Dynamics of Urban Seismic Risk

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Question

- How is urban seismic risk changing?
  - total risk
  - distribution of risk
  - rate of change

Stress buildup
& transfer

Population growth
More high-vulnerability populations
More structures at risk
Greater interdependency, . . .

$$\text{Risk} = \text{Hazard} \times \frac{\text{Vulnerability}}{\text{Resilience}}$$

Stress release

Engineering advances
Better codes, construction practice
Greater awareness
Higher incomes, insurance, . . .

probability

consequences

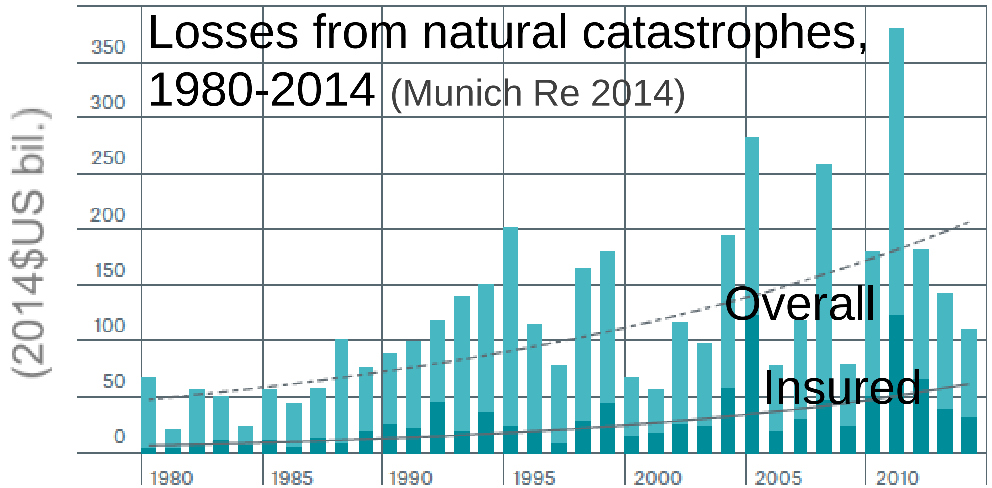
Outline

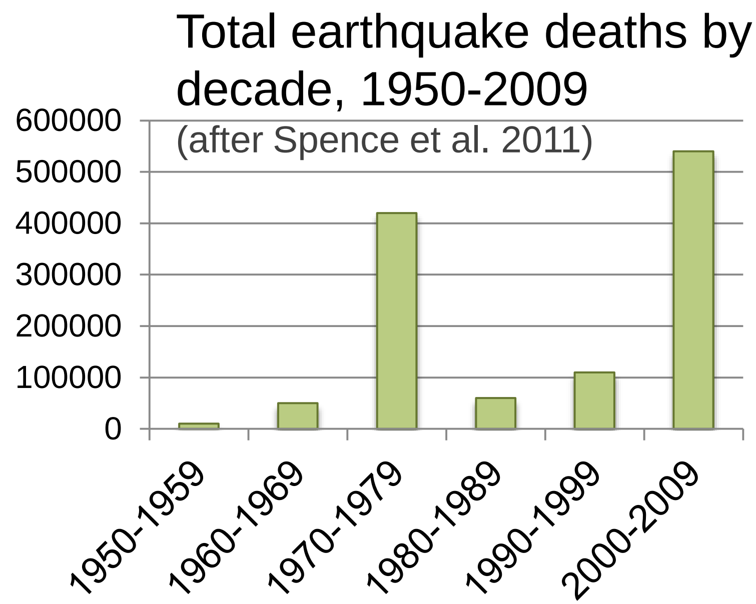
- What evidence do we have on how seismic risk is changing?
- What can models tell us?
  - Case study of Vancouver, Canada
- How might findings differ across cities?
- Why are risk dynamics important?

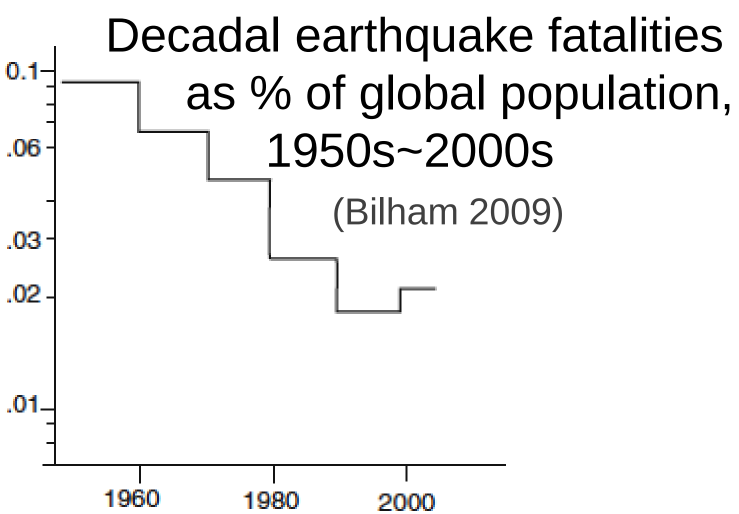
Current Evidence

- Loss trends
- Risk factor trends
- Repeat events

Earthquake Loss Trends

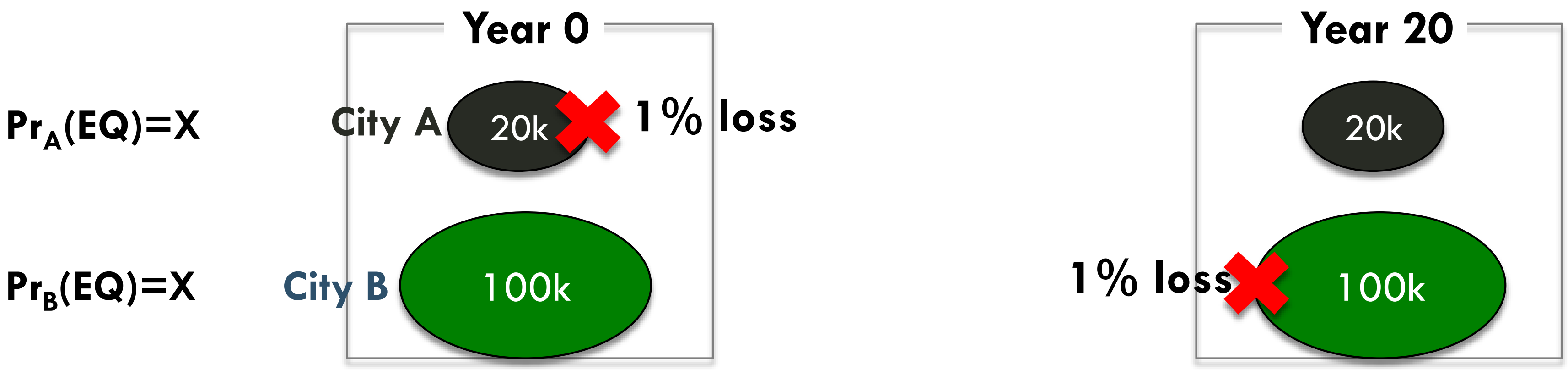


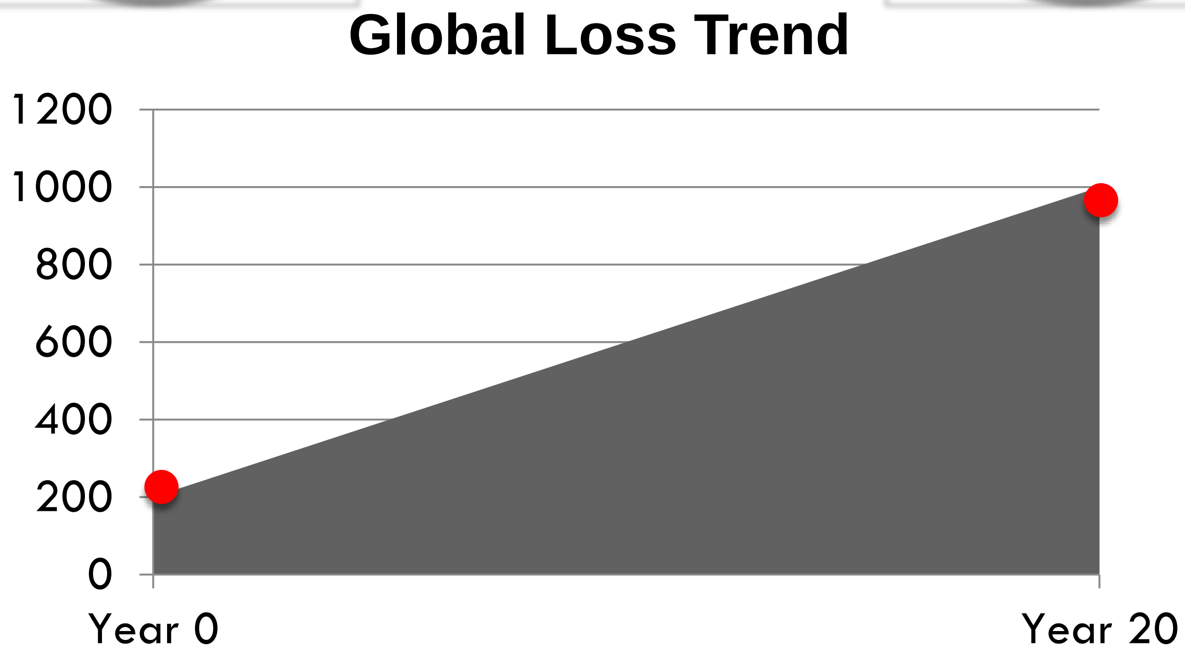




"As opposed to widely publicised claims of rapidly increasing loss trends, we find decreasing trends for both casualties and [economic] losses, when population growth and urbanisation are accounted for." (Scawthorn, 2011)

Global v. Local Trends





Global trends do not necessarily translate to local trends

Risk Factor Trends

- **Increasing Risk**
  - **Suburban sprawl** encroaching on hazard-prone areas (NRC 2006)
  - **Federal policies** encouraging risk reduction and sharing rather than risk avoidance (Burby et al. 1999)
    - Development encouraged by false sense of security
  - **Planned land use** – Los Angeles (Olshanky and Wu 2002)
  - **Population change** - coastal migration, aging, race/ethnic composition, income & housing profiles (Cutter et al. 2007)
- **Decreasing Risk**
  - **Improved building codes** – balance out building inventory accumulation; North Carolina hurricanes (Jain and Davidson 2007)

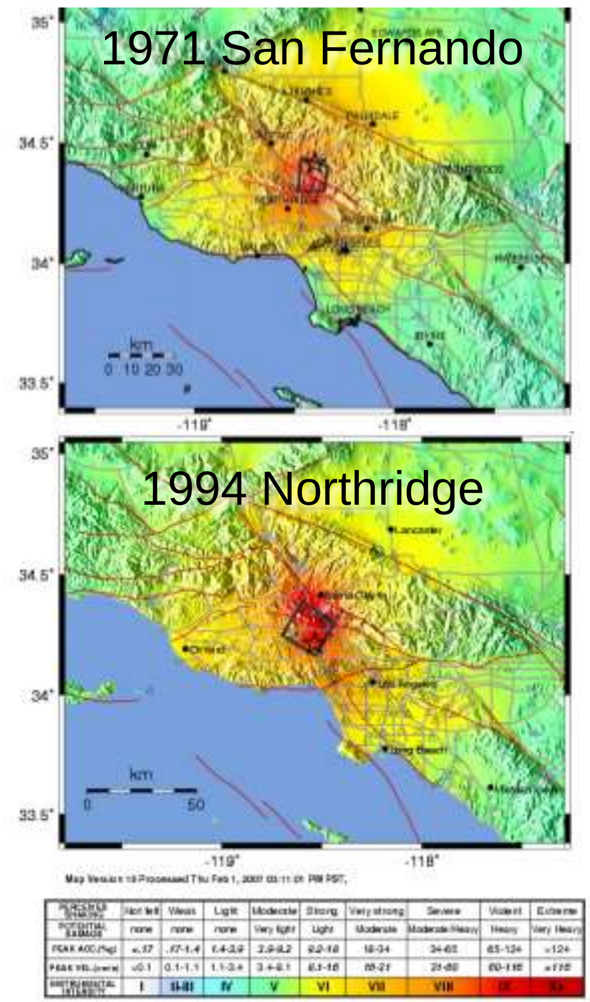
“Repeat” Events

	1971 San Fernando	1994 Northridge
Magnitude, depth	M_w 6.6 8.4 km	M_w 6.7 18.4 km
Population, L.A. County	7.0 million (in 1970)	8.9 million (in 1990)
Casualties	58 deaths, 2000 injuries	57 deaths, 9000+ injuries
Direct losses (1994$)	1.8 billion	24~44 billion

Sources: SCEC; US Census; CA OES; Eguchi et al. 1998

Codes, retrofits, professional awareness since San Fernando did contribute significantly to reducing losses in Northridge (Olshansky 2001)

(earthquake.usgs.gov)



Vancouver Case Study

- Loss model (casualties)
- Retrospective analysis (1971~2006) and forecast (2041)

Student research assistants: M. Gregorian, L. Yumagulova, W. Tse, M. de Ruiter

Earthquake Loss Model

Buildings

- Census (pop., dwellings)
- Ventura et al. (2005) (structural type)

Damage

- Ventura et al. (2005)
- BC buildings
- local engineers
- MMI

Casualties

- HAZUS-MH
- Deaths and serious injuries

Buildings

Allocation of Dwelling Units Across Structural Type Classes

Occupancy type & vintage[2]	**Structural Type**[3]									
	Wood frame			Masonry		Concrete frame				Mobile
	WLFR	WPB	WLFLR	URM-LR	URM-MR	CFIW	CFCW-LR	CFCW-MR	CFCW-HR	MH
Single-detached house - 1946 to 1960	80%	20%								
- all other vintages	100%									
Apartment 5+ storeys *- medium-rise* - pre-1945					40%	45%		15%		
- post-1945								100%		
- high-rise									100%	
Movable dwelling										100%
Other dwelling *Semi-detached house*	100%									
Row house	100%									
Apartment, duplex	100%									
Apartment <5 storeys - pre-1970			90%	10%						
- 1971-2006			90%				10%			
Other single-attached house	100%									

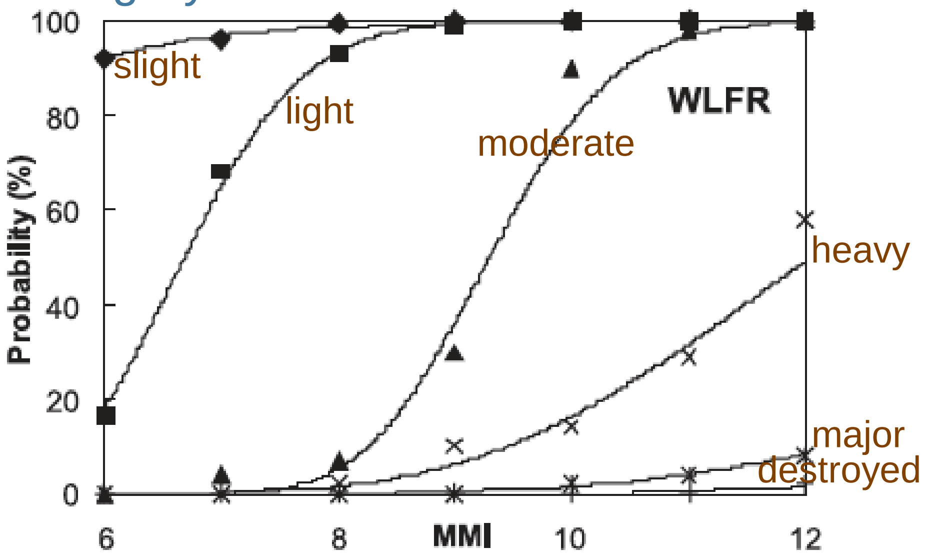
Notes: Based on Ventura et al. (2005). WLFR= wood light-frame residential, WPB= wood post and beam, WLFLR= wood light frame low-rise residential, URM-LR (-MR)= unreinforced masonry low-rise (medium-rise), CFIW= concrete frame with infill walls, CFCW-LR (-MR, -HR)= concrete frame with concrete walls low-rise (medium-rise, high-rise), MH= mobilehome.

Damage Model

Source:

Ventura, C.E., et al. 2005. "Regional Seismic Risk in British Columbia – Classification of Buildings and Development of Damage Probability Functions," *Canadian Journal of Civil Engineering* 32: 372-387.

Fragility Curve for WLFR Construction



MMI Scale for VI and Higher

MMI	Description of effects
VI	Felt by all, many frightened; some heavy furniture moved; a few instances of fallen plaster; damage slight
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built structures; some chimneys broken
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures; fall of chimneys, factory stacks, columns, walls; heavy furniture overturned
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings, with partial collapse; buildings shifted off foundations
X	Some well-built wooden structures destroyed; most masonry and frame structures with foundations destroyed; rails bent
XI	Few, if any, masonry structures remain standing; bridges destroyed; rails bent greatly
XII	Damage total; lines of sight and level distorted; objects thrown into air

Casualties Model

Table 13.5: Indoor Casualty Rates by Model Building Type for Extensive Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	1	0.1	0.001	0.001
2	W2	1	0.1	0.001	0.001
3	S1L	1	0.1	0.001	0.001
4	S1M	1	0.1	0.001	0.001
5	S1H	1	0.1	0.001	0.001
6	S2L	1	0.1	0.001	0.001
7	S2M	1	0.1	0.001	0.001
8	S2H	1	0.1	0.001	0.001
9	S3	1	0.1	0.001	0.001
10	S4L	1	0.1	0.001	0.001
11	S4M	1	0.1	0.001	0.001
12	S4H	1	0.1	0.001	0.001
13	S5L	1	0.1	0.001	0.001
14	S5M	1	0.1	0.001	0.001
15	S5H	1	0.1	0.001	0.001
16	C1L	1	0.1	0.001	0.001

Deaths

Life threatening injuries

Non-life threatening injuries requiring medical attention (e.g., x-ray)

Source:

HAZUS-MH (Earthquake Model)

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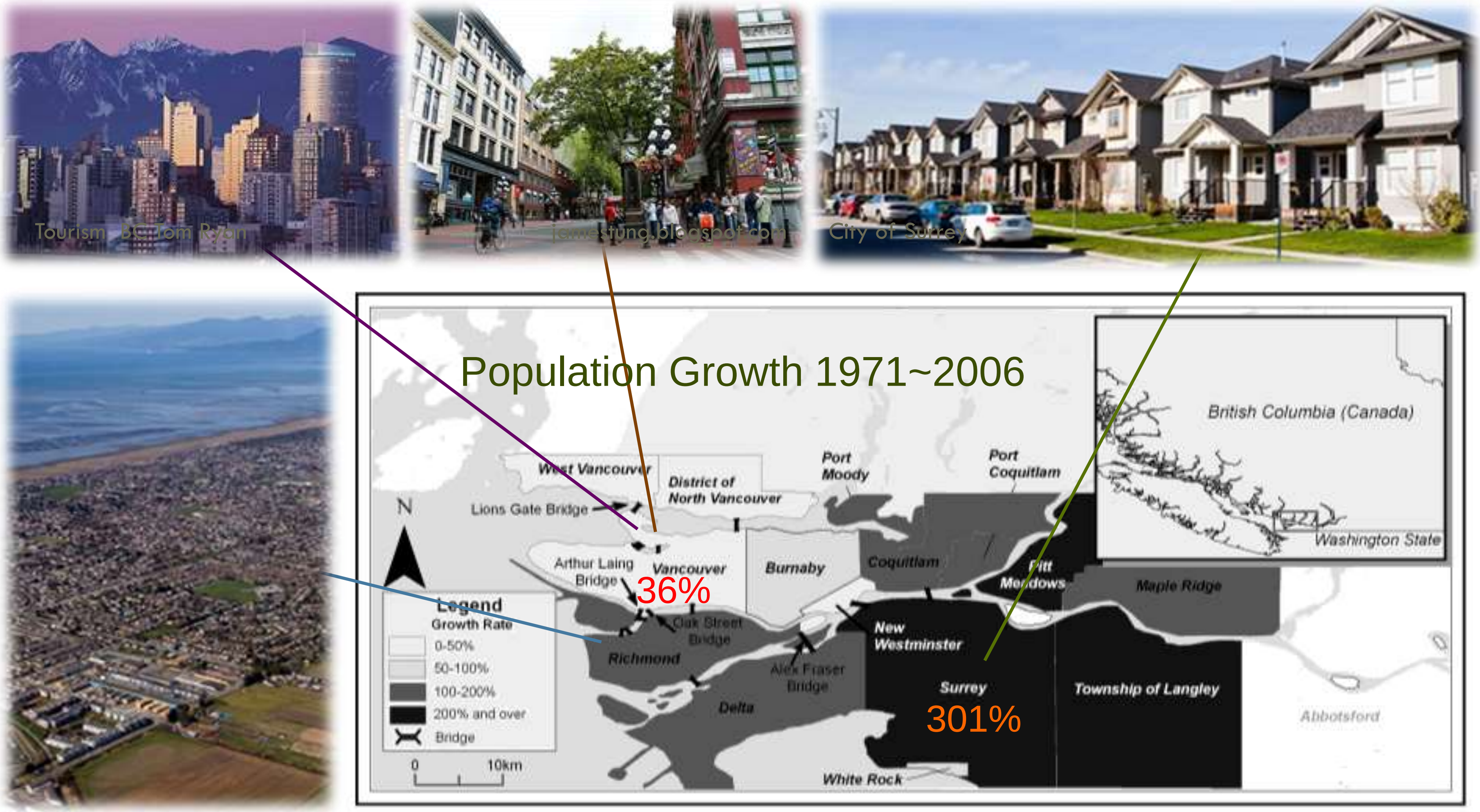
Spatial Change



Building Stock Changes

Construction

	1971	2006
Population (millions)	1.08	2.12
- in masonry buildings	2.8% (31,000)	0.9% (18,900)
- in concrete buildings	6.7%	11.4%
Dwellings	256,000	803,000
- single-detached houses	43.8%	35.6%

(Census; Ventura et al. 2005)

Codes

- NBCC adopted in 1973 (seismic provisions by Vancouver in 1965); revisions in 1985, 1999, 2005 (Finn 2004)
- "...most buildings constructed in British Columbia **prior to the 1970s** have limited resistance to seismic effects." (Ventura et al. 2005)
- Currently 1/3 of housing units in metro area built before 1971

Earthquake Loss Model

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- Census data – pros and cons
- Modeling challenges and solutions
- Single scenario
- Consistent assumptions for 1971 and 2006 models
- Uncertainty and errors

Scenario Event

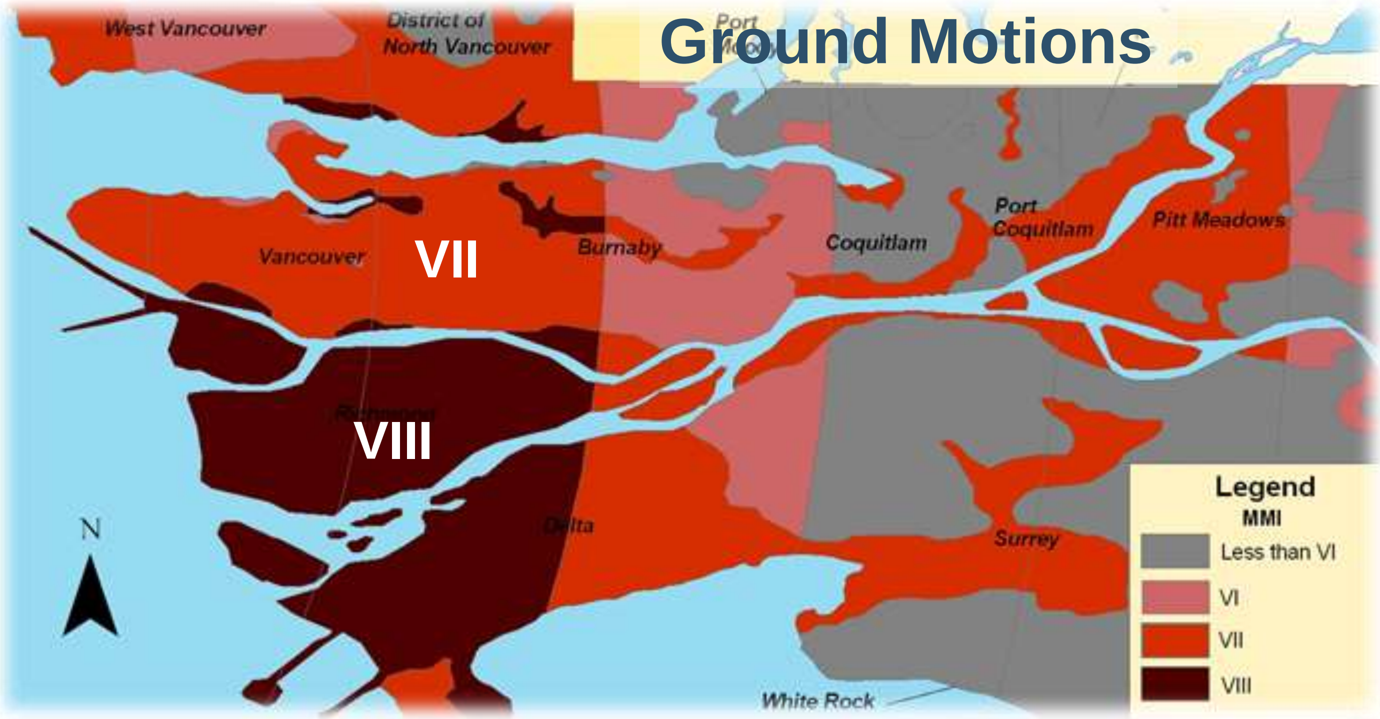
M7.3

Strait of Georgia

Subcrustal earthquake

4am

BC PEP (EMBC)



- Similar to 1946 Vancouver Island earthquake
- Strong but realistic event
- Same scenario for 1971 and 2006
- Residential casualties only

Damage and Casualties

	1971	2006
Deaths	35	22
Fatality rate (deaths per 1,000)	0.032	0.010
Serious injuries	51	38
Serious injury rate (inj. per 1,000)	0.047	0.018
Population in significantly damaged dwellings	31,200 2.9%	50,700 2.4%

How realistic? Compare:

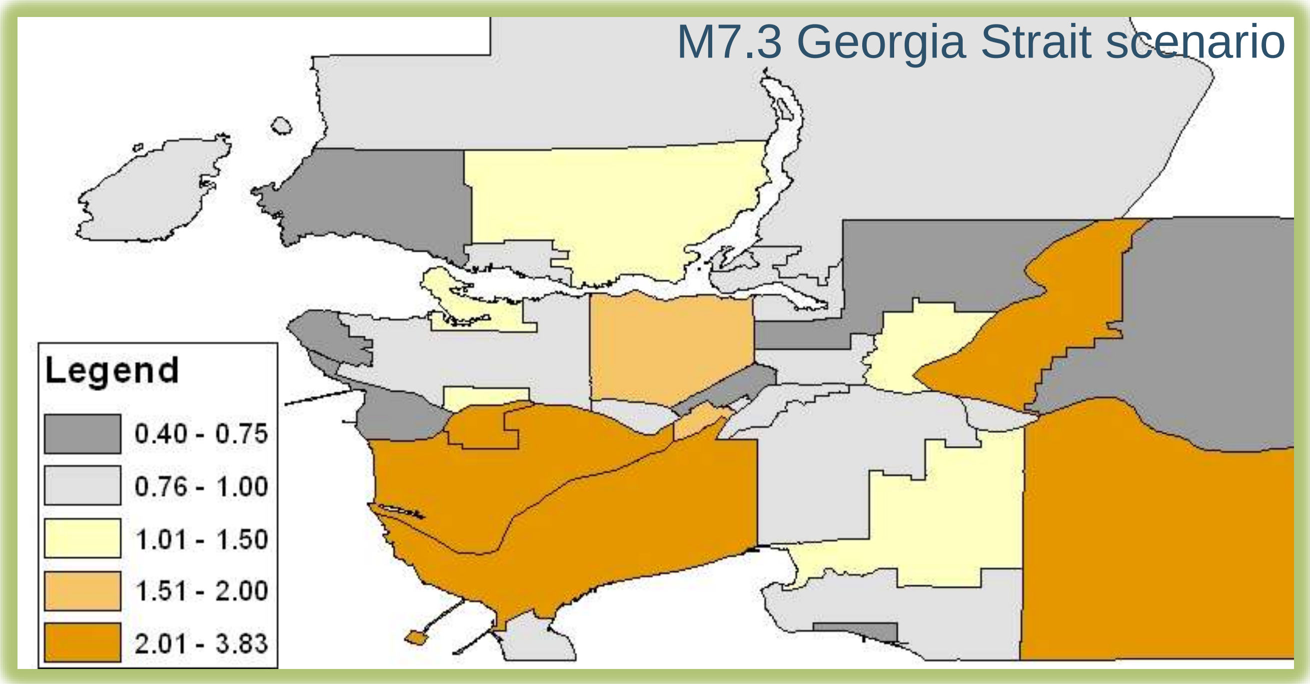
- Northridge Earthquake
- Other models (Ventura; NRCan)

Spatial Differentials

Population in Significantly Damaged Buildings
(Ratio 2006: 1971)

Risk decreased

Risk increased



Sensitivity Analysis: Ground Motions

Population in Significantly Damaged Buildings

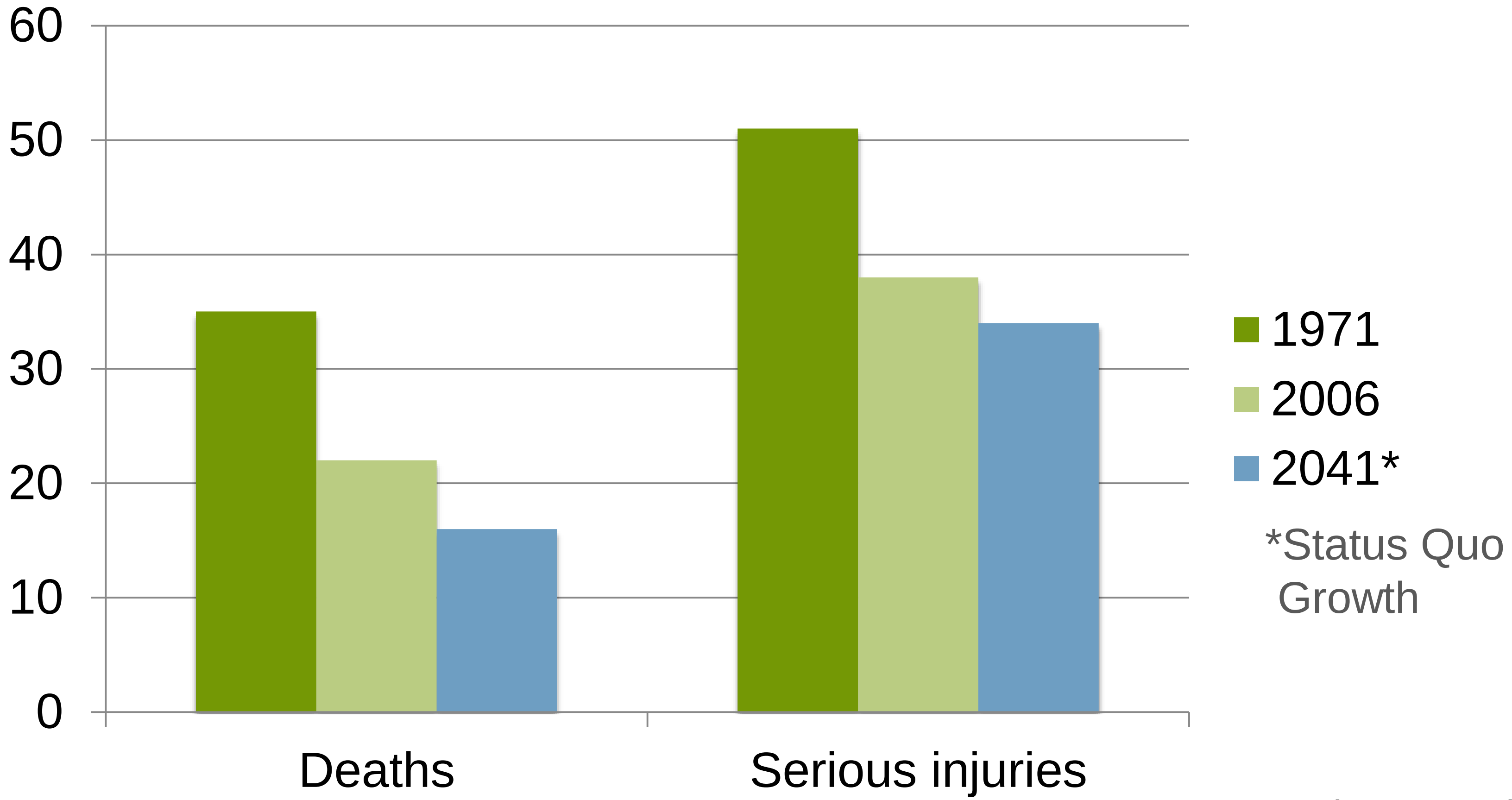
Ground Motion	1971	2006	Ratio 2006:1971
M7.3 scenario	31,200	50,700	1.63

Forecast to 2041

(M7.3 earthquake)

Population 2006~2041: + 1.2 million

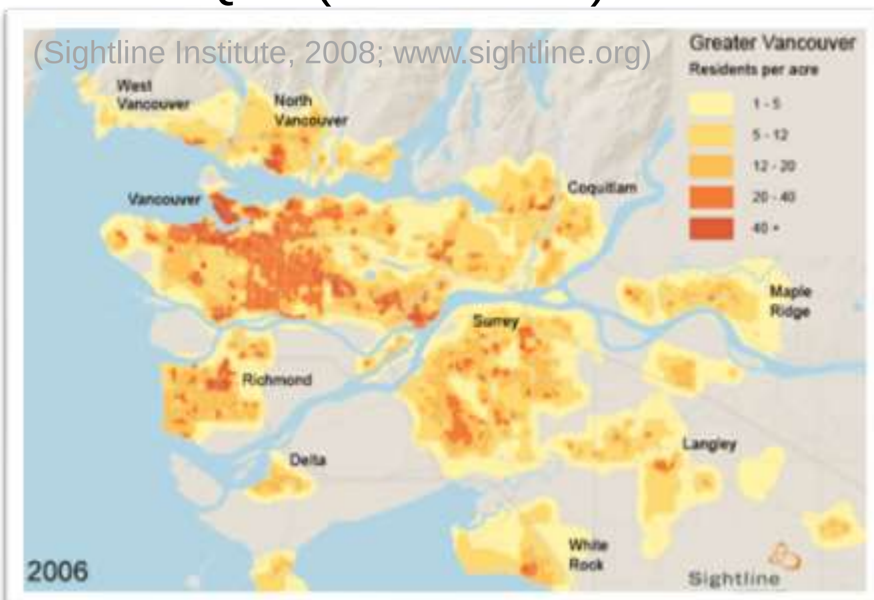
(Metro Vancouver Regional Growth Strategy)



(Tse, 2011)

Land Use Forecasts

Status Quo (distribution) Growth



(Sightline Institute, 2008; www.sightline.org)

Compact Growth

0% single-family dwellings

Sprawled Growth

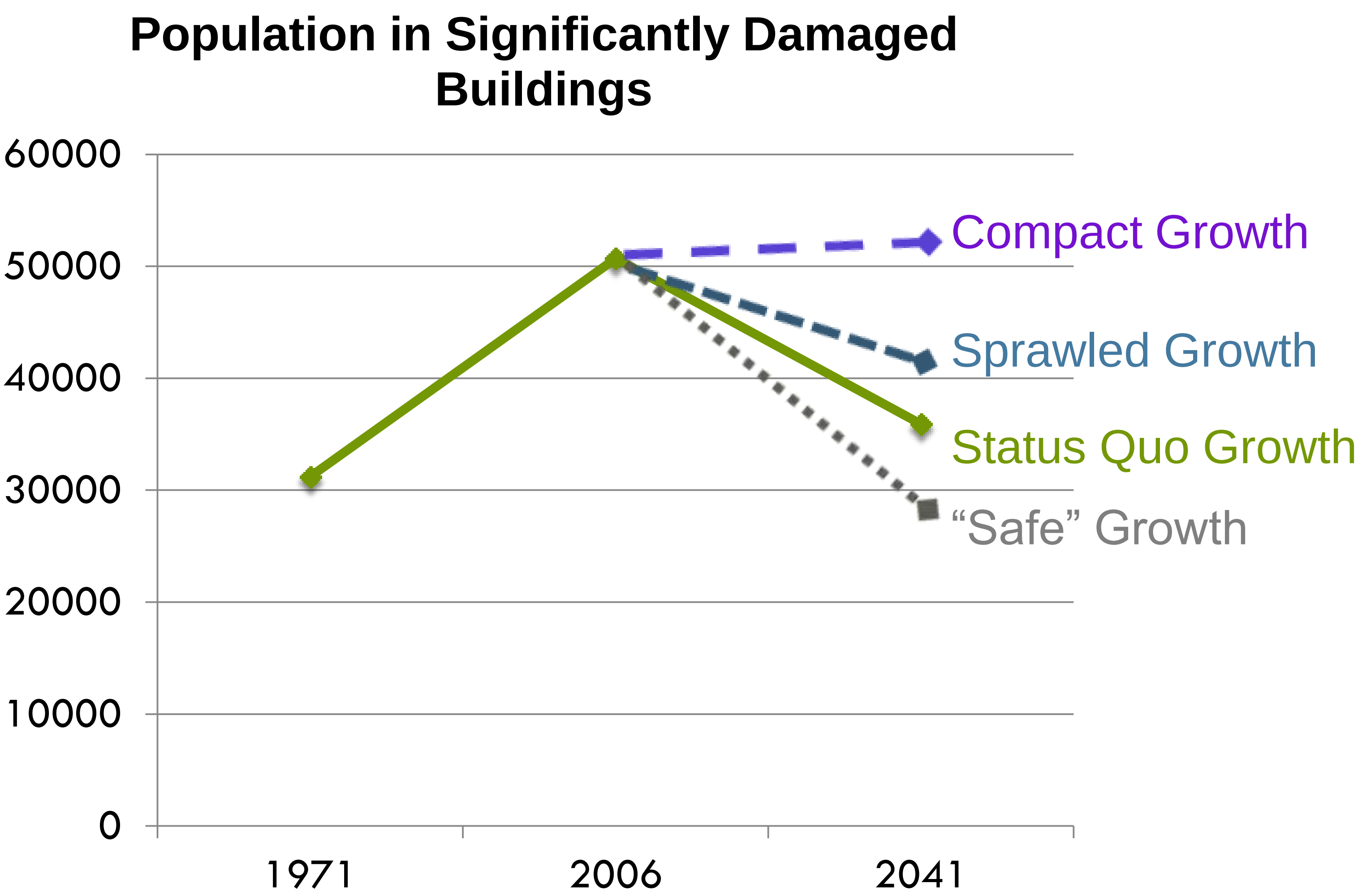
85% SFR

“Safe” Growth

40% SFR

(Tse, 2011)

Sensitivity to Land Use Forecast



(Tse, 2011)

Discussion

Trend more reliable than loss estimate

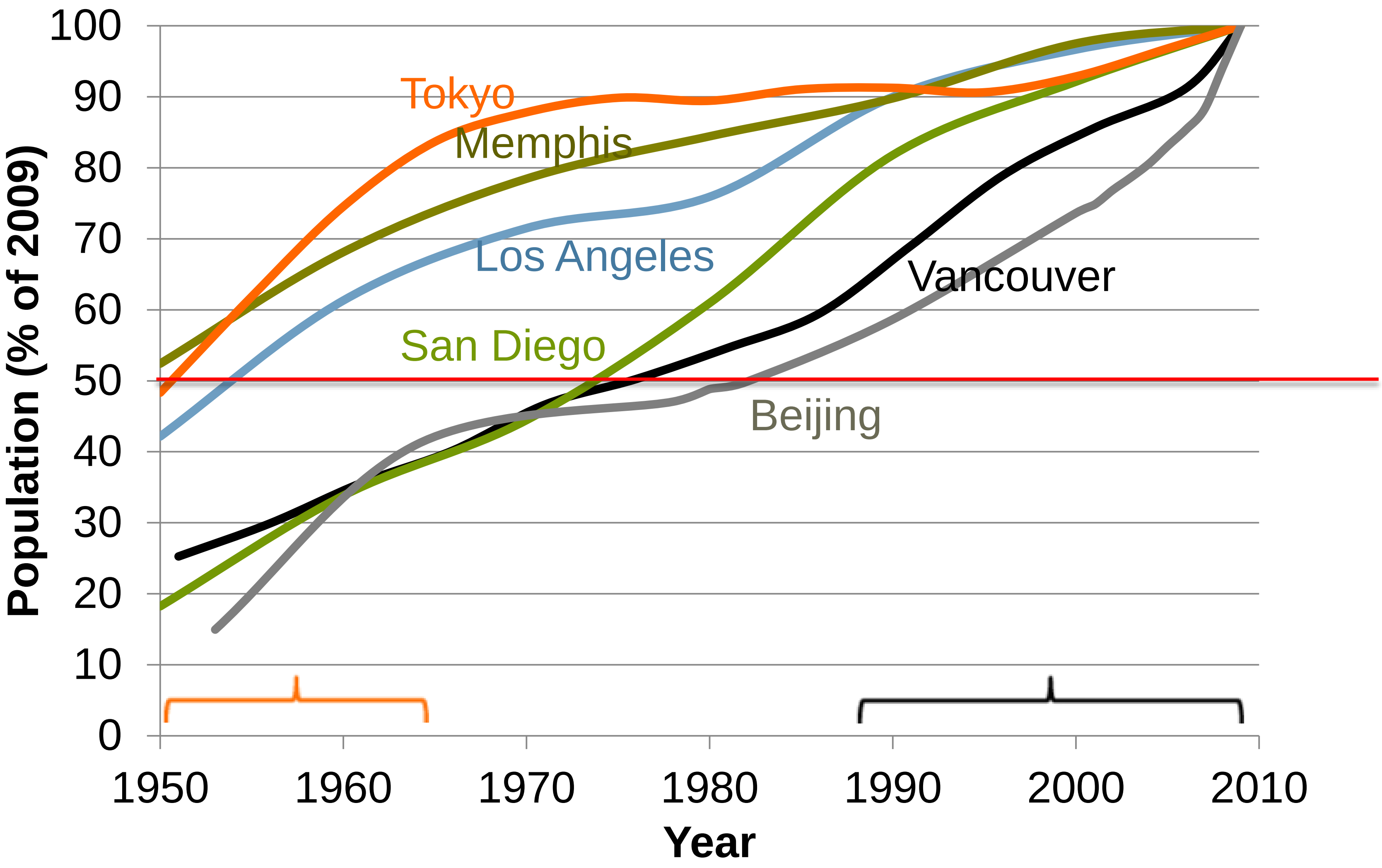
- **Findings**
  - Total casualties: net neutral (slight decrease)
  - Casualty risk per person: reduced (=safer?)
  - Building damage and displaced persons: increased risk
  - In some areas, increased risk
  - Risk decreasing for small earthquakes, increasing for large ones
  - Improvements in earthquake engineering have barely kept up with growth of population at risk
- **Limitations**
  - Single scenario earthquake
  - Residential building damage only
  - Computational and data assumptions
  - Omissions (e.g., code changes)

Conclusions

Can results be generalized to other cities?

Why are risk dynamics important?

Eras of Rapid Growth

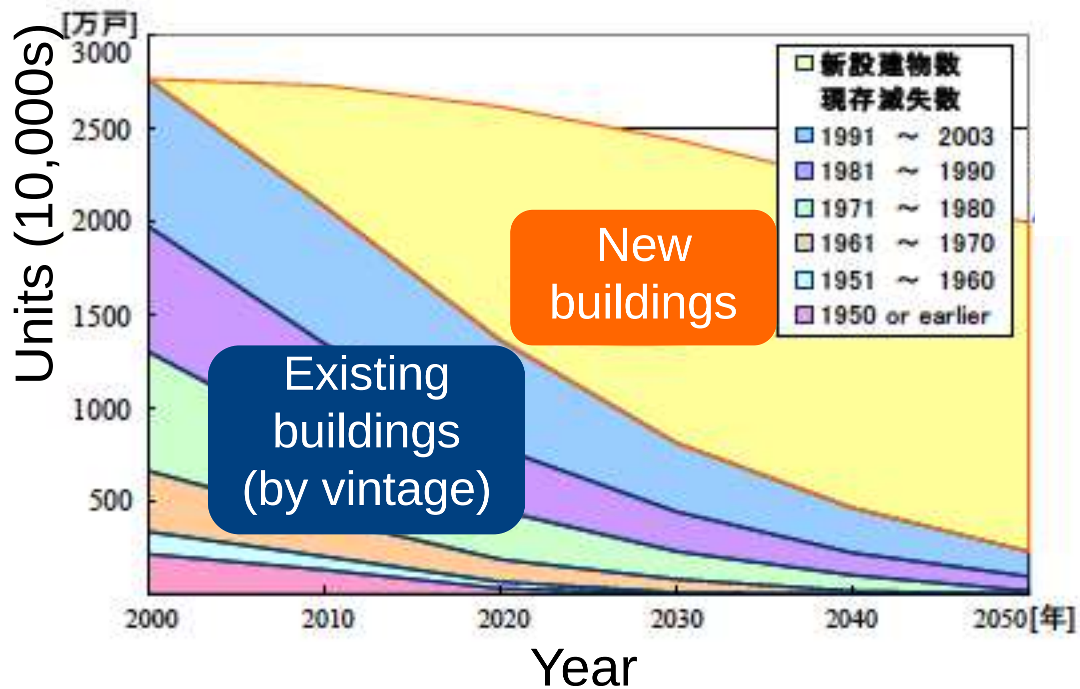


Building Stock Replacement

Tokyo

- 1923 Great Kanto earthquake
- WWII firebombs
- Seismic codes
- Lifetime of buildings, rate of demolition and replacement

Projected Change in Wood-frame Houses in Japan, 2000~2050

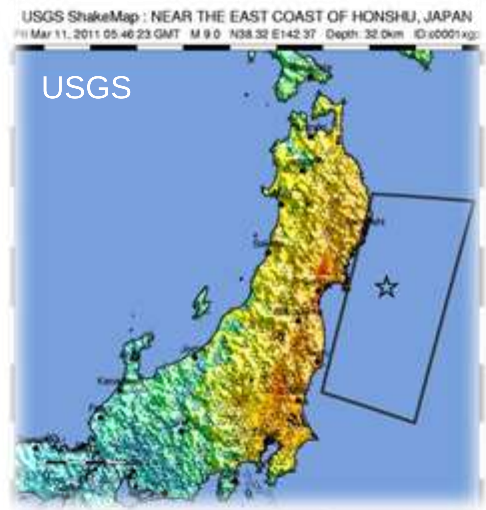


(Ohara et al. 2007)

Land Use Changes

Tokyo

- Landfill / reclaimed land in Tokyo Bay since 1600s



2011 Great East Japan Earthquake

- Ground failure in areas reclaimed after WWII
- ~300 km from epicentral area
- Cost to city: $900 m.
- Damage to sewer, water, gas pipelines
- 77,000 hh lost water
- 1,100+ buildings damaged /destroyed by liquefaction

Important Variables

- Era of rapid growth
- Building stock replacement rate
- Land use change

- Geographic setting (coastal, soils)
- Population size
- Construction practices change
- Building codes change
- Socio-demographic change
- Economic change
- Hazard and risk awareness
- Mitigation policies
- etc.

Key Questions

- Dynamics of **other forms of loss** – repair costs, lifelines, economic disruption, insured loss,...?
- How much did **building code improvements** reduce risk?
- How much can **future** code improvements reduce risk?
  - Need vintage-specific damage models
- Are **other cities** experiencing similar risk changes?
  - Need comparative / collaborative research
  - Developing countries
- **Which cities** will be at greater risk? Which neighborhoods?
- **Mitigation** strategies?

Significance for the Insurance Industry

- Risk dynamics can be modeled by catastrophe models quite readily
- As with climate change, the dynamics of earthquake risk may affect decisions about:
  - Premiums
  - Reserves
  - Reinsurance purchases
  - Insurability
  - Incentivizing risk reduction
- In the risk equation, Vulnerability (and Resilience) change more quickly than Hazard