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STRONG MOTION RECORDS FROM THE 2 MARCH 1987 EDGECUMBE EARTHQUAKE IN NEW ZEALAND

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SUMMARY

Five accelerographs on the 86-metre high Matahina earth dam in the Central Volcanic Region of New Zealand recorded the magnitude 6.3 normal-faulting Edgecumbe earthquake of 2 March 1987 at a distance of 11 km from the main fault trace. A maximum horizontal ground acceleration of 0.33 g was recorded at the base of the dam, with the 5% damped acceleration response spectrum peaking at 1.0 g. Comprehensive sets of records were obtained of the response of the dam in the magnitude 5.2 foreshock, the main shock and largest aftershock of magnitude 5.7, showing significant nonlinearity of the dam in the maximum centre crest response of 0.42 g.

INTRODUCTION

The magnitude 6.3 Edgecumbe earthquake was the most damaging in New Zealand since the magnitude 7.1 Inangahua earthquake of 1968. The intensity of MMIX assigned to the epicentral region in general with several instances of MMX (figure 1) is the highest intensity in New Zealand since MMXI was experienced in the Inangahua earthquake.

Edgecumbe is situated on the young alluvial sediments of the Rangitaiki plain of the Central Volcanic Region (CVR) of New Zealand. The CVR is a region of extensional rifting landward of the Hikurangi subduction zone which forms the convergent plate boundary between the Pacific and Australian (or Indian) plates. It is a region of active volcanoes and geothermal areas. Compared to the other parts of New Zealand, it has a small crustal thickness of only 15 km, with a low velocity upper mantle.

There are several unusual features of the seismicity of the CVR associated with its tectonic regime. The area is noted for very localised areas of high intensity shaking in moderate magnitude earthquakes. Swarm activity is an important component of the seismicity. The Edgecumbe earthquake was the third this century of around magnitude 6 to produce surface faulting in the CVR, while magnitudes near 7 or greater are usually required to produce surface faulting in New Zealand. The CVR is mainly associated with normal faulting, as expected for an extensional rifting zone, rather than thrust and strike-slip faulting more common in the rest of the country, although these fault types also occur in the CVR.

A series of normal faulting surface scarps were produced in the Edgecumbe earthquake. The principal scarp, on a pre-existing but unrecognised fault, ran about 7 km south-west from near Edgecumbe (figure 1), with a maximum vertical displacement of about 1.5 metres and an opening of about 1 metre across the scarp. Associated with the normal faulting was a considerable drop in ground elevation in the areas north-west of the main rupture, severely affecting drainage and flood-control in the low-lying flood plain. There was extensive compressional ground deformation caused by the earthquake, demonstrated by buckling of railway lines and road curbing and the crumpling of road surfaces. Soil slumping, particularly along river and drainage canal banks, and sand blows were common. Some minor slips occurred. Seismological and geological features of the earthquake are summarised in reference 1.

From the earthquake engineering point of view, the most significant lessons related to the damage to industrial facilities. Although the earthquake occurred in a predominantly rural area, it caused considerable damage to both structures and machinery of one of New Zealand's major industrial plants, the Tasman paper mill at Kawerau. At the Bay Milk Products dairy factory at Edgecumbe, there were many spectacular collapses of stainless steel tanks, gross settlements of the foundations of the plant, extensive damage to milk processing equipment, and the collapse of storage racks.

Engineering features of the earthquake have been described in a reconnaissance report compiled soon after the earthquake (reference 2).

STRONG-MOTION INSTRUMENTATION AND RECORDS

Five New Zealand MO type film-recording strong-motion accelerographs are permanently installed on Matahina dam, about 11 km south of the main fault trace and 22 km from the epicentre of the main shock (figure 1). Three of the accelerographs are deployed near the crest of the dam, one around midheight in the centre of the dam, and one on the ground only a few metres from the toe of the downstream face.

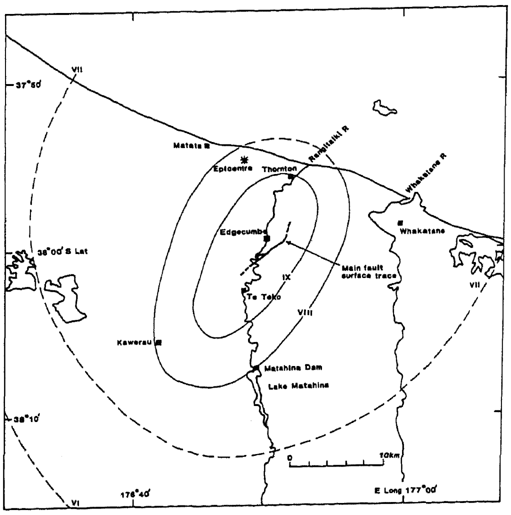

Fig 1. Location of Matahina dam, showing the epicentre, the main fault trace and the MM intensity pattern.

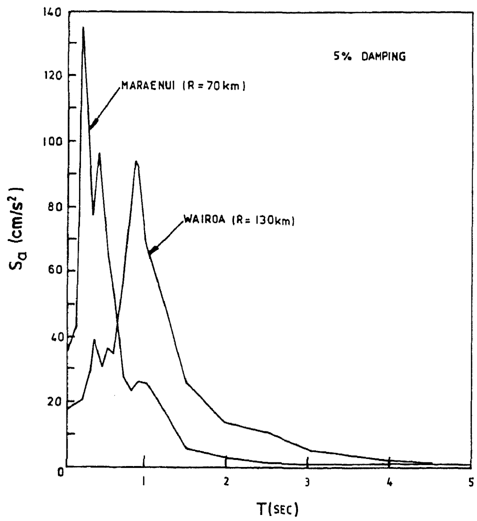

Fig 2. Mean acceleration response spectra for the two horizontal components recorded at Maraenui and Wairoa (from reference 5).

The geology in the vicinity of the dam is unusual in that extensive ignimbrite sheets lie on top of older sediments. At the dam site, the river has eroded through the lava flow into compact gravels, sands and silts of Tertiary age. The dam abutments are hard tuff underlain by compact alluvial sediments. The dam base accelerograph is situated on at least a 40 metre depth of alluvium (reference 3).

Complete sets of records from all five accelerographs on Matahina dam were obtained in the M_L 5.2 foreshock at 01:35:36 UT and in the M_L 6.3 main shock at 01:42:34 UT on 2 March 1987. Records were obtained at the base, midheight and eastern end of the crest in the largest aftershock, of M_L 5.7 at 01:50:57. The instruments at the other two crest sites had already run out of film by this time.

The main-shock and strongest aftershock were also recorded at Maraenui, 72 km east of the epicentre, and the mainshock at Wairoa 137 km to the south-east. Previous records from both sites have shown pronounced resonances, which were repeated in the Edgecumbe earthquake records at 1.0 Hz at Wairoa and 4.8 Hz at Maraenui (figure 2). A scratch-plate acceleroscope at Opotiki, 49 km east of the epicentre, gave a peak horizontal ground acceleration of 0.08 g.

A number of aftershocks of magnitude 3.6 to 4.5 were recorded by the accelerographs installed the day after the main shock at the electrical substations at Kawerau and Edgecumbe, several at epicentral distances between 2 and 5 km.

GROUND-SITE RECORDS FROM THE DAM-BASE

The record produced by the Matahina dam-base accelerograph in the magnitude 6.3 Edgecumbe main-shock was the strongest ground acceleration history yet recorded in New Zealand, and the first with response spectra comparable to the design-level 150 year return period spectra for the more seismic parts of the country. Stronger horizontal earthquake ground accelerations of up to 0.42 g have been recorded in New Zealand, but only on peak acceleration scratch plates.

Several parameters of the ground acceleration record were remarkably similar to those of the El Centro 1940 NS record, long used as a standard earthquake design accelerogram in New Zealand as elsewhere around the world. The peak horizontal ground acceleration was 0.33 g, with 0.14 g vertically (0.35 g NS and 0.21 g vertically for El Centro). The 5% damped acceleration response spectra for both the N07W component (figure 3) and the N83E component are very similar to the El Centro north-south spectrum, with the Matahina N07W spectrum peaking at 1.00 g and 0.37 seconds period. Both the Matahina and El Centro records had about 10 seconds duration for the strongest portion of the acceleration history. The El Centro record was obtained at a similar distance from the fault, 10 km, in an event of similar magnitude, M_L 6.3, but with strike-slip rather than normal faulting.

The ground acceleration, velocity and displacement of the almost radial N07W component (the epicentre lies at N11W from Matahina) are shown in figure 3. A striking feature is the very periodic nature of the N07W ground displacement, which builds up in amplitude over about 10 seconds and then resembles a moderately damped sinusoid with a period of 3.4 seconds, decaying from the maximum value of 100 mm over about 7 cycles. The Fourier spectrum shows a corresponding strong peak at 0.293 Hz, at an amplitude about 100 times greater than the noise spectrum at this frequency. The next two peaks are at frequencies of 0.630 Hz and 0.866 Hz, near harmonics of 0.293 Hz. It has been suggested that this strong peak may correspond to a vibration mode of the Rangitaiki basin or may be a characteristic of the earthquake source. However, it does not appear as a prominent peak in the foreshock or aftershock records from Matahina, nor does it appear in the more distant main shock records from Maraenui and Wairoa. The long period component is unlikely to be caused by vibration of the dam, which has an effective fundamental period in the 0.8 to 1.3 second range.

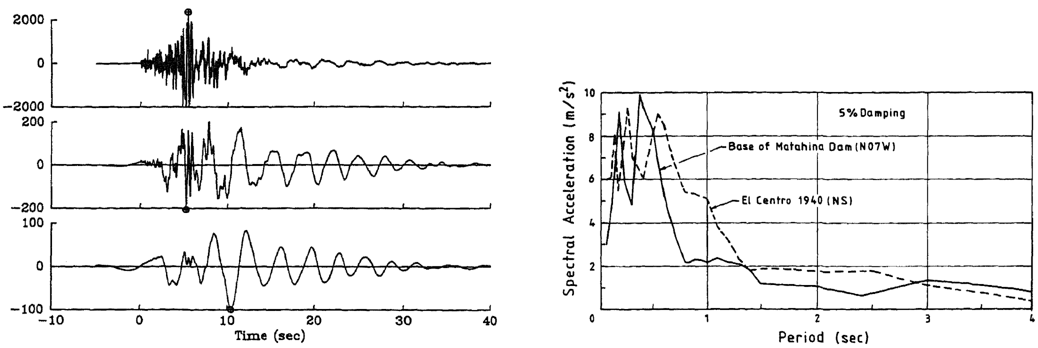

Fig 3. Ground acceleration (mm/s/s), velocity (mm/s) and displacement (mm) for the N07W component at the base of Matahina dam, and a comparison of the response spectrum with the El Centro 1940 north-south component.

DAM RESPONSE RECORDS

The shaking on Matahina dam in the main shock, 0.35 g centre crest response in the transverse N07W direction with a peak horizontal acceleration of 0.42 g in the S20W direction, was several times stronger than previously experienced by the dam. The transverse response at the centre of the crest in the foreshock was 0.054 g, similar to the 0.045 g acceleration recorded in an earthquake in 1977. The eastern crest instrument gave a peak N07W response of 0.10 g in the strongest aftershock. The records from these smaller amplitude motions are useful for calibration purposes to indicate any changes to the vibrational characteristics of the dam produced by the severe earthquake motions of the main shock.

The transfer function between the N07W crest response acceleration and the dam-base acceleration is quite different in the mainshock from the foreshock (figure 4). The foreshock curve shows a fundamental mode peak at 0.88 seconds. The mainshock curve has double fundamental mode peaks, at 1.0 and 1.39 seconds. The maximum fundamental mode amplification is less than in the foreshock.

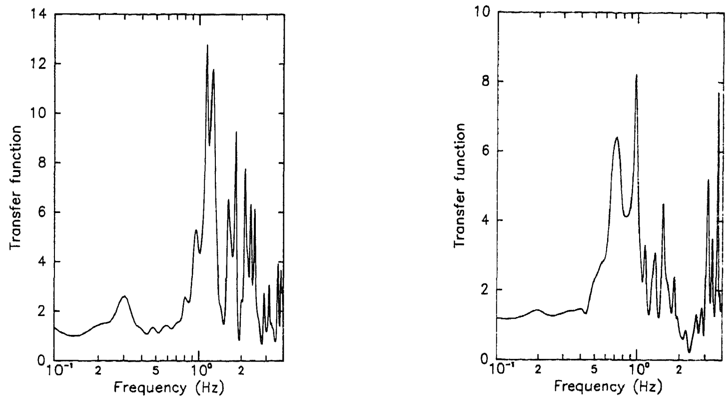

Fig 4. The transfer function between the N07W component of the base acceleration and the centre crest response in the magnitude 5.2 foreshock (left) and the magnitude 6.3 mainshock (right) of the Edgecumbe earthquake.

Systems identification techniques (reference 4) have been applied to obtain the best least-squares matches possible between segments of the recorded motions and those calculated for constant parameter linear modal models subjected to the base excitation. Considerable variations were obtained in the effective linear parameter values for different portions of the response. For example, the effective first mode transverse period lengthened from 0.80 seconds in the foreshock to 1.36 seconds around the time of the strongest response in the mainshock before dropping to 0.94 seconds in the decaying portion of the response (figure 5a). An effective first mode period of 1.27 seconds was identified from the full duration of the response. The periods of the two transfer function peaks correspond closely to the effective period for the second half of the response and the longest effective period identified from the strongest part of the response. The transverse first mode dampings also varied during the main shock response, dropping from about 25 per cent of critical around the time of the strongest response to about 7 per cent of critical in the decaying amplitude portion of the response.

The behaviour of the effective fundamental transverse mode period and damping over the course of the response is indicative of mainly amplitude dependent hysteretic behaviour with some permanent softening. The partial recovery towards the initial period during the second half of the response, together with the nearly constant effective parameter values in this part of the response, indicate there was no continuing degradation of the stiffness.

Detailed studies of the response using nonlinear models are now underway to determine the hysteretic force-displacement characteristics of the dam.

Immediately after the earthquake, there were concerns about the safety of the dam. Monitoring in the following months at first suggested that there were no major problems. However in early 1988 major repairs were undertaken in the regions adjoining both abutments after the detection of marked increases in the seepage flows.

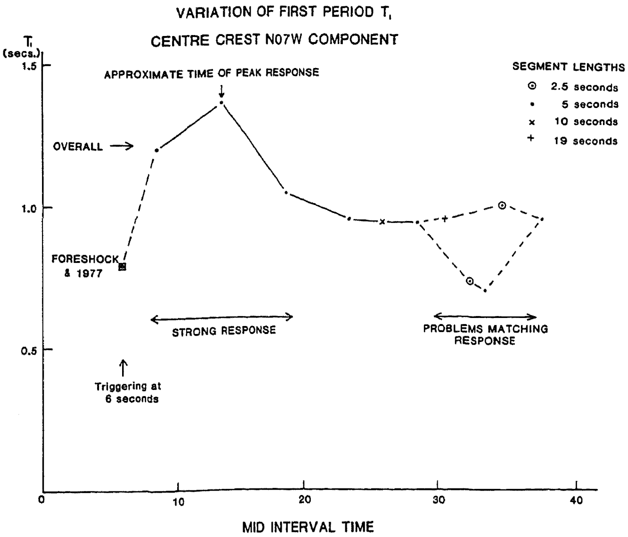

Fig 5. The variation of the N07W (transverse) fundamental mode period of Matahina dam estimated from various segments of the centre crest response in the main shock as a function of mid-interval time.

CONCLUSIONS

Accelerograms from the magnitude 6.3 Edgecumbe earthquake are important as near-fault records of a normal faulting earthquake, for providing the first design-level records from New Zealand, and providing a comprehensive set of records of the earthquake response of a large modern earth dam in both moderate and very strong motions up to 0.42 g crest response.

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