Effects of microzoning and foundations on damage to houses in the Inangahua earthquake

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ABSTRACT: In a recent study the present authors examined the damage ratios for houses and household contents in the Inangahua earthquake for intensities MM5-MM10, including the effects of chimney damage. The present study continues this work by examining the effects of ground class and construction type on damage levels. Houses from six towns are considered, i.e. Inangahua, Reefton, Westport, Greymouth, Runanga and Hokitika covering a range of intensities from MM10.5 down to MM7.0. A range of ground classes is also considered, covering the three classes described in the draft joint Australian/New Zealand loadings standard. The structural types considered comprise two foundation types (piled vs. concrete perimeter wall footings).

1 INTRODUCTION

The Inangahua earthquake of M_s 7.4, M_w 7.2 occurred on 24th May 1968. In a recent study of this event by the present authors (Dowrick *et al*., 2001) of about 8000 insurance claims, the vulnerability of domestic property was evaluated in terms of damage ratios, D_r, defined as:

$$D_r = \frac{\text{Cost of damage to an Item}}{\text{Value of that Item}} \tag{1}$$

D_r was determined across the range of Modified Mercalli (MM) intensities MM5-MM10 for one and two-storey houses and household contents. The present study examines a subset of the 8000 insurance claims from the "global" study of the 1968 earthquake, so as to evaluate the different vulnerabilities of domestic property (houses and contents) on different ground classes, i.e. microzoning effects, and those of houses with different types of foundations and wall construction.

Three studies of the effect of microzones on damage to houses in New Zealand earthquakes have previously been carried out. The earlier two of the studies, those of Grant-Taylor *et al.* (1974) and Suggate and Wood (1979) did not use damage ratios or engineering ground classes as the basis of their comparisons, and hence were less quantitative in their approach than has been possible in the present study. The other previous study, that of Napier in the 1931 Hawke's Bay earthquake (Dowrick *et al*., 1995) was carried out using damage ratios and ground classes in the same manner as used in the present study, but was limited to houses situated in a zone of Modified Mercalli intensity X (MM10).

The present study offers an opportunity to quantify microzoning effects for short period structures for four ground classes at MM7, two at MM8 and one ground class at MM9 and MM10. This extends our knowledge of microzoning effects, as well as differentiating between houses of different structural types. We have also taken the opportunity of relating the above microzones to damage ratios for household contents, which to the best of our knowledge has not been done before. Only a sample of our results can be presented in the space available here.

2 DESCRIPTION OF THE HOUSES

The houses considered in this study were of one and two-storeys and were timber framed with a variety of wall claddings, including: Weatherboard, Corrugated iron, Fibrous (asbestos) cement, Stucco (roughcast), Brick {Veneer}, Artificial stone {Veneer}.

Foundations of houses were of three types:

(i) Fully piled (generally unbraced)

(ii) Concrete foundation wall around complete perimeter

(iii) Partial concrete foundation walls.

Type (iii) foundations were few and so were not analysed as a separate subset, but were lumped together with type (i).

3 THE MICROZONES

Six towns were microzoned in this study, with a range of intensities, as follows: Hokitika (MM7.0), Greymouth (MM7.5), Runanga (MM7.8), Westport (MM8.5), Reefton (MM9.0), and Inangahua (MM10.5).

The above intensities were determined by linear interpolation of the locations of the centroids of the towns between the isoseismals, which are as determined by Adams *et al*. (1968).

The microzones were based on the geology of any deposits overlying bedrock, as mapped in the earlier microzoning study of Suggate and Wood (1979).

The Ground Classes AB, C and D conform to the definitions used in the draft new joint Australian/New Zealand loadings standard. These definitions are as follows:

GROUND CLASS AB - ROCK Rock with less than 3m thickness of stiff overburden. (Classes A and B in the draft loadings standard.)

GROUND CLASS C - SHALLOW SOIL Sites where the low amplitude natural period is less than or equal to 0.6 s, or sites with depths of soil not exceeding those listed in the draft loadings standard, but excluding very soft soil sites.

GROUND CLASS D - DEEP OR SOFT SOIL Sites where the low-amplitude natural period is greater than 0.6 s, or sites with depths of soils exceeding those listed in the draft loadings standard, but excluding very soft soil sites.

GROUND CLASS CD Soil sites which could be either Class C or D.

4 THE DATA

In each of the towns studied, every house was accounted for, either to be included in or excluded from the database, depending on whether it was insured or not. For each house in the database the following information was listed: Number of storeys, Foundation type, Wall construction, and Ground Class. This information was gathered during field trips in which every house was characterized by the first author.

5 DAMAGE RATIOS

The damage ratios presented below were calculated from equation (1) in terms of Replacement

Values for houses and Insured Values for contents. The Replacement Values used were those determined in our previous study.

5.1 *Mean damage ratios*

The mean damage ratio for all buildings in a given MM intensity zone is a useful parameter for various purposes, e.g. in comparing the earthquake resistance of different classes of property. Considering all *N* buildings (damaged and undamaged) in an MM intensity zone, we give here two principal ways of defining the Mean D_r. Firstly

$$\overline{D}_r = \frac{\sum_{i=1}^{n}[\text{cost of damage to building i}]}{\sum_{i=1}^{N}[\text{value of building i}]} \tag{2}$$

where *n* is the number of damaged buildings.

Secondly,

$$D_{rm} = \frac{\sum_{i=1}^{n}[D_{r_i}]}{N} \tag{3}$$

Next we compare the vulnerability of different subsets of property in terms of their mean damage ratios, a sample of which is given in Table 1.

Table 1: Sample of basic statistics of the distribution of damage ratio by class of domestic property in the Inangahua earthquake

Property Class	*n*	N	μ	σ	D_{rm}	$\overline{D}_r$
MM7.5 Greymouth excl. chimney damage						
1 storey houses, w/b*, piled foundations						
GC AB	23	65	-5.51	1.09	0.0021	0.0019
GC C	368	996	-5.70	1.10	0.0021	0.0018
GC CD	219	433	-5.45	1.14	0.0040	0.0039
GC D	19	61	-5.55	1.01	0.0017	0.0015
1 storey houses, w/b, concrete foundations						
GC AB	16	62	-6.08	1.35	0.00087	0.0011
GC C	69	214	-5.86	1.26	0.0017	0.0018
GC CD	85	244	-5.65	1.08	0.0019	0.0021
GC D	2	4	-5.37	0.92	0.0026	0.0030
Household contents, piled foundations						
GC AB	22	71	-4.99	1.01	0.0030	0.0030
GC C	258	1046	-4.74	1.08	0.0038	0.0033
GC CD	166	444	-4.52	1.11	0.0070	0.0070
GC D	13	65	-5.42	0.88	0.0013	0.00095

*w/b = weatherboard

5.2 *Effects of foundation construction on damage to houses*

The effects of foundation construction type on mean damage ratio over a range of intensities are shown in Figure 1. The comparisons are made for single storey houses on Ground Class C with weatherboard wall cladding, and the costs of chimney damage are excluded. It is seen that houses with concrete perimeter wall foundations perform better than those on piled foundations.

5.3 *Effects of microzoning on damage to houses*

On Figure 2 are plotted the mean damage ratios for single storey weatherboard houses, (excluding chimney damage) at intensity MM7.5, with the two types of foundations, and on the four different ground classes described in Section 3. Two very different patterns are seen. First, houses with concrete foundations have steadily increasing damage levels as the ground becomes more flexible. This pattern follows the well established trends of the peak ground acceleration (PGA) and peak spectral acceleration (SA), both of which can be expected to increase (at this intensity) as the ground becomes more flexible. Second, houses with piled foundations respond very differently, with those on Ground Class CD being the most damaged, and the least damaged being on the most flexible soil (Ground Class D).

The behaviour of the houses on piles is surprising, but is presumably explained by dynamic response effects. The peak response at Ground Class CD suggests that some resonance is occurring. This possibility is supported by the likelihood that the natural period of vibration for piled weatherboard houses and Ground Class CD are both about 0.4 seconds

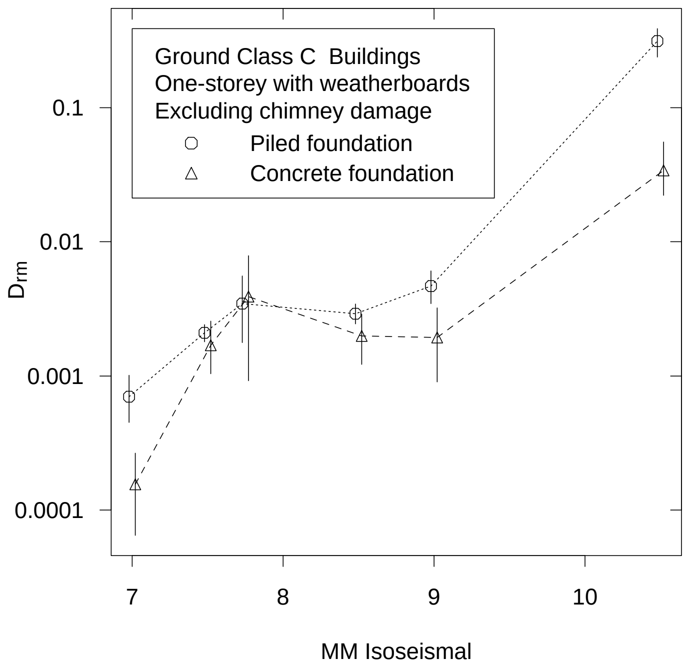

Figure 1: Mean damage ratio and its 95% confidence limits for single storey weatherboard houses, excluding chimney damage, as a function of MM intensity and two types of foundation, in the 1968 Inangahua earthquake.

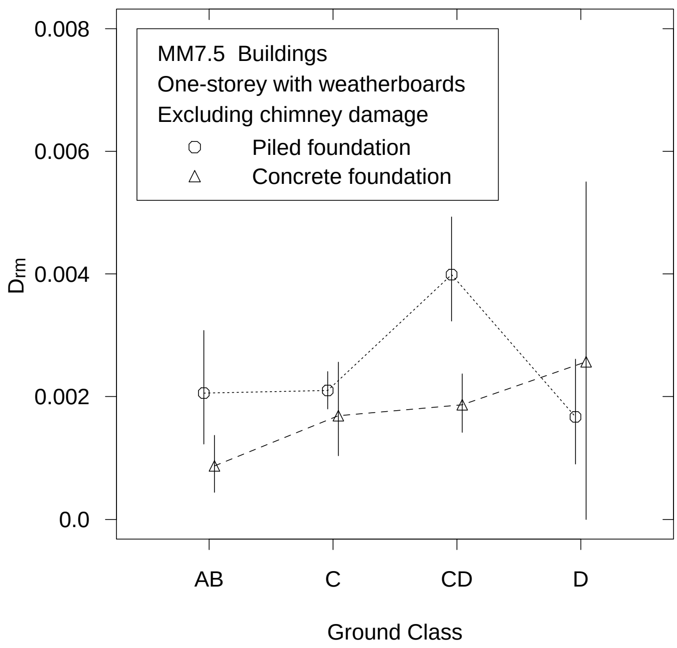

Figure 2: Mean damage ratio and its 95% confidence limits for household contents, at intensity MM7.5 (Greymouth) in houses with two types of foundation and four ground classes, in the 1968 Inangahua earthquake.

5.4 *Household contents*

The mean damage ratio for contents of houses as a function of Ground Class and foundation construction follows similar trends as D_{rm} for the houses in which they are located. This is seen by comparing Figures 2 and 3, for the piled houses case, in particular, where the results are statistically significant.

6 CONCLUSIONS

As a result of this study the following conclusions have so far been drawn:

For single storey weatherboard houses excluding chimney damage, at intensities MM8.5-10.5, houses with concrete perimeter wall foundations are less vulnerable than those on piles.

For single storey weatherboard houses excluding chimney damage, at intensity MM7.5, houses with concrete foundations suffer increasing damage as the ground flexibility increases.

At intensity MM7.5, D_{rm} for weatherboard houses on piled foundations is twice as high on Ground Class CD as it is for Ground Classes AB, C and D. This difference is statistically significant at the 0.01 level, and probably indicates that some soil-structure resonance occurs on Ground Class CD.

The mean damage ratio for contents of houses as a function of ground class and foundation type, follows similar trends to D_{rm} for the houses in which they are located.

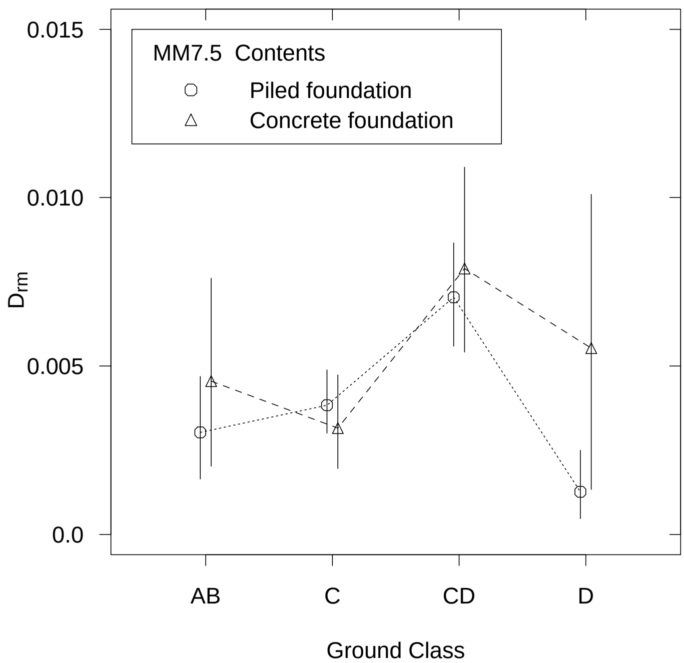

Figure 3: Mean damage ratio and its 95% confidence limits for household contents, at intensity MM7.5 (Greymouth) in houses with two types of foundation and four ground classes, in the 1968 Inangahua earthquake.

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