Quantifying downtime due to building demolitions in Christchurch

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ABSTRACT

Over 900 buildings in the Christchurch central business district and 10,000 residential homes were demolished following the 22nd of February 2011 Canterbury earthquake, significantly disrupting the rebuild progress. This study looks to quantify the time required for demolitions during this event which will be useful for future earthquake recovery planning. This was done using the Canterbury Earthquake Recovery Authority (CERA) demolition database, which allowed an in-depth look into the duration of each phase of the demolition process. The effect of building location, building height, and the stakeholder which initiated the demolition process (i.e. building owner or CERA) was investigated. The demolition process comprises of five phases; (i) decision making, (ii) procurement and planning, (iii) demolition, (iv) site clean-up, and (v) completion certification. It was found that the time required to decide to demolish the building made up majority of the total demolition duration. Demolition projects initiated by CERA had longer procurement and planning durations, but was quicker in other phases. Demolished buildings in the suburbs had a longer decision making duration, but had little effect on other phases of the demolition process. The decision making and procurement and planning phases of the demolition process were shorter for taller buildings, though the other phases took longer. Fragility functions for the duration of each phase in the demolition process are provided for the various categories of buildings for use in future studies.

1 INTRODUCTION

On the 22nd of February 2011, Christchurch was struck by a magnitude 6.3 earthquake. As a result of this, an estimated 900 buildings in the Christchurch central business district (CBD) and a further 10,000 residential homes around Christchurch had to be demolished (Kaiser et al., 2012); such as those shown in Figure 1.

Figure 1. Examples of demolitions in Christchurch following the 22nd of February 2011 earthquake

In the months following the earthquake, the government established the Canterbury Earthquake Recovery Authority (CERA) in an effort to lead and coordinate the recovery of the region considering the large scale of the earthquake damage. One of the tasks assigned to CERA was to oversee the demolition work. As part of this, key milestones in the demolition process were recorded in a database for over 2,000 buildings in both the CBD and suburbs. Such information is valuable for recovery planning purposes for future earthquake events around New Zealand where similar demolition processes would likely be implemented.

This study uses the CERA demolition database to quantify the duration of each phase in the demolition process to aid in future recovery planning efforts. Furthermore, the dependency of these findings on the initiator of the demolition process, the location of the building, and the height of the building is investigated. Reasons for observations made from the data are discussed, and probabilistic distributions of the duration of each phase of the demolition process are provided for use in future modelling. It should be noted that the factors influencing the decision-making process has already been studied by Chang et al. (2014) and are not covered in this paper.

2 OVERVIEW OF THE DEMOLITION PROCESS

As discussed previously, CERA was established a few months after the 22nd of February 2011 Canterbury earthquake event to oversee the rebuild efforts in the region. Part of their role involved overseeing demolition works as described in Section 38 of the Canterbury Earthquake Recovery Act (2011), and includes having the authority to determine what demolition works should be done to a building which has been identified as being dangerous. An overview of the key demolition process phases is shown in Figure 2.

The first phase of the demolition process is the duration taken before deciding a building required demolition either due to (i) the building being dangerous, or (ii) a completed risk assessment indicating that such works are required. The project can then either be initiated by the building owner or managed by CERA. If the project is owner-initiated, the owner needs to prepare documents such as health and safety plans, traffic management planes, and demolition methodology, among others. CERA will then review the documents and issue a work approval certificate if the documents are deemed satisfactory. The building owner or contractor returns a completion certificate to CERA once the project is finished. If the project is managed by CERA, the process is identical except that a work approval certificate was not required.

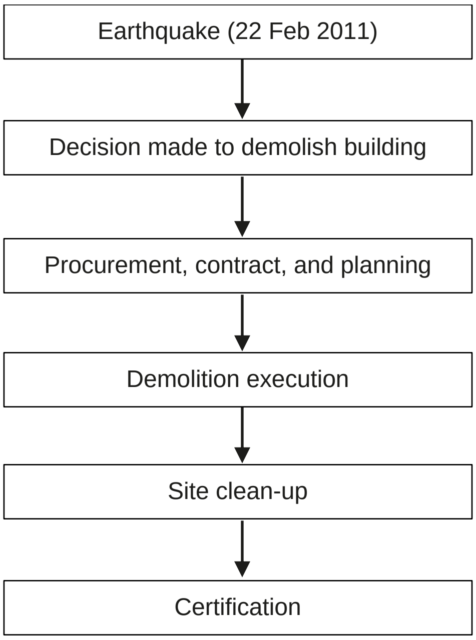


Figure 2. Overview of demolition process

3 METHODOLOGY

3.1 Obtaining and filtering the demolition database

The authors had submitted an official information request to Land Information New Zealand for obtaining the demolition data for research purposes. This request was granted on the 17th of November 2016. The data was provided in an excel spreadsheet and contained information from over 2,000 demolitions. Variables included in the data included variables such as building address, project initiator, and key dates for important milestones in the demolition process. From this information, the duration of each key demolition phase from Figure 2 were obtained by calculating the number of days between each milestone date. Filtering was then performed to remove null entries or cases where a negative number of days were calculated, resulting in just over 1,000 buildings remaining in the filtered data.

3.2 Identifying building heights

One of the key building properties which was not included in the data provided was building height. Instead, this information was obtained manually by using the “Street View” feature on Google Maps. This feature does contain an archive of past photos taken before the 22nd of February 2011 earthquake. However in some cases, the only available archived photo on Street View before the earthquakes dated back as far as 2005. Due to a lack of easily obtainable information, it is assumed that the building had not changed since the archived photos were taken. The building height was recorded in terms of the number of stories above including and above the ground level. Due to this time consuming process, the building heights were only recorded for 750 of the filtered database entries. Sensitivity checks showed that this is a sufficient quantity of data to represent the entire demolition database. The 750 database entries where building height information was obtained were considered for post-processing

3.3 Post-processing of the demolition database

The filtered data was categorized into six groups as follows:

1. CERA-managed in suburbs, 1-3 stories
2. CERA-managed in city centre, 1-3 stories
3. CERA-managed in city centre, 4+ stories
4. Owner-initiated in suburbs, 1-3 stories
5. Owner-initiated in city centre, 1-3 stories
6. Owner-initiated in city centre, 4+ stories

It should be noted that very few buildings in the suburbs were taller than 3-stories high. Due to a lack of data, this category was excluded from comparisons in this paper. Once the buildings have been categorized, a lognormal distribution is then fitted to the durations of each phase in the demolition process. Reasons for adopting the lognormal distribution are discussed later in the paper. The calculation for the median, x_m, and dispersion, β, of the distributions are shown in Equations 1 and 2, respectively.

$$x_m = \exp\left(\frac{1}{N}\sum_{i=1}^{N}\ln(d_i)\right) \tag{1}$$

$$\beta = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\ln(d_i) - \ln(x_m)\right)^2} \tag{2}$$

where d_i is the duration of the demolition phase of interest for the i^{th} data entry, and N is the total number of data available for the demolition phase of interest.

3.4 Sources of error and excluded considerations

One of the major limitations of this database is that CERA was only established several months after the earthquake. By this time a significant number of severely damaged buildings had already been or were in the process of being demolished, and without the processes established by CERA the data keeping for those cases are not as thorough. Another source of error arises from the number of data entries which were filtered out due to having null or incorrect date entries. Furthermore, the effect of some other variables which are difficult to obtain on the demolition duration, such as the number and availability of contractors to perform demolition works or the building plan area, are not considered in this study.

It should also be noted that the durations provided in this study are the length of time between each key date, and not the actual time spent on the particular activity. For example, not all building owners have the same urgency to demolish their building, and delays may be introduced between each stage of the process. This may result in the actual time to perform each activity being shorter than reported in this study. However, these delays do contribute to the total demolition duration, and as they are difficult to identify and quantify on their own, there are benefits for these delays to be treated as uncertainty regarding the duration of each stage of the demolition process as currently done.

Despite these issues, it should be acknowledged that there are no other such information regarding the demolition process available, and that there are still plenty of rich data available in the database to draw observations and conclusions from.

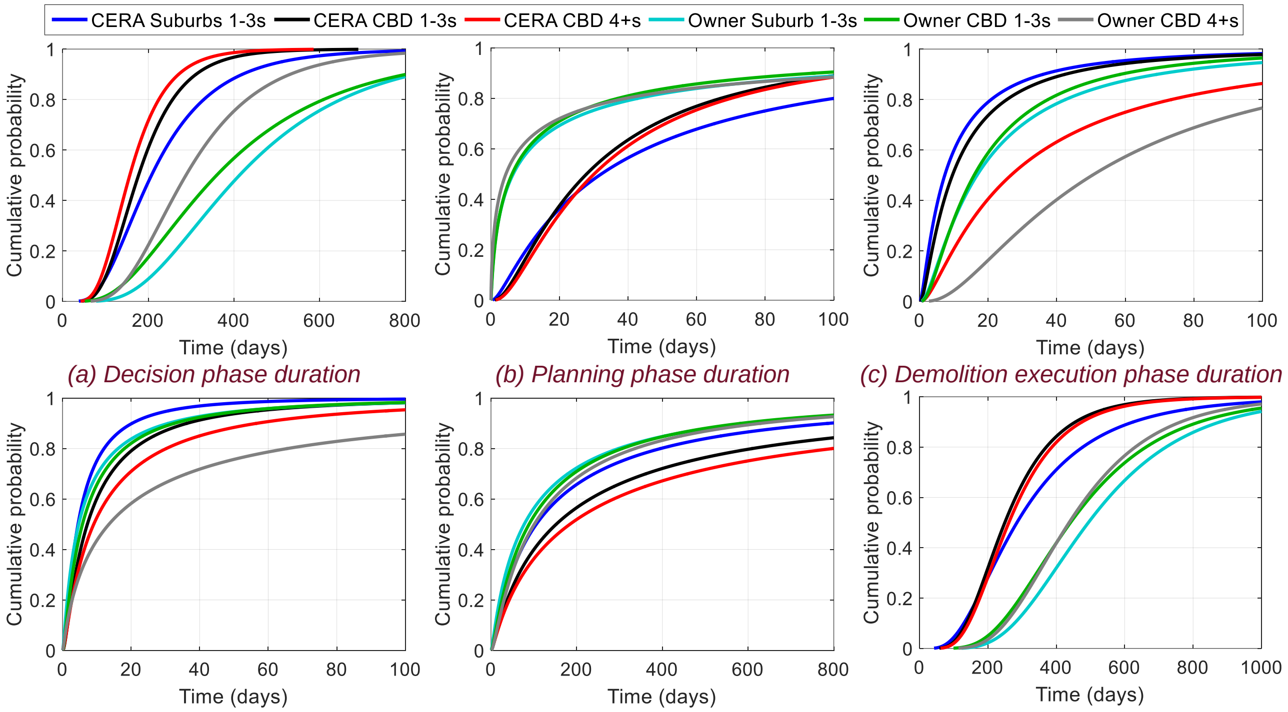
4 RESULTS AND DISCUSSION

4.1 Overview of findings

The lognormal distributions of the duration for each phase in the demolition process for each category are shown in Figure 3. The median and dispersion of the lognormal distribution fitted to data for each demolition phase are provided in Table 1.

One observation which can be made from Figure 3 and Table 1 is that the duration of the completion certification phase is unusually long with the median equalling or exceeding 78 days across all building categories. However, in discussions with Crow (2017), a completion certification is not required to continue further development on the site following site clean-up, and as such there is less urgency to complete this phase of the demolition process. Therefore, this phase is not considered to be important and is excluded from further discussions in this paper.

It can be observed from Table 1 that the decision phase duration accounts for a majority (between 60-84%) of the duration for the total demolition process (excluding completion certificate phase). Therefore, one method to speed up the demolition process is to aid the decision making process. One such approach could be to use building monitoring devices to quickly evaluate the residual life capacity and stiffness remaining in the building, though this will unlikely affect cases where insurance plays a major role in the demolition decision making. Nonetheless, this finding highlights that the soft components of demolition downtime could far outweigh the active phases (procurement and planning, demolition execution, and site clean-up).



(a) Decision phase duration *(b) Planning phase duration* *(c) Demolition execution phase duration*

(d) Site clean-up phase duration *(e) Certification phase duration* *(f) Total duration (excluding certification)*

Figure 3. Lognormal distributions for duration of each phase in the demolition process

Table 1. Lognormal distribution parameters of duration of various demolition phases

Demolition phase	**Lognormal distribution parameter**	**Grouping Category**					
		CERA Suburb 1-3 storey	CERA CBD 1-3 storey	CERA CBD 4+ storey	Owner Suburb 1-3 storey	Owner CBD 1-3 storey	Owner CBD 4+ storey
Decision phase	x_m (days)	208	177	157	413	360	288
	β	0.55	0.44	0.43	0.54	0.63	0.48
Procurement and planning phase	x_m (days)	32	28	30	6	6	4
	β	1.3	1.0	1.0	2.2	2.1	2.6
Demolition execution phase	x_m (days)	7	10	27	17	16	50
	β	1.2	1.2	1.2	1.1	1.0	0.9
Site clean-up phase	x_m (days)	4	7	9	5	6	14
	β	1.2	1.3	1.4	1.5	1.3	1.9
Completion certification phase	x_m (days)	106	152	184	78	89	101
	β	1.6	1.7	1.7	1.6	1.5	1.4
Total process (excluding completion certification)	x_m (days)	285	250	261	494	442	438
	β	0.61	0.47	0.47	0.45	0.48	0.43

4.2 Influence of demolition initiation party

Projects which are managed by CERA tend to have shorter decision, demolition execution, and site clean-up phases, as shown in Figure 3. The former is expected as building owners will have to provide additional documentation before CERA approves of them initiating the demolition process which results in extra delays compared to when CERA manages the project themselves. The latter two observations were perhaps a result of familiarity of demolition contractors with CERA's approach, resulting in faster execution and site clean-up. Further discussions with Crow (2017) also indicated that CERA had 130 operational staff whom are able to oversee more demolitions with greater efficiency.

Interestingly, CERA-led demolition projects tended to have a longer procurement and planning duration. This could be because of the large portfolio of demolition projects which CERA manages, which reduces their efficiency to actively produce demolition plans compared to building owners who may only oversee a small number of projects.

Overall, the total duration for CERA-led demolition projects (excluding the completion certification phase) is much shorter than owner-initiated demolition projects, as shown in Figure 3f.

4.3 Influence of building location

Demolition of buildings in the suburbs tend to have a longer decision phase compared to those in the city centre as observed from Figure 3 when comparing the 1-3 storey results. This could be because the buildings located in the suburbs are located further apart compared to that in the city centre, and hence are less likely to pose a threat to people and surrounding properties. As such, there is less urgency regarding whether demolition is required.

Building location appears to have little influence on the duration of other phases in the demolition process in cases where the building owner initiated the demolition work. For CERA led projects, however, the duration of the procurement and planning phase for buildings located in the suburbs is longer than those in the city centre, while the site clean-up phase is shorter. The former could be due to suburban demolitions posing a greater risk of disturbance to nearby households, or that plans regarding health and safety or traffic management needed to be more rigorous compared to the city centre where large portions had already been cordoned off. The longer site clean-up phase in the city centre may be due to contractors being allowed (and preferring) to crush waste concrete on-site for reuse rather than transporting it to ports for disposal (Austin, 2012), which may have lesser effect on suburb sites where less concrete may have been used. Location effects do not appear to have much of an influence on the demolition execution phase durations. Overall, the total duration for demolition projects in the suburbs (excluding the completion certification phase) is longer than those located in the city centre, as shown in Figure 3f.

4.4 Building Heights

Shorter buildings tend to have a longer decision phase compared to taller buildings as observed in Figure 3 for buildings in the city centre, and is due to the larger danger posed by taller buildings to the surroundings if collapse does occur which increases the urgency for a decision to be made. In contrast, shorter buildings have much shorter demolition execution and site clean-up. This is to be expected since more work is required for demolition of taller buildings, and more material needs to be removed from the site. Furthermore, specialist equipment may be required for buildings taller than five stories high, and for some methods of demolition only one storey may be deconstructed at once for safety reasons (Work Safe New Zealand, 2013). Overall, building height does not have a significant effect on the procurement and planning phase, and the total duration for the demolition process (excluding the completion certification phase), as shown in Figure 3f.

4.5 Goodness-of-fit test of lognormal distribution

One reason why lognormal distributions were considered in this study was that comparisons between the different building categories are easier to observe compared to the use of empirical distributions. The goodness-of-fit of the lognormal distribution fit could, however, be evaluated using the Lilliefors test (Lilliefors, 1967).

An example of the Lilliefors test with a significance level, α, of 0.1 is shown in Figure 4 for site clean-up duration of 1-3 storey building demolitions in suburbs initiated by CERA. It can be seen here that the lognormal fit does capture the trends of the empirical distribution reasonably well. However, the lognormal distribution actually fails the test in this case. This is because with the large number of data entries available for each building category, the critical statistic, which is the allowable difference between the lognormal fit and the empirical distribution, is small. Out of the thirty different lognormal distribution curves provided in Table 1, only four of these past the Lilliefors test despite most of them capturing the trends reasonably well. However, as the trends are still reasonably well captured, the findings discussed in previous sections are still valid. Furthermore, application of other probabilistic distributions showed worse fits, meaning that the lognormal distribution is still a reasonable approximation despite failing the Lilliefors test.

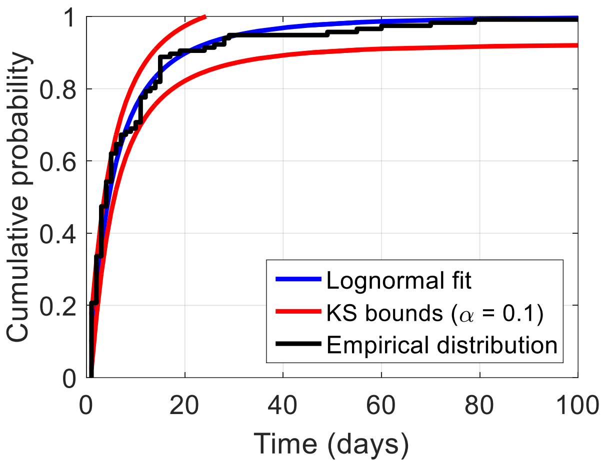


Figure 4. Application of Lillefors test for the site clean-up duration of 1-3 storey building demolitions in suburbs initiated by CERA with significance level of 10%

5 FUTURE DATA REFINEMENT AND APPLICATION

Much of this study's focus was to give an overview of the findings from the demolition data. However, further refinement could be made to consider the exact location of the building relative to the centre of the city, the exact number of stories within the building, and the building's construction material; in addition to other factors previously discussed (e.g. number and availability of contractors and building floor area). Investigations into the possible reason for each demolition, such as whether the building posed immediate life-safety from excessive damage or from incurring large residual deformation, or whether it was simply not economical to repair the building, would also be useful. These information could then be combined together to obtain fragility functions which are then adaptable and applicable to a wide range of buildings.

The application of such frameworks to other regions around New Zealand provide an opportunity to evaluate (i) whether the process implemented by CERA could be modified for better efficiency to speed up the demolition phase of the rebuild, and (ii) to evaluate the resiliency of the entire region. The latter could aid in informing decision making and policies at a wider regional level, and would fit with the Resilient Wellington strategy (Wellington City Council, 2017)

6 CONCLUSIONS

Based on processing of demolition-related data collected by CERA, it was found that:

1. A large proportion of the duration from the time of the earthquake until the competition of demolition arises from the decision phase of the demolition process. This shows that the soft-component of the demolition process is more critical overall, and speeding up this phase would greatly shorten the overall duration.
2. Demolition projects managed by CERA had a longer duration of procurement and planning compared to owner-initiated projects due to the large number of projects which CERA oversees, but is generally faster for other phases in the demolition process. CERA-led demolition projects were generally completed faster overall.
3. Buildings located in the suburbs had a longer decision making phase due to its lower threat to surroundings. Location may also play a factor in the duration of other phases in the demolition process if the project was managed by CERA. Otherwise, location has negligible influence on other demolition phases. Demolition projects in the suburbs were generally slower overall.
4. Buildings taller than 3-storeis high had a shorter decision making phase and procurement phase compared to 1-3 storey tall buildings. However, every other phase in the demolition process was longer due to the larger scale of work required. Overall, building height has little effect on the total duration of the demolition process.
5. The lognormal distribution values for fragility functions regarding the duration of several aspects of the demolition process were provided for different categories of buildings.

7 ACKNOWLEDGEMENTS

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