Assessing the seismic resilience of an underground lifeline: Case study of the Christchurch City potable water network

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1. Introduction and context

This poster proposes an approach to understand the seismic resilience of underground lifelines. Lifelines are essential systems upon which the well-being and functioning of societies depend. They deliver a service or a good to the population using a network, a combination of spatially-distributed links and nodes. As they are interconnected, network elements' functionality is also interdependent. In case of a failure of one component, many others could be momentarily brought out-of-service. Further problems arise for buried infrastructure when it comes to buried infrastructure in earthquake and liquefaction-prone areas for the following reasons:

- Technically more demanding inspections than those required for surface horizontal infrastructure
- Infrastructure subject to both permanent ground displacement and transient ground deformation
- Increase in network maintenance costs (i.e. deterioration due to ageing material and seismic hazard)

These challenges suggest careful studies on network resilience will yield significant benefits. For these reasons, the potable water network of Christchurch city (Figure 1) has been selected for its well-characterized topology and its extensive repair dataset.

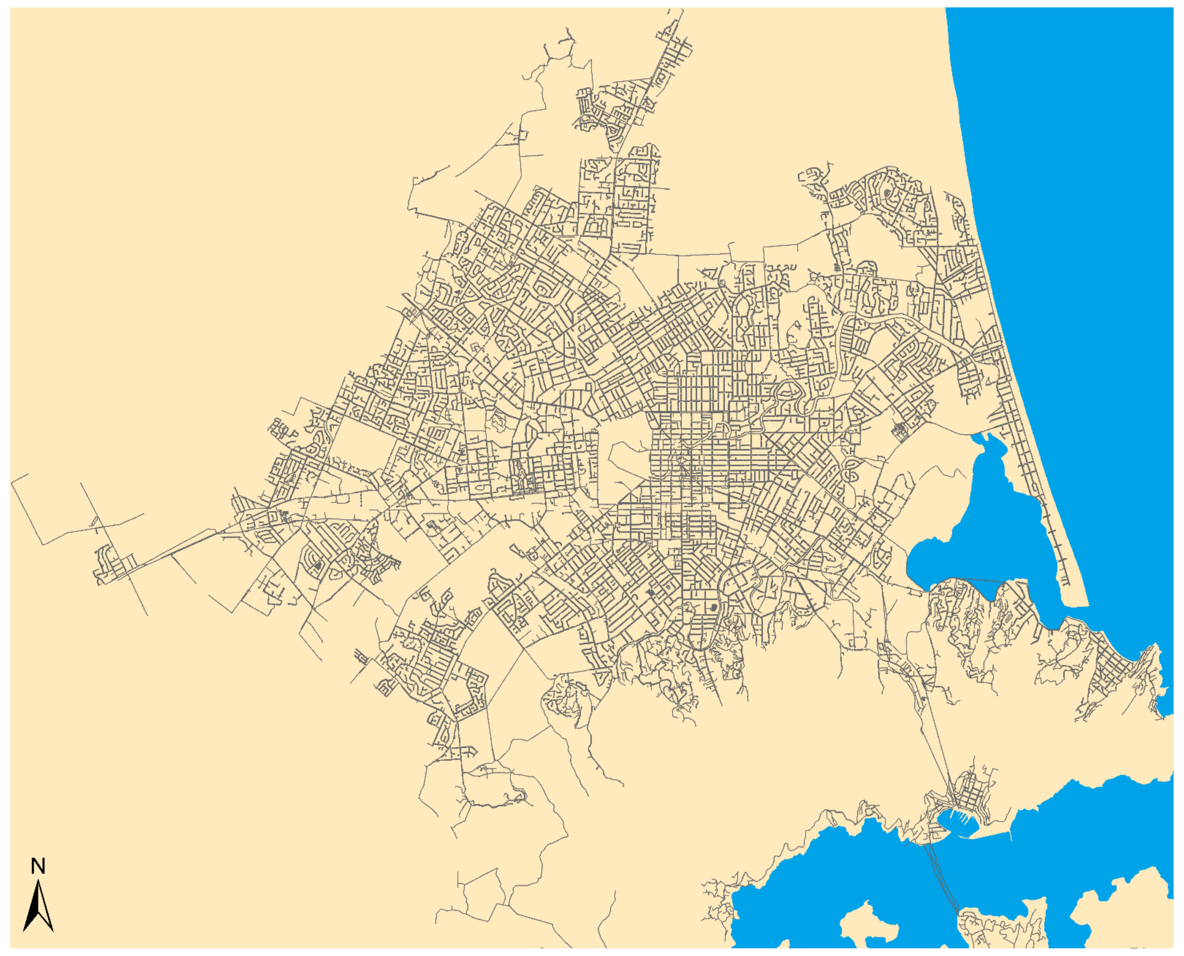

Figure 1: Potable water network of Christchurch

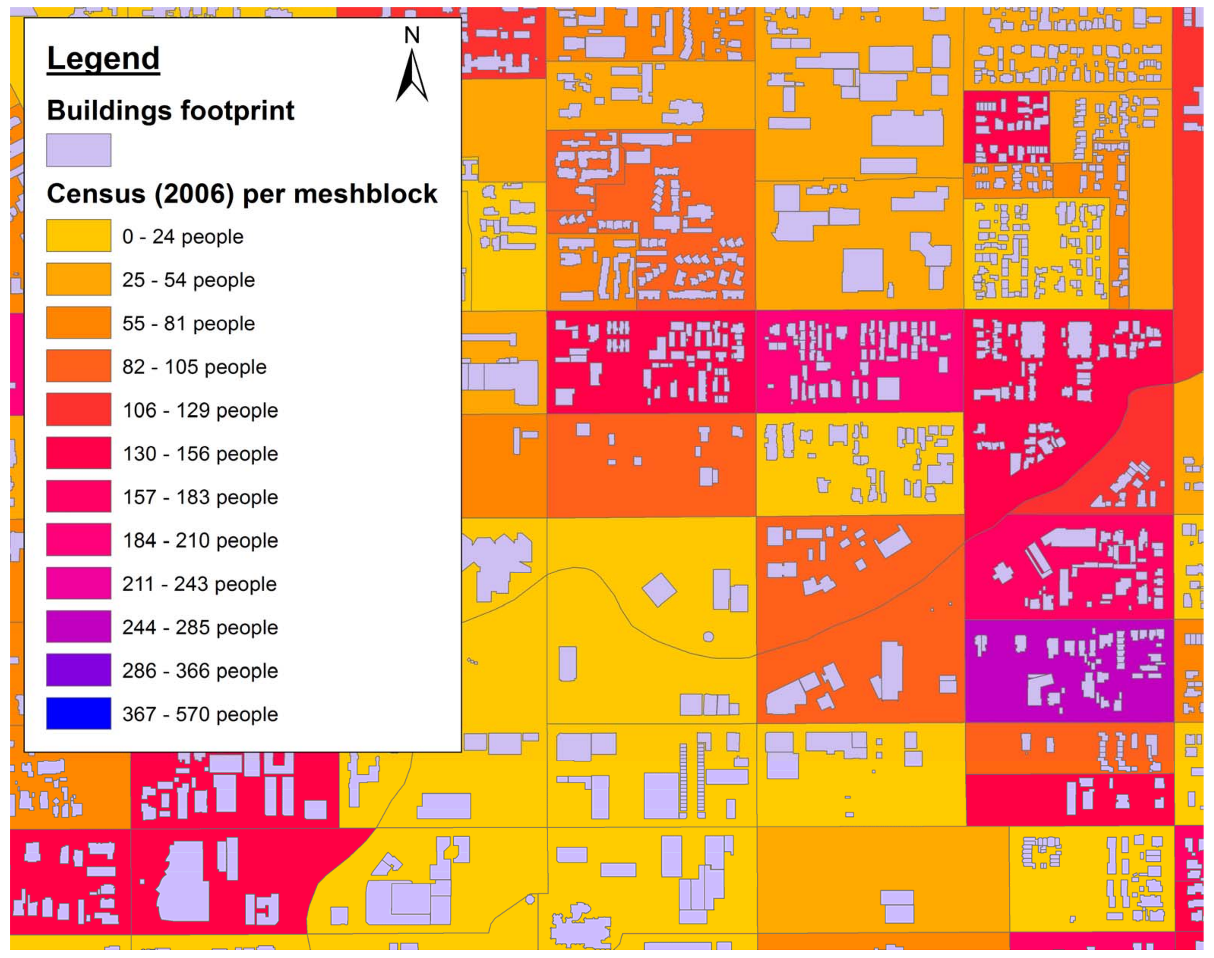

Figure 2: Community data of Christchurch city represented by the number of people per parcel and the building footprints

2. General approach to assess systemic resilience

To assess the seismic resilience of a system using existing recovery data, two major steps are necessary:

1. Examine observed recovery in order to:
   a. Estimate the fragility of the system components, ground motion intensity and physical properties of the structure and its natural environment (i.e. soil conditions)
   b. Mathematically derive the recovery rules, i.e. model the applied recovery strategy
2. Quantify resilience in order to:
   a. Estimate the extent of system damage, which, combined with combinatorial optimization, is used to express the performance of the network employing service-specific performance indicators
   b. Estimate the impact of the disruption on the population during the recovery phase
   c. Quantify the resilience of the system, quantified as the performance loss of the infrastructure during the recovery period.

In the particular case of a water distribution network, the components representing the links are the buried pipelines. In order to better understand how the pipe repairs are prioritized during the recovery process, repair data must be coupled with the community data including, as shown in Figure 2, the number of inhabitants, and the critical infrastructure like schools and hospitals. To predict the resilience of the system, estimates of the network damage are realized by applying the fragility functions to the simulated ground motion intensity maps. Using the census data (Figure 2), the impact on the population over the recovery period can be measured as the number of households, businesses, or people experiencing water outage. Finally, by knowing the initial performance of the system and its functionality recovery, its resilience can be computed.

3. Recovery study

a. Characterizing the pipeline fragility

Pipeline fragility is generally expressed as a break rate (i.e. number of breaks over a length unit). Using data from the Canterbury earthquake sequence (Figure 3), new break rate functions for buried pipelines are formulated. Among the available information on the network and the breaks, input parameters include:

- Ground motion intensity
- Cyclic resistance ratio
- Pipe material
- Pipe diameter

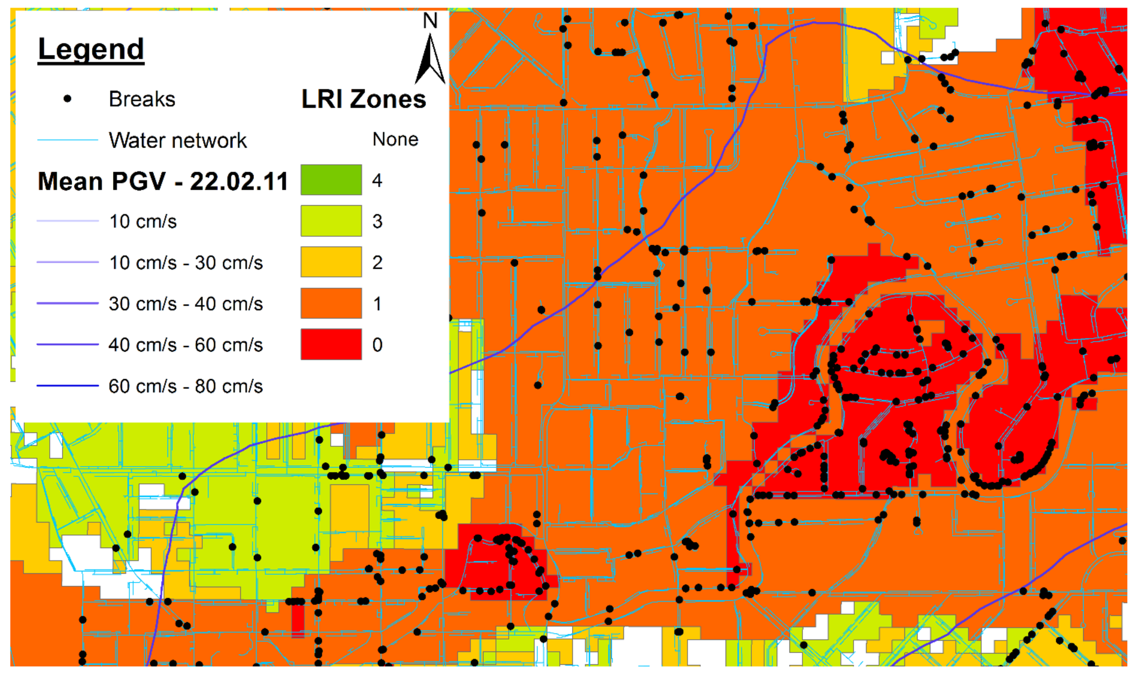

Figure 3: Breaks, GM intensity of the February earthquake and liquefaction resistance index zones of Edgeware - Dallington

b. Derivation of the recovery rules

Recovery rules are derived from a temporal and spatial analysis of the break repairs taking into account the community (e.g. number of people, critical facilities, or businesses) benefiting from the repairs. To illustrate this concept, Figure 4 provides an example of the recovery of Southshore after the 22nd of February earthquake (2011).

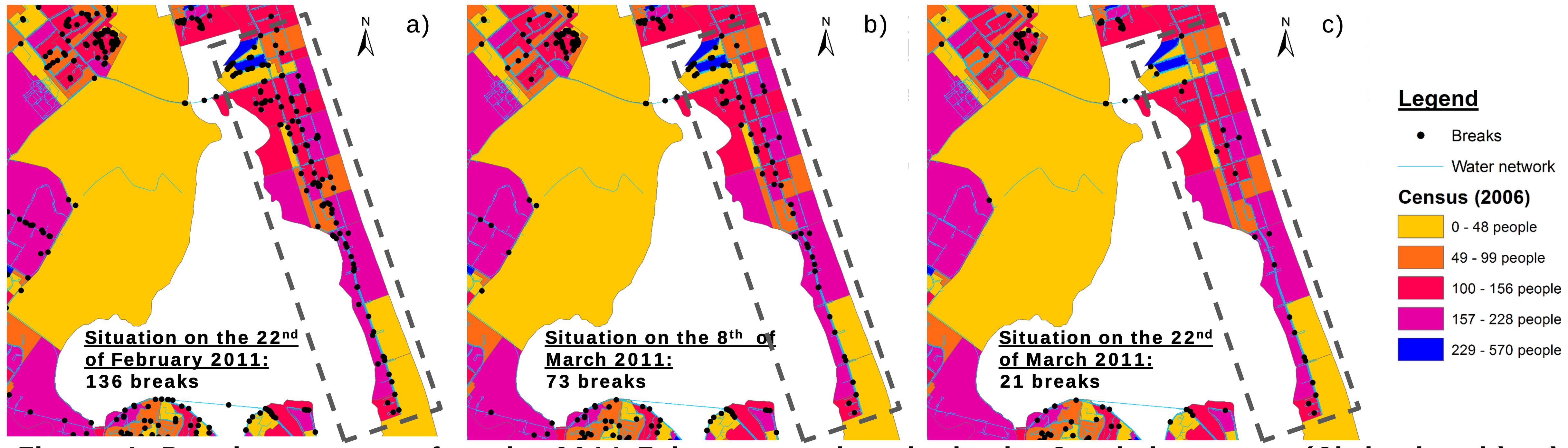

Figure 4: Repair sequence after the 2011 February earthquake in the Southshore area (Christchurch). a) number of breaks after the earthquake, b) reduction of remaining breaks after two weeks of repairs and c) after one month

3. Prediction of the network resilience

a. Estimation of damage extent

Using ground motion estimates and the developed pipeline fragility functions, the number of breaks after an earthquake can be estimated. Results will be similar to the ones displayed in Figure 3 for the February earthquake.

b. Impact on the population

Applying the recovery rules on the simulated damage maps and knowing the community data (i.e. Figure 2), the number of people impacted by an outage can be tracked over the recovery period. The impacts can be characterized for each service delivered by the water network using appropriate performance indicators (Davis, 2014):

- Delivery
- Quantity
- Fire protection
- Quality
- Functionality

c. Computation of the system resilience

Finally, by knowing the performance of each service as illustrated in Figure 5 for the water network of Los Angeles, the resilience of the system can be computed for each of the abovementioned services by integrating their performance loss over their respective recovery time.

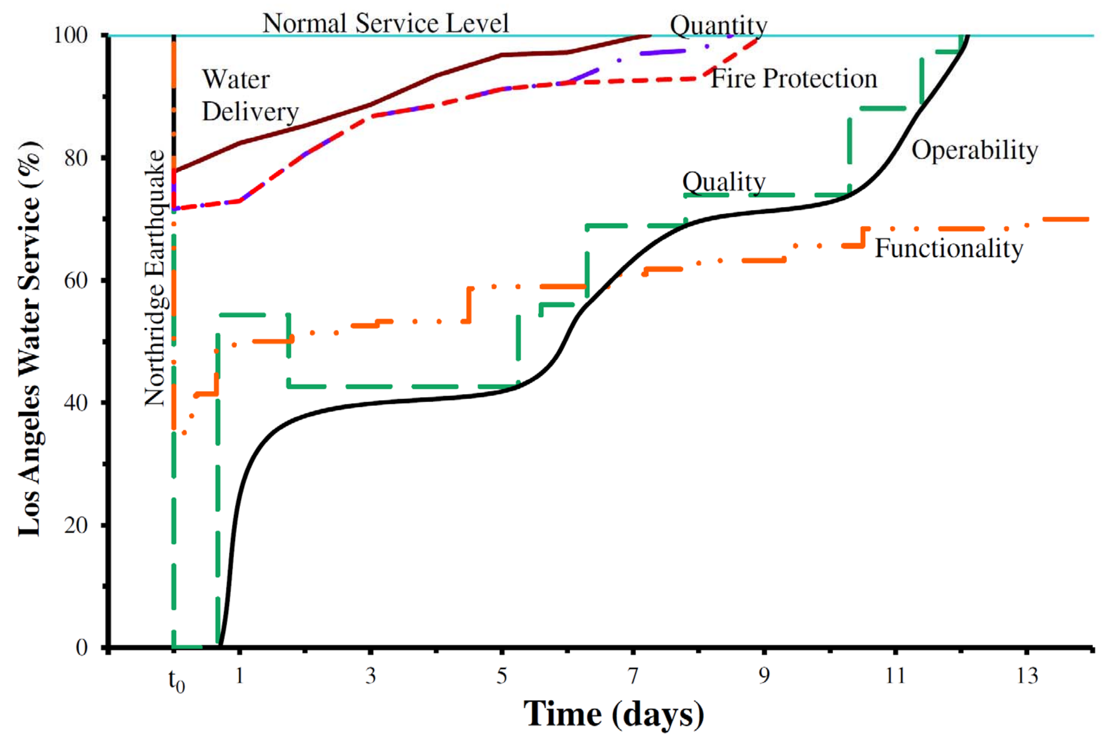

Figure 5: Recovery of the Los Angeles water network services after the Northridge earthquake (Davis, 2014)