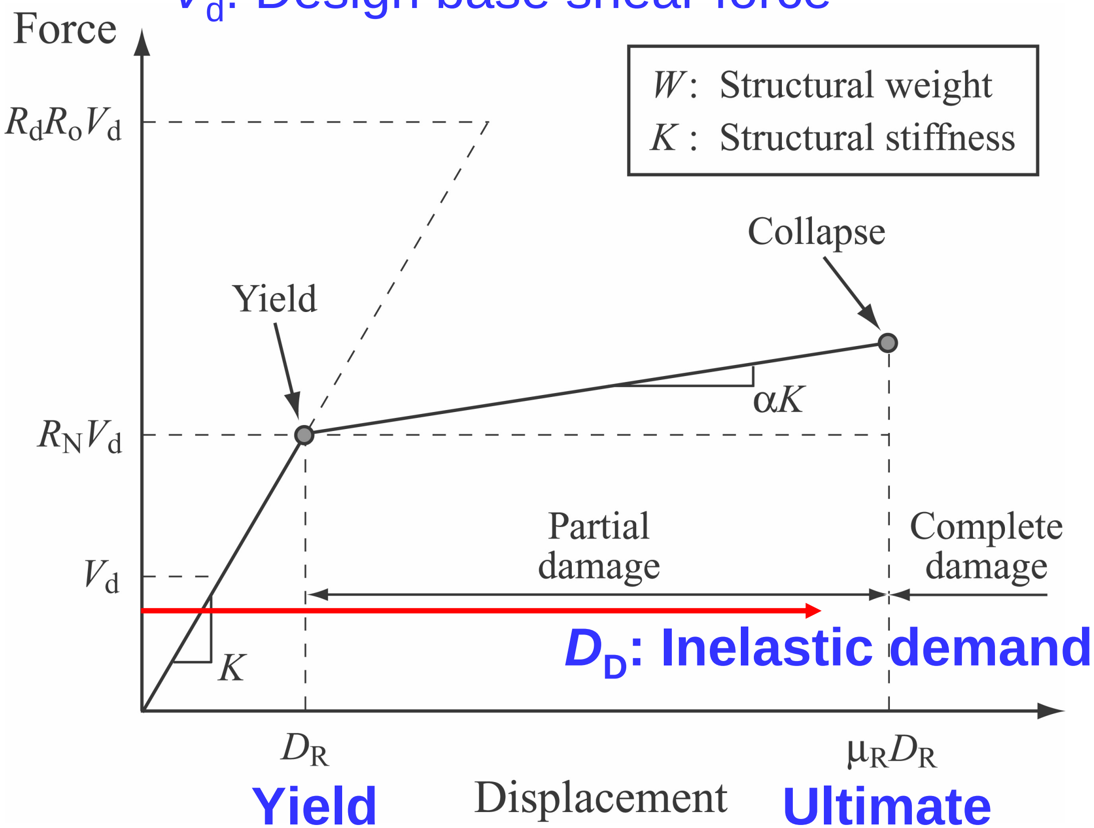
Panel 4: Damage severity assessment

V_d: Design base shear force

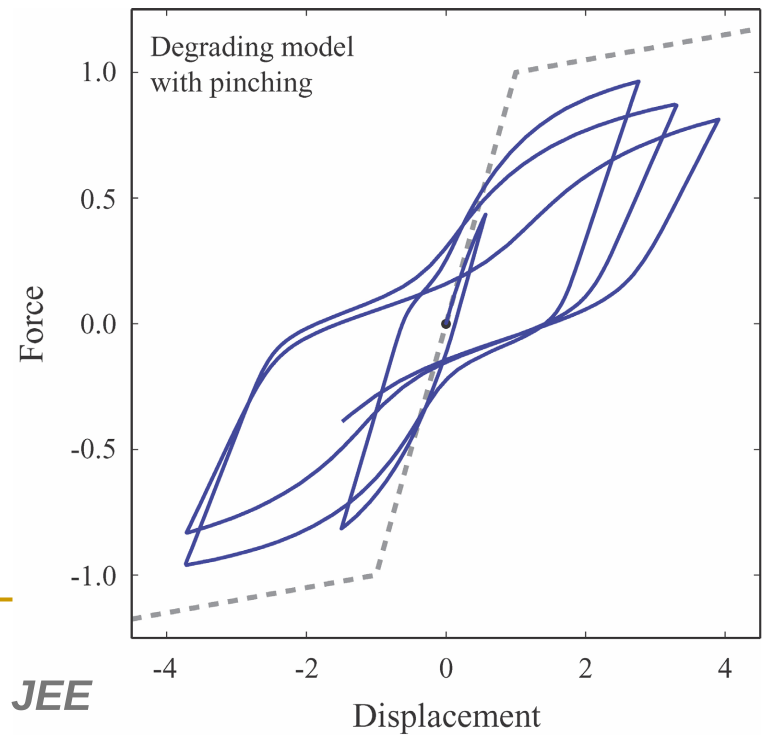


Yield capacity

Ultimate capacity

A structural system is modeled as an inelastic single-degree-of-freedom system.

The inelastic seismic demand D_D is evaluated by nonlinear dynamic analysis.



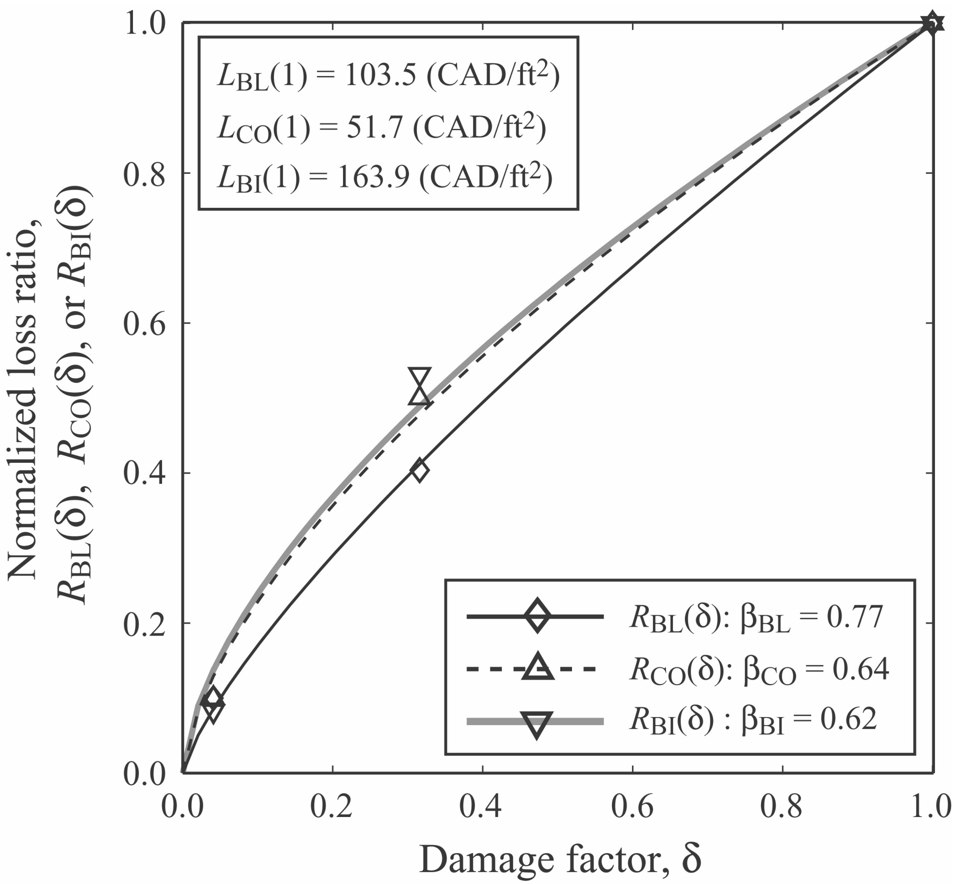
Damage factor δ:

$\delta = (D_D - D_R)/(\mu_R D_R - D_R)$

Goda, Hong, & Lee (2009) in *JEE*

Panel 4: Damage-loss function

Concrete building with commercial occupancy



The damage-loss function relates the damage factor δ to the normalized seismic loss.

The seismic loss is categorized into three types: $R_{BL}(\delta)$ for repair/reconstruction costs, $R_{CO}(\delta)$ for loss of contents, and $R_{BI}(\delta)$ for business interruption costs.

$$L_{BL}(\delta) = L_{BL}(1) \times R_{BL}(\delta)$$
$$L_{CO}(\delta) = L_{CO}(1) \times R_{CO}(\delta)$$
$$L_{BI}(\delta) = L_{BI}(1) \times R_{BI}(\delta)$$

Damage loss functions for various structural and use types are constructed based on extensive information given in HAZUS software.

Panel 5: Insurer's payments for seismic loss coverage of multiple policies

- The total insurer's payment for seismic loss coverage of *m* policies over a period of *t* years due to *n*(*t*) earthquakes, $L_{EQ,I}(t)$, can be evaluated as,

$$L_{EQ,I}(t) = \sum_{j=1}^{n(t)} \sum_{i=1}^{m} I_P\left(L_{EQ,ij}(\delta_{ij})\right) = \sum_{j=1}^{n(t)} \sum_{i=1}^{m} I_P\left(L_{BL}(\delta_{ij}) + L_{CO}(\delta_{ij}) + L_{BI}(\delta_{ij})\right)$$

where $L_{BL}(\delta)$, $L_{CO}(\delta)$, and $L_{BI}(\delta)$ represent the building-related loss, content-related loss, and business interruption-related loss, respectively.

- A typical insurance payment function I_P is given by,

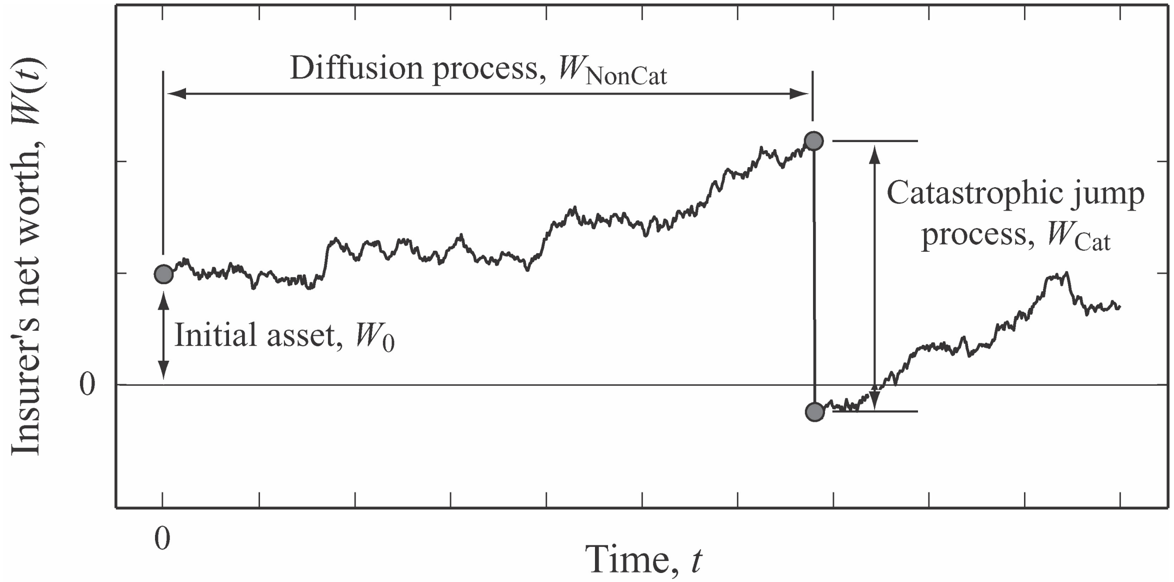
$$I_P(L_{EQ,ij}) = \begin{cases} 0 & L_{EQ,ij} \le D \\ \gamma(L_{EQ,ij} - D) & D < L_{EQ,ij} < C \\ \gamma(C - D) & L_{EQ,ij} \ge C \end{cases}$$

where *D* is the deductible, *C* is the cap, and γ is the coinsurance.

Assessments of insurer's solvency due to catastrophic seismic risk

1. Stochastic process of an insurer's worth
2. Numerical example – Evaluation of insurer's ruin probability under catastrophic seismic risk

Insurer's net worth



Stochastic process of insurer's net worth

Insurer's ruin is defined as an event resulting in $W(t) < 0$

Insurers face two kinds of risk exposures: non-catastrophic risks $W_{NonCat}(t)$ and catastrophic risks $W_{Cat}(t)$: $W(t) = W_0 + W_{NonCat}(t) + W_{Cat}(t)$

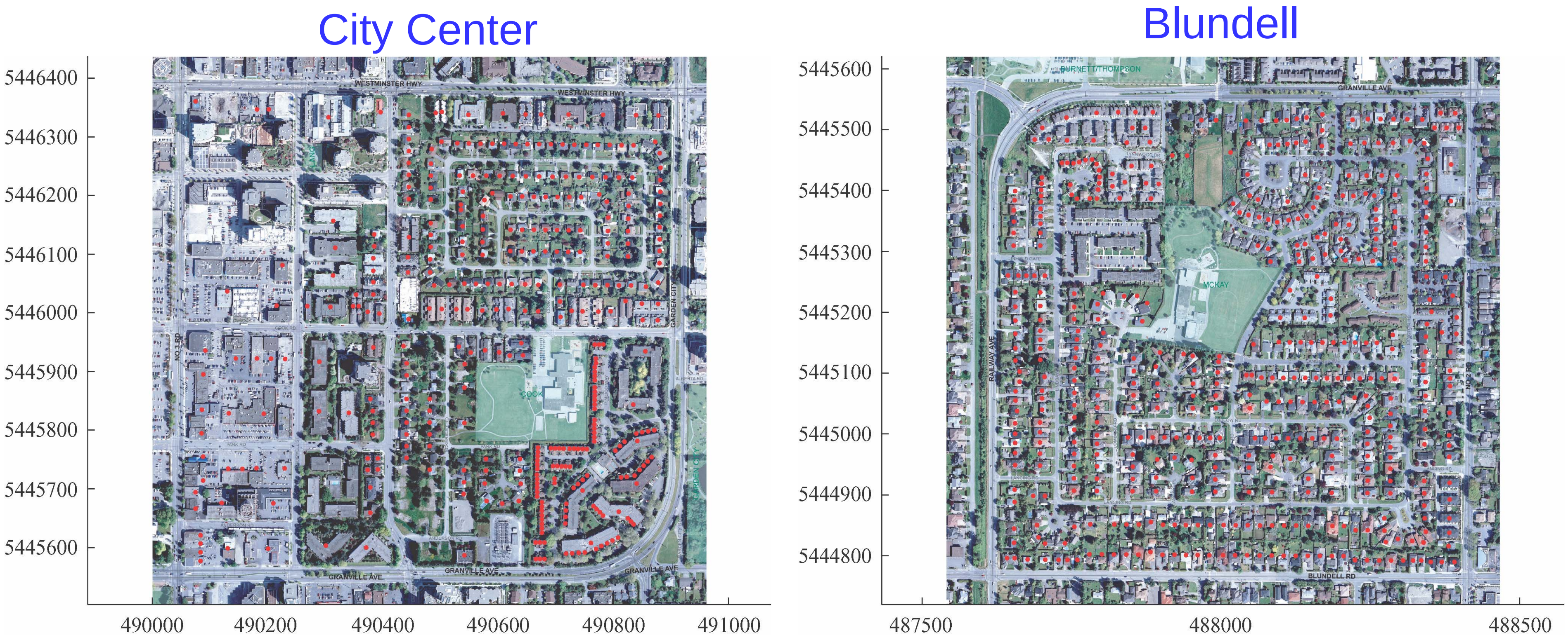
Non-catastrophic risks $W_{NonCat}(t)$ can be modeled as a diffusion process (e.g., Brownian process or geometric Brownian process)

Catastrophic risks $W_{Cat}(t)$ can be modeled as a jump process: for this, engineering-based seismic risk models can be used.

Numerical example set-up

- The ruin probability of an insurer who underwrites earthquake insurance for a group of 1574 wood-frame buildings located in the City of Richmond (see next slides) is evaluated.
- Up-to-date seismic hazard models as well as vulnerability models for wood-frame buildings are considered.
- The considered time horizon is 10 years – insurers are concerned about exposures for finite duration.
- Insurance parameters are set as: D = 0.1x(Total replacement cost), C = 0.5x(Total replacement cost), and $\gamma = 1.0$ – this is a typical policy setting for earthquake insurance (e.g., California and Japan).
- The total replacement cost of 1574 wood-frame buildings amounts to 735 million Canadian dollars (CAD) – maximum insurance payments per event is about 294 million CAD.

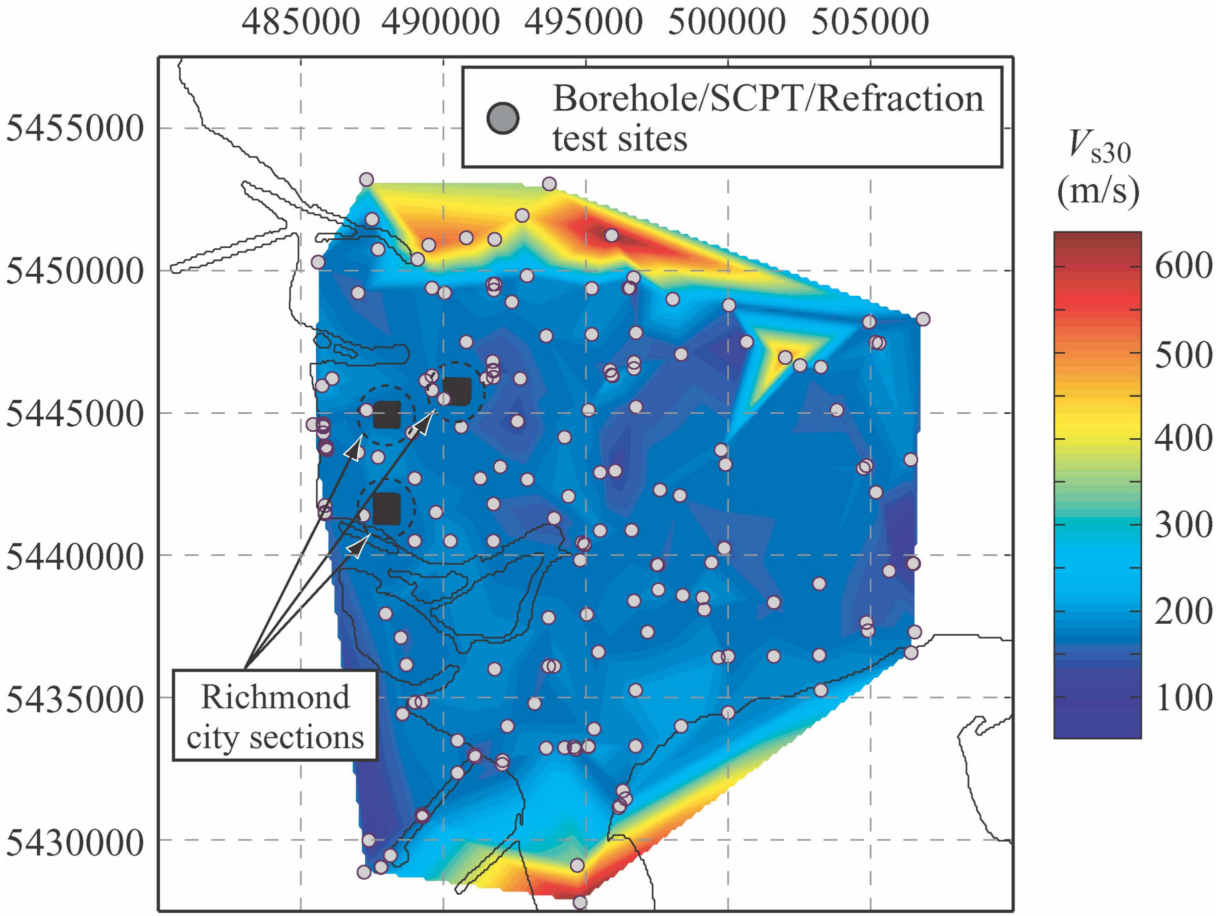
Wood-frame buildings in Richmond, B.C.



Building inventory information of existing 1574 wood-frame buildings (three city sections with an area of 1km by 1km) is obtained from the City of Richmond.

The database includes: locations, year built, story number, structural type, use type, floor area, values and etc – structural and cost information is obtained.

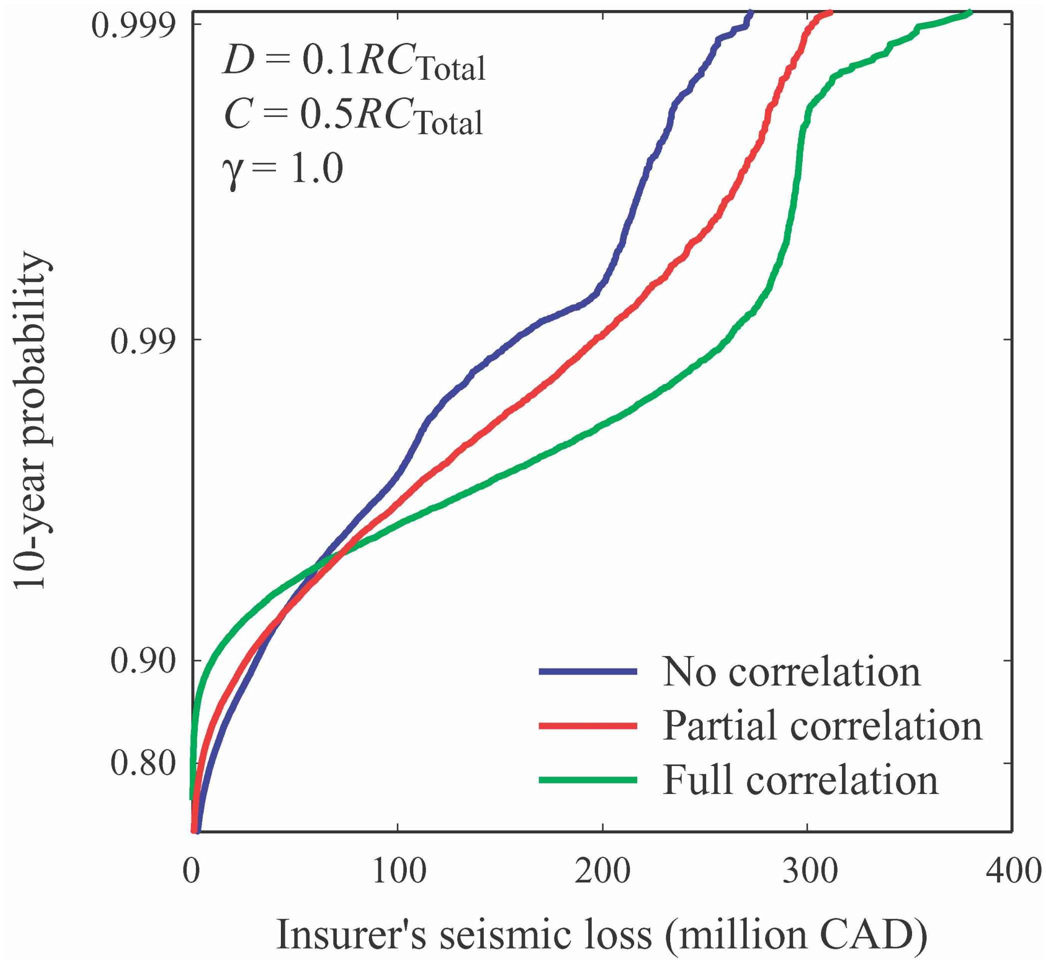
Local soil conditions in the Fraser River Delta



The Richmond wood-frame buildings are located on soft soil sites (around V_{s30} equal to 100 to 300 m/s) where ground motions tend to be amplified.

Detailed information on local soil conditions (Hunter et al., 1998), which is represented by V_{s30}, is gathered.

Insurer's earthquake risk exposures



In conventional seismic loss estimation of multiple buildings, a simplified correlation model of seismic excitations (i.e., no/full correlation) is used.

To investigate the impact of the treatment of spatial correlation, three correlation cases are considered: no correlation, full correlation, and partial correlation based on the developed empirical equations.

The curves for three correlation cases intersect, and the partial correlation case is bounded by the other two cases.

Statistics of insurer's earthquake risk exposures

Variable	No corr.	Partial corr.	Full corr.
Annual occurrence rate	0.100	0.063	0.028
E[Annual payment]	1.06	1.07	1.05
Std[Annual payment]	9.07	10.85	13.44
E[payment|payment occurs]	10.63	17.10	37.67
Std[payment|payment occurs]	26.83	40.06	71.27

The expected risk exposures are similar for the three correlation cases, whereas the dispersion of risk exposures (riskiness) differs. Note that the variability of the payment is significant.

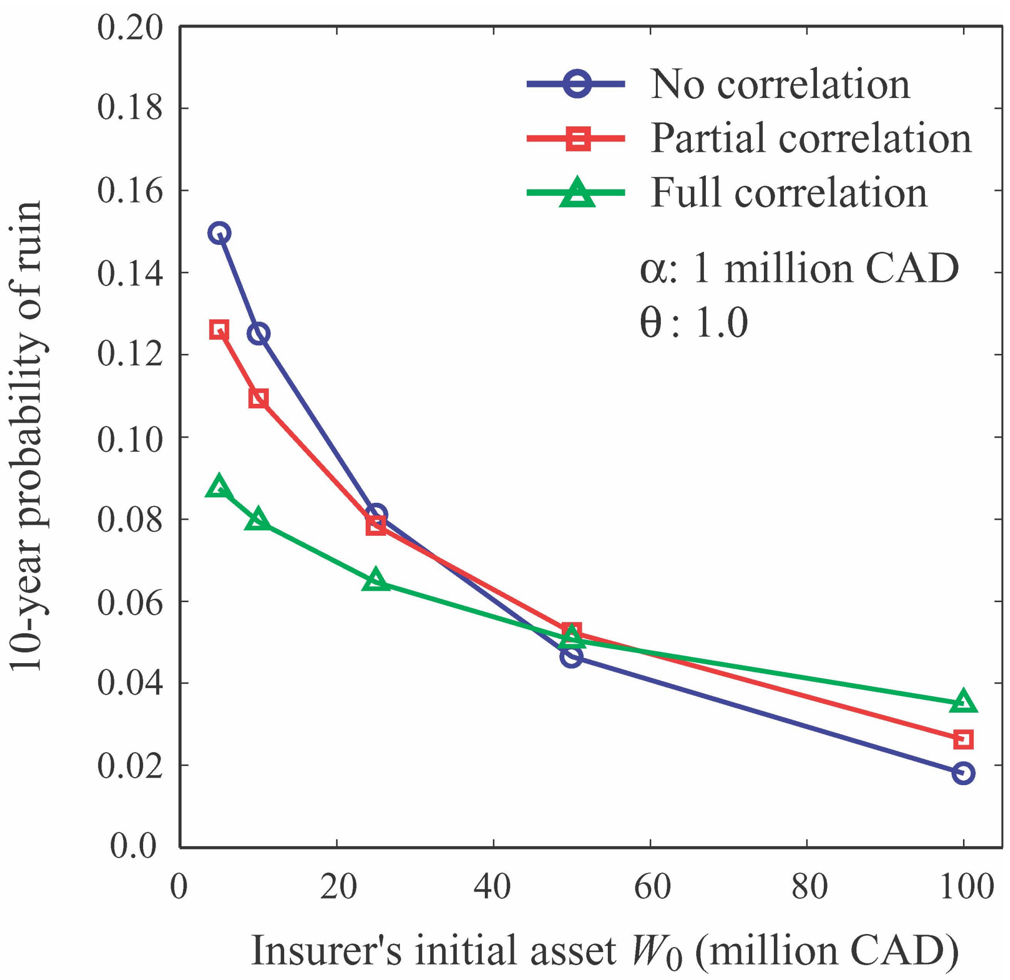
The statistics of the annual insurance payment can be used to determine the earthquake insurance pure premium rate per year P_A. For the considered cases, P_A is approximately 1 million CAD.

In general, an insurer charges risk premiums. If the expected value principle is adopted, the charged premium equals $(1+\theta)P_A$.

Sensitivity analysis of insurer's ruin probability

- The ruin probability of an insurer who underwrites earthquake insurance for the 1574 wood-frame buildings, is evaluated by considering various combinations of the insurer's initial asset W_0 , the size of non-catastrophic business, and the safety loading factor θ.
- Non-catastrophic risks are represented by a Brownian motion with the instantaneous growth and standard deviation of the insurer's worth α and β: $dW_{NonCat}(t) = \alpha dt + \beta dZ(t)$, where $Z(t)$ is the standard Brownian motion.
- For numerical analysis, the ratio β/α is set to 2.0, and the value of α is varied to change the relative size of non-catastrophic business of the insurer.
- Parameter ranges: W_0 – 5 to 100 million CAD; α – 1 to 10 million CAD; and θ – 0.0 to 5.0.
- Note: P_A (pure premium for earthquake coverage) is equal to 1 million CAD and the maximum exposure for the insurer is about 300 million CAD (based on the deductible, cap, and coinsurance factor).

Effects of the insurer's initial wealth



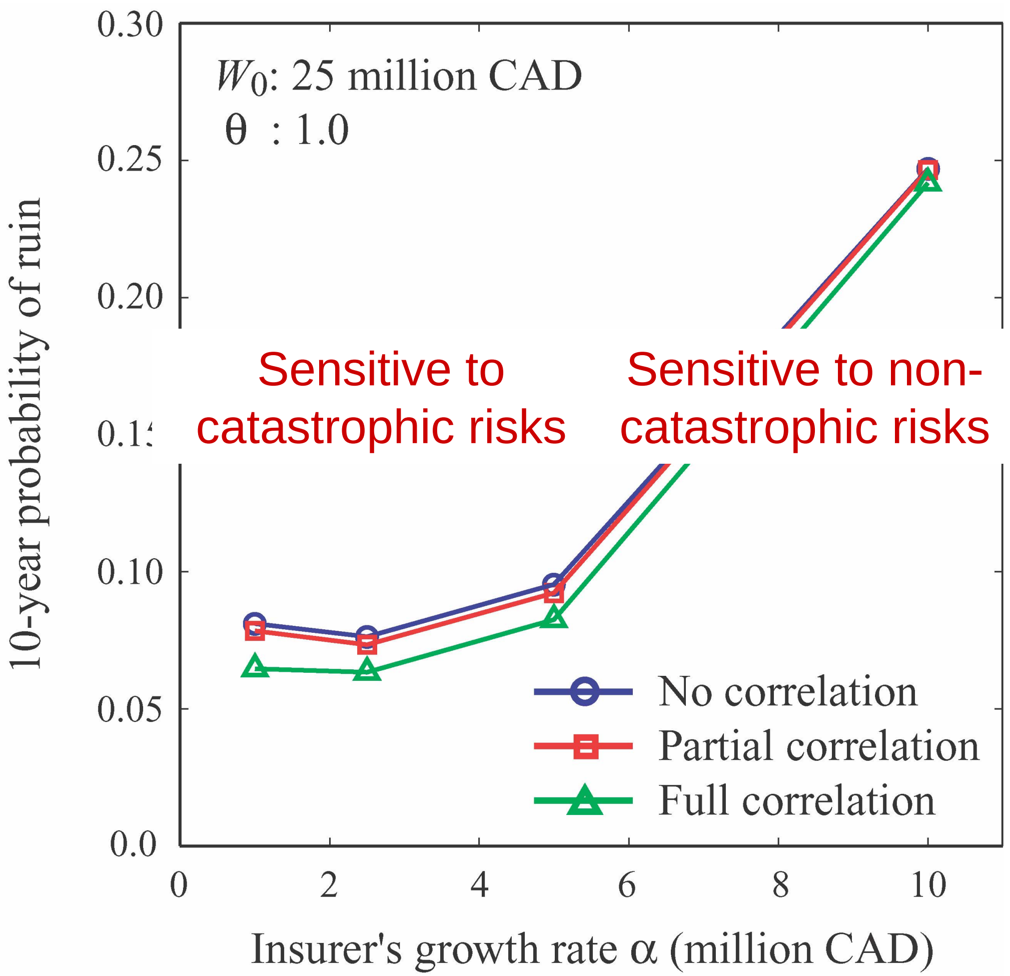
The initial asset W_0 is varied by keeping α = 1 (on average, the same expected profit level for both types of risk exposures) and θ = 1.0 (unfair insurance).

The ruin probability decreases as W_0 increases.

The order of riskiness of seismic risk exposures changes with W_0 depending on spatial correlation.

The diversification of correlated portfolios only through the increased reserve fund is more difficult than uncorrelated portfolios.

Effects of the size of non-catastrophic risk exposures

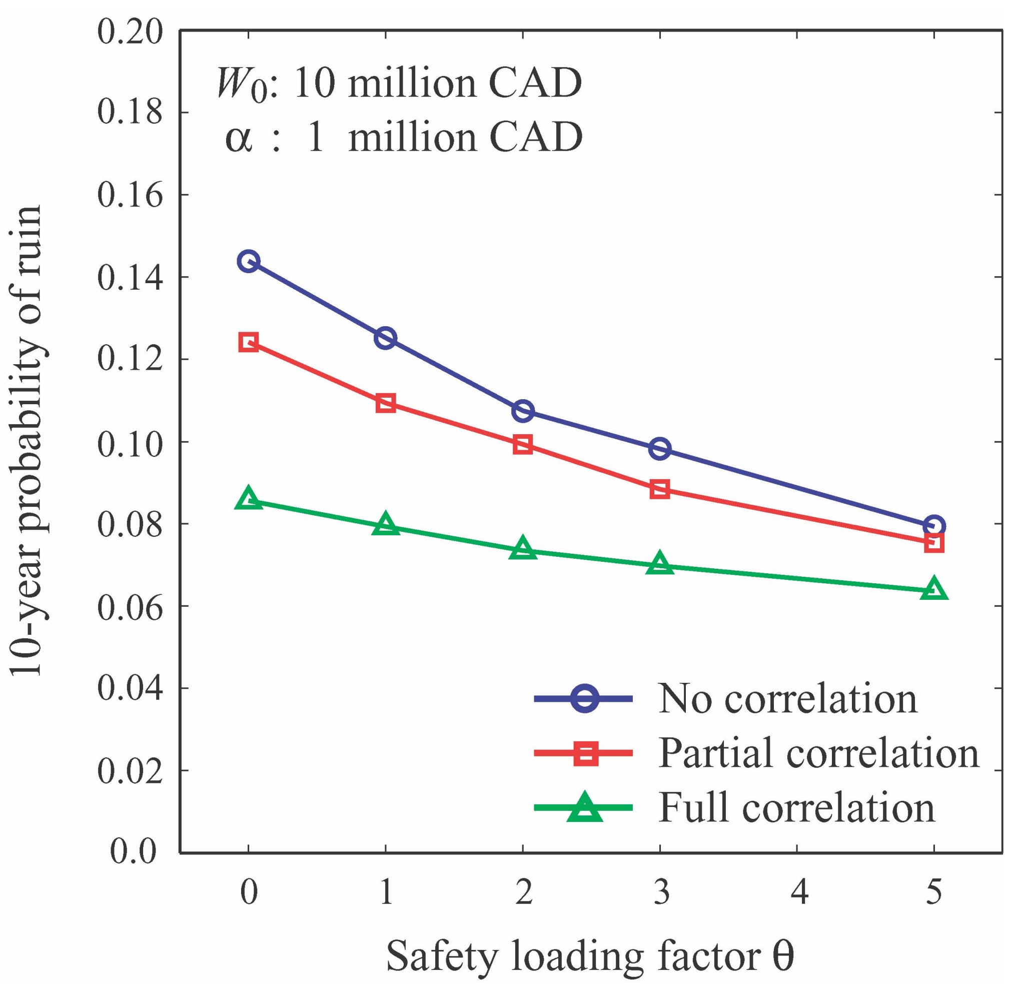


The size of non-catastrophic business α (with $\beta/\alpha = 2$) is varied by keeping $W_0 = 25$ million CAD and $\theta = 1.0$ (unfair insurance).

The ruin probability increases rapidly as α increases.

For given earthquake risk exposures, there is a range of α where the effects of α are not significant: for example, if the target ruin probability is 0.1 in 10 years, the insurer can manipulate the size of the non-catastrophic risk exposures to maximize the expected profit.

Effects of the safety loading factor



The safety loading factor θ is varied by keeping α = 1 (on average, the same expected profit level for both types of risk exposures) and W_0 = 10 million CAD.

The ruin probability decreases as θ increases.

The diversification of correlated portfolios only through the increased risk premium is not effective in reducing the ruin probability.

This result suggests that an alternative risk transfer instrument (e.g. reinsurance) for an insurer may be required.

Summary

- A comprehensive simulation-based framework to assess seismic risk for multiple buildings is developed by accounting for the simultaneous occurrence of structural damage and collapse of a group of buildings.
- An insurer's net worth process is modeled as a diffusion-jump stochastic process.
- The spatial correlation of seismic excitations must be treated adequately in estimating earthquake risk exposures of an insurer who underwrites both non-catastrophic and catastrophic risks.
- The more correlated earthquake risk exposures of the insured portfolio become, the less effective the diversification techniques become (e.g., increased reserve funds for emergency and increased risk premiums). In such cases, an alternative "affordable" risk transfer mechanism (e.g., national reinsurance program) may be needed.

Future studies and related investigations

- In the future, the following topics will be investigated:

1) Incorporation of reinsurance contracts for insurers
2) Different insurance portfolios (different spatial distributions of portfolios and different building types)

- I have carried out some other research projects related to earthquake insurance and efficient portfolio management of earthquake risk exposures.

1) Dependence of aggregate seismic losses for different portfolios of buildings using copulas
2) Optimal seismic design level of a building with earthquake insurance considering risk attitudes and risk perception of decision makers

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- Please feel free to contact me at **kgoda2@uwo.ca** if there are any questions.