The basin effect and liquefaction in the catastrophe models: Case study – Vancouver region, Canada

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Prepared for EGU General Assembly 2020

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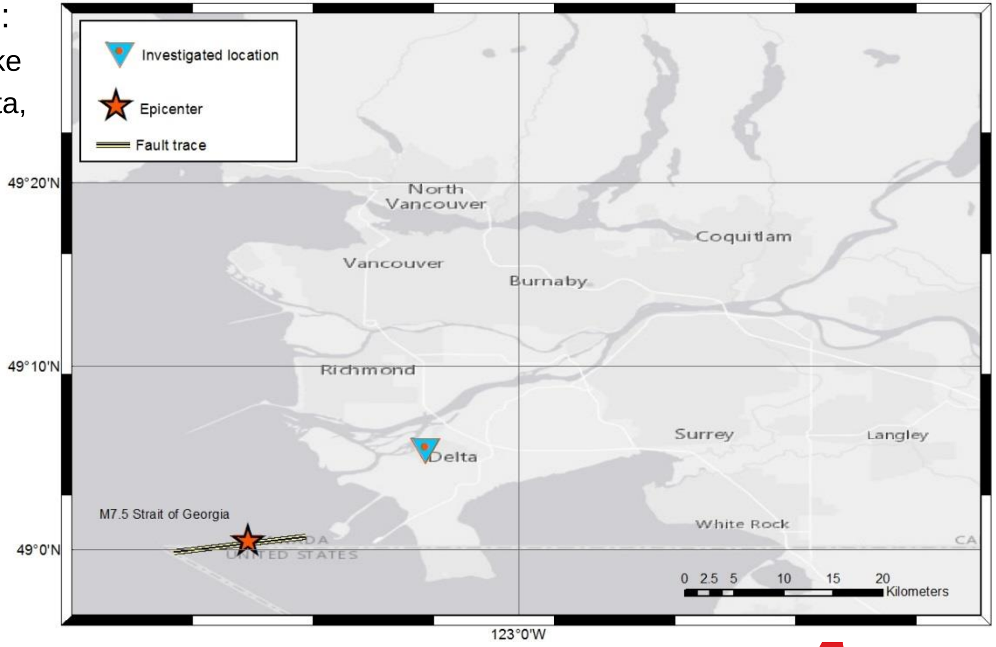
Abstract

The presence of thick soft alluvial sediment-filled basins, like in river's deltas, can significantly amplify and prolongate the earthquake ground motion. Moreover, the high-water saturation of such soft sediments and cyclic earthquake loading can lead to liquefaction. The basin and liquefaction effect can contribute to substantial modification of the seismic motion and increase of the potential losses at a particular location. Well-known examples of such high financial losses during earthquakes for basin effect is Mw 8.1 Mexico City 1985 and for liquefaction is Darfield and Christchurch earthquakes series in 2010 and 2011. Thus, the quantification of these effects is particularly important 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 center of excellence, has been committed to help (re)insurers on that matter.

This paper presents case study of the quantification of the basin effect and liquefaction for Vancouver region, Canada for specific scenario Mw 7.5 Strait of Georgia crustal earthquake. The southern part of the Vancouver region is located on a deep sedimentary basin created in the Fraser River delta. In case of deep Vancouver sedimentary basin considering amplification only due to shallow site response Vs30-dependent site term is not sufficient. Therefore, we derived (de)amplification function for different periods to quantify basin effect. We used NGA – West 2 ground motion prediction equations (GMPEs) for crustal events which include basin depth term. Amplification function was derived with respect to standard GMPEs for crustal events in western Canada. Amplification, considering site response including Vs30 and basin depth term at period 0.5 s can reach values as high as 3 at the softest and deepest sediments. The liquefaction potential was based on HAZUS and Zhu et al. (2017) methodologies calibrated to better reflect local geological conditions and liquefaction observations (Monahan et al. 2010, Clague 2002). We used USGS Vs30 data, enhanced by local seismic and geologic measurements, to characterize soil conditions, and topographical data and IF proprietary flow accumulation data to characterize water saturation. Liquefaction hazard is calculated in terms of probability of liquefaction occurrence and permanent ground deformation. For the chosen scenario the potential contribution to mean loss due to basin effect could be in the range 15% - 30% and 35% - 75% due to liquefaction depending on structural types of the buildings.

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 location:**
  - City of Ladner, Delta, British Columbia
  - Basin depth ~ 950 m
  - Vs30 ~ 180 m/s



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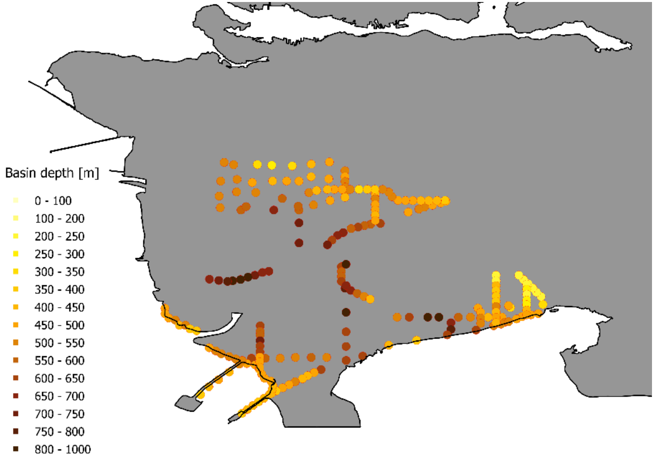
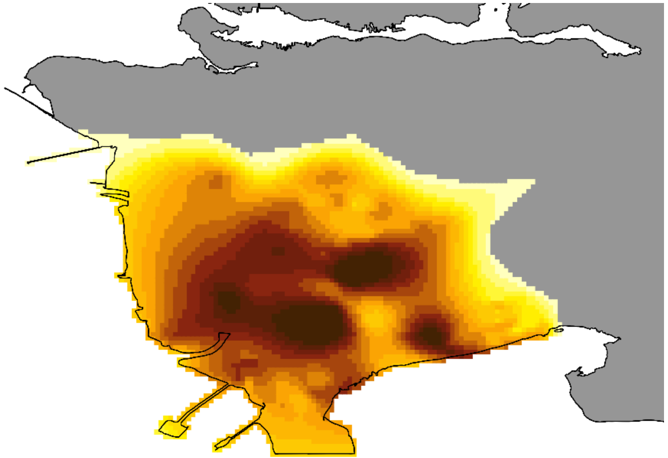
Fraser River delta – Sedimentary basin model

- The southern part of the Vancouver (Canada) region is located on a deep sedimentary basin created in the Fraser River delta
- **IF uses depth of sediments from reflection measurements** (depth to tertiary bedrock) and microtremor measurements interpolated to obtain a depth model of sediment-filled Vancouver basin

Basin depth



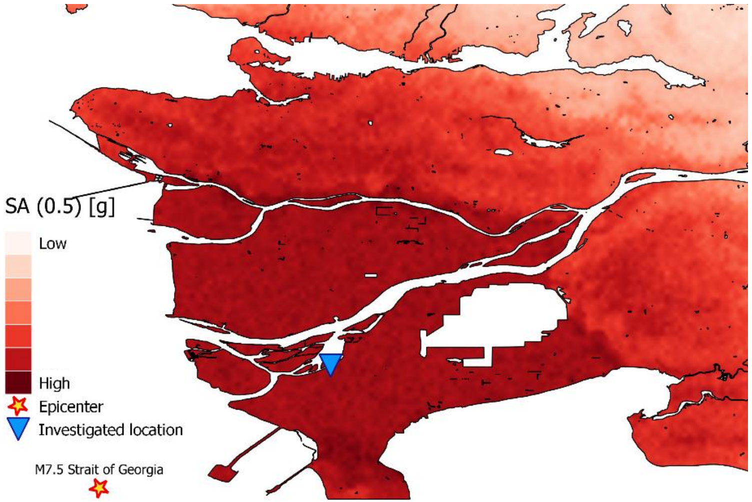
Measurement data points
Hunter et al. (2016), Ventura et al. (2004)



Modelled basin depth

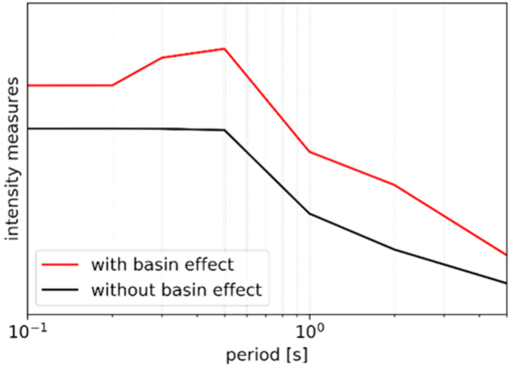
Basin effect – Amplification function

- We derived (de)amplification function for different periods to quantify basin effect
- NGA – West 2 ground motion prediction equations (GMPEs) for crustal events which include basin depth term were used with weight 1/3 each:
  - Abrahamson et al. 2014
  - Boore et al. 2014
  - Chiou and Youngs 2014
- Due to Vs30 and basin depth the amplification at period 0.5 s can reach values as high as 3 at the softest and deepest sediments thus affecting mid-rise buildings that comprise 15% of the total building stock in Vancouver



Spectral acceleration at period 0.5s for selected scenario

Intensity measures amplification at different periods due to basin effect for investigated location



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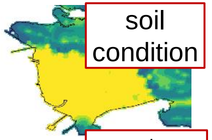
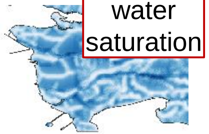
Liquefaction - General

Methodology

soil condition



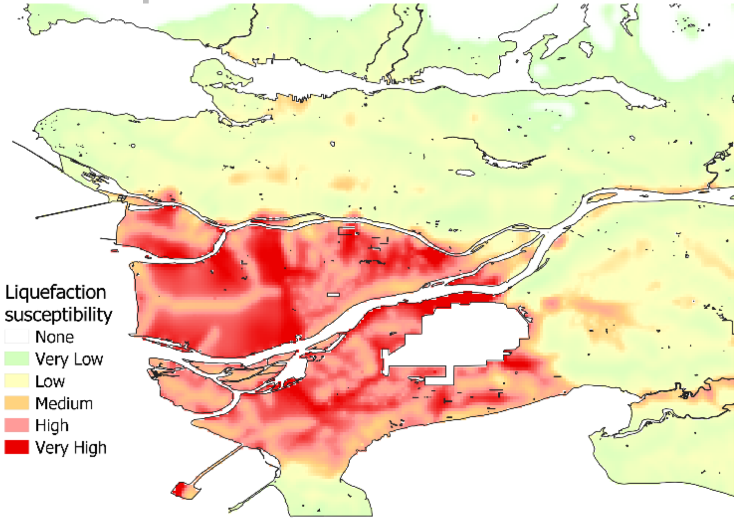
water saturation



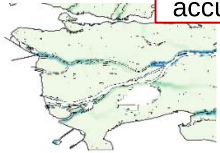
LIQ susceptibility

Liquefaction susceptibility – how soil is prone to liquefaction

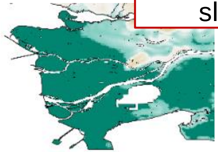
- Liquefaction potential was estimated using HAZUS and Zhu et al. (2017) methodologies calibrated to better reflect local geological conditions and liquefaction observations (Monahan et al. 2010, Clague 2002)
- We used USGS Vs30 data, enhanced by local seismic and geologic measurements, to characterize soil conditions, and topographical data and IF proprietary flow accumulation data to characterize water saturation



flow accumulation

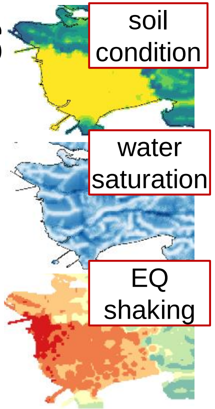


topographical slope



Probability of liquefaction and PGD

Methodology



probability of LIQ occurrence

permanent ground deformation

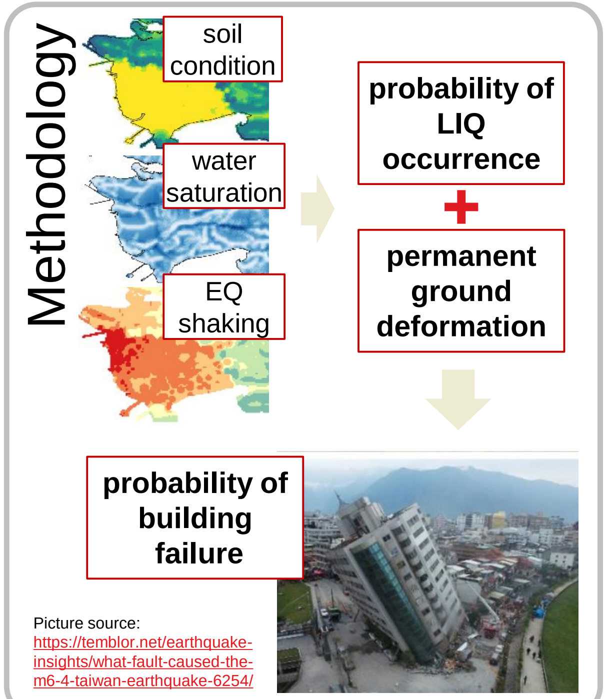
Probability of liquefaction occurrence

- Liquefaction hazard is calculated in terms of probability of liquefaction occurrence and permanent ground deformation
- Probability of liquefaction is close to 0 if:
  - soil is stiff (Vs30 > 620 m/s)
  - soil is dry (water saturation measure = 0)
  - low EQ shaking (PGA < 0.12 g) the loading is not strong enough to liquefy the soil
- P_{LIQ} is factorized depending on susceptibility class in order to consider also non-liquefied part of map unit/grid cell

Permanent ground deformation (PGD)

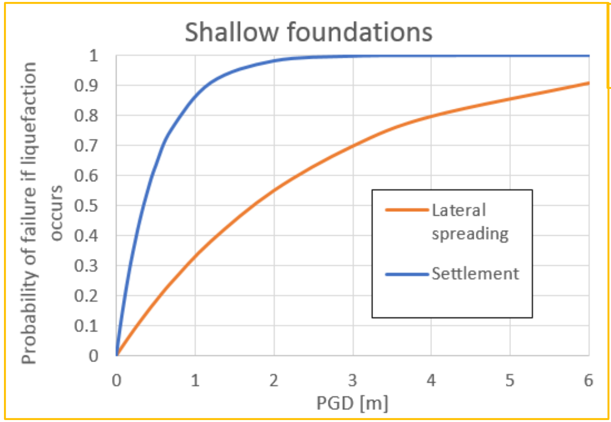
- The liquefaction of the soil is related with two different phenomena of permanent ground deformation: **lateral spreading** and **vertical settlement**.
- Vertical settlement is assumed to be related with the susceptibility category assigned to each location (Tokimatsu and Seed 1987, Ishihara and Yoshimine 1992)
- Lateral spreading is determined using the relationship Youd and Perkins (1978)

Probability of building failure due to liquefaction



Picture source: https://temblor.net/earthquake-insights/what-fault-caused-the-m6-4-taiwan-earthquake-6254/

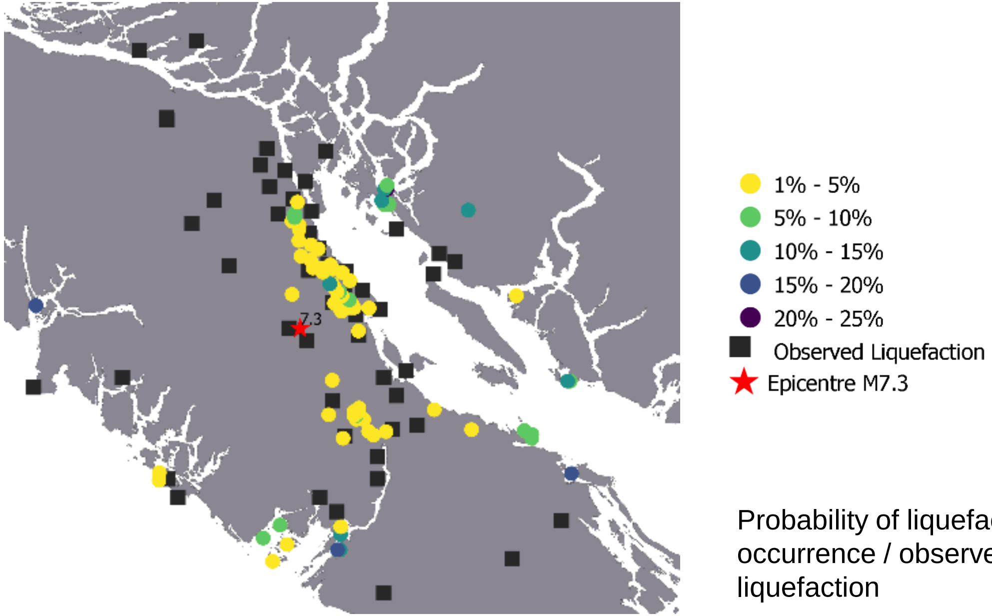
- Probability of building failure is calculated using probability of liquefaction and **empirical fragility curves** from calculated permanent ground deformation
- Most significant effect have the **foundations**, the **deeper** the **less prone to failure** if liquefaction occurs
- Probability of building failure represents percentage of collapsed buildings in investigated area



Empirical fragility curves for shallow foundations

Liquefaction – validation

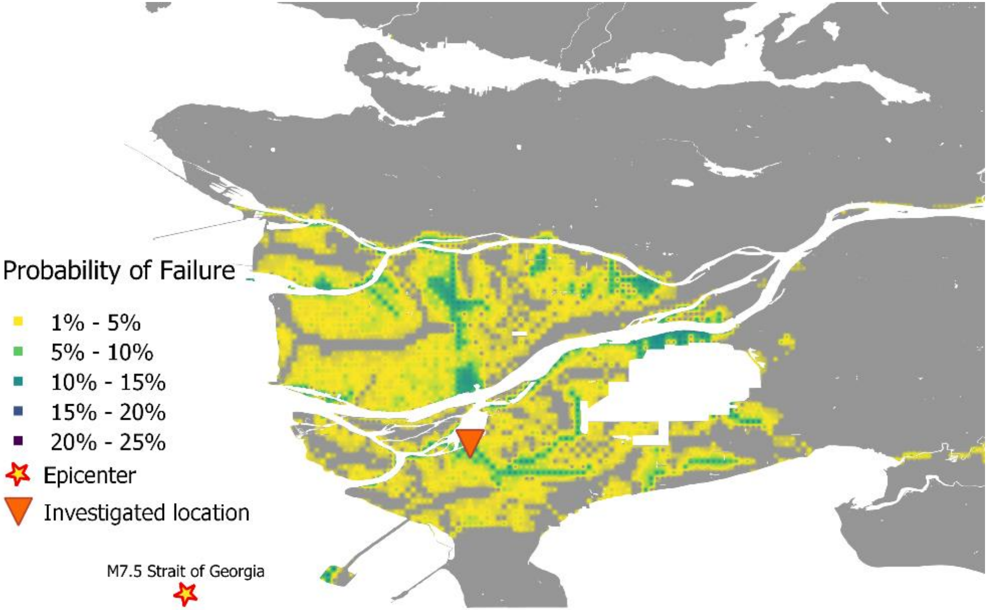
- Liquefaction phenomena and also property damage was observed during 1946, Vancouver Island Mw 7.3 earthquake (Clague 2002, Rogers 1980)
- Vancouver Island 1946 event was used for validation of methodology
- Modelled liquefaction occurrence corresponds to observations



Probability of liquefaction occurrence / observed liquefaction

Contribution to mean loss

- For the chosen scenario the potential contribution to mean loss due to basin effect could be in the range 15% - 30% and 35% - 75% due to liquefaction depending on structural types of the buildings



Probability of building failure for selected scenario

Concluding remarks

- The contribution of the effects of basin depth and liquefaction to the overall losses varies spatially with respect to soil conditions, basin depth and water saturation as well as constructions types built atop of the sediments
- For the chosen scenario in Vancouver the potential contribution to mean loss due to basin effect is estimated in the range 15% - 30% and 35% - 75% due to liquefaction depending on structural types of the buildings
- The quantification of these effects is very important for the modern underwriting products. The industry requires their further detailed consideration in the catastrophe models and pricing approaches in order to provide comprehensive insurance protection on the market considering also these secondary earthquake effects

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