Is there a relationship between observed felt intensity and parameters from strong motion instrument recordings?

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ABSTRACT: Felt intensity, commonly represented as Modified Mercalli Intensity (MMI), has been used for a long time to quantify the impact of earthquakes. Values are often presented in the form of isoseismal maps for significant seismic events. More recently, with strong motion recorders being increasingly widespread, it has become possible to compare the observed felt intensity to parameters derived from the instrumentally recorded strong motion. In this study, we have selected the strong motion records obtained in New Zealand since 1965 where there is a matching isoseismal map available, and compared the MMI value at the recorder site to instrumentally derived parameters. These include the peak ground acceleration, Arias seismic intensity, JMA seismic intensity and some selected spectral values.

1 INTRODUCTION

Seismic intensity is a measure of the severity of ground shaking at a specific site during an earthquake event. Over the years various subjective scales of what is often called felt intensity have been devised. These assess the felt effects by observers present during the shaking, or evidence, usually damage, that can be observed after the event. Such intensity scales are classifications of the strength of shaking and are essentially qualitative. With the advent of strong motion recording instruments more quantitative, physically based information has become available and the use of the time history of the shaking motion to provide a more objective measure of seismic intensity is desired.

In this study, parameters derived from the strong motion records obtained in New Zealand are compared to the felt intensity information to assess if there are any useful relationships. The motivation for this is to determine if there is some strong motion parameter that could be used as an analogue of seismic intensity. This research is “work in progress” and only preliminary results are presented at this stage.

2 REVIEW OF INTENSITY MEASURES

The use of subjective scales of felt intensity is historically important because no instrumentation is necessary, and useful measurements of an earthquake can be made by an unequipped observer. They were introduced as an attempt to empirically quantify the intensity or severity of ground shaking in a given location by the observed effects. The most significant scales are the ten degree Rossi-Forel (Rossi, 1883); the Mercalli-Cancani-Sieberg, also known as MCS (Sieberg, 1923); the twelve degree Modified Mercalli, 1931 and 1956 versions (Wood & Neumann, 1931; Richter, 1958); and the eight degree Japan Meteorological Agency, JMA (Kawasumi, 1951) amongst others. The more recent scales have generally been the result of evolution of the older ones. A review of the early history of seismic intensity scales is given by Davison (1900, 1912, 1933).

The most widely used seismic felt intensity scale in the English speaking world is the Modified Mercalli intensity scale (commonly denoted as MM or MMI), which has twelve degrees or grades. A detailed description of a revision of this scale applicable to New Zealand conditions is given by Dowrick (1996).

The fact that the felt intensity scales are based on a classification rather than a physical parameter leads to some special conditions of their use. Every degree in a scale is a description of the effects of ground motion on the natural or the built environment. These effects are usually adverse and therefore they are associated with damage. Due to the physical nature of ground shaking, damage and thus intensity, ranges through a continuum of possible values from nothing to the maximum. Nevertheless, by using descriptions of typical observed effects at each level, discrete values of felt intensity are assigned and are represented by an integer quantity. Traditionally, Roman numerals have been used to represent felt intensity values to emphasise this point. Nowadays the use of Roman numerals is largely a matter of taste, and most seismologists find Arabic numerals easier to write (eg 8 rather than "VIII") and process by computer.

Unfortunately this trend overlooks the fact that while the felt intensity scale grades are a set of ordered categories or classifications, they are certainly not numerical values. It is becoming a problem in that it is increasingly common to see them used as such. The concept of a "difference measure" between two categories just does not exist. While we can say that MM V is a higher intensity than MM IV, we cannot say by how much. Also the steps between levels may differ. For example, it cannot be ascertained that the change in intensity from MM IV to MM V is the same as from MM VII to MM VIII.

A considerable amount of skill is required of the observer to assign felt intensity values at a location. With wide variation of earthquake effects over short distances due to local conditions, the complexity of ground motion, the variation in response of structures and uncertainty of the condition of the buildings before the earthquake, discriminating one scale grade from the adjacent ones can be difficult, particularly when only limited information is available. Changes to the building code and construction practices over the years have generally improved the earthquake resistance of the building stock and may have shifted the Modified Mercalli intensity scale.

A common way to present seismic felt intensity is by means of maps for specific earthquake events. As well as plotting intensity points, it is usually useful to draw contour lines of equal felt intensity, called isoseismals. This is a line bounding the area within which the intensity is predominately equal to, or greater than, a given value. The process of drawing the isoseismal requires some smoothing and extrapolation and so is to some degree subjective.

3 REVIEW OF STRONG MOTION PARAMETERS

Seismologists and engineers have correlated felt intensity with many different ground motion parameters. This is to represent earthquake shaking in an engineering sense, for design purposes, or to measure the potential for damage. These parameters are obtained from information extracted from a time series record, eg an accelerogram. Time series records are characterised by amplitude, duration and frequency. Many other parameters can be deduced from these records. The frequency content of the record is often visualised by using the response of simplified models of structural behaviour such as single-degree-of-freedom systems, SDOF, as a filter. Fourier techniques are also employed to picture the frequency content of seismic signals. This characterisation of ground motion has the advantage that parameters are easier to predict than the whole time series record and synthetic records can be produced to have these characteristics. However, the wide number of available parameters reflect the complexity of this task. The most well known parameters include peak ground acceleration (pga), peak ground velocity (pgv) and response spectra.

There is no doubt that the parameter most used for characterising strong motion is peak ground horizontal acceleration. This value is read directly from the accelerogram as its maximum absolute ordinate. The largest value of the two horizontal components of a three component recording is generally selected, although sometimes the average of the two values is used. This parameter is associated with the process of sudden rupture of the fault. Cancani's early intensity scale amounted to little more than a table of intensity values and an equivalent pga value. Such tables are still often encountered in the literature.

The correlations obtained by Trifunac and Brady (1975), Murphy and O'Brien (1977), and McCann et al. (1980) are the most important historically but there are many other authors who have contributed to this subject. A recent study of Californian data by Wald et al (1999) uses MM felt intensity and one of Northridge data by Boatwright et al (2001) uses a different measure of intensity based on tagging data. In general these studies demonstrated that felt intensity and peak ground acceleration correlate very poorly and with a large scatter. There are a number of reasons for this and a significant one may be that as the peak value represents a single spike in the accelerogram record, this may not be representative of the ground motion as a whole. Indeed, where very high peak values have been recorded they have not been accompanied by any remarkably high felt intensity values.

Other parameters that have been proposed include a spectrum intensity by Housner (1952), an engineering intensity scale by Blume (1970), a measure of earthquake intensity by Arias (1970) and the JMA instrumental seismic intensity scale (JMA, 1996; Davenport 2001).

Because of the high variability of both subjective and instrumental scales, the correlation between these two approaches to describing intensity is inherently weak.

4 STRONG MOTION INSTRUMENT RECORDS IN NEW ZEALAND

The New Zealand strong motion network has been operated by GNS over the period from the mid 1960s to the present. The early instruments were "scratch plate" devices that gave a trace of the motion from which only the peak acceleration values could be determined. Later instruments were film based with timing marks so the trace on the film could be digitised to an acceleration time history. More recent devices are electronic digital instruments that give better quality records directly in a digital format.

The raw records as collected from the variety of instruments need to be subsequently processed to a standard digital format together with the addition of an information header. Some of the film records collected from the early devices were of poor quality and so were not fully digitised but peak values were determined. Also, any records that are very small are not fully processed unless required for a specific purpose. The most significant records collected over the period April 1966 to February 1998 have been placed onto a digital Compact Disk (CD-ROM) by Cousins (1998). There are 609 strong motion records in this collection. Since then, more records have been collected and processed.

Some of the strong motion recorders are located for special studies such as on upper levels of buildings, on dams or at sites where topography is important. A record from such a site is not representative of the general ground motion in the area. In this study, only records from free field, building basement and building ground floor sites are used.

Many of the earthquake events for which there are strong motion records were small or in remote areas and little felt intensity information is available to allow an isoseismal map to be constructed. Where sufficient felt intensity data is available for New Zealand earthquakes, isoseismal maps are presented by Downes (1995). There are 32 earthquake events for which an isoseismal map is available and there are suitable strong motion records. The MMI value for the site of a strong motion recording was determined by linear interpolation to one tenth the interval between the isoseismal lines on the map. There were 489 available records for which a MMI value and a pga value is available. This included some with just the peak acceleration value and no digitised record, and so only 243 records were available with an MMI value and an acceleration time history.

5 COMPARISON OF INTENSITIES AND COMPUTED PARAMETERS

Those records with an acceleration time history were further processed to compute the parameters that are of interest. These are the pga, pgv and pgd values, the Arias seismic intensity, the JMA seismic intensity and the response spectra for acceleration, velocity and displacement at several levels of damping and a range of spectral periods. This resulted in too much information to present in the limited space available here.

In summary, plots of pga, Arias Intensity, JMA instrumental intensity and the 5% acceleration response spectra at 0.5 second period against MMI are given in figures 1 to 4 respectively

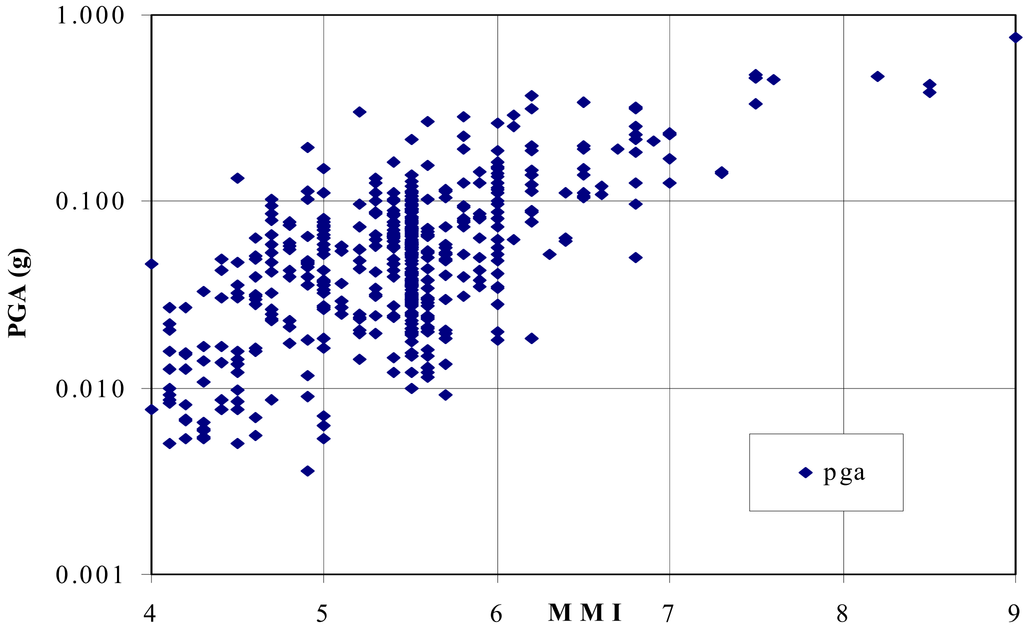

Figure 1 Plot of the resultant pga against MMI felt intensity for 489 New Zealand strong motion records obtained during the period April 1965 to November 1995. The MMI values are interpolated to 0.1 from the isoseismal maps.

In addition a plot of the Arias intensity and pga against the JMA instrumental seismic intensity are shown in figure 5 and 6 respectively.

6 CONCLUSIONS

The major conclusions at this stage of this study are:

- Felt intensity scales have some drawbacks but are based on real damage.
- Instrumental parameters are more objective but have sparse coverage and are not directly associated with real damage.
- Correlation between MMI and various acceleration parameters show there is some relationship but there is a large scatter of the values. There is a low precision in using one to

estimate the other.

˜ It is clear that instrumental seismic intensity measures can not replace the subjective felt intensity measures that are currently in use. There are many more people out there on the ground who can observe the effects of an earthquake, than the sparse network of instruments to record the strong motion waveform during the event.

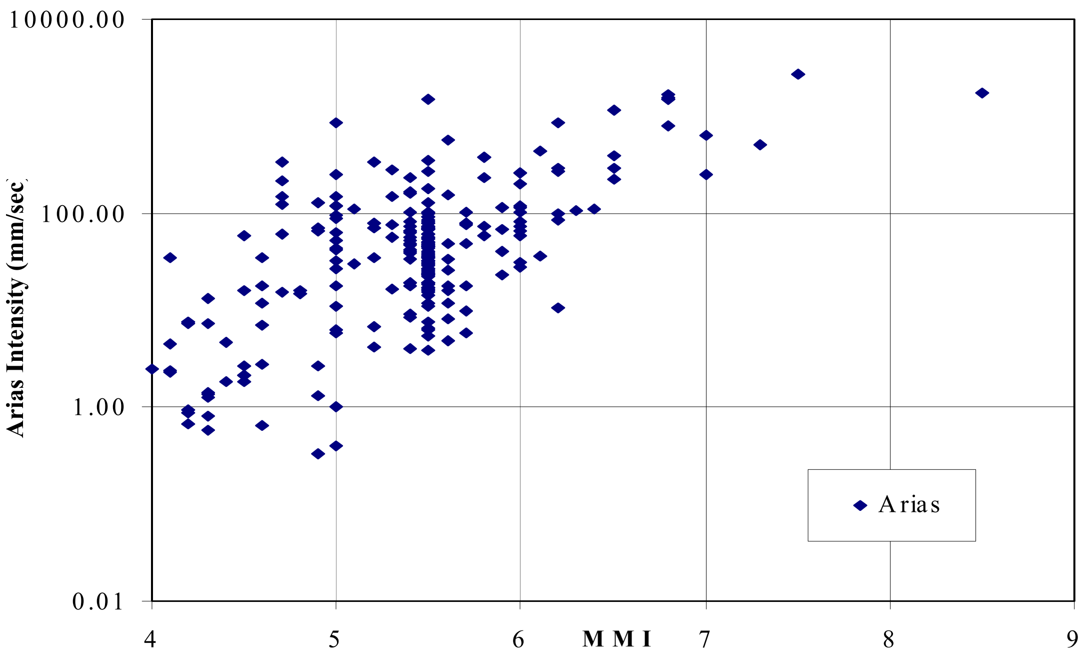

Figure 2 Plot of the Arias seismic intensity against MMI felt intensity for 243 New Zealand strong motion records obtained during the period April 1966 to November 1995. The MMI values are interpolated to 0.1 from the isoseismal maps.

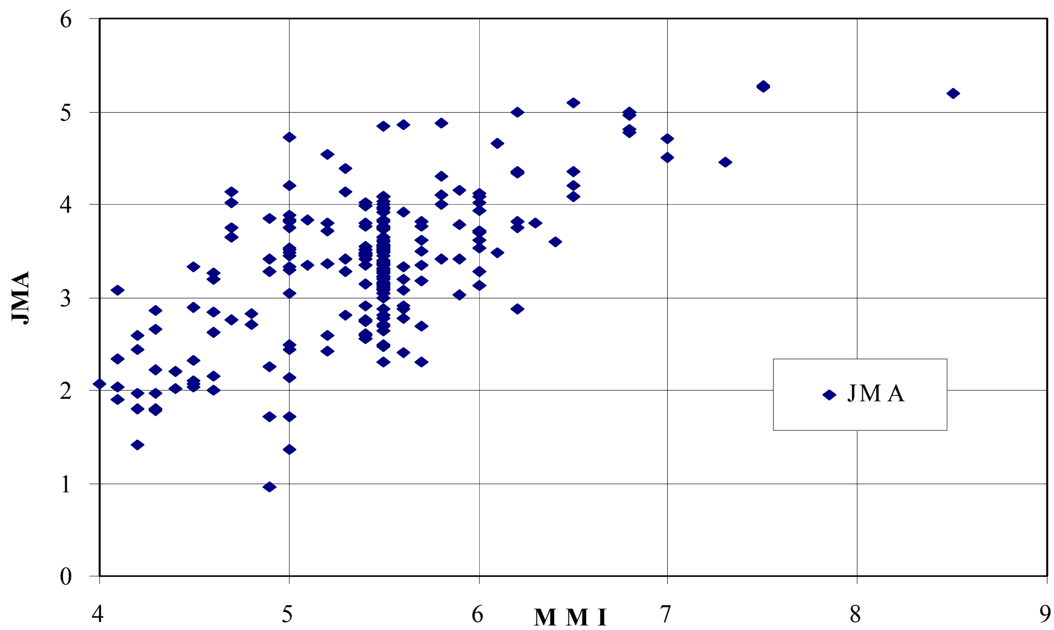

Figure 3 Plot of the JMA instrumental intensity against MMI felt intensity for 243 New Zealand strong motion records obtained during the period April 1966 to November 1995. The MMI values are interpolated to 0.1 from the isoseismal maps.

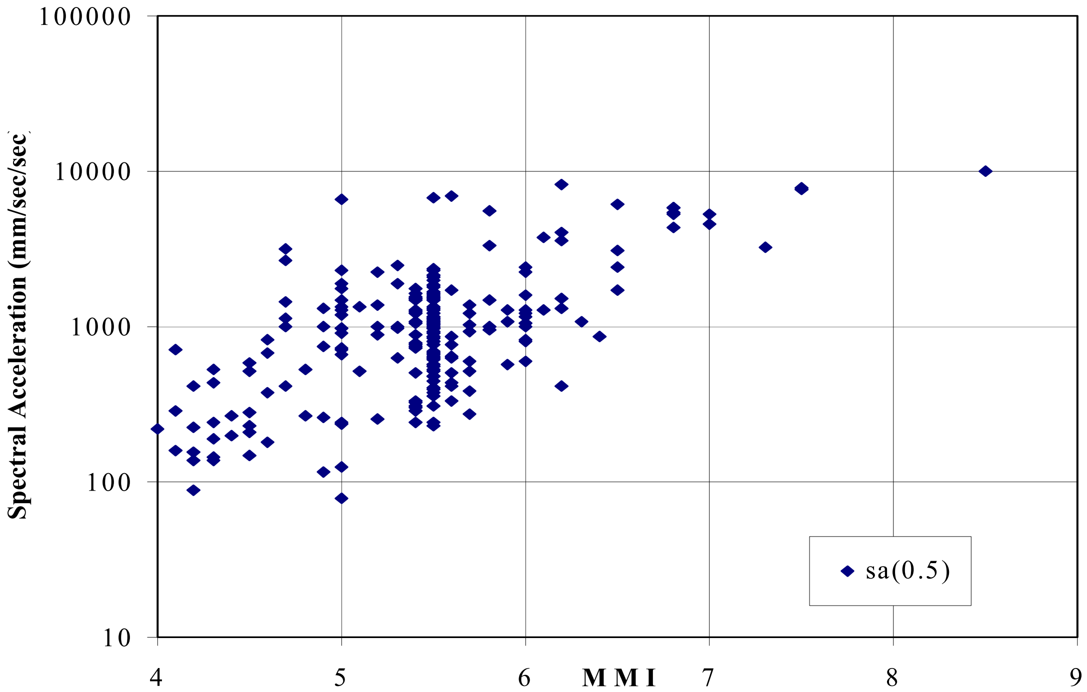

Figure 4 Plot of the 5% damped acceleration response spectra for 0.5 second period against MMI felt intensity for 243 New Zealand strong motion records obtained during the period April 1966 to November 1995. The MMI values are interpolated to 0.1 from the isoseismal maps.

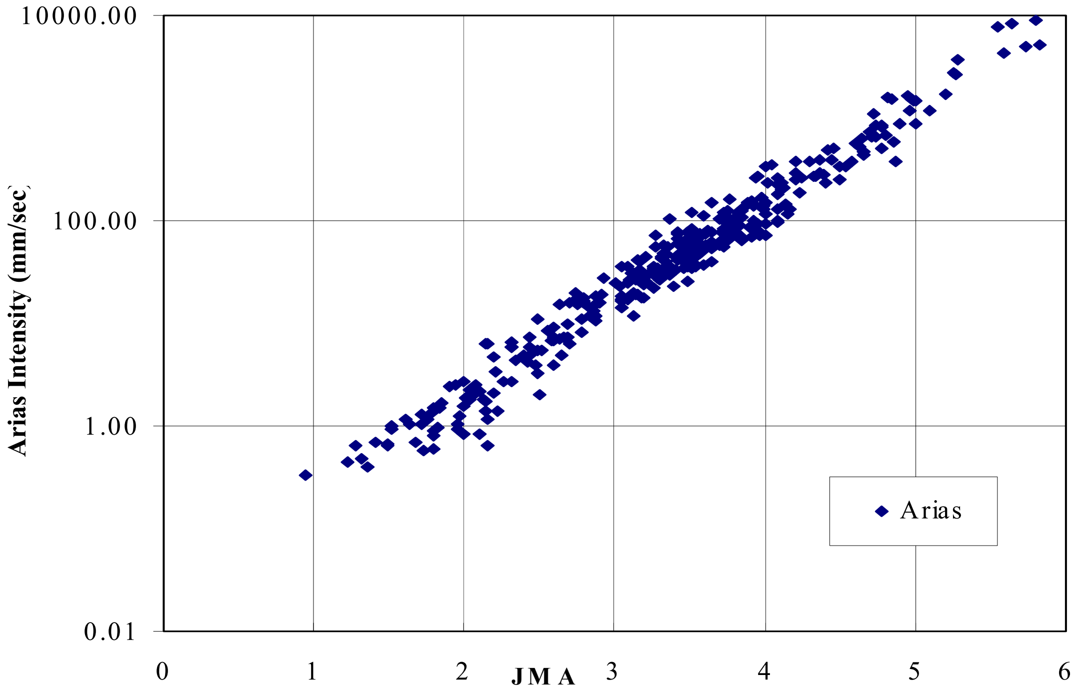

Figure 5 Plot of the Arias seismic intensity against JMA instrumental intensity for 243 New Zealand strong motion records obtained during the period April 1966 to November 1995.

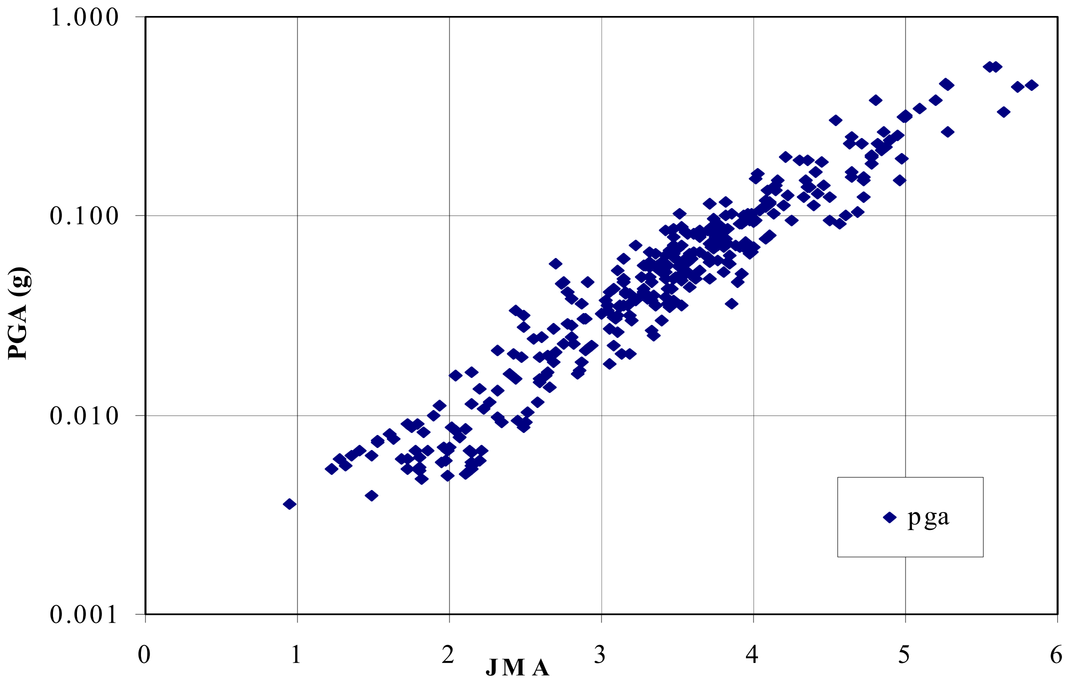

Figure 6 Plot of the pga against JMA instrumental intensity for 243 New Zealand strong motion records obtained during the period April 1966 to November 1995.

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