EDGECUMBE EARTHQUAKE — SOME NOTES ON ITS SOURCE, GROUND MOTIONS, AND DAMAGE IN RELATION TO SAFETY

by David J. Dowrick

ABSTRACT

This paper first describes the basic features of the earthquake, its size, causal mechanism, and fault rupture characteristics, and distribution of felt intensities. The ground motions measured in various places are described in terms of accelerations, response spectra and attenuation. Finally safety aspects are discussed in relation to damage levels, strength of shaking and current code loading requirements.

THE SIZE AND NATURE OF THE EVENT

The Edgecumbe earthquake of local magnitude $M_L = 6.3$ occurred on March 2 1987. Its epicentre was located to the north-west of Edgecumbe in the Bay of Plenty as shown on Figure 1, and the focal depth has been estimated to be about 8 km. At the time of writing the best estimates available [1] for the seismic moment were in the range $4.3 - 6.4 \times 10^{18}$ Nm.

The earthquake was caused by extensional strains in the earth's crust in the East-West direction. In this continuing process the distance of c. 23 km between Matata and Whakatane is increasing by about 7 mm per year, and produces strain energy at a rate sufficient to cause earthquakes of this size at this location about once every 100-150 years.

As shown in Figure 1, surface deformation included multiple surface breaks with the main surface rupture being 7 km long with a maximum vertical displacement of 2 m. The latter displacement was essentially downthrow, with no transcurrent displacement. Establishing the size and shape of the fault rupture surface is difficult to do with certainty, but studies by Darby [2] show that the rupture surface would have an area of about 100-120 km^2 and that the main fault plane would dip at an angle of about 39^o to the horizontal. A focal depth of 8 km implies that the bottom of the rupture surface was 8 km below the Rangitaiki Plains.

* Research Engineer, Physics and Engineering Laboratory, DSIR, Lower Hutt

Figure 1, adapted from Lowry et al [3] , is a map of isoseismals showing intensity on the Modified Mercali (MM) scale. The inner isoseismal pattern is fairly symmetrical, with the strongest isoseismal being MM9. As would be expected from a non-vertical fault plane, neither the surface trace of the main fault nor the epicentre lie on the major axis of the inner isoseismals.

GROUND MOTION

Attenuation of Peak Ground Accelerations

In the main shock the ground motion was recorded on strong motion accelerographs at Matahina Dam (R = 15 km), Maraenui Primary School (R = 65 km) and Wairoa Telephone Exchange (R = 128 km), while there was a scratch plate acceleroscope recording at Opotiki Telephone Exchange (R = 39 km). R has been measured as the nearest distance from the source, where the source is defined as a horizontal line running the 13 km length of the rupture surface (Darby's model [2]), where the line is located half-way down the dipping fault surface, ie 4 km deep. The averages of the two horizontal components of peak ground acceleration at each of the above four sites were 0.261g, 0.035g, 0.0178g, and 0.083g respectively. These accelerations are plotted against distance R on Figure 2, in relation to an attenuation curve for New Zealand, ie the NZ Seismic Risk Committee's modified Katayama attenuation [4] , and an expression for the western USA proposed by Idriss [5].

The NZSRC attenuation curve has the same slope as that for spectral accelerations at T = 0.2 sec, as this should be very similar to the slope for a_{max}. In fact the slope of the NZSRC curve was derived on the basis of

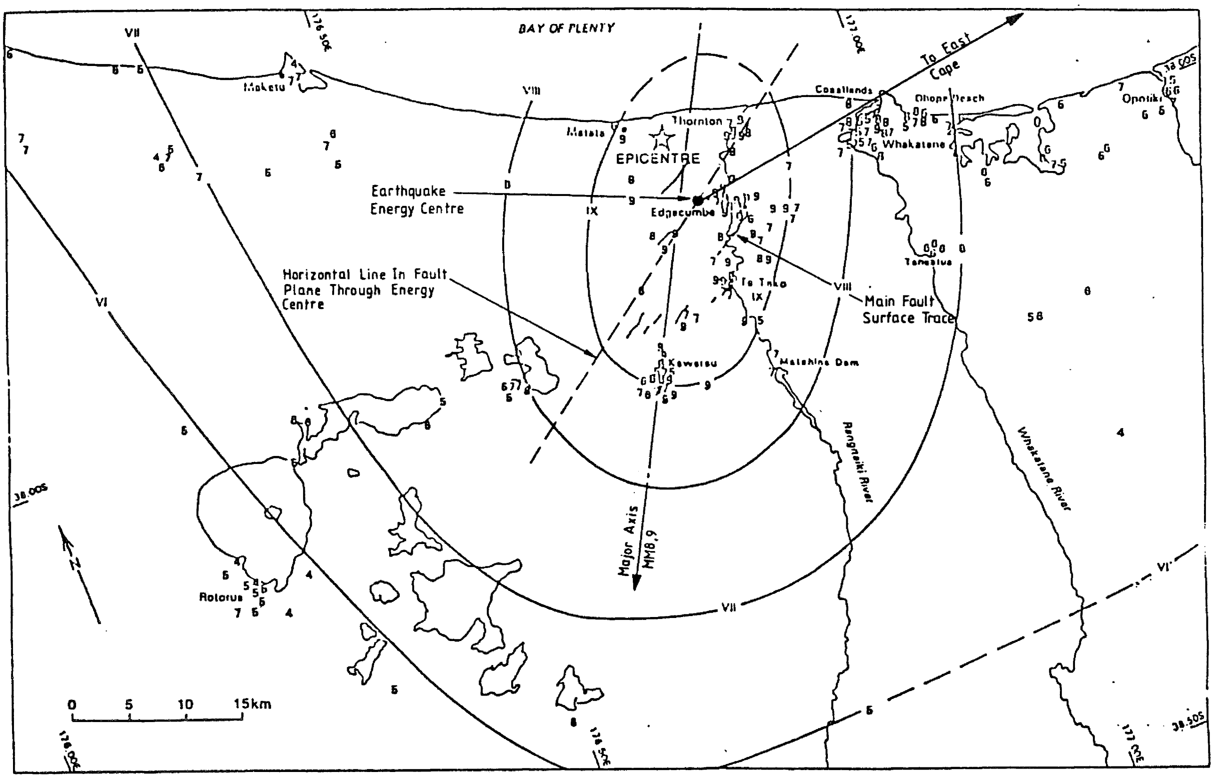

FIGURE 1. STRONG MOTION AREA SHOWING EPICENTRE, FAULT RUPTURES, INTENSITIES, ISOSEISMALS, ENERGY CENTRE, FAULTING (ADAPTED FROM LOWRY ET AL, REF 3).

peak ground accelerations from the 1968 Inangahua earthquake [6] . The level of this line on Figure 2 has been arbitrarily set to start from the field data point for Matahina dam.

Both the Idriss and NZSRC curves fit the data points quite well, particularly the former. The standard deviation of the $\log_{10}a$ values for the four data points in relation to Idriss's curve is 0.08, which is less than half the residual standard deviation of 0.165 found by Idriss for his data set. No comparable significance test of the fit of the NZSRC curve can be carried out, as only its slope is known.

The attenuation of peak ground acceleration in the Edgecumbe earthquake is further discussed elsewhere [7].

Response Spectra

The ground shaking at the base of the Matahina Dam was the strongest acceleration history so far recorded in New Zealand, and was similar in strength to the El Centro 1940 earthquake record which has long been used as a basis for design loadings in this country. This is evident from a comparison of response spectra from these two records as plotted on Figure 3. It follows from Figure 1 that much of the area inside the (undrawn) MM8.5 isoseismal experienced shaking equal to or greater than the code design level for Seismic Zone A, our

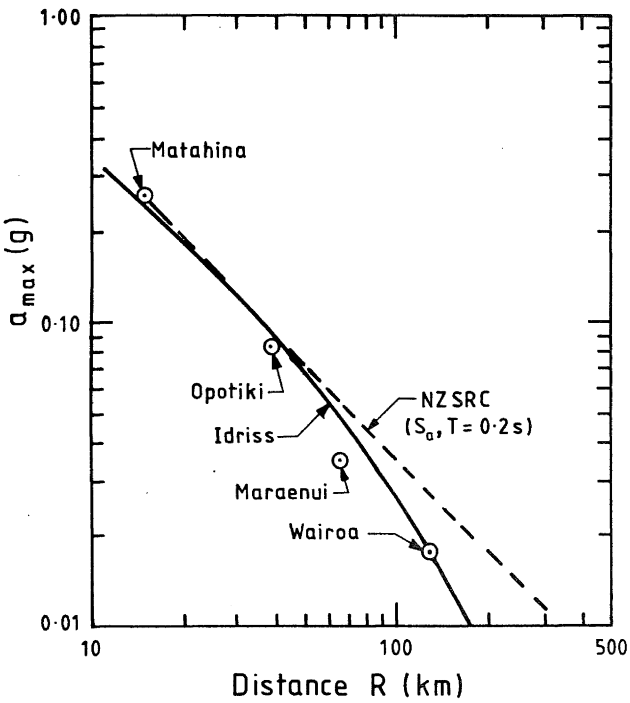

FIGURE 2. ATTENUATION OF PEAK GROUND ACCELERATION FOR EDGECUMBE EARTHQUAKE, COMPARED WITH NEW ZEALAND AND WESTERN USA MODELS.

highest loading zone, in which the Edgecumbe area lies.

The response spectra derived from the Edgecumbe earthquake are further discussed elsewhere [7].

SAFETY ASPECTS

As mentioned in above, much of the area inside the MM8 isoseismal would have been subjected to a strength of shaking equal to or greater than the design level implied by the current loadings code [9]. In these circumstances, the fact that some properly designed structures within this zone were heavily damaged should not come as a surprise to engineers, although it probably surprises most laypersons. The latter would not generally be aware that for reasons of economy we design most normal-use structures to yield with appropriate ductile capacity at the design level of shaking. We thus accept damage in the design event, making our priority the safety of human life and limb.

The degree of damage that we should expect near the centre of earthquakes such as Edgecumbe is indicated by the damage ratios plotted as functions of I_{mm} in Figures 4 and 5, where damage ratio is the cost of the damage divided by the total value of the building (or other item) concerned. It can be seen that damage ratios between about 4% and 60% would be the norm for 8 \ I_{mm} \ 10, depending on the type and age of structure, but as the curves are of mean values, damage ratios up to 100% (ie total write-offs) would not be exceptional (for reinforced masonry at I_{mm}=10, which is somewhat stronger than code design level intensity). Indeed my general impression so far is that most damage levels to structures and equipment were as would be expected for the strength of shaking implied at the respective sites.

The damage ratios in Figures 4 and 5 are not directly comparable because they define the total values of the buildings differently. It should also be noted that the curves on Figures 4 and 5 are highly uncertain because of the scarcity of data, both world-wide and especially for New Zealand construction. This is especially true for the curve for post-1977 reinforced concrete construction on Figure 5, for which of course there was no New Zealand damage data available at the time of that study. Hence this curve was inferred entirely from overseas experience. The relationship between the Birss 1836-1877 and post 1977 curves is unsatisfactory; the two curves should be much nearer the same for about I_{mm} < VIII, ie at response levels less or not much greater than the elastic limit, as the main difference in the damageability of structures of these two eras is in their post-yield performance.

With so much damage to be expected as the witting outcome of even our latest design and construction procedures, in the strong shaking zones of even moderate sized earthquakes such as Edgecumbe, how good is our record on safety? The casualties resulting from the Edgecumbe earthquake were very few. There were no deaths and only one significant injury arising from damage to the built environment (ie a

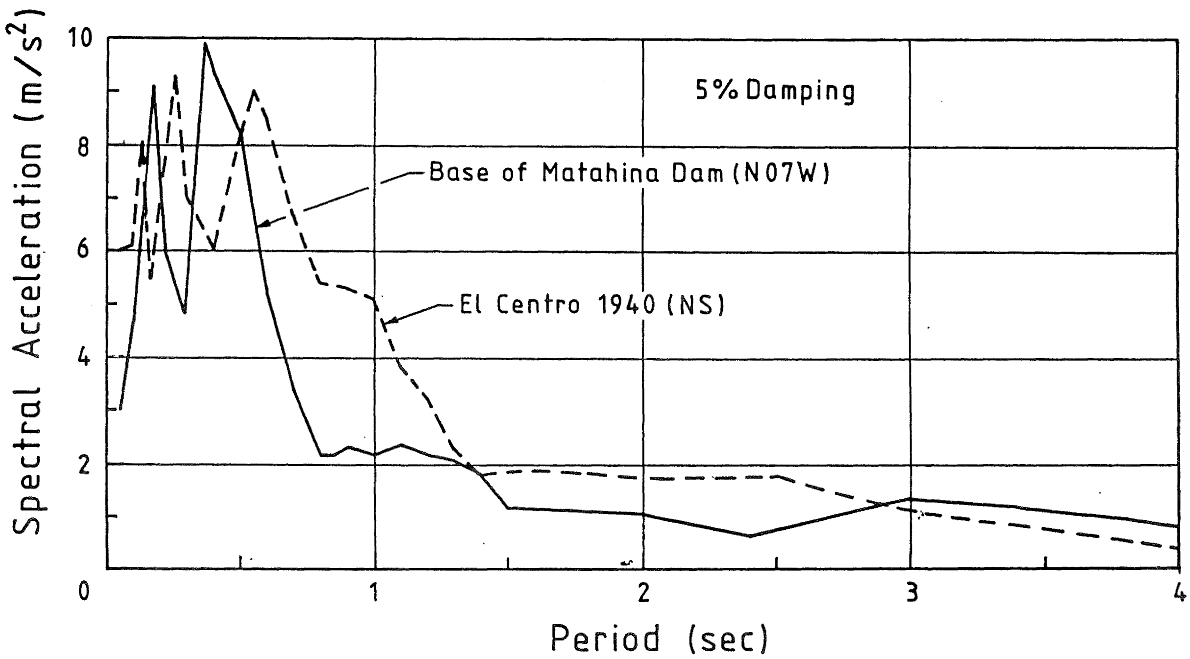

FIGURE 3. ACCELERATION RESPONSE SPECTRUM FROM GROUND MOTIONS AT THE BASE OF MATAHINA DAM COMPARED WITH EL CENTRO 1940 (AFTER DOWRICK, REF.8)

broken arm) from a population of approximately 13,000 within the MM8 isoseismal, but this casualty rate would surely have been much worse if the foreshock, which occurred 7 minutes before the main shock, had not driven many people away from areas where heavy damage occurred (eg at the Bay Milk Products factory).

What are the main sources of danger to people arising from damage to the built environment during earthquakes? Generically, these may be summarized as follows:

(1) Failure of structures or equipment;
(2) Falling portions of structures or equipment;
(3) Falling or escaping stored materials;
(4) Earthquake-induced fires or explosions.

Let us consider briefly each of these hazards, as set out below.

Failure of Structures or Equipment

In this category are included buildings, road and rail structures, dams, stop-banks, tanks, industrial equipment (such as transformers), chimneys, towers, pipelines, power lines, construction and transportion equipment, non-function of emergency services.

Some cases of failure or potential failure in the Edgecumbe earthquake which could have caused death or injury were:

(i) Collapse of a few buildings (generally lesser structures).
(ii) Damage of roads from surface fault rupture and consolidation of bridge approaches (eg 2 m vertical fault displacement across McCracken Road - this of course can't be designed against).

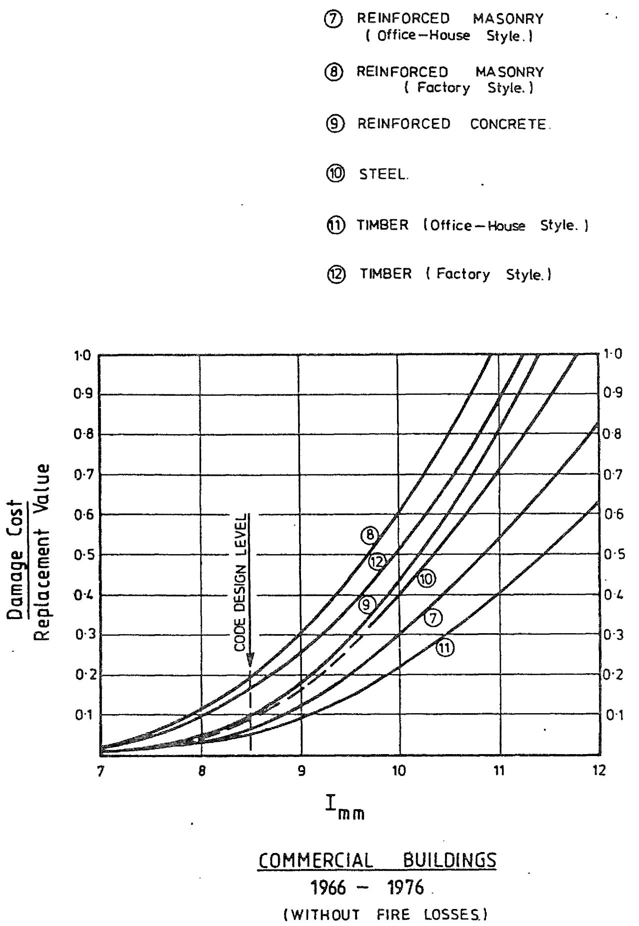

FIGURE 4. DAMAGE RATIOS FOR NEW ZEALAND COMMERCIAL BUILDINGS (AFTER DOWRICK, REF 10).

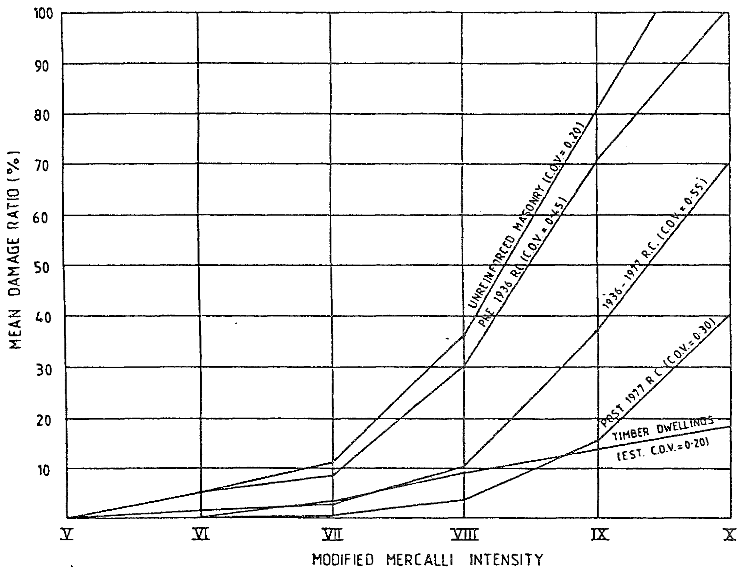

FIGURE 5. DAMAGE RATIOS FOR NEW ZEALAND BUILDINGS (AFTER BIRSS, REF 11).

(iii) Damage to Matahina Dam - Ongoing studies have yet to reveal how much reserve strength the dam had in this event.

(iv) The down-throw of the land near Edgecumbe could have caused breaching of the stopbanks of the Rangitaiki River with consequent flooding. Danger from this hazard will be much worse at the time of the next similar earthquake because of the greater potential depth and area of flooding. A similar event nearer the coast could let the sea in to part of the plains.

(v) Many liquid storage tanks collapsed, notably the stainless steel tanks at Bay Milk Products, Edgecumbe. Traditionally such stainless steel tanks in the food processing industry have not been designed for earthquakes, in the belief that the tanks would become too expensive. But subsequent analysis using the recent NZNSEE recommendations [12] has shown that the cost of extra strength for earthquake resistace would not have been great [13].

(vi) Transformers at local substations failed at their mountings, and were displaced several metres.

(vii) In Edgecumbe two large parked vehicles were overturned, ie a railway locomotive and a timber truck. Although these events presumably cannot reasonably be designed against they could have caused fatalities, and incidentally also imply very strong ground motions.

Falling Portions of Structures or Equipment

In this category are included items such as cladding, roofing, chimneys, partitions, and pipework. There were many examples of this type of damage to houses, especially brick veneer cladding and roof tiles falling off or masonry chimneys failing at the roof line.

Some interesting observations were made about concrete buildings at the Tasman Pulp and Paper Mill by Hodge [14]. His impression was that the concrete structures were all damaged to about the same degree regardless of their age, which ranged through three code revisions from the mid-1950's onwards . Even in their most recent buildings he was concerned about the danger to people from falling lumps of spalled concrete (presumably from plastic hinge zones). These observations need careful examination regarding both safety and cost-effectiveness of our code provisions.

Falling or Escaping Stored Materials

In this category are included materials which are heavy or noxious. Notable examples occurred in Edgecumbe where storehouses of stacked or racked milk products fell down, and only the timely occurrence of the foreshock prevented serious casualties occurring. Such storage areas are a nightmare to earthquake conscious people world-wide, and cost-effective and operationally practicable safer racking remains a great unsolved challenge.

Earthquake-Induced Fires or Explosions

These hazards arise in domestic and industrial situations through the conjunctjon of ignition sources with flammable or explosive substances. They are generally less likely in warm weather, at times away from cooking times, and in the absence of reticulated gas.

The Edgecumbe earthquake occurred after lunch-time on a warm day and there was no reticulated town gas in the strong motion area. The fire hazard was also reduced by the electric power cut caused by the foreshock. To my knowledge no fires or explosions occurred in this earthquake.

CONCLUSIONS

The main conclusions from this paper are as follows:

1 The Edgecumbe earthquake was only of moderate magnitude, but quite strong shaking and large vertical fault displacements (c. 2 m) occurred in the area near the fault rupture zone. The area within the MM8 isoseismal was about 850 km^2 and contained a population of approximately 13,000.

2 Strong ground motion was recorded during the main shock by accelerographs at three locations at distances of 15 km, 65 km and 128 km from the source, and by a scratch plate at 39 km distance. Non-activation of many other operational instruments implies high variability of attenuation.

3 Based on this limited strong motion data, rates of attenuation with distance were greater than that predicted by the NZ Seismic Risk Committee's recent model which is a modification of Katayama's Japanese model. The attenuation of peak ground acceleration conforms well to recent western USA expressions. This may be because the focal depth of 8 km is typical of California. However this depth is at the shallow end of the range for New Zealand earthquakes, so that the attenuation of the Edgecumbe earthquake is unlikely to be appropriate as a model for many New Zealand earthquakes.

4 Although the Edgecumbe earthquake was not large and was centred in a largely rural area, a widely representative range of the elements of the modern built environment was located within the strong motion area (say the MM8 isoseismal). This gives us an opportunity to review our safety measures across a wide multi-disciplinary front. While the damage levels in the strong motion area were apparently largely consistent with the original design levels and a cost-

effective acceptable risk approach, it is not yet clear whether we can conclude from this earthquake that our design principle "safety of people is of paramount importance" is being systematically put into practice. Many sources of danger to people were exhibited by the damage that occurred, but the low casualty rate could be attributed largely to the luck of the timely occurrence of the foreshock. A thorough review of the human danger sources described generically in the section on Safety Hazards in this paper might well reveal areas where more care is warranted, of which some examples have been given, eg

(1) safer methods of storage of goods (stacked or racked) ;
(2) prevention of, or planning for, flooding of the Rangitaiki plains (or similar areas) after future earthquakes;
(3) the need for regulations requiring design for earthquake resistance of liquid storage tanks in the food processing industry. (How many more gaps are there in our regulations?)

5 The low casualty count may be attributed largely to good luck, ie the timely occurrence, and effect of, the foreshock which occurred seven minutes before the mainshock.

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