SOME COMMENTS ON THE RELATION BETWEEN THE ACCELERATION RESPONSE SPECTRA OF REAL EARTHQUAKES AND DESIGN SPECTRA OF BUILDING CODE PROVISIONS

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SUMMARY

The acceleration response spectra of earthquakes recorded in cities where no significant damage was observed show values that are remarkably higher than the design spectra used in those places to build engineered structures. This paper examines some of the sources for such differences from the point of view of computational shortcomings of procedures which are usually accepted as well understood, properly developed and highly reliable. Some important exceptions to the latter are indicated.

INTRODUCTION

SMA-1 (Kinemetrics) accelerographs have recorded two earthquakes in Acapulco and one in Oaxaca City(these earthquakes will referred to as E1, E2, E3) with peak accelerations of 0.54 g, 0.85g and 0.20g, respectively (Refs 1, 2). Since such accelerations usually lead to expect significant damage to structures some studies have been conducted to explain the low damage level observed (Ref 1, 3).

The intensity of a strong earthquake or its potential for destructivity have eluded a widely accepted correlation with any parameter of the ground motion. Many different criteria have been proposed in the literature and, for our purposes, those related to properties of the response spectra (RS), are of particular interest.

With very few exceptions structures in Acapulco have undergone, without visible damage, earthquakes with spectral ordinates 5 or more times higher than those for which they were designed. There are partial explanations for this fact (incursions into the inelastic range, hysteretic behavior, etc.) but not a completely clear and satisfactory one. The gap is sometimes so wide that it is of interest to examine in detail the other side of the question: How reliable is the computation of response spectra (RS), in particular for acceleration, which is directly comparable with design spectra?. It is noted that spectra computation is generarally regarded not only as well understood and highly reliable but, in short, common daily routine. Among the relevant aspects described in more detail in Ref 4, two will be examined in this paper using as examples the Mexican earthquakes referred to above.

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SOME LIMITATIONS OF COMPUTED SPECTRA

Spectral Values for Zero Damping

Due to the long computational times involved, it has become routine (Ref. 5) to compute between 90 and 100 spectral ordinates for periods ranging from about 0.04 to about 10 sec. The resulting separation between consecutive periods often misses higher maxima. This can best be exemplified for low damping values (zero and two percent of critical, $\beta=$ 0,02, respectively) which minimize the differences between the usually computed pseudo spectra and the spectra derived from more precise or exact mathematical expressions.

Figs. 1 and 2 show absolute acceleration response spectra (AARS) for $\beta=0$ and 0.02, respectively, of the NS component of E2. In these figs. the period varies between 0.060 and 0.100 secs, where the highest spectral ordinates (represented by vertical bars) were found. The period increment is 0.001 sec, that is, several times smaller than is usual in routine computations. It may be observed in fig. 1 that even for such small period increments the zero damping RS is still far from being a smoothly varying function. The lines joining the top of the vertical bars are those usually presented as computed spectral values for the following period sets:

Set A-Approximating a uniform geometrical spacing in a log scale (used in Mexico)

Set B-Uniform numerical spacing within intervals (routine in USA, Ref. 5)

It is clear that the two sets miss the highest value (T = 0.091) and that set B would give a better representation than set A. (However, it is still possible that even higher ordinates might be found at intermediate periods). The situation is reversed for E1 in fig 3, where set A would be a better representation then set B, which is off by about 50 percent. Fig. 2 shows a much smoother variation when 2 percent of critical damping is introduced. Either set would represent rather well the much smoother ordinates except for the region just below T = 0.1 sec, where both sets would be about 20 percent short of the actual maxima.

Given that response are not usually computed at 0.001 sec intervals, it may be concluded that sometimes the AARS ordinates for $\beta=0$ may be misleading or in some instances, perhaps even meaningless.

Peaks in Response Time History

The maximum absolute value in the response history is the spectral ordinate for the corresponding period and damping. This definition disregards whether a) the maximum comes from an isolated peak, much higher than any other in the entire history, or, b) whether it is preceded and followed by peaks almost as large, indicating a much more lively (and potentially damaging) response, composed of significantly more high level load application cycles then in a).

As an example, the lower part of Figs 4 and 5 shows the AARS for the two components of E3 in the period range of maximum ordinates. The upper portion of these Figs. presents a graph of T vs $N_{0.7}$ for the same periods (vertical bars in the upper and lower parts correspond in period). $N_{0.7}$ is the number of maxima in the response history which exceed aR_{max}, where a is a constant (here taken as 0.7) and R_{max} is the maximum response, equal to the spectral value.

Even a rapid examination of Fig 4 shows that $N_{0.7}$ is significantly higher, up to about two times, for most of the periods adjacent to that of the maximum S_a. In Fig 5 it is clear that $N_{0.7}$ is small for the maximum spectral ordinate as compared to he three periods on either side, where slightly lower Sa values are associated. Instances have been found (ref 6) where the largest (spectral) peak of the response history is so isolated that no other is half as large. In some other cases related to S_v the shape of the spectrum may even become misleading to a certain degree, as it indicates maximum ordinates for a given period range but few "high load applications", while another, with somewhat lower S_v values is related to many more high level "loadings" (Ref 6). In this case, as in the example provided by Fig 5, it is not obvious what structures would be the most affected. This is a subject of ongoing research at the University of Mexico.

CONCLUSIONS

1. The routine computation of earthquake response spectra for zero damping may lead to missing significantly larger maxima, depending on the set of periods selected for the computations. For small damping the corresponding error decrease, but may still be important.

2. Spectral ordinates by themselves may not be indicative of earthquake damage potential because the number of high level response peaks may vary widely for different structural periods during a given earthquake.

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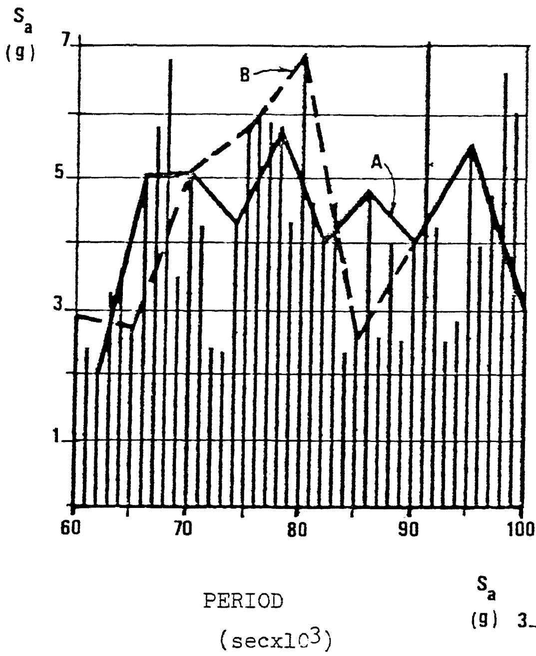


Fig. 1

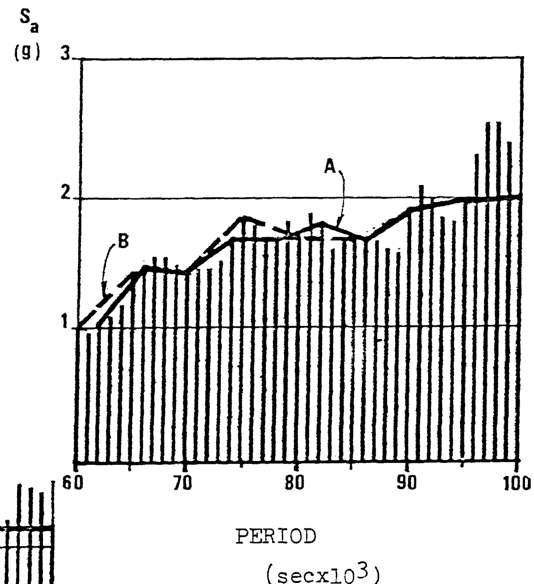
180378 Comp NS

β=0

Fig 2

180378 Comp NS

β=0.02



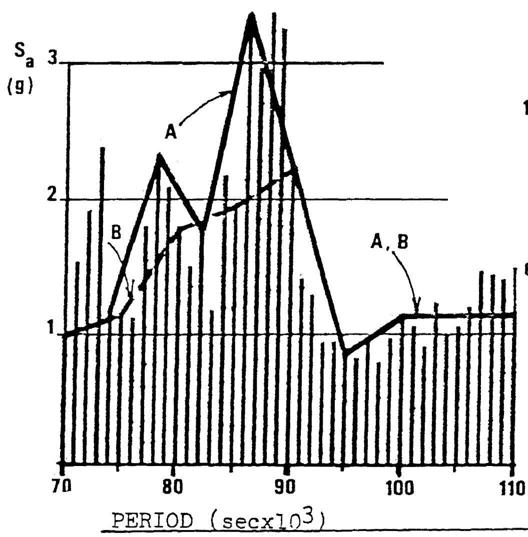


Fig 3

061074 Comp NS

β=0

Figs 1-3 Absolute Acceleration Spectra (Sa)
for Acapulco Earthquakes

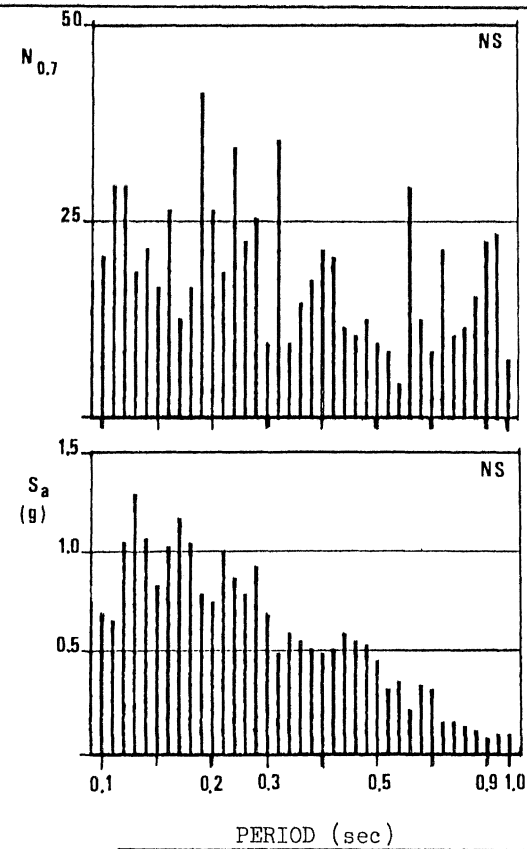


Fig 4 (NS)

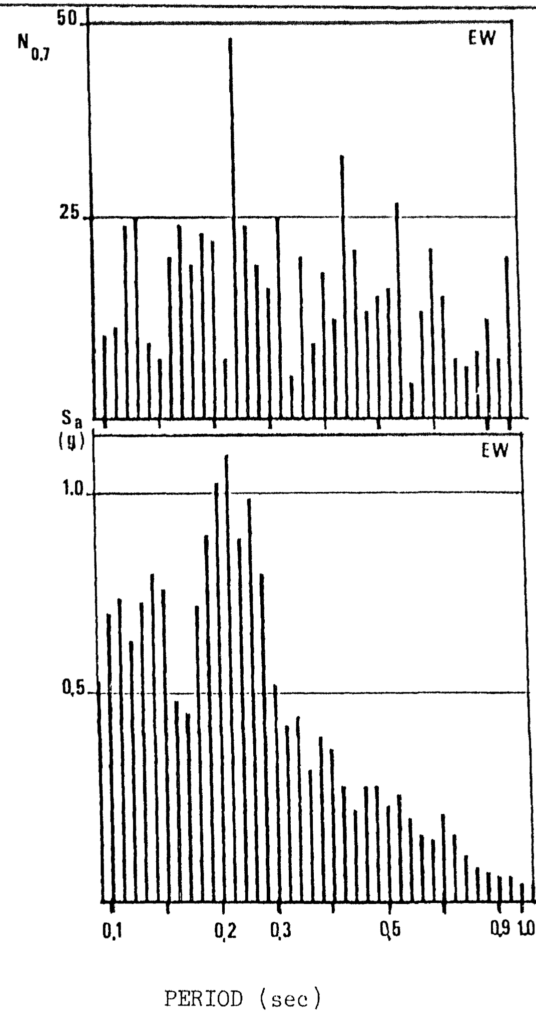


Fig 5 (EW)

Figs 4, 5 Absolute Acceleration Spectra (Sa) and Number of Peaks (N) in Response History Exceeding 0.7 Sa. (β=0.02) (Oaxaca Earthquake 280873)