A GROUND SHAKING AMPLIFICATION MAP FOR NEW ZEALAND

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ABSTRACT

A ground shaking amplification map of New Zealand has been compiled from data held by GNS Science. The resulting map is being used in RiskScape, a tool for comparing risks at a given site from a variety of hazards by estimating potential losses.

A GIS-based geological map with national coverage has been composed from several sources, and is used as the base data. Geological maps from the QMAP project (an ongoing project to digitally compile 1:250,000 geological maps for all of New Zealand) have been used where available, supplemented with detailed geological maps at scales ranging from 1:25,000 to 1:50,000 for the larger urban areas. Gaps in the QMAP series have been filled by the 1:1,000,000 'Geological Map of New Zealand'.

Every geological polygon in the composite geological map has been assigned one of the ground shaking amplification (or site) classes from the New Zealand Standard for Structural Design Actions – Earthquake actions (NZS 1170.5) to produce the result map. These conform to the site class definitions in NZS 1170.5, which describes five classes with respect to ground shaking amplification. Assignment of these classes was straightforward for rock sites but more involved for soils where, for example, at boundaries between weak rock and deep soil sites a buffer zone of shallow soil was applied.

1. INTRODUCTION

Ground shaking varies depending on the strength of the rock or soil units underlying a site. Therefore it is important to know the strength of the rock or soil material underlying a building or proposed building site to ensure that the structure has been/is appropriately designed. The goal of the national ground shaking amplification map is to give a conservative estimate of the seismic response of the soils that construction will take place on.

A ground shaking amplification map of New Zealand has been composed from data held by GNS Science. The resulting map is being used in RiskScape, a tool for comparing risks at a given site from a variety of hazards by estimating potential losses.

A GIS-based (Geographic Information System) geological map with national coverage has been compiled from several sources, and used as the base data. Geological maps at a scale of 1:250,000 from the QMAP project covering New Zealand have been used where available and supplemented with detailed geological maps for the larger urban areas at larger scales (1:25,000; 1:50,000). The gaps have been filled by geology polygons from the 1:1,000,000 'Geological Map of New Zealand'.

Every geological polygon in the composite geological map has been assigned one of the ground shaking amplification classes from the New Zealand Standard for Structural Design Actions NZS 1170.5 to produce the result map. The classes conform to the site class definitions in NZS 1170.5 given as, A: Strong Rock, B: Weak Rock, C: Shallow Soil, D: Deep or Soft Soil or E: Very Soft Soil, with respect to ground shaking amplification.

The product map was checked by comparing it against 687 sites in a database of accelerograph locations where the ground class had been determined from site-specific information. The initial comparison between the ground class map and the site-specific data showed 59% of the site-specific data was consistent with the ground-class map. Every discrepancy between the two databases was analysed and corrected for obvious errors. A common reason for discrepancies between the two databases was found to be accelerographs located in structures founded on rock, but where the surface geological unit was a soil (i.e. both databases are correct but give different results) or where multiple sites with different site classes were located within a single geological polygon (e.g. southern Christchurch where a "Class E" geology polygon contained both "Class D" and "Class E" site-specific ground class assessments). After correcting for errors and other resolvable discrepancies, the comparison between the two databases showed 72% of the site-specific data is consistent with the ground-class map.

2. METHODOLOGY

The methodology for producing a national scale soil and rock ground shaking amplification map for New Zealand involved:

1. Producing a national geological map of New Zealand with best available digital data,
2. Assigning ground classes based on NZS 1170.5 to every polygon on the map to create a ground shaking amplification map,

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3. Testing the validity of the ground shaking amplification map by comparing site specific data on ground class conditions against the assigned ground classes on the map.
4. Adjusting the ground shaking amplification map database according to the comparison results.

The national geological map was produced by combining geological maps from several sources. It was decided that it was appropriate to use the best quality geological information and produce a composite map to give the resulting national map the greatest utility. Also as new geological maps become available digitally (for example, as the QMAP project is completed) the ground shaking amplification map can be updated with the new information. A single data source (1:1,000,000; 'Geological Map of New Zealand') could have been used in isolation but this would have severely limited the usefulness of the resulting ground shaking amplification map.

Geological information from a number of sources was brought together into one digital database in a GIS environment. The compiled information varied in scale and data detail, due to the different sources. Maps at scales of 1:25,000, 1:50,000, 1:250,000 and 1:1,000,000 were used. Larger scale geological maps of the main urban areas in New Zealand at scales of 1:25,000 and 1:50,000 were used where available (approximately 20 sites). Elsewhere, smaller-scale maps were used. Where available, 1:250,000 scale geological maps were used (QMAP data; a GNS Science project to create a seamless regional-scale digital geological database within a GIS; Figure 1). Since this data does not yet capture the whole country, the 1:1,000,000 'Geological Map of New Zealand' was used to fill any remaining gaps. The geological unit boundaries on the composite map are based on the geological unit boundaries of the source maps. Combining maps of different scales and data attributes required the creation of a unified database and, where possible, resolution of any boundary discrepancies on the map. Boundaries were checked for geometry problems and corrected where needed. The unified database contains several information fields: Unit Code, Main Rock, Map Unit, Strata (graphic) Unit, Sequence, Terrane, Strata (graphic) Age, Confidence, Description (material), Rock Group, Rock Class, Source (original map), and Scale. The geological attributes attached to each polygon (Table 1) were used to estimate material strength and to assign a ground class as defined by NZS 1170.5, as described below.

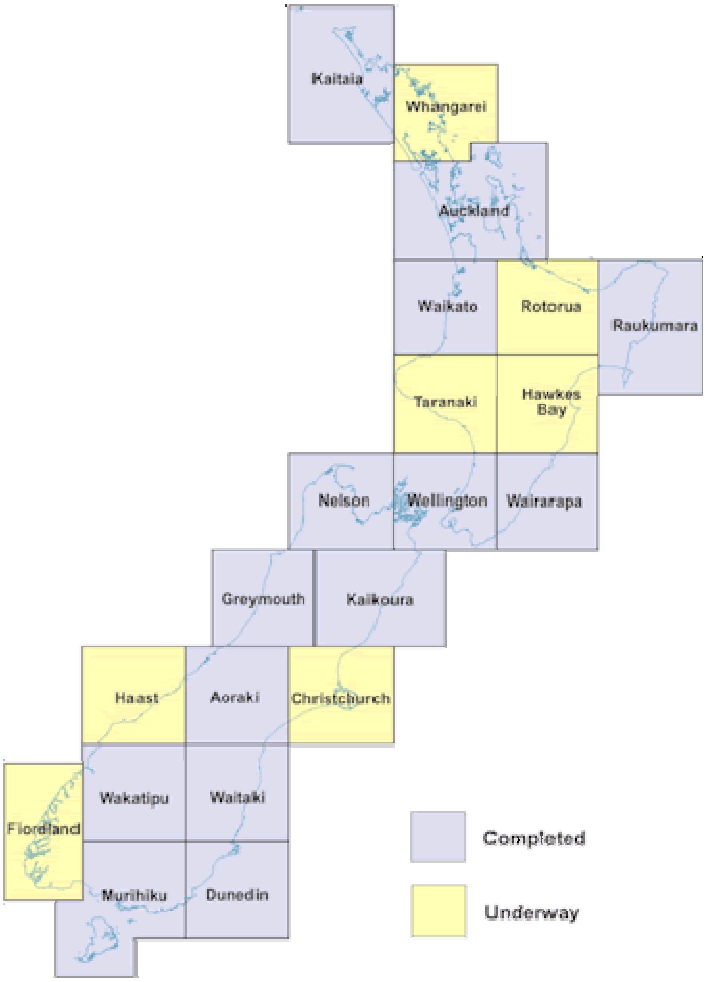

Figure 1: Completed geological mapping for the QMAP project.

Table 1: An example of an entry in the attribute table for a geological unit on the ground shaking amplification map.

UNIT_CODE	Q1a
MAIN_ROCK	Sand
SUB_ROCKS	Peat Mud
MAP_UNIT	Estuarine, Swamp And Alluvial
STRAT_UNIT	Karioitahi Group
SEQUENCE	Karioitahi Group
TERRANE	-
STRAT_AGE	Q1 Q2 Q3 Q4
CONFIDENCE	-
DESCRIPTION	Unconsolidated To Poorly Consolidated Sand, Peat, Mud And Shell Deposits (Estuarine, Lacustrine, Swamp, Alluvial And Colluvial).
ROCK_GROUP	Sandstone
ROCK_CLASS	Clastic Sediment
SOURCE	Isaac, M.J. 1996: Qmap Kaitaia
SCALE	250,000

NZS 1170.5 has five ground classes namely strong rock, weak rock, shallow soil, deep soil and very soft soil. The descriptions in NZS 1170.5 contain detailed geotechnical information to use in assigning a ground class at a site which is not available in the attribute data for the composite geological map. Therefore in assigning a ground class to a geological polygon a number of assumptions were made as follows:

Class A (Strong rock): Very few rocks in New Zealand meets the criteria for this ground class which requires a high strength (>20 MPa) and relatively intact rock mass – i.e. the rock is unweathered and has few joints or other rock mass defects. The only examples that meet the criteria in New Zealand are the plutonic rocks of Fiordland – plutonic and other rocks elsewhere in New Zealand are weathered and/or more closely jointed near the ground surface and therefore assigned to Class B: weak rock.

Class B (Weak rock): Material with a compressive strength between 1 MPa and 20 MPa at the surface, or sites with a soil layer of thickness not exceeding 3 metres overlying rock. The criteria for assigning Class B (or a weak rock classification) to a geological unit were that it be either Pliocene-age or older (i.e. more than 2 million years old) or if it is younger then it must be Quaternary- or Holocene-age volcanic rocks with a strength >1 MPa (e.g. lava flows).

Class C (Shallow soil): Material with a strength <1 MPa and depths less than those defined in Table 2 (from NZS 1170.5). Basically anything that is not Class A or B is a soil and the differentiation of soil classes is based on the depth of the soil unit which varies depending on the soil type (see Table 2). As no detailed information on the depth of soils is available on a national basis, several assumptions were made. The first was that the average slope angle of any surrounding weak rock unit continued beneath the soil unit. Where soil units were narrow and bounded on one or both sides by weak rock, Class C was assigned.

Class D (Deep soil): Soil sites with periods greater than 0.6s or with depths of soil greater than those defined in Table 2, but excluding Class E sites. Units assigned to Class D were generally laterally extensive (e.g. Canterbury Plains). The depth of the soils is not reflected in the geology database and in some instances this resulted in Class D deep soil polygons adjacent to Class A strong rock or Class B weak rock polygons. This problem was addressed for most of the major urban areas by buffering the margins of hills (i.e. ‘rock sites’ with Amplification Code A or B) and changing any ‘deep soils’ (Amplification Code: D) that fell within this buffer to ‘shallow soils’ (Amplification Code: C) (Fig. 2). The width of the buffer was based on the distance required to reach the depth for the transition from shallow soil to deep soil for a given soil type at the average topographic slope angle (e.g. for a deep soil comprised mainly of gravel and with the adjacent rock unit having an average slope angle of 30° a buffer of 175 m of shallow soil was extended over the deep soil unit from the weak rock-deep soil boundary, but if the soil was soft and cohesive the buffer only had a width of 35 m for the same weak rock slope angle). The buffer was only applied to maps at scales of 1:25,000 and 1:50,000 because at smaller scales (1:250,000 and 1:1,000,000) the geological boundaries contain significant generalisation and have locational accuracy of about +/-100 m.

Class E (Very soft soil): Sites with more than a few metres of very soft cohesive soils with undrained shear strength less than 12.5 kPa, or with about 10 m or more of soil with shear-wave velocities less than 150 m/s, or with about 10 m or greater thickness of very high plasticity clays with plasticity index PI>75. Class E materials are restricted to three very specific environmental settings in New Zealand. These are swamp deposits (e.g. Waikato lowlands), estuarine and lagoon deposits (e.g. former Ahuriri Lagoon north of Napier) and some reclaimed land (e.g. Wellington Port reclamations).

Where insufficient information was available to enable a definite assignation of ground class to be made, for a particular geological unit or polygon a conservative approach was adopted.

This entailed assigning the ground class with the lowest soil/rock strength to the geological polygon or unit (e.g. where a geological unit could be Class D or Class E based on the available information, then Class E was assigned).

Table 2: Depth Limits for Classes C and D (modified from NZS 1170.5:2004)

Soil type and description		**Maximum depth of soil** (m)
Cohesive soil	**Representative undrained shear strengths** (kPa)	
Very Soft	< 12.5	0
Soft	12.5 – 25	20
Firm	25 – 50	25
Stiff	50 – 100	40
Very stiff or hard	100 – 200	60
Cohesionless soil	**Representative SPT (*N*) values**	
Very loose	< 6	0
Loose dry	6 – 10	40
Medium dense	10 – 30	45
Dense	30 – 50	55
Very dense	> 50	60
Gravels	> 30	100

Depths no greater than those above qualify as Class C, greater depths qualify as Class D, except where Class E criteria apply. Class E criteria are not included in this table.

For layered sites, the ratios of the depth of each soil type to the limits of the table for Class C should be added, and sums greater than 1.0 assigned to Class D.

*SPT (N): SPT (Standard Penetration Test) is a soil sampling method, which is a commonly standardised site investigation test method to determine the relative densities of noncohesive soils, such as Sands, or Silts. The blow count, which is the N value, is obtained by the total blows required from a standard hammer, over the interval 150 to 450 mm per 0.3 m.

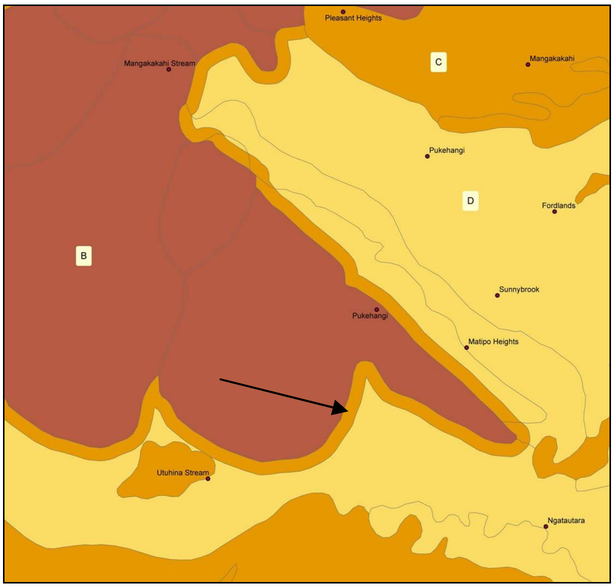

Figure 2: Lake Rotorua area showing weak rock (B) surrounded by shallow soils (C) before reaching the deep soils (D) as a buffering application example.

GNS Science has developed and maintains a database of subsurface information for accelerograph locations throughout New Zealand (Cousins *et al.* undated). The database includes site coordinates, and subsurface geotechnical information which has been used to assign a ground class based on either NZS 1170.5 or the General

Structural Design and Design Loadings for Buildings from 1992: NZS 4203. An initial comparison between the national soil amplification map and the accelerograph site data was done using the 166 locations with NZS 1170.5 site code information. A further 521 accelerograph sites were coded using NZS 4203. These sites needed to be converted from NZS 4203 to NZS 1170.5. The main difference between the two codes is the number of classes. NZS 4203 has three classes and NZS 1170.5 has five classes. All ground classes in both codes are defined in similar geotechnical terms. The ground class correlation between the two codes is shown in Figure 3. Class 'a' -rock (NZS 4203) included some very stiff or dense soil sites, and translated into NZS1170.5 Class A (strong rock); Class B (weak rock) and Class C (shallow soil) sites.. NZS 1170.5 Class 'b' – intermediate soil sites (NZS 4203) translated directly to Class C (shallow soils) in NZS 1170.5 where it was joined by the very stiff and dense soil sites from Class 'a'. Class 'c' –deep soil sites (NZS 4203) translated almost directly to Class D (deep or soft soil sites) in NZS 1170.5. The exception was the new Class E in NZS 1170.5 for very soft soil sites. The site class comparison and assignment was completed by N. Perrin and P. Barker for the accelerograph database.

The updated accelerograph database with 687 locations was then compared with the ground shaking amplification map in the GIS environment. The first step was to import the accelerograph database into a GIS format. This was done using the accelerograph site coordinates to generate a point database. Once this was established, the NZS 1170.5 ground class attributes of the accelerograph points were compared with the NZS 1170.5 ground class attributes of the geology polygon within which the accelerograph site was located. In this initial analysis approximately 60% of the accelerograph sites were located in geology polygons with the same NZS 1170.5 ground class. All inconsistencies were studied one by one to reveal the reason for the discrepancies. Where errors in either data set were encountered these were corrected. This was done in the GIS environment using ArcMAP and its analysis tools and via a visual check of the map. The discrepancies were resolved using expert knowledge (G. Dellow) and the changes applied to the map as needed. Because the ground class is very important for building design purposes, interpretations were kept as conservative as possible. For example, in a few cases, if the accelerograph database identified a site as class 'E' and geology map showed class 'D', then 'E' was selected.

<table>
<tr><th>1170</th><th>Schema used to map 4203 to 1170 in this paper</th></tr>
<tr><td>A Strong Rock</td><td rowspan="3">a
Rock or
Very Stiff Soil</td></tr>
<tr><td>B Rock</td></tr>
<tr><td rowspan="2">C
Shallow Soil</td></tr>
<tr><td>b
Intermediate Soil</td></tr>
<tr><td>D
Deep or Soft Soil</td><td>c
Flexible or Deep Soil</td></tr>
<tr><td>E
Very Soft Soil</td><td></td></tr>
</table>

Figure 3: Site class comparison between NZS 1170.5:2004 and NZS 4203:1992.

3. RESULTS

The ground shaking amplification map derived from the geology database was compared with the site descriptions from the accelerograph dataset. The first comparison was done for the 166 locations with NZS 1170.5 site code information. This first comparison resulted in 76% consistency. After assessing the sites with discrepancies and correcting them, this increases to 82% matching. When the discrepancies between the two databases were investigated, it was found that structures containing accelerographs (site-specific data) were often founded below the ground surface on rock (Class B in NZS 1170.5) but the surface geological unit at the site was a soil (Class C or D in NZS 1170.5). This caused the two databases to give a different, but internally consistent or "correct" answer.

A second comparison was done with the whole accelerograph dataset (687 accelerograph locations with subsurface information). This time 59% of the accelerograph sites had the same NZS 1170.5 ground class as the geology polygons they were located in. The discrepancies seen in this bigger dataset had similar causes to those observed in the initial dataset. The consistency between the two databases is 72% for the whole dataset (687 sites). Part of the produced map can be seen in Figure 4 with a close-up view of Wellington city.

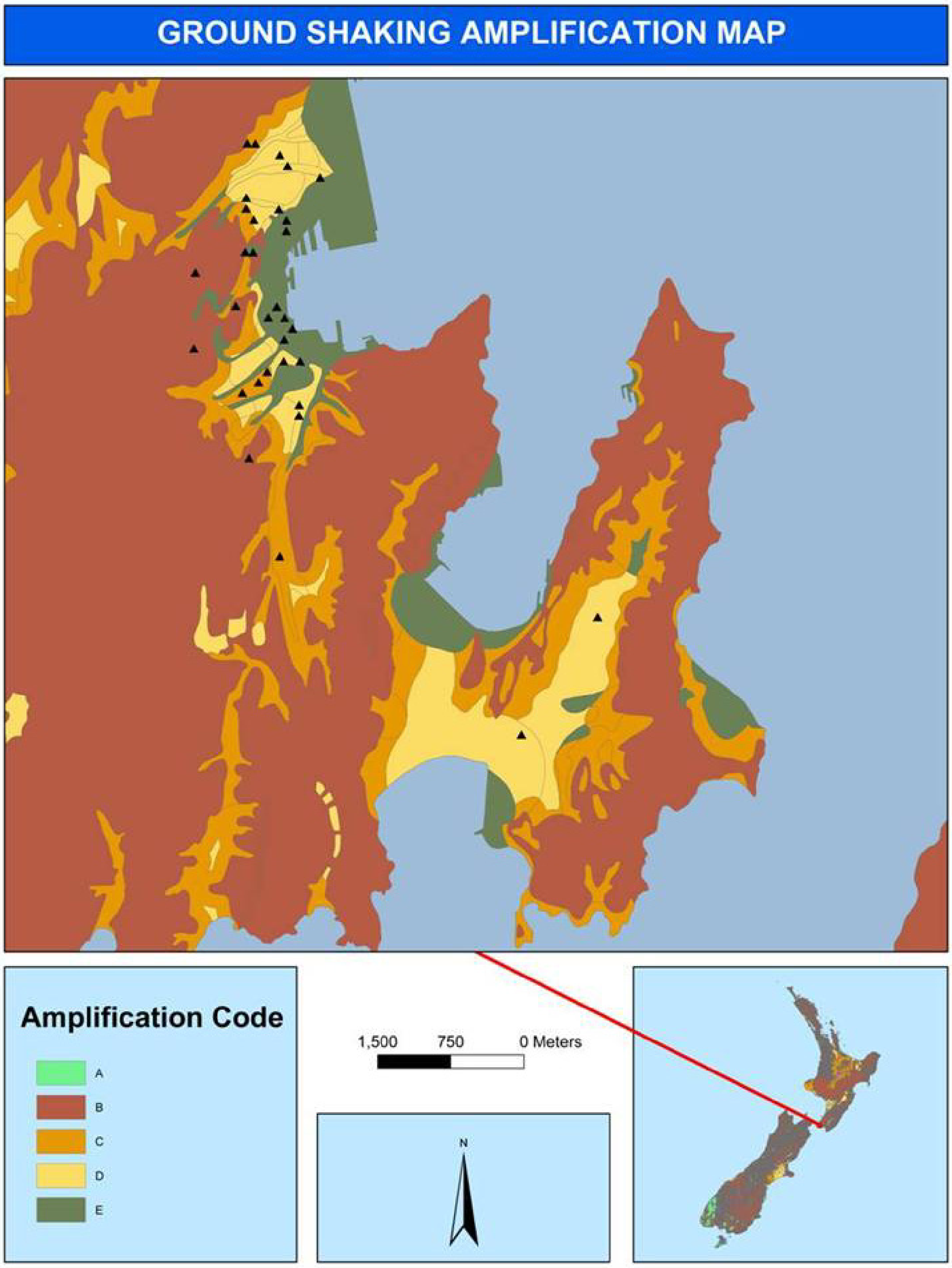

Figure 4: Close-up view of the Wellington Harbour showing the polygon boundaries of ground shaking amplification codes (A; Strong Rock shown as green, B; Weak Rock shown as Dark Brown, C; Shallow Soil, shown as dark orange, D; Deep or Soft Soil shown as light brown and E; Very Soft Soil shown as dark green. Black triangles show the accelerograph locations).

4. CONCLUSION AND DISCUSSION

A national ground shaking amplification map has been made by assigning one of five ground classes described in NZS 1170.5 to every geological polygon in a composite national geological map. This composite geological map was used so that the best quality digital geological mapping for an area could be used. This was considered the best way to maximise the utility of the map and allows for the national ground shaking amplification map to be updated as new information becomes available (i.e. as the QMAP project is progresses).

The national ground shaking amplification map has its limitations. It is important to emphasize the fact that it is a generalized map based on geological mapping rather than geotechnical information. Thus, when it comes to usage, it should be used for initial guidance for the likely ground conditions that will be encountered at a particular site. Geological boundaries between maps of different scale and vintage are another potential source of error in the current ground shaking amplification map. For example, there are discrepancies at the boundaries between the 1:1,000,000 'Geological Map of New Zealand' and QMAP (1:250,000) or other bigger scale maps. These areas need more detailed information to create a better seamless map. Currently, the produced map is used within RiskScape software as a base map for calculating earthquake losses.

The ground-shaking amplification map will be improved and updated as new information comes along. Many reports held by GNS Science contain geotechnical information which could be analyzed to further improve the accuracy of the ground shaking map. This will be done in the near future as a geotechnical database becomes digitally available.

5. ACKNOWLEDGEMENTS

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REFERENCES

1. Cousins, J.W., Barker, P., Perrin, N.D., McVerry, G. H., ‘Compilers’ Unpublished GNS accelerograph locations and information database.
2. QMAP http://www.gns.cri.nz/research/qmap/aboutqmap.html
3. Property Insight http://www.propertyinsight.co.nz/terms.asp
4. RiskScape http://www.gns.cri.nz/research/sub_dir/rrs.html