



Hazard Mitigation and Disaster Management (HMDM) Research Centre



uOttawa
L'Université canadienne
Canada's university

University of Ottawa
Canada's university

How Safe is Our Infrastructure? Earthquakes and Bomb Blasts...

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University Research Chair
Department of Civil Engineering
University of Ottawa

- Mitigation
- Prevention
- Protection
- Monitoring
- Security
- Preparedness
- Education
- Response
- Relief
- Recovery
- Reconstruction



How Many Earthquakes Occur Worldwide Each Year?

Description	Magnitude	Annual Average
Great	8 or higher	1
Major	7 – 7.9	18
Strong	6 – 6.9	120
Moderate	5 – 5.9	800
Light	4 – 4.9	6,200
Minor	3 – 3.9	49,000
Very Minor	2 – 3	1,000/day
Very Minor	1 – 2	8,000/day

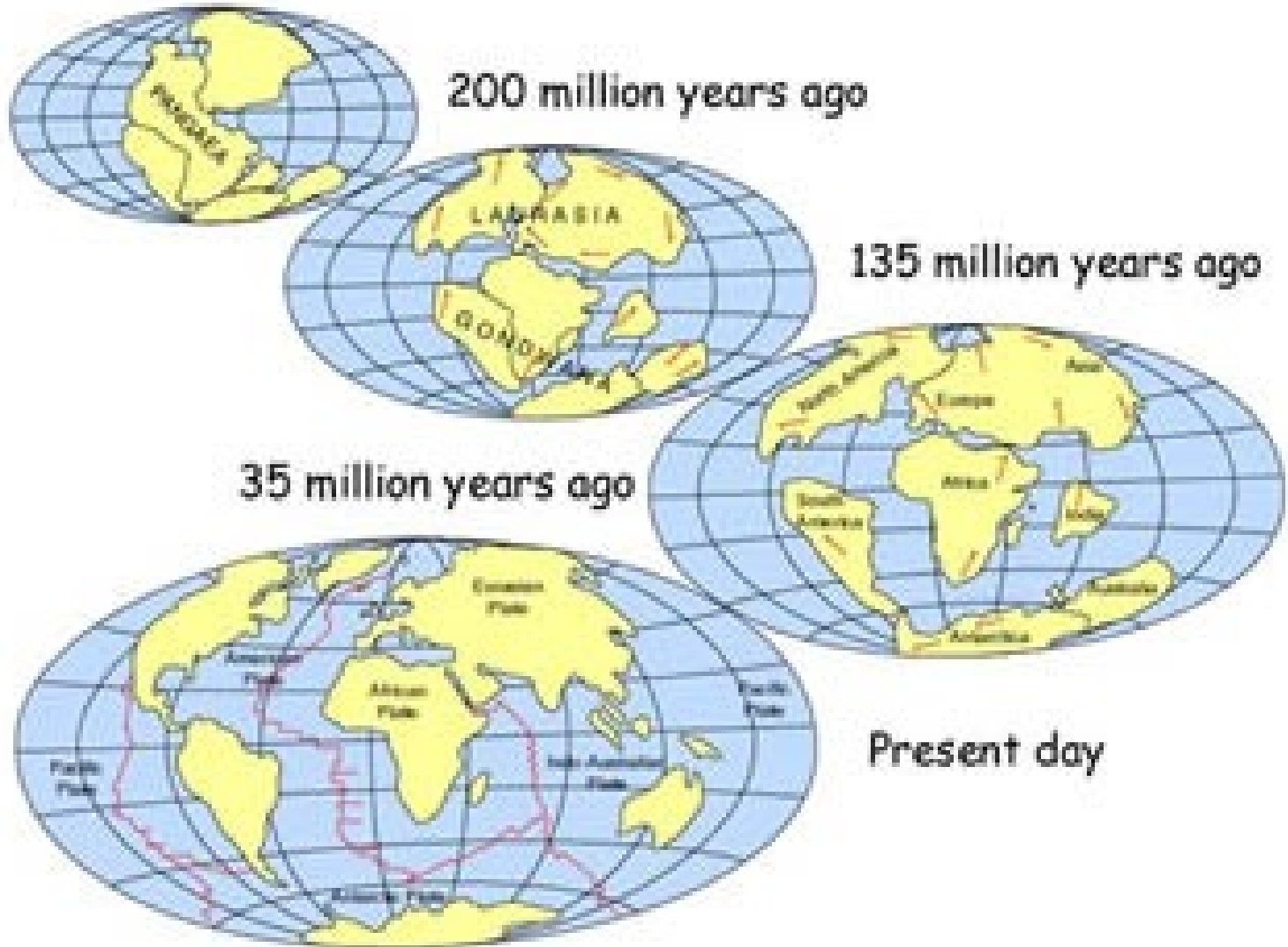
Causes of Earthquakes

Continental Drift Theory



Causes of Earthquakes

Continental Drift Theory



Earthquakes Between 1960 and 1995





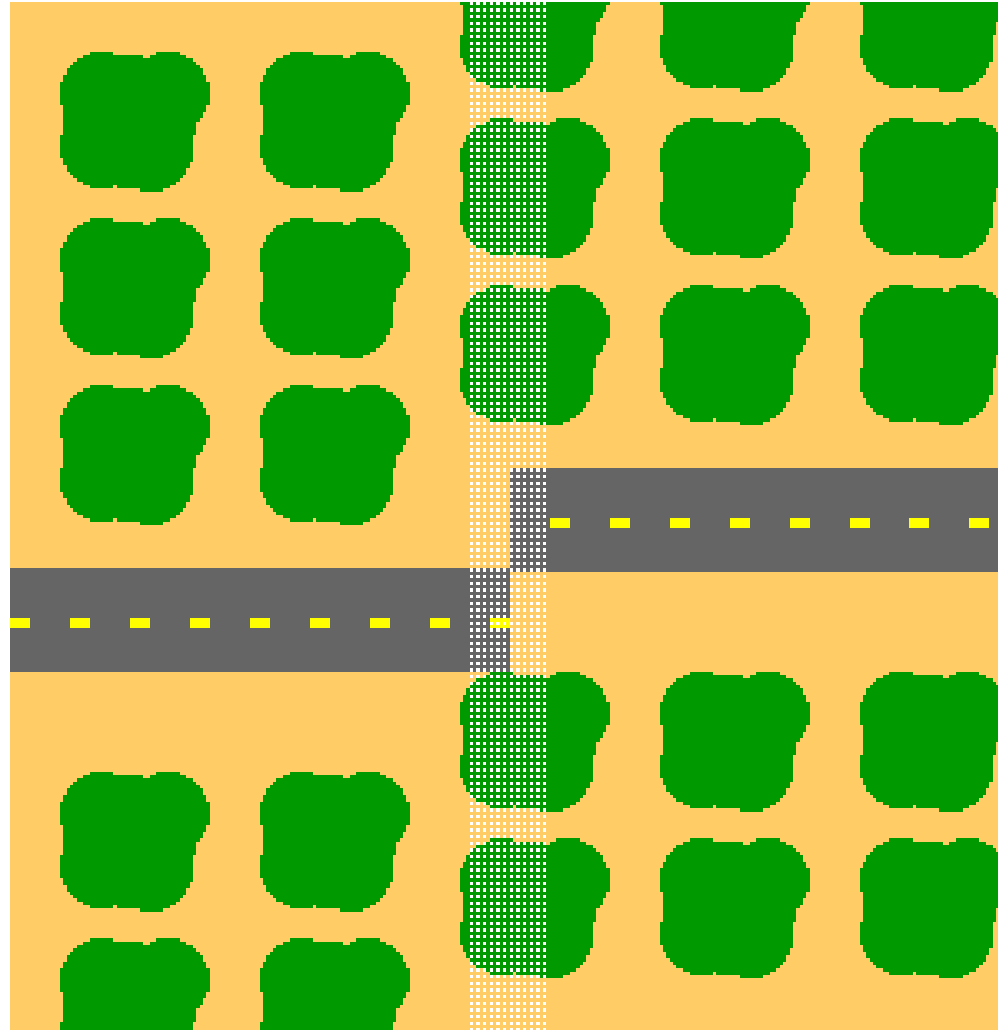
Earthquake!!!



Distant
forces



Distant
forces



Fault zone
(white stippling)

Fault Rupture



Fault Rupture

Vertical Offset Due to
Fault Rupture



1977 Caucete E.Q. in
Argentina

Fault Rupture



How Many Earthquakes Occur in Canada?

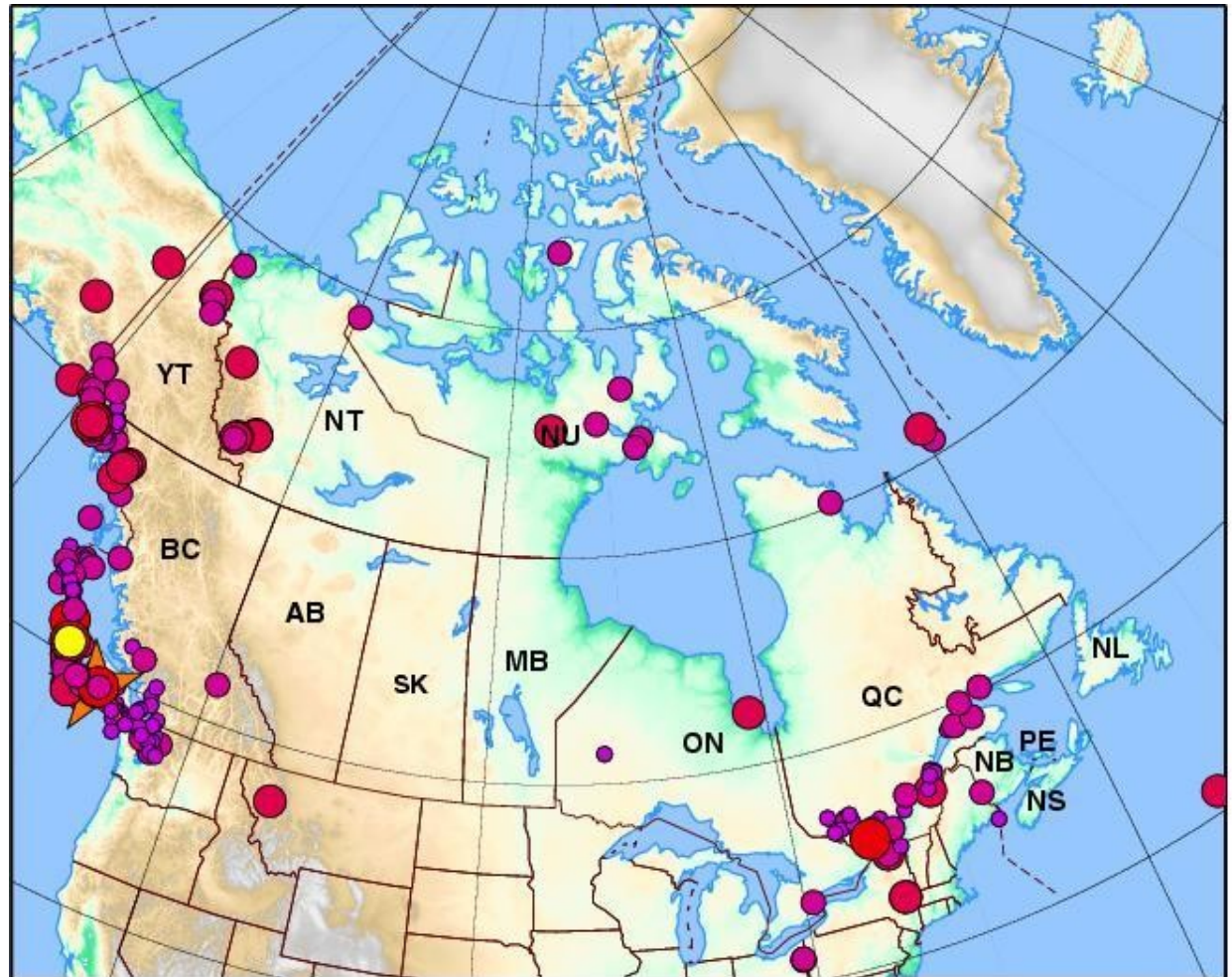
More than 4000 earthquakes are recorded each year in Canada

Approximately 300 earthquakes occur each year in Eastern Canada.

Of this number, approximately four exceeds magnitude 4.0



Earthquakes That Occurred in the Last 30 Days



2011/08/20 - 2011/09/19

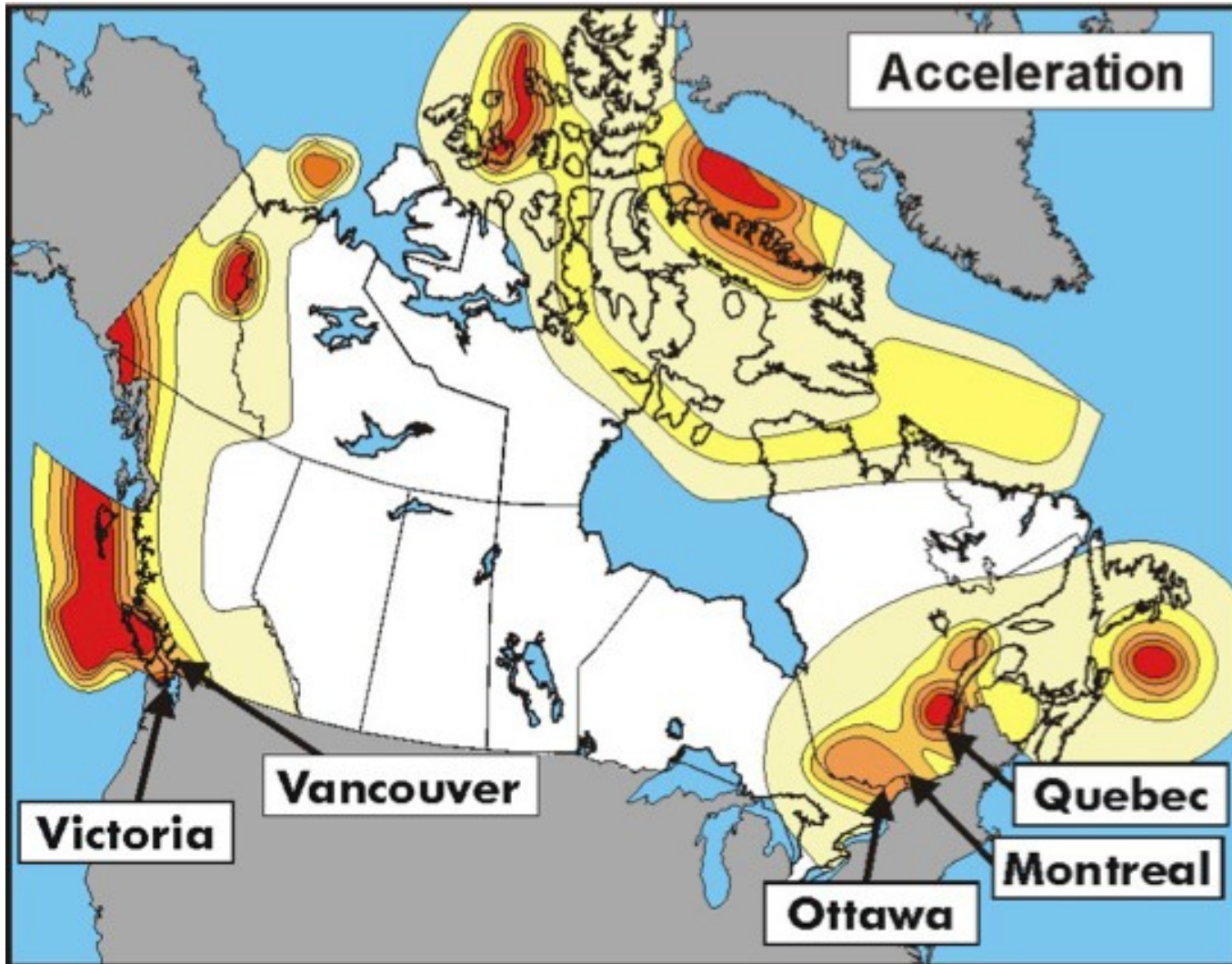
0 km 1000 km 2000 km

Earthquakes Canada
Séismes Canada

Recent earthquakes (most recent is shown in yellow)

- $M < 2.0$
● $M \geq 3.0$
★ $M \geq 5.0$
●
- $M \geq 2.0$
● $M \geq 4.0$
★ $M \geq 6.0$

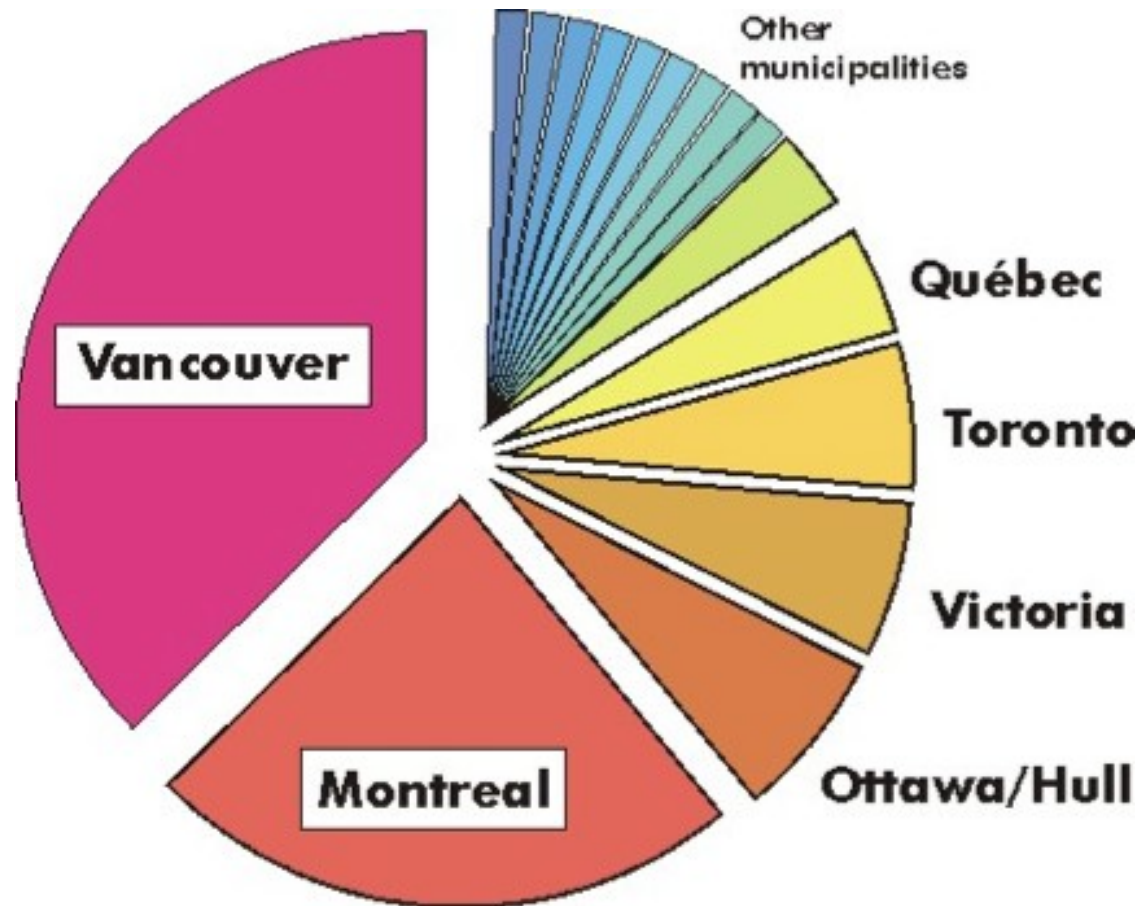
Seismic Hazard in Canada



by GSC

Seismic Risk in Canada

Seismic Risk = Hazard * Vulnerability * Exposure





Seismic Risk in Canada



“the major threat to public safety in the Montréal region is the threat from seismic events”

Centre de Sécurité Civile de Montréal (2005)



“total economic loss from a major earthquake in the Lower Mainland of BC is estimated between \$14 and \$32 billion”

Munich Reinsurance Company of Canada (1992)



A major earthquake is the single largest threat to public safety and security in many Canadian cities and would result in major economic losses



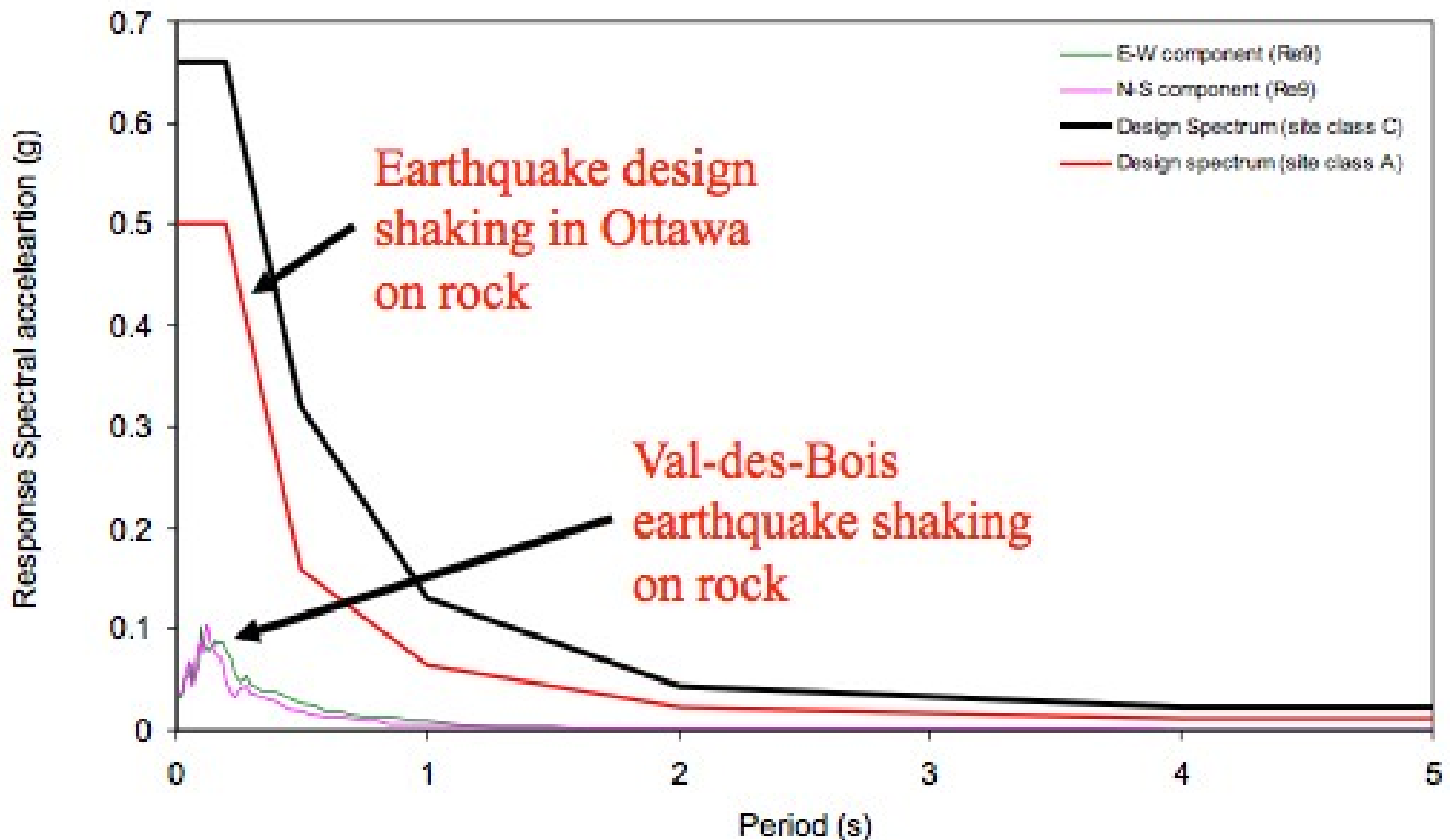
Seismic Vulnerability of Buildings

- ❑ Building designed and built prior to the enactment of modern seismic codes may be vulnerable against seismic motions. In Canada, this means buildings prior to 1970's and 1980's.
- ❑ Buildings on soft soil are more vulnerable than those built on solid rock.



Effect of Soil Conditions

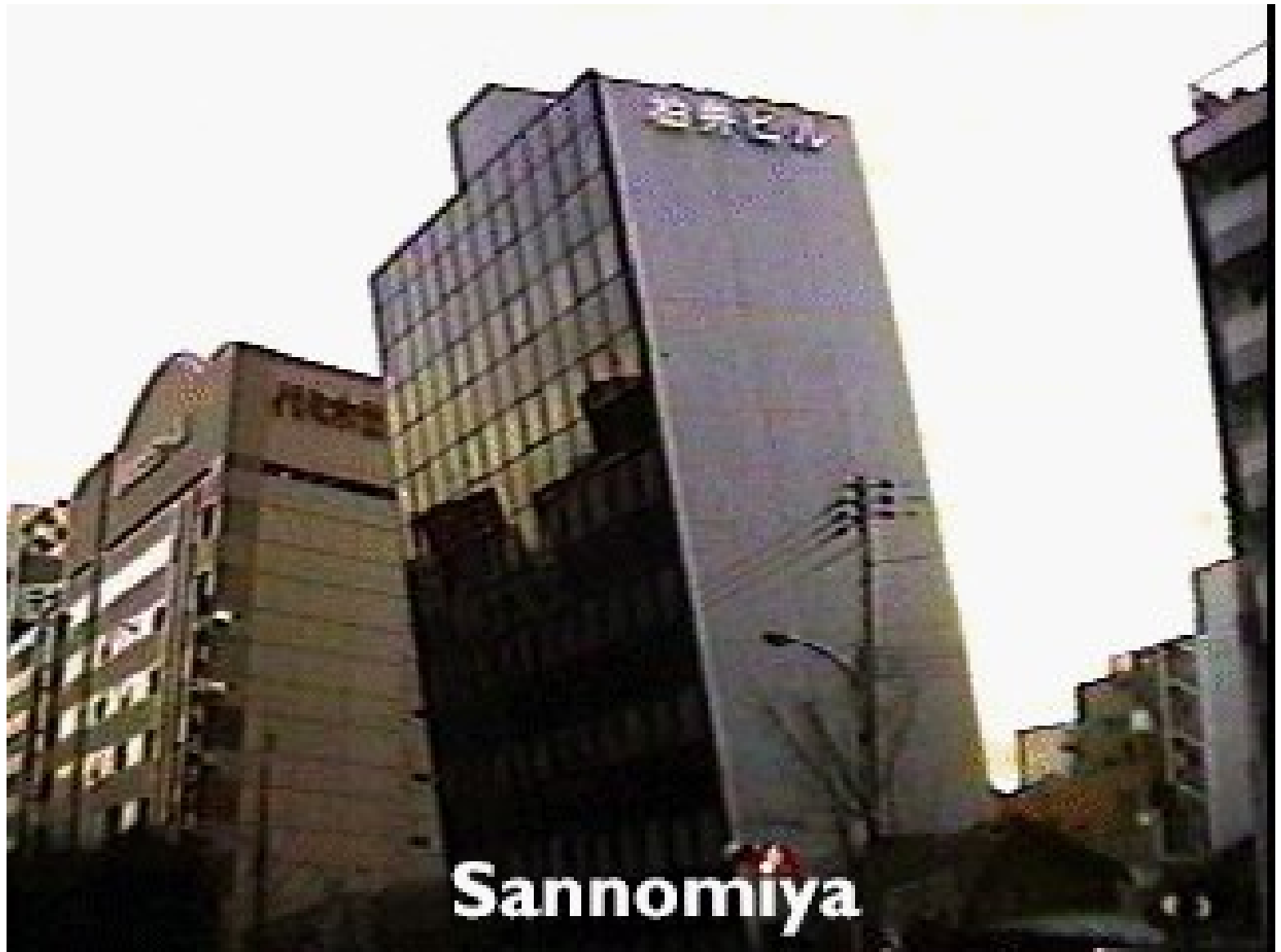
The effect of ground motion is amplified by soft soil



Liquefaction



Liquefaction



Liquefaction



Seismic Vulnerability of Buildings

- ❑ Buildings constructed using brittle construction materials are more vulnerable than those built using ductile materials
- ❑ Typically, old masonry and non-ductile reinforced concrete buildings behave in a brittle manner
- ❑ Steel construction, well-designed reinforced concrete buildings and single-family timber houses often perform favorably



2010 Earthquake in Chile



Church In Curico



2010 Earthquake in Chile



2010 Earthquake in Chile



2010 Earthquake in Chile



May 12, 2008 Wenchuan Earthquake in China



May 12, 2008 Wenchuan Earthquake in China

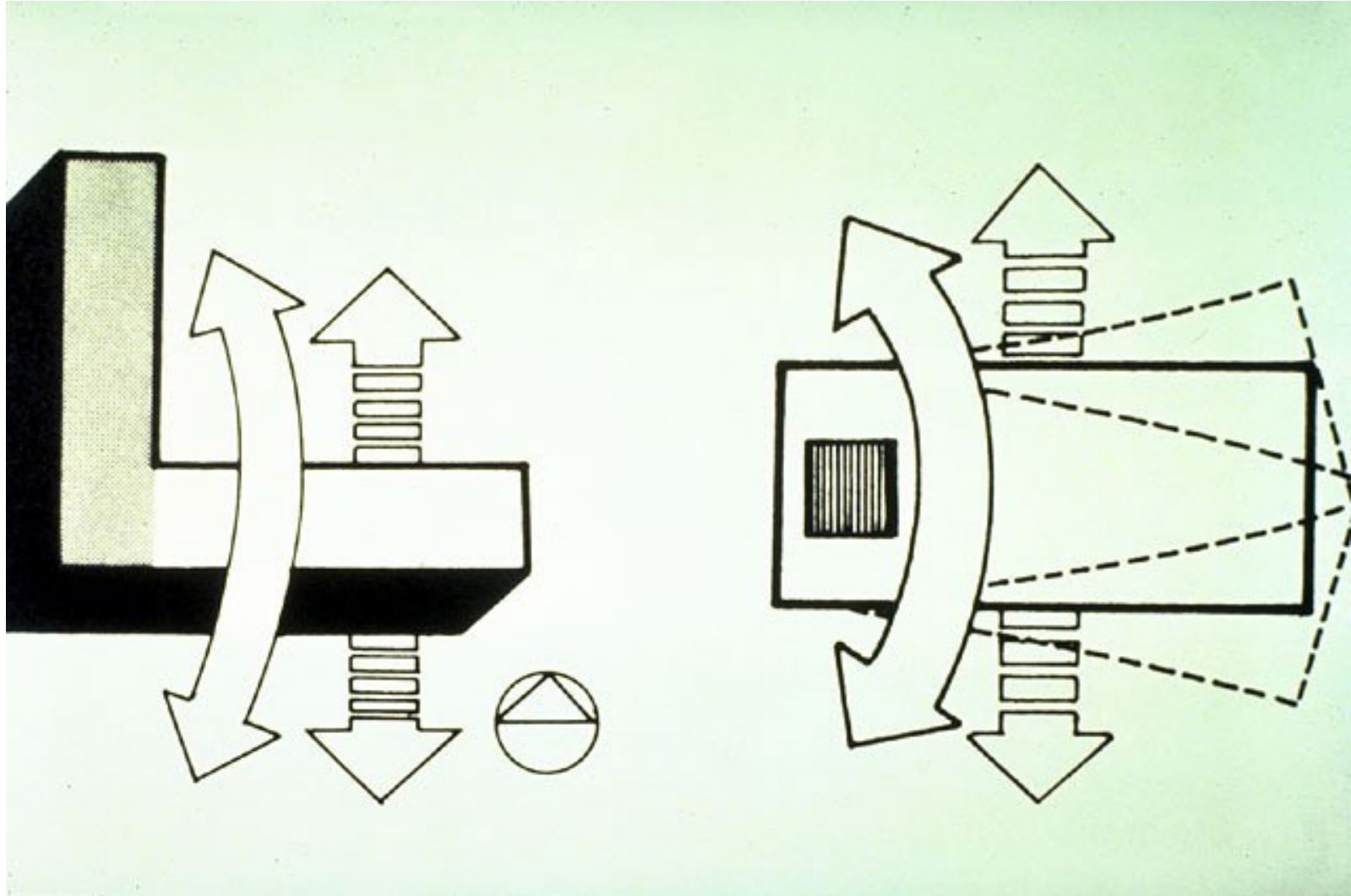


Seismic Vulnerability of Buildings

- ❑ Buildings with irregularities attract higher deformations during earthquakes, and hence are vulnerable.
- ❑ Lack of proper seismic design and detailing practices result in brittle behaviour.
- ❑ Interference of non-structural elements may cause unexpected deficiencies in seismic capacities.



Effect of Torsion



Effect of Torsion



Effect of Torsion



Effect of Vertical Discontinuity



Effect of Vertical Discontinuity



Effect of Vertical Irregularity



Office in Concepcion



Effect of Vertical Irregularity



Effect of Vertical Irregularity



Effect of Soft Storey



Effect of Soft Storey



Effect of Soft Storey



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Seismic Design and Detailing



Lack of Concrete Confinement



Short Column Effect



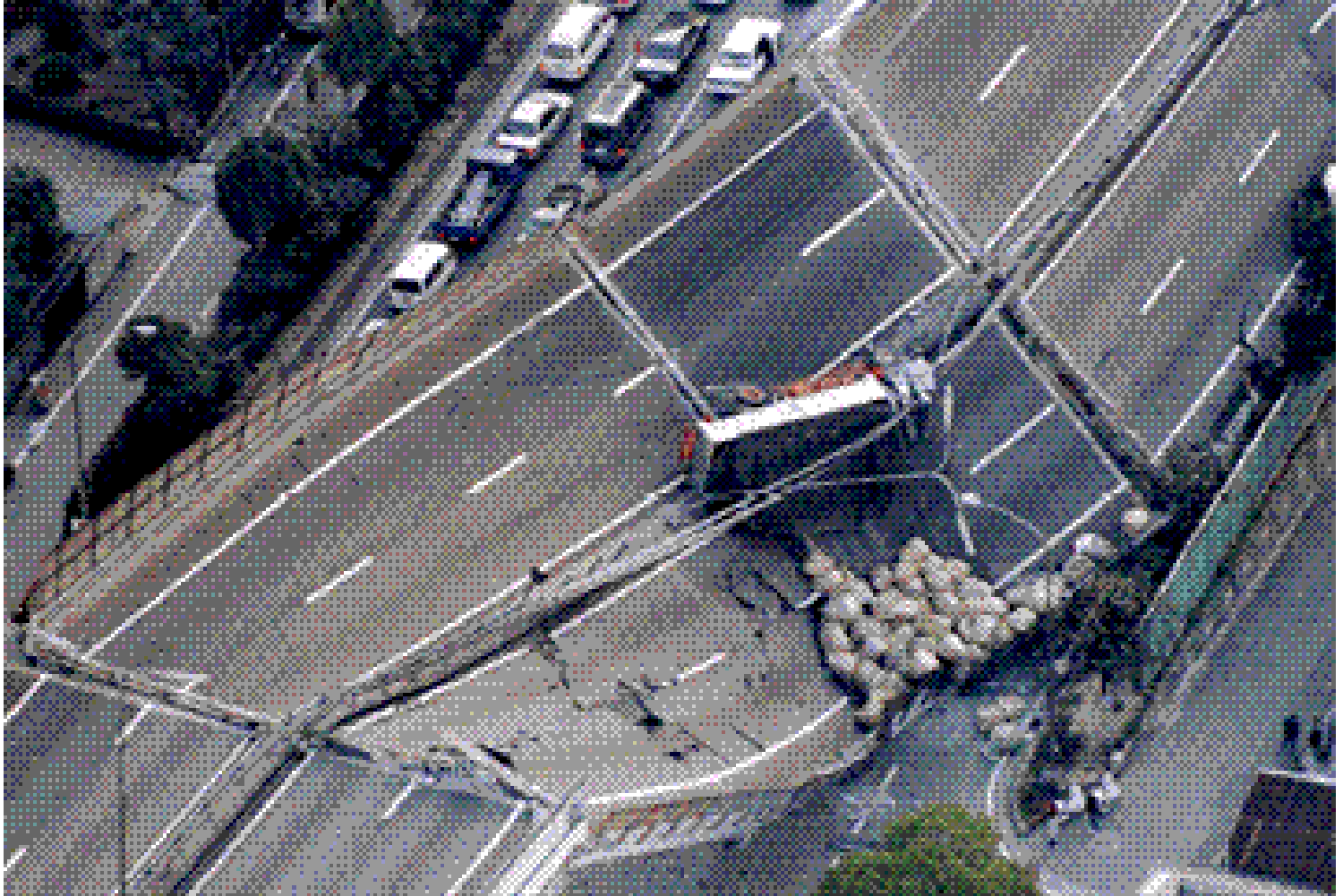
Short Column Effect



Damage to Bridge Infrastructure



1995 Kobe E.Q. in Japan



1999 Kocaeli E.Q. in Turkey



1994 Northridge E.Q.



May 12, 2008 Wenchuan Earthquake in China



2010 Earthquake in Chile

Santiago

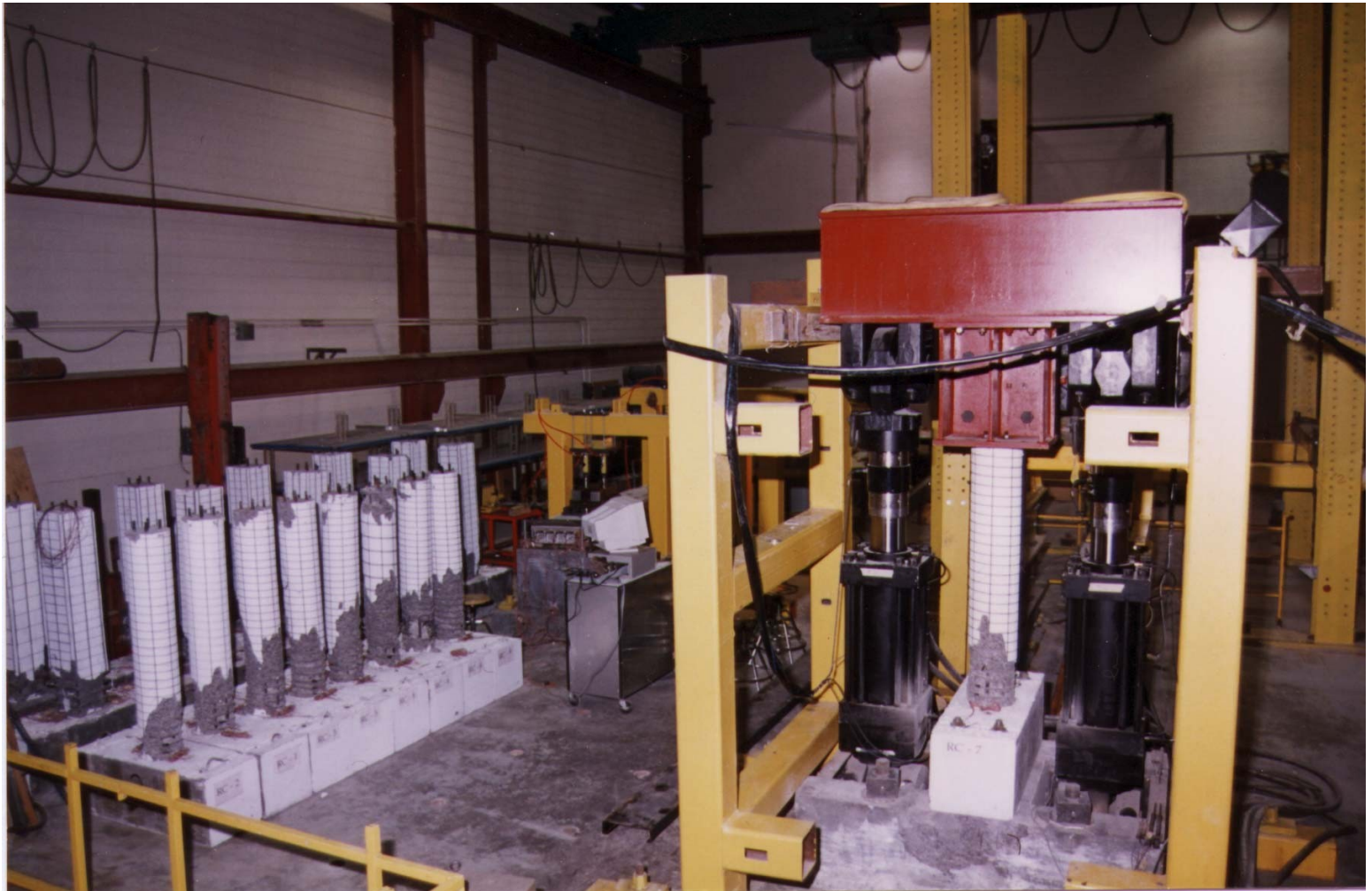


2010 Earthquake in Chile

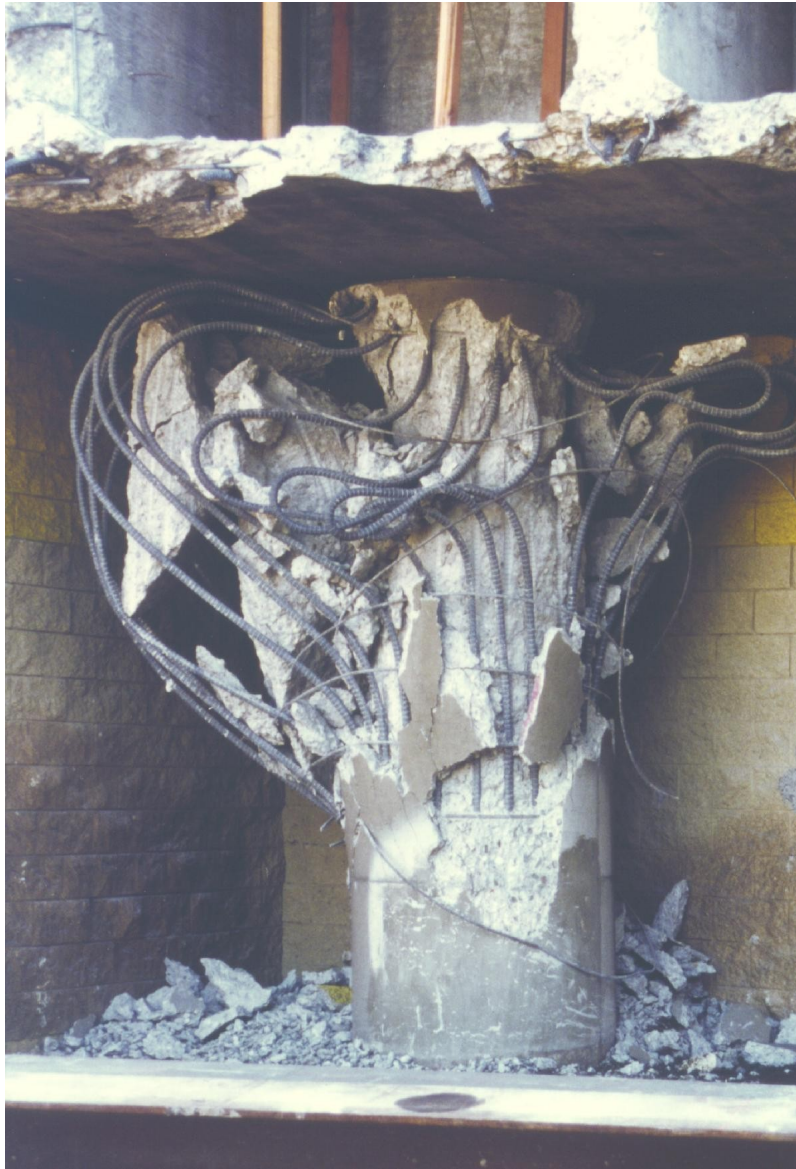


Earthquake Engineering Research

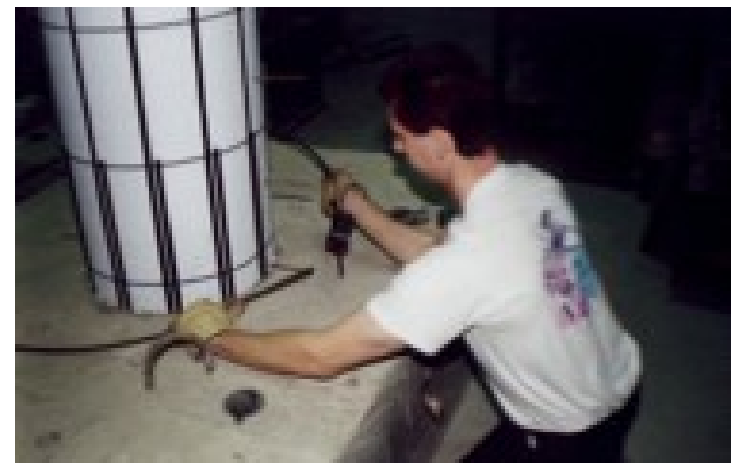
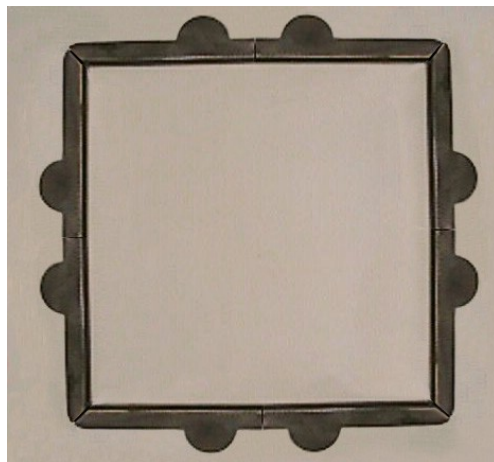
Structures Laboratory



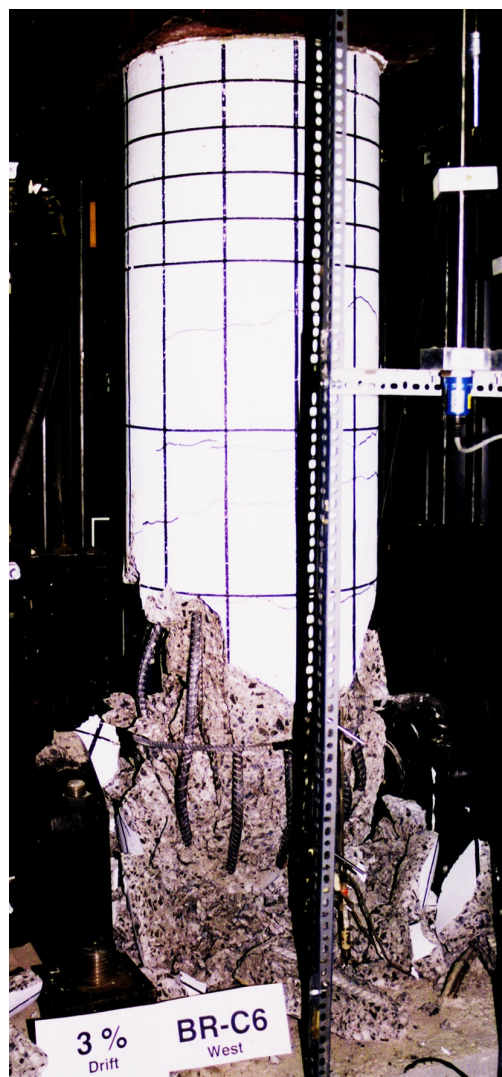
Research on Seismic Retrofit



RetroBelt Seismic Retrofit Technique



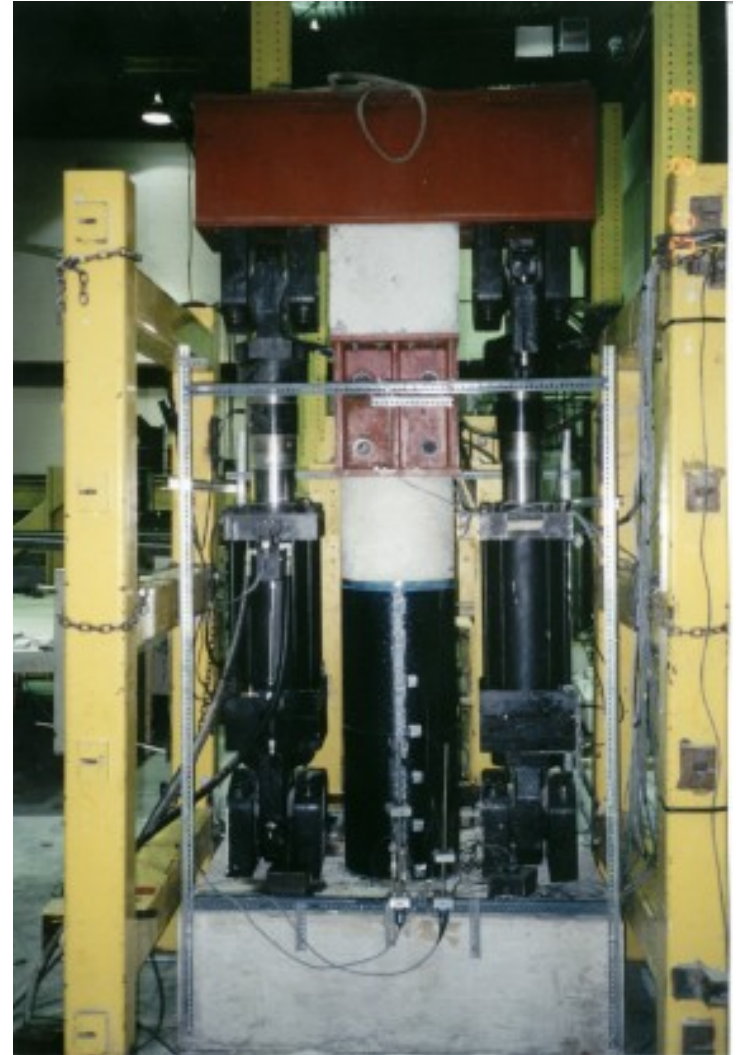
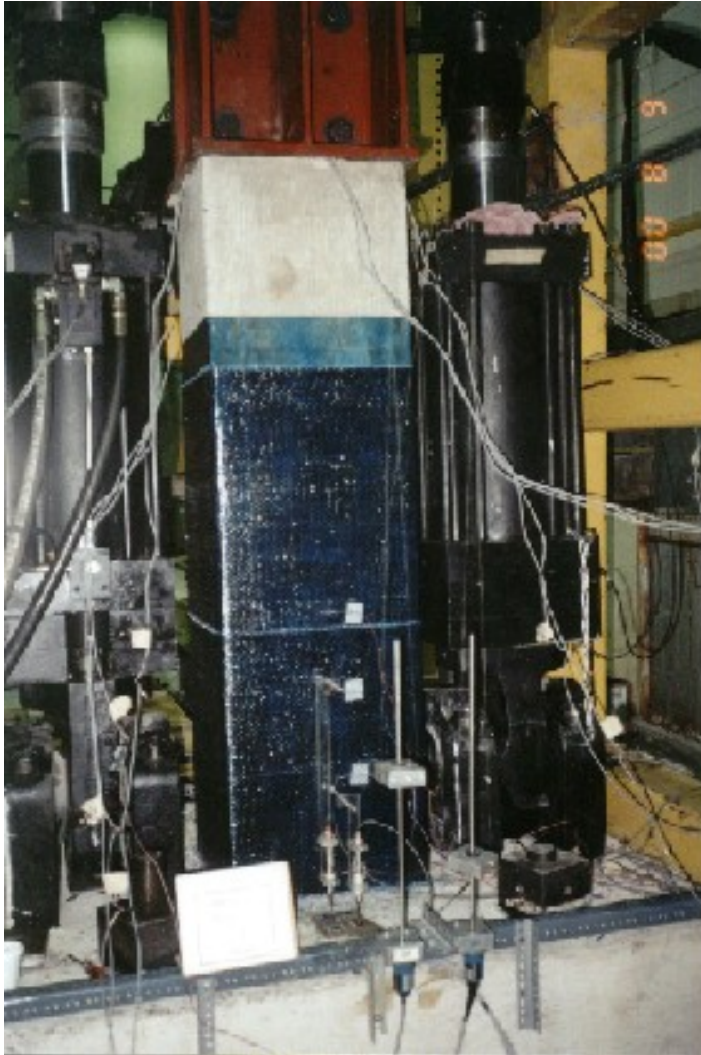
RetroBelt Seismic Retrofit Technique



FRP Jacketing



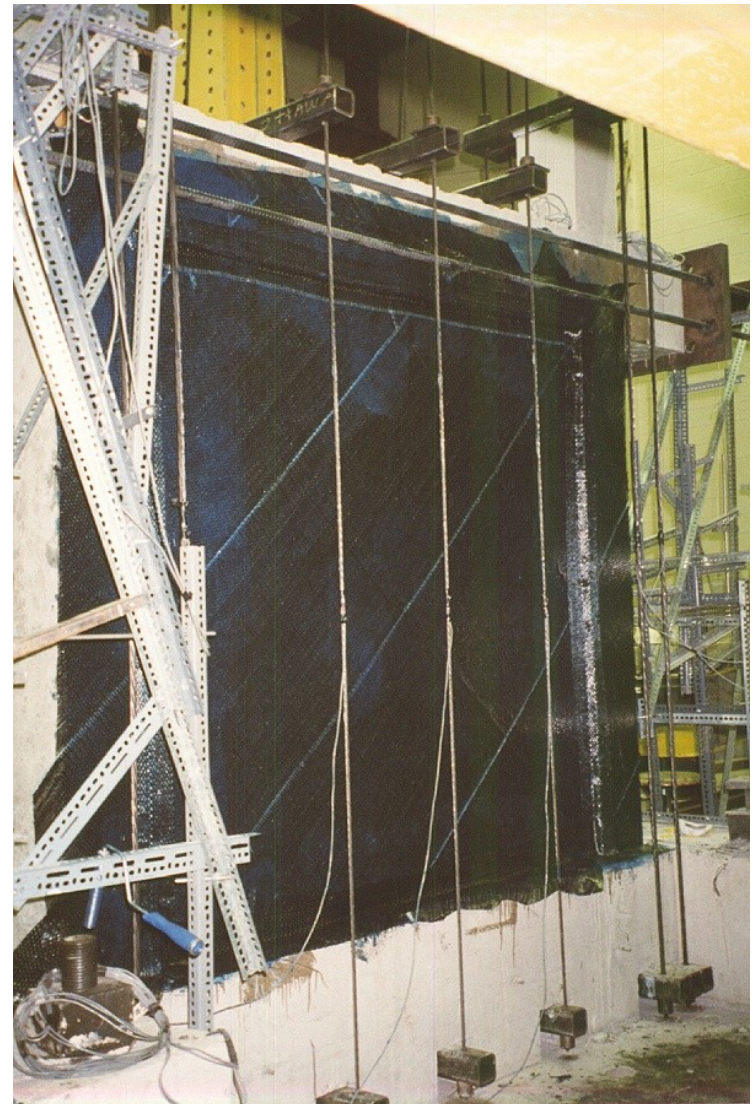
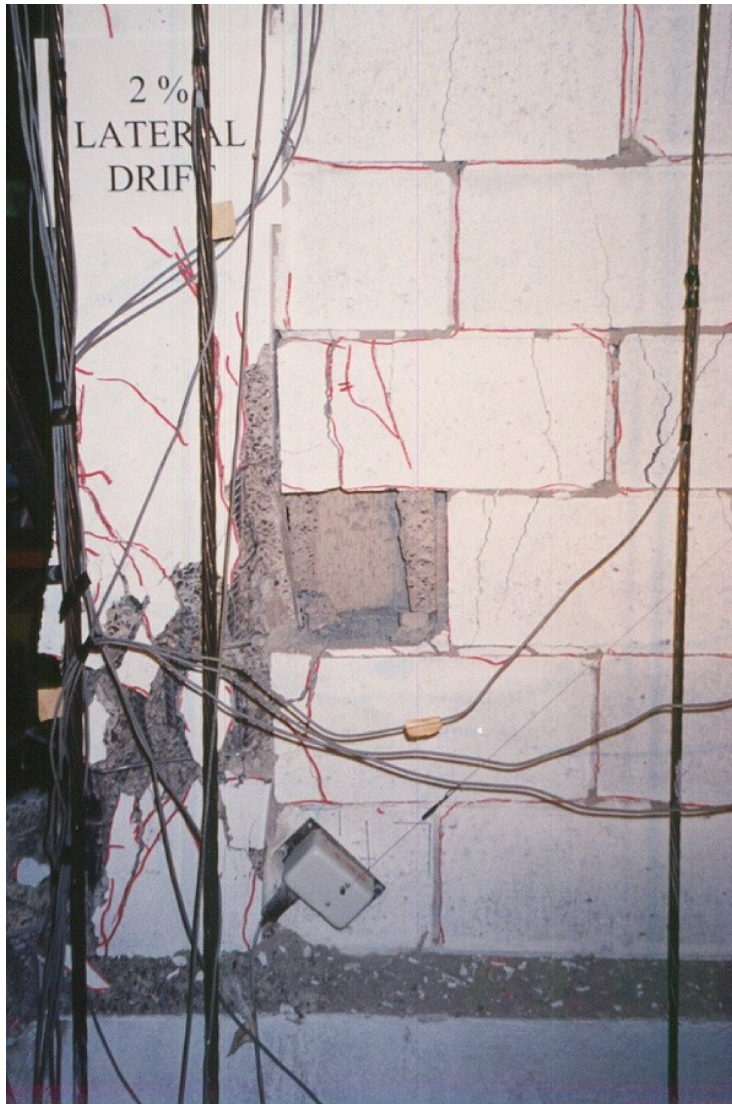
FRP Jacketing



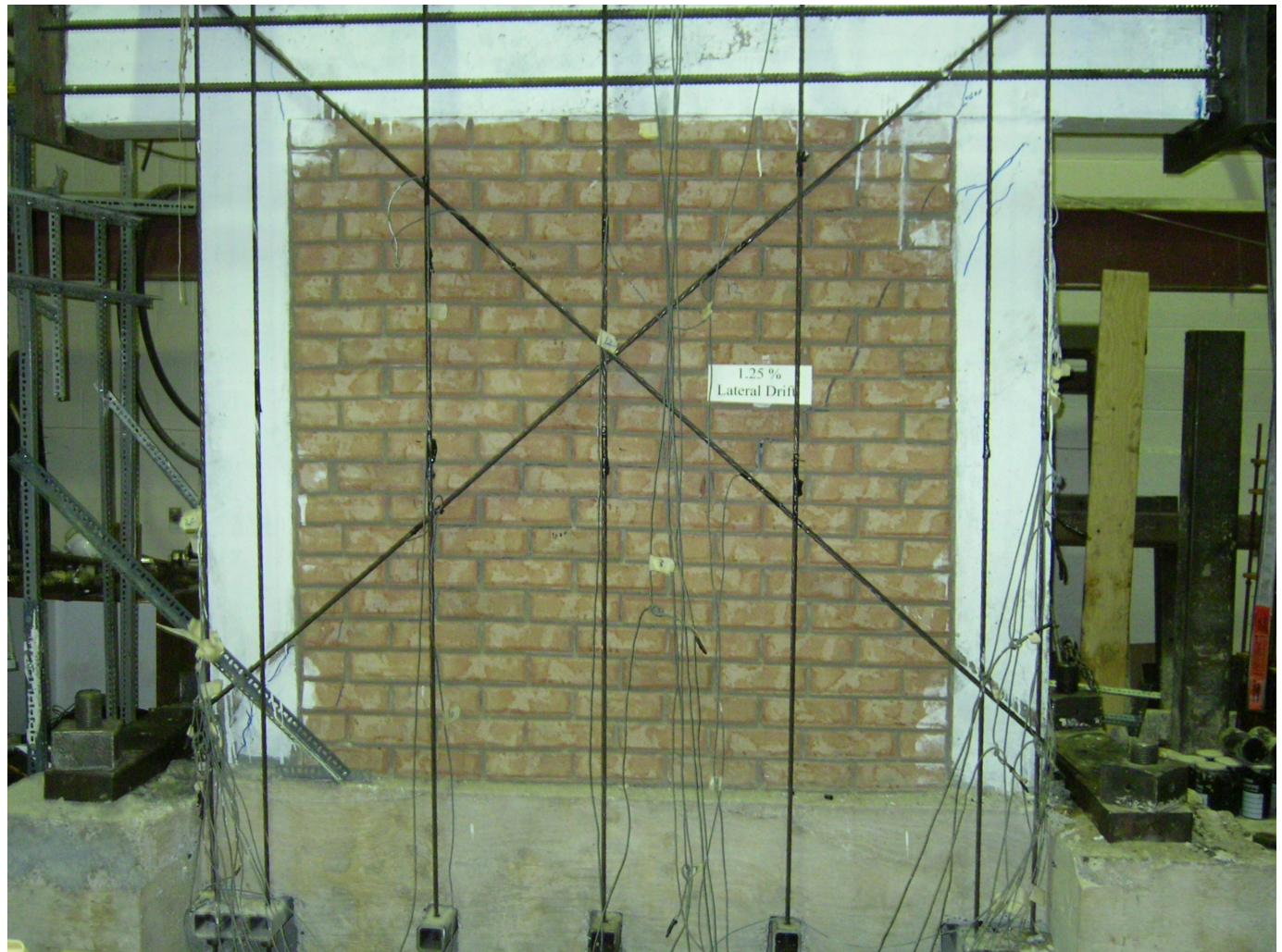
Lateral Bracing as Seismic Retrofit Technology



Lateral Bracing as Seismic Retrofit Technology



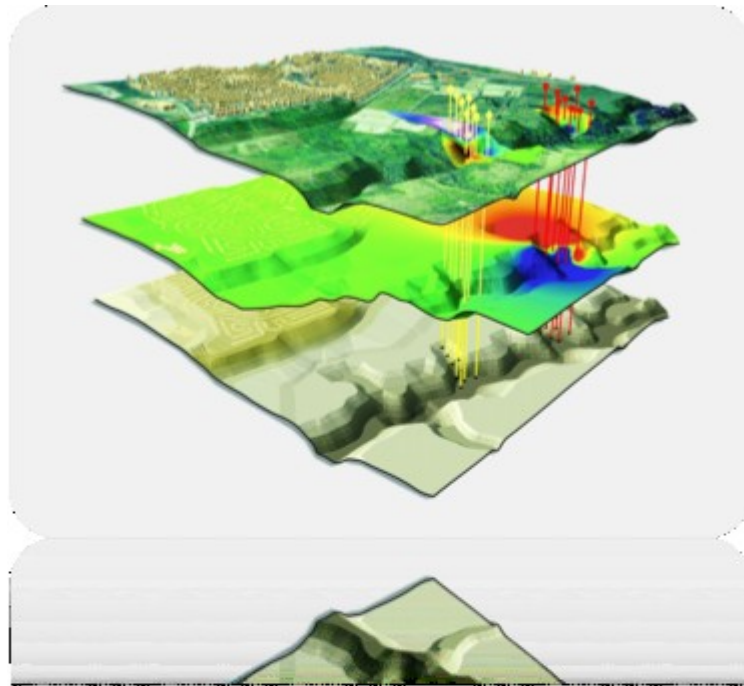
Lateral Bracing as Seismic Retrofit Technology



Lateral Bracing as Seismic Retrofit Technology



Seismic Risk Assessment



arcGisRisk

Building-related information

Building type	CS	Exposure	Occupancy	edu-sch
Number of stories	1	Building use	School	
Vertical irregularity	No	Economic impact	Significant	
Plan irregularity	Yes	Location and site conditions	Soft soil	0
Construction quality	Poor			
Year of construction	1960			

Results

Site Specific Hazard (SSS)
Period (T=0.7s) 647.0 (2.0)

Damage

Building damage index	Building Damage
0.0	Light

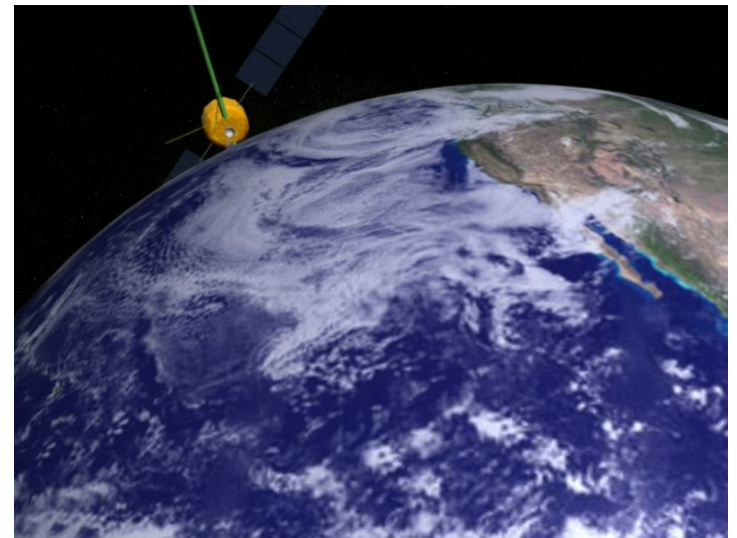
Risk

Building Damage	Light
Exposure/Importance index	0.7
Risk index	0.08
Logarithmic risk index	Marginal

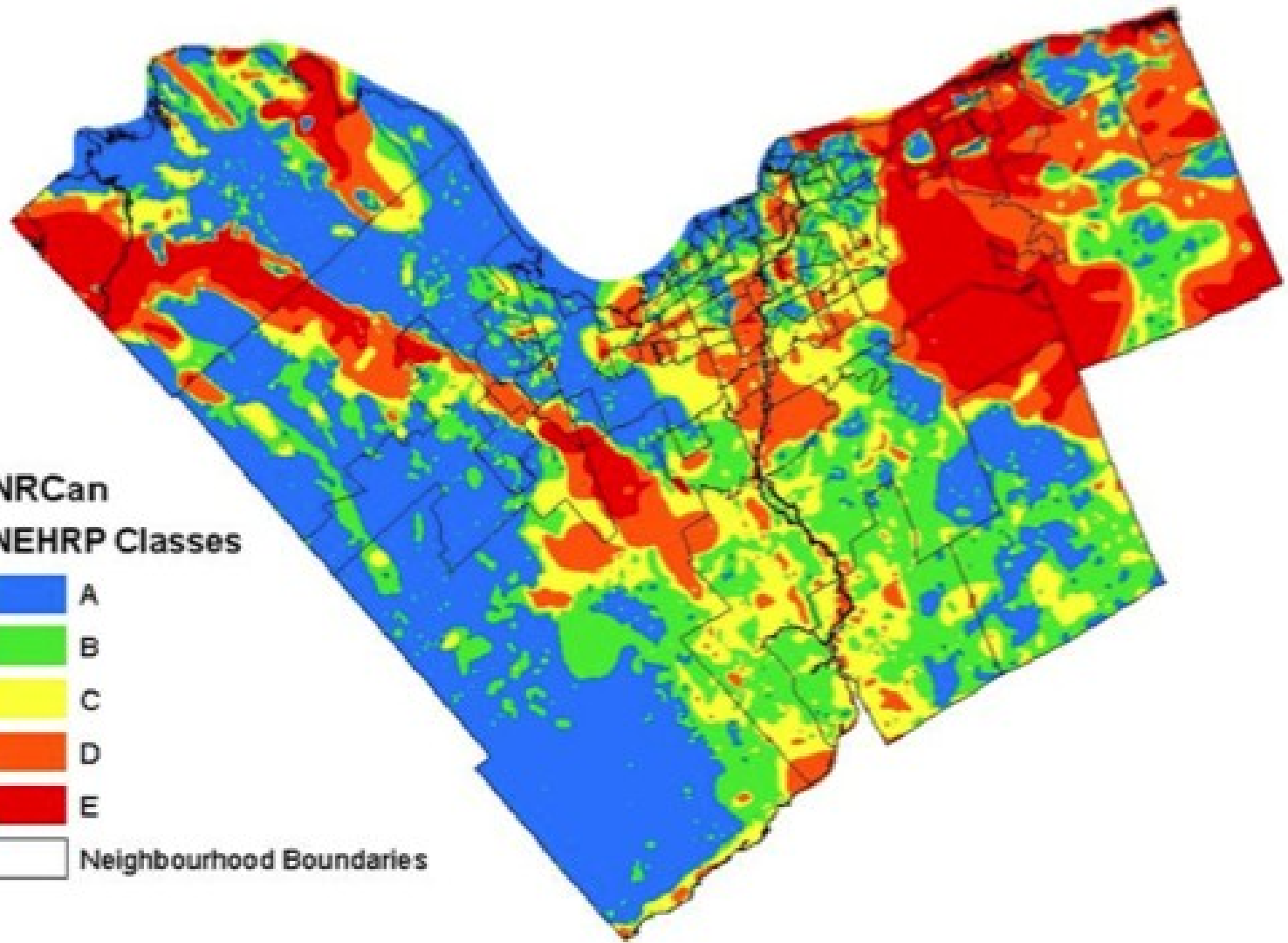
Add to Map Close

WGS 1984 EPSG:4326

Coordinate system: EPSG:4326
Units: meters
Scale factor: 1.0



Microzonation for Ottawa





CanRisk

Tier 1 Evaluation

Event information | **Input** | Damage | Risk

Location and relevant location

City:

Soil type:

Building related information

Building type:

Number of stories:

Vertical irregularity:

Plan irregularity:

Construction quality:

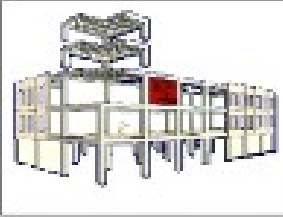
Year of construction:

Height class

Occupancy:

Building use:

Economic impact:



Concrete Moment/Frame

Risk

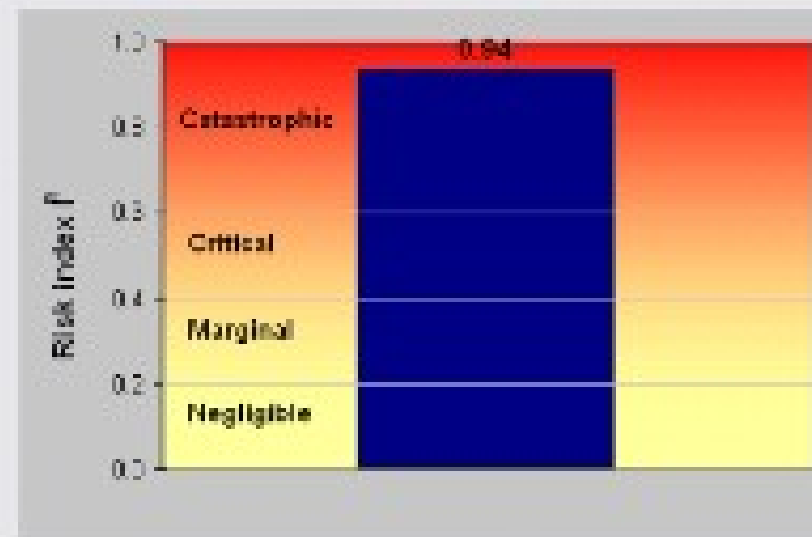
CanRisk

Building damage:

Exposure/Importance Index:

Risk index:

Unquantified risk value:



arcCanRisk



Data Collection for Ottawa



Form1

Building Type	Occupancy Class	Address	Building Name
W1	Single Family Dwelling	221-223 St Andrew St, Ottawa, ON K1N 5G5, Can.	
W2	Mobile Home		
S1L	Multi-Family Dwellings: Duplex		
S1M	Multi-Family Dwellings: 3 - 4 units		
S1H	Multi-Family Dwellings: 5 - 9 units		
S2L	Multi-Family Dwellings: 10 - 19 units		
S2M	Multi-Family Dwellings: 20 - 49 units		
S2H	Multi-Family Dwellings: 50+ units		
S3	Temporary Lodging (Hotel/Motel)		
S4L	Institutional Dormitories (Group Housing/Units)		
S4M	Nursing Homes		
S4H	Retail Trade (Stores)		
S5L	Wholesale Trade (Warehouses)		
S5M	Personal/Repair Services (Service Station/5)		
S5H	Professional/Technical Services (Offices)		
C1L	Banks		
C1M	Hospital		
C1H	Medical Office/Clinics		
C2L	Entertainment & Recreation (Restaurants/Ba		
C2M	Theaters		
C2H	Parking (Garages)		
C3L	Heavy Industrial		
C3M	Light Industrial		
C3H	Food/Drugs/ Chemicals		
PC1	Metal/Mineral Processing		
PC2L	High Technology		
PC2M	Construction (Offices)		
PC2H	Agriculture		
RM1L	Church/Non-Profit		
RM2M	Government General Services (Office)		
RM2L	Government Emergency Response (Police/F		
RM2M	Grade 5 schools		
RM2H	Colleges/Universities		
URML			
URMM			
MH			

Standard Information

Year of Construction: 1940

Number of Stories: 2

Building Area sq.m: 179.650918009028

Occupancy: 0-10

Economic Impact: Negligible

Problems Adjacency: Floor Elevation: Slightly different

Space b/w Adj Bldg: Very far apart

Construction/Design Construction Quality: Extremely poor

Design Quality: Extremely poor

Vertical Irregularity: No

Plan Irregularity: No

Decrease in Resistance Deterioration: Extremely severe

Code Enforcement: High - Code

Previous Quake Damage: Extremely severe

Cancel

OK

Data Collection for Ottawa



Blast Risk



Blast Risk

Bomb blasts generate:

☐ Shock Waves

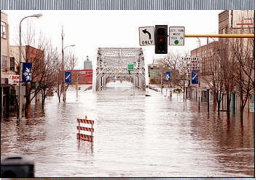
☐ Flying debris (fragmentation)

☐ Fireball effect

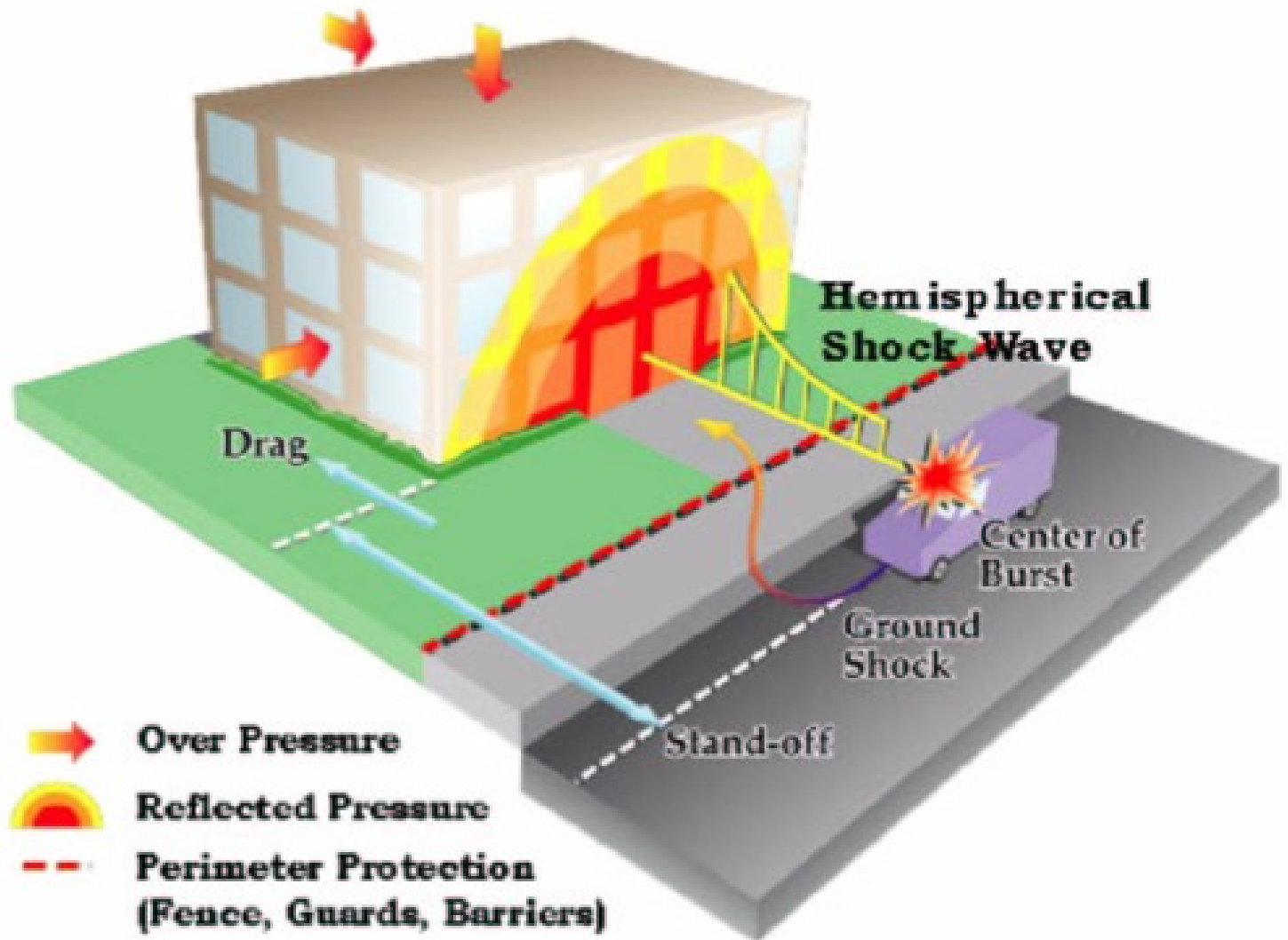


Blast Hazard

- ❑ Car Bombs Pose High Hazard
- ❑ Parcel Bombs Pose Low Hazard
- ❑ The primary parameters that define blast hazard are **charge weight** and **standoff distance**



Shock Waves





To Reduce The Effects of Shock Waves...



An important step is to reduce deformation and/or force demands in structural and non-structural building components. This is achieved through;

☐ proper selection of structural layout and/or structural system

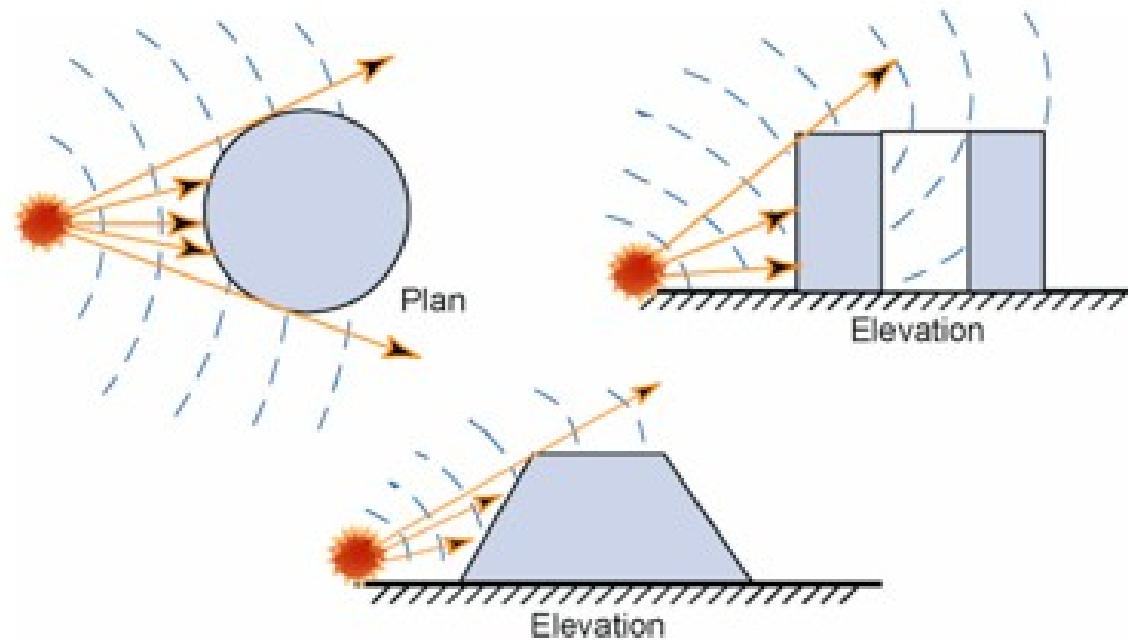
☐ providing sufficient protection by increasing protected standoff distances against external attacks, and providing security and controlled access against internal attacks

Selection of Building Layout

The building shape and layout should be selected to minimize the effects of blast loading. Re-entrant corners and overhangs are likely to trap shock wave and amplify the effect of blast. The reflected pressure on the surface of a circular building is less intense than on a flat building. When curved surfaces are used, convex shapes are preferred over concave shapes.



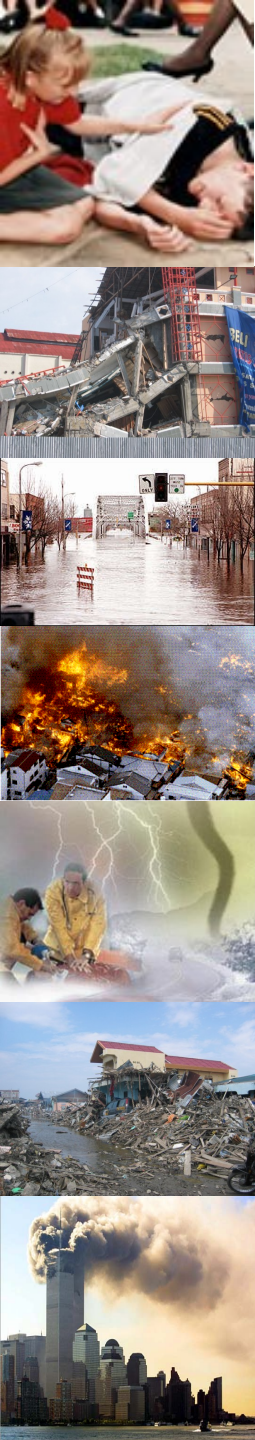
Selection of Building Layout



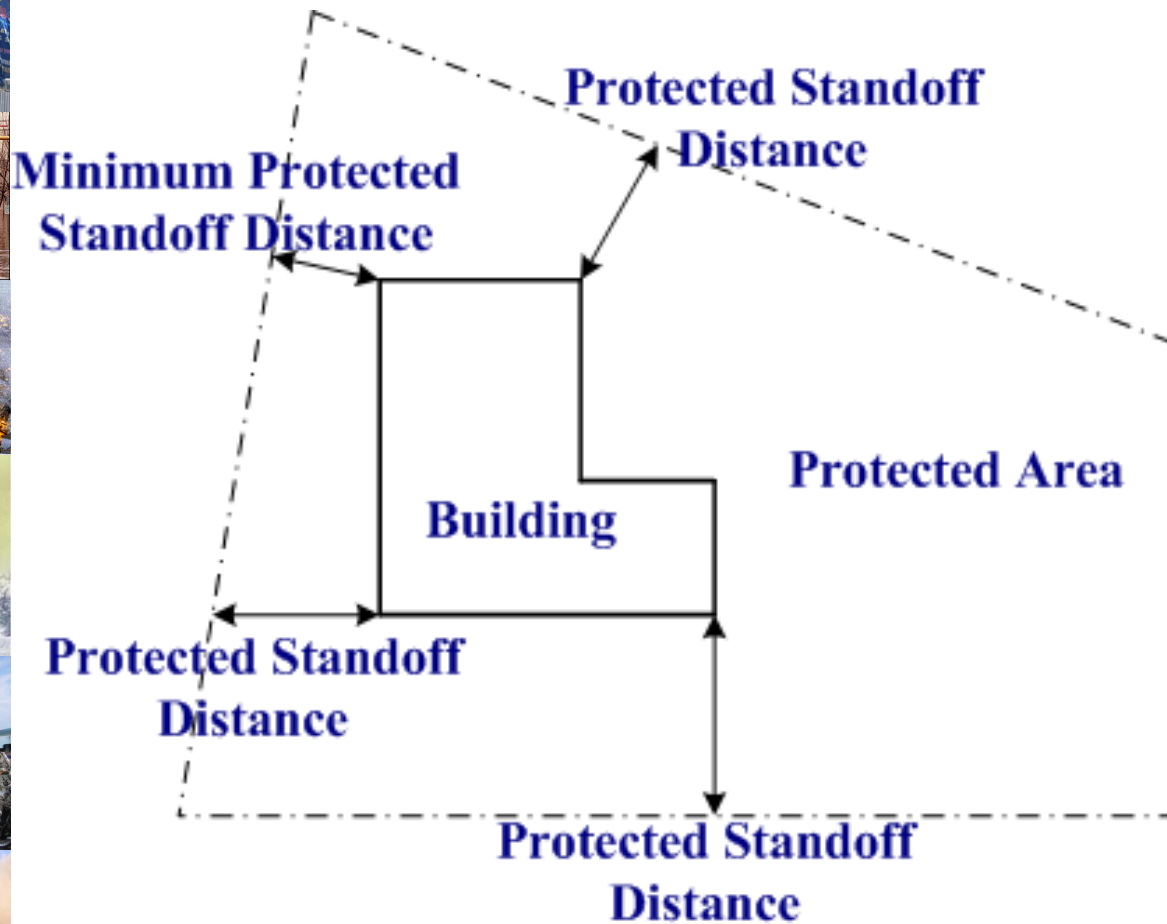
SHAPES THAT DISSIPATE AIR BLAST



SHAPES THAT ACCENTUATE AIR BLAST



Standoff Distance





Standoff Distance

Construction Type	Minimum Protected Standoff Distance in Meters		
	Level of Protection		
	Low	Medium	High
Monolithic reinforced concrete construction	8	10	30
Precast concrete construction	16	30	50
Steel construction with rigid frames	8.0	10	30
Lightweight steel framed structures (i.e., Butler style buildings, etc)	16	30	50
Reinforced masonry walls with steel or reinforced concrete frame	8	10	30
Unreinforced masonry bearing walls	16	30	87
Timber frame construction	28	36	108

Selection of Structural Type and Material

- ❑ Cast-in-place reinforced concrete is the structural system preferred for blast-resistant construction. This is the material and structural type used for military bunkers. The military has performed extensive research and testing of its performance



Selection of Structural Type and Material

- ❑ Lightweight construction is unsuitable for providing air-blast resistance. For example, a building with steel deck roof construction will have little air-blast resistance. The performance of a conventional steel frame with concrete fill over metal deck depends on the connection details.

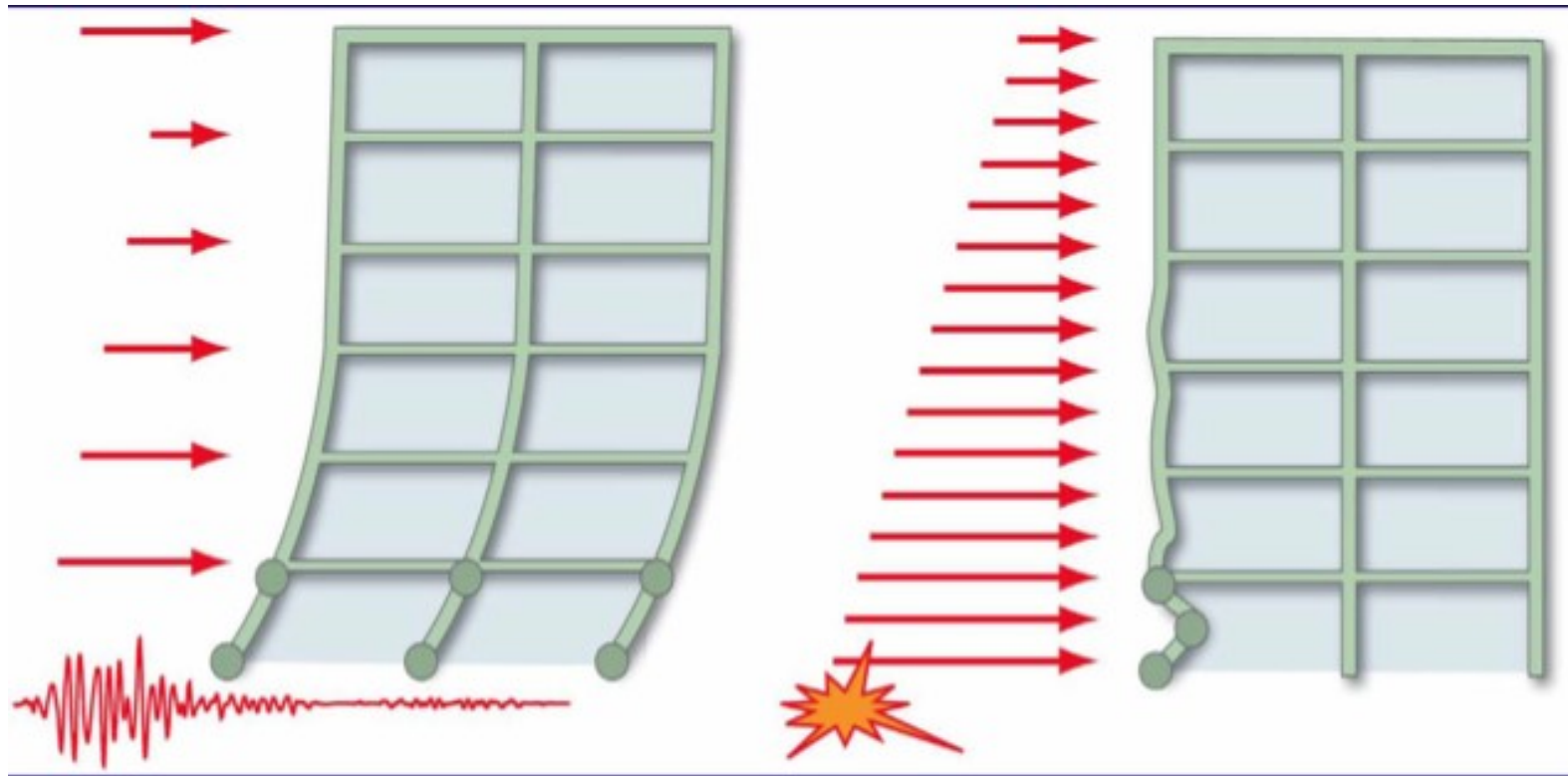


Selection of Structural Type and Material

- ❑ Unreinforced masonry provides some resistance at far standoff distances due to its mass. However, it does not possess any ductility, and fail catastrophically beyond the elastic limit.
- ❑ Reinforced masonry may show improved behaviour. However, it does not allow sufficient continuity, ductility and redundancy



Seismic Versus Blast Loading

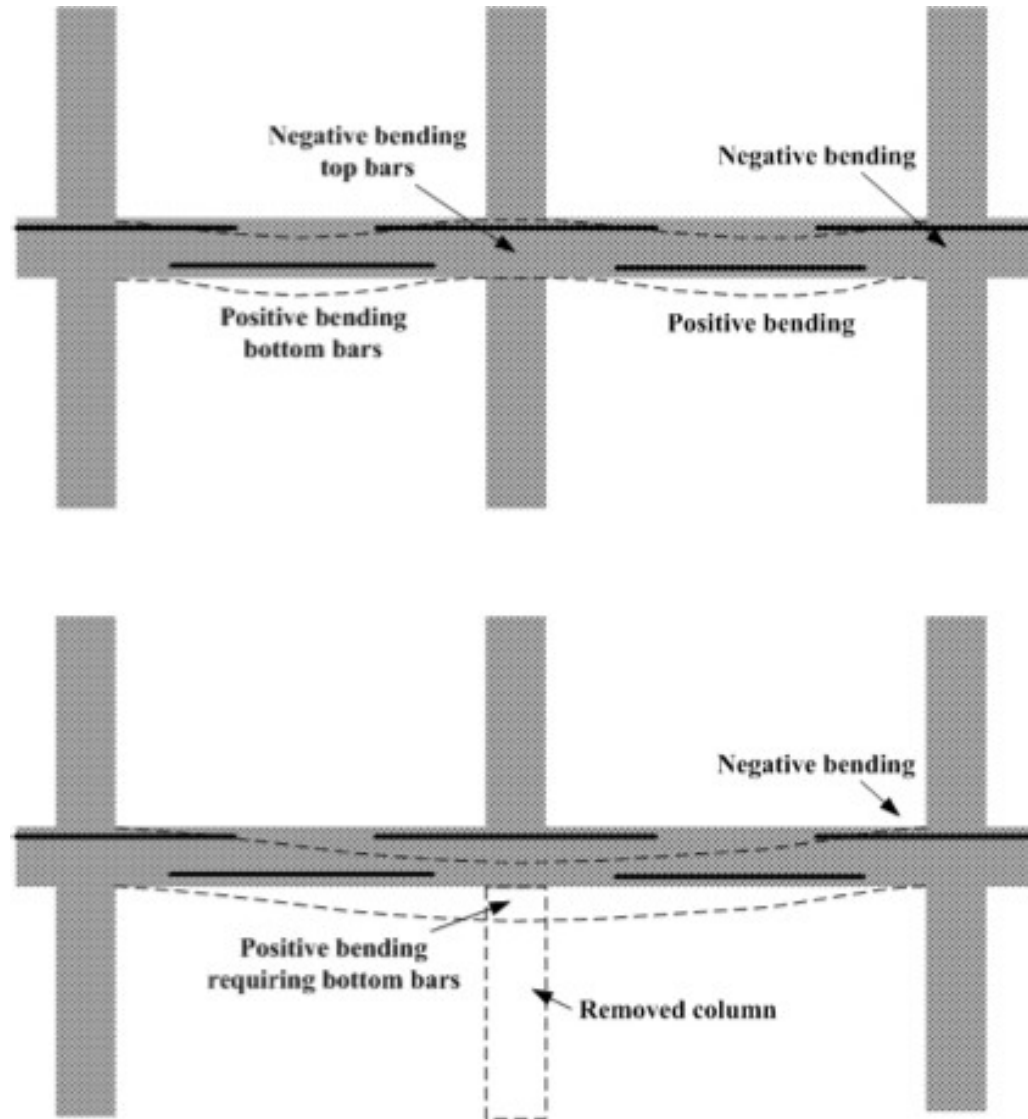


Structural Damage Due to Blast

- ❑ Element Damage (near the exposed surface)
- ❑ Progressive collapse
- ❑ Global response (not likely to cause damage unless very light structure)



Progressive Collapse



Progressive Collapse





Test Area: 2 m x 2 m

Shock Tube



12.12.2008

Shock Tube



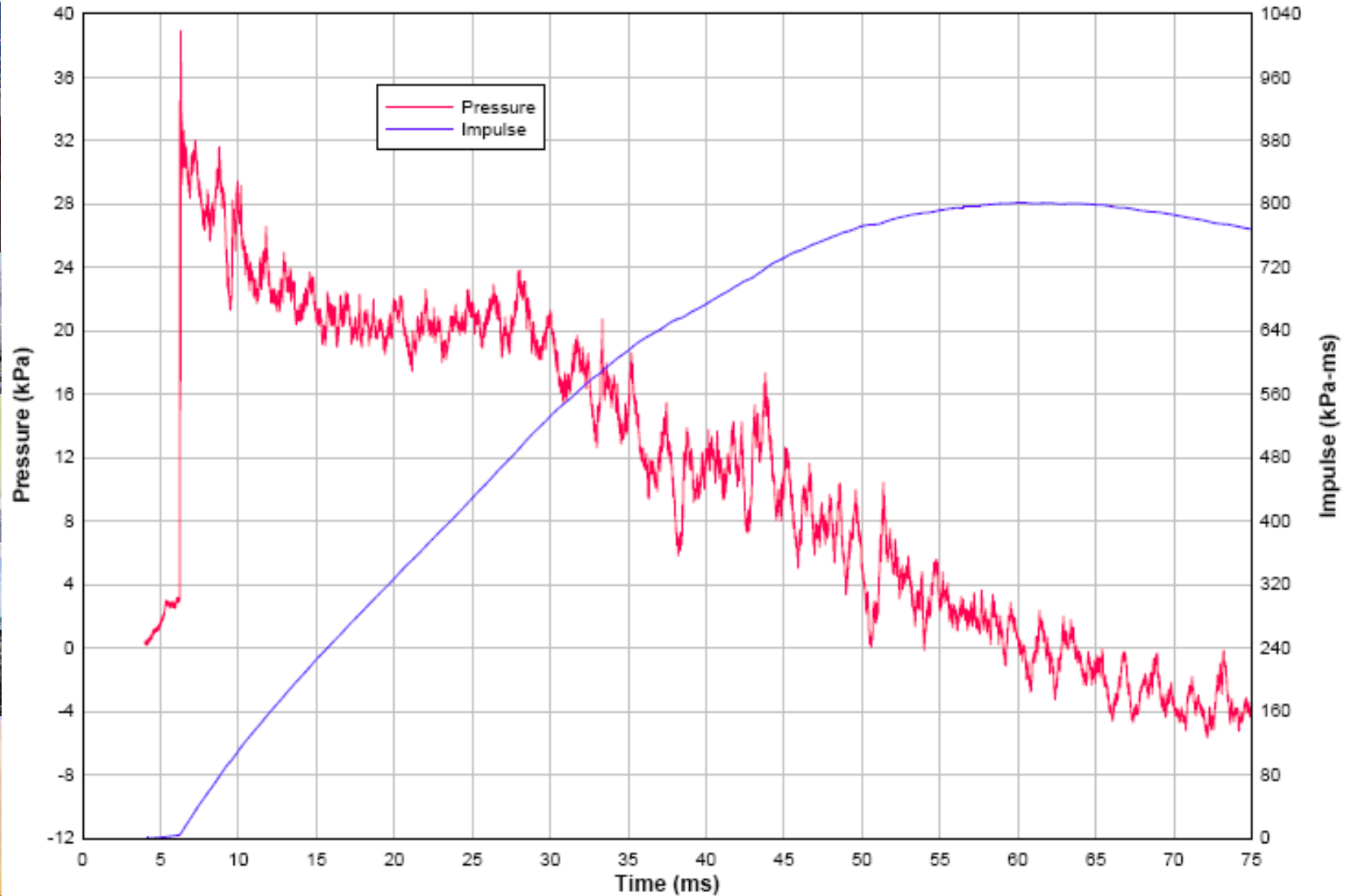


Example Shock Wave

Test 3

173 kPa Driver

4.88 m Driver



Shock Tube Testing - Slab



Shock Tube Testing - Timber



Shock Tube Testing - Columns



Shock Tube Testing - Columns





Conclusions...

Questions or Comments?