Seismic intensities derived from strong motion instruments in New Zealand

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ABSTRACT: Intensity of ground shaking during an earthquake has generally been estimated using scales based on felt effects at the time of the earthquake and on later observation of damage to the built environment. By their nature, these measures of felt seismic intensity are subjective and it requires a skilled observer to determine reliable values. An example of such a scale is the Mercalli scale and later adaptations. Where strong motion instrument recordings are available, it is desirable to have a way to determine a seismic intensity from them. Measures that have been used include the peak value of acceleration amongst others, and such measures have their drawbacks. In this paper, a seismic intensity measure developed in Japan is investigated and applied to strong motion records obtained in New Zealand. Comparisons with other measures of intensity are also reported.

1 INTRODUCTION

Seismic intensity is a qualitative or quantitative measure of the severity of ground motion at a specific site. 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. With the advent of strong motion recording instruments, more qualitative, physically based, information has become available and the use of the time history of the shaking to provide a more objective measure of seismic intensity is desired.

Initially strong motion records needed to be retrieved by a visit to the site after the event but with digital recorders and telemetry available, the information can now be available in near real time. Unfortunately the time required to transmit a complete, three component record can be significant and for a large earthquake, there can be many instruments trying to report simultaneously to a control centre. The long data records and contention for service can cause significant delays in forming an overview of what level of shaking took place and over what area it happened. This is a case of information overload. The fine detail of the strong motion records is not required in the first hour after an earthquake but what is needed is some concise measure of the severity of the shaking. The complete record and fine detail can be transmitted later when the immediate urgency has passed and more time is available. Towards this end, the computation of an instrumental seismic intensity that can be done in real time at the instrument site is investigated. A technique developed in Japan is applied to strong motion records obtained in New Zealand to gauge the usefulness of the method.

Instrumental seismic intensity measures can not replace the subjective felt intensity measures that are currently in use. There are many more people out there who could observe the effects than the sparse network of telemetered instruments to record the strong motion waveform.

2 REVIEW OF SEISMIC INTENSITY MEASURES

Seismic intensity scales have a long history of development and use and various subjective scales of what is often called felt intensity have been devised. 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 1958 versions (Wood & Neumann, 1931; Richter, 1958); the eight degree Japan Meteorological Agency, JMA (Kawasumi, 1951) amongst others. The more recent scales have generally been the result of the evolution of the older ones. Every degree in the scales is a description of the effects of ground motion on nature 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 ranges through a continuum of possible values from nothing to the maximum. Nevertheless, discrete values of felt intensities are assigned to give robustness and distinctiveness in practice. A considerable amount of skill is required of the observer to assign felt intensity values at a location.

The most widely used seismic felt intensity scale in the English speaking world is the Modified Mercalli scale (commonly denoted as MM or MMI), which has twelve grades denoted by Roman numerals I to XI, although Arabic numerals 1 to 12 are also used. A detailed description of a revision of this scale applicable to New Zealand is given by Dowrick (1996).

Several parameters have been proposed by different researchers to represent earthquake shaking in an engineering sense, for design purposes, or to measure the potential for damage. These parameters are obtained with 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 records. The frequency content of the record is often visualised by using the response of simplified models of structural behaviour like single-degree-of-freedom systems, SDOF, as a filter. Fourier techniques are also employed to picture the frequency contents of seismic signals. Characterisation of ground motion has the advantage that parameters are easier to predict than whole time series records. However, the wide number of available parameters reflects 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.

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

3 DESCRIPTION OF JMA INSTRUMENTAL SEISMIC INTENSITY

The JMA seismic intensity scale was revised (JMA, 1996) to allow the use of a seismic intensity computed from strong motion records rather than the former scale based on felt intensity.

The process used to determine the JMA seismic intensity is described in Japanese and very little information is available in English. Details of it were obtained from JMA to investigate the suitability of the technique for use in New Zealand. As an overview, the computations involve all three components of the motion, ie the two horizontal and the vertical, being bandpass filtered separately, then, after being combined, the numerical seismic intensity value is determined from the acceleration value that persists for a sufficient duration. Details of the processing follow.

First, a bandpass filter is applied separately to each of the three acceleration time history components of motion. It is convenient to carry out this filter operation in the frequency domain and so a Fourier transform is applied to the acceleration time history. The filter in the frequency domain is given by Equation (1) as an amplitude function of the frequency f in Hz. In effect it is three cascaded filters, and is illustrated in Figure 1.

$$F(f) = F_1(f).F_2(f).F_3(f) \qquad (1)$$

The three cascaded filter components are given by:

$$F_1(f) = (1/f)^{1/2} \quad (2)$$

$F_2(f)$ is a high-cut filter given by

$$F_2(f) = (1 + 0.694y^2 + 0.241y^4 + 0.0557y^6 + 0.00966y^8 + 0.00134y^{10} + 0.000155y^{12})^{-1/2} \quad (3)$$

where $y=f/f_c$, with high cutoff frequency f_c=10 Hz. $F_3(f)$ is a low-cut filter given by

$$F_3(f) = (1 - \exp(-(f/f0)^3))^{1/2} \quad (4)$$

with low cutoff frequency f_0=0.5 Hz.

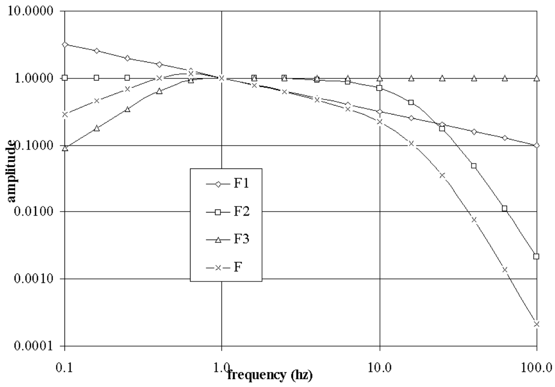

Figure 1 The bandpass filter F(f) made up of three cascaded filters $F_1(f)$, $F_2(f)$ and $F_3(f)$ shown as a function of frequency f in Hz.

Having applied the filter to each component in the frequency domain, the inverse Fourier transform is used to return to the time domain and give each of the three components as a bandpass filtered acceleration time history. The three components of motion are then combined as a vector sum at each time step. The direction information of the combination is not used and only the absolute value of the magnitude of the vector sum is retained as a single waveform.

The peak value of acceleration is the greatest value but in a rapidly varying signal, it will be appreciated that it only occurs during a single time step of the digitised signal. As such it is not representative of the overall motion. To give a better measure of the effect of the shaking, the acceleration level that persists for a longer duration is considered. The way this is achieved is to sort the absolute magnitude of the acceleration values into descending order. The maximum occurs for one time step, the second highest for two time steps and so on. It will be appreciated that for any given acceleration level the individual time steps where it is exceeded are not necessarily consecutive, but are accumulated during the entire record. Figure 2 illustrates this for a strong motion record and shows for a given total duration time, the acceleration level that has been exceeded. The JMA seismic intensity procedure selects the acceleration value a_0 having total duration t_0 of 0.3 sec and computes the new JMA instrumental seismic intensity I by:

$$I = 2.0 \log(a_0) + 0.94 \quad (5)$$

The parameters for this process were chosen by JMA so the resulting numerical values could be easily related to the former discrete integer numbers (0 to 7) for felt intensity. This was done to minimise confusion to the Japanese public and provide continuity from the old values to the new values as determined automatically from strong motion records. Other parameter values could be used. Special “Seismic Intensity Meters” are used in Japan and these compute, at the recorder site, the seismic intensity and then transmit the value to a central location for dissemination.

4 APPLICATION TO NEW ZEALAND STRONG MOTION RECORDS

The New Zealand strong motion network has been operated by GNS over the period from the mid 1960s to the present. The raw records as collected from a variety of different instruments, need to be subsequently processed to a standard digital format together with the addition of an informational header. Many of the collected records are quite small and so 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 and they include free field sites as well as structural arrays such as locations in building and on dams.

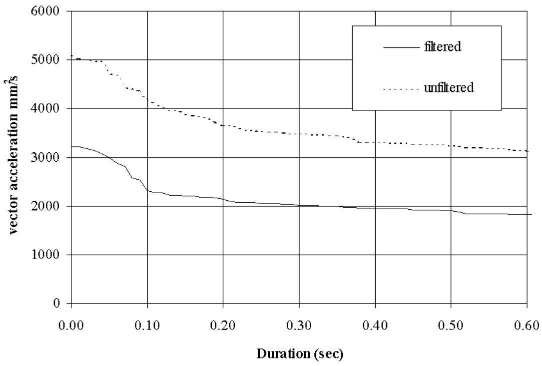

Figure 2 The level of acceleration for a strong motion record as a function of the total accumulated duration. The absolute value of the vector sum of the three components (two horizontal and vertical) is show before (dotted line) and after (full line) applying the bandpass filter.

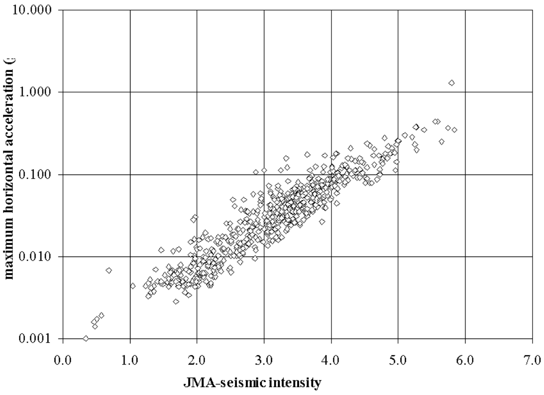

Figure 3 Plot of the maximum horizontal PGA against the JMA seismic intensity for 609 New Zealand strong motion records obtained during the period April 1966 to February 1998.

Computer code was developed to determine the JMA seismic intensity, by the method outlined previously, when applied to the standard format of strong motion records as used in New Zealand. To test that the code gave results consistent with those of the Japanese implementation, some Japanese strong motion records together with the associated seismic intensity, were obtained from JMA. These Japanese records were transformed into the New Zealand standard format of strong motion records and were then processed to obtain the seismic intensity. The resulting computed seismic intensity was consistent with the value supplied from Japan.

The 609 New Zealand strong motion records on the CD collection were processed to obtain the JMA seismic intensity for each record. The resulting values ranged from 0.68 to 5.83. In addition other parameters were determined for each record. Amongst these was the maximum horizontal acceleration, ie the maximum value of the PGA of the two horizontal components. Figure 3 shows a plot of the 609 values against the JMA seismic intensity. As will be seen, the correlation of these two measures is strong.

Not all of the recorded strong motion records were of sufficient strength or at locations that they were felt by people. Where such felt information is available for locations near where a strong motion record was obtained, the MMI value has been associated with that record. This is only sensible for free field recording sites and not for records obtained from sites on upper levels of multi storey buildings or crests of dams and the like. At present, only 142 of the strong motion records have an associated MMI value ranging from 3 to 7 and further refinement of associating an MMI value to more records is yet to be carried out. A preliminary plot of the maximum horizontal acceleration against MMI for this limited set of records is shown in Figure 4. By its nature, MMI takes on discrete values, and as shown, it results in clustering of the points along these discrete values. By comparison of Figures 3 and 4, it can be seen that the correlation of maximum horizontal acceleration to MMI is not as good as it is to JMA seismic intensity. Figure 5 shows a plot of MMI against JMA seismic intensity for the limited set of records.

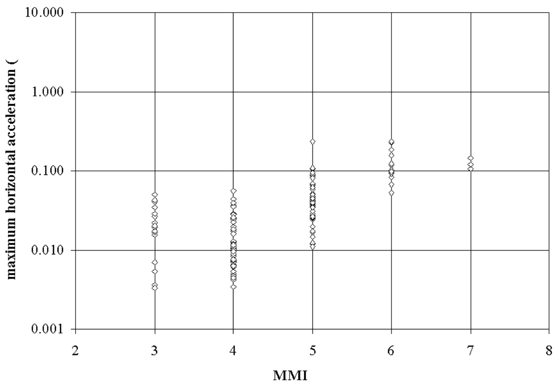

Figure 4 Plot of the maximum horizontal PGA against the MMI felt intensity for 142 New Zealand strong motion records obtained during the period April 1966 to February 1998. The MMI values are restricted to integer values and range from 3 to 7 for this set of data.

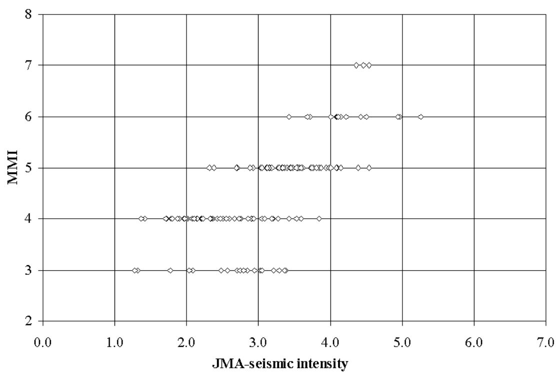

Figure 5 Plot of the MMI felt intensity against the JMA instrumental seismic intensity for 142 New Zealand strong motion records obtained during the period April 1966 to February 1998.

5 CONCLUSIONS

Measures of seismic intensity based on felt effects can be difficult to determine as it requires considerable skill on the part of the observer and may be subjective. The technique developed by the Japanese Meteorological Agency to compute an instrumental seismic intensity has been explained. This measure of seismic intensity is more objective and computer code has been developed to allow the determination of instrumental seismic intensities of New Zealand strong motion records. Results for the collection of 609 significant strong motion records gathered in New Zealand during the period April 1966 to February 1998 have been presented and include comparison with other intensity measures.

While the results presented here are for records that were collected in the past, one of the major benefits is to carry out the processing in real time or at least immediately after the shaking has finished. With modern digital recorders, this could be done at the site of the strong motion recorder, allowing a single number to be sent to a central control site. This avoids overloading communication channels and possible contention for service that can happen when many recording sites are trying to report back with large quantities of data contained in the full length strong motion records. In the period immediately following strong shaking, a clear overview of the extent of shaking is needed rather than the fine detail contained in the full records. With such a setup, many sites can report the quick result of seismic intensity and at a later time, when the immediate urgency is over, the full strong motion record can be sent.

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