Earthquake recovery versus routine maintenance of the waste water network in Christchurch

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Earthquake recovery versus routine maintenance of the waste water network in Christchurch

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ABSTRACT

Cities have waste water networks that are ageing and offer little or no resilience to disasters. Parts of these networks will have been designed and constructed in accordance with design guidelines that are long since outdated. After a disaster, the damage to a wastewater network will vary throughout a city, partly depending on the prior state or level of service (LoS) of the assets. Repairs will be done to bring assets back to the same LoS or remaining asset life as before the disaster according to design guidelines. Local asset owners must therefore know the state of their assets prior to disasters so that they can prove what damage is caused by the disaster, especially because there are usually different organizations responsible for repair and for later maintenance expenditures. A way to affect the level of repair is by changing design guidelines. It is recommended that asset owners maintain up-to-date asset registers and anticipate disasters by preparing design guidelines ready for emergency situations.

KEYWORDS
Disaster recovery; wastewater network; asset life

Introduction

In Darfield near Christchurch, New Zealand, a magnitude 7.1 earthquake occurred on 4 September 2010. It was felt over most of the country and caused considerable damage in central Canterbury, especially in Christchurch. Christchurch was considered to be in a moderate seismic zone; historically, the earthquakes affecting Christchurch were in distant faults. Now, significant damage was suffered by buildings constructed without adequate reinforcement. Some walls collapsed, and a number of historic buildings were badly damaged. An initial estimate of the cost of the earthquake was NZ$4 billion (Wood, Robins, & Hare, 2010). The earthquake caused the soil in Christchurch and surrounding cities, mostly consisting of water-saturated layers of soft sand and silt, to liquefy. Locally, areas had been offset up to 5 m laterally and up to 1.3 m vertically (Hornblow, Quigley, Nicol, Van Dissen, & Wang, 2014). In the liquefied areas, there were cracked footpaths and roads, damage to the water supply and especially the city sewerage system suffered major damage.

On 22 February 2011, Christchurch was again hit by an earthquake. The earthquake was considered to be an aftershock of the earlier Darfield earthquake and was less powerful with a magnitude of 6.3. Although the earthquake was less powerful, the shaking was much more destructive due to the proximity of epicentre to the centre of the city. In the city, the ground accelerations were up to four times larger compared to the earlier quake. This time there was much more damage to buildings. Over a quarter of the buildings in the central business district were damaged so severely that they had to be demolished. Also, the liquefaction was much more extensive than in the September 2010 earthquake (Van Ballegooy et al., 2014). In Christchurch, most of the liquefaction occurred in the central city and the eastern suburbs, where nearly 400,000 tonnes of silt mixed with wastewater caused not only significant damage to the infrastructure but also formed a public health risk (Heiler, Moore, & Gibson, 2012). As a response action, the government activated the National Crisis Management Centre, and declared a national state of emergency the day after the disaster. Christchurch's central business district remained cordoned off for more than two years.

Following the February 22nd earthquake, 40% of the network had limited to no service for a month following the event. Electricity was restored to 75% of the city within three days, and to 95% within 10 days. Water supplies and sewerage systems would take much longer to restore, up to several years in some areas. Christchurch has a very flat terrain, with an average slope of .1–.2% from the western suburbs towards the east near the coast line. The city's existing wastewater network consists of mainly gravity pipes installed in the middle of the road with minimum cover of 1.2 m. Due to the flat topography of the land, the grades in the gravity system are significantly less than normal wastewater networks, with velocities of less than .7 m/s. As a result of the flat grades, traditional maintenance included regular flushing of the network with water from shallow wells. Since 1986, when the Drainage Board Manual was last revised, more robust self-cleaning velocities coming with the use of higher grades were introduced (Christchurch City Council, 2015). The pipe materials used in the development of the network include earthenware, concrete, PVC and asbestos. The use of different materials is reflective of the preferred choice of materials at the time of development (Cubrinovski et al., 2011). During the earthquake sequence in Canterbury, different pipe materials performed differently with PVC and PE pipe materials performing better in lateral movement, differential settlement and areas of liquefaction than asbestos and earthenware (Cubrinovski,

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Henderson, & Bradley, 2014; O'Rourke et al., 2014). Overall, the damage to the wastewater network mainly consisted of loss of grade in gravity pipes, damage to pipe joints and high levels of liquefaction infiltration into the network (Cubrinovski et al., 2011). The majority of damage to pipes occurred in areas with high levels of liquefaction, with 80% of broken pipes found in areas of high levels of liquefaction (Cubrinovski, Hughes et al., 2014). The implications of the broken network ranged from increased overflows into the local rivers which led to environmental consent breaches, secondary damage at the city's wastewater treatment plant with sand and silt entering the plant and also the use of chemical toilets in areas where no service was available following the earthquakes.

The emergency response that followed the September 2011 earthquake used the contractors that were at that time already under contract for routine maintenance with the city council who pre-determined day rates for emergency restoration works. Contractors that already had a presence in the area called all available staff into action according to the standing maintenance contracts' conditions. Following this, a programme of works managed by the local City Council was established to start the systematic repair of the city's broken infrastructure. This programme was referred to as 'Infrastructure Rebuild Management Office' (IRMO). IRMO was created as a collaborative effort between delivery teams for rebuilding Christchurch. It divided the city into four geographical areas. Repair of the infrastructure in each area was allocated to a New Zealand construction company that was already involved under the emergency response. Each construction company was responsible for engaging its own design consultancy and managing the necessary designs. This programme worked effectively and provided a quick response to the city's infrastructure rebuild needs. Contractors operated under a cost plus arrangement. The method created cost transparency allowing for reimbursement with an additional margin. With the increase in damage, caused by 22 February 2011 earthquake, a different procurement model for delivering the repair programme was required, and the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) alliance was formed. SCIRT is an alliance between various participants and is ideal for projects with high risk associated with unknown scope of works and significant time pressures (Gransberg & Scheepbouwer, 2015); alliances also provide access to early contractor involvement (ECI) during the design phase to provide constructability advice and reducing risk (Department of Treasury and Finance, 2006; Gransberg, 2013). The SCIRT alliance was created between Central Government, Local Government and the New Zealand Transport Agency as the owner participants and five of the major construction companies in the New Zealand civil construction industry as the non-owner participants (Botha & Scheepbouwer, 2015) that were involved in IRMO.

SCIRT became responsible for repairing the damaged horizontal infrastructure that included Christchurch's water supply reticulation and reservoirs, wastewater reticulation and pump stations, storm water reticulation and pump stations, road networks including bridge repairs and retaining walls of both the Local Council and the New Zealand Transport Agency. The repair consisted of assessing the earthquake damage of the networks, managing, co-ordinating, prioritizing, designing, estimating and delivering the various work packages associated with the rebuild of the Christchurch infrastructure programme. The alliance included staff seconded from different consultancy companies, client organizations as well as from the construction companies.

In response to the lack of resilience and to include modern materials in the rebuild, the Christchurch City Council developed and introduced the Infrastructure Recovery Technical Standards and Guidelines (IRTSG) at the start of SCIRT. These cleared the way for an immediate response to the worst affected areas by specifying the requirements for the replacement of the damaged infrastructure. Later during the rebuild, the design guidelines were changed as more information about the damage became clear. Three revisions of the IRTSG have been issued to date. The revisions included refinements to the acceptance criteria of earthquake damage as well as separating construction and service defects identified during the inspection of the pipe (Heiler et al., 2012). It also allowed the use of more modern materials in the rebuild. Initially, the cost of the earthquake damage to the infrastructure was $2.94 billion; later using the newer guidelines, this was adjusted downwards to $2.4 billion (Office of the Auditor General [OAG], 2013).

In this paper, the different wastewater design guidelines that were developed and implemented during the rebuild of Christchurch's horizontal infrastructure will be evaluated. Initially, the design guidelines prescribed quick repairs, and later versions were less likely to classify damage as earthquake related. The progressive development of these guidelines to recognize the remaining asset life of the wastewater pipe network, together with the causes of the design guidelines, will be discussed. In a disaster, there are a number of public agencies involved, local and central governments, and also functional governmental organizations like transport organizations. Each will have a certain role in the repair organizations and likely a different role in the subsequent maintenance period. Tension between these organizations will have to result in different opinions on the amount of repairs (Lee, Rueda-Benavides, & Gransberg, 2016). The actual financial implication of the various design guidelines is outside the scope of this paper.

Literature review

Horizontal infrastructure is inherently vulnerable to geological hazards. Due to its linear extent, it is at an increased risk of suffering damage in a natural disaster like an earthquake that comes with changes in geological formations (Free, Anderson, Milloy, & Milian, 2006). Besides the direct effects of the actual disaster, the loss of infrastructure can cause a significant impact on the physiological and economic well-being of communities. Reconstruction projects should therefore aim to reduce the vulnerability of societies through building back better infrastructure (Palliyaguru & Dilanthi, 2008). Moreover, a lack of resilience in infrastructure can lead to ongoing disruptions, poor recovery following a disaster and also increases the likelihood of permanent loss of the infrastructure (Hudson, Cormie, Tufton, & Inglis, 2012). According to the Centre for Resilience of Critical Infrastructure (University of Toronto, n.d.) 'resilience in infrastructure' is the ability of the operations to respond to and absorb the effects of shocks and stresses and recover as rapidly as possible. According to Alexander (2014), a natural disaster can be shown in the performance levels of infrastructure against time (Figure 1).

After disasters, the performance level of infrastructure can drop as low as zero during or straight after the event. The immediate emergency response is targeted at bringing the performance level of infrastructure back to a minimum performance capacity or minimum level of service (LoS). This is then followed by a more organized 'Response' period to bring the performance

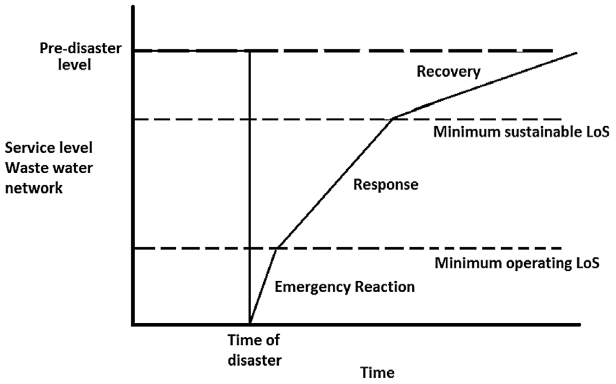

Figure 1. Timeline showing the service level of a wastewater network after a disaster versus time (after Alexander, 2014).

levels up to a minimum sustainable level. It is during the longer 'Recovery' phase that the performance levels are restored to the same routine level as prior to the event (Alexander, 2014).

Methodology

Case study research is well suited to answer the research question (Yin, 2003). How various design guides were used after a disaster depends on the reactions of local and national authorities. The Christchurch infrastructure rebuild programme, following the Canterbury earthquake sequence of 2010 and 2011, provided an ideal case to study. A programme of this magnitude creates a level of complexity that is difficult to evaluate using classical quantitative research methods. Thus, the study patterned itself after the methodology proposed by Gransberg, Shane, Strong, and del Puerto (2013) for complex projects. Furthermore, it is acceptable to use a single case study as a basis for scientific generalization as the purpose is to generalize the found procedures and behaviour (Yin, 2003).

In this paper, a qualitative analysis is made of the different, subsequent design guidelines that were approved and implemented during the infrastructure rebuild programme in Christchurch. The following data are used: documents from SCIRT, (design guidelines and/or progress reports) relevant research literature and interviews. The interviews were held with key personnel from SCIRT and related rebuild organizations. They were focussed but open ended and served to gain correct understanding of the evolution of the design guidelines and the relation with contextual happenings.

SCIRT repair programme

One of the first priorities of SCIRT was to undertake asset investigations of the asset types including the wastewater network. The wastewater network in Christchurch consists of more than 1600 km of gravity pipelines. With over half of New Zealand's closed-circuit television (CCTV) resource assisting with the CCTV programme undertaken by SCIRT, the estimated time to complete the investigation was expected to be four years from October 2011, when the alliance agreement was signed (Cubrinovski, Hughes et al., 2014). With December 2016 as the planned completion date of SCIRT (OAG, November 2013) and the asset investigation forming a critical component of the programme for informing the design teams, SCIRT developed a range of assessment tools, including visual inspections and a Pipe Damage Assessment Tool (Heiler et al., 2012). These tools were all used to assist in assessing the damage to the wastewater network across the city. As the asset assessment programme progressed and more information on the damage of the network became available, the design requirements were reviewed and adjustments were made to the design guidelines.

As the investigation works moved west across the city into areas that experienced much lower levels of liquefaction from the earthquakes and where modern pipe materials such as PVC have been used to construct the original network, the wastewater pipes performed better with less damage while service was still available. The reduction in the damage to the network combined with the council's regular maintenance programme, which included the flushing of the wastewater network, resulted in the amendments to the design guidelines by taking into consideration the remaining asset life of the pipes.

SCIRT also developed a tool for prioritizing the repair work by recognizing the worst affected areas as the highest priority. Generally, the work commenced with the deeper waste water repairs, followed by the roading, water supply and storm water. Geographically, the work started in the eastern suburbs where most of the liquefaction and subsequent pipe damage occurred and progressed towards the least affected western suburbs. SCIRT as an alliance encouraged innovation in design which was achieved through the submission of papers by the design teams working in SCIRT to a scope and standards committee (SSC). The SSC consisted of the asset owners from the local council as well as financial advisers from local and central governments that were authorized to approve departures or amendments from present design guidelines.

During the second half of 2012, the estimate for the rebuild of Christchurch's horizontal infrastructure was updated based on more accurate information on the damage in the network as well as the cost associated with the repairs. From the completed investigation works, it became apparent that not all the damage required immediate repair actions and as a result, significant changes to the design guidelines were developed and approved by SSC. These amendments to the design guideline recognized the remaining asset life of the pipes with the aim of restoring the network to the same LoS as prior to the earthquakes and also offered a significant saving to the client organizations with less repair work included in the rebuild programme of works.

Design guidelines during the Christchurch rebuild

During the SCIRT rebuild programme, several wastewater design guidelines were developed, approved and implemented during various stages within the programme as outlined in Figure 2.

As the wastewater network inspections in Christchurch progressed, it was realized that not all the damage had to be replaced immediately as the assets still had sufficient asset life remaining. This was recognized by the asset assessment team within SCIRT who in collaboration with CCC developed a set of Design Guidelines that provided guidance for assessing earthquake defects in gravity wastewater pipes utilizing asset life where appropriate. Design Guideline 43 (DG43) was approved by SCC and deferred all defects in the pipe network if the remaining asset life is more than 15 years (Heiler et al., 2012) to the routine maintenance programme (Figure 2). Approximately 30% of the network was designed and constructed in accordance with this Design Guideline (Trout, 2015). Early 2014, DG 43A was developed by SCIRT. This guideline, even though not implemented, worked on the basis of addressing only critical repairs that are expected to lead to failure of the particular asset within the next 15 years.

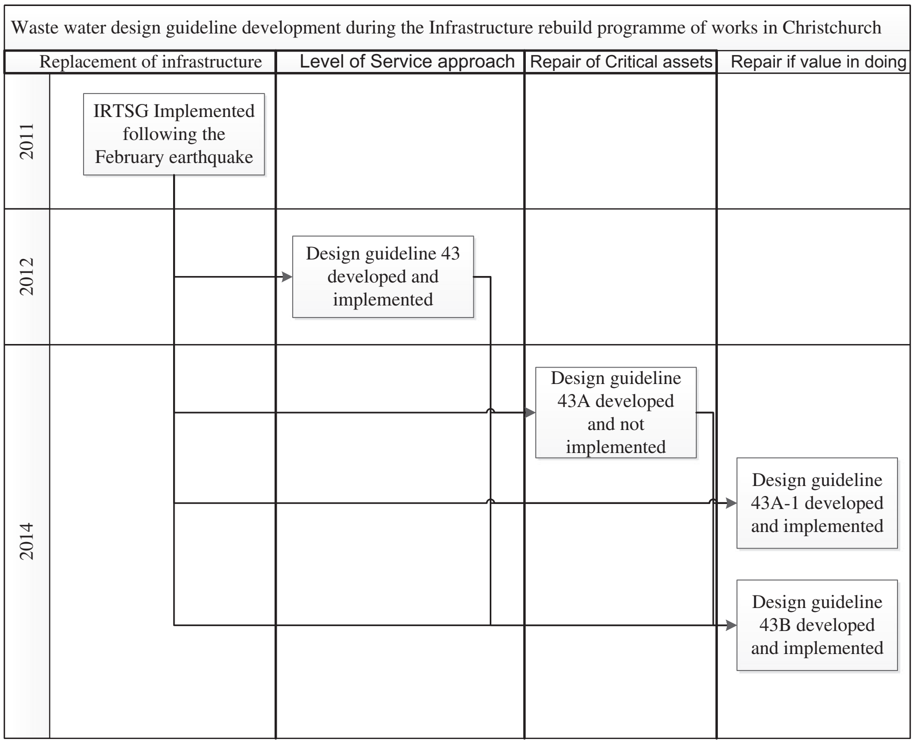

Figure 2. Development of wastewater design guidelines used during the Christchurch rebuild.

In June 2013, the cost share agreement between the Christchurch City Council and central government was signed which capped the central government contribution towards the rebuild and in particular to the council-owned wastewater network. This was then followed by an optimization process, which led to the development of a new set of design guidelines by central government which became the basis for their financial contribution for the remainder of the programme of works. This DG43B was specific on which defects were to be deferred to the maintenance programme by excluding defects pipes with a remaining asset life of more than five years from the rebuild programme of works and only repair critical assets where there is value in doing so and if the asset was impacting on the performance of other assets (Trout, 2015). As part of this optimization process, the Infrastructure Programme Steering Group (IPSG) was formed. This group was made up of representatives of the client organizations' asset managers as well as financial advisers from central government and replaced the SSC for all further approvals of technical decisions and amendments to specifications and design guidelines.

Parallely, the local government asset owners developed another DG43A-1, as a result of the possible impact on the maintenance budgets of deferred work from DG43B. DG43A-1 for instance accepted blockages in lower grade pipes as less critical for repairs than the integrity of the pipe. It was agreed between local and central governments that the remainder of the wastewater projects designed by SCIRT would be designed in accordance with both design guidelines followed by a cost review. At the end of detailed design, one of the designs would be constructed. The preferred design was selected through a discussion between representatives from both central and local governments based on the cost of doing additional repairs. The two Design Guidelines (DG43B and DG43A-1) set parameters around requirements for replacing an asset if it had a remaining life of less than five years, if the asset has been identified as a critical asset, had a high maintenance cost and impacted other assets (like cause a local road failure). The proposed designs were submitted to the IPSG with a recommendation and if the client organizations agreed to the merit of additional scope added to DG43B, the scope was adjusted for construction or else, DG43A-1 formed the design used for the rebuild of the particular project (Trout, 2015).

Discussion

After the earthquake sequence, the repair works started. The guides for the repairs were the design guides; these specified which damage would be repaired in what way. The repair effort can be split into three separate phases: reaction, response and recovery. After the last recovery phase, the situation would again be as it was before the disaster occurred. All the separate repair phases have a different goal and therefore need a different design guide for the repair effort. In Christchurch, the initial design guide, IRTSG, was developed based on routine maintenance. This was a conservative guide that resulted in a lot of repair and replace projects. After some time and upon realization that not all faults needed asset replacing or complete repair projects, a next design guideline was implemented. This guideline started repair only if an asset was at a service level that indicated it had a remaining asset life left of less than 15 years. If the remaining asset life was longer than 15 years, any faults would be deferred to the routine maintenance programme of the city council. This phase can be called the response phase. After this phase, the recovery phase should start that takes the network back to the level as before the disaster. In Christchurch, this started with another push to limit repairs by central government, although the local government developed its own design guide parallel. This meant that from this point on, all repairs and designs would be made in accordance with both design guides. After having made two cost estimates and two designs, the choice would be made in discussions between national and local government agencies.

The use of the different design guidelines entailed that the original procedure of getting a repair up to design specification was slowly changed towards repairing only the earthquake damage. In that later stage, it changed further towards only repairing earthquake damage if it had resulted in an asset with a very low service levels. More and more discovered conditions would become categorized as 'normal wear and tear.' This meant that more and more repairs would become the responsibility of the local government. Repairs would fall under the responsibility of the maintenance programme and not the earthquake repair programme. Each amendment to the design guidelines decreased the acceptable remaining asset life of the pipe to be used in the design of the repairs. This resulted in less damage in the network being accepted as earthquake-related damage, and less need of repairs. The amendments to the design guidelines became revised damage thresholds of acceptable earthquake damage. Different damage thresholds applied to different areas in the city because of the varying ground conditions and also different pipe materials performing differently with certain materials performing better than others.

The collaborative environment created by the alliance provided an opportunity for the designers and asset owners to work together to challenge and amend the design guidelines on remaining work packages without the risk of claims from contractors, a risk that would be far greater in more traditional forms of contracting. By taking into account the remaining asset life, a considerable saving to the client organizations can be offered by recognizing the remaining asset life of the pipes. Further research is recommended to look at the long-term financial implication of the various damage thresholds accepted as earthquake damage and also the impact of the amendments to the design guidelines on the LoS of the whole network after the rebuild.

There is another aspect to restoring assets to the same level or improving assets to a more 'resilient' level. General repairs and maintenance of existing assets such as buildings and equipment are regarded as operational expenditure (OPEX), but if improvements are expected to increase the useful life of the asset, the expenditure is regarded as capital expense (CAPEX). An important difference between OPEX and CAPEX is how they are treated for accounting and taxation purposes. OPEX are expensed immediately and are fully deductible. CAPEX are depreciated over the life time of the life of the asset. These differences in accounting can affect repair programmes by influencing design guidelines and vice versa. The question what disaster repair is OPEX and what is CAPEX is not easy to answer upfront. The case becomes even more difficult if different parties are responsible for CAPEX and OPEX expenditures.

Finally, insurance typically covers bringing the insured assets back to the situation as before the disaster. As it is often not known exactly what the remaining life of the assets was, there is some difficulty in assessing what damage is disaster related and what is normal wear and tear. For some assets, it is also not feasible to bring them back to a similar remaining life as before the disaster. Then, there are new building code requirements which may simply forbid to reuse the same materials, like asbestos as insulation. Then, there is the question what is betterment and what is repair. This is easy to see if a road is upgraded from having two to having four lanes. However, if the before situation is a road that had a reconstruction planned in two years, but after the disaster it developed longitudinal cracks along the entire length due to liquefaction, the question becomes more difficult. In the end, this road would become either better than before or it stays worse than before.

According to the United Nations, natural disasters around the world are increasing and, during the 10 years from 1992 to 2012, $3 trillion of damage occurred as a result of natural disasters. It is therefore becoming more important for organizations such as insurers, local and central governments to accurately know the state of their assets and estimate the cost of repair to infrastructure after disasters.

Conclusions

Here follow some conclusions and lessons learned that were found during the course of the investigations. First of all, it is important for asset owners to have a current asset register. This register should contain all assets including their state or LoS and the maintenance history. This register becomes a baseline when a disaster occurs. After a disaster, asset owners need to show what faults are disaster related and which are due to wear and tear.

After a disaster, there are various phases in the recovery process. Initially, there is an emergency reaction to bring the network back to a minimum operating level. Behind this, a more planned approach will follow that incorporates remaining asset life into repair decisions. This process of attributing more and more faults to normal wear and tear will increase until maintenance is again responsible for the work on the network. These separate phases need different design guides. The first is based on immediate repair to get the city up and running, while the second is aimed at more long-term repair. It is recommended that asset owners anticipate disasters by preparing different design guides.

Disclosure statement

No potential conflict of interest was reported by the authors.

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