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Microzonation of Perth, Australia, using microtremors

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ABSTRACT: An Australian - Japanese project was set up to investigate seismic amplification in Australian sedimentary basins. Perth, Western Australia, was chosen for the first of these investigations due to its rapid development in recent times, its geological setting on Perth Basin and its proximity to one of the most active seismic zones in the country. Simultaneous recordings of microtremors were made over most of metropolitan Perth, using a 3 km grid as a basis and hard rock reference site throughout. Spectral ratios were plotted and contoured. It is shown that previously established earthquake risk estimates probably underestimated ground amplitudes by up to a factor of two. Spectral ratio contours, appeared to correlate well with various geological surface.

INTRODUCTION

In their assessment of earthquake risk in the region of Perth, Western Australia, Gaull and Michael-Leiba (1987) strongly recommended a microzonation study to assess the possibility of seismic amplification in the Perth Basin, upon which the city stands (see Figure 1). It was apparent from their paper, that without such a study, their estimates, which were based on average site conditions,may well be underestimates. As there are, at this time, over a million people living in and around this rapidly expanding metropolis, which is under threat from relatively active regional seismicity, it is becoming increasingly important to attempt to address this problem. The best example of the vulnerability of Perth to earthquake hazard was during the Meckering earthquake of 1968, when ground intensities up to MM VII were experienced (Gaull et al in prep). Hence greater intensities are possible from a closer or larger event.

It has been shown in the literature that microtremors can be a very useful tool in quantifying seismic ground amplification for earthquake hazard assessment (Kagami et al,1986). In 1989, a cooperative Australian/Japanese project to delineate such seismic amplification in the Perth Basin throughout the Perth Metropolitan Area commenced. A recent example of how this factor can contribute significantly to overall loss was the moderately-large Newcastle earthquake of 1989 (McCue et al, 1990), during which 13 people lost their lives and estimates of greater than 1.5 billion Australian dollars of damage was done to the city.

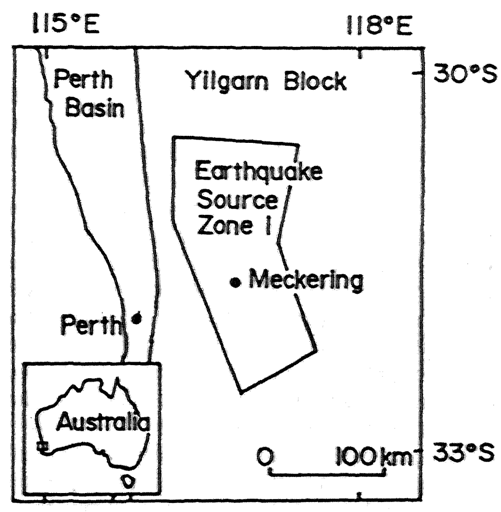

Fig. 1 Location map of the Perth Basin and closest seismic source zone.

EQUIPMENT

The equipment used in this project consisted of 6 recording systems comprising of digital seismographs and one-second seismometers. Five of 6 seismographs run at least two nights, before they were moved to the next set of sites (or traverse), whilst the six set, operated for the whole exercise at Mundaring Geophysical Observatory as the major reference station. Seismometer damping of about 0.6 of critical damping was achieved. An approximate response curve for the system is given Figure 2. A sampling rate of 32 sps was used. The effects of the anti-aliasing filter can be seen in frequencies greater than about 7 Hz in Figure 2.

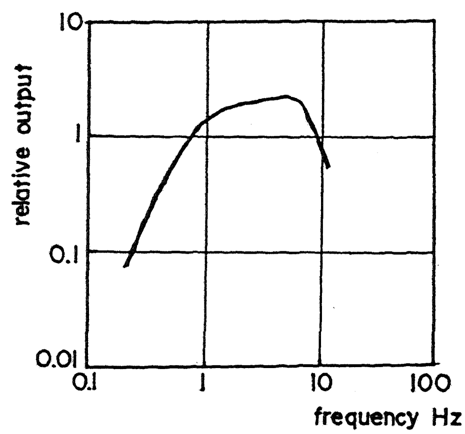

Fig. 2 Relative response curve for digital seismograph system used in this study

METHOD

In an endeavour to minimise changes in environmental conditions and increased microtremor recordings in the daytime, it was decided to take late-night simultaneous measurements for each traverse. To reduce wind noise, the seismometers were buried. In the majorities of traverses, deployment of instruments were chosen to be in a north-south orientation to reduce attenuation problems as at least for the longer period end of the spectrum, the course distance (from the Indian Ocean to each of sites), was similar. Hence the network of traverses, or arrays, occupied over the whole project, had the appearance as shown in Figure 3. It was decided that in order to to be able to resolve various geological features in a sedimentary basin of thickness 10 - 15 km, the grid spacing should be of the order of 3 km. This required the illustration of more than 100 stations in order to achieve this (see Figure 3). Each station was chosen mainly on the basis of the array location, but the criteria for the exact location, was based on getting as much variation in surface geology as was possible to investigate whether the surface deposits had a measurable effect on the recorded spectra. Recordings for each traverse was taken over two nights at 4 a.m. Western Standard Time for 100 seconds. This meant that potentially, there was enough data for up to 6 independent sets of data at each station, thus allowing some room for redundancy in case of intermittent local noise and other problems.

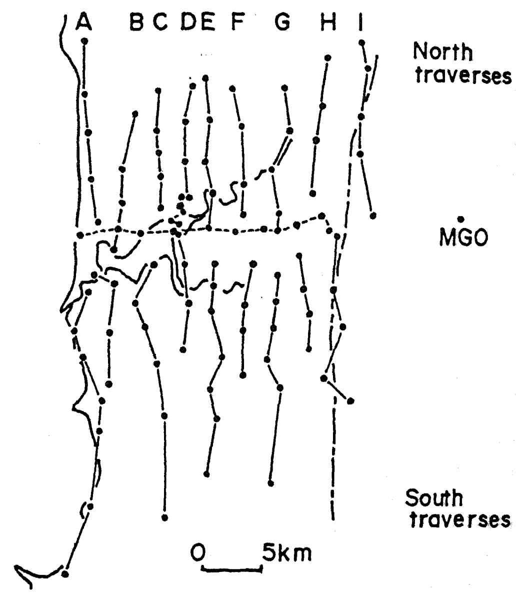

Fig. 3 Location of traverses and the sites occupied.

Spectral ratios for each site, over the frequency range of interest (0.2-5 Hz), were obtained by dividing the Fourier velocity spectra by the corresponding spectra at the reference site according to the following procedures;-

1) Select the quietest 32 s simultaneous record on each of the 2 days microtremor recordings for both basin site and reference.
2) Operate the Fourier Transform and smoothing function on each of the horizontal components for both days.
3) Run the Spectral Ratios programme, and produce 4 plots, including one for each recording day and for each component.
4) The four plots produced in 3) are then averaged by meaning the respective ordinates.
5) Apply the attenuation rules shown in Figure 4.

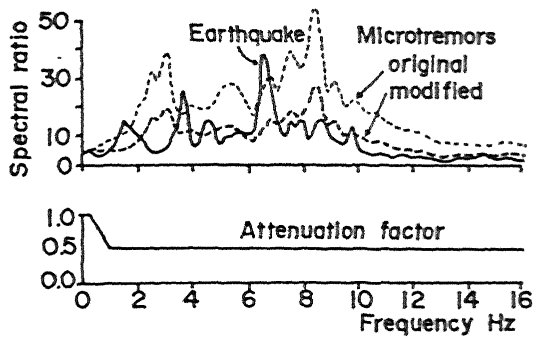

Fig. 4 Spectral ratios for earthquake motions (solid line) and for microtremors (broken line) with attenuation factors used (below).

This attenuation rule was derived by comparing the simultaneous spectral ratios from microtremors as described above with those of earthquake recordings obtained from corresponding sites. As can be seen from Figure 4, the adjusted spectral ratio plots from the microtremor data was a good approximation to the earthquake equivalent at the respective sites.

An additional attenuation factor of 2 was applied whenever temporal, localised sources were identifiable throughout the recording eg traffic. In cases where large-amplitude industrial sources were identified, minima of the spectral plots in the frequency range of the disturbance, were used as a rough approximation, in order to remove their effect from the plots.

RESULTS

Spectral ratios at ground frequencies of 0.2, 0.5, 1.0, 2.0, 3.0 and 5.0 Hz were interpolated from the plots which have been described in the previous section and are plotted onto maps of Perth and contoured as shown in Figures 5(a)-(f). Figures 5(a)-(d) should be compared with Figures 6(a)-(d) respectively and and Figures 5(e) and (f) with 6(e). These respective figures show similar trends providing evidence that these spectral ratios are related to the geology of the sites. As can be seen from Figures 5(a)-(f), the regions that show the greatest amplification across the frequency range, is shown to be near the city block itself. To have a better appreciation of this, the maps in Figure 5 were combined into 3 maps showing the ratios over various frequency intervals and are shown as Figures 7(a)-(c).

DISCUSSION

Perturbations introduced from stormy meteorological conditions and from local sources of seismic noise were experienced and largely removed from the results by:-

(a) Using a common reference and simultaneous records for 6 sites at a time.

(b) Not using noisy records generated during stormy conditions.

(c) Not using parts of records where local sources have obviously disturbed the normal background.

(d) Removing easily identifiable industrial noise on the basis of its consistency in frequency seen on spectral plots.

Latest search shows that the response of an unsaturated soil over the many orders of ground amplitude between microtremors and strong motion, is linear for frequencies below 10 Hz (Jarpe et al 1988, Seale and Archuleta 1989, and King 1984).

Investigation of stability (or repeatability) of the spectra is important, as it is an index to the confidence in the results. This was done by ascertaining the typical scatter in them, by measuring the fluctuations of the spectra over several traverses at a second reference, which was set up on the Perth Basin. The standard deviation of the spectral ratios averaged about 15% of their respective mean ratios, indicating that spectral stability is attainable.

It so happens that the regions of Perth which are enclosed by the X 6 spectral ratio contours in Figure 7, correlate well with those that experienced the maximum observed intensities during the Meckering earthquake (Gaull et al, in prep). Because these ground intensities were about one greater than that expected of this earthquake, according to the attenuation function in Gaull and Michael-Leiba (1987), it can easily be interpreted that, these contours in Figure 7 should therefore correspond to one intensity greater than that obtained by this study. Using almost any of the many empirical formulate which converts this one unit of MM intensity to peak horizontal acceleration or velocity, a factor near 2 is generally obtained and hence this factor is used to obtain the results shown in Figure 8. Essentially the important results here is that Perth city and adjacent areas have been estimated to have double the value shown in the most recent study of Gaull, Michael-Leiba and Rynn (1990).

CONCLUSIONS

1) A methodology to use microtremor spectral ratios

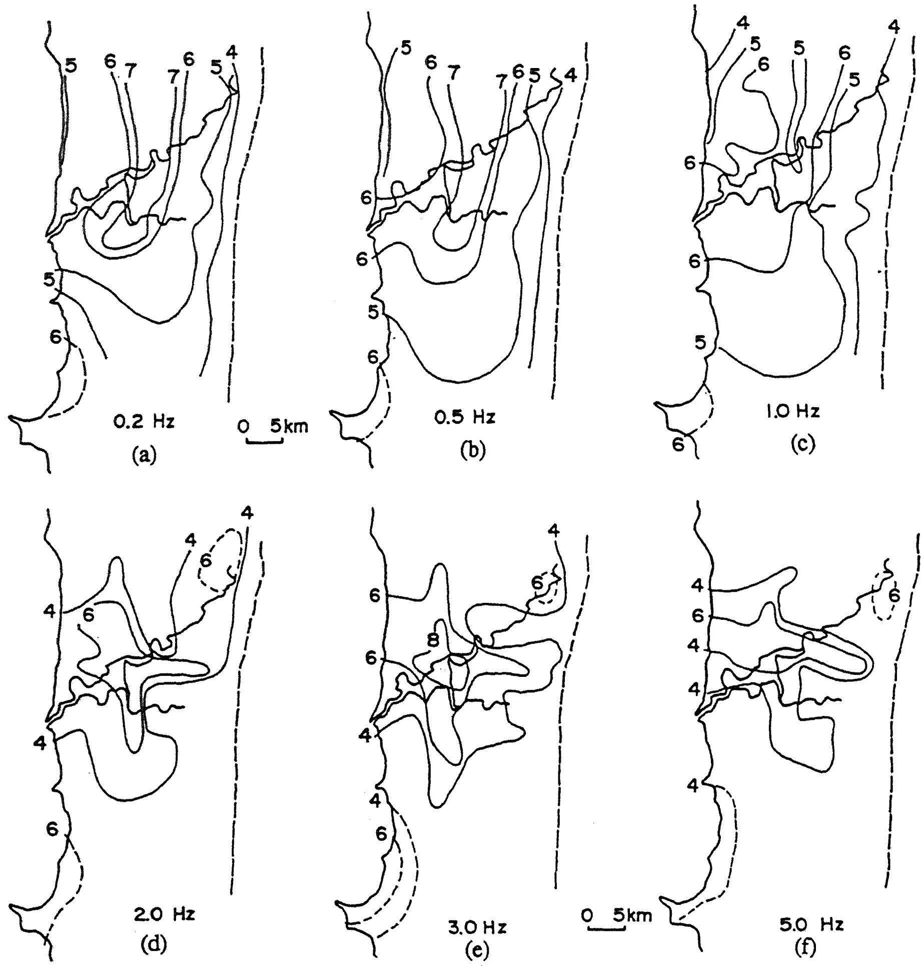

Fig. 5 Spectral ratio contours at frequencies shown.

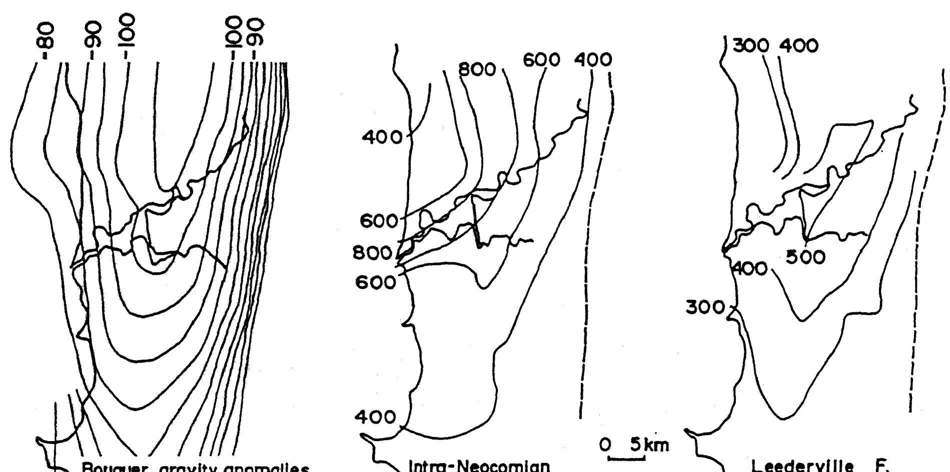

Fig. 6 Geological contours [(a), (b) and (c)].

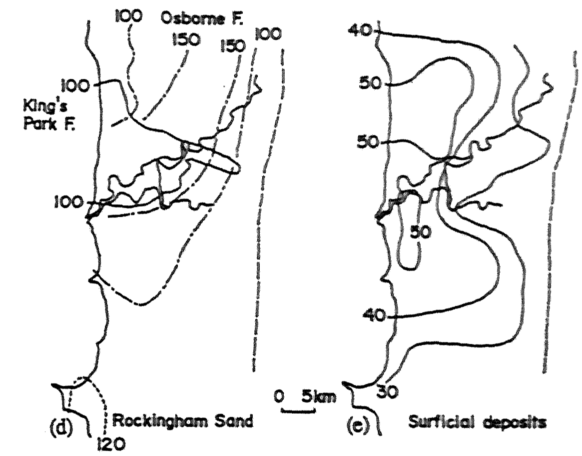

Fig. 6 Geological contours [(d) and (e)].

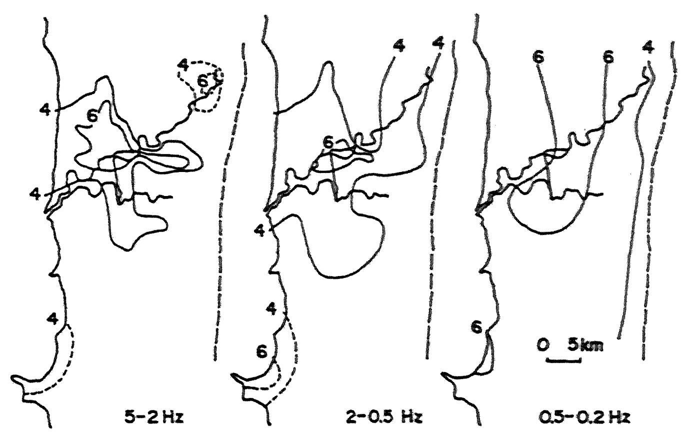

Fig.7 Common spectral ratios for the ground frequencies shown.

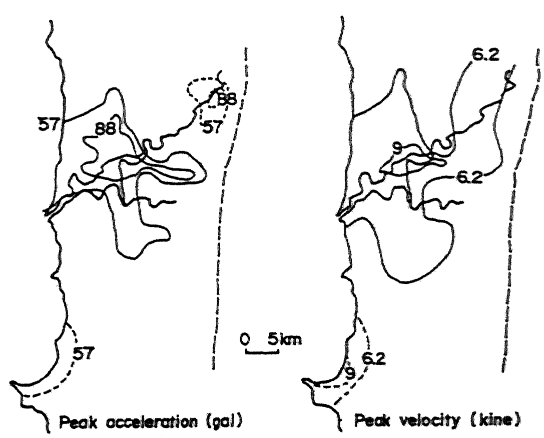

Fig. 8 Contours which have a 10% chance of exceedance in 50 years.

as an aid to microzonation of the intensely populated areas of Australia has been developed. This method requires the accumulation of (preferably) simultaneously and relatively undisturbed microtremor data over a grid of sites over the region of interest, using a common reference site throughout the recording.

2) This methodology was used in the Perth Basin in the region of metropolitan Perth, using earthquake spectral ratios to calibrate the microtremor equivalent. Overall it was found that these low-strain vibrations can provide reasonable first-approximations to stronger ground motion operating when earthquake occur.

3) In the study region it was found that Perth experiences variable amplification over the frequency band of interest but spectral ratios of 4 or more over this range was common. It is discussed that in terms of ground intensity this represents, an intensity differential of about 2 on the Modified Mercalli Scale between the hard crystalline rocks of Mundaring, to sites on the soft sedimentary sequences on the Basin.

4) As a consequence, it has been estimated that near Perth, an increase in ground motion values (for a particular probability) of being exceeded, of about double the least previous evaluation may be appropriate.

5) When the spectral ratios were plotted and contoured, quite strong correlations were noted between various geological sequences underlining Perth.

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