Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.II)

3-2-10

VARIABILITY OF STRONG GROUND MOTION : INFLUENCE OF LOCAL CONDITIONS AND INSTRUMENT ORIENTATION

Fernando PIMENTEL [1], Carlos S. OLIVEIRA [2] and João AZEVEDO [3]

[1] Research Assistant, CMEST, Technical University of Lisbon *.
[2] Researcher , Laboratório Nacional de Engenharia Civil *.
[3] Associate Professor, CMEST, Technical University of Lisbon *.
* Lisbon, Portugal.

SUMMARY

The analysis of the variability of strong ground motion, namely the influence of the local conditions and instrument orientation, is made based on information available from the SMART-1 array in Taiwan. The study focuses on the distribution of the peak values and the variability of these peak values from site to site. It can be concluded that local variability of the earthquake motion is important enough not to be ignored in the forecasting of the severity of the strong ground motion. The same conclusions apply to the variability of the response spectra. Also studied is the influence of the instrument orientation showing that accurate information can only be obtained if the earthquake is looked at on its 3-dimensional content.

INTRODUCTION

This research work provides an useful insight on the study of the variability of strong ground motion from site to site. It was made with the records of 35 earthquake events occurred in Taiwan, obtained on the SMART-1 array (Ref.1).

In a previous work (Ref.2); variability of ordered peaks was studied. In here, a possible explanation of the causes of variability is presented, by looking simultaneously at the three-component acceleration vector and extending the analysis of variability to response spectra of the same records.

SMART-1 (**S**trong **M**otion **Ar**ray in **T**aiwan) is a dense seismic array located in the northeast corner of Taiwan near the city of Lotung. The array consists of a set of 36 force-balanced triaxial accelerometers displayed evenly in three concentric circular rings of radii 200, 1000 and 2000 m and one at the center as shown in Fig. 1. All stations are placed at the surface of a relatively flat recent alluvium made of a 15-20 m thick gravel topping a gray silt clay. Water table is almost at the surface.

Taiwan is part of a zone of high seismicity with a complex tectonic environment. This environment originates several types of source-mechanism earthquakes, which combined with different ranges of magnitude events and focal distances, suggests a classification of the events into 4 classes (Ref.2), as presented in Fig. 2:

1 - Nearby shallow small amplitude earthquakes, originated most probably at small size shallow faults (M_L in the range 3-4).
2 - Medium to large magnitude events (M_L in the range 5-8) occurring at great depths (50-100 Km), underneath the array, probably related to the dipping subduction.

3 - Shallow moderate to large magnitude events at intermediate distances from the array (15 to 30 Km). The tectonic mechanism should be similar to the one referred in 1.
4- Distant (larger than 50 Km) moderate to large magnitude events at moderate depths.

Fig. 2 is a global representation of the hypocentral distance with respect to the array and irrespectively of the azimuth. For each class a typical event was chosen and its location signaled (# 35, 30, 32 and 24).

The 35 events were recorded in the array between September 1980 and September 1985, and were classified according to the previous criteria. These events which produced strong motion at 712 different situations, were recorded in 3 orthogonal components: NS, EW and vertical (DN).

STATISTICAL DISTRIBUTION OF THE ORDERED PEAKS

Assume that a peak is the largest value of a set of recorded accelerations with the same sign. The peaks are ordered by decreasing absolute value and the first one is the peak ground acceleration, PGA (x1).

Usually the distributions of the ordered peaks are studied by either the Exponential, Rayleigh or Weibull laws (Ref.3). Fig. 3 presents the general trend of these three distributions plotted on exponential probability paper. Rayleigh distributed peaks are concentrated in the high acceleration part, whereas in the Weibull distribution they concentrate in the lower acceleration zone.

In this study the type of distribution that better characterizes the data set is analyzed. The selection criteria is based on minimization of the mean square error (Ref.4). Fig. 4 presents the relative percentage of the different types of distributions for each class. Fig. 4a refers to horizontal components and Fig. 4b to the vertical component. As it can be observed from these figures, there is a large tendency for Exponential and Rayleigh distributions. Weibull type is only observed for horizontal components and classes 1 and 3 (short hypocentral distances). The tendency for Rayleigh distributed ordered peaks is largely noted for class 4 events (large epicentral distances)

VARIABILITY OF FIRST ORDERED PEAKS FROM SITE TO SITE

The repetition of this analysis for other stations showed great variations not only in the PGA values for each station but also in the type of distribution. Fig. 5 shows the qualitative variation of PGA throughout the array for event 32, components NS and vertical. The extension of this study to the 35 events showed that there is no common trend on this variability: no relation to the type of earthquake mechanism or class and no relation to geology.

The variations in PGA for a given event, measured as a ratio of high to low value, varies from 2:1 to a maximum of 6:1. The coefficient of variation $\sigma/\bar{x}$ varies from a minimum of 0.17 to a maximum of 0.49. The largest variations are observed in nearby earthquakes. Fig. 6 presents the statistical distributions of PGA values recorded in all stations for 4 different events, one in each class, emphasizing the dependence on class and component. The variability is not, however, very much dependent on distance among stations, as can be seen in Fig. 7, where the ratio of PGA (event #24-NS) for any possible combination of two stations is plotted against distance between them.

The study of the 2nd, 3rd,... 11th peak values across the array was also made. Fig. 8 shows, for each class of events, the average decrease of the mean values of these ordered peaks with respect to the order number. The decrease is rather smooth following approximately an exponential type law. Differences among classes reflect the predominance of the distributions referred in the previous section. The coefficients of variation are almost independent of the order number and depend also on class and component. Values vary between 0.15 to 0.3 for horizontal components and between 0.25 to 0.4 for vertical components.

INFLUENCE OF INSTRUMENT ORIENTATION

How does instrument orientation influence previous findings ?

In reality ground motion is a 3 component entity which is not invariant under a change of the reference system. Several authors have addressed this problem (Ref.5) trying to identify principal directions of motion, and correlating them to the epicentral orientation. Imagine an horizontal rotation of a station by an angle α . The distribution of the ordered peaks of the record obtained in that station, was studied and is presented in Fig. 9. Each curve corresponds to a given order peak. On the lower portion of Fig. 9 the type of distribution which better fits the data is plotted against the angle α . Several comments should be made:

a) There is a remarkable dependence of both, the peak values (PGA included) and types of distribution on the orientation of the instrument.

b) PGA values vary 1: 1.8 as shown in the figure.

c) The higher and lower PGA values occur at approximately 90º apart denoting the presence of principal directions as obtained for the first three peaks (1st, 2nd and 3rd) for the different stations during event #24. Fig. 10 shows that there is some consistency among all stations.

d) An analysis of the peak values in just any two orthogonal directions without taking into consideration the above mentioned features, may lead to quite erroneous estimates. In the present case to a value which is approximately 75% of the maximum possible (see Fig. 9 at α = 115º and α = 205º).

.e) The type of distribution is very much dependent on the larger values, near the principal direction.

In the previous analysis the records were looked at in their globality, loosing their time evolution. If the time evolution of the horizontal acceleration values (as a function of its amplitude and direction is analysed, the "record" has an aspect as shown in Fig. 11, which consists on a dimetric projection of the acceleration vector as a function of time (event #24, station I03). It is clear from this figure that there are sudden changes both in the amplitude and direction of the motion indicating that there should be a definition for peak value which could consider this aspect.

In Fig. 12 the NS and EW components and the absolute horizontal value of the acceleration vector (event #24, station I01) are presented, showing that it is necessary to deal with both components (time envelope of the record) if a more realistic analysis of the peak values is to be made.

RESPONSE SPECTRUM ANALYSIS

The influence of the class of the earthquake on the average 5% damping response spectra is represented in Fig. 13. The average is made for all the EW records in all the stations and for all the earthquakes belonging to a given class, normalized to the same PGA value (0.175 g). It is remarkable the difference between the spectra, especially for classes 1 and 4. For each class the variability of the spectra (not shown) is of the same order of the variability of the peak values.

ACKNOWLEDGMENTS

Data from SMART-1 records were kindly provided by the Seismographic Station, University of Califórnia, Berkeley.

REFERENCES

1 - Bolt, B. A. ; Loh, C. H. ; Penzien, J. ; Tsai, Y. B. and Yeh, Y. T. (1982) " Preliminary Report on SMART-1 Strong Motion Array in Taiwan", Report UCB/EERC-82/13, University of California, Berkeley.

2 - Oliveira, C. S. ; Pimentel, F. and Azevedo, J. (1986) " Variability of Strong Ground Motion Ordered Peaks at a Site, Based on Dense Seismic Array", Proc. 8th European Conf. Earthq. Eng., Vol. 6, LNEC, Lisbon.

3- Azevedo, J. (1984) " Characterization of Structural Response to Earthquake Motion", Ph. D. Dissertation, Dep. Civil Eng., Stanford Univ., Stanford.

4- Pimentel, F. (1987) " Análise da Variabilidade da Acção Sísmica " M.Sc. Thesis, Technical University of Lisbon, Lisbon (In Portuguese).

5- Penzien, J. and Watabe, M. (1975) "Characteristics of 3-Dimensional Earthquake Ground Motions" Journal of Earthq. Eng. & Struct. Dyn., Vol 3, pp 365-373.

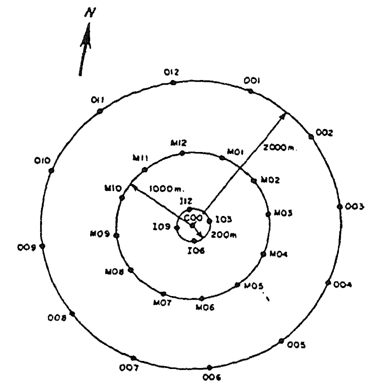


Fig. 1 - Stations location in Array Smart-1.

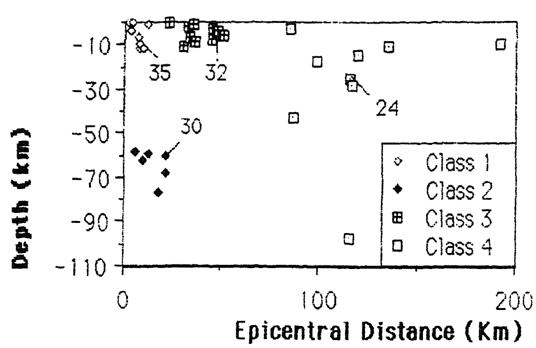


Fig. 2 - Hypocentral location of the recorded events.

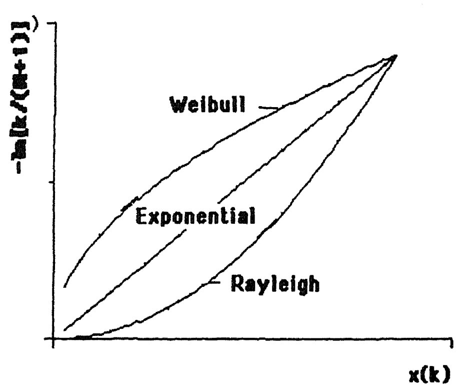
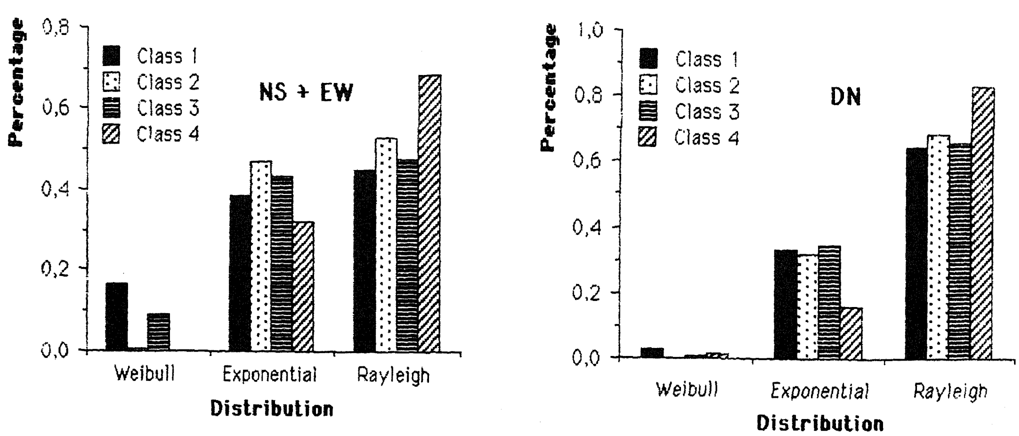


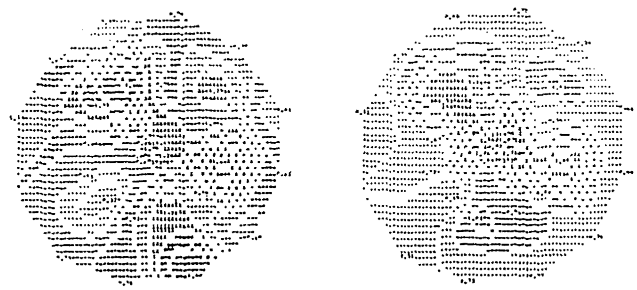
Fig. 3 - Ordered peak distributions.



a) NS + EW Components

b) DN Component

Fig. 4 - Relative percentage of type of distributions for each class of events.



a) EVENT 32 - NS Component   b) EVENT 32 - DN Component

Fig. 5 - Variability of 1st peak across the array.

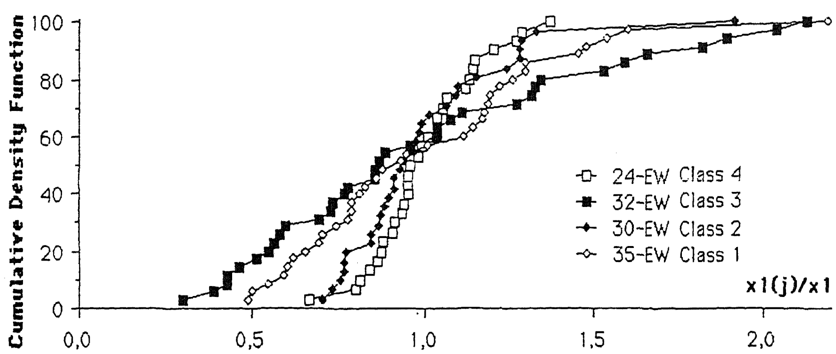


Fig. 6 - Statistical distributions of the PGA values across the array.

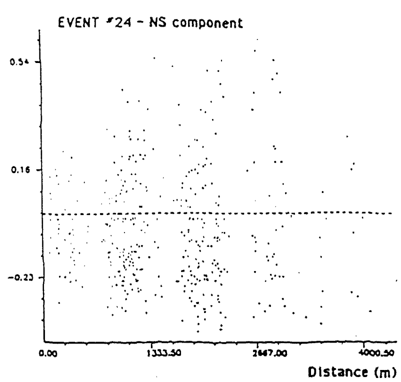


Fig. 7 - Interstation variability of PGA values.

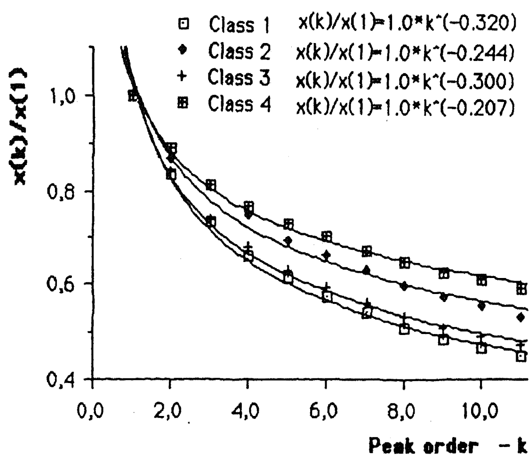


Fig. 8 - Decrease of peak value with the peak order. (Average for all stations)

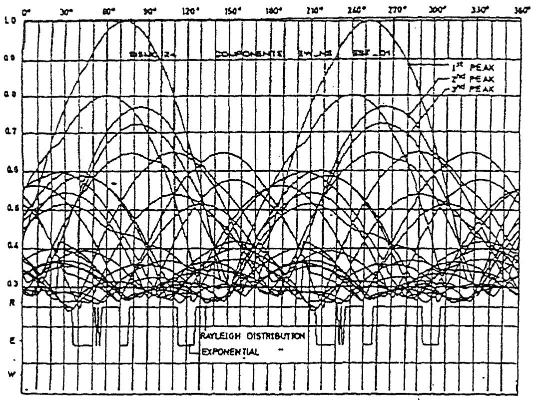


Fig. 9 - Influence of the station orientation in the peak values.

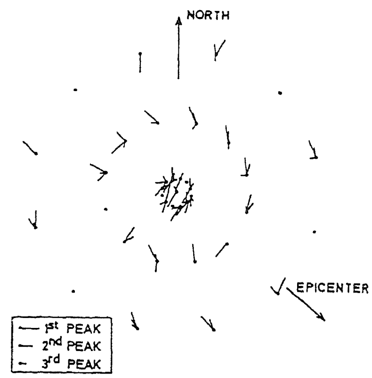


Fig. 10 - Orientation of the 3 largest peaks across the array (Event 24).

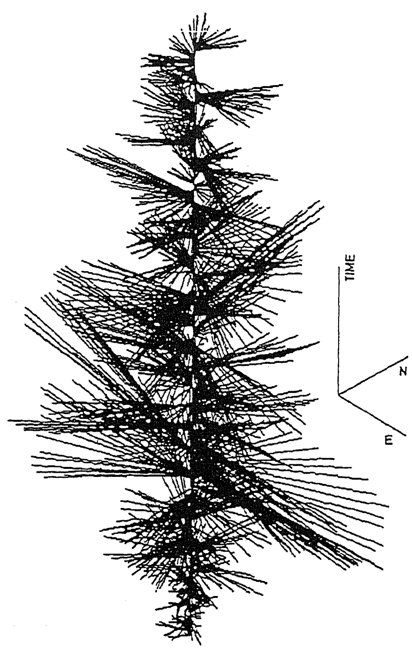


Fig. 11 - Dimetric projection of the time evolution of the acceleration vector.

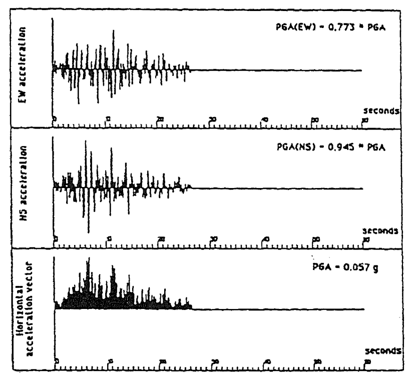


Fig. 12 - Influence of station orientation on the record. Event 24 - (NS, EW component - Vector amplitude)

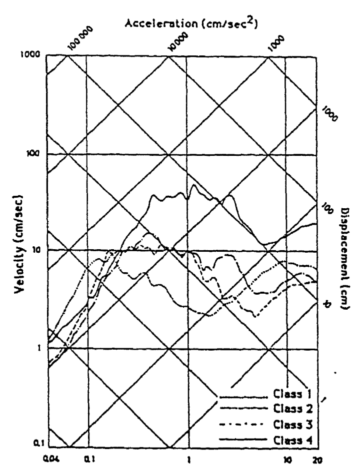


Fig. 13 - Mean value response spectra.