A COMPARISON OF STRONG MOTION EARTHQUAKE DATA BANKS FOR JAPAN AND THE WESTERN UNITED STATES

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SUMMARY

Least-squares regression analyses of horizontal acceleration response spectra calculated from strong motion accelerograms in Japan and in the Western United States are compared. Average spectra for the two regions show many similarities of shape, level, and distribution of values about the mean. For each country the data set is large enough to permit a significant statistical study.

INTRODUCTION

Since the first recording of a strong earthquake ground motion in 1933, the number of suitable instruments in the world was for many years so small that measurements did not accumulate very rapidly. In fact, the first attempt some 25 years later to arrive at an "average" earthquake spectrum was based on accelerograms from just four earthquakes (Housner, 1959).

In just two regions of the world are there now big enough samples of strong motion accelerograms so that a statistical treatment based on standard regression analysis can be attempted. Recent investigations in Japan and in the United States have reported studies of this type, and although the methods used differ in details, the general results can be compared in a meaningful way.

DATA BANKS

Table I gives a direct comparison of the data sets used for the present purpose. The records were all obtained from three-component accelerographs with the horizontal components being treated as independent events, and in each country the accelerograms were uniformly processed. A recent study of Japanese accelerograms using standard U.S. data processing procedures has shown that the results do not differ significantly from the Japanese results except for some records having relatively high frequency components (Crouse and Turner, 1979). This is not an important factor for the comparisons of the present paper, since the general conclusions are based on the intermediate portion of the frequency spectrum for which both the Japanese and the U.S. instruments and processing procedures produce essentially the same results.

By referring to Table I, it will be seen that the main points of difference between the two data sets are: (1) The U.S. set includes some records from smaller earthquakes, and is dominated by the large number of records from the M = 6.4 San Fernando earthquake of 1971; (2) The Japanese

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data contain a significantly larger number of records from earthquakes of a larger size, above M = 6.8; (3) The Japanese set includes a large proportion of distant events, 12% > 200 km compared to 4% for the U.S. Histograms of recorded peak acceleration show that both data sets peak at about the same value of 60 cm/sec^2; (4) The Japanese classify ground conditions at the recording site into four categories while the U.S. use three. For Table I, the two softest Japanese categories are combined into one to compare with the U.S. "soft alluvium." On this basis, Japan has more rock sites than the U.S., 14% compared to 7%, with a corresponding decrease in intermediate sites.

REGRESSION ANALYSIS OF JAPANESE DATA

A recent regression analysis of the Japanese data is presented in a convenient form by Katayama, Iwasaki, and Saeki (1977), which will be the basis for the present comparison. Their results are expressed in terms of the amplitude of "predicted" maximum absolute acceleration response spectrum values, SA cm/sec^2, at a damping value of 5% of critical. The regression analysis involved 18 discrete natural periods from 0.1 sec to 4 sec, the five magnitude and distance categories corresponding to Table I, and four ground condition categories. The assumed regression relationship was of the form of a product of factors:

$$SA = f_M \cdot f_d \cdot f_{GC}$$

where f_M is a weighting factor for each magnitude category, f_d for each distance category, and f_{GC} for each ground condition category. The weighting factors are functions of period and damping. The criteria used for best agreement is a minimization of the sum of squares of the differences between the observed and the predicted values. The results are presented in tabular form giving the weighting values for the magnitude, distance and ground condition categories at each of the response spectrum period points.

U. S. REGRESSION ANALYSIS

The U.S. regression analysis selected for comparison was that presented by Trifunac and Anderson (1977). The form of the relationship assumed for the least-squares analysis was:

$$\log SA = M + \log A_0(d) + f_{M1} + f_{M2}M^2 + f_d + f_{GC} + f_p + f_T$$

where SA = maximum absolute acceleration response, g's, M = earthquake magnitude, and $\log A_0(d)$ = distance attenuation factor, as defined empirically by Richter for Southern California earthquakes. For a given damping value, f_{M1}, f_{M2}, f_d, f_{GC}, f_p, f_T are functions of period T to be determined by a least-squares regression analysis. Included as a variable is a confidence level, p, which is an approximation to the probability that SA will not be exceeded. The function f_p which is determined in the course of the regression analysis will thus describe the scatter of the data.

COMPARISON OF AVERAGE SPECTRUM CURVES

To compare the Japanese and U.S. results a particular set of parameters was selected which would represent a typical application, and which would fall in the range of both data sets for which the recorded data are relatively complete. As an example, a magnitude 6.4 earthquake occurring at a distance of 40 km is assumed, and average ($p = 0.5$) acceleration response spectrum curves are plotted versus period at 5% damping for two site conditions corresponding to the hardest and softest categories.

Figure 1 shows the results of the two regression analyses for the above example. The solid curve without points is derived from the smoothed curves of Trifunac and Anderson for the U.S. data. The solid curve with circular points is the average curve as plotted directly from the tables given by Katayama, Iwasaki, and Saeki for the Japanese data.

From Fig. 1, it will be noted that there are several remarkable similarities between the two data sets, and also some significant differences. The overall shape of the average response spectrum curves is much the same, and in both cases a hard site responds more than a soft site at low periods, and less at high periods. The cross-over period for the hard-soft spectrum curves occurs at practically the same period of 0.25 sec for both the Japanese and U.S. data sets. The main difference between the sets is the lower level of the Japanese average curves, which are smaller by factors of 2 to 3. Accurate statements as to the relative levels of the response spectra are difficult to make because of the very large spread of data. Also, because of the way in which the Japanese data are subdivided into discrete categories, a wide range of earthquake conditions would produce the same response curves. For example, taking an extreme case, a magnitude 6.0 earthquake at a distance of 59 km would produce from the tables the same response spectrum as a magnitude 6.7 at 20 km ($SA = 26$ cm/sec^2 on rock at 1.0 sec period). The calculations of Trifunac and Anderson would show for these two events $SA = 28$ cm/sec^2 and $SA = 398$ cm/sec^2 respectively, a very large difference. The single Japanese response spectrum should thus be compared with a broad band representing U.S. results. To minimize this effect and to facilitate an examination of trends, the earthquake magnitude and distance values selected for the example were chosen to be in the middle of the range of the Japanese categories. The identity of the hard-soft cross-over period suggests that the interpretation of ground conditions in the two countries is at least roughly comparable. The apparent lower level of the Japanese average curves may perhaps be explained by systematic differences in magnitude determinations, or in different distance attenuation relationships. Incompleteness and other inadequacies in the data sets may also account for some of the difference, although as will be discussed later, both sets appear to be sufficiently large to give a reasonably stable regression analysis.

DISTRIBUTION OF SPECTRAL VALUES

It is a well known fact that a comparison of strong earthquake ground motion parameters measured under supposedly similar conditions always reveals a large scatter. Uncertainties in the details of earthquake source characteristics, of the real nature of complex wave transmission paths, and of local site effects, combine to produce a disconcerting spread of peak ground accelerations, velocities, displacements, or spectrum values. An important element in a regression analysis of such data is a description of the distribution of the values, in a form that will have a probabilistic interpretation.

For the Japanese data, each measured point was compared with the predicted value resulting from the least-squares regression analysis, and a histogram was prepared at each period point (Katayama, Iwasaki, and Saeki, 1977). It was observed that a lognormal distribution gave a reasonable fit to most of these histograms. As an example, the results are indicated for the 1.0 sec period point on the Japan average spectrum curve of Fig. 1. The point marked "average" is the result of the regression analysis for the particular case shown for a soft site. The "MAX" and "MIN" levels indicate the extremes of the measured values corresponding to the appropriate categories, and the level marked "0.95 C.L." is the 95% confidence level resulting from the statistical analysis assuming the lognormal distribution.

The regression analysis of Trifunac and Anderson for the U.S. data includes a parameter which approximates the confidence level of the results, assuming a distribution of the Rayleigh type. Fig. 1 shows as a dashed line the 95% confidence level for a soft site for the U.S. data. It will be noted from Fig. 1 that the spread from average to 95% confidence level is about the same for both countries. As a consequence of the wide spread of both average curves there is considerable overlap of the two data sets, although again there is a clear indication that the trend is for the Japanese values to be somewhat lower than the U.S. The scatter also appears to be compatible with the wide differences mentioned above resulting from the small number of categories selected, which in one sense justifies the ranges chosen for the categories.

STABILITY OF DATA SETS

For the Japanese records, there have been several additional investigations based on essentially the same data set. An earlier paper by Iwasaki and Katayama (1976) using the same data described above carried out a regression analysis assuming a summation type relationship rather than the product type described above, with numerical results which were substantially the same.

In another investigation, Kuribayaski, Iwasaki, Iida, and Tuji (1972) studied the effect of subdividing the data set into random subsets. Forty-four records from the Japanese data set were classified randomly into three groups, and it was found that the average acceleration response spectrum curves were practically the same for the three groups. It was thus concluded that the sample size of forty-four was sufficient to study the effects of various parameters on response spectra.

In the U.S., several independent statistical studies have been made using data from the same uniformly processed data bank. As an example, an investigation of McGuire (1978) will be cited. This study examined Fourier amplitude spectra rather than acceleration response spectra, but a direct comparison is available because Trifunac (1976) had applied essentially the regression analysis described above also to the Fourier amplitude spectrum. For purposes of the present comparisons, the two types of spectra should behave in essentially the same way. McGuire calculated two regression relationships, each of a somewhat simpler form than that used by Trifunac, and compared the results with those of Trifunac. For the regression analysis, McGuire used 70 strong motion records from the same basic set of uniformly processed data used by Trifunac and Anderson. Eliminated from the data set were near-field records, and many of the records from the San Fernando earthquake of 1971 so that no one earthquake would dominate the sample.

The results of McGuire's investigations indicated that the average spectrum curves were similar in many respects for the various models and for the two data sets. Although some differences were noted that could be significant for some studies, for the purposes for the Japanese comparisons it would appear that the details of the assumed regression relationship and the size of the sample are of secondary importance.

POINT-BY-POINT SPECTRUM COMPARISONS

In view of the very large scatter of the average response spectrum curves described above, an alternate way of presenting the basic information was developed. In Fig. 2 the acceleration response values for two periods, 0.25 sec and 1.0 sec, and one damping value of 5% critical are plotted as calculated from 60 U.S. accelerograms. The open bars indicate the values for the two horizontal components for each accelerogram, and the shaded bar is the value that would be predicted by the Japanese regression analysis described above for the particular magnitude, distance, and ground condition applying to that accelerogram.

Worthy of comment is the large difference often seen between the spectral values for the two horizontal components. Since no analysis of the above type can distinguish directional effects, this difference sets one kind of bound on the accuracy of predictions based on simple statistical analyses of the above kind.

The representation of Fig. 2 reveals a very diverse and complicated pattern of behavior, with few obvious trends. In many cases the Japanese prediction is lower than the U.S. measurement, in many other cases higher. A closer look shows that at 0.25 sec Japan $<$ U.S. for 41 out of 60 cases. At 1.0 sec it is 45 out of 60. This confirms the feeling derived from the average spectrum curves that the Japanese data predicts somewhat lower values than would be expected for U.S. earthquakes.

CONCLUSIONS

It appears from the above investigation that earthquakes in Japan are much like those in the Western United States. In both countries the sample size of available accelerograms is now sufficient for a meaningful statistical analysis, although there are notable deficiencies in data such as a lack of near-field records of larger earthquakes. At the present rate of accumulation of new accelerograms it will likely be many years before the sample size in either country grows to the point that a significant increase in the accuracy of such statistical analyses can be achieved. This suggests that an increased study of the present data bank would be justified, bringing in supplementary information from geological, geophysical, and structural dynamics sources.

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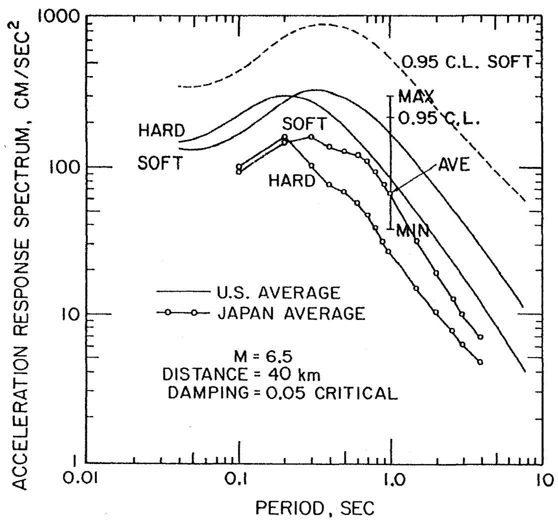
TABLE I
JAPAN-USA STRONG MOTION ACCELEROGRAM DATA SETS

M = MAGNITUDE; d = DISTANCE, KILOMETERS

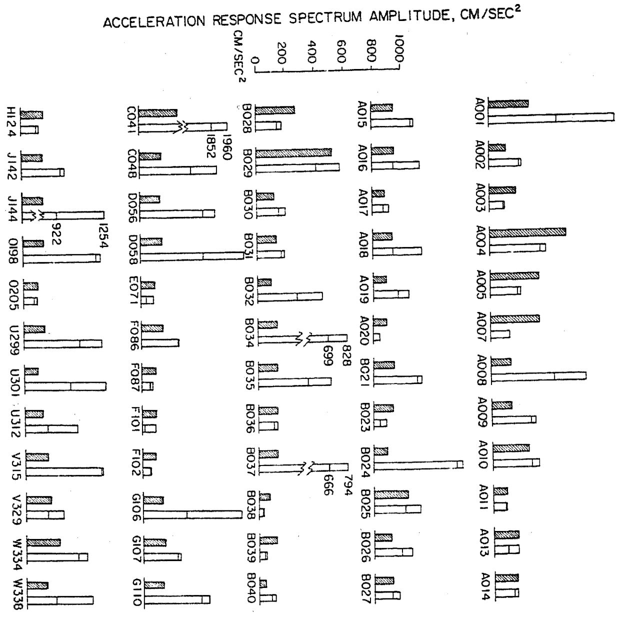
	JAPAN[I]	USA[II]
NO. HORIZONTAL COMPONENTS	277	364
NO. EARTHQUAKES	68	45
3.8 < M < 4.5	—	10
4.5 < M ≤ 5.4	60	44
5.4 < M < 6.1	48	42
6.1 < M ≤ 6.8	102	254
6.8 < M < 7.5	29	4
7.5 < M < 7.9	38	10
d < 20	42	40
20 < d < 60	92	222
60 < d < 120	72	58
120 < d < 200	39	28
200 ≤ d	32	16
ROCK	39	26
INTERMEDIATE	52	104
ALLUVIUM	186	234

I KATAYAMA, IWASAKI, & SAEKI, 1977
II HUDSON, 1976



AVERAGE ACCELERATION RESPONSE SPECTRUM AMPLITUDES FOR U.S. AND JAPANESE EARTHQUAKES

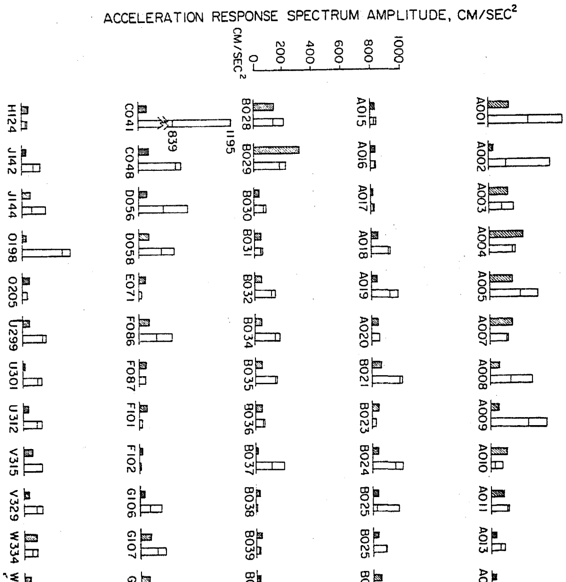
FIG. 1



ACCELERATION RESPONSE SPECTRUM AMPLITUDES

SHADED BAR = JAPAN "STANDARD AVERAGE"; OPEN BAR = U.S. MEASURED
TWO HORIZONTAL COMPONENTS; PERIOD=0.25 SEC; DAMPING=0.05 CRITICAL

FIG. 2



ACCELERATION RESPONSE SPECTRUM AMPLITUDES

SHADED BAR = JAPAN "STANDARD AVERAGE"; OPEN BAR = U.S. MEASURED,
TWO HORIZONTAL COMPONENTS; PERIOD = 1.0 SEC; DAMPING=0.05 CRITICAL