Technical Note 08 – Sensitivity Analysis for Seismic Damage Prediction

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1 Background

Predicting seismic damage is important but like all forecasting it is an inherently uncertain process. Break rates are usually determined by fragility functions, but some of these can give a false impression of accuracy and some sensitivity analysis is appropriate to ensure responses are adequately robust.

This document reviews potential sources of error and indicates how to accommodate uncertainty and variations.

2 Sources of Error

The process for predicting break rates in buried services as a result of seismic events is summarised below:

- Identify seismic hazard(s);
- Identify ground response;
- Determine buried system response.

Apart from the inherent limitations of predictions, potential sources of error include:

- Limited geological knowledge;
- Asset data errors;
- Fragility function accuracy.

2.1 Limited Geological Knowledge

The events in Canterbury in 2010 and 2011 and in Seddon 2013 showed that not all faults and hazards have been reliably identified.

Seismic events are unique occurrences. Variations in local geology influence the detailed path for seismic energy to travel from the epicentre to any specific point, and the ground response is then influenced by local conditions (Morris et al, 2014). The response of the buried systems to disturbance of the surrounding soil is then influenced by factors including intensity, timing, relative orientation of the direction of motion and the system, materials construction, installation practices, and operating conditions. The detailed response at any one point could potentially be different from that of a nearby system.

There is a substantial body of evidence that liquefaction of soil increases damage rates in buried services. Liquefaction risk indices have been developed, but for practical reasons these are applied across convenient land areas or segments of the utility system. This means that any one area will have a single risk indicator index when in reality it could include several soil types and risk factors. Liquefaction is also influenced by local water table levels and the risk will, accordingly, vary throughout the year by season and by specific rainfall and groundwater details.

2.2 Asset Data Errors

Many asset owners have incomplete data records on their assets. In some cases this is because historic records are incomplete, in others because information has been lost during system changes or mergers and restructures. Older asset management systems also had limitations such as not being able to record repairs without over-writing existing records – for example, a repair in 1988 could overwrite the date and material type of an existing older system.

Another issue can arise where a new system is introduced but the existing data is either not entered or is not updated promptly. As an example, one of the major urban centres in New Zealand had asset records which recorded that almost 80% of one buried pipeline system had Unknown material type. Checking of existing as-built records and comparison with nearby contemporary assets (data cleansing) reduced this to around 20% (Morris, 2015). The data existed, but the system had not been updated until the problem was identified.

Many pipeline systems are described using terminology that over time results in multiple codes for the same material (PVCU, PVC, UPVC for example are all used to describe Unplasticised PVC (Stephens and Morris, 1993)). In some cases two variants of material are known by the same name – for example HDPE could describe an older medium-strength form of PE or could describe a modern PE100 with superior strength and crack resistance. Descriptions of steel pipelines often fail to clearly distinguish between older forms of manufacture with low quality joints and modern systems with high quality integral corrosion protection or external corrosion suppression systems.

2.3 Failure Records

There are limitations on predicted earthquake damage that need to be considered over and above the inherent limitations of any form of forecasting. These mainly relate to the difficulty of obtaining accurate information following a major and disruptive event and because the priority of the recovery teams is to restore some functionality under very difficult conditions rather than to accurately record the form of damage observed and likely causes (Tromans, 2004, Hughes et al, March 2015).

Even in Christchurch where mobile phone cameras were reasonably commonplace, images taken at night in wet and dirty conditions often provide only limited information and often lack clear location data (Hughes, 2015). This is not a criticism of the repair teams who are working under very trying conditions while also concerned about their family and friends. It could be argued that it marks the quality and dedication of a recovery team that they still remember to take pictures under such circumstances.

It can also be difficult to determine whether observed damage was caused by an earthquake, was pre-existing damage that was aggravated by the event or if the damage was present before and was unchanged by the event (D Heiler, private communication 2013). A related issue is that determining what damage requires intervention can also be difficult, as reflected by changes in practice over time in Christchurch (Heiler and Appledoorn, IPWEA 2015).

Identifying the impact of defects in stormwater systems which are designed to accommodate specific severe (and usually infrequent and irregular) rainfall events is particularly challenging. A degraded stormwater system could perform acceptably in normal conditions, when the peak flow capacity has been substantially reduced.

Despite these limitations, some general trends can be identified:

- In gravity systems, recorded damage will tend to overstate that caused by an earthquake because gravity systems often include detectable defects that do not have a significant impact on performance;

- Gravity systems can remain functional when damaged so that damage might not be identified until well after the event. The number of failures could be under-estimated if damaged systems were not identified and fixed following an event;

- In traditional pressure systems, loss due to leaks means that most damage is likely to be detected and repaired. The number of failures could be slightly overstated if pre-existing leaks were identified and fixed following an event;

- In more modern ductile pressure systems, the ability to deform and experience sub-critical damage means that damage reported in the immediate aftermath of an event is likely to understate the total damage caused;

- Where areas are red-zoned, the damage in these areas is unlikely to be documented, so the areas that suffered the most are least likely to provide damage statistics.

Where multiple events affect the same area - Düzce in Turkey or Christchurch for example – or where there are multiple severe aftershocks, the challenge is increased, since a fault could develop or could become worse as a result of any one of the events. Damage could also initiate in one event and become worse in a subsequent one.

A further issue is that where only small amounts of a system or material are exposed to a particular hazard, the apparent failure rates can be highly unrepresentative (Kongar et al, 2014). This is particularly important if an unrepresentative part of the system with limited geographic spread is exposed to liquefaction or ground deformation, since the reported failure rate will be very high over short segments of pipeline. Work on Kaiapoi (McFarlane, 2016) also showed that acceptance standards can change as work progresses. This reflected changes in the understanding of the ability to repair damaged systems as well as economic necessities. However, decisions about above ground assets also had an impact, since there is rarely benefit in restoring a system serving a red-zoned area, or a district whose future use has not yet been determined.

Observation-based systems for classifying the severity of liquefaction necessarily require an element of judgement in determining which grade to apply across a specific area. Where liquefaction is often classified on a 1 to 6 scale, the analysis of its effect on buried systems and surface structures often relies on a simplified system which aggregates one or more liquefaction classes or indices. This is a practical consideration based on the need to include sufficient pipeline in a sample to provide a meaningful analysis, but it introduces another source of error.

2.4 Fragility Function Plots

Figure 2-1 shows an example fragility function. For any given event, a straight line or curve indicates the relationship between break rates and shaking intensity for a specific event. The range of predicted break rates spans an order of magnitude across different events.

In part this wide variability is because each event is different, but also because the range of materials, the size range, the construction history, operating requirements, maintenance practices and interactions with other buried services and with surface structures is all different. Add in historic changes of use and differences between in manufacturer specifications and products, and the range starts to become less surprising.

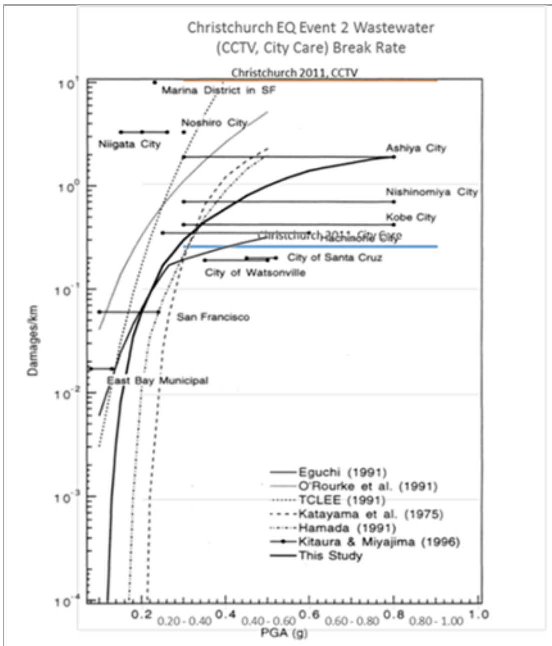

Figure 2-1: Fragility function for several historic events from Tromans, 2002. Break rates for water supply systems in Christchurch February 2011 have been added in blue.

Despite their limitations, fragility functions provide one of the most useful initial guides to estimating overall patterns of behaviour. Some form of sensitivity analysis is recommended to allow for the inherent inaccuracy of forecasting, and to address the impact of uncertainty on response plans.

3 Sensitivity Analysis

While predicted break rates have limitations, they are still the best tool for understanding the likely impact of a seismic event on buried infrastructure. Despite the limitations noted above, in practice the local and historic factors mean that the range between different events is wider than the variability expected between similar systems subjected to similar events. This means that a simple sensitivity analysis can be used.

For planning purposes, using the extreme range for recorded break rates (an order of magnitude or more) does not add value and instead risks degrading the credibility of the forecast. Consideration of events from similar time periods reduces the differences in systems composition, and indicates that a narrower range (more like half an order of magnitude) is more representative.

Given the inherent uncertainty of forecasting break rates, it is important to remember that these are broad brush indications of what can be expected. For planning purposes, the scale and distribution of damage is more important than the specific numbers. Based on this unless specific accuracy levels are provided with fragility functions, we have proposed using a sensitivity range of x 2 and x 0.5.

4 Recommended Break Rate Approach

- Forecast break rate based on predicted event, soil risks, system composition (which materials) and fragility functions. This is the base condition for planning the impact on customer levels of service;
- Apply a worst case scenario using double the break rates;
- Apply a best case scenario of half the break rates.

The following approach can then be used to test the likely impact:

- If the worst case scenario (double the base level) is within your community's ability to cope, then both of the other cases will also be manageable;
- If the best case (half the base level) is unacceptable, then both of the other cases will also be unacceptable;
- If some cases are acceptable and others are not, then a range of options can be considered. These could include one or more of making the system more resilient; identifying triggers for calling in outside help; identifying triggers for relocating people either within the community or to the outside to ensure that acceptable service can be maintained to those remaining.

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