How many houses can we expect to suffer land-related building damage from earthquakes in New Zealand?

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ABSTRACT: Land effects caused one third of the insured loss to residential dwellings in the Canterbury Earthquake Sequence. These effects were largely unexpected by the re/insurance community and inadequately represented by risk models.

Separating land damage from building damage in Christchurch has been complicated. Negotiations between EQC and private insurers have significantly delayed many claims and above cap claims are still being received by private insurers. Treasury is currently reviewing the cover and operation of EQC with the goal of simplifying procedures to provide a better service to the insured public.

One controversial proposal in the review is to combine land and building under a single coverage with a single cap. The proposal comes soon after the insurance industry's change from replacement to sums insured policies. As proposed, home owners and insurers will need to agree a sum insured in advance to cover possible land damage in a future earthquake. Most land-related claims in Christchurch were modest but some were extremely large. Large claims in the future could exhaust the specified sum insured on earth works alone leaving the home owner to foot the bill for all work on the superstructure.

To inform the important debate on how to cover land-related damage we present annual exceedance probability functions for the modelled number of houses affected by liquefaction and landslide damage from a stochastic set of possible New Zealand earthquakes. We break the number of houses down by land damage severity. We discuss how the Christchurch experience compares to the modelled results

1 INTRODUCTION

Most members of the public had never heard of liquefaction before the Canterbury Earthquake Sequence in 2010-2011.

The New Zealand insurance industry was prepared to handle claims caused by shake damage. In step with normal practice in other countries around the world, private insurance companies had not considered damage to the land. Unusually, in a global insurance sense, EQC did offer cover for land damage. The historical reasons for this provision include storm-related land slips, which tend to be frequent and of small spatial scale and also the larger scale Abbotsford land slide in 1979 which left 69 houses uninhabitable (see http://www.eqc.govt.nz/our-history/event-timeline-1942-to-today) For decades EQC land cover provided a social safety net for home-owners unlucky enough to lose the land under their houses from natural disasters.

The wording of the Earthquake Commission Act 1993 and the wording of insurance policies issued by the private market were not designed to deal with the complexity of claims from damage caused by earthquake related land failures on the scale seen in Christchurch. Working through the vast number of claims, has been enormously challenging for the public, local and central governments, EQC, the local insurers and their global reinsurers. EQC's cover is dictated by legislation and insurance and reinsurance policies are legal contracts. It was therefore inevitable courts would be required to provide clarity on legal interpretations and, given the financial impact of the event, it should not be surprising

there are some legal issues still being resolved more than six years after the CES.

Historically, large disasters in New Zealand and internationally have led to changes in building codes, legislation and regulation. In that regard at least, the Christchurch events are no exception. Treasury is undertaking a review of the cover provided by EQC. Treasury issued a discussion document on proposed changes to EQC in 2015 (http://www.treasury.govt.nz/publications/reviews-consultation/eqc/pdfs/eqc-rev-discussion-doc.pdf). The local insurance market examined the proposals and provided feedback through the Insurance Council of New Zealand (http://www.icnz.org.nz/issues-submissions/submissions/). Many of the proposed changes are straightforward. For example, there is little debate around streamlining the claims handling procedures (indeed, a memorandum of understanding, perhaps anticipating future legislation changes, has been set up to handle claims from the Kaikoura EQ, http://www.icnz.org.nz/wp-content/uploads/Memorandum-of-Understanding-on-website-20-Dec-2016.pdf). Similarly there appears to be general agreement on the removal of contents from EQC's cover and the need to raise the EQC cap on building cover from $100k to a higher value, yet to be determined.

The controversial aspect of Treasury's proposed changes is the cover of land. Treasury proposes to combine land with the building under one cover and apply a single cap, higher than the current $100k. EQC will pay up to the cap and the private market will provide cover up to the policy sum insured. Treasury argues this will simplify claims handling and remove the debate over what is land damage and what is building damage caused by land failure. Insurers are not convinced. They point to the uncertainties involved in quantifying the risk of land failure in the first place and highlight the challenges home owners and insurers will face in trying to set a sum insured that covers not only the cost of replacing the building but also repairing the land, should it be damaged in a natural disaster. Such an assessment would be difficult for geotechnical experts let alone lay people. Faced with uncertainty, insurers need to be conservative and they point out that will inevitably lead to a rise in premiums which will not be popular and may start a downward spiral of unaffordability. One approach for insurers would be to assume EQC's cap will be completely absorbed by repairing land damage so the private market will be covering the full value of the building. Home owners wishing to proactively apply a conservative estimate of their sum insured to cover possible land costs would incur higher premiums.

There are higher level questions of course. Why should New Zealand separate out land cover in the first place when land is not covered by insurance in other countries? Is New Zealand society prepared to accept the situation where insured home-owners lose their house and section in a natural disaster but are not compensated for the loss of their land? At the other extreme, is it reasonable for EQC to be paying to fix cracks in driveways after a large earthquake. What is insurance for?

Treasury's review of EQC was originally planned to be completed by 2013 (https://www.beehive.govt.nz/release/govt-confirms-earthquake-commission-review). Going into an election year it seems likely the parliamentary process will be delayed even further.

The public debate over land cover has focused on who will pay for land damage. There has been little public discussion on the magnitude of expected losses. The purpose of this paper is therefore to provide some preliminary results from a probabilistic insurance loss model that may be useful to quantify the debate and help government and the insurance industry reach a compromise which satisfies social objectives in a commercially sustainable way.

2 PROBABILISTIC INSURANCE LOSS MODELS

Insurers have a good understanding of risks such as fire, theft and life because their actuaries can analyse large datasets of historical claims. They do not have sufficient data to apply the same analysis to natural disaster risk. Instead, for several decades, the re/insurance industry has used probabilistic loss models for guidance.

Probabilistic models consist of four modules: stochastic, hazard, vulnerability and financial. For an earthquake model, the stochastic module contains a large catalogue of possible earthquake events, a synthetic future of events, hundreds of thousands of years in length. The hazard model describes the

ground motions and land deformations at each location of interest for each stochastic event, taking into account local site conditions. The vulnerability module estimates the cost of repairing the damage caused by the hazard to any type of insured building and its contents as well as the cost of business interruption. Finally, the financial module computes the monetary consequence to the re/insurer given their position on the portfolio being analysed.

Building a probabilistic model from end to end is a large undertaking involving experts from a range of disciplines. Each module needs to be calibrated both independently and as part of the overall objective to estimate insured losses. Accessing commercially sensitive claims data often comes with restrictions on publication and, in the commercial world, the investment required to build a model means vendor companies guard their intellectual property closely, typically providing details only under non-disclosure agreements. Where possible, lessons learned from developing these models are shared with the research communities, for example Drayton & Verdon 2013, Fitzenz & Nyst 2014, Apel & Nyst 2014. A high level overview of the RMS New Zealand HD Earthquake Model, released in 2016 is provided online at http://forms2.rms.com/rs/729-DJX-565/images/New-Zealand-Earthquake-Datasheet.pdf

3 LAND DAMAGE IN THE MODEL

The RMS model's hazard module outputs acceleration spectra to quantify the shake hazard and a range of parameters to quantify the liquefaction and landslide hazard in each stochastic event with the purpose of quantifying damage to buildings.

The liquefaction methodology was redesigned after the CES. The previous version followed an approach based on ATC-13 whereby liquefiable soils were pre-assigned an index from 1 to 5 and then the building damage from shake at a location was factored up by an amount dependent on the local soils index. Christchurch revealed the simplicity of this approach and, more importantly, provided the data whereby new approaches could be developed. RMS wanted to ensure any new approach was not customized to Christchurch where extremely detailed soil information is now available but could be applied anywhere in the world using ubiquitous geotechnical data.

The new approach works in two steps. First the probability of liquefaction is computed for each location in each event. The probability is a function not only of the soil profile and ground water depth (Ancheta & Lee 2014) but also of the event intensity and duration. Should liquefaction be initiated, the second step is to compute the local vertical settlement or horizontal displacement in the case of lateral spreading near a free-face.

The improvements offered by the new methodology can be seen in comparisons of predicted surface expression of liquefaction in Christchurch in the February 2011 event, figure 1.

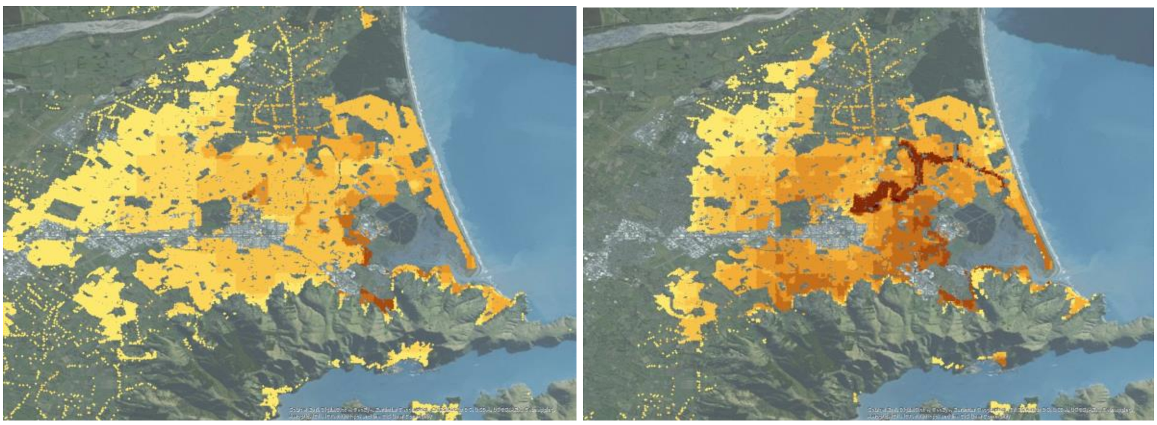

Figure 1. Modelled residential building mean damage ratio from land deformation in the February 2011 event. Darker colours represent higher damage ratios. Liquefaction index method on the left, new method on the right.

The RMS landslide methodology remains unchanged. A landslide susceptibility index is precompiled using information on soil strength, slope, rainfall and historical evidence of landslides. This approach reveals many susceptible slopes but few in populated areas. In the stochastic model the probability of landslide is computed based on the MMI and landslide index. When landslides occur the damage is assumed to be 100%.

Liquefaction-related damage functions in the model were calibrated from observations and insurer claims data (Ancheta & van Ballegooy 2014). Claims provided the total repair cost to each building, regardless of the whether the damage was caused by direct shaking, land deformation or a combination of the two. The calibration of the model needed to proceed in stages. Firstly the shake-damage functions were re-calibrated using data from locations outside areas with observed liquefaction. The recalibrated functions were then used to estimate the shake damage in areas with liquefaction. The difference between observed total building damage and the predicted shake-only damage was assumed to be caused by land deformation and the land damage curves were calibrated against these differences.

It is important to note the “land” damage curves used in the model are in fact used to estimate the increase in building and contents damage, caused by deformation of the land, over and above the damage caused directly by ground shaking.

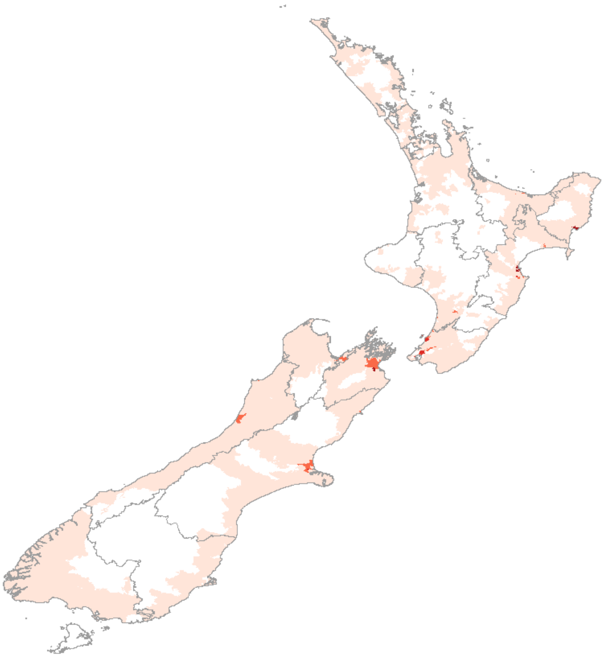

Figure 2. Postcodes where land deformation contributes to insured loss

4 LAND DAMAGE IN CHRISTCHURCH

The land damage in Christchurch has been clearly reported starting from the initial surveys after the September 2010, Darfield earthquake. Tonkin & Taylor (2010) assigned damage by property into five categories: very severe, major, moderate, minor and no apparent land damage. They assigned very approximate repair costs to these categories and the appendix to their report gave photographic examples of the categories and schematics of building damage mechanisms.

The repair strategies proposed in the 2010 report were made redundant by the February 2011 event when it became clear it was uneconomic to repair or rebuild in areas of increased future liquefaction risk.

The high cost of conventional engineering solutions, piles for residential houses on liquefiable soils lead to extensive research into new mitigation and repair techniques. EQC’s Ground Improvement Programme (EQC 2015) summarises a variety of methods, their effectiveness for different soil types

and their approximate costs per unit area under controlled conditions.

The wealth of data from Christchurch will undoubtedly lead to improved models for future costs of repairing damage to land. Despite the technical advances in the field, the first step to building a model of land damage will be to agree on a simple, unambiguous definition of “damage”. (This definition must be generic and not tailored to liquefaction in a suburban setting). As loss adjustors are quick to point out, when determining repair costs, damage is whatever the policy says it is.

In terms of repairs to buildings, both extreme cases are straightforward. If the land is unchanged by the shaking, the cost to repair the land is zero. If the building must be demolished and rebuilt the cost of repairing the land can be separated from the cost of rebuilding the structure. For all cases in between there is a varying level of ambiguity between how to allocate the final repair bill. Unless a workable definition of land damage is agreed, changing the way EQC covers land will only lead to different legal disputes in future events.

A probabilistic loss model for land damage can be developed following the same conceptual approach used to develop models for buildings and contents loss. Despite the wealth of data from Christchurch, calibration is difficult when fundamental questions remain about how to define damage and who will pay to repair it. It therefore seems necessary to develop a model in conjunction with revising the legislation. Methodologies and assumptions need to be open to all involved. Some iteration and refinement to both strands will be required.

To help the discussion and to put the Christchurch experience into context we present results from the RMS model. Rather than assign dollar costs we simply output the number of residential buildings affected by damage induced by land deformation in the model’s stochastic event set.

5 MODEL METHODOLOGY FOR PRELIMINARY ANALYSES

The RMS model works on a Variable Resolution Grid (VRG) covering New Zealand. Grid cells range from 10km in size in very sparsely populated areas down to 100m in densely populated areas with variable soils.

The number of residential buildings by meshblock is available from Statistics New Zealand. RMS has mapped the building count from meshblock to VRG using in-house GIS techniques involving land-use, land-cover data as a proxy for building density.

The site conditions, precompiled by VRG, are the same as used in the probabilistic calculations of loss to buildings and contents.

The model was run in-house and intermediate files were post-processed to simulate the land-related statistics. The process worked through each stochastic event in two stages. In the first stage the probability of landslide or liquefaction was calculated for each VRG and then deformation was simulated. Did it occur or not? The second stage applied in cells where deformation occurred. In those cells the damage distribution was calculated given the deformation and that distribution was sampled for every residential building in the VRG. In this way every building in a VRG experiences the same hazard but not every building in a VRG experiences the same level of damage.

We assigned the land-induced building damage ratio into six categories: <1%, 1-5%, 5-10%, 10-20%, 20-50% and 50-100%. This categorisation is in keeping with the approach of Tonkin & Taylor (2010) although our categories are arbitrary and should not be mapped to those bands. The damage ratio is defined as the cost of repairing the building divided by the replacement cost of the building. The two highest damage bands are dominated by lateral spreading and landslide.

Note, we are computing the cost of repairing the building, over and above the cost of repairing the shake damage. These damage ratios are therefore proxies for the land damage. As discussed, the proxies are intended only to start quantifying the industry discussions. We do not present a final result.

6 RESULTS

Figure 3 is an annual exceedance probability plot for the number of residential buildings in New Zealand today (with the Christchurch red zone removed) which can be expected to suffer damage due to land deformation in a single earthquake. Each damage ratio band has its own curve. The figure shows there is a 10% probability in any year at least 4,500 buildings will incur some, but less than 1% damage ratio, from land deformation in a single earthquake. Similarly, there is a 2.5% probability at least 6,500 buildings will incur 10-20% damage from land deformation in a single earthquake, in addition to the damage they incur from shaking.

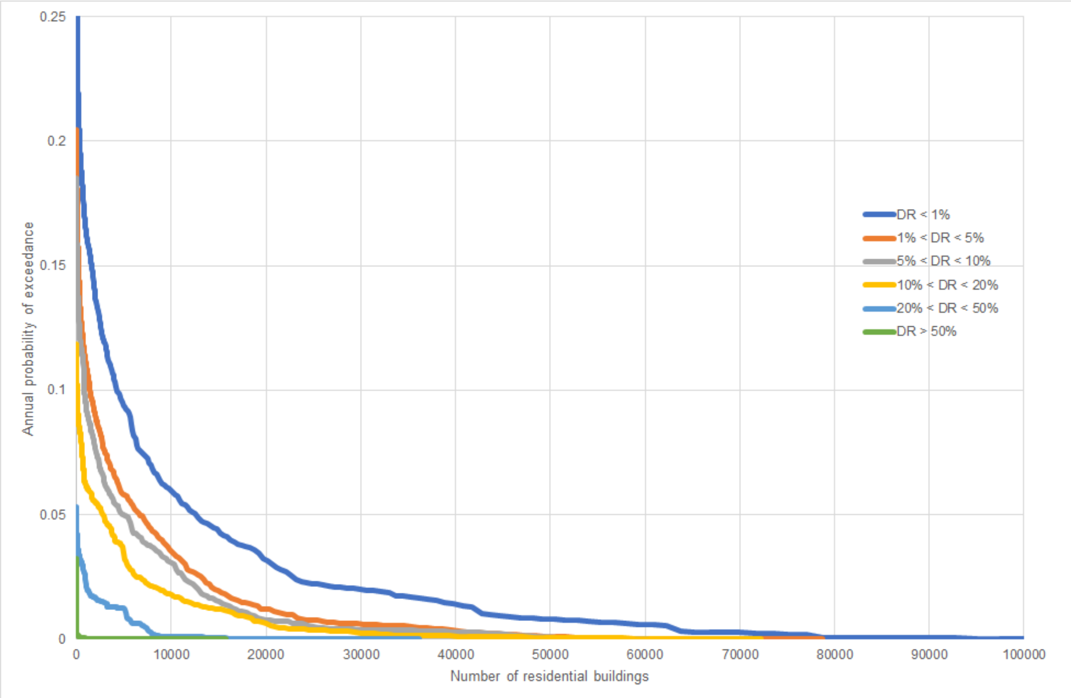

Figure 3. Annual exceedance probability for the number of residential buildings in New Zealand suffering damage due to land deformation in a single earthquake.

It is notable the EP curves have long thin tails. Insurers, reinsurers and regulators are particularly interested in how bad the problem may be. The curve for 20-50% damage ratio reaches 20,000 buildings at an annual exceedance probability of 0.02%, or approximately a 5,000 year return period.

Remember, the damage ratio here is relative to the repair cost of the building and not to the real estate value of the section. A decision to repair land clearly needs to consider the land's market value. Major repairs will be more economically feasible in sought-after suburbs than in less affluent areas. It is conceptually straightforward to include a real estate threshold for each location to cap the land cost and then to run sensitivity tests on how this threshold affects total losses. Such an analysis is beyond the scope of this paper.

6.1 Christchurch in perspective

The calculations for all of New Zealand were also run for just the exposure in the Christchurch City Council Territorial Local Authority, see figure 4. The effect of removing the red zone houses can be seen on the curves for lower levels of damage. Differences for the higher levels of damage are less obvious. The model is only outputting additional building damage due to land deformation whereas the decision to abandon the red zone was because of the increased risk of liquefaction in future events. Some red-zoned houses in the eastern suburbs settled uniformly and suffered little structural damage. The cost of abandoning the red-zone, over the estimated cost of repair, was born but the government not by the insurance market. Predicting the locations of future red zones and costing them in the model would require more detailed analysis, if indeed criteria for defining red zones can be agreed in advance.

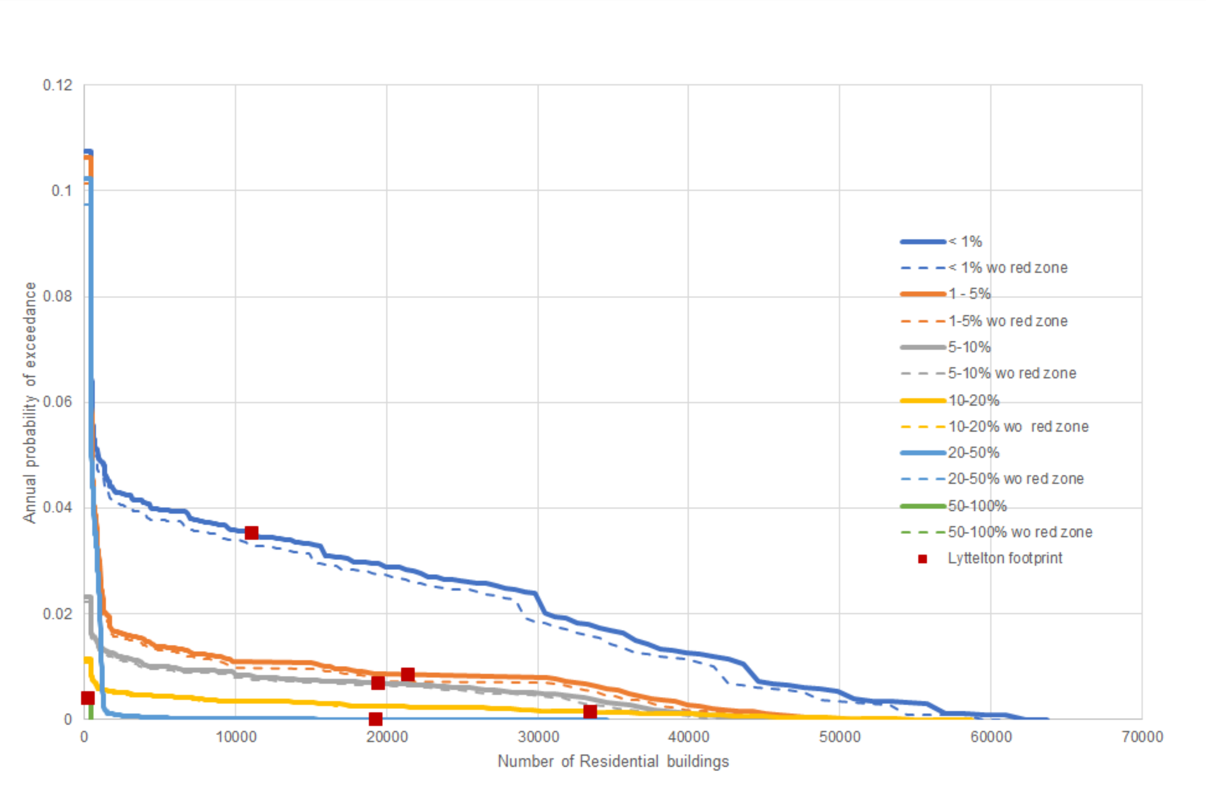

Figure 4. Annual exceedance probability for the number of residential buildings in Christchurch City Council TLA suffering different levels of damage due to land deformation in a single earthquake. Solid curves include the red zone, dashed curves exclude the red zone. Red squares show the modelled numbers of buildings from February 2011.

It is interesting the 20-50% damage ratio curve for Christchurch crosses other damage ratio curves. The two highest damage bands are dominated by lateral spreading while the lower curves are predominantly vertical settlement so while we are interested in the single cost of land deformation it is important to remember we are considering more than one deformation mechanism.

Every earthquake has a unique footprint and the combination of shaking intensity, soil conditions and built environment will produce a unique damage ratio distribution. Reading off the number of buildings by damage ratio band for the same EP threshold does not deliver the total number of buildings or the total cost for that probability level.

Using the GNS / USGS shakemap footprint for the February 2011 event on its own, the model expects just over 100,000 houses experienced some damage from land deformation. Of these 33,500 houses experienced 10-20% damage from land deformation and 19,300 houses 20-50% damage, see table 1. The building counts by damage band have also been plotted on the Christchurch EP curves in figure 4.

Table 1. Simulated number of residential buildings by land-related damage ratio band for February 2011

Damage ratio band	Number of buildings
< 1%	11,000
1-5%	21,400
5-10%	19,400
10-20%	33,500
20-50%	19,300
50-100%	200

There is no simple answer to the question "what was the return period of Christchurch?" It depends on the aspect one is interested in (fault rupture, pga by location, loss etc). If we look at the situation of 33,500 residential buildings anywhere in New Zealand experiencing 10-20% damage ratio from land deformation, the model says this number has a 0.16% probability of being exceeded in any given year for today's exposure. Such an EP is approximately the same as a return period of 600 years. The return period for 19,300 buildings experiencing 20-50% damage from land deformation is just over 4,000 years.

Return periods of hundreds to thousands of years means the scale of the damage from land deformation in Christchurch was out of the ordinary but not so far out that it can be dismissed as an anomaly. Treasury and the insurance industry are right to be addressing how to handle future land damage. Probabilistic models are likely to play an increasingly important role in their deliberations.

7 CONCLUSIONS

We have used a probabilistic model of insured loss to buildings and contents to output a proxy for land damage. We have presented preliminary findings for the number of residential buildings expected to experience different levels of land damage as a way of quantifying the discussion about the future of land cover by EQC and/or the private market. The public debate so far has been about who will pay and not how much. The preliminary analyses pose many questions but the model provides a framework through which these questions can be addressed. With further third party input and consensus on definitions, sensitivity tests could be performed to help increase understanding of the problem. The market and the government need to settle this issue before the next major earthquake occurs and all parties need to have confidence in the solution derived.

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