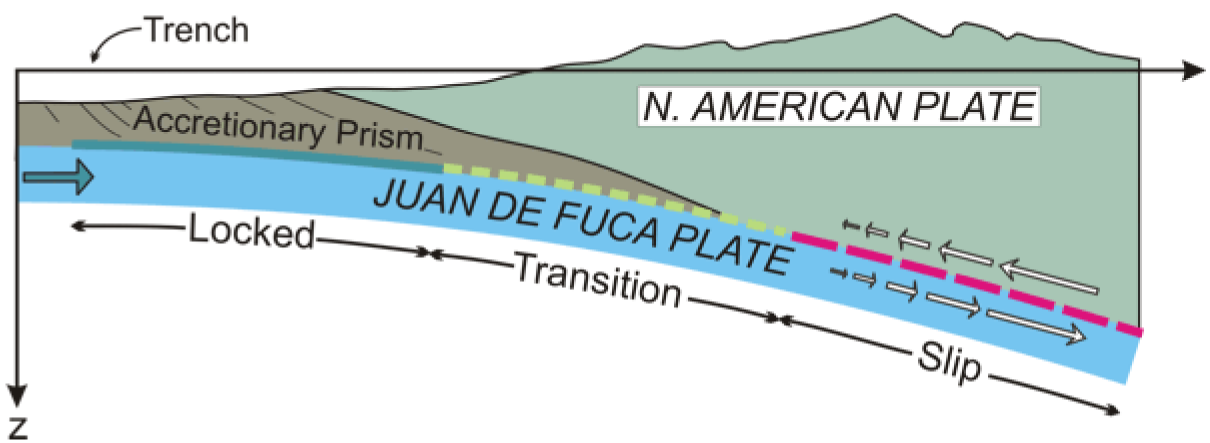

“Risk”

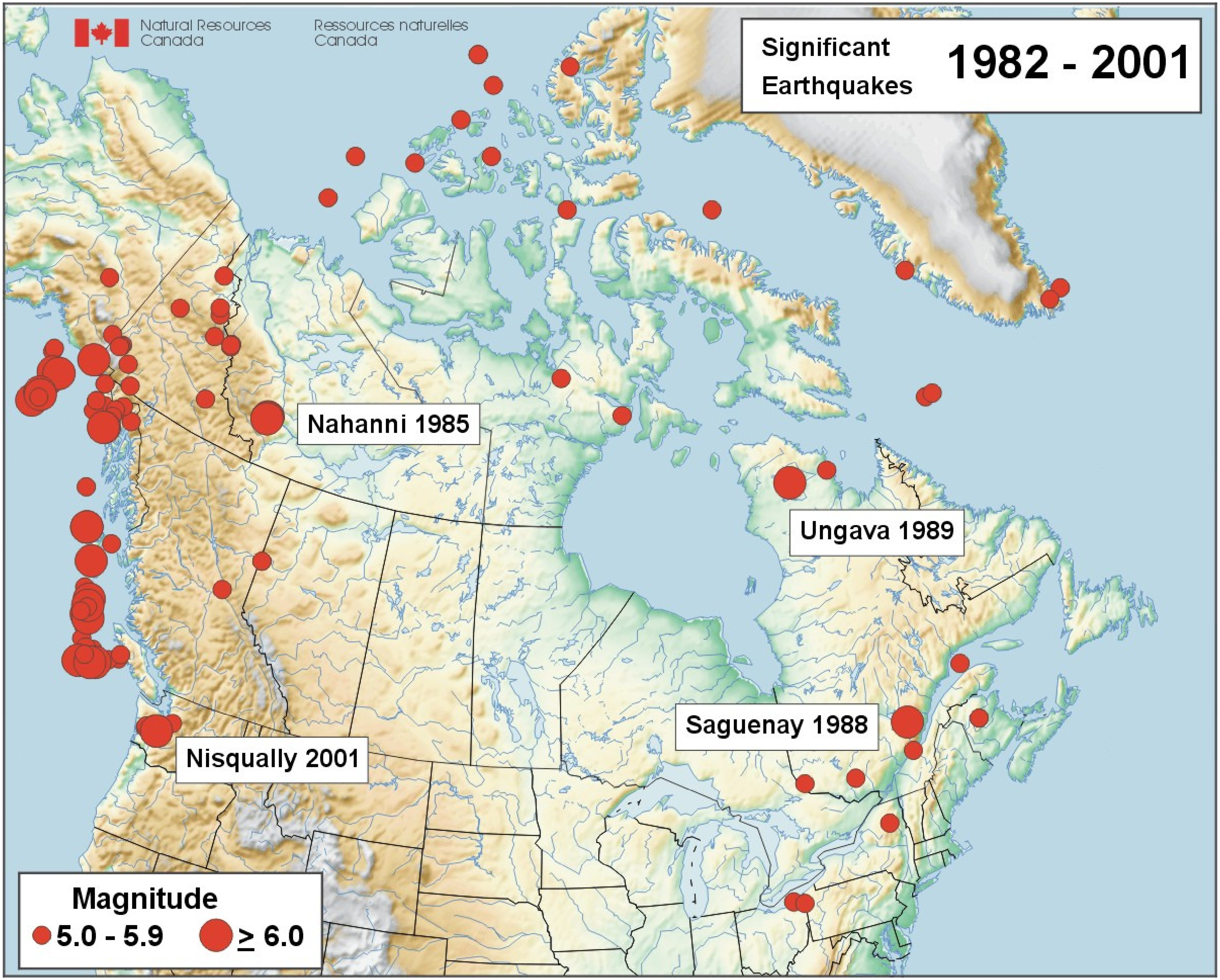
Cascadia Subduction Zone



1700 A.D.
Magnitude 9

Jan de Fuca Plate Slip




Natural Resources Canada
Ressources naturelles Canada
Significant Earthquakes
1982 - 2001
Nahanni 1985
Ungava 1989
Saguenay 1988
Nisqually 2001
Magnitude
5.0 - 5.9
≥ 6.0

2005 National Building Code of Canada Seismic Design

- Basics of Seismic Design
- Changes Incorporated in 2005 NBCC
  - Seismic Loads – New Hazard Map
  - Structural Analysis
- Rationale Behind the Changes
- Changes in CSA A23.3 Design Of Concrete Structures Standard.
- Implications for the Insurance Industry

Factors Influencing Seismic Effects

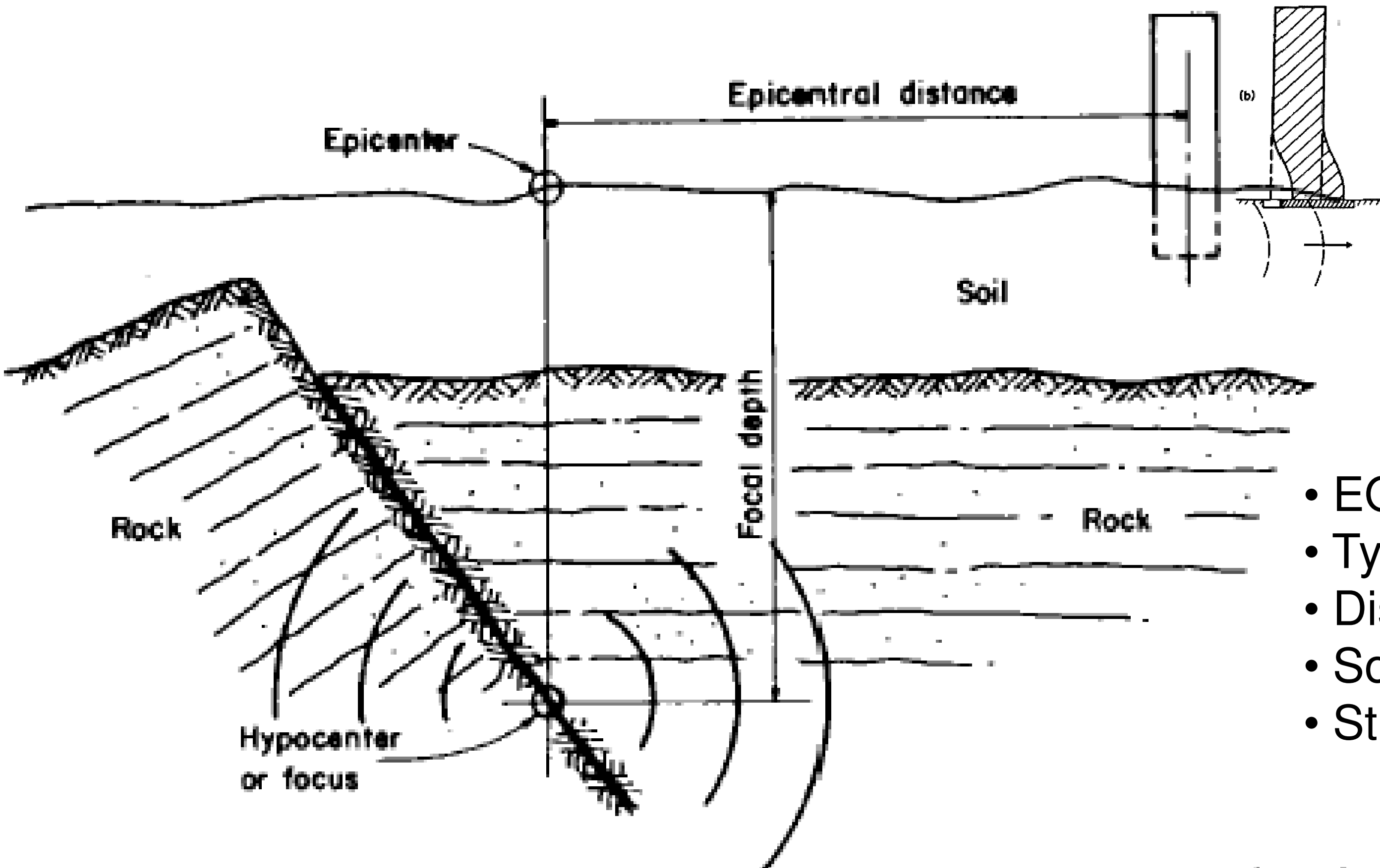


Fig. 12-1 Illustrating definition of common earthquake-related terms.

- EQ Magnitude
- Type of EQ
- Distance
- Soil
- Structure

Ductility – Dissipating Seismic Energy

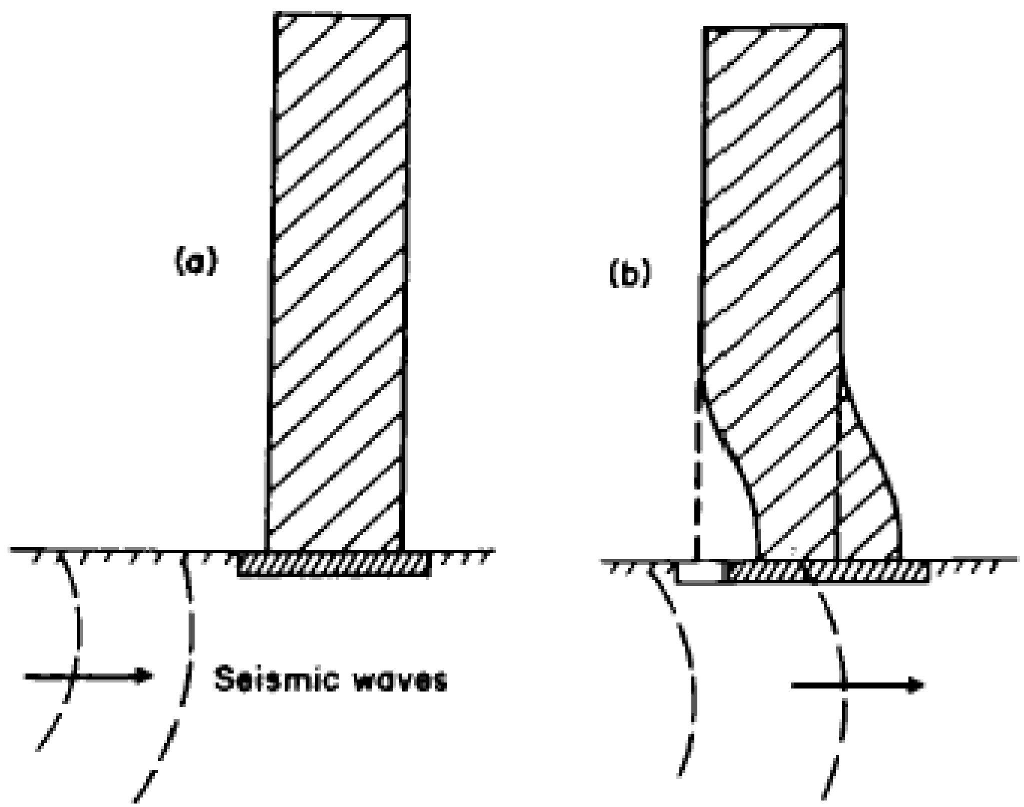
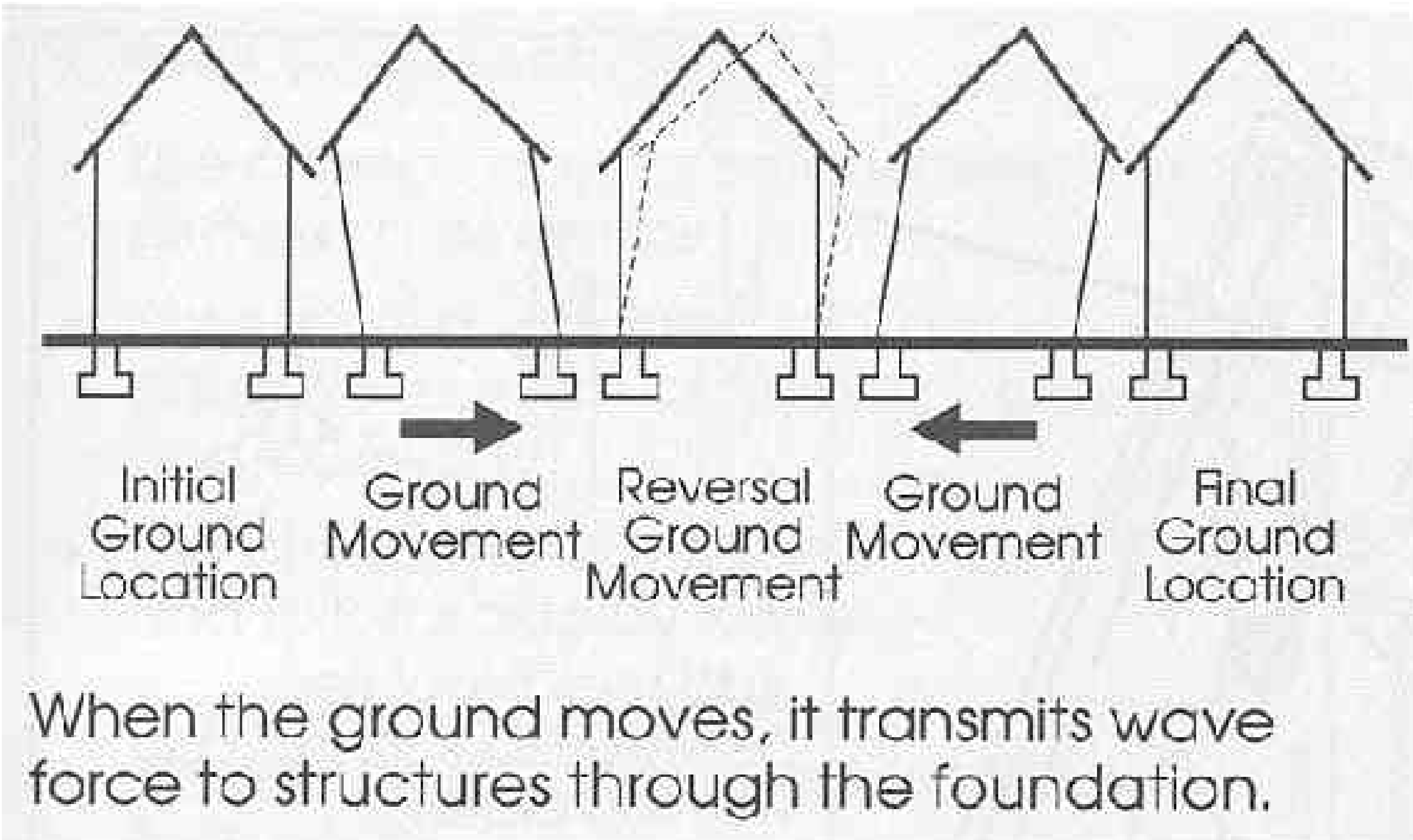
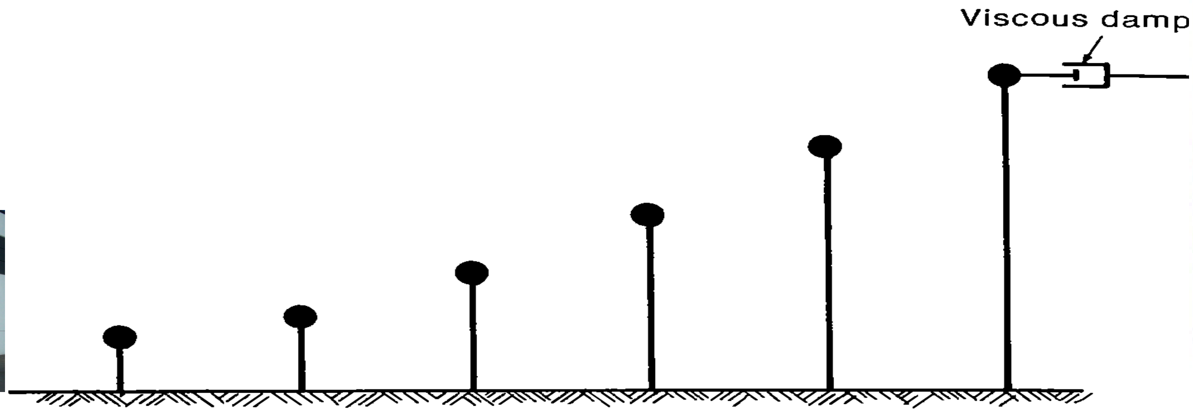


Fig. 12-7

Structural Response To Earthquakes

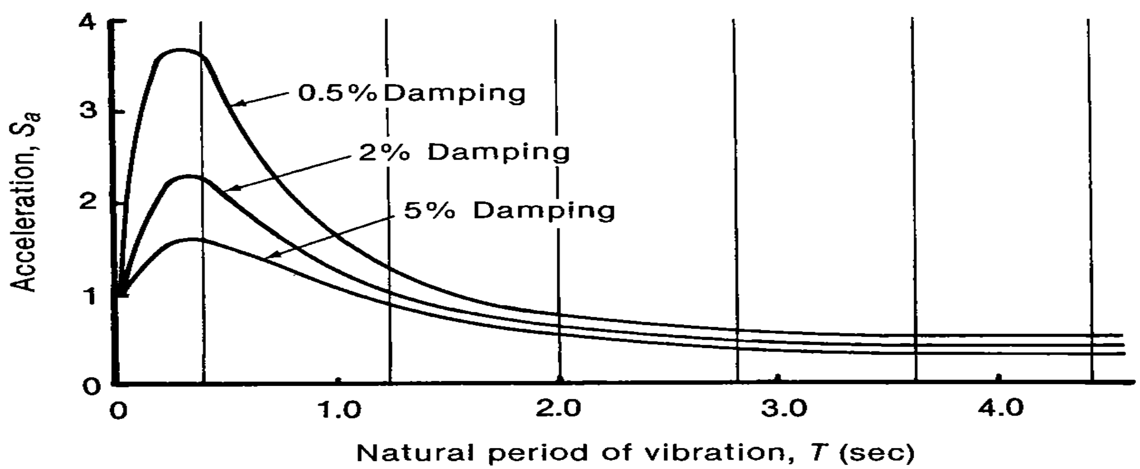


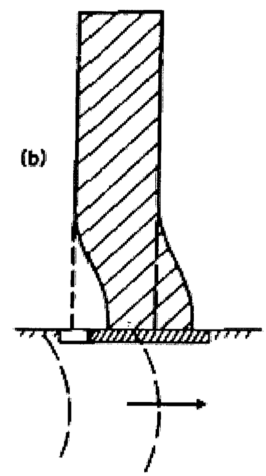
Acceleration Response Spectrum



(a) Damped pendulums of varying natural frequencies.

Scotia Plaza, Toronto, ON





V = m x a

Natural Modes of Building Vibration

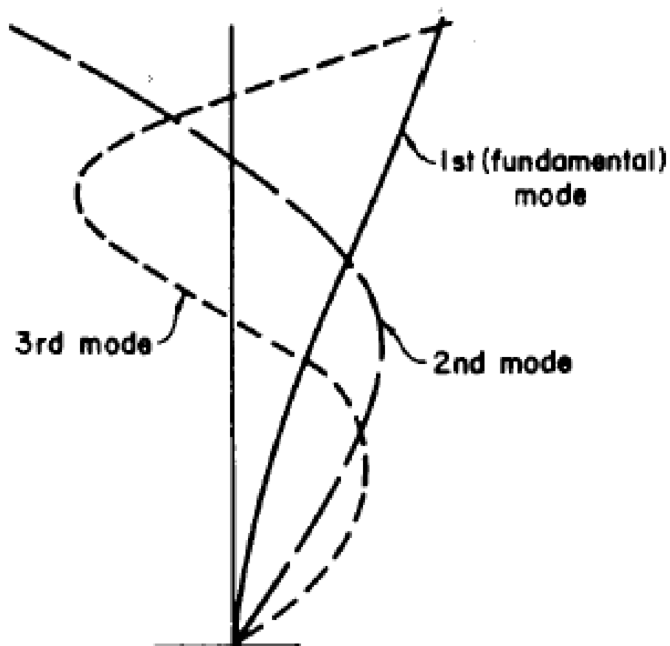
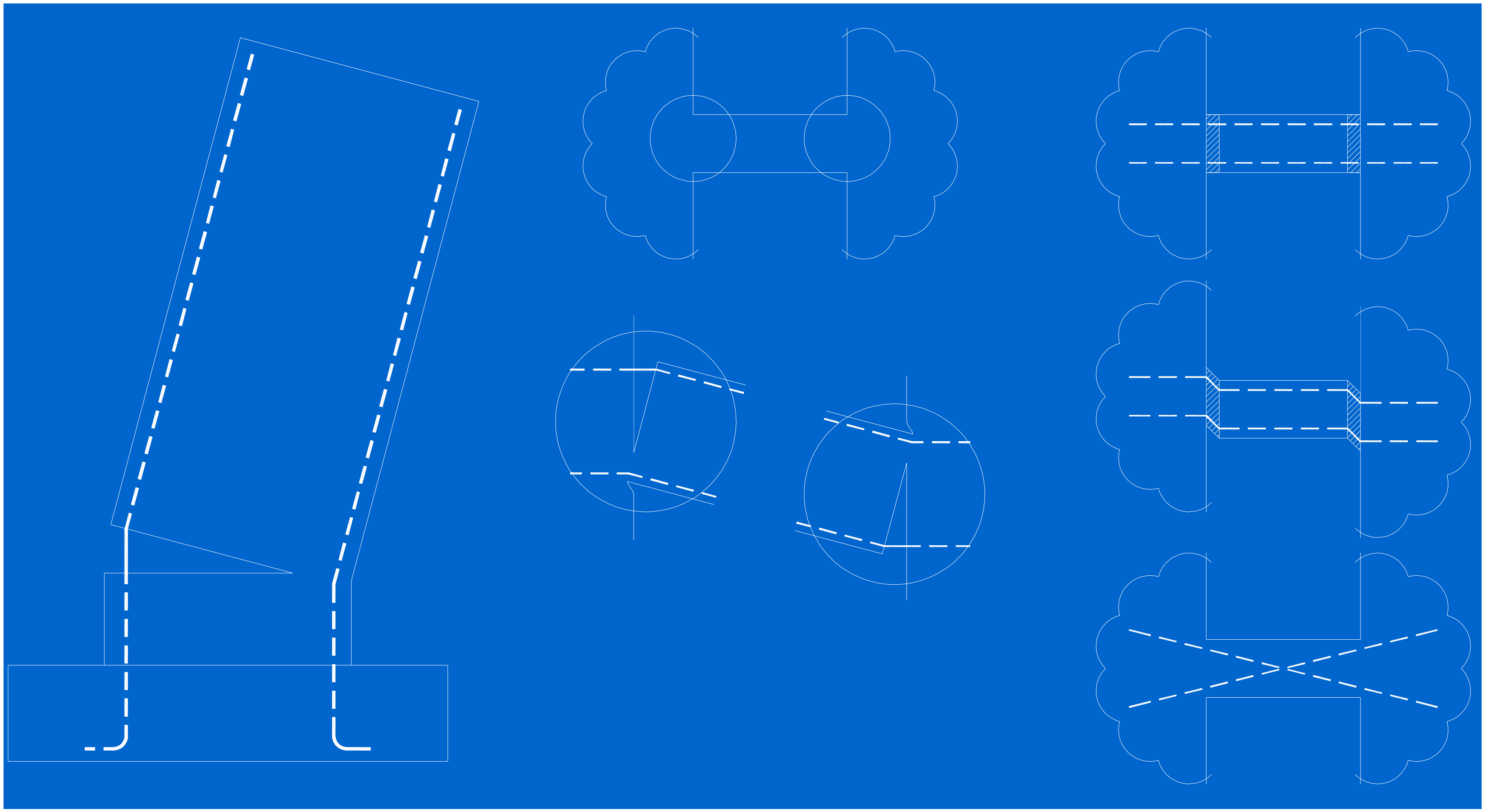


Fig. 12-8 Typical shapes of the first three natural modes of vibration of a multistory structure.

Scotia Plaza, Toronto, ON

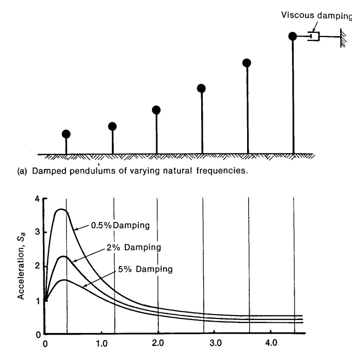
← Seismic Motion →

Concrete Plastic Hinges

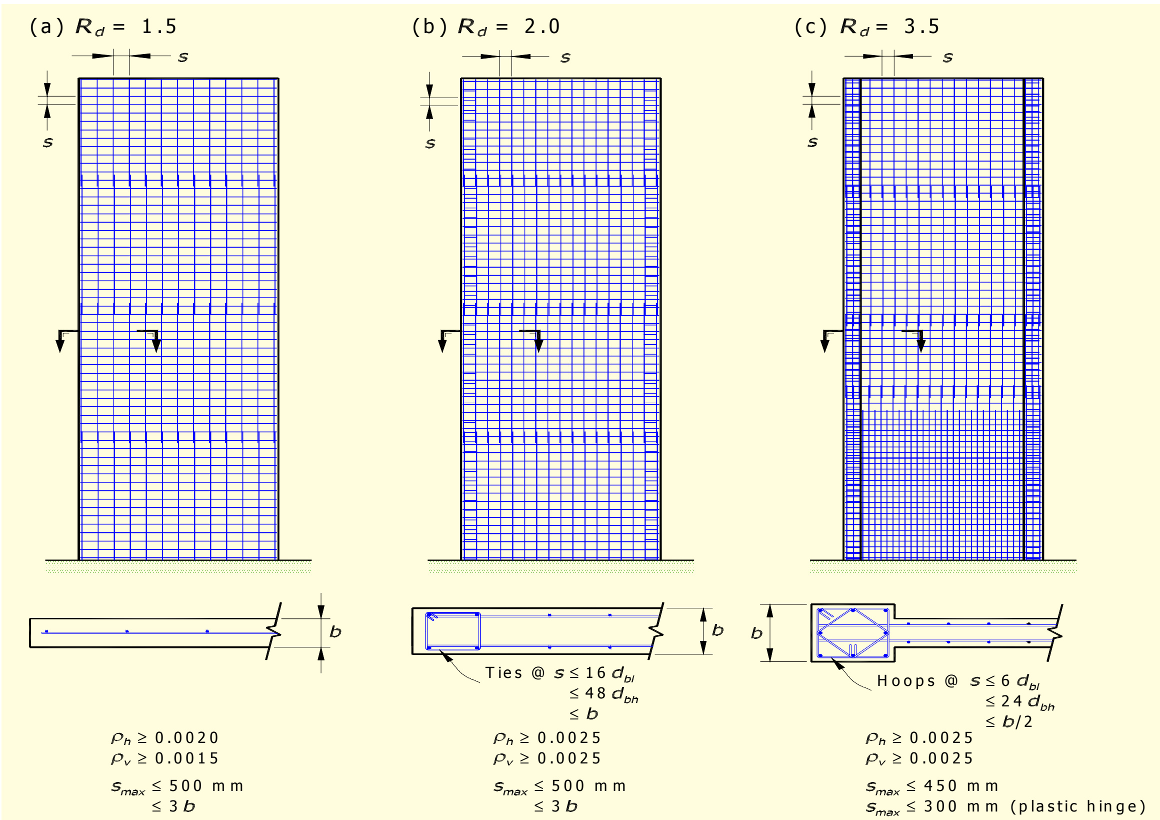


Seismic Shake Table Testing

Figure 6. Full-scale wooden house on shake table for testing.



Ductility - Shear Wall Structures



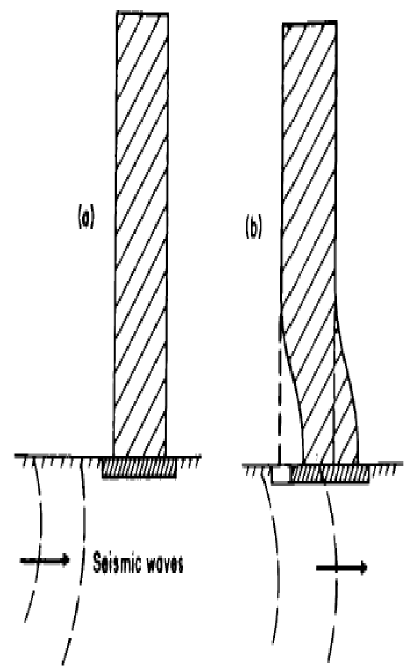
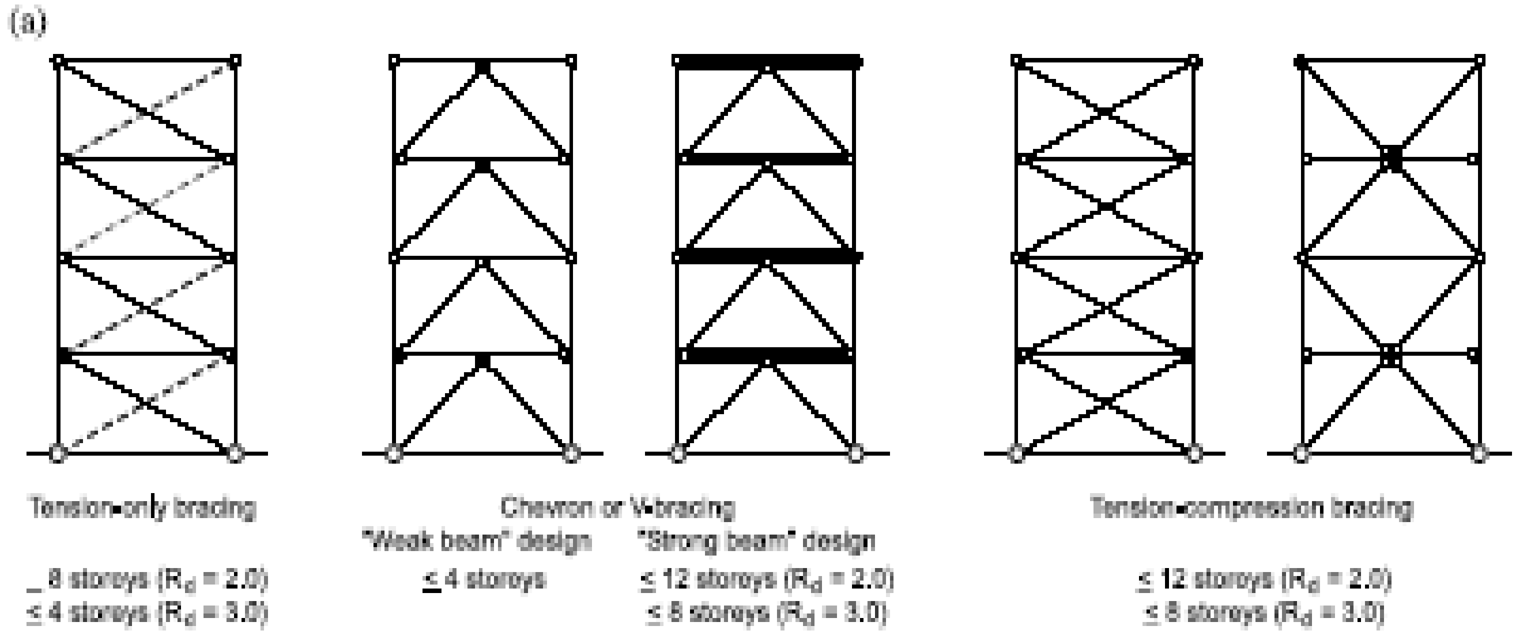


Fig. 12-7

Braced Steel Structures



2005 NBCC - Uniform Hazard Spectrum

- More uniform margin of collapse (NEHRP), 1997 and Building Seismic Safety Council, 1997)
- Seismic hazard at a lower probability of exceedance, nearer probability of failure
- Maximum considered earthquake ground motion
- 2% in 50 year probability of exceedance (2500 year return period)
- New seismic hazard maps

2005 NBCC Seismic Design

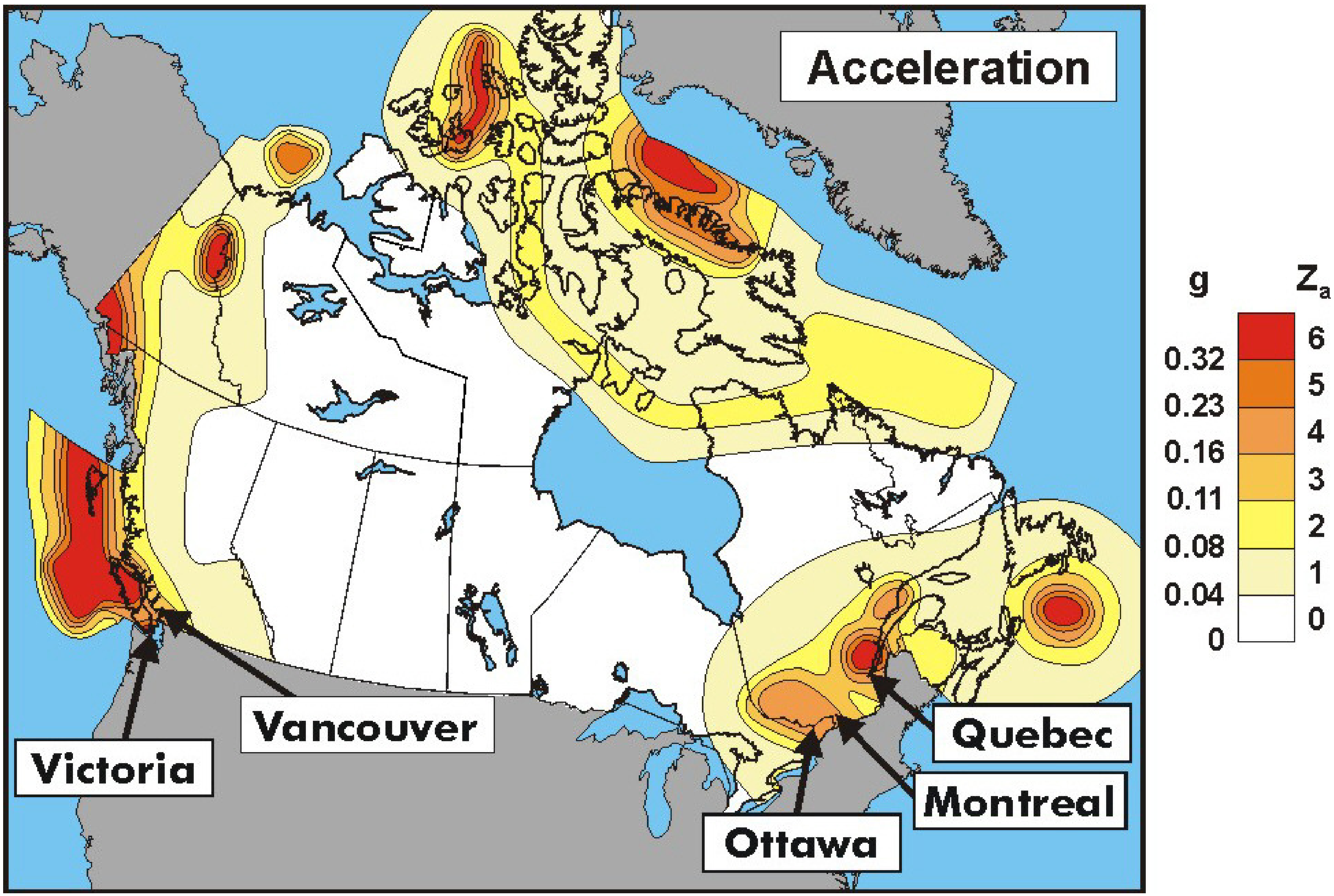
Bad News

- 1995 Seismic Risk Level
  - 10% in 50 yrs => 1 / 475 yrs return period
- 2005 New Seismic Risk Level
  - 2% in 50 yrs => 1 / 2400 yrs return period

- Good News:

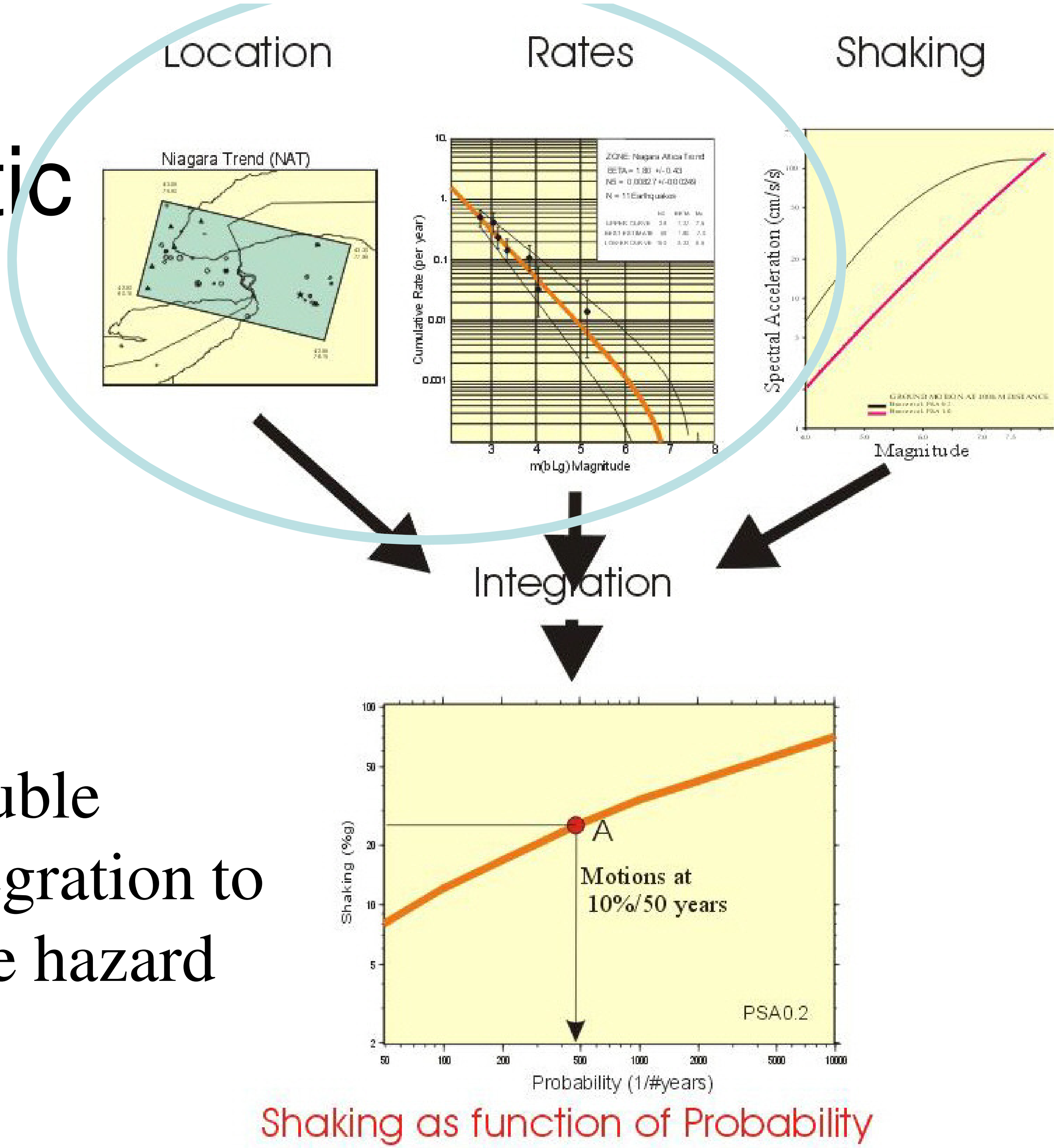
  $500 \times 5 \neq 2500$

Hazard



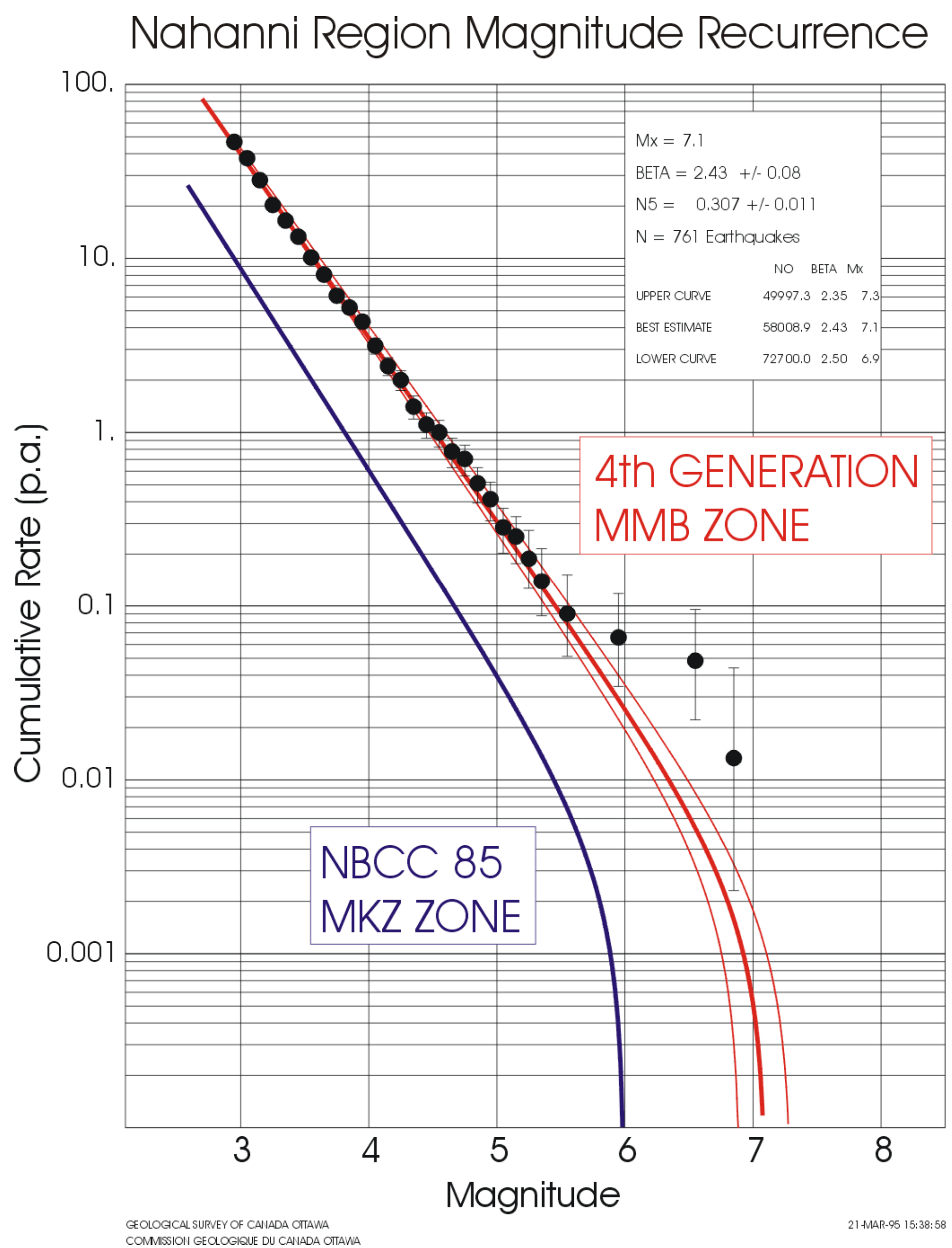
Acceleration
g
Z_a
0.32
0.23
0.16
0.11
0.08
0.04
0
6
5
4
3
2
1
0
Vancouver
Victoria
Quebec
Montreal
Ottawa

Probabilistic seismic hazard

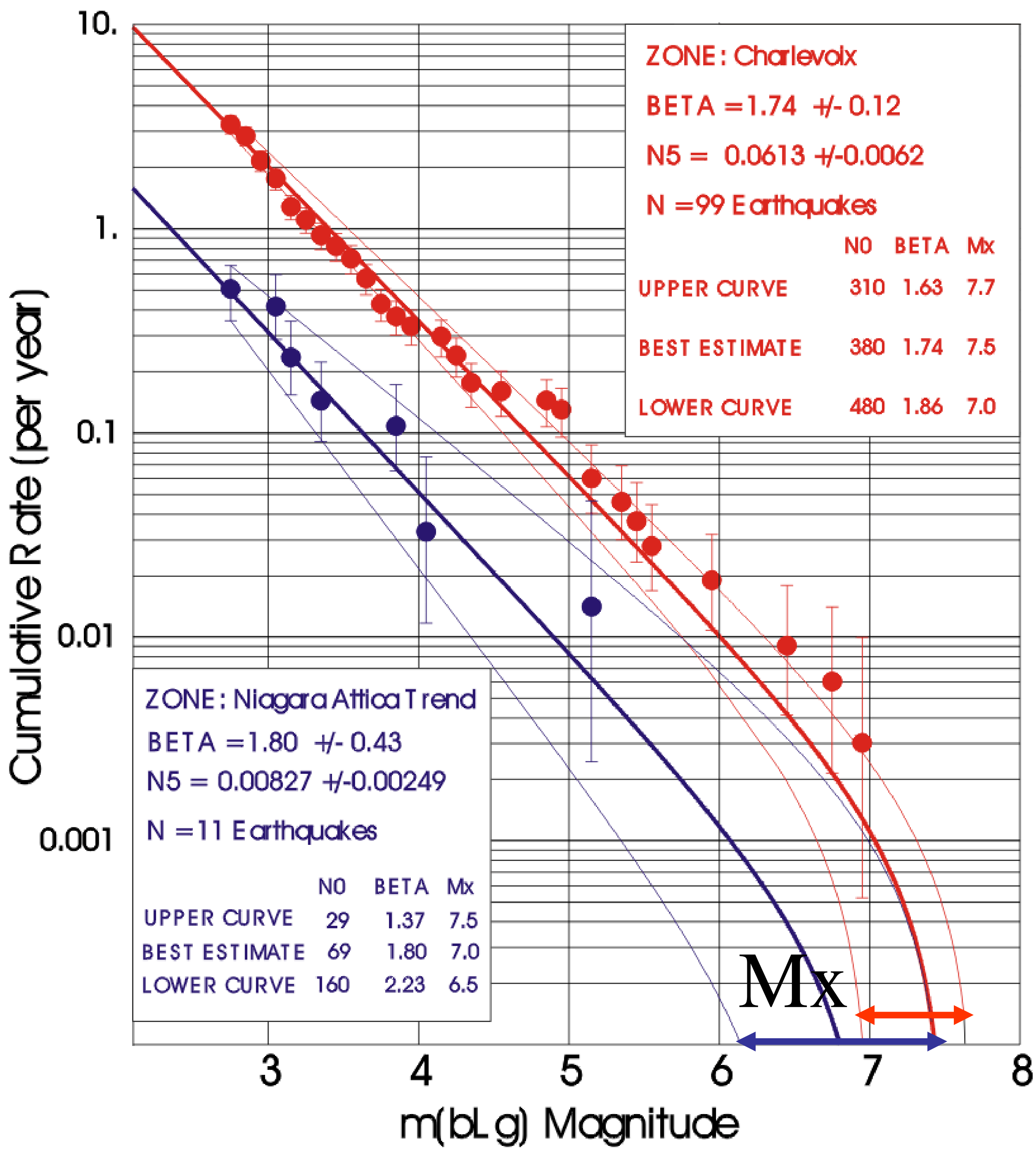


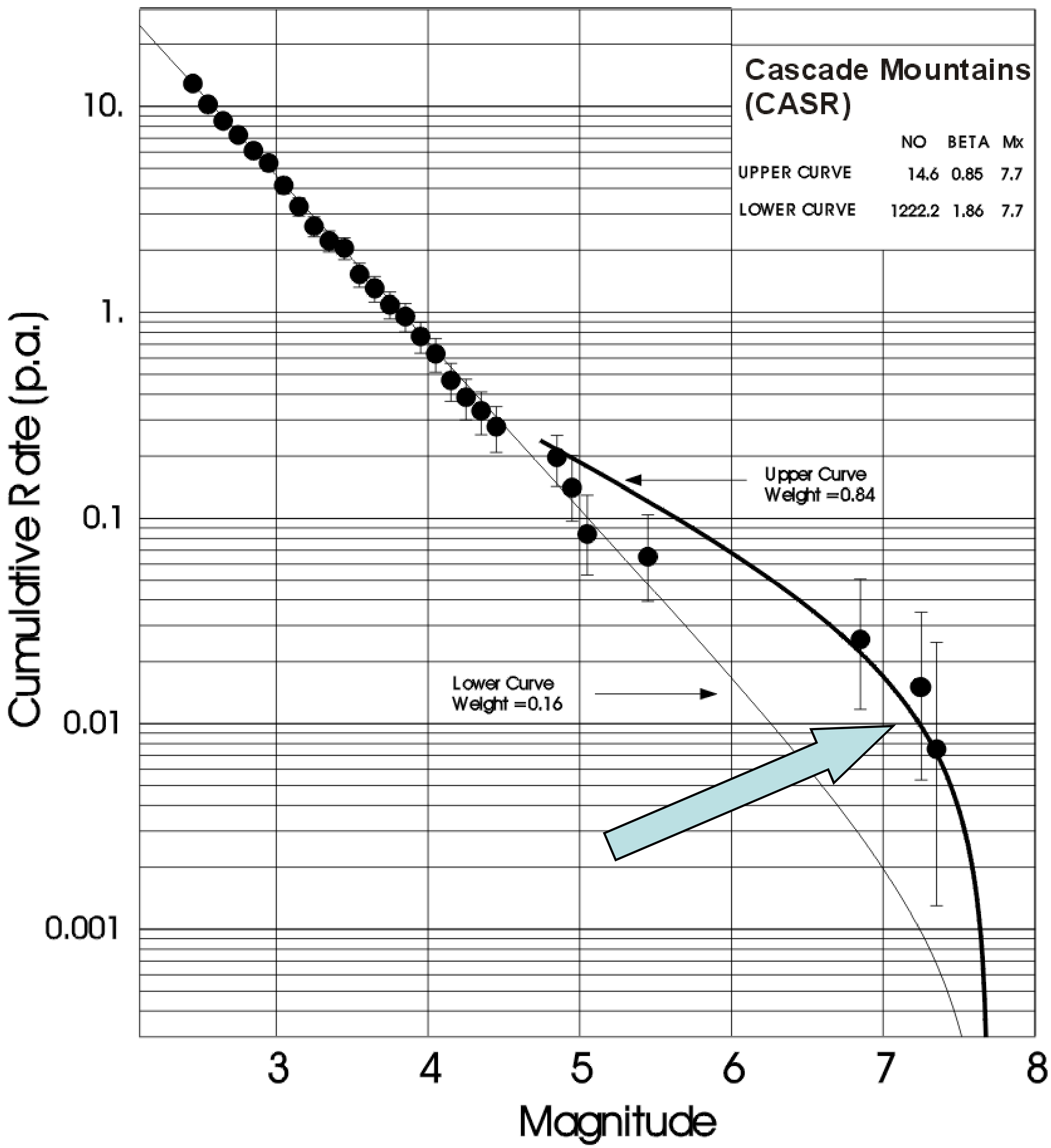
Double integration to give hazard

Rates of activity, and sizes of the biggest events were underestimated



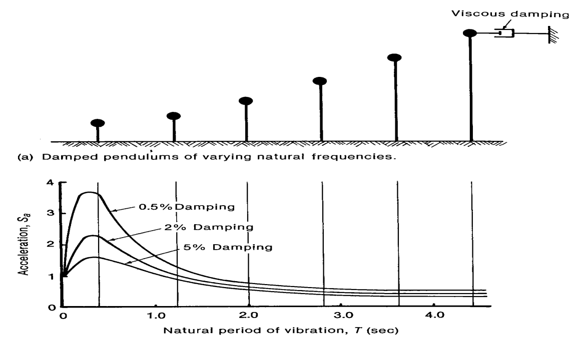
Different rates, different errors in rates for magnitude-recurrence curves





Some data do not appear to fit the simple model

Full Robust Hazard Model



Highest value of:-

Probabilistic H model

Probabilistic R model

Deterministic Cascadia model

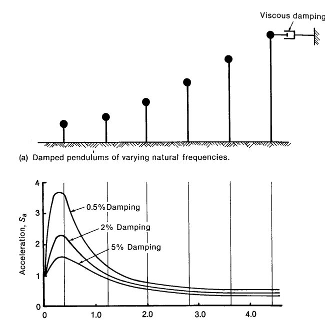
Probabilistic Stable craton model

Base Shear NBCC 1995 vs 2005

1995

$$V = \frac{V_E}{R} U$$

$$V_E = v \, S \, I \, F \, W$$



2005

$$V = \frac{S(T_a) \, M_v \, I_E}{R_d \, R_o} W$$

Design Spectral Acceleration

defined by 4 spectral hazard parameters and 2 site factors

$$S(T) = F_a S_a(0.2) \quad \text{for } T \le 0.2\text{ s}$$

$$= F_v S_a(0.5) \text{ or } F_a S_a(0.2)$$

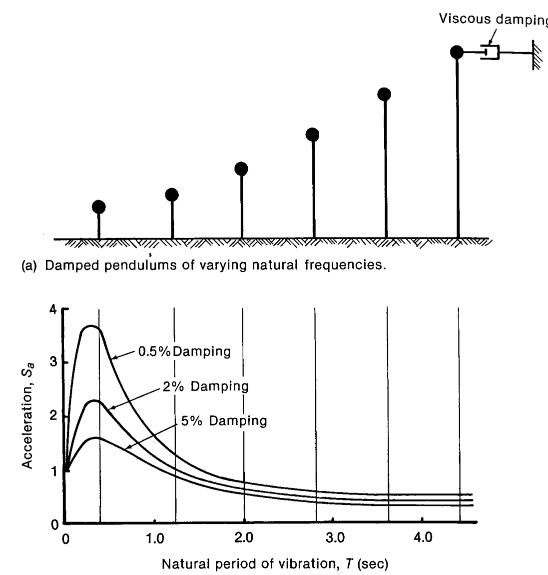
whichever is smaller,

for $T = 0.5$ s

$$= F_v S_a(1.0) \quad \text{for } T = 1.0\text{ s}$$

$$= F_v S_a(2.0) \quad \text{for } T = 2.0\text{ s}$$

$$= F_v S_a(2.0)/2 \quad \text{for } T \ge 4.0\text{ s}$$



Influence Of Soil

- **The Soil Factor**

Can change the characteristics of earthquake motions.

- **Poor - deep loose sand; silty clays; sand and gravel; and soft, saturated granular soils.**

Amplify earthquake forces on water-saturated soils

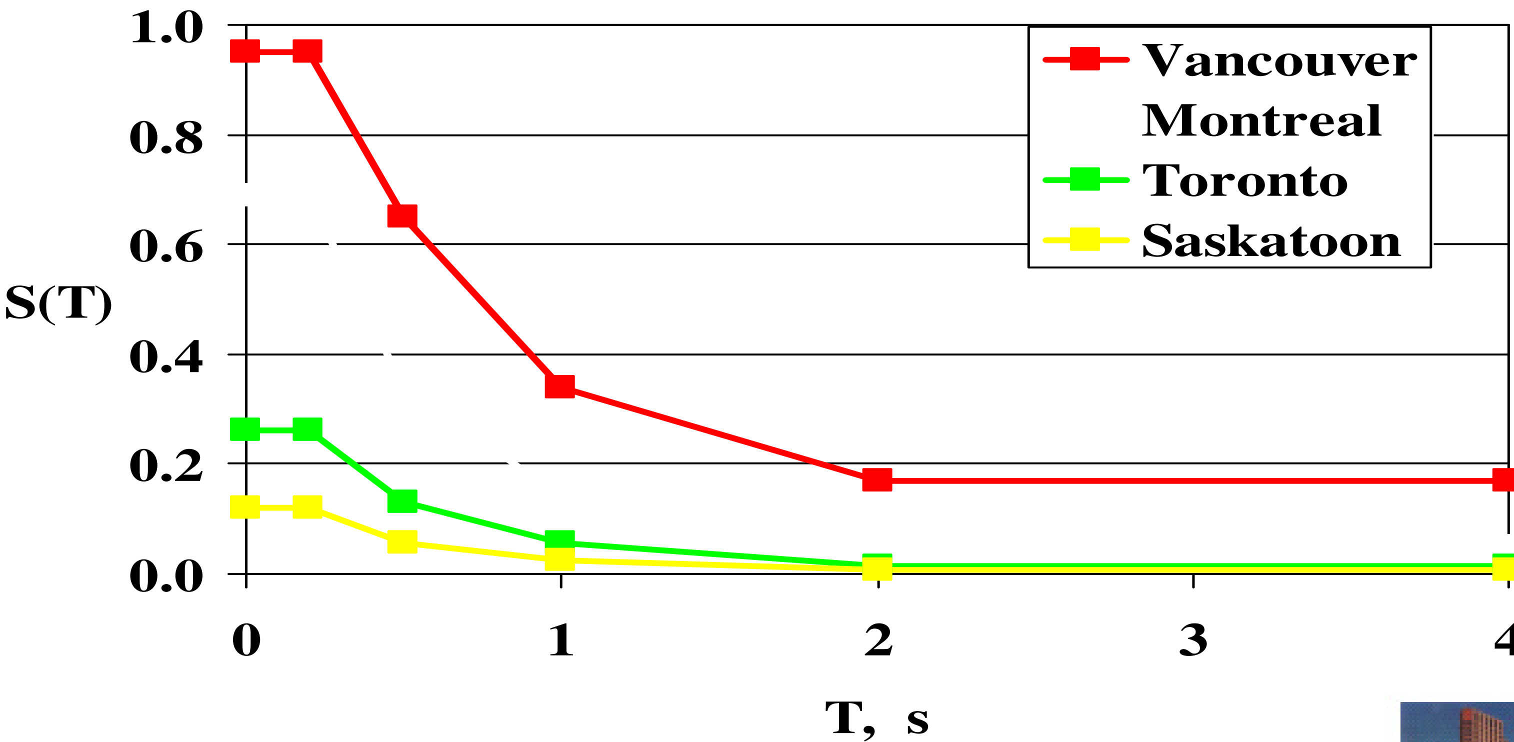
- **Good - bedrock stiff soils.**

Much less vibration is transferred through the foundation to the structure above.

Site Classification for Seismic Site Response

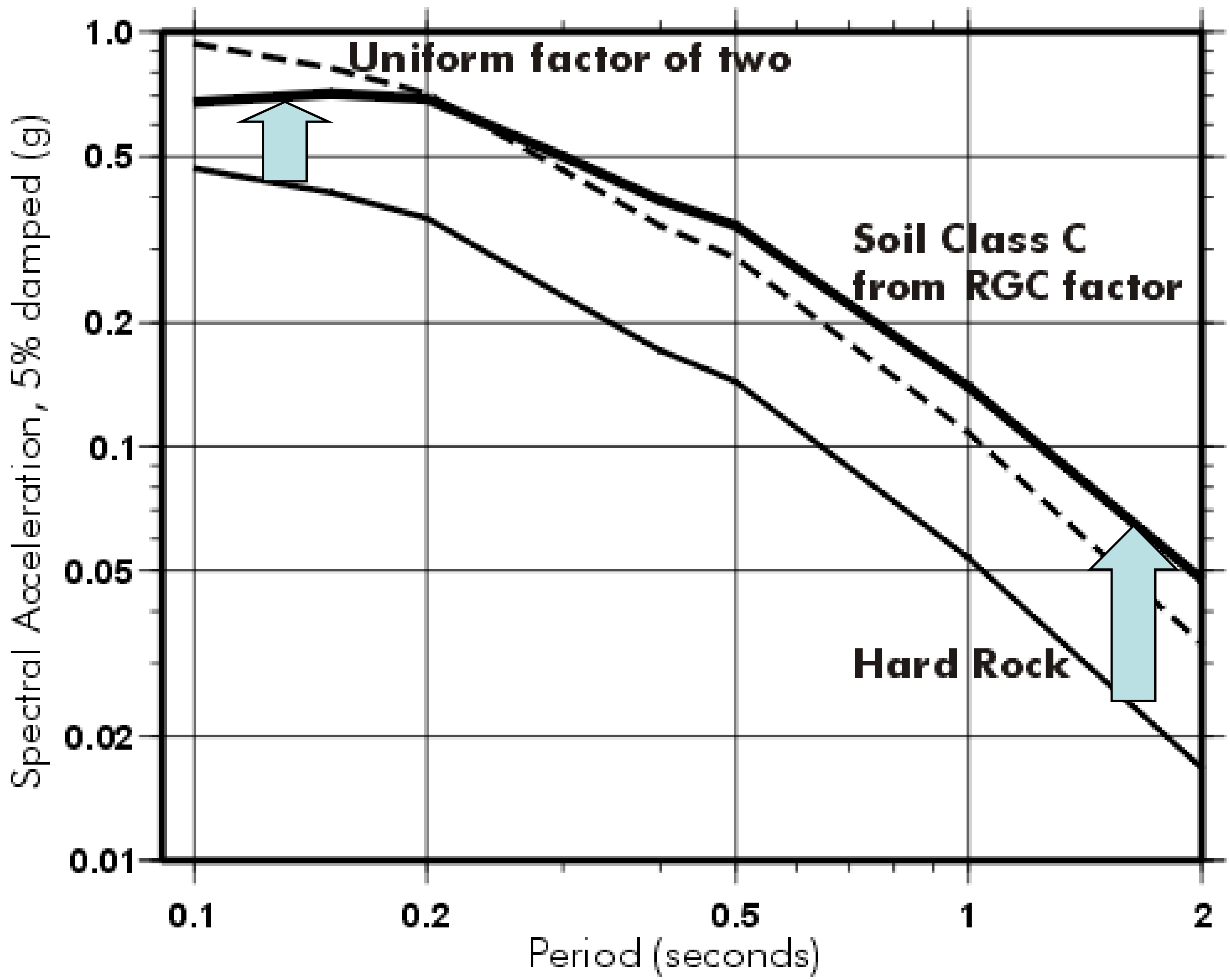
- A = hard rock
- B = rock
- C = dense soil or soft rock
- D = stiff soil
- E = > 3 m of “soft soil”
- F = others (liquefiable, peat, etc.)

Design Spectral Response Acceleration – Class "C" Soil

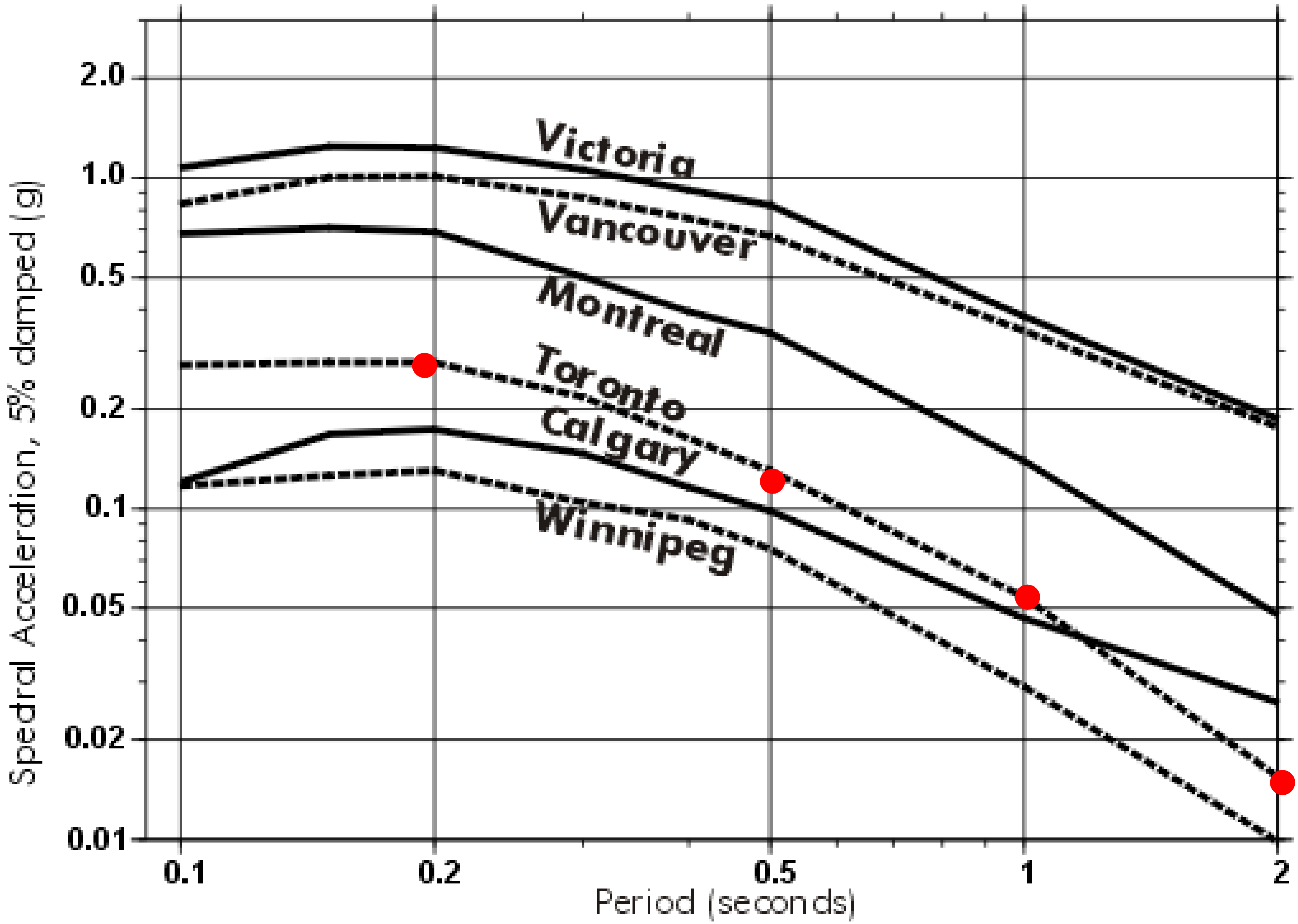


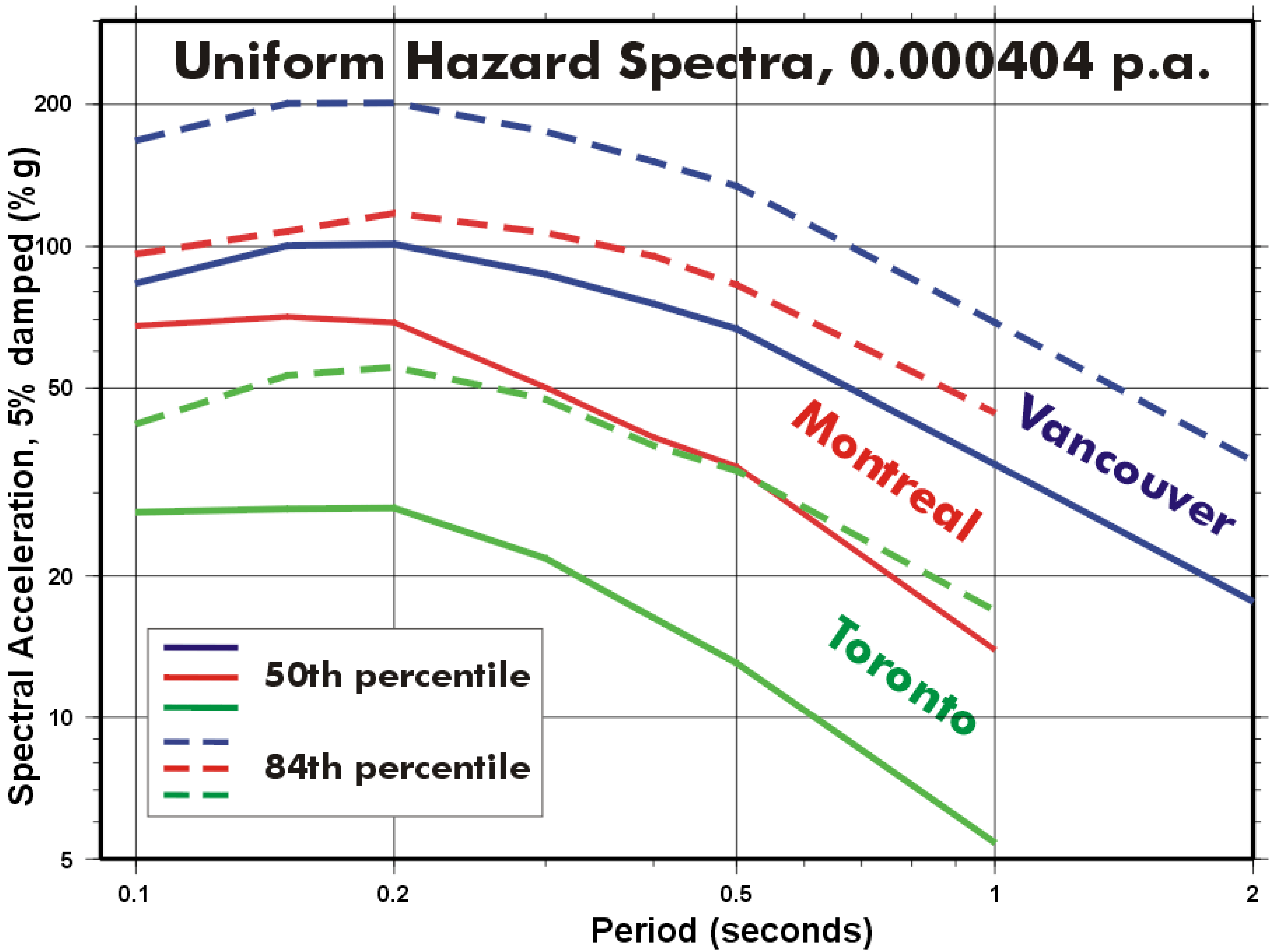
Scotia Plaza, Toronto, ON

Conversion factors have been derived to ensure all hazard values are for site Class C



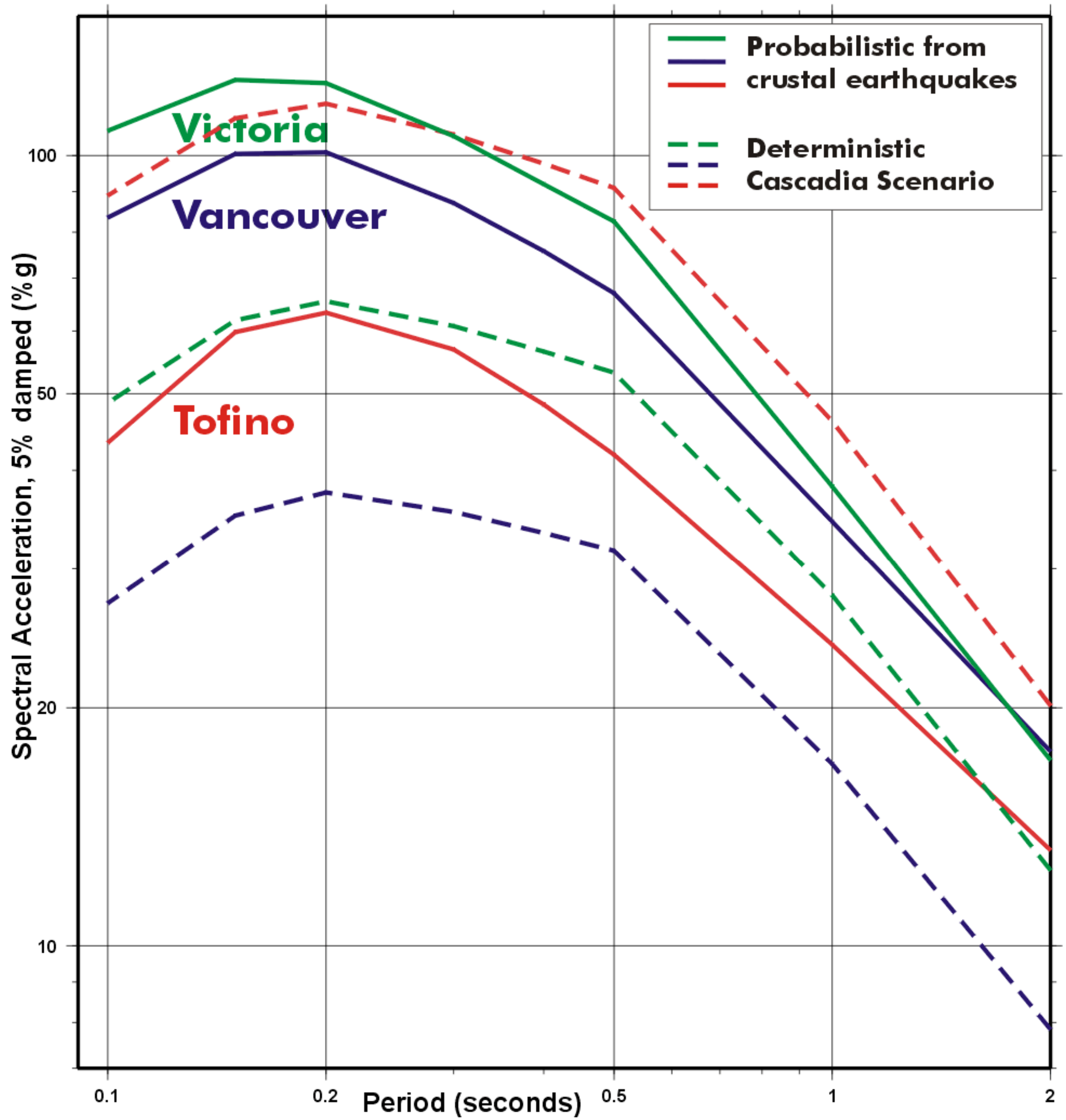
Uniform Hazard Spectra





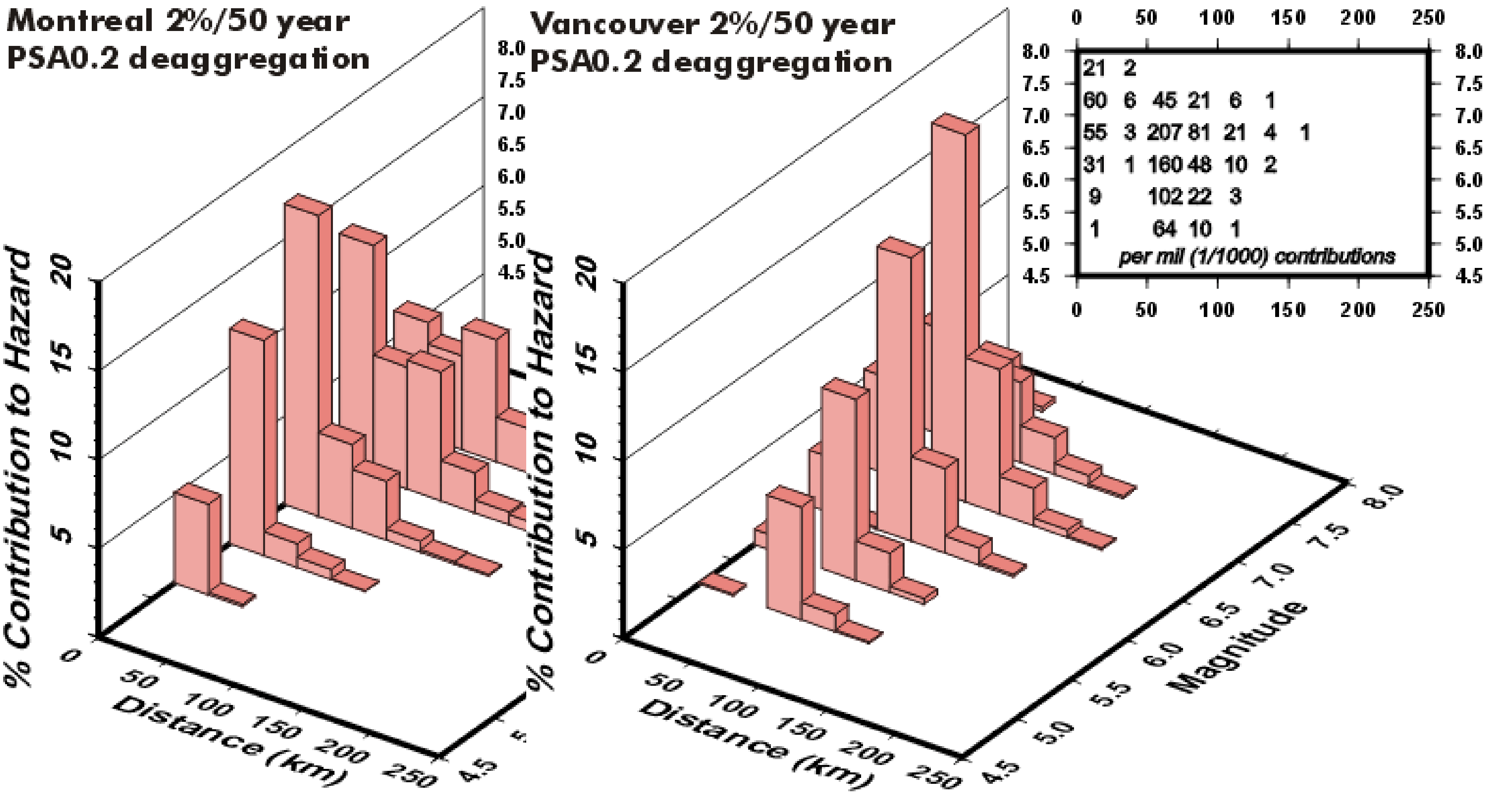
Uniform Hazard Spectra, 0.000404 p.a.
Spectral Acceleration, 5% damped (% g)
200
100
50
20
10
5
0.1
0.2
0.5
1
2
Period (seconds)
Vancouver
Montreal
Toronto
50th percentile
84th percentile

Uniform Hazard Spectra probabilistic and Cascadia



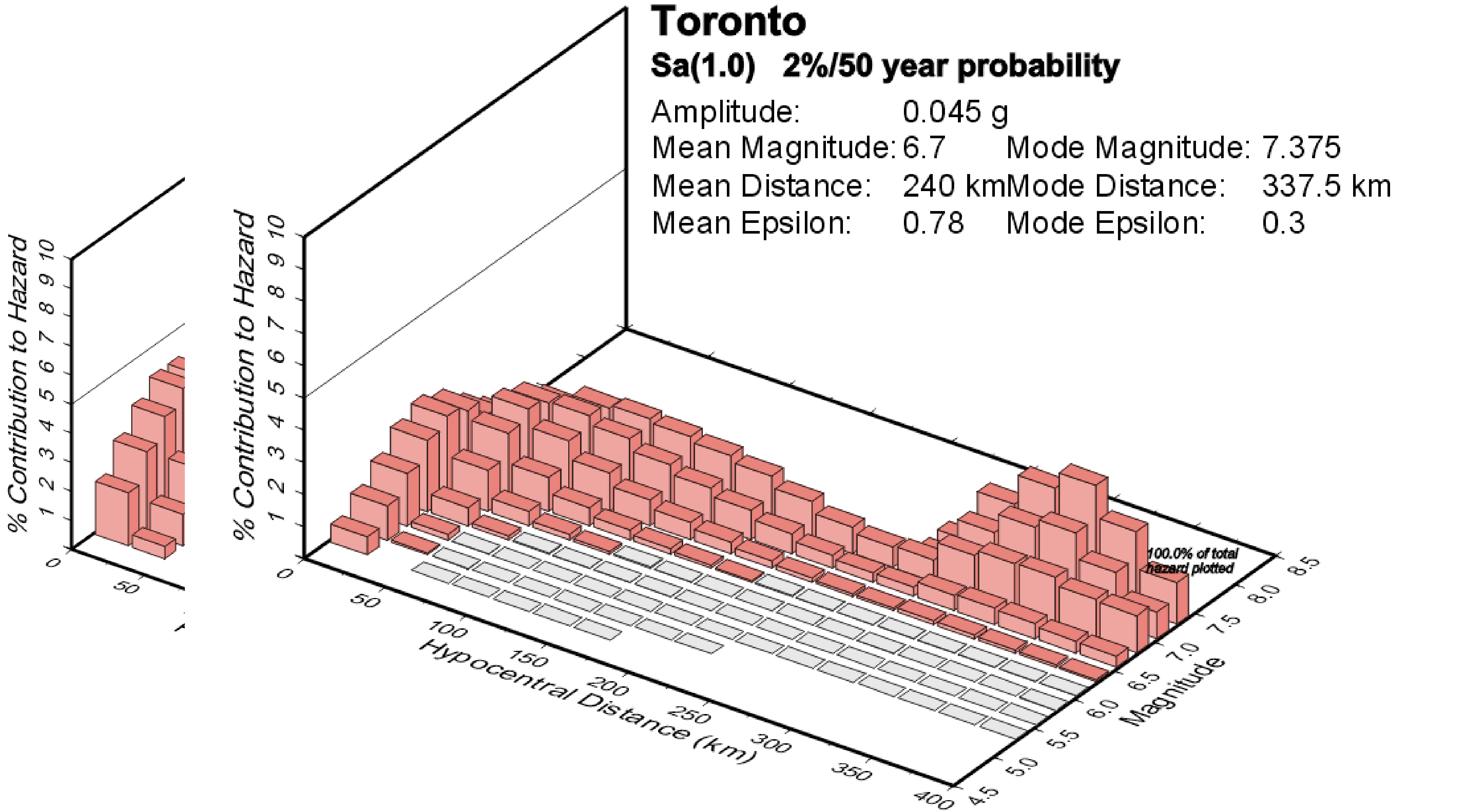
Deaggregation of hazard

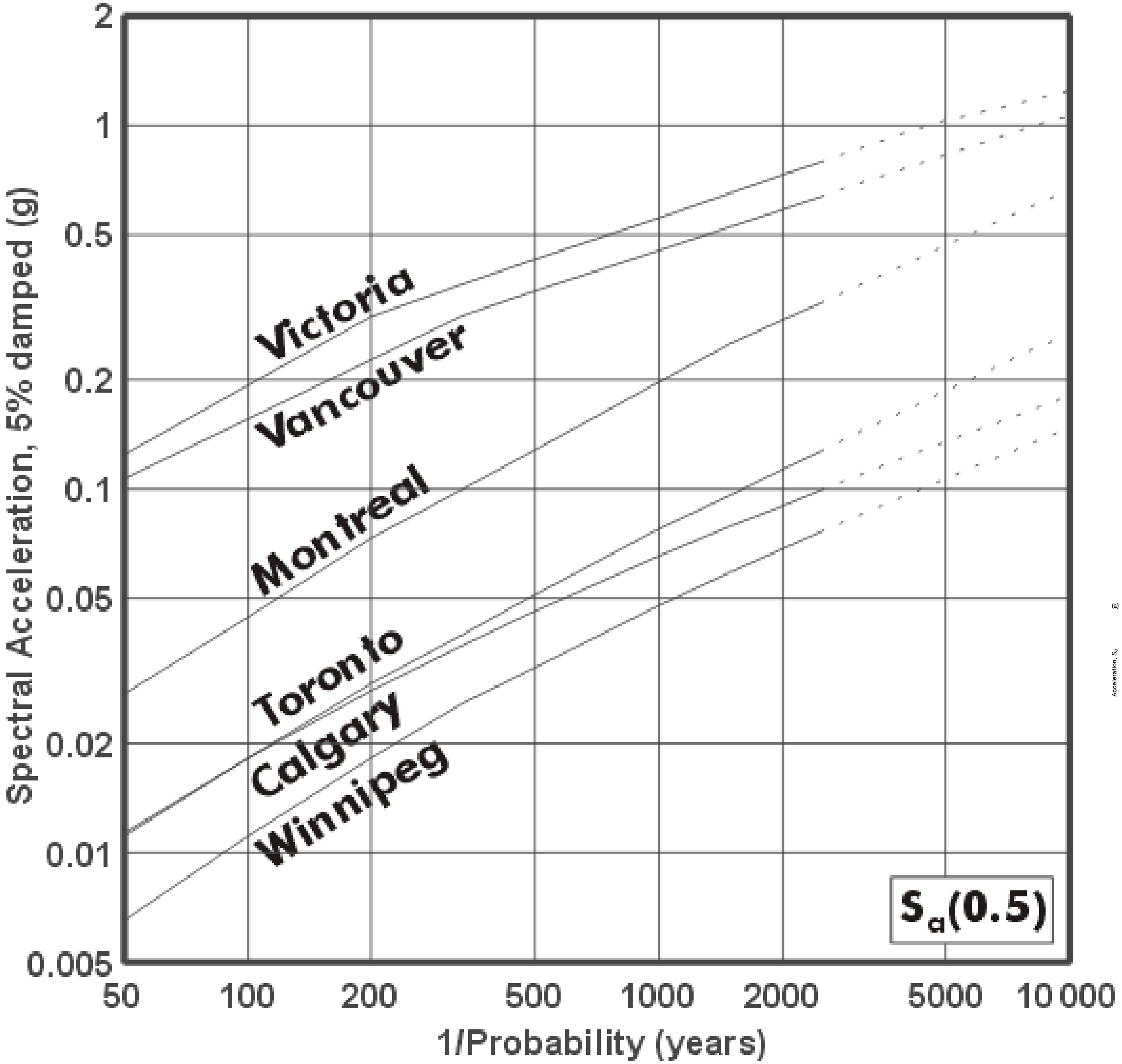
contributions by magnitude and distance

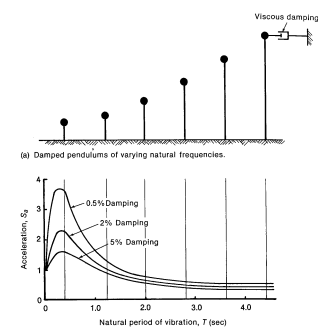


Deaggregation of hazard

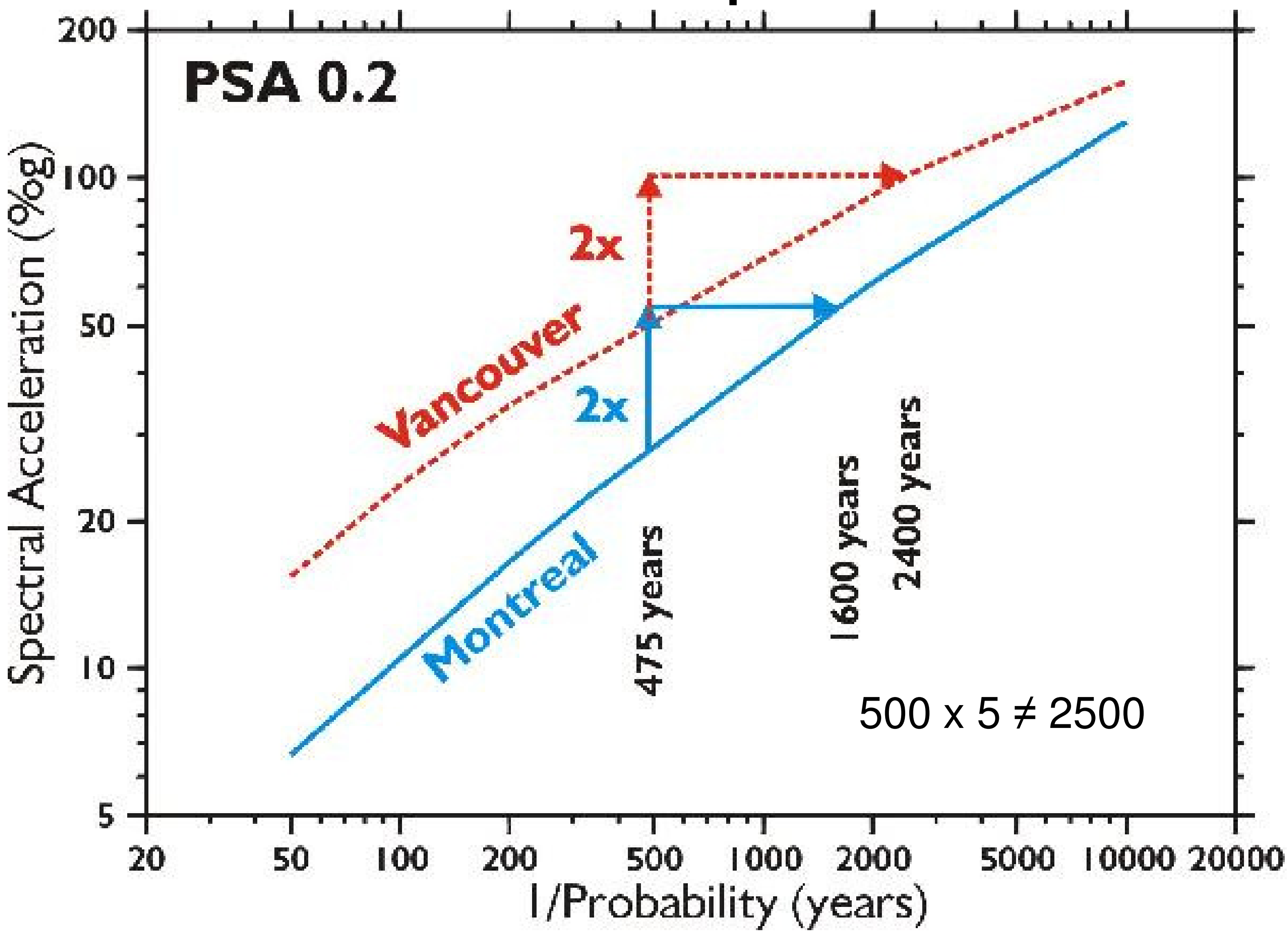
contributions by magnitude and distance




Spectral Acceleration, 5% damped (g)
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
Victoria
Vancouver
Montreal
Toronto
Calgary
Winnipeg
$S_a(0.5)$
50
100
200
500
1000
2000
5000
10 000
1/Probability (years)


Viscous damping
(a) Damped pendulums of varying natural frequencies.
Acceleration, S_a
4
3
2
1
0
0.5% Damping
2% Damping
5% Damping
0
1.0
2.0
3.0
4.0
Natural period of vibration, T (sec)

New probability level will lead to more uniform protection



Uniform Hazard Spectrum

- More uniform margin of collapse (NEHRP), 1997 and Building Seismic Safety Council, 1997)
- Seismic hazard at a lower probability of exceedance, nearer probability of failure
- Maximum considered earthquake ground motion
- 2% in 50 year probability of exceedeance (2500 year return period)
- New seismic hazard maps

General Requirements NBCC 2005
Seismic Structural Design

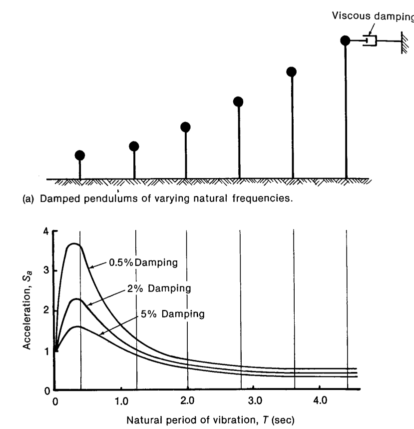
- Design for clearly defined load paths
- Must have a clearly defined Seismic Force Resisting System (SFRS)
- Stiff elements not part of SFRS to be separated from structural components or made part of SFRS and accounted for in analysis

Base Shear NBCC 1995 vs 2005

1995

$$V = \frac{V_E}{R} U$$

$$V_E = v\, S\, I\, F\, W$$



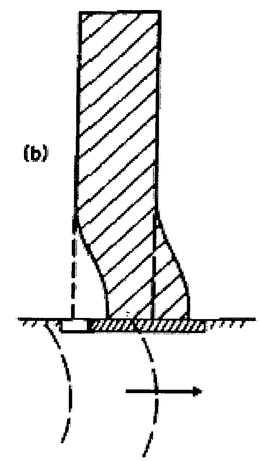
2005

$$V = \frac{S(T_a)\, M_v\, I_E}{R_d\, R_o} W$$

R_o (Overstrength) Factor 1.3-1.7

$$V = \frac{S(T_a)\, M_v\, I_E}{R_d\, R_o}\, W$$

$$V = \frac{V_e}{R_d\, R_o}\, W$$

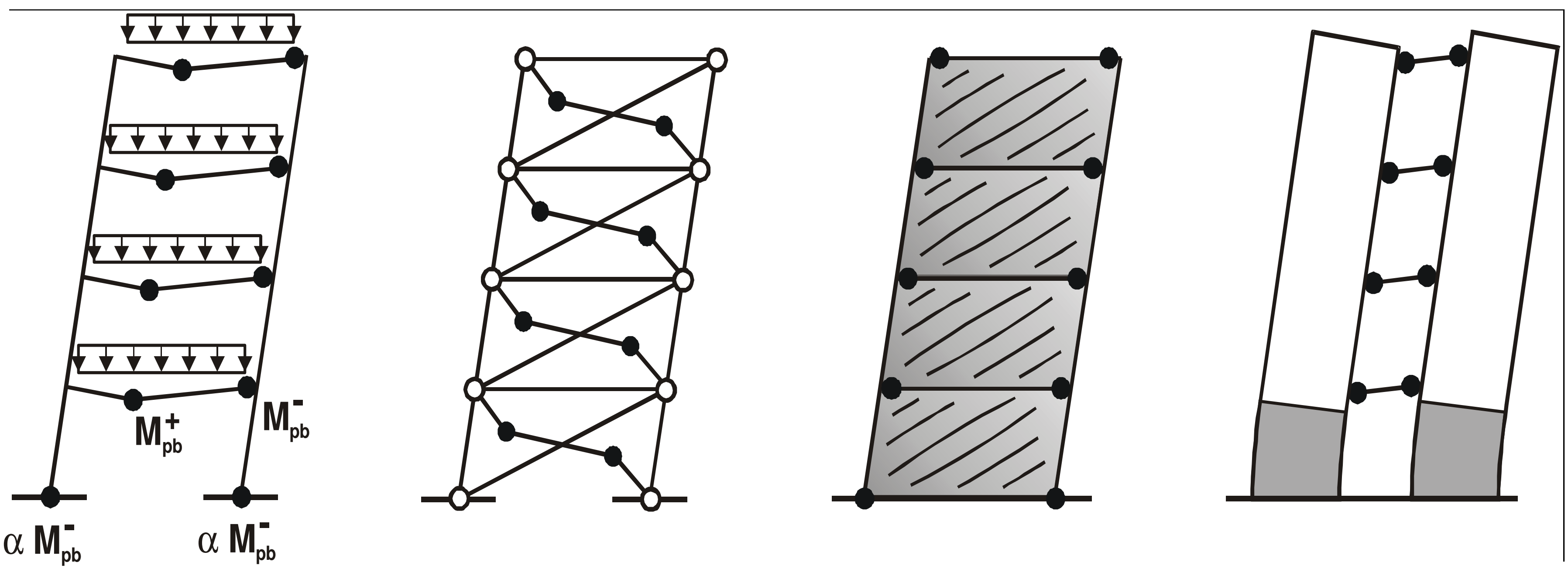


R_d = Ductility 1.5 → 4.0

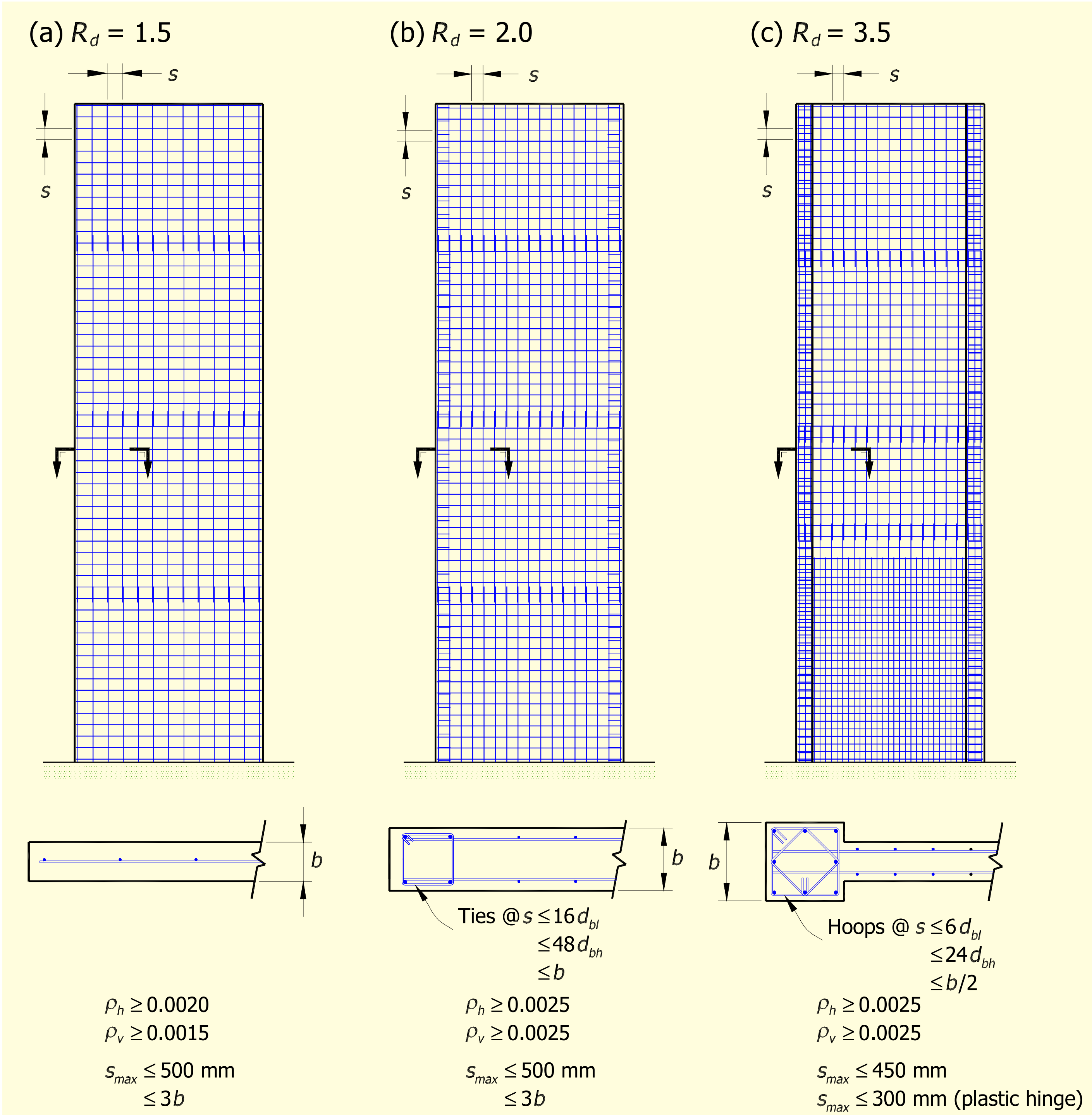
$R_o = R_{size}\, R_{\phi}\, R_{yield}\, R_{sh}\, R_{mech}$

R_o (Overstrength) Factor

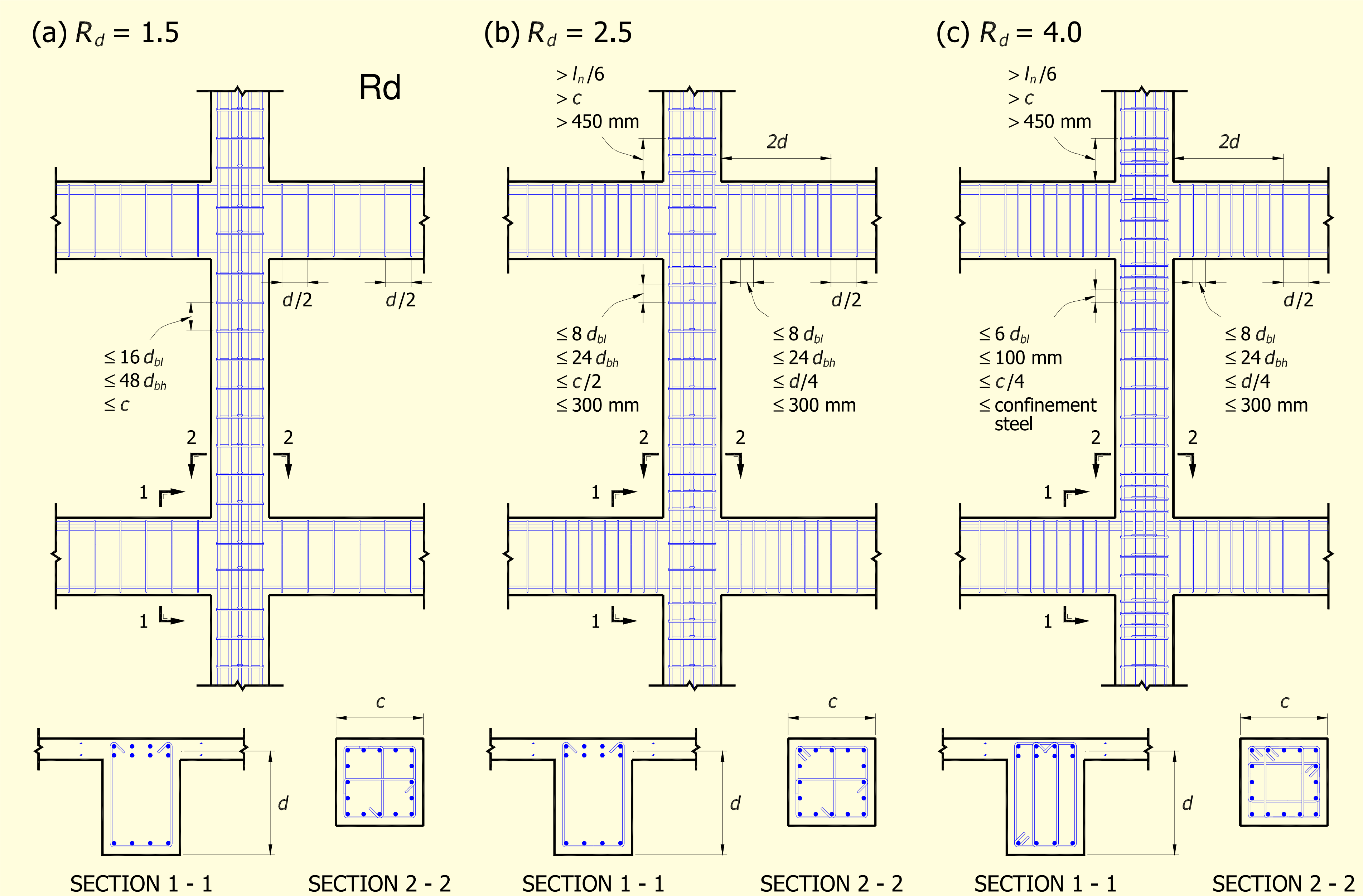
R_o depends on the system :1.3 – 1.7



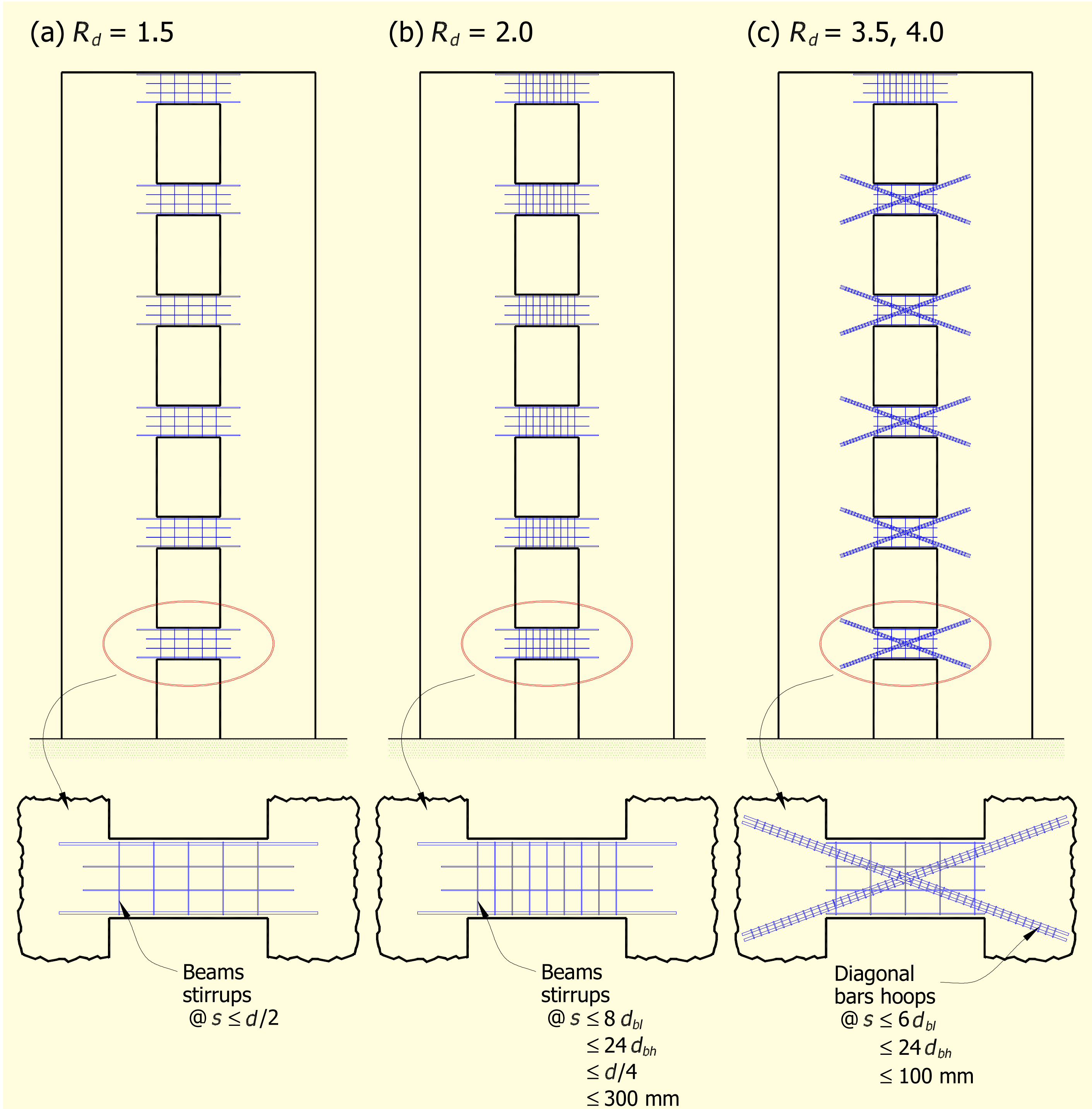
R_d= 1.5 - 4.0



(a) Rd = 1.5
(b) Rd = 2.0
(c) Rd = 3.5
s
b
Ties @ s ≤ 16 dbl
≤ 48 dbh
≤ b
Hoops @ s ≤ 6 dbl
≤ 24 dbh
≤ b/2
ρh ≥ 0.0020
ρv ≥ 0.0015
smax ≤ 500 mm
≤ 3b
ρh ≥ 0.0025
ρv ≥ 0.0025
smax ≤ 500 mm
≤ 3b
ρh ≥ 0.0025
ρv ≥ 0.0025
smax ≤ 450 mm
smax ≤ 300 mm (plastic hinge)

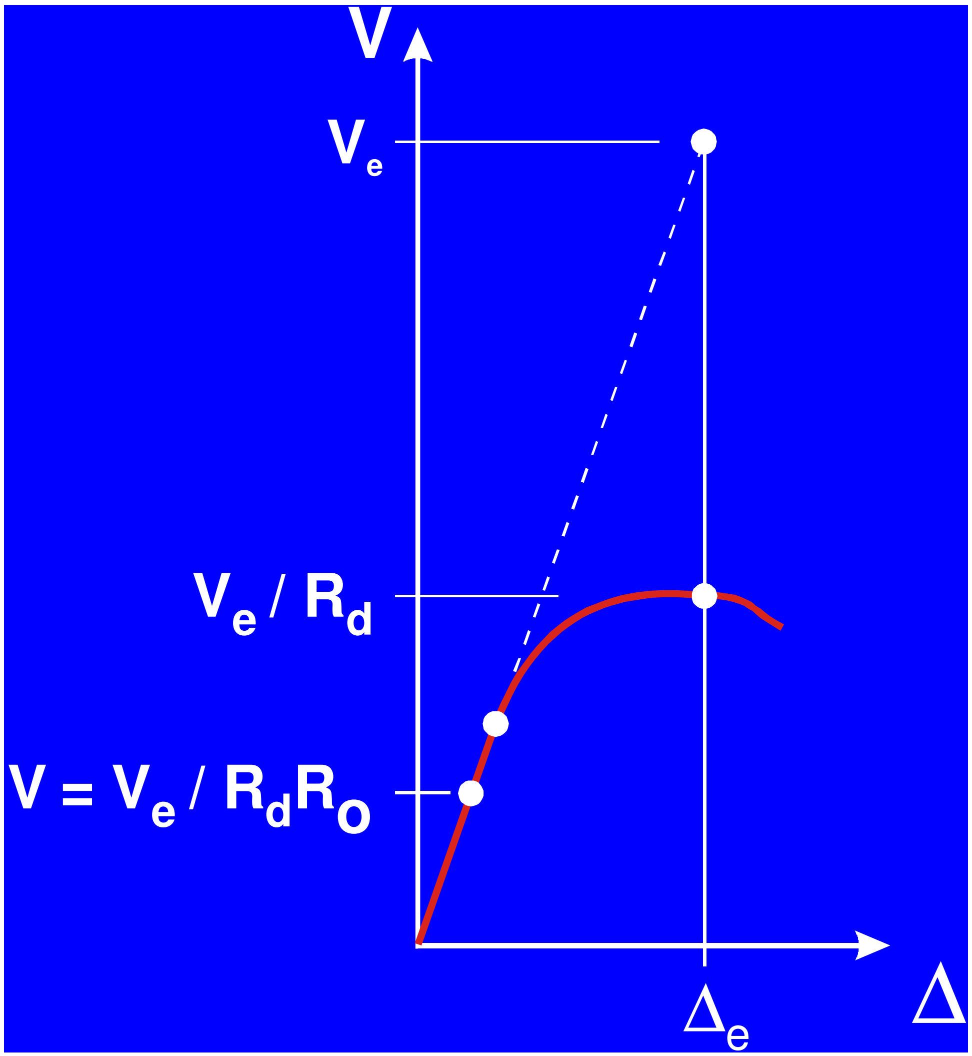


(a) R_d = 1.5
Rd
≤ 16 d_{bl}
≤ 48 d_{bh}
≤ c
d/2
d/2
SECTION 1 - 1
SECTION 2 - 2
(b) R_d = 2.5
> l_n/6
> c
> 450 mm
2d
≤ 8 d_{bl}
≤ 24 d_{bh}
≤ c/2
≤ 300 mm
≤ 8 d_{bl}
≤ 24 d_{bh}
≤ d/4
≤ 300 mm
d/2
SECTION 1 - 1
SECTION 2 - 2
(c) R_d = 4.0
> l_n/6
> c
> 450 mm
2d
≤ 6 d_{bl}
≤ 100 mm
≤ c/4
≤ confinement steel
≤ 8 d_{bl}
≤ 24 d_{bh}
≤ d/4
≤ 300 mm
d/2
SECTION 1 - 1
SECTION 2 - 2



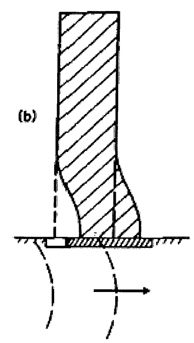
(a) R_d = 1.5
(b) R_d = 2.0
(c) R_d = 3.5, 4.0
Beams stirrups @ $s \leq d/2$
Beams stirrups @ $s \leq 8\,d_{bl}$ $\leq 24\,d_{bh}$ $\leq d/4$ ≤ 300 mm
Diagonal bars hoops @ $s \leq 6\,d_{bl}$ $\leq 24\,d_{bh}$ ≤ 100 mm

R Factors

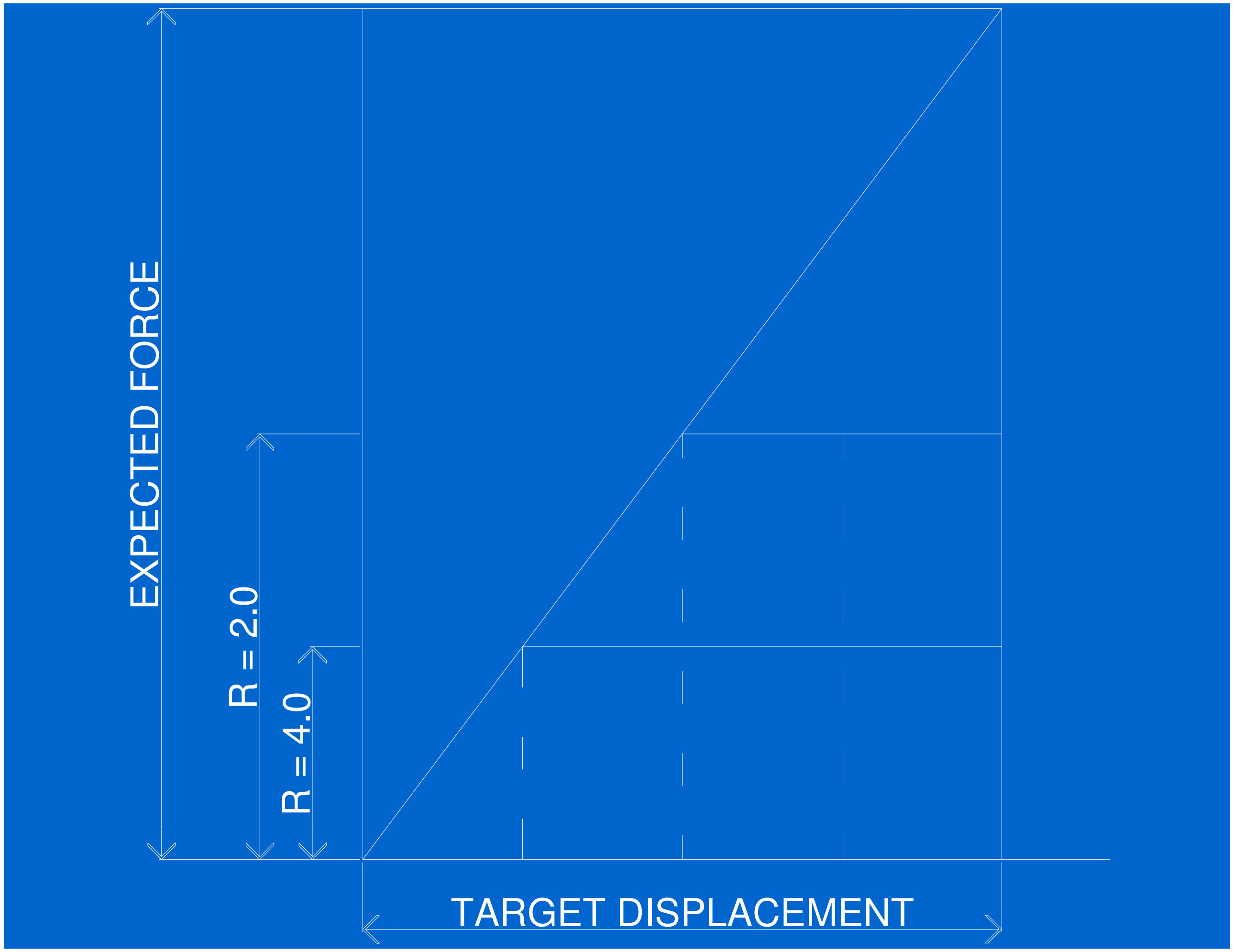


1995: $$V = \frac{V_e}{R} U$$

2005: $$V = \frac{V_e}{R_d R_o}$$



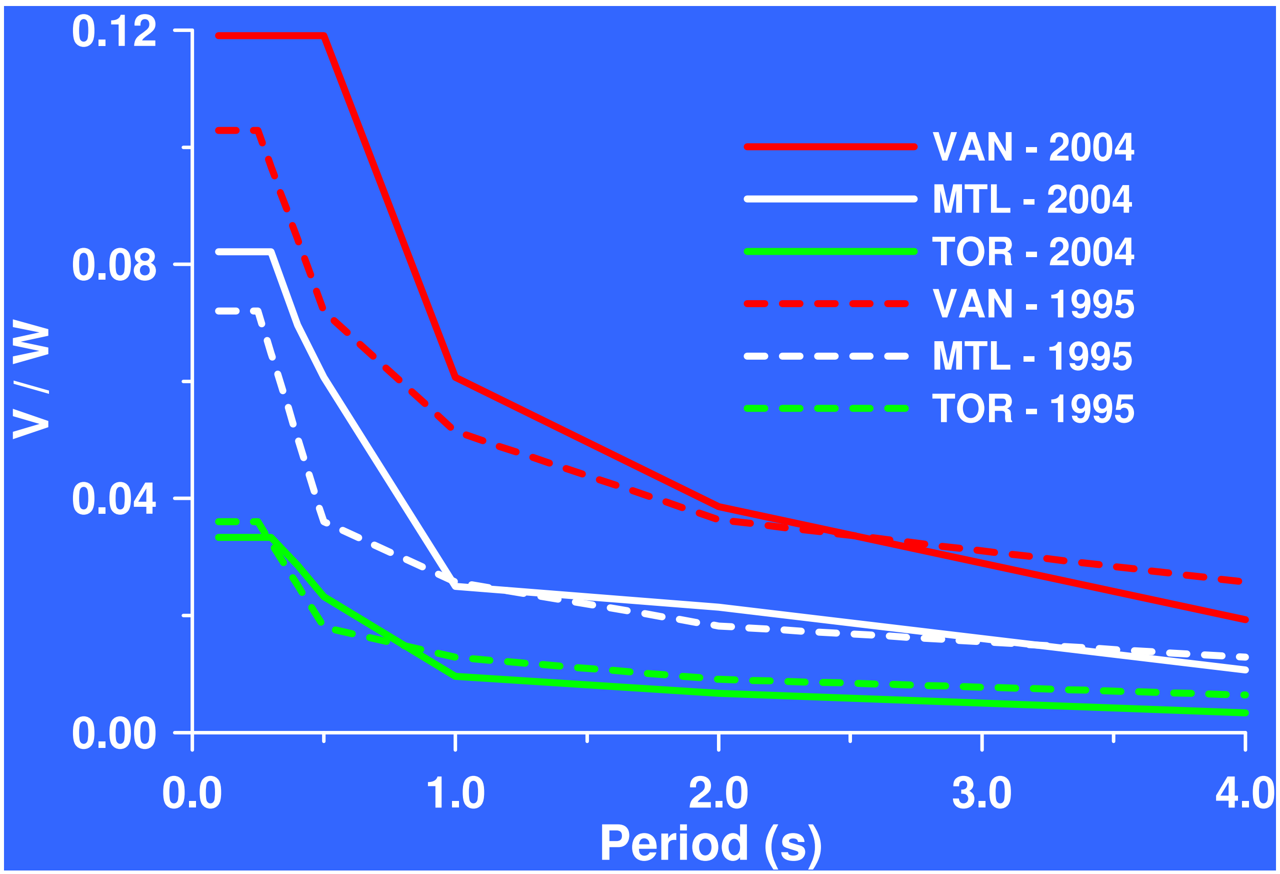
Effect of R values



Base shear comparison

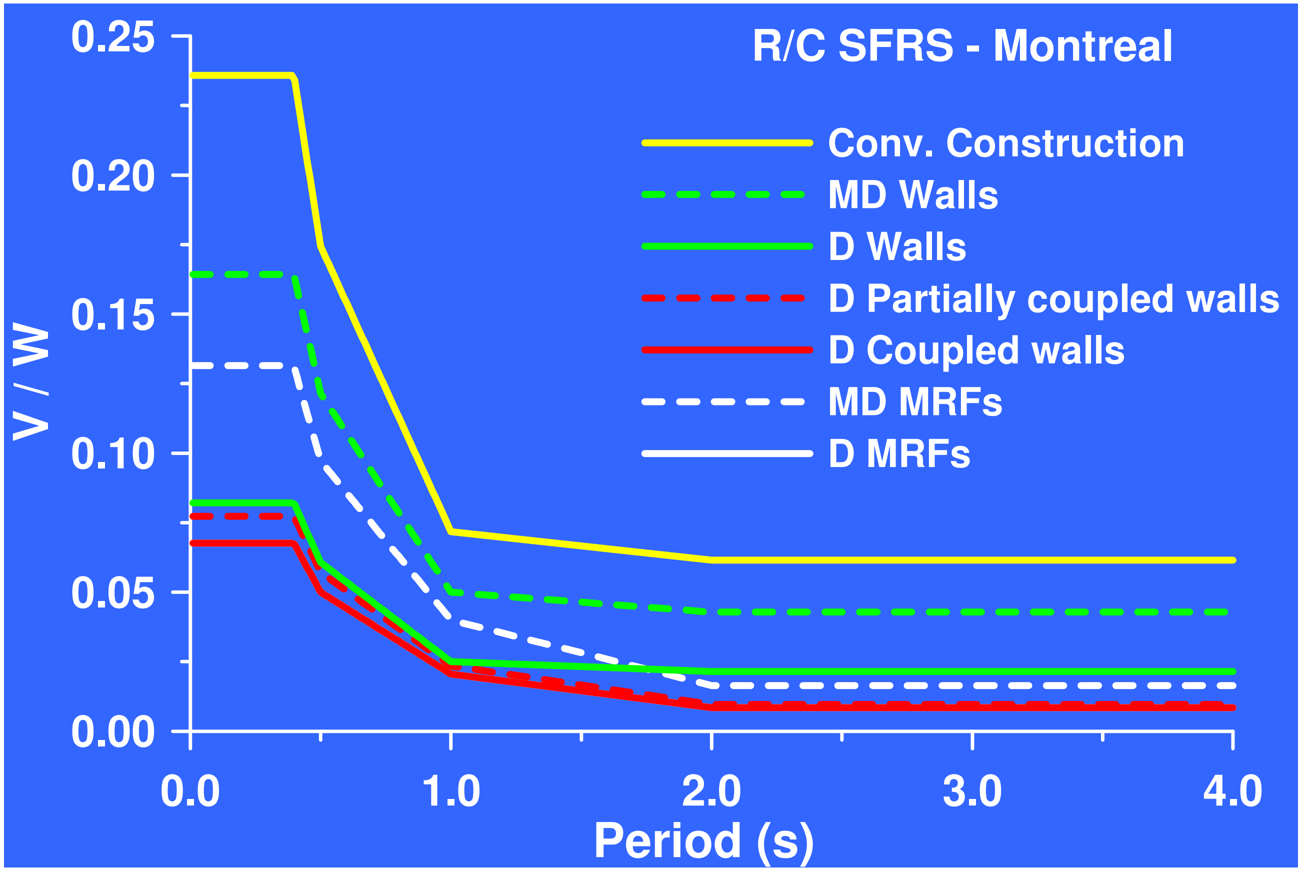
R/C Ductile shear walls, R_d = 3.5

Soil Class C



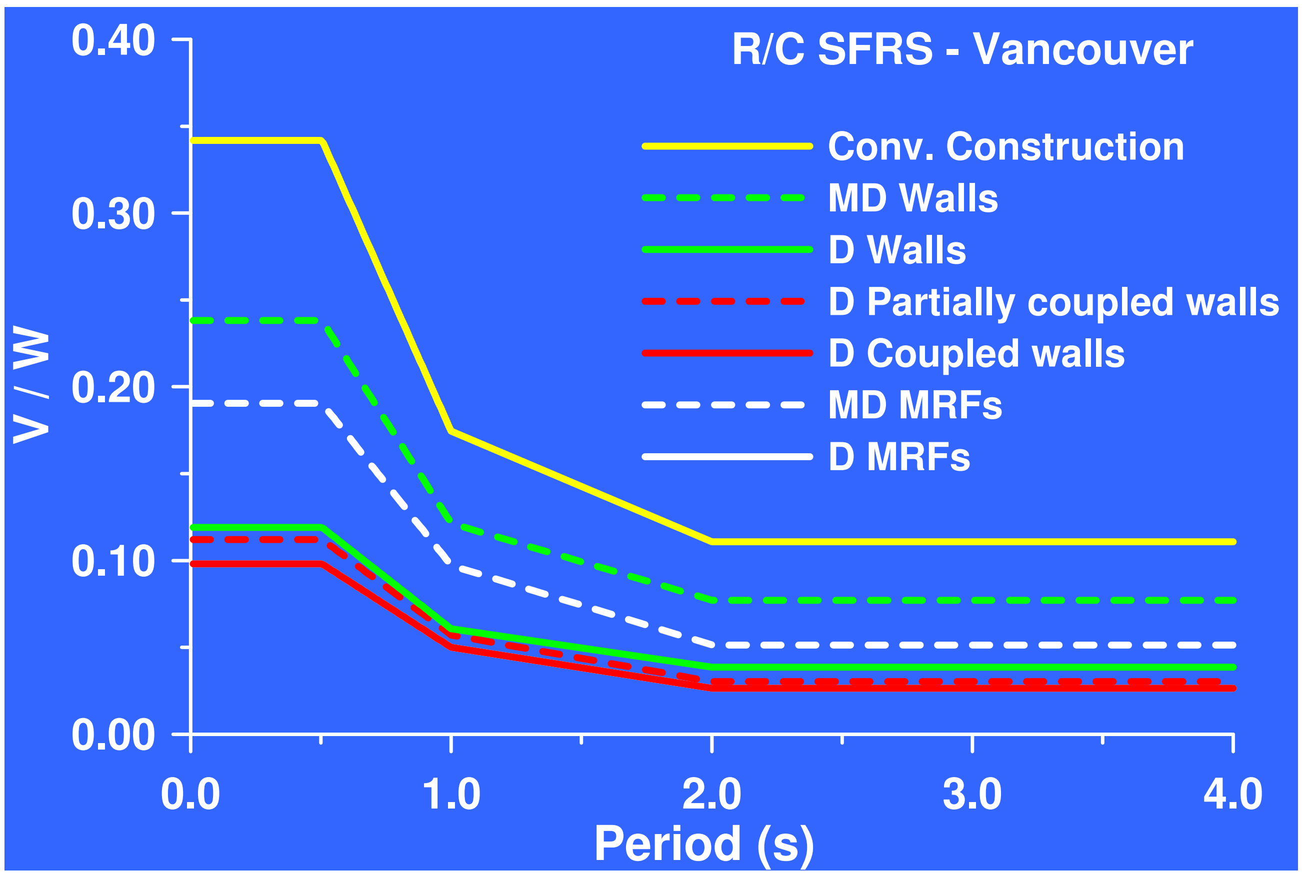
Influence of $R_d R_o$ (R/C SFRS)

Montreal, Soil Class C



Influence of R_dR_o (R/C SFRS)

Vancouver, Soil Class C



2005 NBCC Seismic Analysis

- Better consideration of irregularities
- Requires more dynamic analysis
- Better consideration of torsional sensitivity
- Lateral storey drift limit increased: 2% -> 2.5%. Relates to structural damage.
- Post-disaster buildings shall not have any irregularity

Types of structural irregularities

1 Vertical stiffness irregularity
2 Weight (mass) irregularity
3 Vertical geometric irregularity
4 In-plane discontinuity
5 Out-of-plane offsets
6 Discontinuity in capacity (weak storey)
7 Torsional sensitivity
8 Non-orthogonal systems

Irregularity trigger

When:

$I_E \cdot F_a \cdot S_{a(0.2)} > 0.35$

+ any one of the 8 irregularity types,

the building is considered as *irregular*

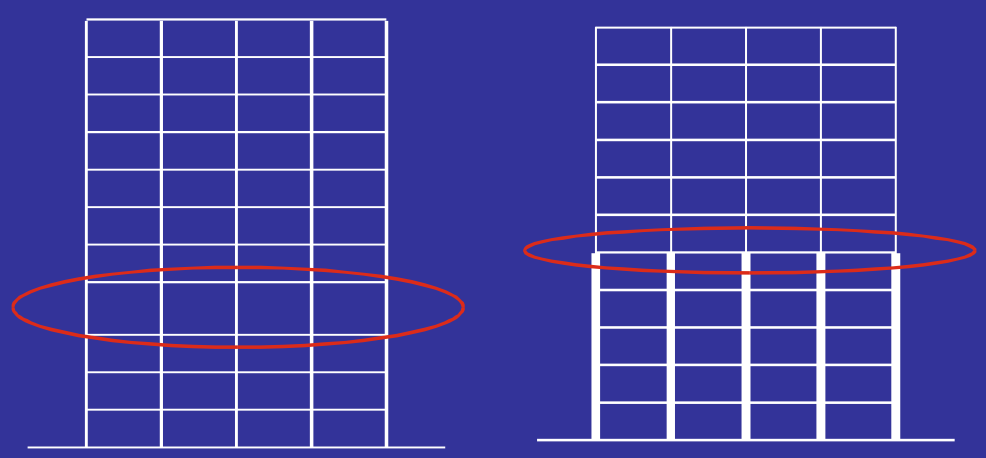
Types of Irregularities

1 Vertical Stiffness

lateral stiffness of the *SFRS* in a storey:

< 70% of that in any adjacent storey, or

< 80% of the average stiffness of the 3 storeys above or below.

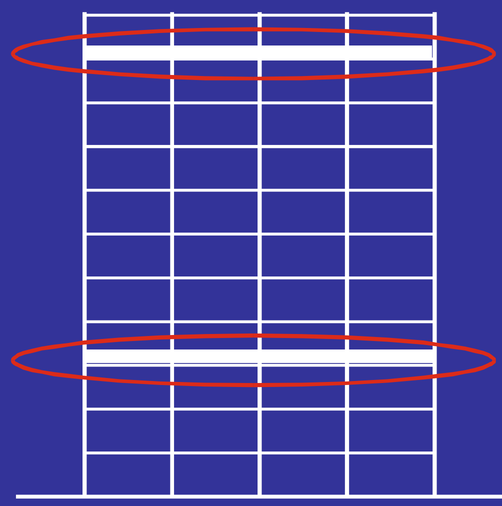


Types of Irregularities

2 Weight (Mass)

weight of a storey > 150% of weight of an adjacent storey.

(a roof lighter than a floor below is excluded)

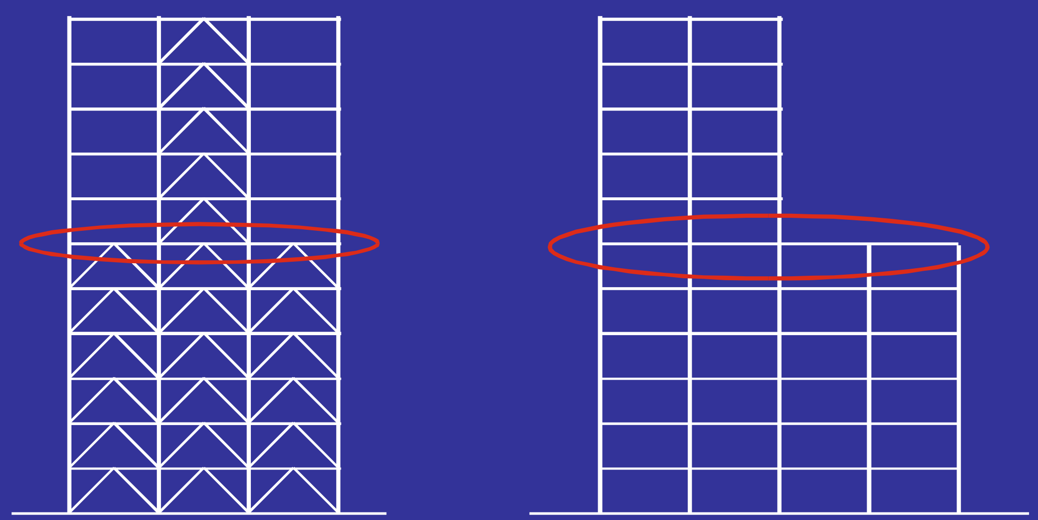


Types of Irregularities

3 Vertical Geometric

horizontal dimension of the *SFRS* in a storey > 130% of that in any adjacent storey.

(one-storey penthouse excluded)



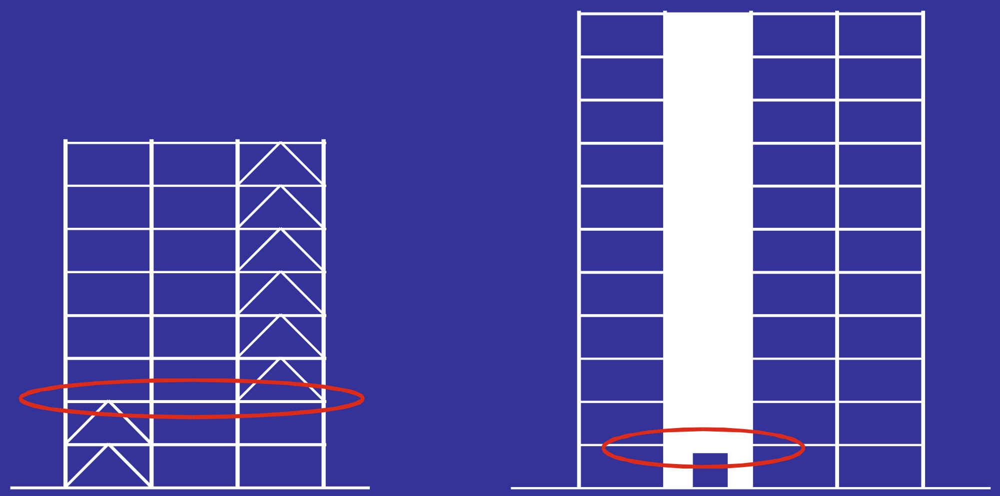
Types of Irregularities

4 In-Plane Discontinuity

- in-plane offset of an element of the SFRS,

  or

- reduction in lateral stiffness of an element in the storey below.



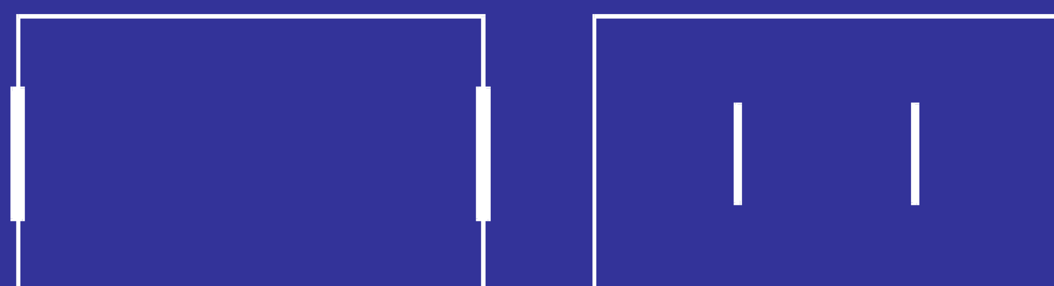
Types of Irregularities

5 Out-of-Plane Offsets

discontinuity of lateral force path

e.g., out-of-plane offsets

of the elements of the *SFRS.*



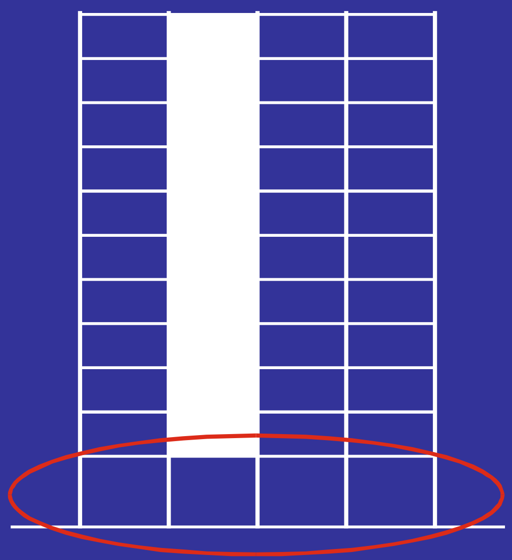
Bottom Floors Top Floors

Types of Irregularities

6 Discontinuity in Capacity - Weak Storey

storey shear strength less than that in the storey above.

(Storey shear strength = total of all elements of the SFRS in the direction considered)



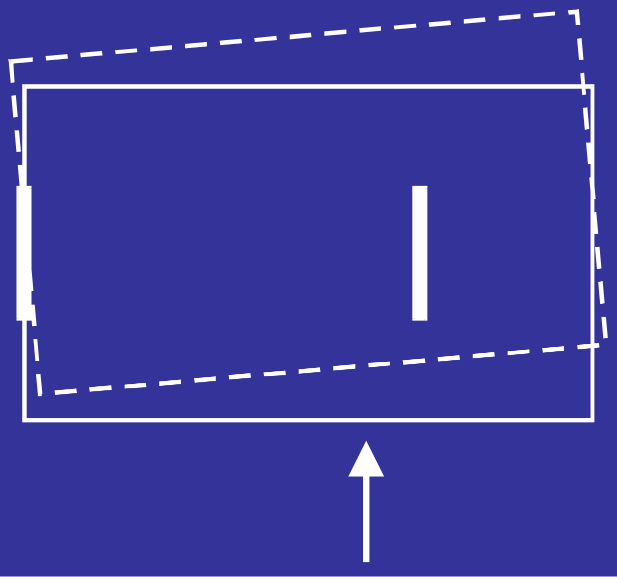
Types of Irregularities

7 Torsional sensitivity

if the ratio B > 1.7.

$B = \delta_{max} / \delta_{avg}$

δ calculated for static loads applied at $\pm$ 0.10 D_n

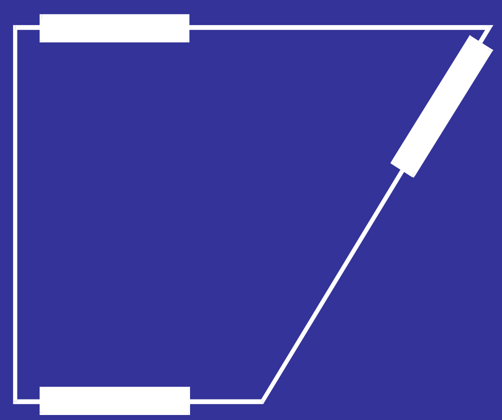


Plan

Types of Irregularities

8 Non-orthogonal systems

SFRS not oriented along a set of orthogonal axes.



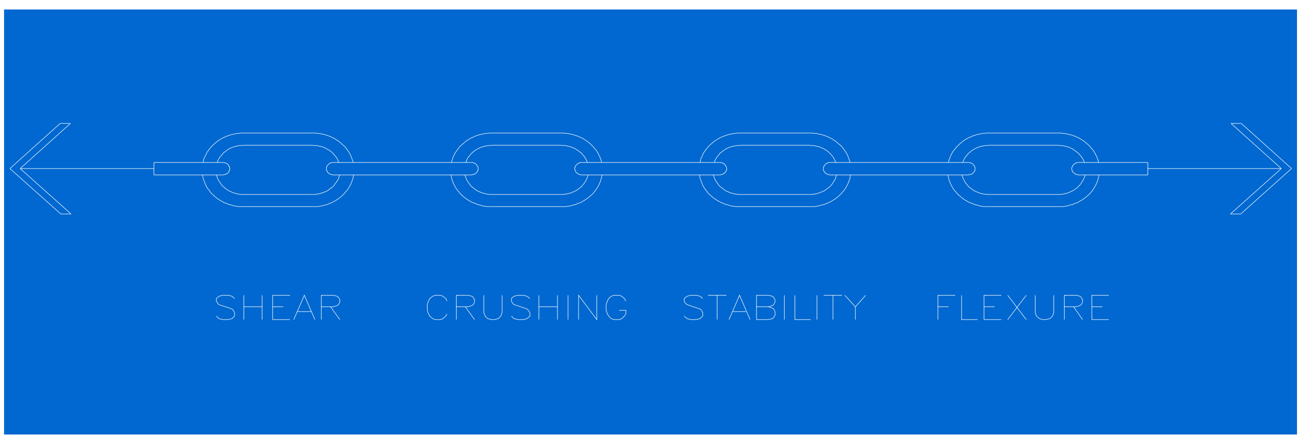
Plan

Seismic Importance Factor

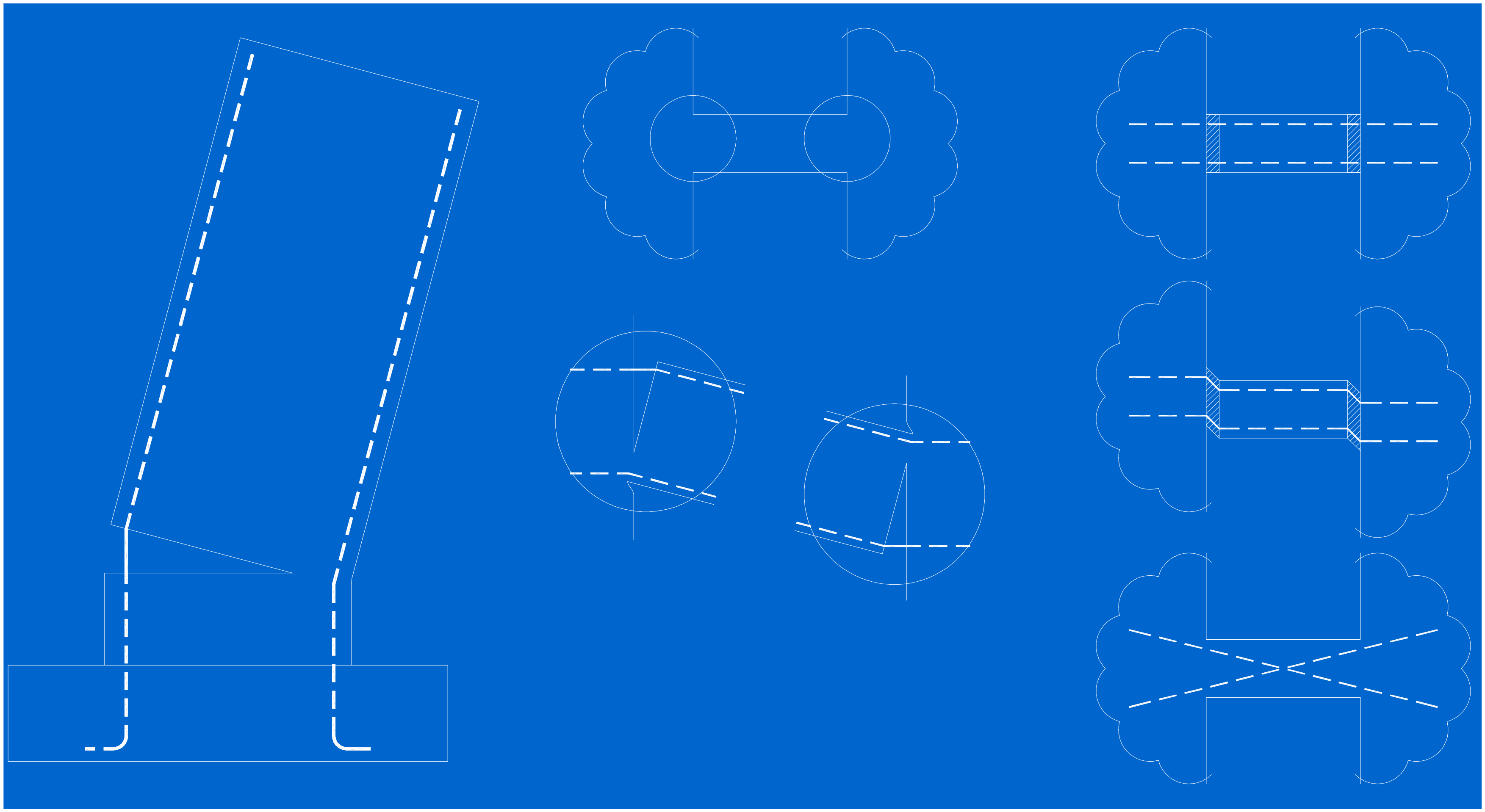
Importance Category	I_E
Low	0.8
Normal	1.0
High	1.3
Post Disaster	1.5

Modern Design Codes

- SEAOC 1988/NBC 1990
- CSA A23.3 1984 Canadian Concrete Design Code
  - Introduced "Capacity Design"



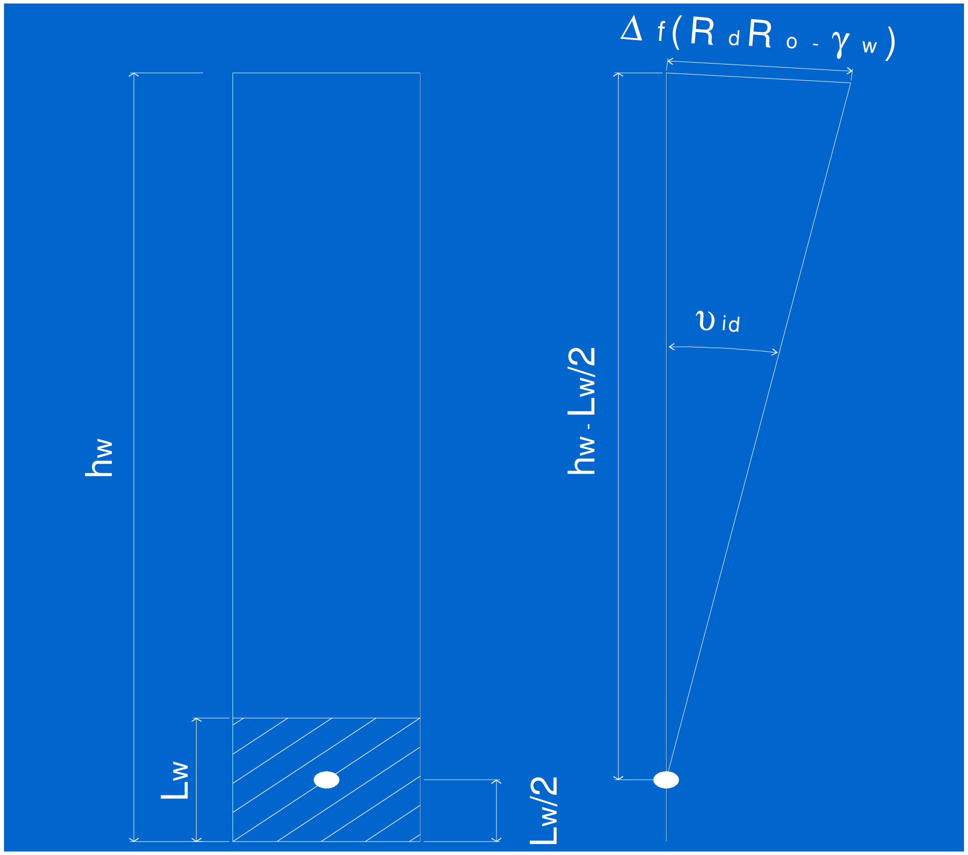
Concrete Plastic Hinges



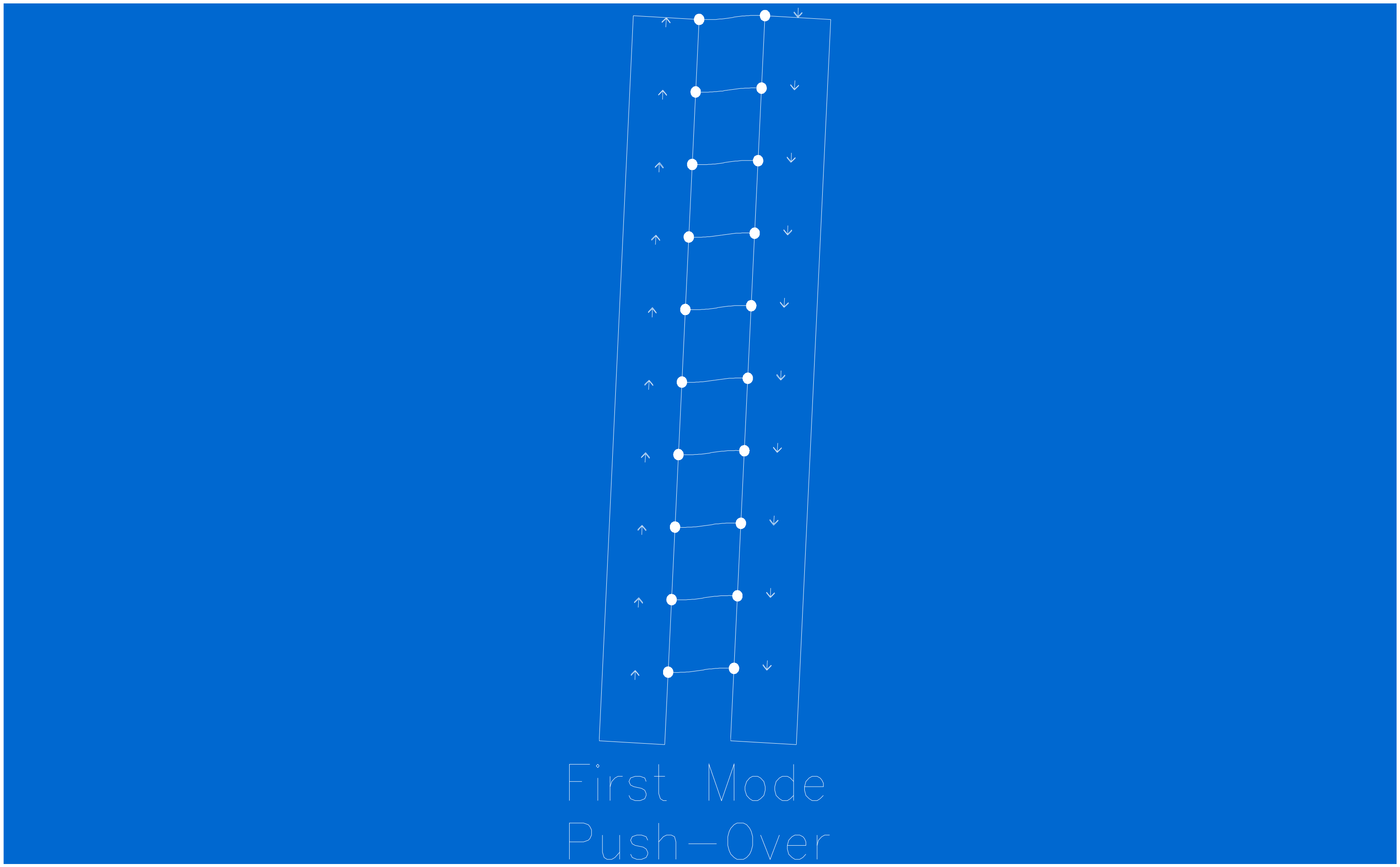
Overview of Clause 21 Changes

- Introduced a “ductility” limit state for plastic hinges in walls and coupling beams
- Rotational capacity ≥ Rotational demand

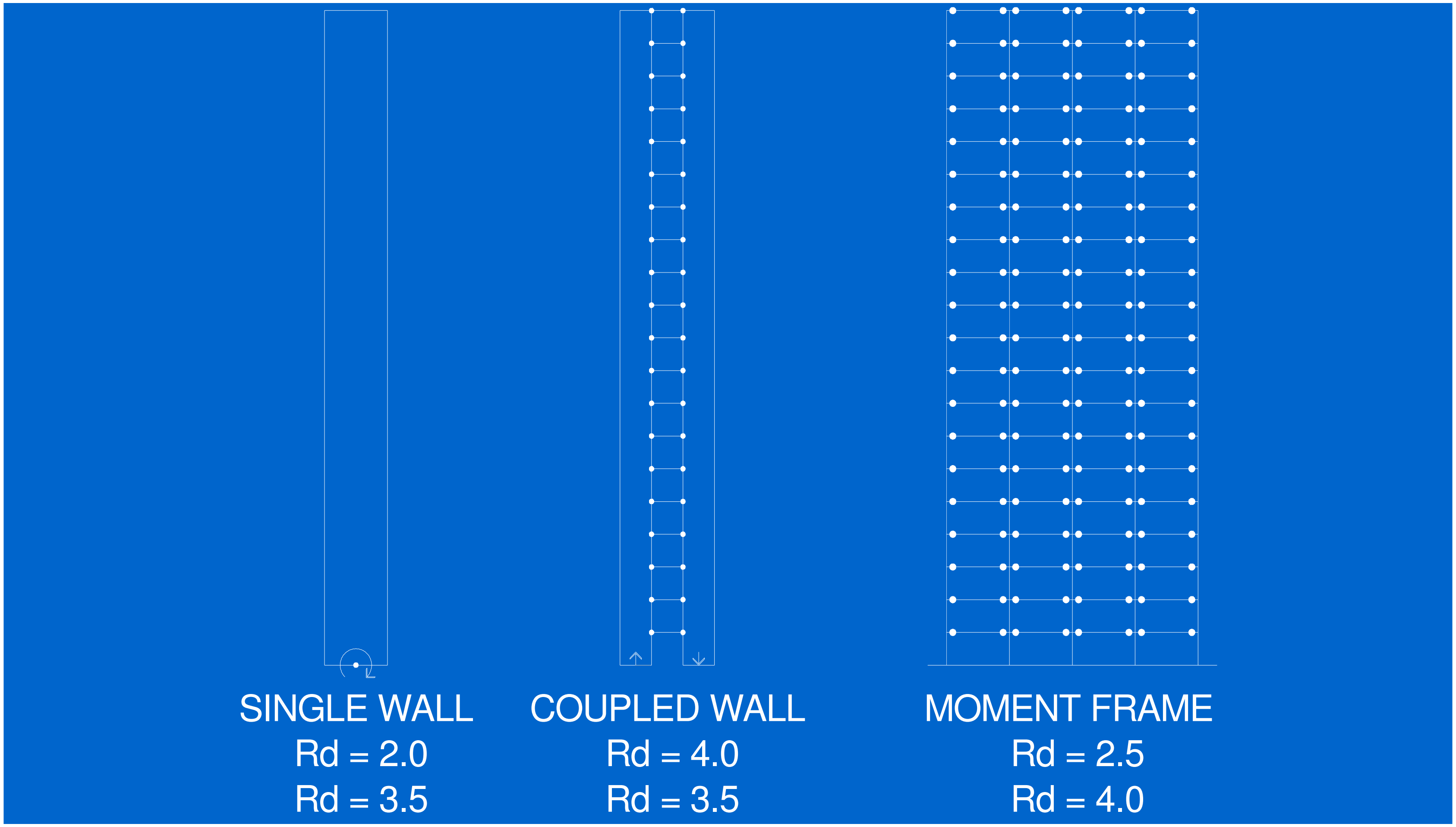
$$\theta_{ic} \geq \theta_{id}$$



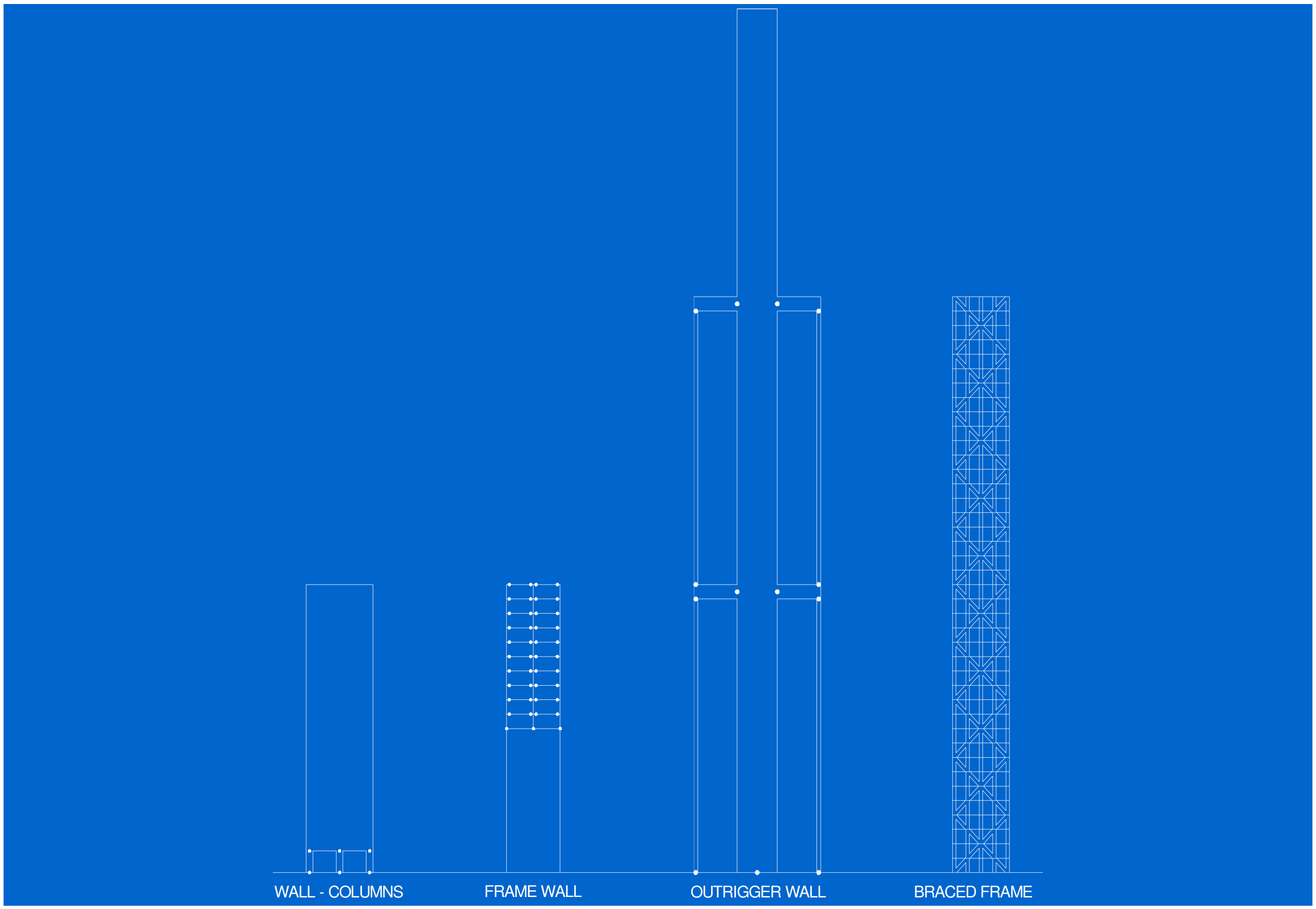
Plastic Hinges to Absorb Energy



NBCC Concrete Ductile Systems



Un-Classified Systems



Earthquake Design Factor of Safety

- “Earthquake” Factored Load Design
  - Factored Load ≈ 0.15 to 0.5 x Expected Load
  - Factored Bending Resistance ≈ 0.17 to 0.6 x Expected Load
  - “Factor of Safety” ≈ 0.17 to 0.6

Philosophical Underpinning

- Earthquakes are rare events, the design event has a 2% probability of exceedance in 50 years. That is, in an assumed 50 year building life, there is a 98% chance that the building will <u>not</u> experience an earthquake of this magnitude in its design life.
- Therefore design only for life safety, not asset protection, the building may be irreparable but no one dies.

2005 NBCC – Objective Based Format

- Part 1 – Objectives of the Code
- Part 2 – Prescriptive Solutions to Objectives

- **1995**
- *Firewalls with a fire rating of 2 hrs or less* shall be constructed of concrete or masonry.
- **2005**
- *Firewalls with a fire rating of 2 hrs or less* not explicitly required to be masonry or concrete.

Further Information

Commentary J - NBCC 2005
Canadian J. of Civil Engineering, April 2003:

- ***overview and background of changes***
- ***seismic hazard maps***
- **ground amplification factors**
- **equivalent static load method**
- **force modification factors**
- **torsion**
- **dynamic analysis**
- **foundation rocking**
- **non-structural components**

Thank You