

THE 2003, M_w 7.2 FIORDLAND EARTHQUAKE, AND ITS NEAR-SOURCE AFTERSHOCK STRONG MOTION DATA

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ABSTRACT

The 2003 Fiordland earthquake was not only the best ever recorded subduction interface earthquake to occur in New Zealand, it also provided the opportunity to collect near-source strong-motion data produced by its aftershocks covering a wide magnitude range. Near-source strong-motion data had been lacking in the New Zealand data set, on which current attenuation models are based. Here the author presents some preliminary results relating recorded peak ground accelerations in the near-source field to current attenuation models. The near-source data from the 2003 Fiordland earthquake sequence has shown that the observed data has a greater magnitude-dependence than that predicted by the current attenuation models. This new data will help to improve current models and will lead to a better understanding of the attenuation process associated with New Zealand subduction interface earthquakes.

INTRODUCTION

The M_w 7.2 Fiordland earthquake of August 21 2003 was the largest shallow earthquake to occur in New Zealand in the past 35 years. The occurrence of this earthquake and its aftershocks provide a unique opportunity to re-examine the attenuation relationship for subduction zone earthquakes in New Zealand and to see how well the current models perform.

Although large subduction earthquakes in the M_w 6-7 range are not that uncommon in the Fiordland region, occurring about once every five years since 1964 (Robinson *et al.* 2003), strong-motion data from the region had been quite limited until the 2003 earthquake. The lack of strong-motion data from previous Fiordland subduction zone earthquakes has in turn resulted in interface earthquakes being poorly represented in the New Zealand strong-motion data set from which the current New Zealand attenuation model (McVerry *et al.* 2000) was developed. Only 6 of the 24 subduction zone earthquakes used in the model were interface events and they contributed only 67 of the 305 records.

With the recent upgrade of the national strong-motion network prior to the 2003 Fiordland earthquake and the deployment of four strong-motion instruments in the epicentral region, many good near-source (within 200 km) strong-motion records have been obtained covering a wide

magnitude range. Here I present a comparison of recorded peak ground accelerations for aftershocks in the magnitude range 5.0 to 6.1 with current attenuation models.

MAINSHOCK STRONG-MOTION DATA

The improvement in data collection is due to the fully upgraded, real-time, digital, national strong-motion network that has been installed throughout New Zealand as a part of the GeoNet project. Further information on the network can be obtained from the project web site www.geonet.org.nz. The upgraded network consists of 170 well-instrumented sites. The strong-motion stations are mostly equipped with digital 3-component Kinometrics Etna recorders and episensor accelerometers. Instruments record in triggered mode with pre-event memory, GPS timing, and data is transmitted back to the data centre mostly by cell phone. Upgraded stations in the New Zealand national seismograph network also have strong-motion capability and transmit back to the data centre via satellite. Two key features of the new network set it a part from its predecessors: the GPS timing and real time data capability. The GPS timing ensures that the network is synchronised and can be incorporated with the New Zealand national seismic network data to locate earthquakes. The real-time data capability not only provides data almost as it happens, but any problems with the network can be picked up quickly and not remain undetected until annual services.

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The impact that the new network has made on strong-motion data collection can be illustrated with a comparison between the 2000, M_w 6.1, Thompson Sound earthquake (Robinson *et al.*, 2003) and the 2003 Fiordland earthquakes, which occurred within 10 to 20 kilometres of each other. The Fiordland earthquake was recorded by ten Etna instruments within a 200 km epicentral distance (Reyners *et al.* 2003) compared to three (only one Etna) instruments for the Thompson Sound earthquake. The Thompson Sound earthquake was recorded by an MO2A instrument (135 km) and a scratch plate instrument was the closest to the epicentre, 69 km away (Robinson *et al.* 2003). The scratch plate instrument was co-located with a MO2A but the latter had used up its film by the time the Thompson Sound earthquake occurred. For other problems associated with

strong-motion data for the Thompson Sound earthquake see Robinson *et al.* (2003). It is for the above reasons along with the upgraded national seismic network that the 2003 Fiordland earthquake is New Zealand's best ever recorded large earthquake.

The 2003 Fiordland Earthquake occurred about one year after the GeoNet strong-motion upgrade and the network recorded it very well. Sixty stations triggered with the closest (44 km) instrument at Manapouri Power Station (surface facility) and the most distant at Taumarunui High School (958 km). The largest peak ground acceleration, 0.17g, was recorded at Manapouri Power Station, a rock site. Although such a large number of stations recorded the mainshock there was a lack of near-source data (Figure 1).

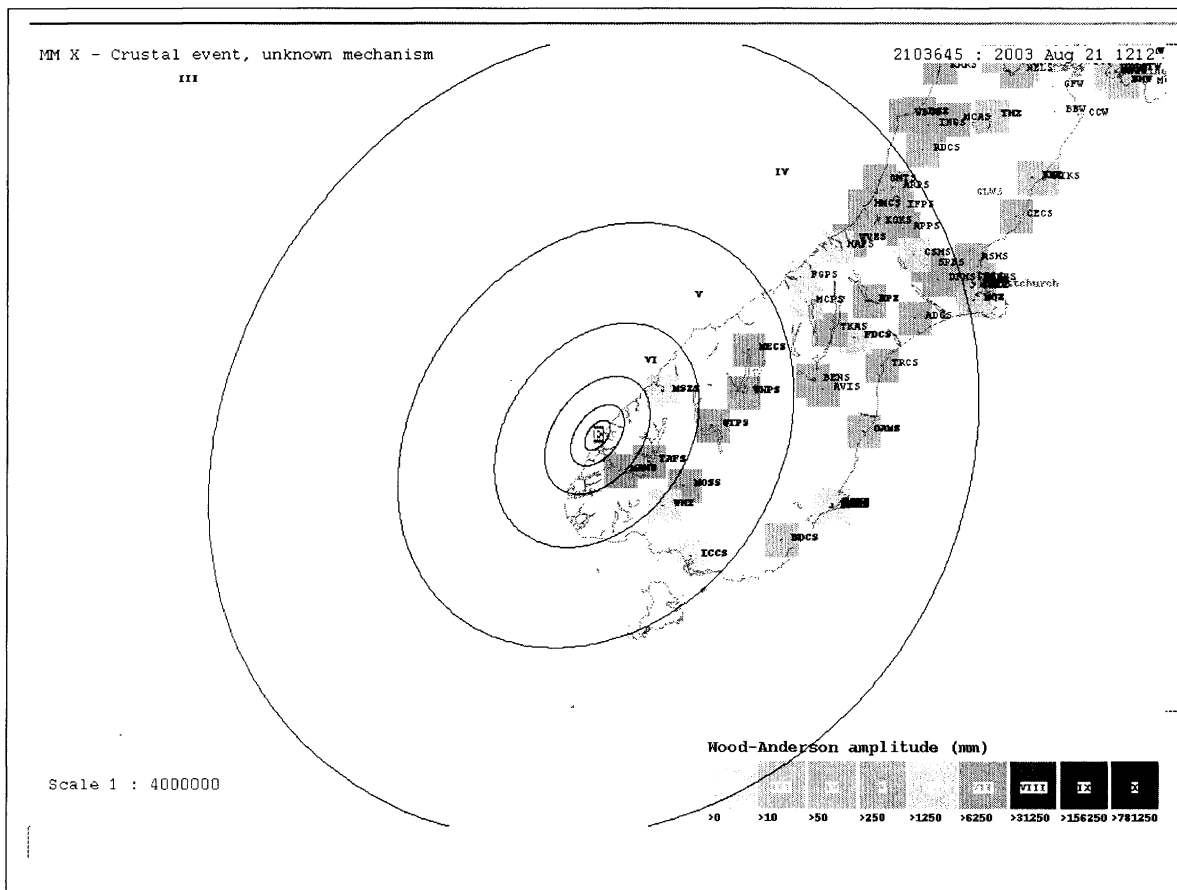


Figure 1. Map showing the real-time strong-motion data recorded by the nation strong-motion network. E represents the epicentre of the 2003 M_w 7.2 Fiordland earthquake. Ellipses and roman numerals indicate Modified Mercalli (MM) intensities estimated from the model of Dowrick and Rhoades (1999).

AFTERSHOCK STRONG-MOTION DATA

To supplement the national strong-motion network four temporary portable digital strong-motion instruments were deployed in the epicentral region. Within 48 hours of the mainshock two instruments were deployed and in the following day and a half two more instruments were deployed along with a total of six portable short period seismometers. The geometry of the portable network (Figure 2) will ensure accurate locations for aftershocks that occurred during their deployment and in turn accurate distances to near-source stations typically within 20 km of the aftershocks. The deployment of the instruments was crucial for recording aftershocks and collecting near-source strong motion data that will help to fill the gap in the New Zealand strong motion data set for interface subduction zone earthquakes.

During the three week deployment of instruments six aftershocks with magnitudes of 5.0 or greater were recorded. The largest had a magnitude of 6.1 with an epicentral distance of only a few kilometres to the nearest strong-motion station; it recorded a peak ground acceleration (pga) of 0.28g. In this study the pga data from these six magnitude 5.0 or greater aftershocks recorded during the time of the portable deployment is presented. These events have been

located using a 1-D velocity model determined for the region by Reyners *et al.* (2003) and are our best locations to date. It must be stressed that the final location will be determined by a 3-D velocity model sometime in the future once all the seismic data has been processed, and locations could change significantly with the 3-D velocity model. This in turn could change the calculated epicentral and hypocentral distances to the recording stations.

The portable stations have also made it possible to calculate preliminary focal mechanisms for these aftershocks with the larger two being better constrained by the network. All aftershocks for which focal mechanisms could be determined (5 out of 6) produced thrust faulting (Figure 2) and are believed to be subduction interface events.

All four strong motion instruments were plastered to rock or concrete structures connected to rock (Figure 3). The highest pga of the two horizontal components from each station is used as read directly from the waveform. Each source is treated as a point source. At this stage we do not have enough information to infer a fault plane for any of these events. Therefore each source distance reported is the direct distance from the hypocentre of the earthquake to the recording station and is in kilometres.

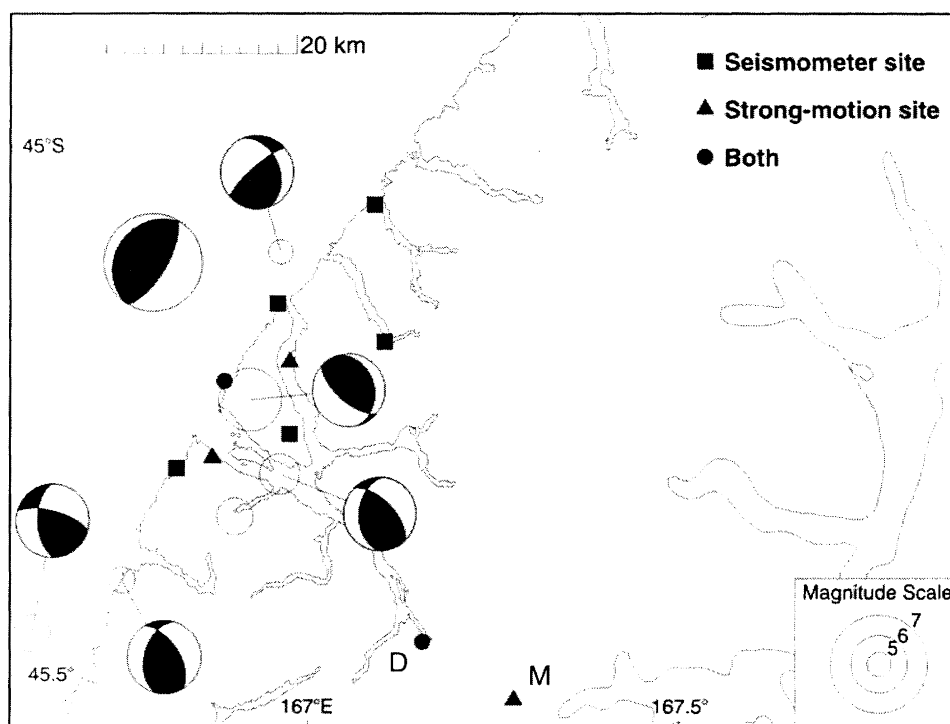


Figure 2. Relocated $M_1 \geq 5.0$ events in the earthquake sequence (circles scaled to magnitude) recorded during the time of the temporary deployment. Focal mechanisms (upper hemisphere) representing the five aftershocks and also the mainshock (the largest symbol). Also shown are the near-source strong-motion and temporary seismometer sites. The D represents the national seismic network site at Deep Cove and the M represents the permanent strong-motion site at the Manapouri Power Station (surface facility).



Figure 3a. Portable Etna site plastered to rock, with GPS antenna in the background. Wire netting is to protect the instrument from Kea's.

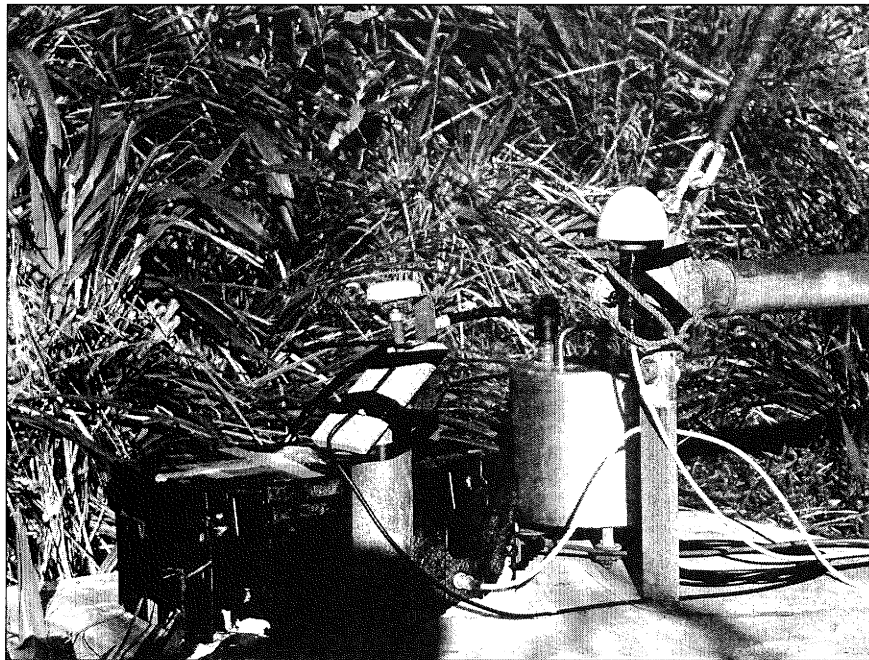


Figure 3b. Portable Etna co-located with a short period seismometer. Both instruments have GPS timing and are sitting on a concrete block connected to or close to rock. The Etna is plastered to the concrete to keep it down and it was this instrument that recorded 0.28g from the magnitude 6.1 aftershock with in a few kilometres from its preliminary epicentre.

ATTENUATION MODELS AND THE 2003 FIORLAND EARTHQUAKE SEQUENCE

The $pgas$ recorded in the mainshock were generally under-predicted by attenuation relations for subduction interface earthquakes, especially for distances up to about 200 km from the source. The data were better matched by both the Youngs *et al.* (1997) model and by a model developed from Japanese data (Takahashi *et al.*, 2004) than by the New Zealand model of McVerry *et al.* (2000). For further details see Reyners *et al.* (2003).

The New Zealand model generally performed better for the aftershock pga data than for the mainshock data. At this stage, the data has not been evaluated for any azimuthal dependence, which was a strong feature in the mainshock

data. As most of the aftershock data, especially for distances up to 100 km, was from strong rock sites, the attenuation relations have been shown in terms of their site class that is most appropriate for this site condition. For the smaller magnitude events (magnitude 5.0 and 5.1), all three attenuation relations generally over-predicted the data (see Figure 4 for the 5.0 relationship). For the two magnitude 5.5 and 5.6 events the New Zealand model gave a reasonable match to the rock $pgas$, while the other models tended to over-predict them (see Figure 5 for the 5.6 relationship). For the largest magnitude aftershock for which data is available ($M6.1$), the New Zealand model generally under-predicted the rock data, while the other two generally over-predicted, apart from the 0.28g value obtained at 23 km hypocentral distance (Figure 6).

Comparison of Fiordland 2003 $M5.0$ aftershock pga data with attenuation models

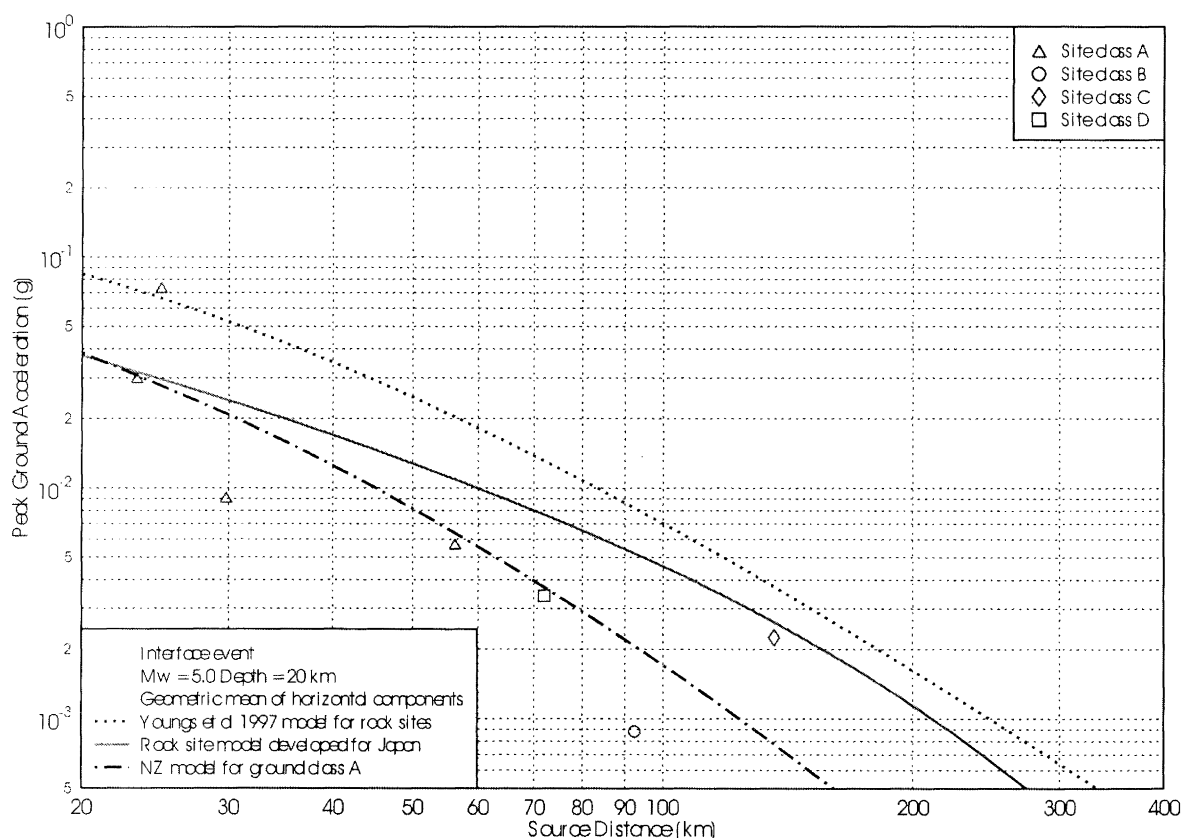


Figure 4. Comparison of the 2003 Fiordland magnitude 5.0 aftershock peak ground acceleration data with the attenuation models. Class A, B correspond to rock sites, class C Shallow soil and class D deep or soft soil (see Reyners *et al.*, 2003).

DISCUSSION

The deployment of the portable network following the 2003 M_w 7.2 Fiordland earthquake to collect near-source strong-motion data has helped to understand why the $pgas$ for the 2003 and other Fiordland interface earthquakes have been under predicted by the New Zealand attenuation model. The

2003 Fiordland earthquake was under predicted by the model by a factor of 1.6, the 1993 M_w 6.8 Secretary Island earthquake by a factor of 1.4 and the 1989 M_w 6.4 Doubtful Sound earthquake by a factor of 1.7 (Reyners *et al.*, 2003).

Prior to the 2003 series of Fiordland subduction interface earthquakes, there was some doubt to whether regional

variation or magnitude-dependent was the reason for the model under predicting the data. As the recorded Fiordland interface earthquakes that had contributed to the strong motion dataset were much larger in magnitude than the Hikurangi interface earthquakes that made up the rest of the data set.

A general observation is that the magnitude-dependence shown by the data was greater than that shown by any of the three models. This is demonstrated by the pga data from the mainshock generally being under-predicted, while those from the aftershocks around magnitude 5.0 were generally over-predicted. The magnitude 7.2 earthquake and its aftershocks spanning magnitudes 5.0 to 6.1 for which data are shown in

this study considerably expand the amount and magnitude range of data from New Zealand subduction interface earthquakes. Thus the situation is not as simple as indicated by the mainshock, where it could be claimed that the Youngs *et al.* model was much better than the New Zealand model, which under-predicted the data. For the aftershocks, the New Zealand model was generally better than the Youngs *et al.* model.

The new data collected from the 2003 Fiordland sequence will help to improve current models and lead to a better understanding of the attenuation process associated with New Zealand subduction interface earthquakes, and in turn improve hazard estimates.

Comparison of Fiordland 2003 M5.6 aftershock pga data with attenuation models

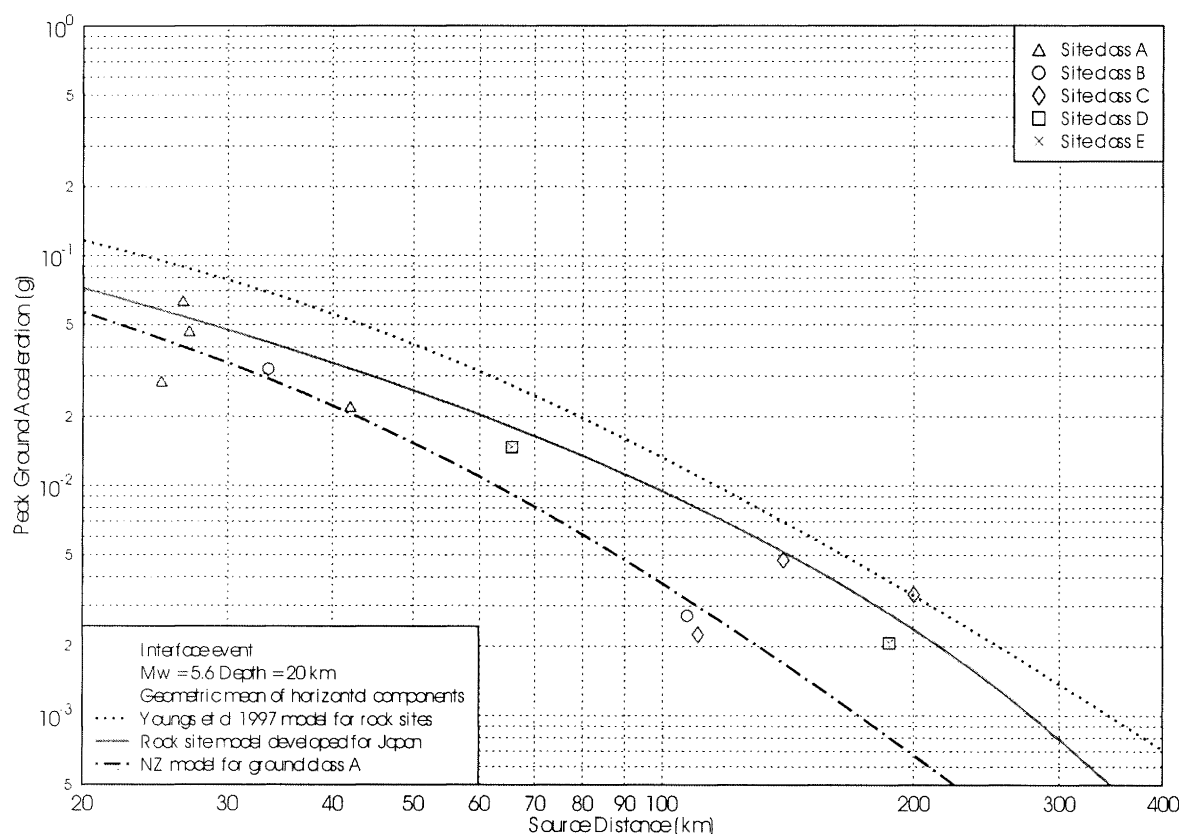


Figure 5. Comparison of the 2003 Fiordland magnitude 5.6 aftershock peak ground acceleration data with the attenuation models. Class A, B correspond to rock sites, class C shallow soil and class D deep or soft soil (see Reyners *et al.*, 2003).

ACKNOWLEDGMENTS

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tandem with GeoNet, five of their instruments recorded the mainshock, including the nearest instrument at the Manapouri Power Station. I would also like to thank the Department of Conservation (DOC) for permission to deploy instruments in the Fiordland National Park. Helpful reviews were provided by Russell Robinson and Jim Cousins. This work was supported by the New Zealand Foundation for Research, Science and Technology.

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Comparison of Fiordland 2003 M6.1 aftershock peak ground acceleration data with attenuation models

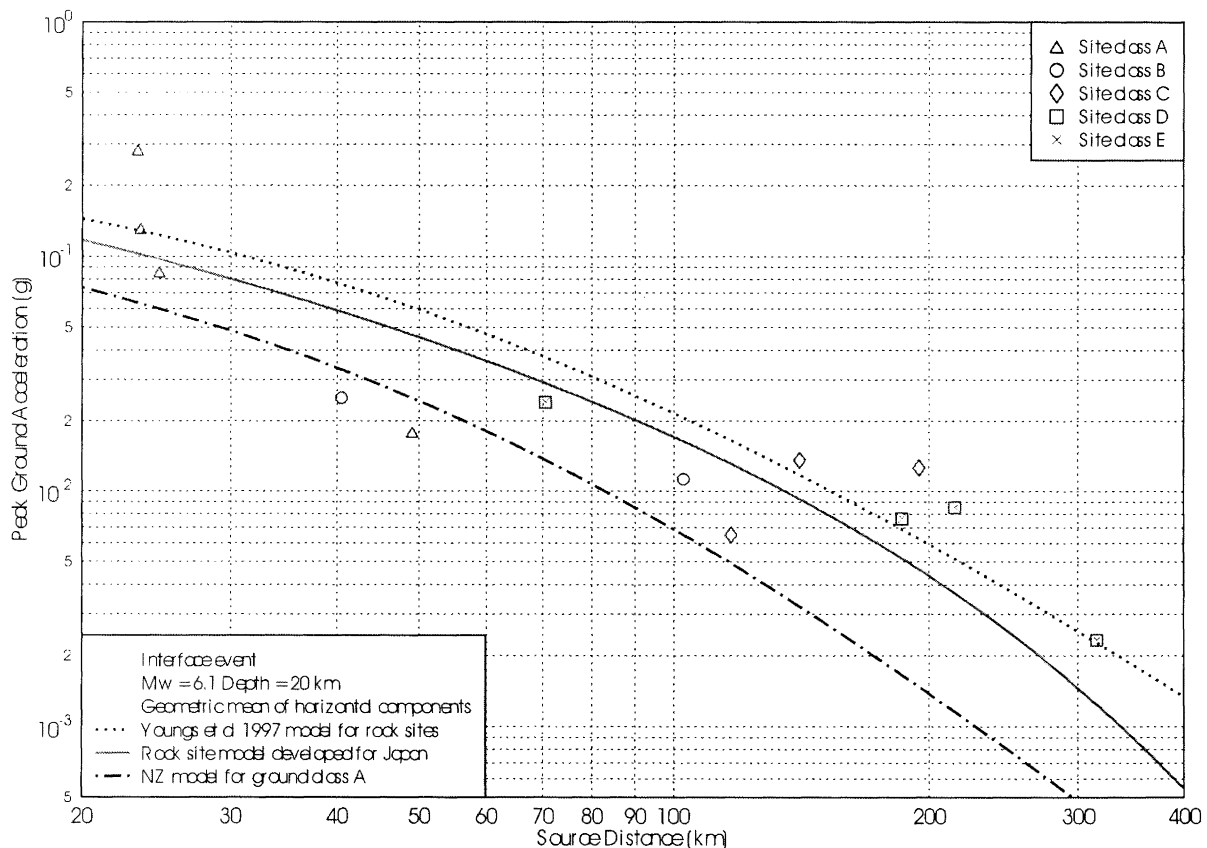


Figure 6. Comparison of the 2003 Fiordland magnitude 6.1 aftershock peak ground acceleration data with the attenuation models. Class A, B correspond to rock sites, class C shallow soil and class D deep or soft soil (see Reyners et al., 2003).