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Local Site Behaviour in The 1976 Friuli Earthquake

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SYNOPSIS. Soon after the main shock of Friuli, Italy, May 6th 1976 earthquake, two strong motion recorders accelerographs were installed in two sites about 650 meters distant one from the other. One instrument was installed on hard outcropping rock, the other at the surface of an alluvial deposit 20÷25 meters thick underlain by a sloping bedrock. Among the numerous records obtained three aftershocks of magnitude about 6 and hypocentral distance whithin 20 Km, are investigated by comparing maximum accelerations, durations, Arias intensity and Husid ratios. A new numerical tool is proposed which consists of a series of plots of the Husid ratios of low-pass filtered accelerograms. The numerical tool seems to be very promising since it allows to describe at the same time energy, duration and frequencies content, of a given ground motion. Moreover the application to the records simultaneously obtained at the two stations suggests that it would be more appropriate to define an accelerogram according to the type of "behaviour" shown by the site during a certain earthquake rather than according to the local site characteristics like soft or hard.

INTRODUCTION

The paper presents the results of a study which originated with the aim to investigate the duration of ground motions during the Friuli 1976 earthquakes. In the course of the study, while attempts have been carried on to apply to the particular situations of the Friuli earthquake the most recent developments concerning the definition of duration, some new interesting features were observed. Such features will be discussed in the following paragraphs after a brief presentation of the current definitions of duration. Since the last five years we assist to a large effort to investigate the duration of ground motions to characterize it for engineering purposes. Several definitions have been proposed, Trifunac and Brady (1975), Vanmarke and Lai (1977), Mc Guire and Barnhard (1977), however it appears that it is not a simple matter to achieve an unique definition. Trifunac and Brady (1975) define duration as the time span required for the Husid ratio to build up from 5% to the 95% value. All the authors consider the duration related essentially to the three fondamental groups of parameters: those pertinent to the source mechanism, those pertinent to the propagation process and those pertinent to the local site conditions. Studies of application of the above definition of duration to strong motion records obtained during past earthquakes have been performed by several authors Dobry and Idriss (1978), Chang and Krinitzsky (1977), Westermo and Trifunac (1976) and relationships among duration and other factors like soil conditions, spectral content and peak acceleration have been obtained. All the authors have been faced with the difficulty to find enough homogeneous conditions to investigate the above relationships. For istance when the effect at local soil conditions have been investigated (soft sites Vs. rock sites) the source mechanisms that generated the several records could be not comparable each other. Also the site conditions defined for istance as soft or rock soil were not always documented by proper investigations performed at the location of the recording stations or information on the topographical and morfological characteristics were not well described. It should not surprise, therefore, if discrepancies of results are obtained by the several investigators Dobry et al (1978), Shaw (1979). Soon after the main shock of Friuli, Italy, May 6th 1976 earthquake two strong motion recorders accelerographs were installed in two sites about 650 meters distant one from the other with the purpose of investigating the ground surface motion in an area where the destruction was almost complete. One instrument was installed on hard outcropping rock (S.Rocco station) the other at the surface of alluvial deposit about 20÷25 meters thick underlain by a sloping bedrock (Forgaria Station). Numerous accelerograms have been recorded simultaneously during the aftershock sequence. The data are of great interest because the sources were varying in magnitude and in distance from the stations which were fixed on well defined site conditions. This situation allowed us to investigate the duration having always the same site condition, presumably also the same source mechanism, and distances from the site to the zone of energy release varying from 5 Km to 20 Km. Besides that, the short distance between the soft site and the rock site (650 m) permitted to investigate the dynamic response of the two different sites during the same earthquake.

HUSID RATIOS OF LOW-PASS FILTERED ACCELEROGRAMS

To characterize the energy content associated with the frequencies of the ground motions a numerical tool has been developed as follows. Any accelerogram record have been low-pass filtered moving the cutting frequency at discrete steps from 27Hz down to 1Hz. After each step a filtered accelerogram $[a\ (t)]_{\omega_c}$, with ω_c selected value of the cut off frequency, is obtained. The filter used, the so called "Ormsby filter", Ormsby (1961), belongs to a class of a digital filter having a transfer function with unit gain and zero phase shift in the pass band. Husid ratio of each filtered accelerograms is than computed as

$$(H(t))_{\omega_c} = \frac{\int_0^t (a(t))^2_{\omega_c} dt}{\int_0^T a(t)^2 dt}$$

where a (t) is the original not filtered accelerogram and T is the total length of the record.

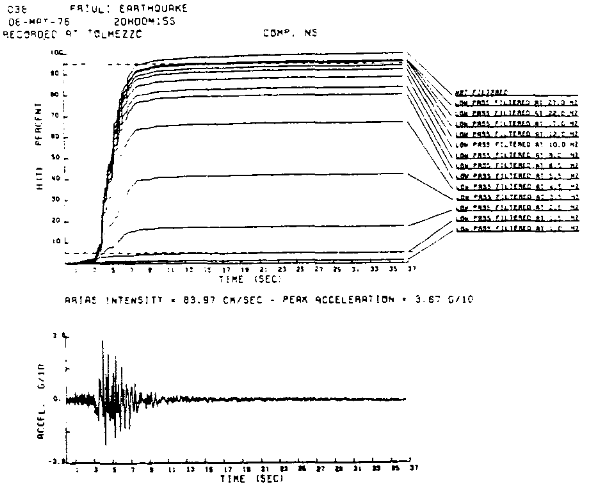

Fig. 1. Husid ratios of low pass filtered accelerogram from main shock of Friuli 1976 earthquake.

Fig. 1 shows plotted on the same graph, Husid ratios $(H(t))_{\omega_c}$ as function of time of the same accelerogram filtered at 13 cut off frequencies ω_c = 1, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, 8.0, 10.0, 12.0, 17.0, 22.0, 27.0, (Hz). The Husid ratio is linked to the build up, as function of time, of energy per unit weigth stored in an ideal population of undamped linear oscillator uniformely distributed as to their frequency, or more precisely describes how fast the Arias intensity, Arias (1969), is reached. The filtered Husid ratios contain the further information of how the build up of energy, and what amount, is related to the several ranges of frequencies. Also the Arias intensity is indicated on Fig. 1. From Fig. 1 it appears, for the particular record analysed, that 80% of the total Arias intensity, or the total energy contained in the vibratory motion, is below 5.5 Hz. On the other hand the graph can be read as if only 20% of the total energy is associated with frequencies higher than 5.5 Hz. Furhermore there is to point out that the energy is not distributed uniformly among the several ranges of frequencies, but same ranges contain more energy than others. For example, referring to Fig. 1, no appreciable energy is within the 22-27 Hz range, while about 25% of the total amount is in the 3.5÷4.5 Hz range. Another consideration can be drawn concerning the shape of the Husid ratio plots which seem not to be particularly influenced by the frequency content of the motion. It is, in fact, always possible to identify three parts in the plot, the initial one, very flat up to about 3 seconds, followed by a steep portion from 3 to 8 seconds, and the last part wich is pratically horizontal. The independence of the duration of the steep portion of the plots from the frequencies indicates, as it has been already suggested by Dobry et al. (1978), that a close relation exists between the time of rupture along the fault and the duration of the strong phase of the motion.

RECORDS OBTAINED AT THE TWO SITES

A cross section passing through the two stations of "S.Rocco" and "Cornino Forgaria" is shown in Fig. 2.

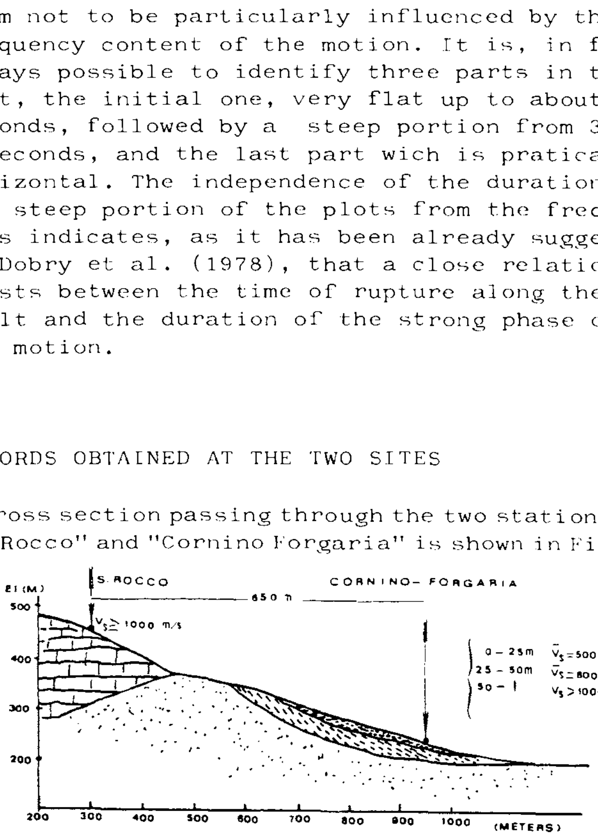

Fig. 2. Cross section passing through the accelerographic stations of "S.Rocco" and "Cornino-Forgaria".

S.Rocco station is on a outcropping of hard limestone which during the cross-hole investigation showed shear waves velocity of the order of 1000 m/sec. Cornino-Forgaria station is on a slope of alluvial material underlain by a sloping bedrock. Beneath the instrument the bedrock has been found at a depth of about 50 meters and the shear waves velocity profile indicates below 20÷ 25 meter $V_s \geqslant 600$ m/sec. The two recording stations are only about 650 meters distant one from the other. Starting from May 17th, 1976 the two stations were both installed and in operation. Table I presents a list of those shocks that triggered at least one of the two instruments together with their magnitudes, hypotentral distances, peak accelerations and duration according to the Trifunac and Brady 1975 definition on the three components. It may be easily noted that among 15 shocks having magnitude varying between 4.2 and 6.1 only 8 were capable to trigger both the instruments, the acceleration at "Forgaria Cornino" being always greater than the correspondent at "S.Rocco". Also the ratio between the peak accelerations of each component of motion of the records obtained at the two stations is given in table I. This ratio indicates that at the surface of the alluvial deposit the maximum acceleration was from 1.5 to 3.8 higher than that at the nerby rock outcropping.

Table I. Comparison of Peak Accelerations, Durations, at S.Rocco and Cornino-Forgaria

DATE	M	D_i	CORNINO-FORG.				S.ROCCO				AMPLIFICATION RATIOS		
1976		km	NS a(g)	V a(g)	EW a(g)	Dur sec	NS a(g)	V a(g)	EW a(g)	Dur sec	NS	V	EW
18 V	4.3	12	.059	.042	.062		.039	.030	.049		1.51	1.40	1.27
1 VI	4.2	9	.027	.016	.025		not triggered						
8 VI	4.5	43	.047	.028	.020		not triggered						
9 VI	4.2	14	.072	.045	.064		.030	.013	.038		2.40	3.46	1.68
11 VI	4.4	18	.100	.056	.089		.065	.031	.035		1.54	1.81	2.54
17 VI	4.4	14	.049	.029	.053		not triggered						
6 IX	4.0	14	.021	.018	.022		not triggered						
7 IX	4.4	11	.033	.019	.024		not triggered						
11 IX 18 31 12	5.5	18	.095	.051	.115		.042	.020	.071		2.26	2.55	1.62
11 IX 18 35 00	5.9	16	.133	.119	.235	5.3 5.0 2.1	.092	.048	.095	6.6 8.1 4.0	1.45	2.08	2.47
13 IX	4.4	25	.026	.020	.016		not triggered						
15 IX 03 15 19	6.1	13	.263	.099	.218	5.0 7.8 4.7	.069	.059	.123	5.7 9.5 5.5	3.81	1.68	1.77
15 IX 04 38 53	5.0	25	.058	.035	.054		not digitizable						
15 IX 09 21 28	6.0	23	.353	.195	.336	3.9 5.3 3.2	.146	.083	.238	5.7 5.2 2.8	2.42	2.35	1.41
15 IX 11 11 11	4.1	21	.029	.022	.044		not triggered						

M = Magnitude

D_i = Hypocentral Distance

a(g) = Maximum acceleration

Dur = Duration (Trifunac Brady 1975) NS V EW

The uncorrected accelerograms have been published by CNEN-ENEL (1976) and a wide discussion on the comparison among the responces of two sites are presented by Muzzi et al. (1977).

LOCAL SITE BEHAVIOUR AS DESCRIBED BY HUSID RATIOS OF LOW-PASS FILTERED ACCELEROGRAMS

The Husid ration plots of the low pass filtered accelerograms for one of the three major aftershoks, having magnitude about 6 and hypocenters within 20 Km, are shown in Fig. 3 Systematic differences between the graphs for the soft and the hard site motions can be observed. All the horizontal components recorded at the soft (Forgaria) site present a non uniform distribution of energy over the frequencies intervals, while the hard site (S.Rocco) shows an uniform distribution. This fact is particularly evident for the E-W component of the motion where for the soft site about 75% of the total energy is released within 4.5 Hz. The fondamental frequency, f, of the soil deposit below the soft site having thickness H = 20-25 meters applying the well known formula $f = V_s/4H$, is about 4.5 Hz, where a mean shear wave velocity, strain compatible, V_s about 400 m/sec, reasonable compared with the measured 500 m/s mean shear wave velocity at low strain, is assumed. This picture is in agreement with the Husid ratios of the filtered E-W component where the 75% of total energy is within 4.5 Hz. The response spectrum of the same component of motion see Fig. 4 , shows two narrow peaks at 2.5 Hz and 4.5 Hz but from that it is quite difficult to express the percentage of the total energy associated with the above frequencies intervals. The response spectrum of the same component for S.Rocco see Fig. 4 can be addressed as a broadband type spectrum. The graphs for the vertical components are much more sinilar for the two site conditions, i.e., the soft site behaves as far as the vertical response closer to the response of the hard site. This could be attributed probably to the behaviour of the soil in the vertical direction stiffer than in the horizontal. The above consideration regarding the amount of Arias intensity (energy) associated to the several frequencies intervals suggest to be very careful in treating with hard site and soft site motions when some filtering is applied to them for structural analysis. In fact, for istance, while filtering at 3.5 Hz for the soft site motion Fig. 3 produces filtered motions containing-still 75% at the Arias intensity for the hard site motion the same cut off frequency removes 50% of Arias intensity.

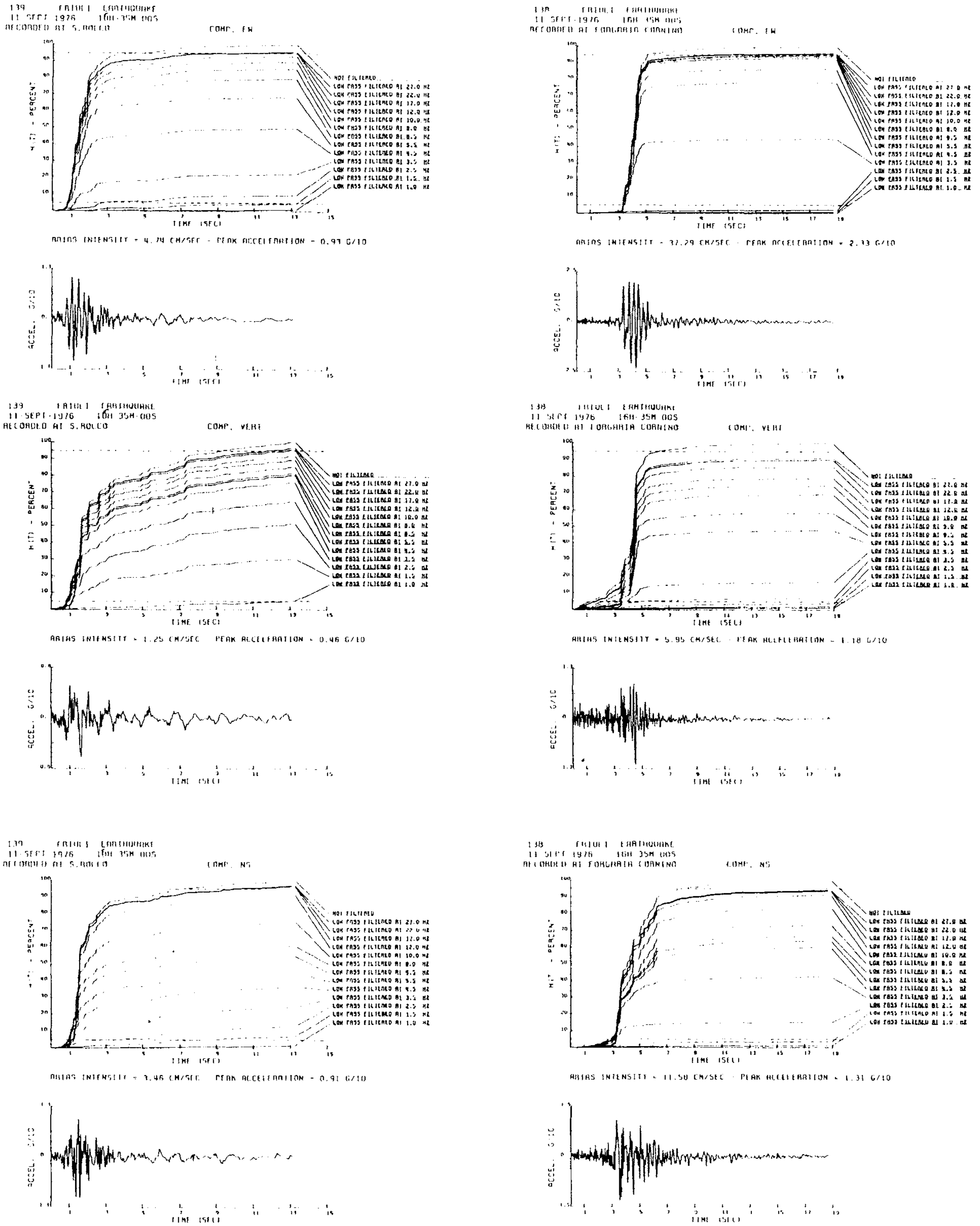

Fig. 3. Husid ratios plots of the low pass filtered accelerograms for the Friuli Sept. 11, 1976 aftershock recorded at "S.Rocco" (hard site) and "Cornino-Forgaria" (soft site).

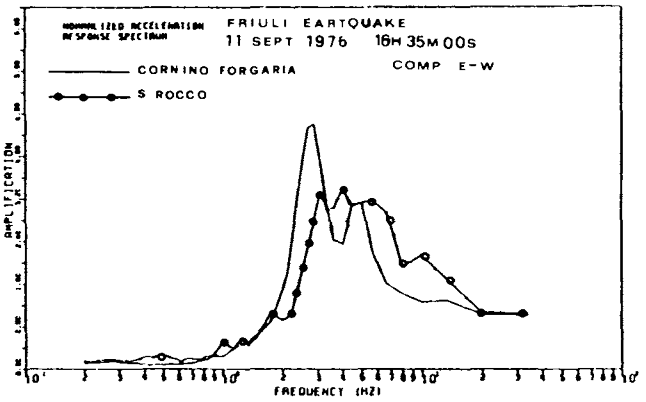

Fig. 4. Response spectra of the E-W component at "S.Rocco" and "Cornino-Forgaria".

FURTHER IMPLICATIONS OF THE LOW PASS FILTERED HUSID RATIOS.

The low pass filtered Husid ratios indicate, that the points where the slope of the curves changes occur pratically for each graph at the same time regardless of the value of the cut off frequency. This implies, as it has been already observed, that relationship could exist between the time of rupture along the fault and the time inverval between the two consecutive points where the slopes change. The time interval does not usually coincide with the duration as defined by Trifunac and Brady (1975), but rather with the length of the S waves phase. Since it is commonly accepted that the distructive part of an earthquake is associated with the S waves phase it would appear more appropriate to link any definition of duration to this phase which varies as funcion of source characteristics, travel paths, local conditions and therefore cannot be fixed once and for all.

One of the most outstanding feature of the low pass filtered Husid ratios is the possibility of describing at the same time how, given a certain ground motion, the Arias intensity, or the energy per unit weight, builds up in time and is stored in a population of undamped linear oscillator within the several ranges of frequencies. In other words it could be regarded as a potential improvement of the concept of response spectra. Such a presentation of the ground motion characteristics could be therefore suitable, for istance, to overcome the difficulty to deal with the problems of having high peak acceleration ground motions with short duration which usually implies very little effects upon the response of ordinary buildings. In fact the low pass filtered Husid ratios of Ancona 1972 earthquake, see Fig. 5, shows that the energy below 5,5 Hz, which covers the fondamental frequencies of most of the ordinary buildings, is only about 5% of the total energy of the ground motion. Moreover it apperars that the total energy is given in two seconds.

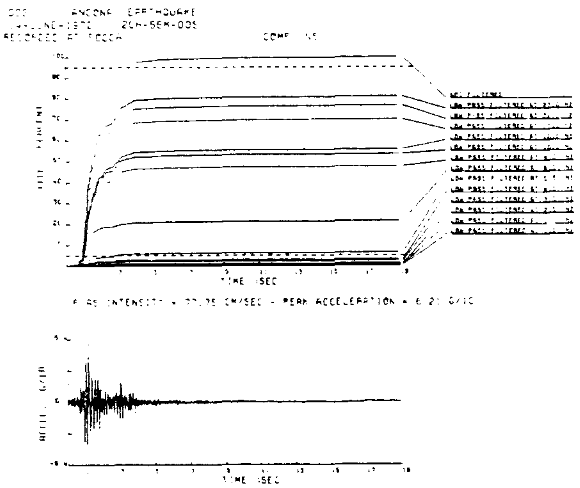

Fig. 5. Husid ratios low pass filtered of Ancona 1972 earthquake.

The above consideration could be applied to the debate of what should be the effective peak acceleration (EPA), ATC-3-06 (1978), in case of records such that of Ancona 1972 earthquake, or similar, where the peak acceleration for magnitude about 4 was 0.6 g. Observing that an ordinary building would have stored at the end of the ground motion only 5% of the total energy per unit weight in two seconds, the effective peak acceleration should be taken considerably lower than 0.6 g.

The response at a certain site is the overall result of the combinations of source mechanism, travel paths and local conditions. The ground motion records contain hidden all the information relative to the whole process. the present state-of-the-art in the engineering seismology represents the results of the several efforts undertaken to make explicit the information hidden in the ground motion records. One of this effort has been to classify data as belonging to hard rock, or shallow stiff, or deep cohesionless soil and so on, according to the local site condition at the recording stations. The authors believe that it could be more meaninguful and appropriate to regard the several records as expresion of the "behaviour" of a specific location during a specific earthquake regardless of the different soil conditions. In fact the combination of source mechanism, travel paths, local morphology and topography could produce at the surface of a hard rock site motions closer to what is presently intended for the response of a soft site and vice versa.

Having this in mind it would be very useful to have available a numerical operator such that it could allow us to classify the ground motion records according to the type of site response they represent and to identify ensambles representing homogeneus behaviours. Under this light the numerical operator "response spectrum" has been extensively used to describe the information contained inside the ground motion records previously selected on the basis of the site conditions, Seed et al.(1974). To classify records we should take in account the "site behaviour" rather than the site condition by alone. We believe therefore, that the numerical operator represented by the low pass filtered Husid ratios could effectively help. Fig. 3 are quite self explaining examples of the possibility offered by the low pass filtered Husid ratio plots as indicator of the behaviour of a certain site during a specific earthquake. Those grafhs showing uniform distributiono of energy along the several frequency ranges could be for istance regarded as those describing a "stiff site behaviour", while those showing distribution of energy mainly concentrated in few ranges of frequencies as those describing a "Soft site behaviour".

CONCLUSIONS

The low pass filtered Husid ratios have been described and applied to the analysis of records obtained during the Friuli 1976 earthquake, at two locations only 650 meters distant each other, one on outcropping hard rock the other on a slope of alluvial deposit. The numerical operator seems to be very promising to describe the actual behaviour of sites where records have been collected. "Soft site behaviour" is easily distinguished at the Forgaria site by the high concentration of the energy (Arias intensity) over few frequency ranges. "Stift site behaviour" can be well characterized by the almost uniform distribution of energy over the frequencies. The low pass Husid ratio plots are capable to describe the differencies between real ground motion and the effective one as far as the structural responces is concerned. The application to Ancona 1972 type records have been discussed. The observation that the time interval between the two points on the Husid ratio plots where the slope changes, is independent of the frequency, confirms the hypotesis of Dobry et al. (1978) that the duration is controlled by the time rupture of the fault.

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