



Fire Following Earthquake in the catastrophe models: Case study – Vancouver region, Canada

Svetlana Stripajova, Jan Vodicka, Peter Pazak, and Goran Trendafiloski
Aon, Impact Forecasting (svetlana.stripajova@aon.com)

Abstract

Fire following earthquake (FFE) can pose considerable threat in densely populated urban area with significant earthquake hazard and presence of non-fire-resistant buildings typology. Severe building damage and consequently broken pipelines can lead to release of flammable gasses and liquid, which increase possibility of fire occurrence when they come into contact with ignition sources, like short circuits or open flames. Numerous simultaneous ignitions followed by uncontrolled fire spread to adjacent buildings can lead to major fires and conflagrations, whose damage can substantially exceed the earthquake shaking damage. Well-known example of such high financial losses due to FFE is Mw 7.9 San Francisco 1906, where Great Fire losses were 10 times higher than due to earthquake shaking itself. Thus, the quantification of FFE losses has particularly important role for the current underwriting products and the industry requires their further detailed consideration in the catastrophe models and pricing approaches. Impact Forecasting, Aon's catastrophe model development centre of excellence, has been committed to help (re)insurers on that matter.

This paper presents quantification of FFE contribution to mean losses for case study of the Vancouver region, Canada for specific scenario Mw 7.5 Strait of Georgia crustal earthquake. FFE methodology encompasses 3 phases: ignitions, fire spread and suppression and loss estimation. Number of ignition (fire that require fire department response) and their location were calculated using HAZUS empirical equation with input variables earthquake shaking intensity and estimated total building floor area. An urban fire spread is a complicated phenomenon that includes numerous uncertainties. An advanced cellular automata (CA) engine is used for simulation of the fire spread and suppression based on Zhao (2011). The CA engine represents collection of grid-arranged cells, where each grid cell changes state as a function of time according to a defined set of rules that includes the states of adjacent cells. The CA simulations include only matrix mathematical operations that allow us to take into account building construction types and their damage due to earthquake shaking, meteorological and environmental data and fire suppression modifiers. Unlike in older empirical approach, the fire spread CA engine enable to consider fire spread not only from initially ignited building as well as fire developing within a single building, building-to-building fire spread, and fire extinguishing works at the same time. An output of CA engine is the building fire-state grades based on which damage functions are created with PGA as input parameter at the level of 3-digit postal codes. For the chosen scenario potential contribution to mean loss due to FFE could be up to 75% depending on typical buildings setting within 3-digit postal codes.

Mw 7.5 Strait of Georgia crustal earthquake scenario

- **Scenario:** Strait of Georgia crustal earthquake

- Theoretical scenario by Vancouver Island coast mountains active shallow crust area source zone with fault trace orientation indicated in the figure

- Cassidy et al. (2000) source parameters used:

- Scenario: Strait of Georgia 1997 Mw 4.6 earthquake
- Modifications: epicentre closer to Fraser River delta, larger magnitude

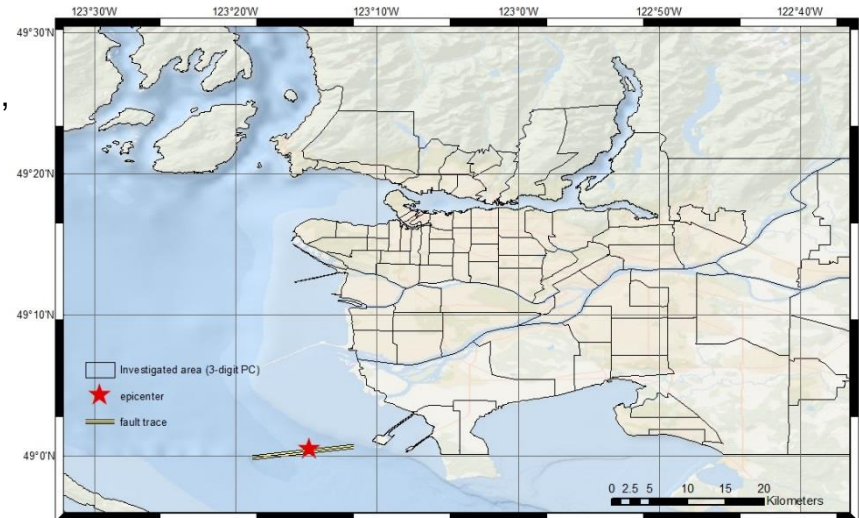
- Magnitude Mw = 7.5

- Hypocentre

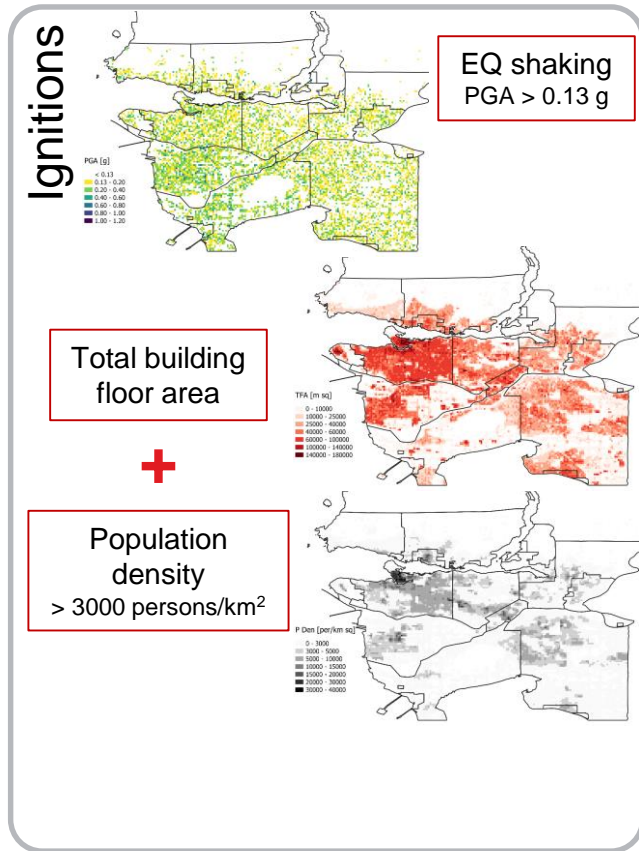
- Latitude = 49.009523
- Longitude = -123.245988
- Depth = 10 km
- Rake 98° , Strike 262° , Dip 47°

- **Investigated region:**

Greater Vancouver Area, British Columbia



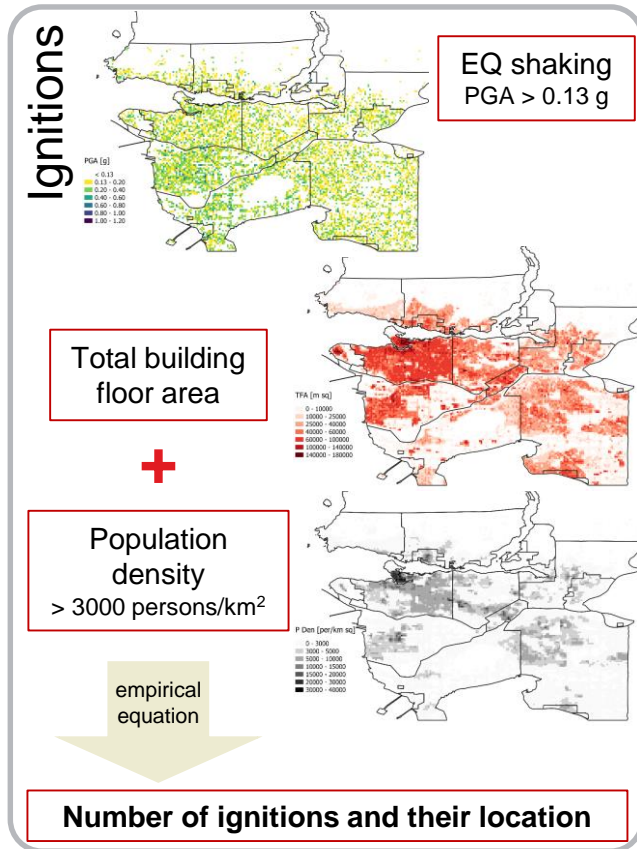
Fire Following Earthquake - Ignitions



Number of ignitions

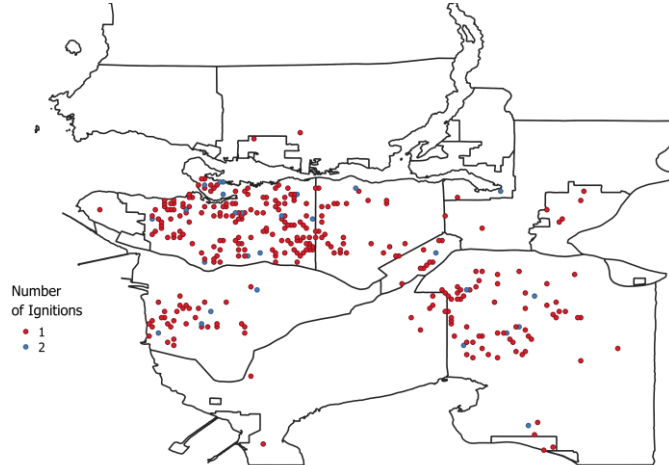
- Ignition refers to each individual fire that starts (ignites) after an earthquake that ultimately requires fire department response to suppress
- We used HAZUS and Scawthorn (2009) methodology to calculate number of ignitions and their location using empirical second order polynomial equation relating ignitions pre million sq. ft. of total building floor area with earthquake shaking intensity in PGA (in g)
- Two conditions restrain where fire ignition can occur, and they are related to earthquake shaking level and population density
 - PGA > 0.13 g
 - Population density > 3000 persons/km²

Fire Following Earthquake - Ignitions



Number of ignitions

- We estimated 0, 1, 2, 3, ... and more ignitions assuming Poisson process based on mean number of ignitions per 1 mil. sq. ft. of total building floor area calculated from empirical equation
- Due to randomness of the ignition calculation process, we performed several simulations and created stochastic catalogue of fire-genic events, with number of ignitions and their location for each event



Example of number of ignitions and their locations for Mw 7.5 Strait of Georgia earthquake scenario

Fire Following Earthquake - Fire spread and suppression

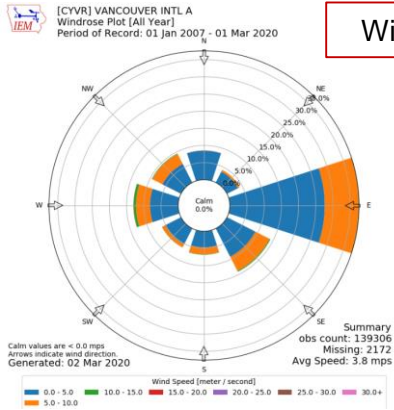


Cellular automata engine

- An urban fire spread is a complicated phenomenon that includes numerous uncertainties
- We used advanced cellular automata engine for simulation of the fire spread and suppression based on Zhao (2011)
- The engine is represented by collection of cells arranged in a grid, such that each cell changes state as a function of time according to a defined set of rules that includes the states of neighboring cells
- Includes only matrix mathematical operations

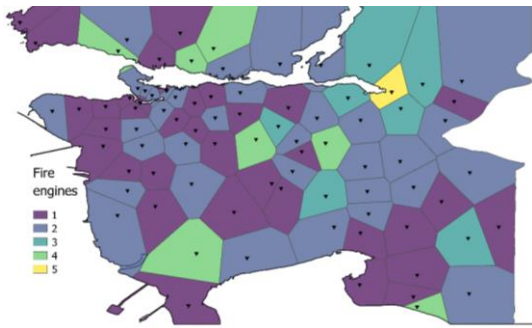
Fire Following Earthquake - Fire spread and suppression

Spread and suppression



Wind rose*

Fire suppression data



Cellular automata engine

- Allows us to take into account:
 - Building construction types and their damage due to EQ shaking
 - Meteorological and environmental data
 - wind speed & direction (wind rose for international airports)
 - humidity (data from international airports)
 - rivers, water bodies
- Fire spread not only from initially ignited building and fire development within the building depending at time of burning represented by fire stage grades
- Fire suppression modifiers
 - fire station locations
 - number of available fire engines
 - so-called first response area represented by Voronoi polygons

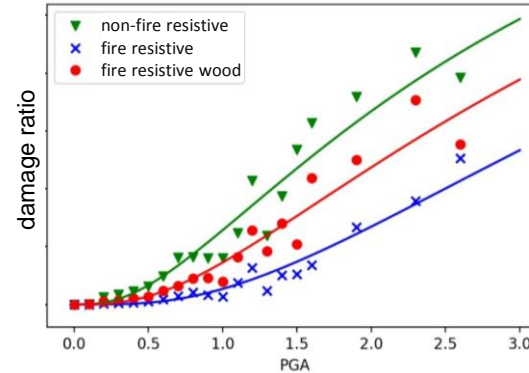
Fire stage	Grade
Original stage	{0}
Ignition	{1}
Flashover	{2}
Full development	{3}
Structural fire	{4}
Collapse	{5}

*Wind rose created using website:
<https://mesonet.agron.iastate.edu/sites/locate.php>



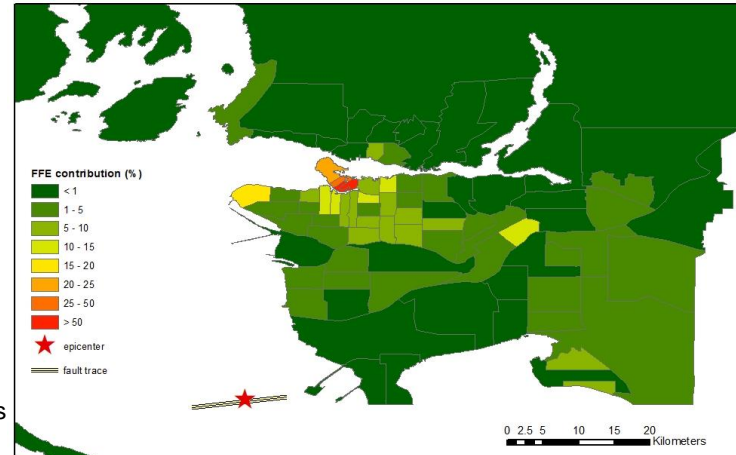
Damage functions and FFE contribution to mean losses

- **Output of cellular automata engine:**
 - Building fire-state grades (FSG = 0 to 5)
- **Damage functions**
 - For 3-digit postal codes with PGA as input parameter
 - Building types: non-fire resistant, fire-resistant wood, fire-resistant
 - Coverage: structure, contents and business interruption
- For the chosen scenario potential contribution to mean loss due to FFE could be up to 75% depending on typical buildings setting within 3-digit postal codes assuming census-based portfolio



Example of created damage functions based on output of cellular automata engine

Distribution of FFE contribution to mean losses for Mw 7.5 Strait of Georgia earthquake



Concluding remarks

- The contribution of fire following earthquake to overall losses varies spatially with respect to population density, built-upness of the city and typical building construction types as well as fire protection system
- For the chosen scenario in Greater Vancouver metropolitan area the potential fire following earthquake contribution to mean loss could be up to 75% depending on typical buildings setting within 3-digit postal codes assuming census-based portfolio
- The fire insurance can significantly exceed earthquake one, consequently fire losses would outrank earthquake shaking and other losses, that could lead to serious impact at insurance industry in countries with high fire following earthquake risk (like e.g., Canada, USA, Japan)
- The quantification of fire following earthquake is very important for the modern underwriting products and the regulators require its consideration in the catastrophe models and pricing approaches in order to provide comprehensive insurance protection on the market

References

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- FEMA. (2014). HAZUS-MH 2.1 technical manual: Earthquake model.
- Scawthorn, C. (2009). Enhancements in HAZUS-MH Fire Following Earthquake Task 3: Updated Ignition Equation. SPA Project No. 10010-01-07-01
- Zhao, S. (2011) Simulation of mass fire-spread in urban densely built areas based on irregular coarse cellular automata. *Fire technology*, 47, 721-749

Thank you

