Statistical Damage Survey of the 2010 and 2011 Christchurch Earthquakes

T. Lai, & A. Nasseri
AIR-Worldwide Corporation, Boston, MA, USA

F. Turner
California Seismic Safety Commission, USA

SUMMARY
The two recent earthquakes in Christchurch, New Zealand provided an opportunity for researchers to collect information on seismic performance of buildings. A team organized by the Earthquake Engineering Research Institute (EERI) visited the area and conducted a damage survey addressing a variety of interests including structural and geotechnical engineering, emergency management, disaster recovery and socio-economic impacts. The authors focused on identifying the spread and severity of damage by sampling areas in order to capture the overall performance of buildings and to estimate economic and insured losses. Several locations close to seismic recording stations were examined and information about building attributes and the state of structural and non-structural damage for about 200 buildings, mostly typical non-engineered dwellings, was collected. This paper presents some statistics of the observed damage for typical residential dwellings around Christchurch. Results from this study suggest a low level of shaking-induced damage for wood structures during these earthquakes.

Keywords: Christchurch earthquake, damage survey,

1. INTRODUCTION

The recent earthquakes around the world have once again highlighted the substantial economic and human impact of seismic events in regions of large population and exposure value. The need for seismic loss estimation has long been recognized by government and financial organization and has led to development and advancement of risk and loss estimation models. These models, which inevitably have limited resolution, rely considerably on observational data from damage surveys. Post-earthquake damage surveys serve a major role in understanding seismic behaviour of structures. In a majority of cases the primary focus of reconnaissance efforts has been to identify weaknesses and/or strength of specific structural systems and detailing. While examination of the performance of individual structures is important for improving analysis and design procedures, it is also important from both economic and mitigation perspectives to determine the spread and severity of damage in various building types within sampled areas. The two recent earthquakes in Christchurch (M7.1, September 2010 and M6.3 February 2011), monitored by an extensive seismic recording network (GeoNet), provided a great opportunity for collecting information on building performance that could be used for validating risk assessment models and for vulnerability studies.

Although New Zealand is located in the world's most active seismic region, known as the "Pacific Ring of Fire", the Christchurch area had experienced only moderate shaking from distant earthquakes prior to the 2010 Darfield earthquake. For this reason, Christchurch was thought to be in a moderate-low seismic zone and where no mandatory retrofit provisions were required. Relatively underprepared for a disaster of such level, some areas such as the Central Business District (CBD) were hit by overwhelming damage to the old masonry construction, business interruption and widespread liquefaction in the 2010 earthquake. Damage in CBD was particularly large in the 2011 aftershock due to closer proximity to the epicentre. The authors –as part of the EERI reconnaissance team– conducted damage screening of large areas and a performed a detailed survey for about 200 buildings near some selected seismic stations. Due to tight security measures within CBD and deployment of other groups to document liquefaction damage, the authors focused on areas outside CBD and only on shaking related damage.

Following the ASCE/SEI 31-03 classifications for building types, a large amount of information on building attributes including construction type, number of stories, age, usage, siding, and roof type was collected in the survey. Description of the damage states (per HAZUS classification) in structural and non-structural elements of the surveyed building was documented. This paper gives an overview of the damage survey as well as statistical analyses of the data to offer some insight on overall performance of the typical residential buildings in Christchurch. Statistical data presented in this study is derived from a localized survey around Southern Cross Hospital near the Resthaven seismic recording station. Moreover, the paper presents some comparison of the performance of buildings in the two earthquakes.

2. DAMAGE SCREENING OF THE CHRISTCHURCH EARTHQUAKES

The September 2010, M7.1 earthquake in Christchurch occurred at a previously unknown fault and its epicentre was approximately 40km west of the city. The quake affected a large area and triggered massive liquefaction in Christchurch and neighbouring towns. Severe damage from shaking, however, was limited to old unreinforced masonry commercial buildings in the CBD area. Fortunately, due to the time of the event, which occurred at 4:35 am, it did not cause any major injury or death.

The M6.3 February 2011 earthquake was a large aftershock of the 2010 event. It affected a much smaller area, but because of the proximity of the epicentre to the city centre (about 10km) it generated more violent shaking and resulted in larger destruction in the already damaged CBD and the liquefied areas. Collapse of several multi-storey buildings claimed about 180 lives.

2.1. Surveyed Area

The authors surveyed areas as far as Timaru and Rangiora, respectively, 160km southwest and 25km north away from Christchurch in order to determine the extent of the affected areas. A total of 200 buildings from 14 different areas around Christchurch were surveyed. Due to the limited accessibility and resources only generalized descriptions of damage were recorded for most of these locations. Table 1 lists the surveyed locations and some ground motion information from the closest recording station. In order to estimate the mean damage over a relatively large area, a comprehensive and systematic investigation was carried out on about 100 buildings from several city blocks centred on Southern Cross Hospital near the Resthaven seismic station. This block consists, mostly, of typical dwellings in Christchurch and some engineered construction such as light metal and pre-stressed reinforced concrete (RC) buildings. Fig. 1 shows the surveyed area and the selected city blocks relative to the CBD.

2.2. Classification of buildings and damage states

Each surveyed buildings was assigned to a proper common building type in accordance with the classification of ASCE/SEI 31-03. The most common building types observed in the survey are W1 (light wood frame, residential), W2 (wood frame, commercial and industrial), S1 (steel moment frames), C1 (concrete moment frames) and URM. Buildings in each category are further classified by age. Generally, buildings constructed before the 1980s were referred to as “old” and those constructed after 1980 were considered “new”.

Five states for structural and non-structural damage of 1) None, 2) Minor, 3) Moderate, 4) Extensive, and 5) Complete are considered in the survey in accordance with the definitions in HAZUS (FEMA/NIBS 1999). Damage states are evaluated based on a visual screening of the accessible exterior elevations of the surveyed buildings and communication with local residents when applicable.

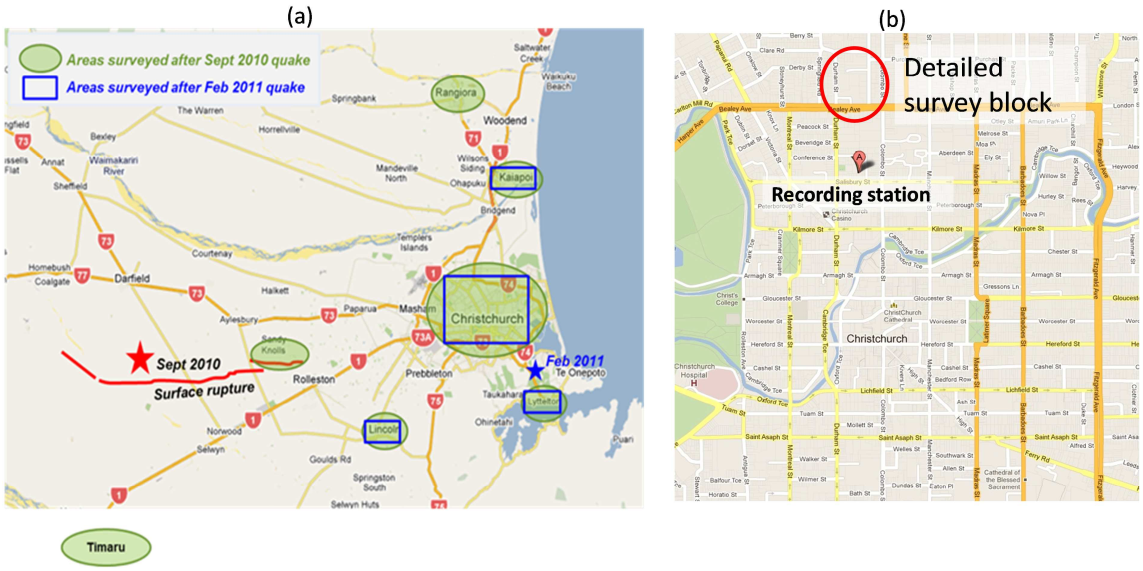

Figure 1. a) Surveyed areas in the 2010 and 2011 earthquakes b) Surveyed block near CBD

Table 1. Ground motion parameters (geometric mean) at closest recording station to the surveyed locations

No.	Location	Lat.	Long.	Sept 2010 *			Feb 2011 *			Surveyed	
				PGA	Sa0.3	Sa1.0	PGA	Sa0.3	Sa1.0	2010	2011
1	Resthaven	-43.524	172.635	0.342	0.794	0.383	0.802	0.899	1.389	Y	Y
2	Heathcote	-43.581	172.709	0.831	1.389	0.188	1.877	3.653	0.670	N	Y
3	Botanic	-43.531	172.620	0.230	0.401	0.277	0.682	0.898	0.731	N	Y
4	Cathedral	-43.539	172.646	0.305	0.592	0.355	0.606	0.906	0.609	N	Y
5	Woman Hospital	-43.536	172.626	0.198	0.496	0.339	0.361	1.019	0.759	Y	Y
6	Lincoln	-43.625	172.468	0.600	0.501	0.565	0.180	0.204	0.152	Y	Y
7	Cashmere	-43.567	172.624	0.343	0.580	0.411	0.532	0.712	0.992	N	Y
8	Lyttelton	-43.606	172.722	0.401	0.414	0.162	1.177	0.967	0.284	Y	Y
9	Pages Rd	-43.528	172.683	0.305	0.450	0.255	0.888	0.933	0.524	N	Y
10	Kaiapoi	-43.378	172.664	0.456	0.833	0.284	0.285	0.499	0.173	N	Y
11	Courtenay	-43.388	172.664							Y	Y
12	Knolls	-43.544	172.156							Y	N
13	Rangiora	-43.305	172.597							Y	N
14	Timaru	-44.413	171.250							Y	N

* Ground motion is in unit of g

2.3. Extent of damage from qualitative screenings

This section presents a description of the qualitative damage observed from some key locations in the affected areas, and outlines the variation of damage resulted from the two earthquakes. At Sandy Knolls and Heathcode Valley, the epicentral area of the 2010 and 2011 earthquakes, despite the very high levels of ground shakings, the wood dwellings, even those with masonry veneer performed well. The most common observed damage was limited to fallen chimneys and unreinforced masonry fences. The satisfactory behaviour is believed to be related to firm anchorage of wood frames to foundations and of veneers to frames.

The Women's Hospital, which is located on the west side of the restricted CBD area, consists of several multi-storey RC buildings. Their structural system includes frames, shear walls and precast

RC. Among these building there was an interesting 6-storey hybrid structure which was originally built as a 3-storey steel frame; the upper 3-storey RC shear wall was added a few years later. The main hospital building is base isolated, and performed well during the main shock. One of its rubber bearings had about 2.5cm permanent displacements, and adjoining buildings experienced some minor pounding damage as expected. The hybrid building showed no stress after the shaking. However, in most of the buildings some light non-structural damage such as broken glass and fallen ceiling was reported. During the 2011 aftershock, although the hospital was shaken more violently than the main shock, most of the buildings except the hybrid performed well. The latter was cracked and was evacuated after the quake.

15 km north of Christchurch, the Courtenay Drive area in Kaiapoi which is located right along wetland, was hit severely by liquefaction during the main shock. Although this area is quite far from the epicentre, recorded ground motions at the nearby Kaiapoi North School indicated moderate shaking probably due to soil amplification. The liquefaction broke water main and drainage system, and sand residual was extensive on yards, private driveways and public roads. One dwelling slid toward wetland as much as 1.2m. Interestingly, lateral spreading and liquefaction damage showed considerable spatial variations within close distances. Out of the 24 building units along Raven Quay, six might need to be demolished while another six looked intact from exterior. The remaining had varying levels of damage. During the February 2011 aftershock, although the shaking severity was much less than the main shock, the liquefaction damage in the area was further exaggerated. The observations clearly indicated high liquefaction susceptibility in this area. A dwelling, that previously slid 1.2m, moved another 0.6m away as shown in Fig. 2.

In Timaru which is about 160km southwest of Christchurch, two authors screened about 39 houses. All these houses were 1-2 storey wood constructions (75% being 1-storey and 70% having masonry veneer and light roof). Most of these buildings seemed intact, and only one old house sitting on a slope suffered damage to retaining walls and foundation. More details about the qualitative damage survey at other locations can be found in the full reports posted on EERI website (EERI 2010).

Figure 2. Damage due to sliding in Courtenay Dr.

3. STATISTICAL DAMAGE SURVEY IN A SAMPLE AREA

About 100 buildings near Southern Cross Hospital were systematically surveyed. The surveyed area was about $0.5km^2$, and about half a kilometre away from Resthaven seismic station. The geometric mean of the recorded peak ground acceleration (PGA) was 0.34g and 0.80g respectively in the 2010 and 2011 events. The buildings consist of mostly typical one-storey wood residential dwellings in Christchurch with some other engineered constructions such as RC frame, pre-stressed RC and light metal. Since liquefaction was not observed at this location, the statistics of collected data presented in this section provides some insights on building performance subjected to shaking only.

3.1. Distribution of buildings by type and age

A breakdown of the construction mix, shown in Fig. 3, indicates that 75% of the building stock in this block is of wood construction (62% W1 and 13% W2) which is known to perform relatively well in earthquakes. With respect to age of the buildings, as defined in previous sections, 44% of the building stock is considered "new" and 33% is considered "old" while age of the rest is not clear from the survey. For wood and masonry buildings which collectively comprise the majority of the surveyed buildings, Fig. 4 presents the breakdown by age. It can be inferred from these figures that "new" wood construction is prevalent.

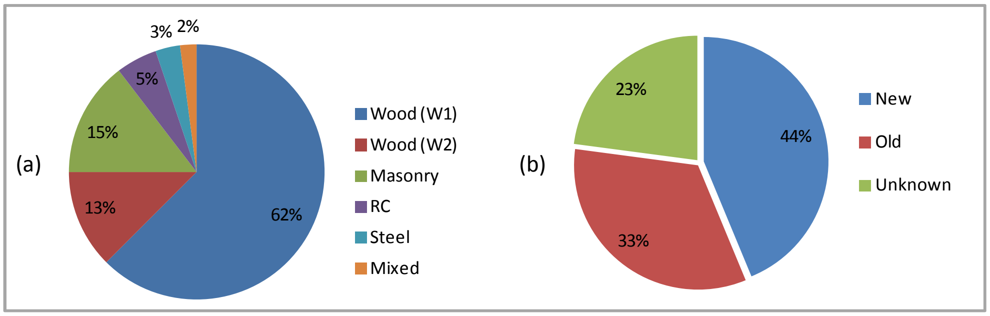

Figure 3. Distribution of buildings in the surveyed region a) by construction type b) by age

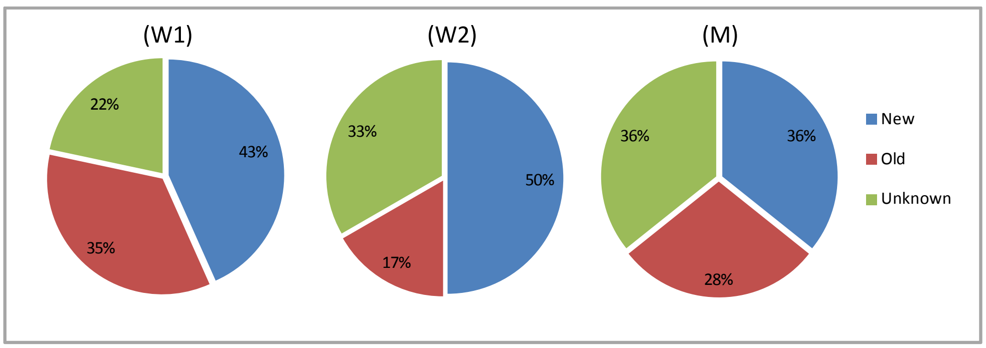

Figure 4. Distribution of wood and masonry structures by age

3.2. Spatial distribution and statistics of damage

Each building in the studied region was assigned a damage state as defined in section 2.2. Fig. 5 shows, for both 2010 and 2011 earthquakes, the distribution of structural and non-structural damage over the surveyed area using colour codes that represent each damage state. As can be seen in the figure, the pattern of damage in the two earthquakes is similar; both events caused more non-structural damage than structural damage, and both created comparable spatial distribution. Severity of the damage, however, is somewhat higher in the 2011 event. This can be visualized by contrasting the colour codes of the two panels in Fig. 5.

Statistics of the observed damage states for the entire building stock (not separated by construction type) is shown in Fig. 6 for the 2010 and 2011 events. During the 2010 earthquake, as much as 88% of the buildings in the surveyed area did not suffer any visible structural damage. Only 3% experienced moderate damage and 5% suffered extensive damage whereas no building was completely damaged. With regards to non-structural damage, 75% of the buildings were found to be unscathed while 11% sustained extensive damage. No complete damage was observed in non-structural component either. In the 2011 earthquake the percentage of buildings that experienced structural damage rose to 21%. Out of all the damaged buildings, 15% suffered extensive and 3% complete damage. Nevertheless, still 79% of the buildings did not experience any notable structural damage. Examination of non-structural components shows that about 41% of the buildings suffered some levels of damage among which 10% experienced extensive damage and 5% sustained complete damage.

Figure 5. Damage distribution near Southern Cross Hospital: a) September 2010 b) February 2011 S: structural damage and N: non-structural

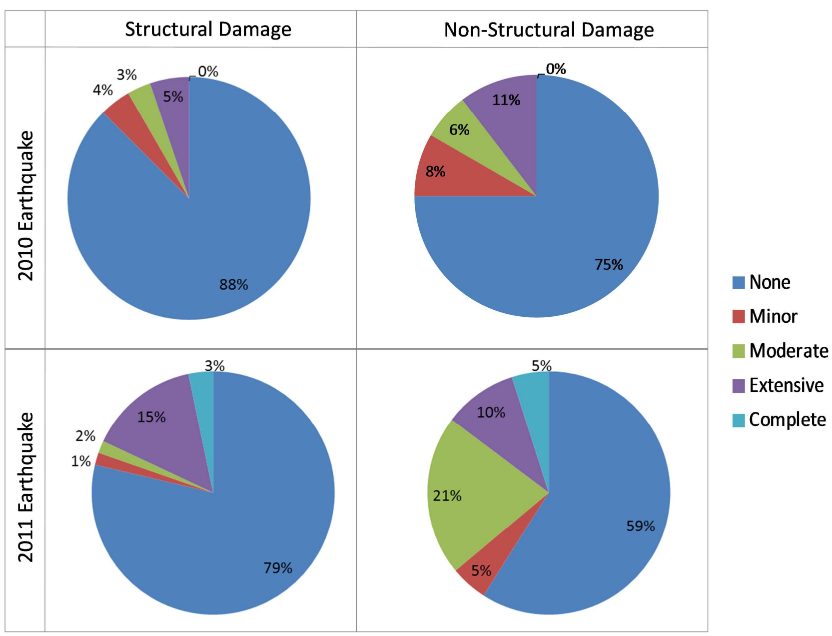

Figure 6. Statistics of the observed damage in the surveyed area for the 2010 and 2011 Earthquakes

Data is further interrogated to determine the statistics of damage by construction type and age of the building. It must be noted, however, that as the size of the samples becomes smaller due to segregation of data, uncertainty of the statistics increases. Considering that RC and Steel comprise only a small fraction of the building stock in the surveyed area, they were combined into a single construction group to increase the sample size. Thus, three main categories of “wood”, “masonry” and “others” are considered in the remaining part of the study. Fig. 7 shows the statistics of structural and non-structural damage for the three categories in the 2010 and 2011 earthquakes. As one expects, the distribution of damage states in each category follows the one presented previously for the entire stock; i.e. the majority of the buildings did not sustain damage that was noticeable from the exteriors. In the 2010 event, 8% of “wood” and 7% of “masonry” buildings suffered structural damage. These numbers for non-structural damage were respectively 19% and 21%. No complete structural damage was seen in the either wood or masonry buildings. In the 2011 earthquake, 21% of “wood” and 34% of “masonry” experienced structural damage. In 4% of the ‘wood” buildings damage was considered complete. Non-structural elements in 47% of “wood” and 34% of “masonry” buildings experienced varying levels of damage with 17% in both “wood” and masonry being classified as extensive or higher. In general, one can conclude that the 2011 earthquake caused higher damage in this area than the 2010 earthquake, and that damage in masonry buildings was higher than in wood dwellings. As mentioned previously, higher uncertainty in the statistics for the “other” due to smaller sample size does not allow reliable comparisons.

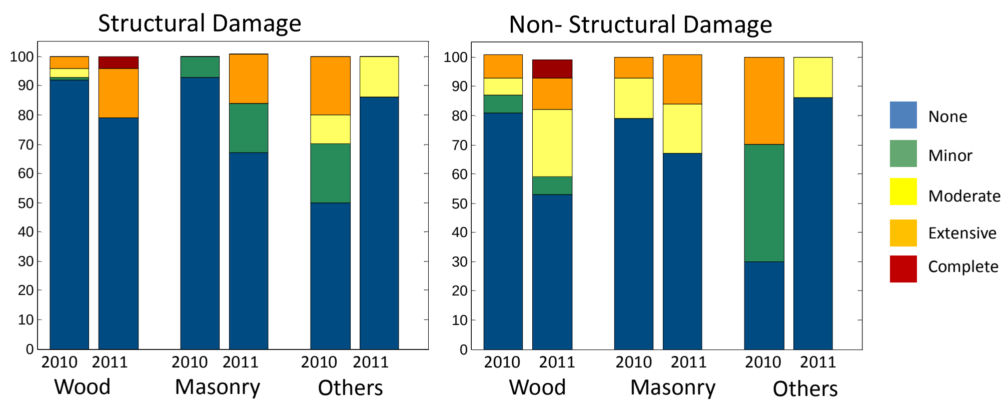

Figure 7. Breakdown of damage state for different construction types

Breakdown of damage states for buildings of different age, namely, “old” (pre-1980) and “new” (post-1980) is illustrated in Fig. 8. The outcome of this illustration is not surprising; old buildings have experienced higher damage states than did new buildings. In the 2010 earthquake, 28% of the old buildings experienced structural damage and 50% suffered non-structural damage. The percentage of those with extensive to complete damage was 16 and 19 respectively for structural and non-structural damage. None of the new buildings suffered moderate or higher damage. In the 2011 earthquake, 37% of the old buildings suffered structural damage while 63% experienced non-structural damage. Among those, 30% of structural damage and 23% of non-structural damage was classified as extensive to complete. From the “new” buildings only 8% suffered extensive and complete damage.

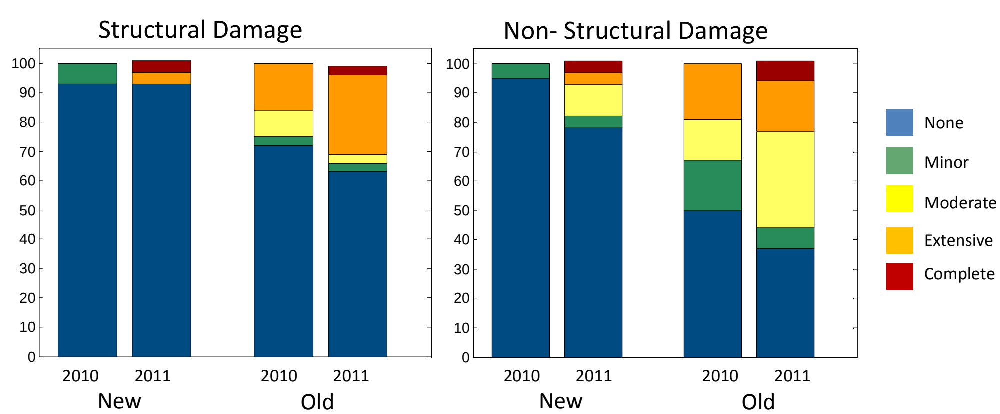

Figure 8. Breakdown of damage state for different age

Statistics of the damage data presented above clearly indicate a low level of damage in the surveyed areas for both of the Christchurch earthquakes. This observation is attributed to the composition of the building stock which is dominated by low rise (mainly one story) wood structures. These types of buildings, in light of the ductile behaviour of wood material, their relatively low mass and good construction quality, have performed very well in past earthquakes. Moreover, as seen in the building age distribution, newly constructed buildings comprise a considerable fraction of the data. Having small proportions of old and vulnerable building and the fact that no liquefaction occurred in this area contributed to such low levels of observed damage in the survey.

3.3. Application of statistical damage surveys

Reconnaissance efforts often focus on buildings which suffered significant damage in order to identify similar patterns of defects and to understand the weakness of particular structural systems. Although detailed studies of individual damaged structures have been instrumental in enhancing analysis and design procedures, in the context of assessing the impact of catastrophic events over a larger area, those detailed individual studies may not be fully representative of the range of overall performance. Observations in this survey, as well as other similar studies, have once again demonstrated how damage levels vary significantly from building to building even in a relatively small area. Investigation of only the severely damaged buildings irrespective of the surrounding area, therefore, falls short of drawing a big picture of the overall damage in the region and often leads to overestimation of the earthquake impact. For estimating economic and insured losses in the affected region, which is of interest to government agencies and financial organizations, statistics of the damage data collected from sample areas that represent the typical construction environment bear more valuable information.

The data for which the statistics are presented in this study are collected from an area covering a reasonably large size which consists of typical dwellings in Christchurch. The statistics presented here, therefore, can be used in model validation processes.

4. ADDITIONAL BENEFIT FROM SYSTEMATIC SAMPLING OF BUILDING PERFORMANCE

Documenting the performance of dozens of buildings that experienced slight or no visible damage after the September earthquake was considered by the authors to be tedious at times. Making the effort to capture digital images of relatively undamaged buildings is arguably questionable now that online services like Google Streets can provide low resolution images.

However, the author’s perspectives changed after the February earthquake regarding the perceived value of collecting higher resolution images during the September surveys. In a few cases upon further review, high resolution images taken in September captured tell-tale signs of minor damage that manifested into much more severe damage in February.

The sequence of earthquakes in Christchurch provided an opportunity to document and to compare the performance of buildings that experienced less severe ground motions from the September 2010 earthquake followed by stronger shaking from the February 2011 aftershock. This type of information can not only help calibrate performance-based earthquake engineering, but also sensitize safety assessors, regulators (consent authorities), loss modellers, and claims adjusters about the nature, extent and potential consequences of subtle forms of response to earthquakes as illustrated in Fig. 9. The Structural Engineers Association of California recently established an Earthquake Performance Evaluation Program to mobilize large numbers of volunteers to help capture and interpret this type of response more systematically (Turner et al., 2010).

Figure 9. a) Modern wood frame home in Christchurch that experienced subtle dimpling in its finish at attachments and along edges around wall panel perimeters after the September 2010 earthquake. b) Severe damage from the February 2011 earthquake

5. CONCLUSIONS

The September 2010 and February 2011 earthquakes in Christchurch provided an opportunity to collect information about building performance in New Zealand. In light of an extensive seismic station network (GeoNet) and effective disaster management by local organizations and researchers an abundance of recorded motion and damage data has been archived. This paper aimed to complement this archive and document the authors' first hand observations of damage extent and statistics regarding its variability. The authors performed damage survey of various locations with a focus on understanding the spread and severity of damage over sampled areas. Statistical analysis of the damage data presented in this paper suggests a generally low level of shaking-induced damage. This low level of damage is attributed to the superior quality of wood construction in New Zealand. Undoubtedly, information from these events will help to better understand and enhance New Zealand's seismic regulation, and will serve as a benchmark in future development of earthquake risk assessment for New Zealand.

AKCNOWLEDGEMENT
The authors would like acknowledge AIR Worldwide, the Earthquake Engineering Research Institute (EERI) and the New Zealand Society of Earthquake Engineering (NAZSEE) for organizing and assisting the survey and Yuchuan Tang for assisting in data analysis.

REFERENCES

ASCE. (2002). Seismic evaluation of existing buildings (ASCE/SEI 31-03). *American Society of Civil Engineers*. Reston, Virginia.

National Institute of Building Science (1999). HAZUS99 Technical Manual. *Federal Emergency Management Agency (FEMA)*. Washington, DC.

Earthquake Engineering Research Institute (2010). *Canterbury, New Zealand Earthquake Clearinghouse.* http://eqclearinghouse.org/20100903-christchurch/reports-from-the-field/.

Turner, F., McCormick, D., Court, A., and Valancius, J. (2010). SEAOC's earthquake performance evaluation program: An update. *Proceedings National Conference on Earthquake Engineering*