Aftershock communication during the Canterbury Earthquakes, New Zealand: Implications for response and recovery in the built environment

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ABSTRACT: On 4 September 2010, a Mw7.1 earthquake occurred in Canterbury, New Zealand. Following the initial earthquake, an aftershock sequence was initiated, with the most significant aftershock being a Mw6.3 earthquake occurring on 22 February 2011. This aftershock caused severe damage to the city of Christchurch and building failures that killed 185 people.

During the aftershock sequence it became evident that effective communication of aftershock information (e.g. history and forecasts) was imperative to assist with decision making during the response and recovery phases of the disaster, as well as preparedness for future aftershock events. As a consequence, a joint JCDR-USGS research project was initiated to investigate:

- How aftershock information was communicated to organisations and to the public;
- How people interpreted that information;
- What people did in response to receiving that information;
- What information people did and did not need; and
- What decision-making challenges were encountered relating to aftershocks.

Research was conducted by undertaking focus group meetings and interviews with a range of information providers and users, including scientists and science advisors, emergency managers and responders, engineers, communication officers, businesses, critical infrastructure operators, elected officials, and the public. The interviews and focus group meetings were recorded and transcribed, and key themes were identified. This paper focuses on the aftershock information needs for decision-making about the built environment post-earthquake, including those involved in response (e.g. for building assessment and management), recovery/reduction (e.g. the development of new building standards), and readiness (e.g. between aftershocks). The research has found that the communication of aftershock information varies with time, is contextual, and is affected by interactions among roles, by other information, and by decision objectives. A number of general and specific insights into improving the communication of aftershock information are provided.

1 INTRODUCTION

On 4 September 2010, a Mw7.1 earthquake, named the Darfield Earthquake, occurred in Canterbury, New Zealand. This was followed by an aftershock sequence, with the most devastating aftershock occurring on 22 February 2011. The 22 February aftershock was located near the city of Christchurch and caused severe ground shaking and liquefaction, and damage to buildings and infrastructure that killed 185 people (NZ Police 2012). Significant aftershocks also occurred on 13 June and 23 December in 2011.

The Canterbury earthquake sequence provided a unique experience to study the communication of aftershock information and contribute towards informing recent developments in Operational Earthquake Forecasting (Jordan et al. 2014). Aftershock information pertains to both the record of what has occurred and the forecast for what might follow, as well as background information on geological processes. To understand the factors of effective communication about aftershocks, a joint JCDR-USGS research project was initiated, investigating:

- How aftershock information was communicated to organisations and to the public;
- How people interpreted that information;
- What people did in response to receiving that information;
- What information people did and did not need; and
- What decision-making challenges were encountered relating to aftershocks.

This paper focuses on effective communication of aftershock information for post-earthquake decision-making about the built environment. The decisions pertain to the response phase (e.g. building assessment immediately after the earthquakes, building management), the readiness phase (e.g. preparedness for each new aftershock), and the recovery/reduction phases (e.g. the development of new building standards, building demolition).

2 METHOD

To understand what contributes to the effective communication of aftershock information, we conducted 9 focus group discussions and 17 interviews with those involved in the Canterbury earthquake response and recovery. These focus group discussions and interviews took place predominantly in May and June of 2013. Participants included scientists, emergency managers, engineers, communication officers, elected officials, businesses, critical infrastructure operators, and the public. Participants were asked about their roles in the earthquakes, aftershock knowledge prior to the earthquakes, relevance of aftershock information to their decision-making, experiences with aftershock information during the earthquake sequence, and interpretation of aftershock information products (a text article, aftershock frequency and probability tables, an aftershock rate forecast graph, and a shaking intensity probability map). The focus group discussions and interviews were digitally recorded and transcribed, and analysis was conducted to code for key themes using the method described by Braun and Clarke (2006). Analysis of the transcripts is on-going, thus the results presented here are preliminary.

3 RESULTS

The preliminary results presented here focus on the communication of aftershock information for decisions about the built environment. The participants mentioned several activities relating to the built environment where aftershock information was needed. In terms of an immediate response to earthquakes, aftershock information was needed for Urban Search and Rescue (USAR) purposes, building assessment, emergency management, and in making decisions about placement of cordons around areas of dangerous buildings. In the recovery phase, aftershock information was used in making decisions about building demolition, repair and reconstruction, utilisation and revision of the building code/standards (Building Act 2004, Building Regulations 1992, 2005; Standards New Zealand 2004, Gerstenberger et al. 2014), insurance, and land zoning decisions. Table 1 summarises the need for aftershock information to aid in making decisions about the built environment.

Table 1. Relevance of aftershock information in reference to the built environment.

Activities during the response phase	
Search and Rescue	Urban Search and Rescue (USAR) personnel wanted to know the aftershock hazard (size, number, location) and consequences to determine when, in their opinion, it would be 'safe' enough to re-enter buildings to save lives.
Building assessment	Emergency managers and building assessors wanted to know the aftershock hazard (size, number, location) and consequences to determine when it is 'safe' enough, in their opinion, to re-enter buildings for assessment and how to sticker them (Green – no restrictions, Yellow – restricted access, Red – unsafe do not enter).
Placement of cordons around areas of dangerous buildings	Emergency managers needed to know the risks in a fragile building environment to aid decision-making about where to place cordons around dangerous buildings and infrastructure, how long to keep those in place, and how to control the entry and exit of people needing access to the area.
Activities during the readiness phase (i.e. between earthquakes/aftershocks)	
Preparing to respond	Critical infrastructure operators wanted to know the probability of larger earthquakes in order to prepare resources (e.g. size of labour force needed) and develop relationships for response to potential aftershocks.
Activities during the recovery/reduction phase	
Demolition	Construction/emergency mangers needed to know the aftershock forecasts to evaluate the risks of building demolitions.
Repair and re-build	Insurers and recovery leaders needed to know when the aftershock rate had decayed beyond a threshold before commencing with insured repairs and to encourage recovery.
Insurance	Insurers needed to know the uncertainty in aftershock forecasts to decide when to re-enter the market and how to set insurance premiums.
Utilisation and revision of the building code/standards	"Policy makers" needed to know the forecasted 50 year decay rate of aftershocks for devising a local building standard that would be applied in the Canterbury rebuild.
Land zoning decisions	Recovery leaders needed to know the forecasted aftershock rates over future decades to inform decisions regarding the delineation of red zones for retirement and other land for remediation.
Rebuild of critical infrastructure systems	Critical infrastructure providers needed to know the probabilities of earthquake magnitudes and/or risks of liquefaction over periods of time to determine repair scope and standards.

Aftershock information was used mostly in longer-term decisions pertaining to the built environment because these decisions afforded time for the development of information and deliberation in decision-making. Use of the information was constrained by the need for complementary information in the broader context of the decision. There were also interactions that affected the delivery of information and the use of it in decision-making. We elaborate on effects of time, context, and interaction on the receipt and use of aftershock information.

3.1 **Effects of time**

Both the need for and the development of recent and forecasted aftershock information evolved with time. Scientists reported difficulty in getting people's attention about the likelihood and risks of aftershocks early on in the sequence, after the Darfield mainshock earthquake. Immediately after the 22 February Christchurch aftershock however, there was a greater interest and need for aftershock related information.

Information about earthquakes that had recently occurred (magnitude, location, depth) was posted on the GeoNet website and often accessed from other internet sites or received from agencies such as Civil Defence Emergency Management (CDEM). In the first few days after the more significant earthquakes hunger for information was substantial, but access to detailed information was difficult due to the time scientists required to process information and also the efficiency of the communication channels. Responders, for example, used whatever information was available to them, from avenues such as the news media or personal contacts. In these cases, decisions were often based upon very limited information. As one participant stated, "We were making decisions on the tiniest slivers of information". Communications about aftershocks that had occurred were not directly set up for USAR and response engineers, and most received their information via indirect sources. One structural engineer participant stated that following the 22 February earthquake he called a colleague located in the Wellington Region to ask him to download some earthquake-response data. He was able to get this within an hour and a half of the event, and then use it in response decision-making.

Likewise responders received aftershock forecasts from alternative channels. On the accessibility of forecast information, a structural engineer stated that:

> "I received my aftershock information from the news media, after the September earthquake. […] That information was essentially limited to […] there's a probability of "X" of a magnitude or whatever it was in the area. I don't know how long it took for them to get models done for that because obviously that's not, you know instant information to re-model the Canterbury Basin, but that information I think came from the media rather than direct information to engineers".

Some building assessors had to be 'educated on the job' about aftershocks and others were informed by the news media.

During the time period immediately after significant earthquakes, personal relationships were the key for some people to get and discuss forecast information. Participants reported making contact with people they already knew (e.g. scientists, engineers, consultants, CDEM sector) to try and find out more information about the potential aftershock sequence. For example, people called individuals they knew directly at GNS Science to get more information about aftershocks forecasts.

Some participants felt that aftershock information was not always accessible, which hampered immediate and short-term decision-making. For example, the ATC-35 (Rojahn et al. 1994) guidelines on building re-entry were discovered after the fact. However, it was suggested that even if the aftershock information had reached responders in a timely fashion, they may not have been prepared to use it. Access to information in the immediate and short term could potentially be improved by making efforts before an event to streamline the information process, equip responders with smart phones, and ensure relationships with information providers are in place. Responders would need to be trained in the use of the information.

As response stretched into the time frame of recovery, information on aftershocks, that had already occurred in the sequence, and on forecasts became more detailed and more accessible. Our preliminary analysis indicates that this information was used for decision-making in a number of ways.

When the aftershock rate in Canterbury flattened out and became comparable to projected future earthquake activity in other cities, such as Wellington, it was interpreted by recovery leaders as an indication of the time to actively encourage recovery of the built environment. Similarly, insurance companies reportedly used a rule of thumb to hold off on repairs until no Mw4 or greater earthquakes had occurred for a number of months. A delay was put in place to avoid further damage to infrastructure by aftershocks. The delay was reflected in the following participant's quote, and confirmed by those in the insurance sector:

> "Their understanding of aftershock potential impact intensity has been quoted many times in the media over the last 12 months as being reasons why […] insurance companies were not acting on their claims, were not starting repairs. There was a period of […] moratorium, […] there was evidence that insurers were not acting, they were waiting."

The probabilities of aftershocks were forecast for periods of time and ranges of earthquake magnitude. These were regularly posted in tables on the GeoNet website, and were updated as the earthquake sequence progressed. The aftershock probability tables and rate graphs were fed into complex considerations around the re-build and recovery process, insurance, building codes/standards, infrastructure scope and standards, and land-zoning decisions. For example, decision-making about revising the building code and standard after the more significant earthquakes had occurred involved deliberations with a group of experts about how a 'local' standard might be applied in Canterbury, as well as what it meant for the overall New Zealand standard. In addition to considering the impact of the aftershocks in general, it was also necessary to consider how the overall aftershock frequency and likelihood was evolving over time. The complex analysis involved multiple earthquake forecasting models that many participants saw as confusing and may have required a better explanation.

It is evident from this research that there are different aftershock information needs at different stages of an earthquake disaster, and such needs should be considered and catered for. The critical time period to communicate aftershock information is immediately after a large earthquake when the risk is highest and life safety decisions are paramount.

3.2 **Effects of context**

Context played a large part in the types of information that people and agencies were seeking and how they wanted to use that information. It was evident that prior knowledge of aftershocks was predominantly self-rated by participants as 'a little', except for among scientists and half of the emergency managers. This indicates the need for general, and also context-specific, information on aftershocks to be communicated. During the response phase, emergency managers wanted information about the nature and occurrence of aftershocks so that they could give general advice to responders about what to expect when undertaking search and rescue and building assessment operations. They were also interested in what the consequences of future earthquakes could be and so framed their quest for, and and use of information in this context. In the focus group discussions a government official emphasised how a better understanding of consequences could have aided decision making:

> "My point is, if greater understanding of the aftershock potential in a fragile building environment had been recognised we may have managed the cordons better, may have managed the buildings better."

Additionally, emergency managers were concerned with welfare, sanitation, etc., and these issues took up more of their time and consideration than aftershock information.

Conversely, there were a number of other participants (including engineers) who required more detailed and diverse information about the earthquakes that were occurring in order to assist with their decision making. General information about the occurrence of aftershocks formed a part of this, but participants also reported that they needed information about the locations of earthquakes that had occurred, as well as the potential magnitude, ground motion and directivity, intensity (e.g. represented through earthquake-response spectra, MMI), consequences of future aftershocks and the long-term evolution and decay of the earthquake sequence.

The type of information that people utilised depended on the types of decisions they were making. For example, a participant who was a structural engineer stated that:

> "To us engineers, magnitude is a completely useless piece of information to get […]. To be honest all we want to know is what's the likely intensity of shaking [with a later reference to earthquake-response spectra] in the Christchurch CBD, in the Kaiapoi CBD… and that means you've got to give a range of numbers for any area you think could be affected by an aftershock."

A geotechnical engineer continued the discussion reiterating how different injects of information are required to make decisions related to aftershocks. His comment was:

> "A structural engineer [uses] different information than a geotechnical engineer. You're talking about spectra, I would not use a spectra. I would use accelerations. The likelihood of acceleration and the spatial occurrence where they are likely to occur. And also I would like to actually see where the active faults are located, hidden faults and the way they actually rupture. So again you need to actually cater to the, for the right professions".

These comments highlight an important finding of this research. Thought should be given to the differing information needs of personnel and agencies involved in earthquake response and recovery operations. Additionally, supporting information may also need to be provided to assist with people's interpretation of aftershocks and the use of the information in decision-making.

3.3 **Interactions**

A theme that was evident in the analysis of the interviews and focus group discussions was the interactions around aftershock information. Interaction occurred between aftershock information providers, types of information and decision-making objectives.

Linkages existed between agencies in terms of information flow. As an example, many of the personnel doing building assessment did not get their aftershock information directly from a science provider; rather, their information came via the CDEM sector, or avenues such as the news media. People tended to make indirect linkages to seek information, particularly in the response phase, when uncertainty was high and information was sparse. The reasons for not receiving information directly from a scientific source included concern about the availability of a scientist for their questions, or not having a direct connection to the information and/or relationship with a scientist. Some community leaders and lifeline operators did not actively seek and use aftershock forecasts suggesting that these roles need to be targeted in the future. When scientists did interact with engineers, the engineers needed clear explanations of the different forecast models.

Aftershock information was not usually used in a stand-alone fashion, but integrated with other vital pieces of information. In making their decisions people drew upon aftershock information in combination with a range of other contextual information. As the geotechnical engineer stated above, as well as seeing information that related to future earthquakes, he was also interested in seeing information about the nature of the faulting that had occurred during the earthquake sequence. Furthermore, aftershock was one of many inputs into decision-making. For example, aftershock information was combined with information about land stability and life safety in land-zoning decisions. Putting a number of information 'puzzle pieces' together was necessary in order to make informed decisions.

Interactions among affected parties were evident in tension relating to the management of the cordons that had been placed around areas of dangerous buildings following the earthquakes of 4 September and 22 February. Future aftershock risk was considered when the cordons were put in place after 4 September, but economic pressures from business wanting to get back into operation may have meant the cordons were not as extensive as needed (given the injuries and deaths caused by falling building material in the February 22 earthquake). Following the 22 February earthquake, cordons were placed extensively around the Christchurch city centre, essentially preventing business owners from entering their premises to retrieve items for up to several months. This created a great deal of dissatisfaction in the business community, who on one hand were aware of the aftershock risks, but on the other hand were subject to economic risk from the closure of their businesses. As one participant stated:

> "It's a difficult situation, cos' officials are wanting to manage a potential or on-going risk and you're trying to balance that against getting your communities back to normal functioning. So somebody has to make the call around that."

The interactions demonstrate some of the challenges of obtaining aftershock information, applying it in the context of a decision, and justifying decisions with costs and benefits. Consideration of such interactions will be essential to effectively providing and using aftershock information.

4 CONCLUSIONS

This paper has focussed on what aftershock information was delivered, and how it was used by those involved in addressing the needs of the built environment during the Canterbury earthquake sequence. It presents a snapshot of some of the issues that have arisen during the analysis of our focus group discussions and interviews. Further analysis is currently being undertaken.

The findings from this research highlight the complex environment in which the communication of aftershock information takes place. First, there is a time-varying aspect to aftershock information with limitations on the amount of information that is available during the immediate response phase of an earthquake, when decision timeframes are days. More information becomes available as the response phase evolves into recovery, when decision timeframes may extend into multiple decades. This means that during the response period people are subject to making decisions under a great deal of uncertainty. Subsequently, more detailed aftershock information can inform more deliberative decision-making about recovery. Second, the need for aftershock information is very contextual and depends on the roles and responsibilities of the decision-makers. Finally, many interactions occur around the provision, application, and decision outcomes of aftershock information. These interactions occur between people and agencies, and between types of information. Effective interactions often rely on developing good working relationships with key partners prior to a disaster occurring.

Many of the findings from this project (e.g. understanding information needs in relation to context and timeframes, and building relationships) are common to other types of emergencies, and aftershock communication can draw upon such experiences to aid improvement (Paton et al. 1999).

To enable effective aftershock communication in the future, providers and users of historical, recent and forecasted aftershock information should work together to:

- Define in more detail the different content, formats, conduits, and timing of information that are needed by different users, and at different stages of the reduction, readiness, response and recovery cycle;
- Develop standard information templates that would be available and ready for use in a disaster situation.

Some specific considerations for providing aftershock information to decision-makers concerned with the built environment include:

- Building assessors and emergency managers may need to be trained in the use of aftershock information (e.g. ATC-35);
- Guidelines may need to be developed for the delivery and use of aftershock information for USAR;
- Emergency managers may need to be educated about the aftershock potential in the context of a fragile built environment, which requires further translation of the potential hazard into risks;
- Different types and a mix of earthquake information may need to be coordinated for geotechnical and engineering decisions;
- Time and engagement is needed to deliberate and debate information for restoration and recovery decisions pertaining to the built environment as was demonstrated for building design standards, red zones, and infrastructure rebuild;
- When aftershock forecasts are based on multiple models, scientists need to be prepared to explain the different models to engineers.

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