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QUANTIFICATION OF LOCAL SITE AND REGIONAL EFFECTS ON THE NONSTATIONARITY OF EARTHQUAKE ACCELERATIONS

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SUMMARY

The Evolutionary Spectral Analysis allows the interpretation of seismic waves from strong motion records and besides body waves the existence of surfache waves were proved in the strong motion records of the Friuli Earthquakes (M=5-6). Also the unusual high PGA and energetic 0,5 Hz. component in the strong motion records from Mexico City, 1985 (M=8) can be explained to be the fact of surface waves. Therefore seismic load models have to be extend by this kind of waves leading to a random process which is nonstationar in both amplitude envelope and frequency content. The frequency content of body waves is highly determined by the local site conditions whereas the surface waves are mainly determined by the regional conditions.

INTRODUCTION

The seismic risk assessment of important structures demands a detailed knowledge of the seismic excitation. Usually strong motion do not exist at the location of the structure and therefore artificial records have to be established on the basis of a probabilistic seismic theory. Various models are accepted but all of them are crude and insufficient in a certain way for a reliable fore-casting of the seismic hazard lacking of seismic phenomens and/or probabilistic methods. The most sophisticated probabilistic methods have to fail if the seismic phenomens are not modelled appropiately or even dropped partially. An example which revealed our limited knowledge on the seismic process was the Michoacan Earthquake 1985 with its unexpected high and long strong motions in Mexico City. The features of the accelerograms are partially explained by the local site amplification effects but the significant prolongation of the records and the small attenuation at the rock stations, i.e. the unusual high PGA, are totally unknown.

The Evolutionary Spectral Analysis was recently developed (Ref.1) and rigorously applied to a moderate earthquake. The Friuli Earthquake Sequence 1976, Italy, M=5-6 (Ref.2,3) showed that the acceleration time history is nonstationary in both amplitude envelope and frequency content. This nonstationarity pattern is in accordance with a simplified wave theory, containing classical P-,S-, Love and Rayleigh waves only. The most surprising result was the existence of surface waves in strong motion records of moderate earthquakes and its increasing importance for strong and shallow earthquakes (M > 7) was pointed out (Ref.4).

The strong motion records obtained in Mexico City show such characteristic features of surface waves in the time histories. This encouraged us to start a detailed investigation of the Michoacan strong motion records with the Evolutionary Spectral Method in order to find out wether or not the supposed theory of surface waves in the frequency range up to 1-2 Hz is valid and the unexpected small attenuation of the seismic energy at Mexico City can be explained. Preliminary results of this investigation are given below.

REVIEW OF THE EVOLUTIONARY SPECTRAL ANALYSIS

An evolutionary random process with zero mean is definded according to (Ref.5) through

$$x(t) = \int_{\infty}^{\infty} e^{i2\pi ft} A(t,f)\, dZ(f) \qquad (1)$$

where A(t,f) is the amplitude modulating function and dZ(f) is the differential of an orthogonal random process. The Evolutionary spectrum is given by

$$S(f,t)df = E(\, [A(t,f)\, dZ(f)]^2 \,) \qquad (2)$$

with E() denoting the expected value.
For the estimation procedure a multi-filter technique is adopted whereby the following assumptions are introduced: a) the basic random process Z(f) is a white noise process and b) the evolutionary process is ergodic and therefore the expectation E() over the ensemble can be replaced by the expectation over the time.
The quality of the result depends on the selected filter element. From the Uncertainty Principle one can choose between a higher time or a higher frequency resolution always leading to a greater leakage in the other domain. A damped oscillator (Single Degree of Freedom System) is proposed as the filter element because the time leakage of this element can be described by a very simple formular - by introducing some approximations of course. The application to some test records showed very promissing results (Ref.1). The frequency leakage was kept small by the appropriate choosen filter parameter - half-power band width of 0,25 Hz for each element which leads to a damping coefficient of less than 5% - and the time leakage was controlled by the simplified time-dependent response function of the filter element which allowed a high resolution in both, time and frequency. The improvement of some inherent shortcomings of the filter procedure are under current work, for instance the qualitiy of the filter response can be improved by adding simple low-pass filters to the pre- and intermediate domain of the SDOF-filter procedure. Some of this improvements are included in the present analysis, however for the adopted level of interpretation of the computed Evolutionary Spectra the procedure given in (Ref.1) would not lead to significant different results.

RESULTS FROM THE FRIULI EARTHQUAKES

The systematic application of the Evolutionary Spectral Analysis to the strong motion records of the Friuli Earthquake Sequence results in a uniform pattern of the evolutionary spectral amplitudes. The only but systematic difference is the prolongated time band in the low frequency range 0-2 Hz in the tail, which is always present at certain stations (see fig. 1) and nearly not detectable at the other stations. A detailed investigation of this phenomen leads to the conclusion that the time band represents surface waves. This is supported by the computed particle motions of the band-pass filtered records which show brilliant elliptical orbits in the vertical planes. All the stations exhibiting such a time band are located on a sedimentary basin which extends from the

southern border of the Alps, where the epicenters were located, and ends up with a depth of several hundreds of meters at the Adrian Sea.
The other significant feature of the computed Evolutionary Spectra is the band-like concentration of high spectral amplitudes at the beginning of the records which extends over the whole analysed frequency range up to 25 Hz. The duration of this frequency band is always in the order of the estimated rupture time and fit quite well with the estimated Strong Motion Part for the stations which were not located on the sedimentary basin, i.e. which showed not the prolongated tail. The frequency bands are structured by very pronounced riples with their peaks always around the same frequencies in both horizontal components for the different records obtained at the same station. The riples in the vertical components are shifted to higher frequencies by a factor of 1,5 to 2,0 and the frequency band starts somewhat earlier. This evidence leads to the conclusion that the frequency band in the horizontal components represents the S-wave impact and in the vertical component the P-wave impact overlaid - depending on the angle of incidence - by the S-wave impact. The peaks of the riples are the soil resonances. The computation of the soil transferfunction using a 1-D model for several stations (Ref.2) supports that conclusion.

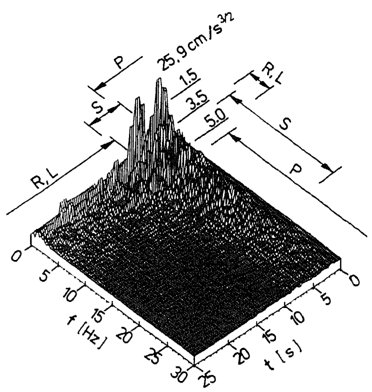


Fig. 1 Evolutionary Spectrum,
Buia 15 Sept 1976 9h21 NS

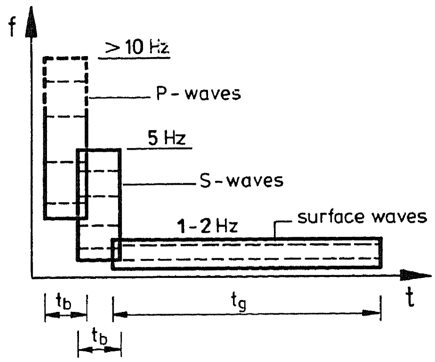


Fig. 4 Simplified Pattern of the Seismic Acceleration in Time and Frequency

The systematic analysis of the riples in the frequency and the time band shows that the location of the peaks of the riples from the S-wave impact (nonbasin station fig. 2) depend on the max. ground velocity. The ground velocity depends on the soil stress and therefore is a measure of the actual stiffness of the soil. The riples of the frequency band are therefore highly influenced by the local soil conditions. This is not the case for the riples of the time band. They are independent of the max. ground velocity and constant for all investigated quakes which is illustrated in fig. 3 through the 0,5 and 1,5 Hz resonance frequencies obtained for Buia, a sedimentary basin station. This points out that this waves are not governed by the soft local soil which may change its stiffness significantly in the investigated range of the ground velocity but that they are governed by deeper and stiffer rock layers. However the soft layers of the sedimentary basin could have amplified the surface wave amplitudes significantly.
The Evolutionary Spectral Analysis of the Friuli records reveals a pattern of the ground acceleration (fig. 4), which is highly nonstationar. It consists out of three dominant random subprocesses, a P-wave, a S-wave and a surface wave process. Each subprocess can be modelled by a stationary random base process which is uniformly amplitude modulated (Ref.2,6). This extends the presently used probabilistic seismic load models considerably. They consist only out of one

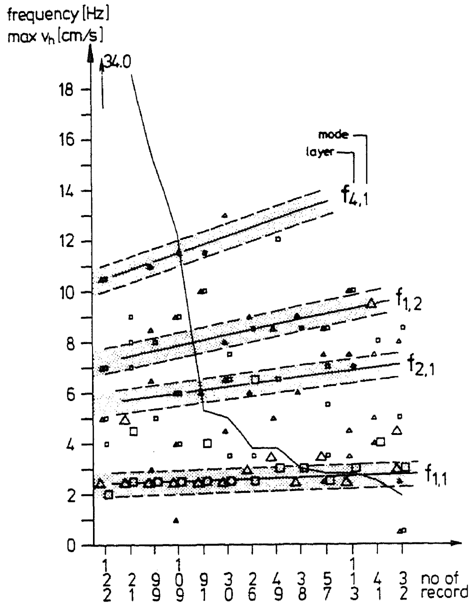


Fig. 2 Resonance Frequencies at Forgaria (outside sed. basin)

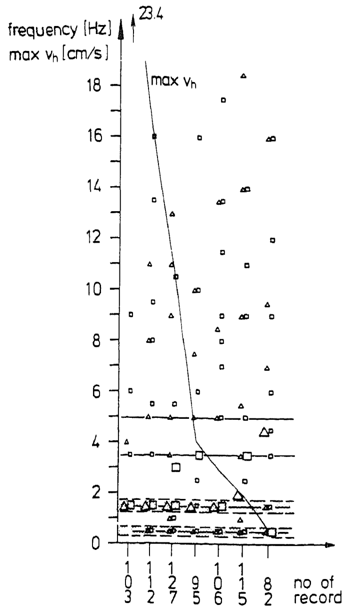
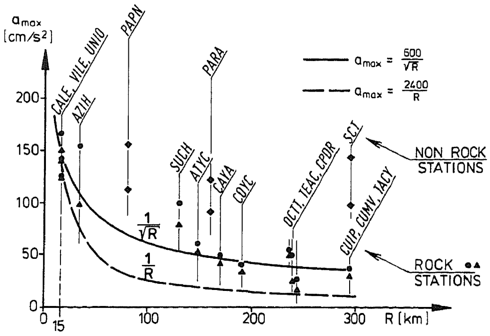


Fig. 3 Resonance Frequencies at Buia (sedimentary basin)

subprocess and if a nonstationarity is considered it is limitated to a uniformly applied amplitude modulating function.
Civil Engineering structures are sensitive to both kinds of seismic excitations, the impulsive and strong impact of body waves - also in the vertical direction, for instance the punching problem of columns - and the long durating and weaker impact of surface waves. The later can lead to the detoriating of structural links which may be predamaged and weakened by the first one. The neglection of the surface wave impact in the anti seismic design of a structure may lead to very misleading damping elements, because such damping elements can often not sustain such a long seismic excitation because they are optimized to a short strong impact. Also very dangerous is the frequency range of the surface waves for two different aspects: a) the first eigenfrequency of vibrational sensitive structures is in the range of 0,2 to about 1,0 Hz and b) antiseismic spring support of structures leades to a shift of the structural eigenfrequencies out of the body wave range but into the surface wave range. Additionally surface waves attenuate only with $1/\sqrt{\text{distance}}$ compared to body waves which attenuate with 1/distance.

PRELEMINARY RESULTS FROM THE MICHOACAN EARTHQUAKE

The unexpected high and prolongated strong motion time histories at Mexico City and the strong coherence between the horizontal and the vertical components with a time shift of about one quarter of the predominant period indicating an elliptical movement of the ground particles points strongly to the fact that the strong motion records are dominated by surface waves which additionally were - comparing rock and lake zone stations - amplified by the soft sedimentary layers.



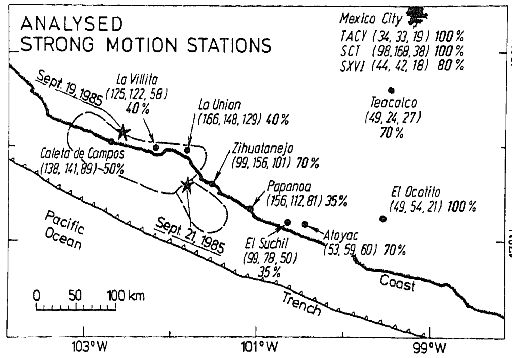


Fig. 5 PGA-attenuation for Rock
Stations, Michoacan
19 Sept 1985

Fig. 7 Analysed Stations with a) PGA
(NS, EW, V), b) mean ratio of 0,5 Hz-
component to max $\sqrt{ESP}$ in %

The PGA attenuation relation of the rock stations (values are taken from (Ref.7)) clearly exhibits a $1/\sqrt{\text{distance}}$ - attenuation (see fig. 5) an indication for surface waves, too.
The first strong motion records analysed by the Evolutionary Spectral Method (8 stations from the coast, 3 in Mexico City, 1 inbetween) support the predominance of surface waves in Mexico City. The Evolutionary Spectra at SCT in the lake zone are dominated by the strongly amplified 0,5 Hz component and only during about 60 s (30-90 s) a small contribution of higher frequency components are present. More interesting are the ESPs of TACY, a rock station (see fig. 6). There are only frequency components visuable up to 5 Hz in and before the Strong Motion Duration and only up to 2 Hz in the tail. However during the whole record the time band between 0,25 - 0,75 Hz dominates the acceleration. The time band is

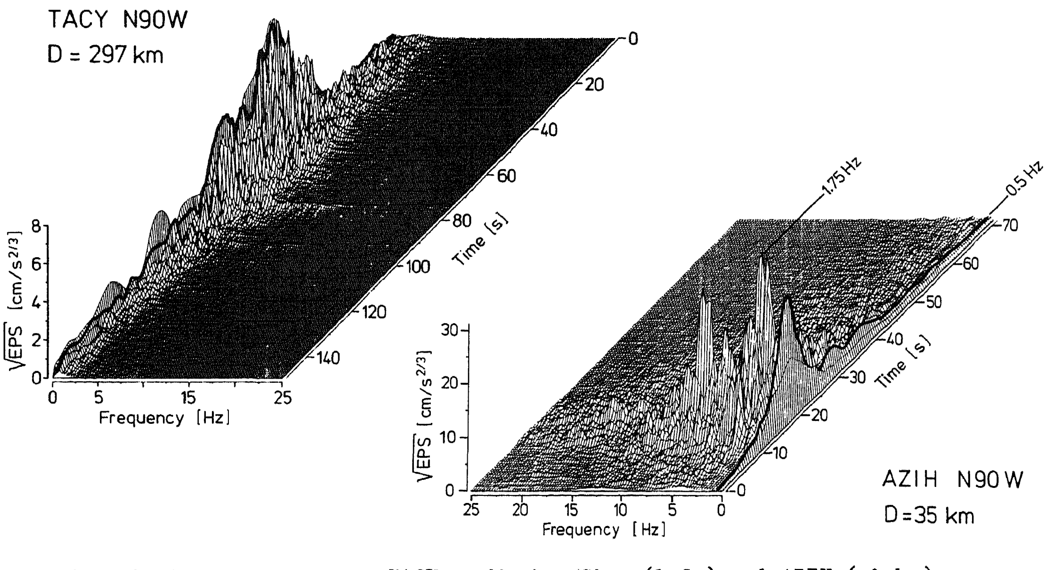


Fig. 6 Evolutionary Spectrum, TACY at Mexico City (left) and AZIH (right),
19 Sept 1985 N90W

very pronounced in the tail, a unequivocal indication of surface waves. The ESPs of TEAC, the station inbetween the coast and Mexico City show a similar pattern, however no definite conclusion can be made because of the short duration of the records (ca. 40s). The ESPs of the stations at the coast show the following features: The ESPs of the stations over the rupture zone show very high frequency components (up to 25 Hz) during the rupture time (body wave impact) like usual strong motion records and a small time band (0-2 or 3 Hz) in the tail indicating the presence of surface wave modes (see fig. 6). With increasing distance from the source the ESPs of the coast station show a change in the frequency content to lower frequencies (low pass filtering effect) and an increasing contribution of the 0,5 Hz component to the overall acceleration, indicating the development of surface waves. In fig. 7 the mean value of the ratio out of the three components [%] of the amplitudes of the 0,5 Hz component to the max. amplitude of the square root of the ESP is given. It shows the increasing contribution of the 0,5 Hz component to the overall acceleration as described above and on the other way the development of a surface wave mode at 0,5 Hz, because of its weaker attenuation compared to body waves.

CONCLUSIONS

The Evolutionary Spectra of strong motion records computed by a multi-filter technique with a lightly damped oscillator as the filter element lead to a high resolution in time and frequency and allows the interpretation of inherent seismic waves up to a certain but promissing high level. With the Evolutionary Spectral Analysis surface waves were shown at certain stations for the Friuli Earthquakes (M=5-6) and the first results from the Michoacan Earthquake (M=8) point also to surface waves for the unexpected high PGA and energetic 0,5 Hz component at Mexico City. However a more detailed investigation is necessary in order to support unequivocally that statement and to explain the hypothesis of a "unusual high radiation of seismic energy at 0,5 Hz in the northeast quadrant" in the Michoacan Earthquake given by (Ref.8).

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