SPECTRAL ANALYSIS OF SEISMIC ACTIONS

by

Artur Ravara(*)

ABSTRACT

Some accelerograms of strong-motion earthquakes recorded in the U.S.A. in the late decades are analysed. The power content of these earthquakes is characterized by their acceleration spectral density determined in a digital computer. The results are compared with values already available in the literature.

1 - INTRODUCTION

From the structural designer's standpoint, an earthquake is a set of acceleration pulses with variable intensities and durations.

The response of a set of linear oscillators to the seismic actions recorded in California was obtained by Professor G.W.Housner in an analogic computer about 15 years ago. Housner determined the maximum and the weighted mean values of the acceleration, velocity and displacements of oscillators the different earthquakes.

He represented the characteristics of seismic loads by means of an average spectrum and of factors concerning the intensity of the different earthquakes.(1)(2)(3)(4)

The observation of Housner's curves shows that dominant frequencies are absent. The small differences between the spectra were satisfactorily accounted for by Housner as due to the particular characteristics of the different earthquakes analysed. It was thus observed that the influence of the higher frequencies decreases very fast as the distance to the epicentre increases and that the nature of the ground has a considerable influence on the load intensities.

About five years ago, using an analogic model, G.N.Bycroft(5) applied to linear oscillators white noise acceleration pulses with a duration of 25 seconds and a uniform spectral density

$$S_o = 0.75 \text{ ft}^2 \text{ sec}^{-4} \text{ Hz}^{-1} = 697 \text{ cm}^2 \text{ sec}^{-4} \text{ Hz}^{-1}$$

(*) Assistant Engineer, Applied Mechanics Division, Buildings and Bridges Department, Laboratório Nacional de Engenharia Civil, Lisbon.

in the frequency band of 0-35 Hz, obtaining maximum values for accelerations, velocities and displacements very near those indicated by Housner for the El-Centro earthquake of 18/5/940, the most intense on record (about IX in the Mercalli scale). This result confirmed the absence of dominating frequencies in the seismic loadings.

At the Laboratório Nacional de Engenharia Civil numerical analysis techniques were applied to the data of four strong motion earthquakes, recorded in California, in an attempt to define the major characteristics of earthquakes from an energy and a statistical point of view.

2 - SPECTRAL ANALYSIS OF SEISMIC ACTIONS

Eight accelerograms of 4 strong motion earthquakes recorded in California were analysed, their principal characteristics being presented in Table 1.

The power spectra of the accelerograms were determined by the Stantec-Zebra computer of the Laboratório.(*) As the computing program is based on equally spaced sampling(6), the accelerograms data had to be interpolated.

The spectral power densities of accelerations were computed in the frequency band of 0-10 Hz. A very marked decrease of densities having been observed for frequencies above 5 Hz, it was decided to determine the spectral densities for the following frequencies:

f = 0.2; 0.4; 0.6; 0.8; 1.0; 2.0; ...; 5.0; 5.4; 5.8; 6;...; 10 Hz

The spectra obtained are presented in fig. 1 to 8.

It is noteworthy that the power content is practically confined to the band 0 to 5 Hz decreasing very fast for higher frequencies.

The mean quadratic acceleration $\bar{a}^2$ can be obtained by integrating the power spectrum S (f)

$$\bar{a}^2 = \int_0^\infty S\ (f).df$$

The values thus obtained are indicated in Table 2.

For reducing the power spectra obtained to the same variance, the most intense earthquake being chosen as standard, the values of the

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(*) Now replaced by an Elliott 803-B computer spectral density must be multiplied by the coefficient defined in Table 2. Computing the mean value of the densities for each frequency, the mean spectrum presented in fig. 9 is obtained.

The following characteristics of this spectrum should be noted:

- the power content is practically confined to the band 0-5 Hz, with maxima in the zone 2 to 3 Hz.

3 - COMPARISON WITH THE RESULTS AVAILABLE

Housner characterized the four earthquazes analysed by means of coefficients relating the maximum accelerations, velocities and displacements in the linear oscillators.(4) These coefficients are easily related with the spectral density.

For a linear oscillator vibrating with a frequency w_o and a percentual damping n under the action of an earthquake with a spectral density S_o, the variance of the displacements is given by

$$\bar{x}^2 = \frac{S_o}{8\ n\ w_o^3}$$

The following relationship between the displacements corresponding to different spectral densities is then obtained

$$\frac{x_1}{x_2} = \left(\frac{S_1}{S_2}\right)^{1/2}$$

i.e. Housner's coefficients are proportional to the square root of spectral densities.

Taking for the earthquakes analysed an average spectral density in the band of frequencies studied by Housner, it is possible to compare Housner's coefficients with a coefficient proportional to the square root of the power density (Table III).

The average spectral density computed from the mean power spectrum (fig. 10) in the band of frequency 0.36 to 2.50 Hz is

$$S_1 = 689\ \mathrm{cm}^2\mathrm{sec}^{-4}\mathrm{Hz}^{-1}$$

which agrees with Bycroft's value

$$S_o = 697\ \mathrm{cm}^2\mathrm{sec}^{-4}\mathrm{Hz}^{-1}$$

4 - STATISTICAL TESTS

The data of El-Centro earthquake were run for a test hypothesis of Gaussean distribution.(8)

The χ^2 test gave a satisfactory answer, as the value obtained falls well in the confidence interval.

5 - CONCLUSIONS

The results obtained can be summarized as follows:

- There is uniformity in the power content of the earthquakes, as can be infered from the existence of a common shape for the power spectral density curve.

- The instantaneous values can be accepted as having normal distribution.

The agreement of the obtained values with those of Housner and Bycroft is very satisfactory. It seems important to make further analysis on other records of earthquakes, in order to define standard values.

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TABLE I

Seism		Epicentral distance km	Depth km	Magnitude	Acceleration cm/s^2	Time duration s
El-Centro	N-S	48	24	6,7	330	30
18/5/1940	E-W	48	24	6,7	230	30
El-Centro	N-S	56	24	6,5	255	25
30/12/934	E-W	56	24	6,5	196	25
Taft	N 21 E	64	24	7,7	170	30
21/7/1952	N 69 W	64	24	7,7	180	30
Olympia	N 80 E	72	72	7,1	310	30
13/4/1949	N 10 W	72	72	7,1	180	30

TABLE II

Seism	El-Centro 1940		El-Centro 1934		Taft 1952		Olympia 1949	
	N-S	E-W	N-S	E-W	N 21 E	N 69 W	N 80 E	N 10 W
Variance cm^2 s^{-4}	3820	2690	1900	2305	1360	1775	2930	2190
Root mean square cm^2 s^{-2}	61,8	51,7	43,4	48,0	36,7	42,0	54,0	46,6
Power reduction coefficient	1,00	1,42	2,01	1,66	2,81	2,15	1,30	1,74

TABLE III

Seism	Housner's coefficient	Coefficient proportional to the square root of the power density
El-Centro 18/5/1940	2.7	2.60
El-Centro 30/12/934	1.9	1.90
Taft 21/7/1952	1.9	1.83
Olympia 13/4/1949	1.6	1.70

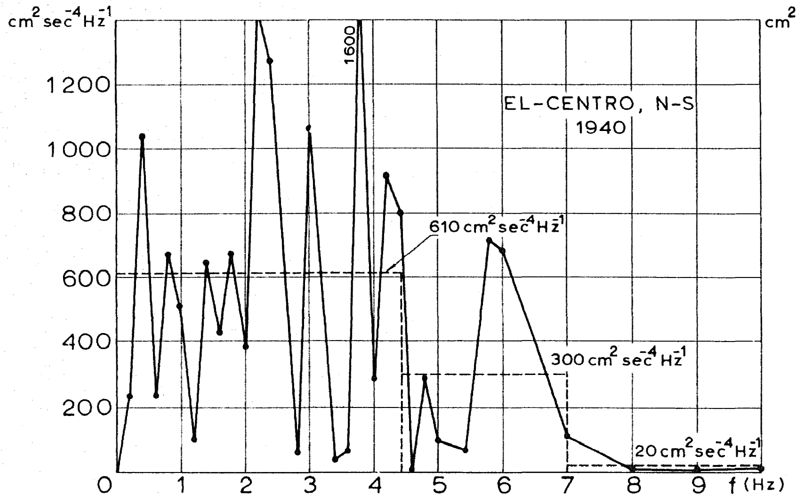


Fig. 1

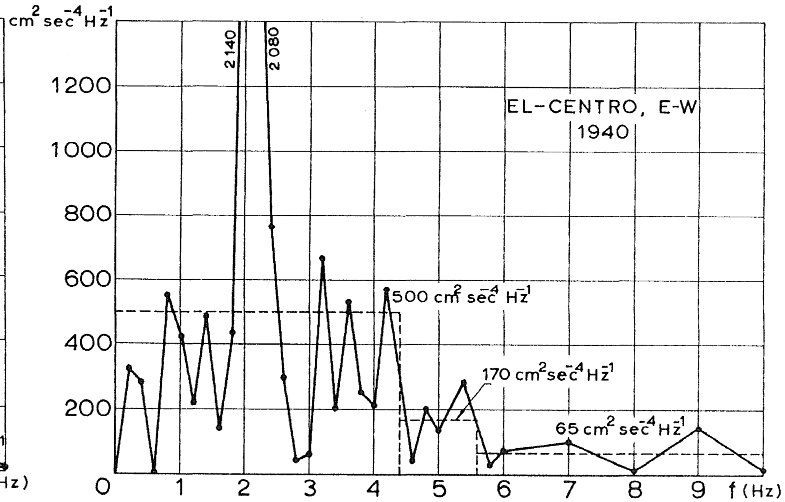


Fig. 2

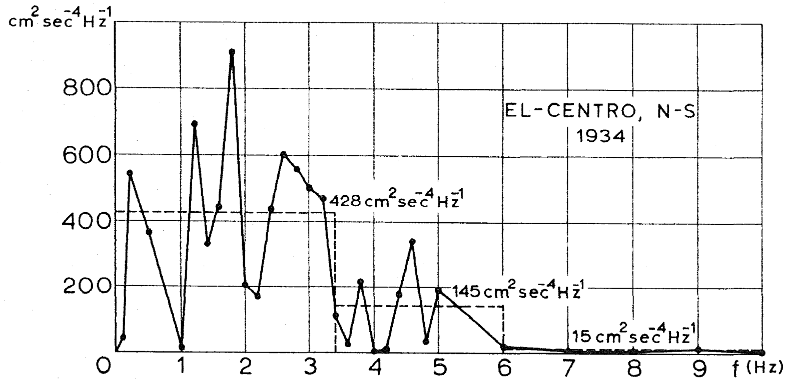


Fig. 3

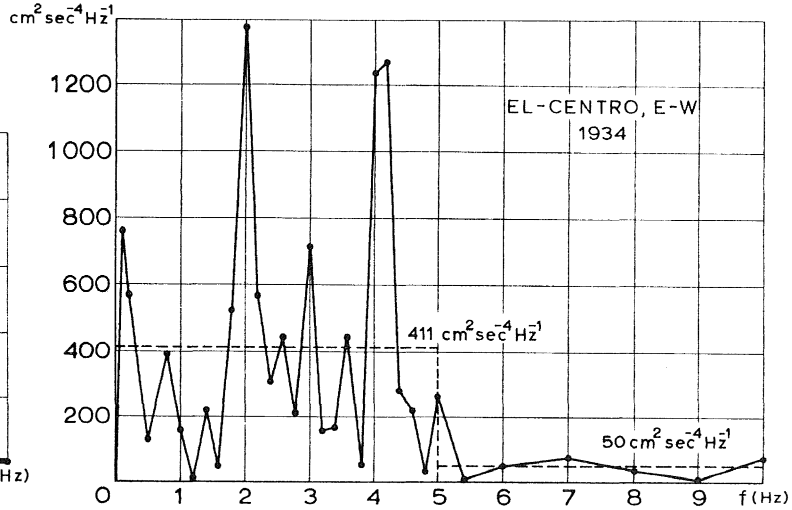


Fig. 4

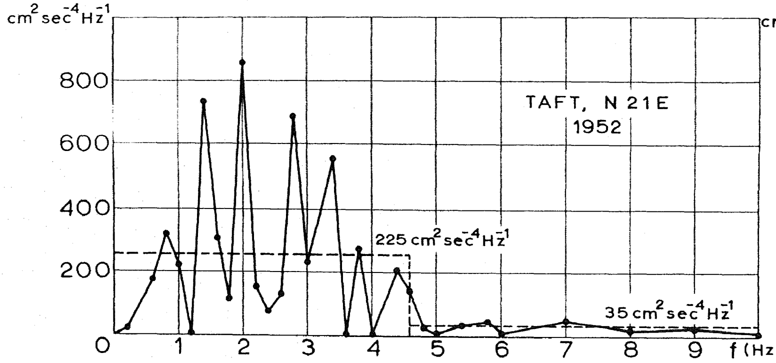


Fig. 5

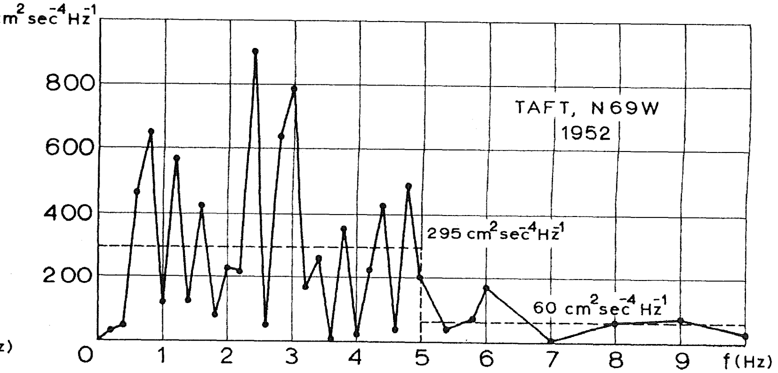


Fig. 6

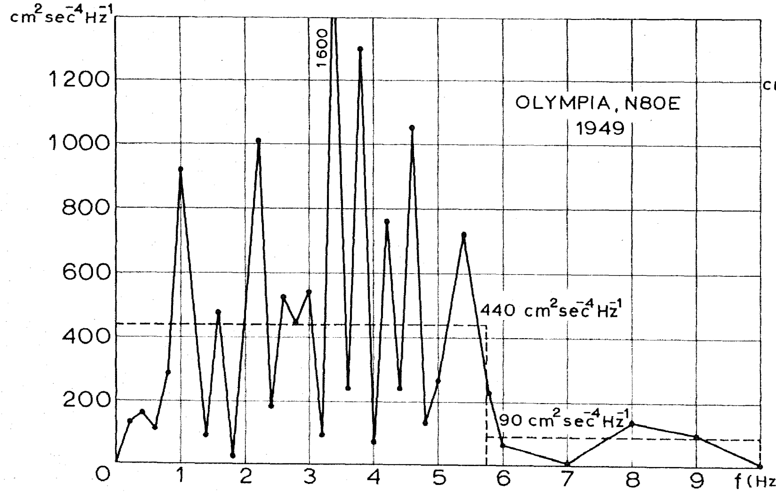


Fig 7

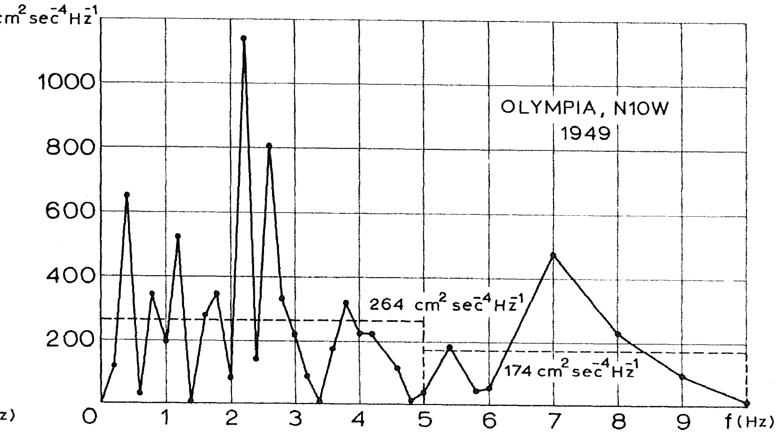
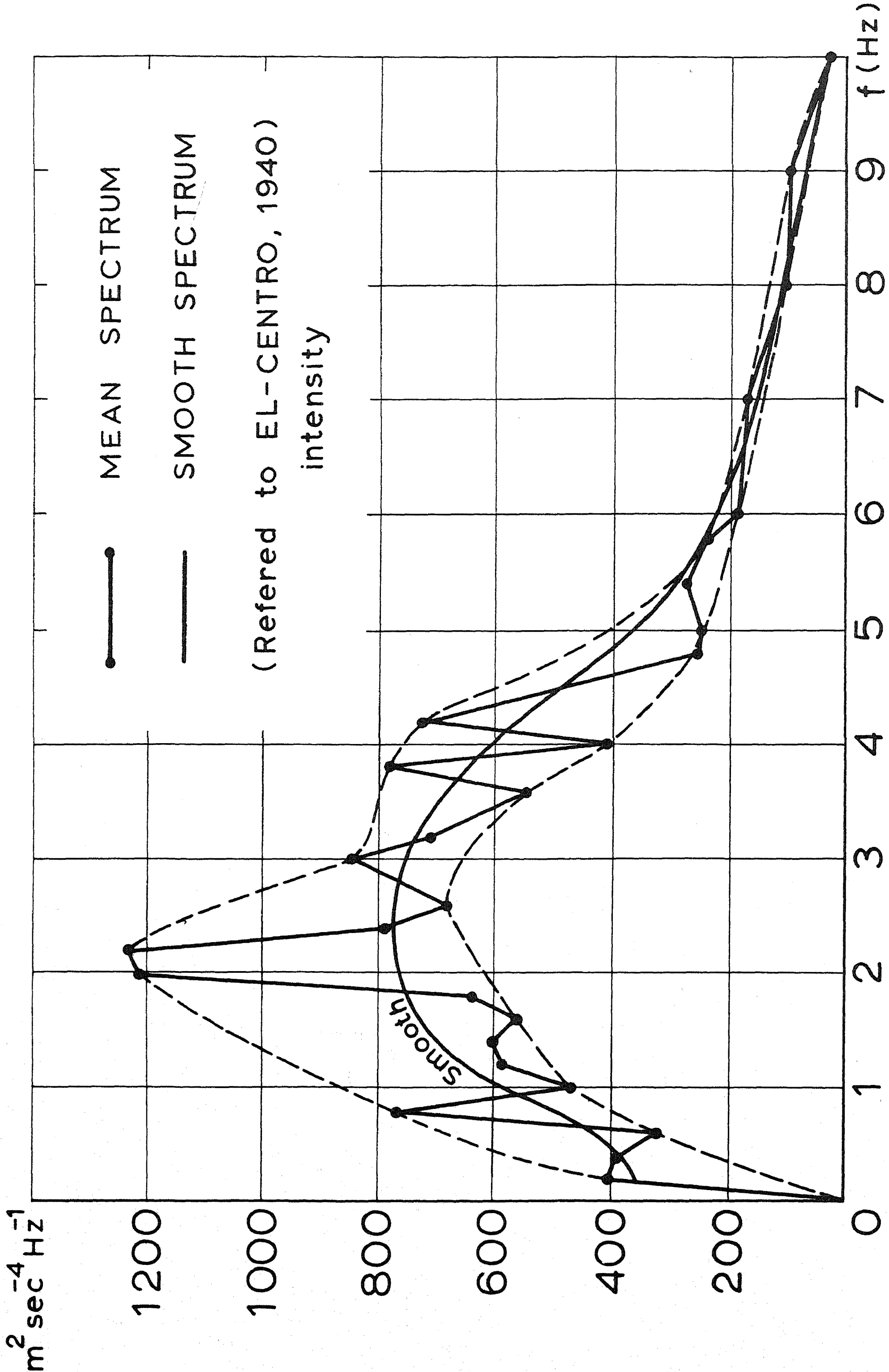


Fig. 8


MEAN SPECTRUM
SMOOTH SPECTRUM
(Refered to EL-CENTRO, 1940) intensity
Smooth
cm2sec-4Hz-1
0
200
400
600
800
1000
1200
0
1
2
3
4
5
6
7
8
9
f (Hz)