Technical Note 12 – Post-Event Damage Assessment

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1 Background

Organising an effective recovery programme following a seismic event requires an appreciation of the scale and distribution of damage. This document shares knowledge gained by previous quake events to help develop assessment plans.

2 Seismic Damage to Buried Services

Damage to buried services is caused by ground movements. The extent and severity of damage is influenced by the type of ground movement experienced. Shaking usually affects the widest area, followed by liquefaction, but fault crossings, permanent ground deformation and slope failures are very damaging though usually more localised in extent (Table 1).

Table 2-1: Summary of extent and severity of different types of ground movement

Type of ground movement	Area affected	Damage severity
Shaking only	Wide	Light to moderate depending on intensity and system affected
Liquefaction	Moderate extent but only affects particular soil types	Moderate (may be severe for gravity systems)
Lateral spread and settlement	Localised to specific areas	Severe (may be moderate for some modern systems)
Slope failure	Localised to slopes	Severe (may be moderate for specifically designed systems)
Fault movement	Limited	Severe

3 Damage Assessment Guidelines

The following questions formed the basis for damage assessment guidelines developed by Opus for Christchurch City Council to assess the extent and nature of damage to the Christchurch Central Library buildings. These were originally used to establish scope of work and cost to repair buildings to a near-new condition to assist in resolving insurance claims but have also been used with bridges.

1 What physical changes occurred due to the earthquake?

2 How do physical changes compare with predicted performance under load?

3 What function of usefulness has been reduced by physical changes

4 What is the impact of any reduction

5 Has all the damage been identified?

6 What further investigations could identify hidden damage?

7 Can what is damaged and lost be restored to as-new condition ?

8 What work is required to restore the higher of 34% of National Building Standards or to pre-quake level?

These questions have been interpreted below to help assess buried services after a seismic event.

1 What physical changes occurred due to the earthquake?

The first stage is to determine which parts of the system are still working. This is easier to determine for a supply system (gas, water, electricity, telecoms) since customers with no service will identify the problem when they try to use the damaged service, and will usually attempt to report the outage soon after the fault is identified. In addition, pressurised water systems will create new water features, puddles, fountains, etc – while gas escapes have a distinctive odour.

Failures in gravity wastewater systems are less readily detected since the systems usually have some storage capacity even if unable to convey waste, and may effectively convey waste from a building while releasing the waste in an inappropriate place downstream.

Damage to stormwater systems may be even harder to identify because they are not required until there is a significant rain event. Citycare reported a case where a Masterton resident only discovered extensive damage to an earthenware stormwater line during heavy rainfall approximately a year after the Eketahuna earthquake (Erasmus, 2014).

Important information to help identify areas where damage can be expected includes:

- Location and number of reported breaks;
- Customer service outage reports;
- Observed distribution and severity of liquefaction and permanent ground deformations (PGD).

2 How do physical changes compare with predicted performance under load?

In most cases, damage predictions for buried systems are expressed as predicted break rates or number of breaks based on expected ground-response, systems construction and fragility functions.

While it is normal to focus on higher-damage areas where the potential benefits of intervention are likely to be greater, it can be useful to also look at areas expected to be relatively lightly damaged. This provides a convenient test of whether the prediction is valid for the actual event, or whether the damage is greater or less than predicted.

Put simply, if:

- the areas expected to be worst are relatively undamaged, the prediction is probably over-pessimistic;
- the areas expected to be good are in bad condition, it is over optimistic;
- both are true then the prediction is probably flawed and may need to be disregarded.

3 What function of usefulness has been reduced by physical changes?

For buried systems this question is not readily answered in detail because many buried systems cannot be inspected directly to determine physical damage However, reports of service outages and problems can be used to build up preliminary assessments based on how buried systems performed in previous earthquakes. This information will have been used when predicting likely damage from earthquakes.

Even without access to more robust data, there are some general principles that can be used to get started. For example, older systems tend to break more readily than newer systems, smaller systems more than larger ones and continuous flexible pipelines tend to have lower break rates than other systems. So if the condition of a newer system is known, it is likely that the condition of a nearby older system is similar or worse, and similarly a damaged distribution system will usually have less damage than the smaller associated service pipes and customer connections.

4 What is the impact of any reduction?

For utility services, the effect of any reduction in usefulness is best considered with respect to impact on levels of service. Water New Zealand Guidelines “Levels of Service Performance Measures for the Seismic Resilience of Three Waters Network Delivery” (Water New Zealand, 2015) are intended to help understand the likely impact of a predicted event on levels of service. The same approach could readily be adapted to assess how levels of service have been affected for utilities other than three waters services.

5 Has all the damage been identified?

It is unlikely that all damage will be identified in a buried system. Buried systems are inherently difficult to inspect and buried systems can suffer damage that is not immediately apparent.

- Sub-critical damage degrades service but without causing failure. Examples of reduced capacity include buckled or deformed pipelines and over-extended PE pipelines which can provide some service but with reduced capacity or increased head loss.

- Sub-critical failures can also lead to delayed failure. An example of this would be where a corrosion protection system is damaged, so that corrosion can now initiate and proceed where it would not have done so before.

- Hidden failures are mainly a feature of gravity systems as mentioned above, but the key feature of hidden failures is that they are not identified unless actively looked for or when service is called upon to provide a service it is no longer capable of providing in full. An example of a hidden failure is where a stormwater pipe has been damaged in a way that reduces its capacity below the design level. It performs acceptably in most conditions but when it is called upon to convey water from a 50-year flood, it fails to do so as its effective capacity has been reduced.

- Operational problems can occur in ducted services where the service is retained, but the ability to install a new cable or remove an existing one for maintenance is compromised by the damage.

If the extent of liquefaction and PGD aligns with predictions, there is greater confidence that any predictions of the amount and distribution of damage will also be more useful. This will be complemented by an appreciation of which systems are likely to experience subcritical, delayed and hidden failures, since initial repair rates will underestimate the total amount of earthquake damage caused to these systems.

It is also useful to appreciate which systems can operate despite the presence of extensive defects (as is the case with many gravity stormwater and wastewater systems). Damage assessments conducted on these systems after an earthquake will include damage that was present before the earthquake as well as damage caused by the earthquake.

6 What further investigations could identify hidden damage?

For water supply services, leakage management processes will usually provide a good indication of location and extent of damage. Initially passive leakage location where public and staff report visible leaks and problems is likely to be an important source of information to identify leaks. This can subsequently be complemented by an active leakage approach when time and resources permit. Even a simple water balance assessment or comparison of bulk meter flows can be useful. A more refined leakage assessment process can be implemented later to locate high leakage areas and to locate specific leaks.

7 Can what is damaged and lost to be restored to as-new condition?

This is an important question, the answers to which are influenced by physical and economic realities of what is possible, and by policy decisions. Examples of policy-oriented decisions could include whether services can or should be restored to an area that is to be red-zoned; whether the original level of service is still appropriate, and whether another location would be a better option (Appeldoorn and Heiler, 2015).

Where there are specific ground-related problems that have been newly identified, the following assumptions can be applied.

- Repair will restore performance to the average condition of the system before the failure, but cannot raise it above this standard.
- Substantial replacement would normally restore condition to as-new.
- Lining such as CIPP might restore an asset to an acceptable or near-new standard but it may not be possible to restore a heavily degraded pipeline to as-new condition.

Experience in Kaiapoi (Mc Farlane, 2016) showed that the work required to restore acceptable function to a damaged wastewater pipeline could be substantially less than that required to restore it to pre-quake condition, and as mentioned above, the original condition could be difficult to establish.

8 What work is required to restore the higher of 34% of National Building Standards or to pre-quake level?

This question is not directly applicable to buried services since the National Building Standards do not apply. When recast as “What work is required to restore the higher of current standards or to pre-quake level of service?” it has relevance for determining which component of restoration work is for replacement and which is for betterment. The answers are likely to be of interest in managing insurance claims, especially where replacing like for like is impossible due to older systems being unavailable, or where current or preferred performance requirements exceed those of the existing system.

It should be possible to determine an effective answer with reference to current asset management practices based on Optimised Renewals Costs (IIMM, 2015) to help define the split between renewals and improvements.

4 Detailed Approach

More specific damage assessment approaches described below are intended to complement lifelines plans.

General damage assessment approaches can include the following:

- Identify which critical systems and components such as bulk storage and transmission lines are damaged and establish the extent and severity of the damage;
- Liquefaction and lateral spreading can be visually identified at the surface without specialist knowledge and both correlate well with higher levels of damage. Slope failure is also readily identified. These areas are likely to have higher break rates than areas with no visible ground damage;
- Map out visible leaks and breaks and customer reports of loss of service and breaks to identify problem areas;
- Compare the reported event magnitude with predictions used in damage forecasts. If the scenario(s) considered are similar to the actual event, forecast break rates, and damage distributions are likely to be useful;
- Compare the estimated damage rates with damage predictions. This will help identify if external resources are required or if the event can be managed with existing resources. Where possible obtain photographs of breaks as this can assist in identifying what kind of repair strategy is appropriate;
- Start with the planned priorities, but keep these under review as the number and distribution of failures becomes known.

While initially the focus will be on high risk systems, in the medium to longer term it is likely that some form of triage system will be required to ensure that available inspection resources are used efficiently. Prioritisation systems such as the Pipe Damage Assessment Tool (PDAT) developed for use in Canterbury (Kiley et al, 2013) provide a useful guide for identifying which gravity pipeline systems are worth inspecting based on exposure to risk of damage. The initial risk assessment is followed by a progressive escalation of inspection methods each using progressively more detailed, but scarcer and more expensive resources (e.g. moving from pole cameras through to CCTV).

The most obvious starting point is to minimise inspection of buried services in red-zoned areas, but ultimately the preferred approach is to focus on restoring acceptable levels of service to customers, which will require reference to the levels of service determined using the "Levels of Service Performance Measures for the Seismic Resilience of Three Waters Network Delivery" guidelines (Water New Zealand, 2015).

Systems specific considerations for three waters systems are outlined below:

All systems

Check on vulnerable customers first following existing policy for dealing with customers who are unable to cope without reliable supply or who are in an area where supply cannot be assured.

Areas with substantial above ground structural damage may be best avoided initially, as rubble is likely to make inspection and repair more difficult. The benefit of repair is also limited if few buildings remain usable.

Pressure systems

Leaks

Identify flow changes at metered and observed locations, visible leaks and ponds, customer service outages and water quality complaints (flow, quality, continuity, pressure). Start with larger pipelines and progressively chase down active leaks, using valves or squeezed off PE pipelines for temporary isolation where repair is no longer cost effective and arrange water distribution points (whether through standpipes or supply to agreed community centres).

Gravity systems

For wastewater systems

Manhole inspections are also useful for this task whereby a manhole holding water indicates a blockage.

A triage type system based on a protocol of risk, visual check for flow, pole camera and CCTV was effective in Christchurch at maximising availability of expensive and scarce CCTV resources for critical lines where repairable damage was expected (Kinley et al, 2013).

Avoid inspecting lines known or suspected to be damaged beyond repair, and where a tolerable temporary discharge route exists.

If there is widespread silt intrusion from soil liquefaction, a flushing protocol will be needed as uncontrolled flushing could block downstream pipelines as silt accumulates.

Stormwater systems

If a stormwater system collapses, it may not be apparent until sufficiently severe rainfall highlights its reduced capacity or if it is actively inspected.

The priority would normally be to confirm condition if the stormwater pipeline provides temporary flow paths for wastewater or are specifically designed to minimise risk to high criticality services and assets including those needed for control and management of the recovery.

5 Conclusions

- It is essential to pre-plan a damage assessment approach to complement established lifelines programme requirements;
- A good plan will refer to damage predictions as a means of highlighting higher-risk areas, and will also take account of the impact of damage on Levels of Service and restoration of services;
- It is important to be mindful that unexpected effects are likely due to a number of sources, including inherent limitations to forecast accuracy and the possibility of unidentified fault movements. This means that it is useful to establish at an early stage how well the event matches the predicted behaviour, especially as detailed behaviour of systems can be influenced by very specific local factors.
- In the short term, the response is likely to draw heavily on the lifelines response plan, but in the mid and longer term some form of triage system is likely to be needed to maximise benefits from scarce resources.

6 References:

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