How to plan for an earthquake event: Essential data collection approaches for underground infrastructure condition assessment

Irmana Garcia Sampedro, Strategic Asset Engineer, Christchurch City Council, Christchurch

Matthew W. Hughes, Lecturer in Geohazards, Risk and Resilience, University of Canterbury, Christchurch

Abstract

Is your organisation ready to cope with underground infrastructure condition assessment data collected after an earthquake?

Drawing on lessons from the 2010-2011 Canterbury and 2016 Kaikōura earthquakes, we provide guidance on how to make small differences in how your organisation currently collects and stores the necessary condition data to prepare for emergencies, especially for small- and medium-size councils without sophisticated asset management systems. Key questions to address include: Are you receiving condition assessment data in electronic format? Are your contractors providing XY coordinates when repairs are undertaken, or when providing photographs as part of visual assessment? Do you have an asset management system able to prioritise critically damaged underground infrastructure? Do you have easy access to your current network condition for insurance purposes? Simple business-as-usual improvements will provide enhanced preparedness and resilience capability in the event of an earthquake. In addition, we provide a framework for future data collection processes.

Key Words

Condition Assessment, CCTV, Emergency Management, Data Collection, GIS, Earthquake

Introduction

Timely and accurate condition assessment data for underground infrastructure play a key role in preparing for, responding to and recovering from the impacts of natural hazard-caused disasters. After earthquakes, large datasets can be produced during asset condition assessments, requiring processes and systems to best manage these data to inform sound decision making in the response and recovery phases. This paper summarises challenges faced in data management for underground infrastructure condition assessment, focusing on waste water systems but of relevance to potable water supply and storm water, through two significant earthquake events - the 2010-2011 Canterbury and 2016 Kaikōura earthquakes. Based on these experiences, we provide recommendations for changing business as usual (BAU) processes for improved disaster response and recovery, with the overall aim of increased infrastructure and wider societal resilience. The advent of new geospatial approaches in post-disaster reconnaissance and infrastructure lifeline assessment provides opportunities to streamline conventional data collection. Here we provide a framework for future data collection processes applicable during BAU, to make post-disaster assessments more efficient and able to be better integrated into response

and recovery. Finally, we provide an overview of future data management challenges.

A tale of two events - the 2010-2011 Canterbury and 2016 Kaikōura earthquakes

The 2010-2011 Canterbury Earthquake Sequence (CES) commenced on 4th September 2010 with the moment magnitude (M_w) 7.1 Darfield Earthquake, which generated seismically-induced soil liquefaction in areas across urban Christchurch, with localised damage to the built environment. This was followed by the M_w 6.2 Christchurch Earthquake on 22nd February 2011. The proximity of the causative faults and resultant high levels of ground shaking caused widespread and severe liquefaction-induced ground deformation (Hughes et al., 2015; Quigley et al., 2016), which strongly controlled the locations and severity of damage to infrastructure lifelines including underground services; older brittle pipes performed worse than more modern ductile materials (Cubrinovski et al., 2011, 2014a, 2014b, 2015; O'Rourke et al., 2014; Bouziou and O'Rourke, 2017). Further major earthquakes occurred in June and December 2011, with Christchurch city experiencing thousands of aftershocks throughout subsequent years. In response to the unprecedented scale of the CES with respect to urban recovery, the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) alliance between asset owners and major contractors was formed in early 2011 for assessment and rebuild of the three waters and roads (Cantillon et al., n.d.; Cusack, n.d.; Moore, n.d.). Crucial to this was development of integrated geospatial data and asset assessment systems (Heiler et al., 2012), ultimately leading to an advanced data analysis system that was handed over to the Christchurch City Council (CCC) to inform evidence-based investment decisions.

The M_w 7.8 Kaikōura Earthquake occurred on 14th November 2016 and impacted the Marlborough and Wellington regions: Marlborough in particular experienced severe shaking, ground surface fault rupture, some liquefaction and widespread land sliding; Wellington experienced severe shaking, occurrences of liquefaction and slope failures (Wotherspoon et al., 2017). Shaking and localised liquefaction were the main causes of damage to potable and waste water systems in Wellington and Blenheim; in Kaikōura township itself, its potable and waste water systems were severely damaged resulting in total loss of services, due to electricity outages and physical damage to the infrastructure (Hughes et al., 2017). Within a week, a range of support personnel from Christchurch and across New Zealand arrived in Kaikōura to assist with underground infrastructure assessments. This programme involved adapting CCC waste water CCTV assessment processes, inherited from SCIRT, to suit Kaikōura's specific context (Figure 1).

The 2010-2011 CES impacts on Christchurch and the 2016 event's impacts on Kaikōura provide valuable lessons for waste water system assessment and data management. These population centres represent extreme end members on a spectrum of population size (Christchurch's population in 2010 was ~370,000; Kaikoura's in 2016 was ~3,500) and therefore ratings base and resources. Although these population centres differed in size, infrastructure network complexity (e.g. Christchurch and Kaikōura have ~1655 km and ~30 km of gravity waste water pipes, respectively), and spatial and temporal scales in response and recovery, both required their pre-disaster asset assessment and data management approaches to be significantly altered. Below we summarise major challenges and issues encountered with a focus on waste water systems, and we present recommendations that will help buried infrastructure managers in city and district councils prepare for and respond to disaster impacts, regardless of the size and complexity of their systems.

Key reticulation condition assessment datasets

Geographic Information System data

Within Geographic Information System (GIS) databases, missing unique identifiers (ID) in the existing reticulation network made it difficult to assign condition assessment results to individual assets. There were instances where the waste water pipe ID was missing, or a pipe ID covered more than one manhole to manhole length. Because Closed Circuit Television (CCTV) assessment crews are instructed to undertake inspections from (manhole to manhole), if a CCTV inspection finds a node in a given pipe the inspection must end at that point. Geospatially, before these inspection data can be linked to the pipe ID the original pipe feature must be split in two, a time-consuming and inefficient process. Another issue is that often GIS data lack key attributes to verify the correct asset is being inspected and to identify discrepancies between the GIS data and condition assessment results; key attributes for asset verification include pipe operational status, length, material, and diameter.

It is recommended that the following be done to improve network datasets:

- Assign a Unique Asset Identifier (ID) to all main components of the reticulation network;
- Apply consistent naming conventions within the three waters networks – this facilitates standardisation processes;
- Ensure to populate in GIS the key attributes to identify the asset to be inspected in the field;
    - Be able to generate map sheets in pdf format suitable for printing hard copies for various uses including field activities. Maps must show street addresses, manholes and pipe IDs;
- Ensure network and assessment data are able to be visualised and updated via online geospatial platforms (e.g. ArcGIS Online) for BAU and emergency response purposes.

Visual condition assessment - manholes

In the disruption of emergency situations and with the urgency of service restoration, multiple teams go into the field to undertake visual condition assessment of network components, in particular manholes. Inspection teams return to the Emergency Operations Centre (EOC) with information in varying and inconsistent formats including photographs on memory sticks and paper forms. Inconsistent data collection processes make it difficult for the EOC Intelligence and Planning team to collate and store the information in a manner that facilitates decision-making and resource prioritisation.

It is recommended that the following be done to improve manhole visual condition assessment:

- Create a manhole inspection layer in ArgGIS Online, where visual condition assessments from the BAU programme are stored. BAU field data collection should be done using the electronic form applications Survey123 or Collector on mobile devices; field data will automatically update the centralised GIS datasets. This process will be utilised in an emergency response;
- Information captured in the forms should be clear and simple to allow consistency between assessors; this is enabled in Survey123 and Collector by specifying drop-downs and check lists. Examples of information to include are:
    - Manhole ID
    - Date of Inspection
    - Manhole Top Lid – Vertical Displacement (Up/Level/Down)
    - Riser - Alignment Skewed – Yes/No
    - Structure Cracking – Yes/No
    - Base Cracking Yes – Yes/No
    - Joints and Seals Intact – Yes/No
    - Infiltration – Yes/No;
- If paper forms are to be used, data should be transferred into an electronic template, such as a Microsoft Excel spreadsheet or Access database, and uploaded into GIS;

- It is important that any photographs taken with mobile devices are georeferenced i.e. the Global Positioning System (GPS) function is turned on. Alternatively, GPS-enable digital cameras should be used.

Closed Circuit Television data

In Christchurch before the CES, contractors provided CCTV data in pdf documents extracted from the CCTV software, or electronic scanned documents of handwritten log sheets. These data were entered manually into the CCC asset management system (AMS). As a result of assessment and data management processes developed at SCIRT, Christchurch currently has a robust CCTV process, as do other major New Zealand cities (Figure 1a). However, other smaller councils still process these by importing the data manually into a database or storing it in physical folders. For those Councils managing relatively small networks this process may be manageable for BAU, but is likely to be insufficient to digest the volume of assessment data required after an earthquake.

It is recommended that the following be done to improve CCTV assessment processes in preparation for an earthquake:

- CCTV inspection header information, video reference, pipe defects code and severity must be compiled and provided by the CCTV contractor in electronic format. Contractors should be able to export the data from the CCTV software;
- These data can be uploaded easily to an AMS such as InfoNet or as a GIS feature layer within, for example, ESRI's ArcGIS Desktop or ArcGIS Online or the ESRI application *CCTV Processor* (this requires modification for New Zealand standards). Mapping CCTV results allows organisations to visualise their network status, and utilise data efficiently to prioritise the works programme based on condition assessment results;
- Consideration should be given to developing a BAU electronic data flow of quality-assured field inspections into an online platform, as proposed above for manhole inspections and for wider emergency response;
- The methodology to prioritise repair must be developed before an emergency. An approach currently being developed by CCC is the Asset Assessment Intersection Framework (AAIF). Current pipe grading using weightings and thresholds proposed in the New Zealand Pipe Inspection Manual (currently under revision; New Zealand Water and Wastes Association, 2006) do not reflect actual pipe condition with respect to likelihood of failure when assessed by experienced engineers. The AAIF implements pipe condition grading based on defect type and not structural condition scores, avoiding high grades calculated due to non-critical defects. A score of 1 to 5 is assigned to every defect based on risk of further deterioration and failure, and the pipe condition grade equals the worst pipe defect. The 1 to 5 scale aligns with the New Zealand Asset Metadata Standards (Land Information New Zealand, n.d.), and must be used in conjunction with other elements (e.g. criticality) to prioritise repairs.

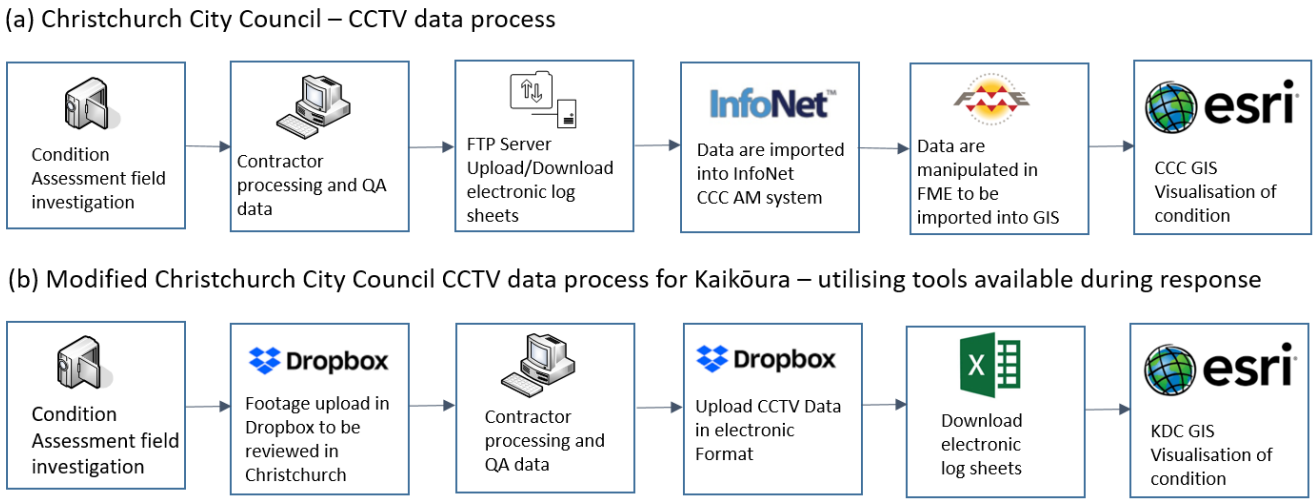

Figure 1 CCTV data process for Christchurch City developed after the 2010-2011 CES (a), and modified process for Kaikōura (b).

Data storage

External resources may be necessary to review, analyse, upload and download data, potentially from other locations in New Zealand or across Australasia. After the Kaikōura earthquake a CCTV crew from Christchurch was continuously filming in Kaikōura, and a dedicated team of experienced reviewers based in Christchurch was coding the pipe observations. Support from external consultants may be needed during the emergency response and recovery. The need for a Cloud-based solution to share data was identified in the Kaikōura EOC as essential for post-event data management.

The following data storage approaches are recommended:

- A Cloud-based storage solution is where organisations should be moving to;
- For small organisations with budget restrictions, Dropbox offers an enterprise account for a reasonable cost;
- A link to the cloud location can be populated on ArcGIS online; this enables wide access to all the data, anywhere on any device.

Repair records

After a disaster when the main objective is to return networks back to service recording of emergency repairs is usually problematic. It is common for contractors to not record basic attributes such as location coordinates, repair date, repair length, damage cause, repair type, material, manufacturer, and details of the contractor themselves. If this information is not collected at the time of the repair it is difficult, if not impossible, to identify post-repair network damage locations. From an operational perspective, if repairs are undertaken after CCTV inspection the lack of records may cause scheduling of repairs already undertaken; from an asset management perspective, these data are crucial for updating pipe condition and estimating remaining useful asset lifetime. From a research perspective these data are essential for establishing relationships between seismic and ground deformation parameters and network performance, and assessing network resilience in future earthquakes.

The following are recommended to improve repair documentation:

- Information captured in electronic forms should clear and simple to allow consistency

between assessors; this is enabled in Survey123 and Collector by specifying drop-downs and check lists.

- This approach should be introduced during BAU to ensure maintenance contractors have appropriate tools and training, and to ensure integration of data in the organisation's AMS;
- Create a 'Repairs' GIS layer with which you can identify if repairs were undertaken after CCTV inspection, and therefore evaluate if another inspection is required before further action. This will also be valuable for BAU.

Access to current infrastructure asset condition for insurance purposes

Post-disaster, organisations need to prove to their insurers the asset condition before the event, and be able to demonstrate that damage is due to the earthquake and not to normal deterioration. The ability to retrieve, analyse and present this information depends on how condition assessments have been stored and processed. Use of hard-copy files (possibly inaccessible after a major disaster), scanned documents, and incomplete GIS asset attribute data can cause difficult and time-consuming information collation efforts. Linking documentation to individual assets in the absence of IDs can be problematic, and poor quality of pre-event data may make pre- and post-event comparisons difficult or impossible. Another consideration is to prioritise proactive CCTV condition assessments before an earthquake occurs; obtaining assessments reactively post-event may show an overly pessimistic picture of what is assumed to be pre-event network condition.

The following are recommended for insurance purposes:

- If budgets allow, digitise hardcopy and scanned spatial records, and subject them to rigorous Quality Assurance scrutiny. This will allow organisations to respond efficiently to questions of: what and how much is damaged, and how much will reinstatement cost?;
- Insurance companies do not expect organisations to have their total network assessed pre-event. However, organisations should be able to present a sample sufficient to extrapolate data across the network to justify differences between earthquake damage and deterioration. When selecting pipe candidates for the CCTV condition programme, ensure that different materials from different installation periods and different ground conditions are assessed.

Towards better integration of post-disaster asset assessment with geospatial platforms

Above we addressed key issues and recommendations for underground infrastructure assessments and data management in preparation for and subsequent to earthquakes. We have alluded to the use of online geospatial platforms for data storage and sharing, and the use of mobile data capture technologies. Seamless asset assessment data from the field would streamline decision making both in BAU and during post-disaster assessment – BAU implementation should be prioritised to ensure post-disaster data capture is based on approaches and technologies that organisations' staff and contractors are familiar with.

The recent establishment of New Zealand Geographic Information Systems for Emergency Management (NZGIS4EM) provides a platform for ensuring post-disaster spatial reconnaissance data, including infrastructure lifeless assessments, are reliably captured and quickly disseminated to decision-makers in local and regional Civil Defence and Emergency Management groups, and to Central Government agencies. In New Zealand there is

a strong push to use widely available technology (ESRI's ArcGIS Online platform), used by most local governments, to enable this. It should be emphasised that if managers of underground infrastructure organise their data consistently across territories, these data can be efficiently disseminated and mapped regardless of the organisation's particular asset management software. There are currently ongoing initiatives to develop spatial data capture approaches, metadata standards (Land Information New Zealand, n.d.) and national infrastructure databases, which will facilitate and be facilitated by the approaches outlined in this paper.

Asset management in the era of accelerating urbanisation and big data

Kurzweil (2003) observed:

> "We're entering an age of acceleration. The models underlying society at every level, which are largely based on a linear model of change, are going to have to be redefined. Because of the explosive power of exponential growth, the 21st century will be equivalent to 20,000 years of progress at today's rate of progress; organisations have to be able to redefine themselves at a faster and faster pace."

Many aspects of our civilisation are now undergoing *superexponential* growth, with accelerating changes in population, urbanisation and technology; new cycles of innovation have in the past supported such growth, and will be essential for future sustainable human development (West, 2017). Our current information age is awash with data which, although posing challenges for analysis and deriving meaning, presents opportunities for improved management of infrastructure systems: initiatives such as the Christchurch Smart Cities programme are taking advantage of these innovations. The increasing availability and lowering costs of sensor technologies mean that smart infrastructure systems will become a reality across New Zealand in the near future.

As the lessons in this paper show, we are still in a transition phase from asset management based on traditional paper forms and manual processes to the age of big data and smart infrastructure systems. The impacts of disasters such as earthquakes highlight the need to prioritise this transition to comprehensive data capture and analytics. Many of these technological developments can be based on existing software platforms already in use, with low- or no-cost options available for organisations with limited budgets. Our communities are expecting infrastructure managers to provide live information and smart decision making based on advanced asset management.

Conclusions

Improvements in underground infrastructure data collection should be implemented and tested during BAU, before disasters strike. Reasons to move in this direction include:

- Improved efficiency in current BAU processes – moving from paper forms and maps to electronic situation reports, with all relevant detail captured live in the field;
- Geospatial condition assessments enable improved decision-making, and facilitate coordination of multiple infrastructure repair activities occurring in the same locations at the same times; such applications were implemented in the Forward Works Viewer in Christchurch post-CES;
- Comprehensive and detailed data collected in response are key for disaster recovery, and will help engineers make better decisions about repair strategies;

- Provision of detailed system performance data is crucial for post-event research – this will enable detailed analysis of system strengths and vulnerabilities, and testing of resilience modelling relevant to infrastructure systems across New Zealand and elsewhere.

References

Bouziou, D. and O'Rourke, T.D. (2017). "Response of the Christchurch water distribution system to the 22 February 2011 earthquake", *Soil Dynamics and Earthquake Engineering*, 97, 14-24.

Cantillon, P., Scott, C. and Livermore, A. (n.d.). "SCIRT asset assessment request process", SCIRT Learning Legacy.

Cusack, M. (n.d.). "Real asset in innovative damage assessment", SCIRT Learning Legacy.

Cubrinovski, M., Hughes, M.W., Bradley, B., McCahon, I., McDonald, Y., Simpson, H., Cameron, R., Christison, M., Henderson, B., Orense, R. and O'Rourke, T. (2011). *Liquefaction impacts on pipe networks*. Short Term Recovery Project No. 6, Natural Hazards Research Platform, Civil & Natural Resources Engineering Research Report 2011-04. University of Canterbury, December 2011. ISSN 1172-9511.

Cubrinovski, M., Hughes, M.W., Bradley, B., Noonan, J., Hopkins, R., McNeill, S. and English, G. (2014a). *Performance of Horizontal Infrastructure in Christchurch City through the 2010-2011 Canterbury Earthquake Sequence*. Civil & Natural Resources Engineering Research Report 2014–02. University of Canterbury, March 2014. ISSN 1172-9511.

Cubrinovski, M., Hughes, M.W. and O'Rourke, T.D. (2014b). "Impacts of liquefaction on the potable water system of Christchurch in the 2010-2011 Canterbury (NZ) earthquakes", *Journal of Water Supply: Research and Technology – AQUA* 63,2, 95-105.

Cubrinovski, M., Hughes, M.W., Bradley, B., Noonan, J., McNeill, S., English, G. and Garcia Sampedro, I. (2015). *Horizontal Infrastructure Performance and Application of the Liquefaction Resistance Index in Christchurch City through the 2010-2011 Canterbury Earthquake Sequence*. Civil & Natural Resources Engineering Research Report 2015–05. University of Canterbury, September 2015. ISSN 1172-9511.

Heiler, D., Moore, J. and Gibson, A. (2012). "Asset assessment using GIS and InfoNet", Water New Zealand Annual Conference and Expo, Rotorua, 26-28 September 2012. SCIRT Learning Legacy.

Hughes, M.W., Quigley. M.C., van Ballegooy, S., Deam, B.L., Bradley, B.A., Hart, D.E. and Measures, R. (2015). "The sinking city: Earthquakes increase flood hazard in Christchurch, New Zealand", *GSA Today* 25(3-4), 4-10.

Hughes, M.W., Nayyerloo, M., Bellagamba, X., Morris, J., Brabhaharan, P., Rooney, S., Hobbs, E. and Wooley, K. (2017). "Impacts of the 14th November 2016 Kaikōura Earthquake on three waters systems in Wellington, Marlborough and Kaikōura, New Zealand: Preliminary observations", *New Zealand Society for Earthquake Engineering Bulletin*, 50,2, 306-317.

Kurzweil, R. (2003). "Understanding the Accelerating Rate of Change", Kurzweil Accelerating Intelligence.

Land Information New Zealand (n.d.). "Metadata (shared data) standards project".

Moore, J. (n.d.). "Christchurch Natural Disaster Response and Recovery", presentation to Water Services Association of Australia conference. SCIRT Learning Legacy.

New Zealand Water and Wastes Association (2006). *New Zealand Pipe Inspection Manual*, 3rd Edition.

O'Rourke, T.D., Jeon, S.S., Toprak, S., Cubrinovski, M., Hughes, M.W., van Ballegooy, S. and Bouziou, D. (2014). "Earthquake response of underground pipeline networks in Christchurch, NZ", *Earthquake Spectra* 30,1, 183-204.

Quigley, M.C., Hughes, M.W., Bradley, B.A., van Ballegooy S., Reid, C.M, Morgenroth, J., Horton, T.W., Duffy, B. and Pettinga, J.R. (2016). "The 2010-2011 Canterbury Earthquake Sequence: Environmental effects, seismic triggering thresholds and geologic legacy", *Tectonophysics* 672–673, 228-274.

West, G. (2017). *Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies*, Penguin Press, New York, 479 p.

Wotherspoon, L.M., Palermo, A. and Holden, C. (2017). "The 2016 M_w7.8 Kaikōura Earthquake: An introduction", *New Zealand Society for Earthquake Engineering Bulletin*, 50,2, i-iv.

Author Biography

Irmana Garcia Sampedro

I am a Spanish Civil Engineer who came to New Zealand in 2012 to help in the Christchurch rebuild. I worked for three years as a member of the Stronger Christchurch Infrastructure Rebuild Team (SCIRT), and after this role at SCIRT I decided to focus my career on Asset Management. I am currently working as Strategic Asset Engineer in the Christchurch City Council Asset Management Unit. In August 2017 I completed the *IPWEA professional certificate in asset management and planning.* In November 2016 I had the privilege of being a member of the Planning Intelligence Team in the Kaikōura Earthquake emergency response and the Christchurch Port Hills fires emergency response in February 2017. I am passionate about the concept of collaborative emergency management within New Zealand, and strongly believe that working in this area increases our capacity to recover quickly from an event.

Email: Irmana.Sampedro@ccc.govt.nz

Matthew Hughes

I am an Earth and Environmental Scientist, with a background in landscape evolution and climate change research. Since 2011 I have worked in the role of Canterbury Earthquake Geospatial Research Fellow at the University of Canterbury, and since 2015 as a Lecturer in Geohazards, Risk and Resilience, with research and teaching interests in GIS, disaster impacts on infrastructure lifelines and on urban and rural systems in general, and communities. I am the Research and Lifelines representative on the New Zealand GIS for Emergency Management (NZGIS4EM) committee. I can committed to using research and education to improve societal resilience and to protect communities.

Email: matthew.hughes@canterbury.ac.nz