# EXPERIMENTAL MEASUREMENTS OF SOIL DYNAMIC RESPONSE USING ACCELEROGRAMS OF LARGE EARTHQUAKES

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## ABSTRACT

Two experimental techniques are presented to measure dynamic soil properties dynamic large deformations of large earthquakes. The techniques are the autocorrelogram and Fourier spectra. They allow estimating the fundamental and higher mode periods as well as modal damping of soil directly from accelerograms.
The presented techniques estimate period and damping for horizontal and vertical mode of vibrations.
Measurement of soil fundamental period are in agreement with 1D – S wave elastic soil model in most analyzed cases, showing a paradoxical elastic response despite the large peak ground acceleration (PGA) of the analyzed accelerograms.
Obtained frequencies of higher modes satisfy the theoretical relation between them of 1:3:5, corresponding to 1D – S wave soil model.
The analyzed accelerograms are from the earthquakes of Mexico 1985; Chile 1985; Northridge, USA 1994; Nisqually, USA 2001 and Whittier Narrow, USA 1987.
Analysis also considers soil measurement at the same accelerographic station for different earthquakes and aftershocks. Measurements do not show important soil properties degradation despite the large earthquake analyzed, however these results are not general.
These methods can be only applied when accelerogram allow time window of soil free vibrations due to seismic wave arrivals from source are not always stationary.

Keywords: Soil, Period, Damping, Measurement, Accelerogram, Earthquake

## INTRODUCTION

Large earthquake is a rare event, which can not be predicted in time or space, making it difficult to organize experiment and tests of theoretical models. Therefore to study amplification of strong motion waves by soils, it has been suggested that microseisms and microtremors could be used (Kanai 1949, 1983; Kanai et al. 1954). However the amplitudes of microseisms and microtemors are $10^5$ to $10^8$ times smaller than amplitudes of a destructive strong motion (Trifunac and Todorovska, 2000; Negmatullaev et al., 1999), therefore the usefulness of microtremors for site amplification studies has been controversial subject, even in the approximately linear range (Uwadia and Trifunca, 1972).

The technique proposed by Nakamura (1989) also uses the horizontal to vertical (H/V) spectral ratio of weak motion records. In Nakamura's method microtremors H/V ratios can be chosen as the resonant frequency at the site, when the value of the peak is large (at least 4 to 5), although there is some discussion on the interpretation of their results (Lachet and Bard, 1994).

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However microseisms and microtremors are used by some researchers to estimate the amplification of strong motion waves, but it is generally acknowledged that their limited due to the non-linear soil response or that nature and propagation path are different from those of strong motion waves.

Therefore the proposal of techniques that measure soil properties as natural period and damping directly from accelerograms of large earthquake could avoid the above mentioned criticisms. In this paper two techniques will be considered for the interpretation of accelerographic measurements of large earthquakes in epicentral zones or for large epicentral distances, such as the classic Mexico case. The techniques are the autocorrelogram and the Fourier spectra.

## ESTIMATION OF SOIL NATURAL PERIOD FROM ACCELEROGRAM BY USING AUTOCORRELOGRAM

The first researcher that considered earthquake accelerograms as a sample of stationary random processes was Housner (Housner 1947). He assumed that accelerograms can be represented as a series of pulses randomly distributed in time as a white noise process. Housner's idea does not consider at all any filtering effect due to the soil. His white noise idea had a strong influence in USA and soil response was considered irrelevant for many years in USA earthquake engineering.

On the other hand, in Japan, Tajimi (Tajimi 1960) based on a Kanai work (Kanai 1957), studied the frequency content of accelerograms. He observed that the pulse duration is similar to the natural period of buildings, since Japanese accelerograms have a predominant period of less than 0.8 sec.

Based on these observations, Tajimi proposed the filtering of an incident random white noise through a one degree of freedom oscillator that represents the soil response. This assumption leads to power spectral density functions with a predominant period. This model proposed by Tajimi has been improved later by other authors, but keeping the two major ideas, i.e. an acceleration random process and a predominant soil period.

A random process is a set of time functions described by probabilistic laws which can be estimated from a large set of samples.

Accelerogram of different earthquakes $x^{(1)}(t)$, $x^{(2)}(t)$,..................,$x^{(n)}(t)$, recorded by an accelerograph at a particular site of time invariant properties, can be considered as samples of a stochastic process.

Earthquake accelerograms due to their transient character must be represented by nonstationary random processes (Saragoni and Hart, 1974). However for the estimation of the experimental properties of soil ground acceleration, random processes will be considered as stationary; which will give more importance to the strong motion part.

Since the number of large earthquake accelerograms is scarce to generate a set of samples, set averages will be replaced by time averages of the only available sample considering the ergodic theorem. Thus the autocorrelation function $\phi_{XX}(\tau)$ can be defined as:

$$\phi_{xx}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} x(t)\,x(t+\tau)\,dt \qquad (1)$$

where x(t) in this case is the ground acceleration at time t and T is the total duration of the accelerogram (Bendat and Piersol, 1986).

The autocorrelation function of an accelerogram is called the autocorrelogram which measure the expected value of the correlation between two values of a time series separated by a time difference $\tau$. The autocorrelation function $\phi_{XX}(\tau)$ has the properties that for $\tau = 0$ represents the mean square value ground acceleration

$$\phi_{XX}(0) = E\{x^2(t)\} \qquad (2)$$

Arias and Petit-Laurent (1963) analyzed the autocorrelograms of accelerograms of USA, Mexico City and Santiago, Chile considered as a random process. They found that the Mexico City 1962 earthquake accelerograms had deterministic components despite the USA and Chile accelerograms that show a high randomness in a wide band of frequencies. For Arias and Petit-Laurent (1965), the frequency band was a consequence of the soil properties at the site.

The autocorrelation functions analysis for different accelerograms shows that some of them have an important presence of sine wave components (deterministic). Arias and Petit-Laurent (1963) found that Mexico City autocorrelograms for the 1962 Mexico earthquake. A similar situation is observed for some autocorrelograms of the Parkfield 1966 earthquake (Liu 1969), Rumania 1977 and 1986 earthquakes (Lungu at al. 1992) and some Chilean earthquakes (Ruiz and Saragoni 2004) (See Figure 1).

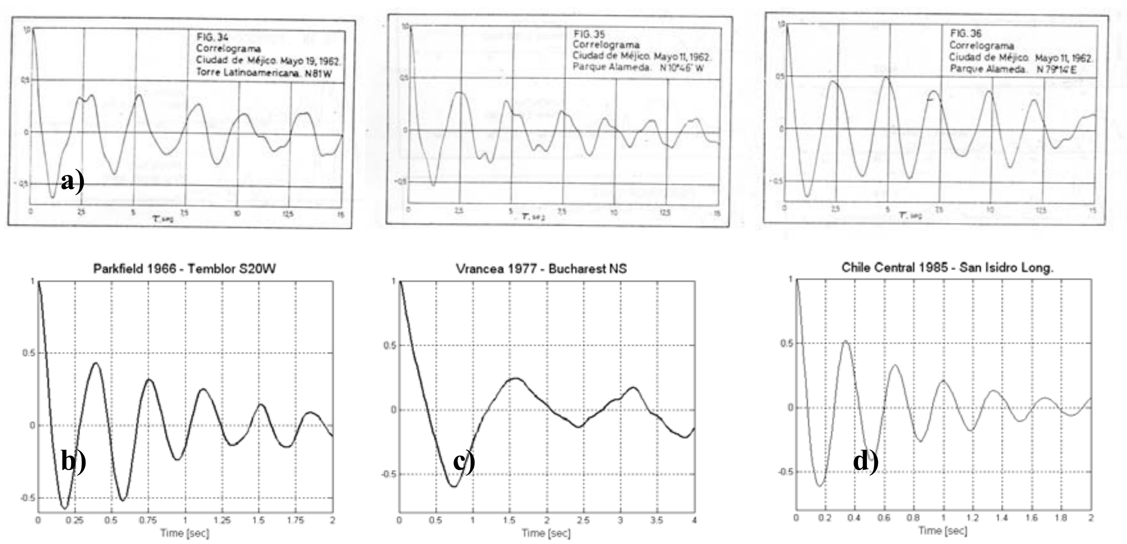



**Figure 1. a** Autocorrelograms of accelerograms of Parque Alameda, Mexico 1962 (Arias and Petit-Laurent, 1963). **b** Temblor S20W, Parkfield, USA 1966 (Liu, 1969). **c** Bucharest NS, Rumania 1977(Lungu et al. 1992). **d** San Isidro Longitudinal, Central Chile 1985 (Ruiz and Saragoni, 2004). Autocorrelograms are normalized to unitary expected square acceleration.

The shape of these autocorrelograms, i.e. the characteristic period and the attenuation constant, allows to assimilate them to the corresponding deterministic function of the displacement of the free vibration of the one degree of freedom oscillator with an initial displacement and zero velocity, i.e.:

$$y(t) = Ae^{-\beta(2\cdot\pi\cdot\frac{t}{T_s})}\cos\left(2\cdot\pi\cdot\frac{t}{T_s}\right) \qquad (3)$$

where $T_S$ is the natural period and $\beta$ the damping ratio.

Making this assumption and choosing adequate values for the natural period and damping ratio of the oscillator, both curves coincide (Ruiz and Saragoni 2004).

In Figure 2a the autocorrelogram of Central de Abastos (CDAO) N00E accelerogram of the Mexico 1985, $M_S$ = 8.1 earthquake is shown. The autocorrelogram has been normalized by the expected quadratic value. For this autocorrelogram the following $T_S$ and β values were estimated: $T_S$ = 3.57 sec and β = 0.05. Then Eq. (3) is reduced to:

$$y(t) = e^{-0.05\cdot(2\cdot\pi\cdot\frac{t}{3.57})}\cos\left(2\cdot\pi\cdot\frac{t}{3.57}\right) \qquad (4)$$

Figure 2b shows an excellent matching between the function of Eq. (4) and the autocorrelogram of CDAO N00E in a time range of 20 sec. This result suggests that soil at CDAO station mainly freely vibrated during the 1985 Mexico earthquake as a simple damped one degree of freedom oscillator, despite the large magnitude of the earthquake ($M_S$ = 8.1) and peak acceleration of the record of 66 [cm/s²].

In Figures 2c, 2d, 2f and 2e shown also an excellent matching between the corresponding autocorrelograms of Ministry of Communications and Transportation (SCT), N00E, Mexico 1985, San Isidro Longitudinal, Chile 1985, Tarzana 90, Whittier Narrows 1987 and Boeing 270, Nisqually 2001 and their corresponding theoretical function of the type of Eq. (3).

Figure 2d also shows an excellent matching between the autocorrelogram of San Isidro Longitudinal accelerogram of the Chile 1985 earthquake and the corresponding theoretical function, despite the large magnitude of the earthquake (Ms = 7.8) and the peak acceleration of the record of 0.7 [g].

The reason why free vibration happens during large earthquakes, which looks like a paradox, is due to the fact that the energy released from the seismic source is not permanently continuous in time; there are relax intervals in-between without important seismic wave arrivals from the source in which soil free vibration happen many times. Therefore, accelerograms can be considered as a random sequence of seismic episodes of seismic wave arrivals and episodes of free soil vibrations.

The autocorrelation function estimation is usually done considering Eq. (2) by using only one sample accelerogram based on the ergodic theorem; however the use of this theorem in practice implies to consider random samples. When the samples, as in the analyzed case, have strong deterministic components, the estimator is only recognizing the presence of many free vibrations along the record due to random initial conditions provoked by intermittent episodes of short-duration random seismic wave arrivals.

The free vibration of a structure of push-back test is used in to measure the natural period and damping of structures, similarly the free vibration of the soil can be used to measure the damping of the soil as the random decrement method. The measurement of soil damping in a probabilistic way from accelerograms has been also proposed by other authors (Huerta et al. 1998).

These deterministic soil free vibrations are observed in different accelerograms as the ones shown in Figure 3: Tarzana 90, Whittier Narrow 1987; Central de Abastos Oficina (CDAO) N00E, Mexico 1985; Boeing 270, Nisqually 2001 and San Isidro Longitudinal, Chile 1985. All these accelerograms show time windows with a noticeable damping of the acceleration amplitudes. This situation is reflected in their corresponding autocorrelograms. Therefore, in these cases autocorrelograms allow to estimate the soil natural period and damping.

In Figure 3, in addition to the accelerograms, in the central part there is close up of a specific region of the strong motion part of the accelerograms where the natural period and the damping of the soil can be clearly observed. To the left of the figure the corresponding autocorrelograms are shown with similar period and damping.

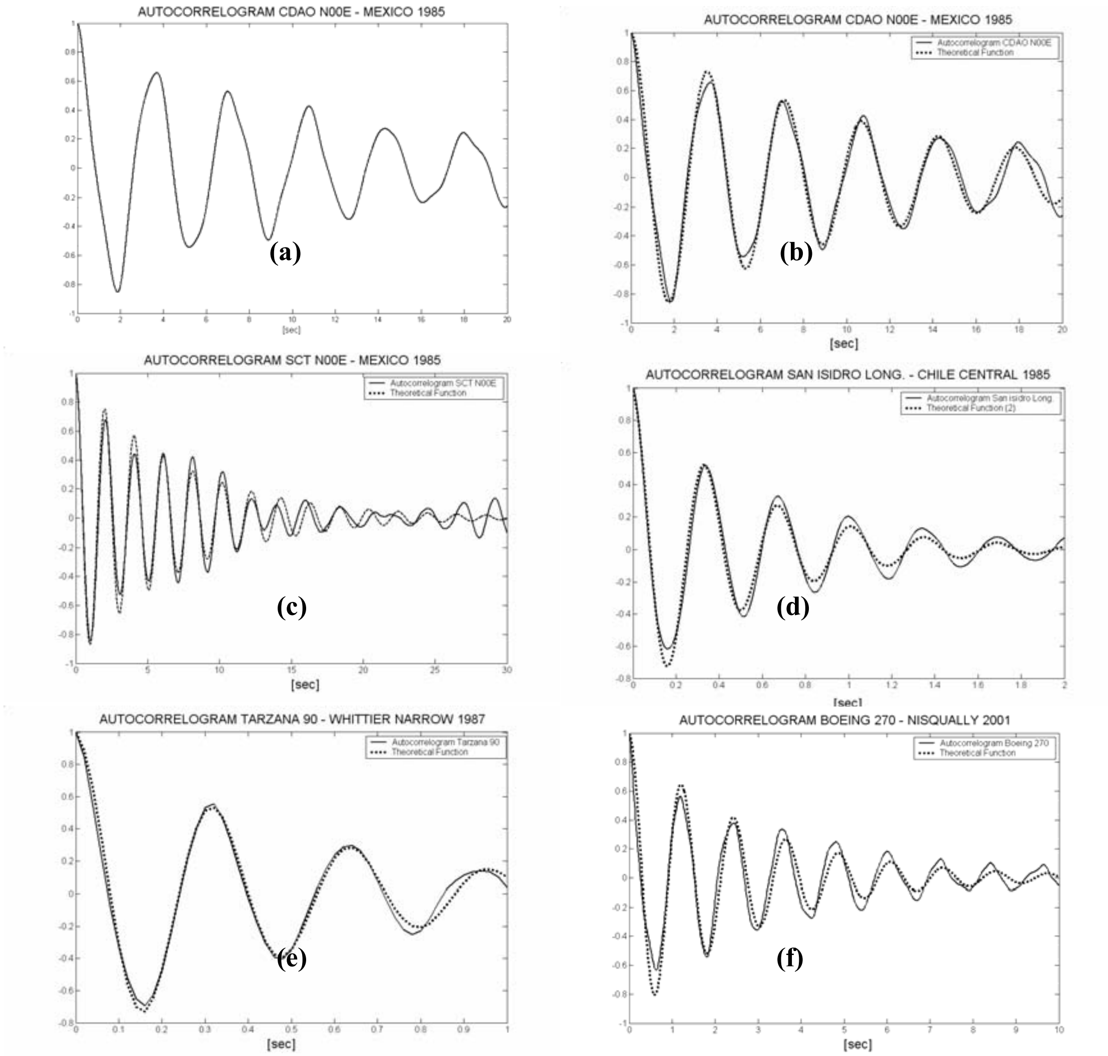



**Figure 2. a** Autocorrelogram for CDAO N00E, Mexico 1985.

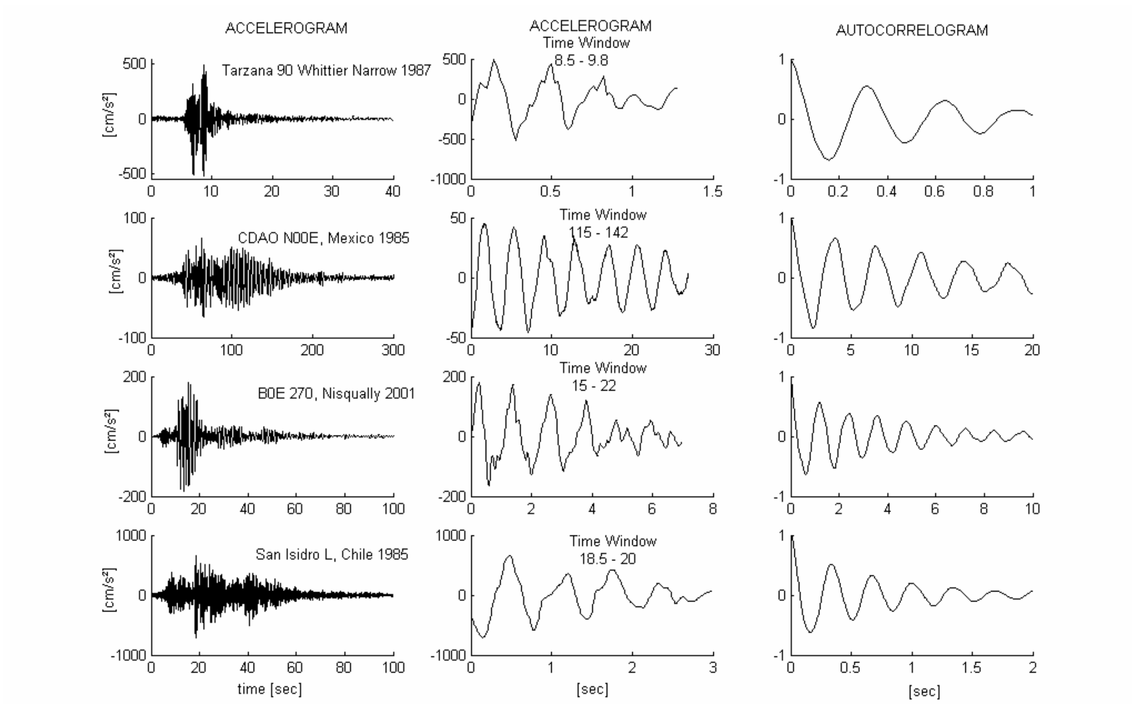
**b.** Comparison between CDAO N00E, Mexico 1985, autocorrelogram and the theoretical function $y(t)=e^{-0.05\cdot(2\cdot\pi\cdot\frac{t}{3.57})}\cos\left(2\cdot\pi\cdot\frac{t}{3.57}\right)$.

**c.** Comparison between SCT N00E, Mexico 1985, autocorrelogram and the theoretical function $y(t)=e^{-0.045\cdot(2\cdot\pi\cdot\frac{t}{2.04})}\cos\left(2\cdot\pi\cdot\frac{t}{2.04}\right)$.

**d.** Comparison between San Isidro Longitudinal, Chile Central 1985, autocorrelogram and the theoretical function $y(t)=e^{-0.104\cdot(2\cdot\pi\cdot\frac{t}{0.34})}\cos\left(2\cdot\pi\cdot\frac{t}{0.34}\right)$.

**e.** Comparison between Tarzana 90, Whittier Narrow 1987, autocorrelogram and the theoretical function $y(t)=e^{-0.1\cdot(2\cdot\pi\cdot\frac{t}{0.32})}\cos\left(2\cdot\pi\cdot\frac{t}{0.32}\right)$.

**f.** Comparison between Boeing 270, Nisqually 2001, autocorrelogram and the theoretical function $y(t)=e^{-0.07\cdot(2\cdot\pi\cdot\frac{t}{1.22})}\cos\left(2\cdot\pi\cdot\frac{t}{1.22}\right)$




**(a)** **(b)** **(c)**

**Figure 3. a** Free vibration in four different studied accelerograms, acceleration amplitude in [cm/s²]. **b** Example of time windows in strong motion part of the accelerograms in which almost harmonic damped acceleration amplitudes are observed. **c** Autocorrelogram of the corresponding accelerograms showing that the period and the damping are equal to the observed in the same record.

The most noticeable of this discovery is that they happen during the strong motion part of accelerograms of large earthquake in epicentral zone or for large distances as the Mexico 1985 earthquake. Furthermore some time the peak ground acceleration of the record corresponds to these free vibrations of the soil as the case of Boeing 270 of the Nisqually 2001 earthquake.

Autocorrelogram measurements do not show important soil degradation despite the large earthquake analyzed, however these results are not general.

This result suggests that accelerograms with harmonic autocorrelograms correspond mainly to episodes of soil free vibrations and the deterministic components found in autocorrelograms by other authors in the past are these free soil vibrations.

In Figure 4 the corresponding autocorrelograms for the three components of Cauquenes station, 1985 Chile, Tarzana station, Northridge 1994 and SCT station, Mexico 1985 are shown. In this figure it can be also appreciated that besides the deterministic autocorrelograms for the horizontal components, the vertical autocorrelograms also shown the same pattern.

This situation which is not always frequent can also be appreciated for the Tarzana vertical, Northridge 1994 earthquake in the near source region of a large earthquake (PGA $\approx$ 1[g]). Figure 4 suggests that in some cases the vertical mode of vibration of the soil can also be estimated from the autocorrelograms.

From Figure 4 it can be appreciated that the characteristic period of both horizontal autocorrelograms are similar, however vertical autocorrelograms have a period that is lower than horizontal ones.

These episodes of vertical soil free vibrations that are due to seismic waves arriving from the source are strongly coupled in the three accelerogram components by high frequency Rayleigh waves (Saragoni and Ruiz, 2006).

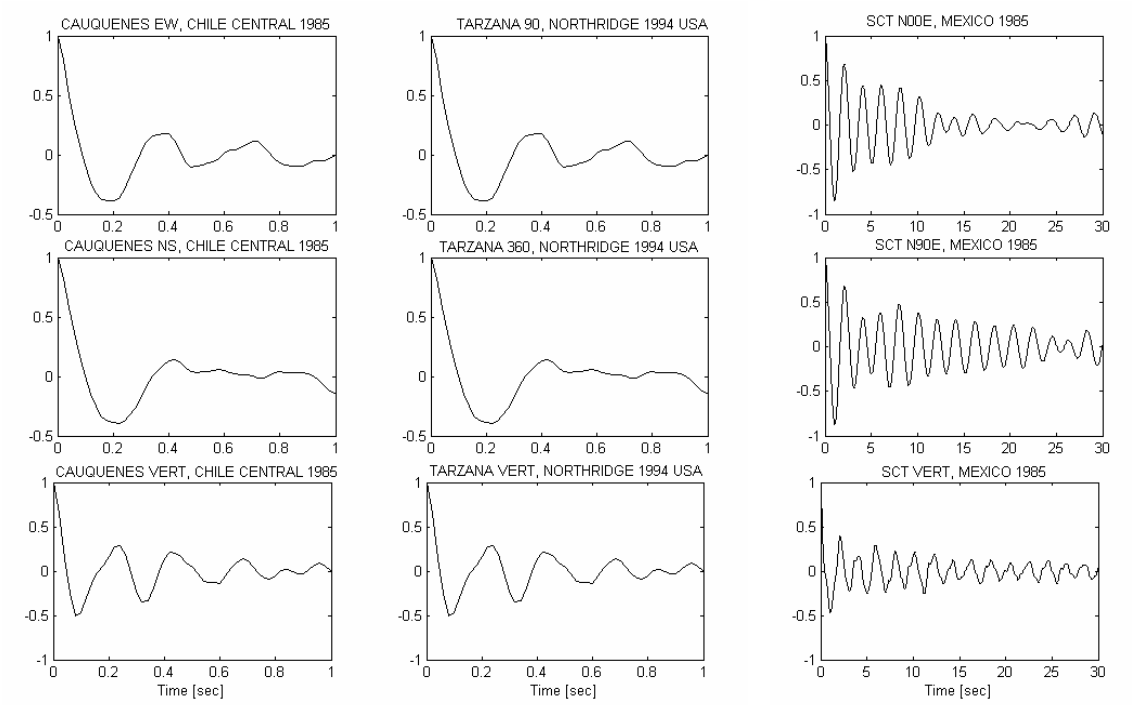



**Figure 4** Autocorrelograms of the three accelerogram components of Cauquenes station, Chile Central 1985, Tarzana station, Northridge 1994 and SCT station, Mexico 1985. Showing free damped vibrations in horizontal and vertical directions.

## ESTIMATION OF SOIL FUNDAMENTAL MODE DAMPING

The soil damping β has been empirically calculated by using the autocorrelogram technique. The obtained values from Figure 2 for San Isidro Longitudinal, Chile Central 1985, SCT N00E, Mexico 1985, Tarzana 90, Whittier Narrow 1987 and Boeing 270, Nisqually 2001, are summarized in Table 1.

**Table 1. Soil damping estimation using autocorrelogram technique**

| Accelerographic Station | Soil Damping Fundamental Mode β |
|---|---|
| 1. San Isidro Longitudinal, Chile Central 1985. | 0.104 |
| 2. SCT N00E, Mexico 1985 | 0.045 |
| 3. CDAO N00E, Mexico 1985 | 0.050 |
| 4. Tarzana 90, Whittier Narrow 1987 | 0.100 |
| 5. Boeing, Nisqually 2001 | 0.070 |

In particular, the soil damping values estimated for SCT and CDAO stations for lake clay of Mexico City are larger than the ones estimated by resonant column test of β = 0.01 – 0.03 (Romo et al. 1988) and by random decrement technique of β = 0.02 - 0.03 (Yang et al. 1989). The β values obtained from autocorrelogram technique usually slightly overestimate soil damping values, due to interference of small seismic wave arrivals during free vibrations and the interference of the other higher mode response.

## SOIL FUNDAMENTAL PERIOD ESTIMATION USING FOURIER SPECTRA AND COMPARISON WITH AUTOCORRELOGRAM TECHNIQUE

In this section the periods of the peaks of Fourier spectra are compared with the periods estimated from autocorrelation functions of the accelerograms, which correspond mainly to soil free vibrations.

During the 1985 Mexico earthquake, important accelerograms were recorded at the Mexico City lake zone. In particular the accelerograms recorded at Central de Abastos Oficinas (CDAO) accelerographic station in Mexico City for the 1985 and other 3 earthquakes are studied in this section. The stratigraphic soil of CDAO station is presented in Table 2.

**Table 2. Soil profile of Central de Abasto Oficinas, Mexico City (CDAO) (Seed et al. 1988).**

| Depth [m] | Soil Type | Shear wave velocity [m/s] |
|---|---|---|
| 0 - 5 | Silty sand | 60 |
| 5-42 | Clay | 60 |
| 42-52 | Sandy silt and silty clay | 110 |
| 52 - 56 | Stiff clay | 110 |
| | Hard Layer | 900 |

The soil fundamental period estimated from the 4 different earthquakes is 3.53 sec (Singh et al. 1988). This value is in agreement with the peaks of the Fourier spectra as well as with the period of the first cycle of the autocorrelograms as indicated in Table 3.

**Table 3. Soil period at CDAO, Mexico City station from different Mexican earthquakes estimated from Fourier spectra and autocorrelogram techniques.**

| Earthquake | Magnitude Ms | Autocorrelogram Period [sec] Component | | Fourier Spectra Period [sec] Component | |
|---|---|---|---|---|---|
| | | N00E | N90E | N00E | N90E |
| 09/19/1985 | 8.1 | 3.69 | 3.93 | 3.62 | 3.78 |
| 09/21/1985 | 7.6 | 3.71 | 3.62 | 3.71 | 3.43 |
| 04/25/1989 | 6.9 | 3.29 | 3.47 | 3.35 | 3.46 |
| 09/14/1995 | 7.4 (Mw) | 3.17 | 2.99 | 3.13 | 2.85 |

From Table 3 it can be appreciated that the soil fundamental period $T_1$ obtained from the peak of Fourier spectra coincide with the one from autocorrelograms for the 2 components of the 4 different studied earthquakes. In addition, these values are in agreement with the results of elastic soil 1D S-wave model for the fundamental period. The soil mode period is given by:

$$T_n = \frac{4H}{V_S(2n-1)} \quad ; \text{n} = 1,2,3,.... \qquad (5)$$

where n is the mode number, H the soil depth and $V_S$ the soil shear wave velocity.

Therefore the fundamental soil period can be also estimated either by autocorrelogram or Fourier spectra techniques from accelerograms of large earthquakes.

## ESTIMATION OF SOIL HIGHER MODES

The presence of different modes of vibration of soils in accelerograms can be also detected by using Fourier spectra. In Figure 5 the first, second and third horizontal mode frequencies of the soil are shown by the three peaks of the Fourier spectra for CDAO N00E and CDAO N90E accelerograms of Central de Abastos station (CDAO), Mexico City; for different Mexican earthquakes and for both components of Ventanas and Almendral, Valparaíso stations for the Chile 1985 earthquake and the corresponding main aftershocks.

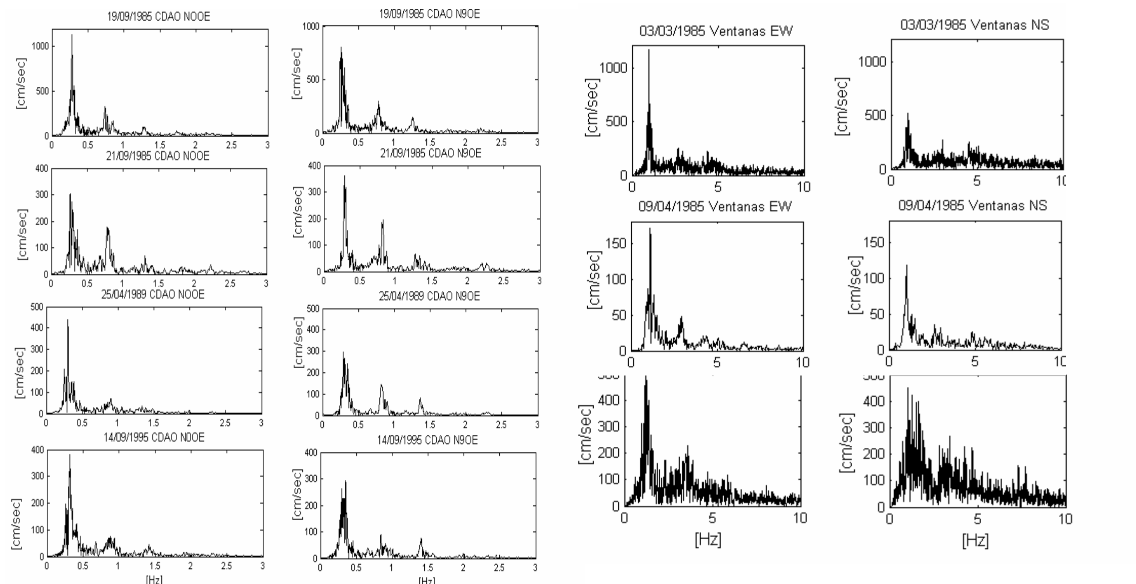



**Figure 5** Fourier Spectra from different accelerograms showing the peaks corresponding to the three first soil mode frequencies of each station. The values remain the same for each station for different earthquakes.

The frequency values of the different Fourier spectra peaks for the CDAO, Ventanas and Almendral, Valparaíso station are presented in Table 4. These values satisfy the approximate relationship 1:3:5 indicated in Table 5. Therefore, the frequency of the Fourier spectra peaks satisfies the relation, expressed in this case as natural period of vibration, by Eq (5).

**Table 4. Natural frequencies of the different modes of vibration of soil estimated from Fourier spectra peaks**

| Earthquake | Soil Mode Natural Frequencies [Hz] | | | | | |
|---|---|---|---|---|---|---|
| | 1$^{st}$ Mode Component | | 2$^{nd}$ Mode Component | | 3$^{rd}$ Mode Component | |
| México CDAO | N00E | N90E | N00E | N90E | N00E | N90E |
| 09/19/1985 | 0.28 | 0.25 | 0.74 | 0.78 | 1.27 | 1.26 |
| 09/21/985 | 0.27 | 0.29 | 0.77 | 0.82 | 1.31 | 1.27 |
| 04/25/1989 | 0.30 | 0.29 | 0.90 | 0.82 | 1.34 | 1.36 |
| 09/14/1995 | 0.32 | 0.35 | 0.88 | 0.84 | 1.42 | 1.41 |
| Chile Ventanas | EW | NS | EW | NS | EW | NS |
| 03/03/1985 | 1.00 | 0.99 | 2.72 | 3.02 | 4.38 | 4.53 |
| 04/09/1985 | 1.11 | 1.02 | 2.93 | 2.66 | 4.22 | 4.84 |
| Chile Almendral | S40E | N50E | S40E | N50E | S40E | N50E |
| 03/03/1985 | 1.21 | 1.07 | 3.59 | 3.44 | 4.74 | 4.26 |

**Table 5. Ratio between the soil mode natural frequency and the first natural mode frequency estimated from Fourier spectra peak values**

| Earthquake | Ratio Between different Soil Natural Mode Frequencies [Hz] | | | | | |
|---|---|---|---|---|---|---|
| | 1st Mode/1st Mode Component | | 2nd Mode/1st Mode Component | | 3rd Mode/1st Mode Component | |
| Mexico CDAO | N00E | N90E | N00E | N90E | N00E | N90E |
| 09/19/1985 | 1 | 1 | 2.6 | 3.1 | 4.5 | 5.0 |
| 09/21/985 | 1 | 1 | 2.9 | 2.8 | 4.9 | 4.4 |
| 04/25/1989 | 1 | 1 | 3.0 | 2.8 | 4.5 | 4.7 |
| 09/14/1995 | 1 | 1 | 2.8 | 2.4 | 4.4 | 4.0 |
| Chile Ventanas | EW | NS | EW | NS | EW | NS |
| 03/03/1985 | 1 | 1 | 2.7 | 3.1 | 4.4 | 4.6 |
| 04/09/1985 | 1 | 1 | 2.6 | 2.6 | 3.8 | 4.7 |
| Chile Almendral | S40E | N50E | S40E | N50E | S40E | N50E |
| 03/03/1985 | 1 | 1 | 3.0 | 3.2 | 3.9 | 4.0 |

From the analysis of these accelerograms of large earthquakes, it can be concluded that upper modes of vibration of soils are also observed in accelerograms of large earthquake and they satisfy the shear soil vibration condition given by Eq. (5).

These last results can only be observed when the soil is allowed by the earthquake source to freely vibrate in time windows with enough duration to show many cycles of free vibration. These time windows are sometime possible between intermittent wave arrivals of large earthquake.

Since soil vibrate in the fundamental and higher modes, the best way to estimate the modal damping is filtering the accelerogram around the fundamental period and then estimate the damping from corresponding autocorrelogram.

With the assumption that Fourier spectra have a narrow band characteristic, it is possible to filter the accelerograms avoiding the influence of the other modes and have a better estimation of the soil modal damping.

This technique is applied to the CDAO N00E 1985 Mexico, Ventanas EW and Almendral S40E, Valparaiso, Chile 1985 accelerograms. Figure 6 shows the corresponding autocorrelograms for the filtered accelerograms around the first and second mode periods. Autocorrelogram have the characteristic given by Eq. (3). In Table 6 are indicated the dampings obtained for first and the second soil modes. It can be appreciated from these figures and Table 6 that the second mode damping is somewhat greater than the one corresponding to the first mode.

**Table 6. Autocorrelogram soil period and damping estimation for the first two soil modes.**

| | **CDAO N00E Mexico 1985** | **Ventanas EW Chile 1985** | **Almendral S40E Chile 1985** |
|---|---|---|---|
| **First Mode** | | | |
| Period [sec] | 3.57 | 1 | 0.83 |
| Filtrate Rank [sec] | 10-2 | 2-0.67 | 2-0.67 |
| Damping | 0.04 | 0.04 | 0.06 |
| **Second Mode** | | | |
| Period [sec] | 1.35 | 0.37 | 0.28 |
| Filtrate Rank [sec] | 2-1 | 0.67 – 0.25 | 0.67 – 0.2 |
| Damping | 0.04 | 0.08 | 0.09 |

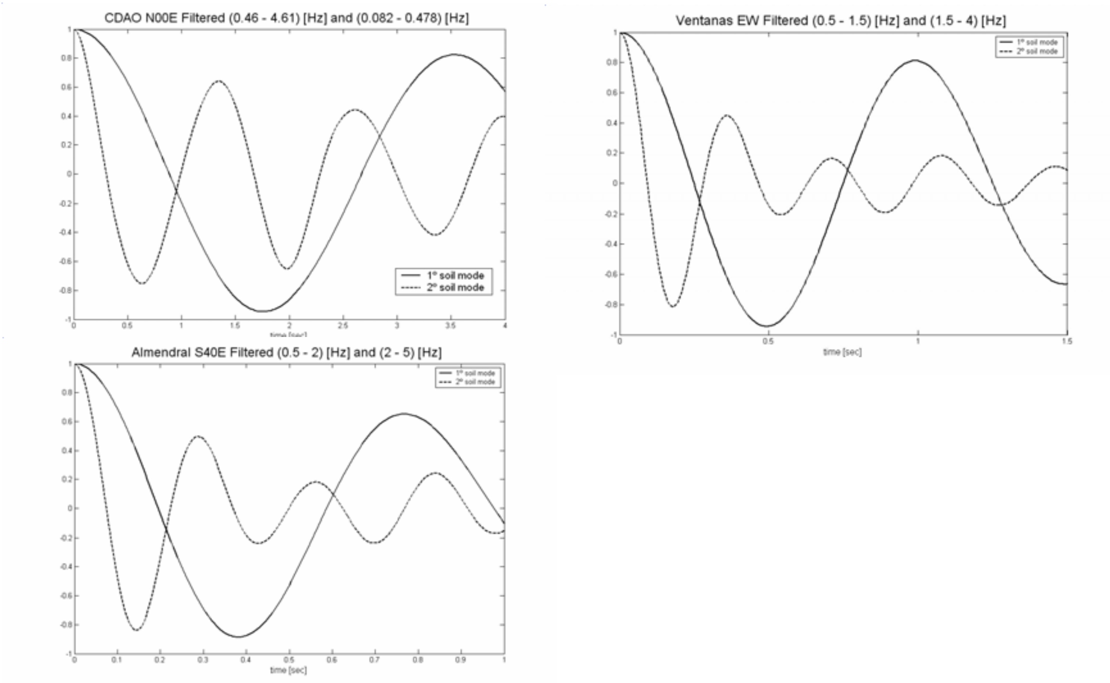



**Figure 6**. Comparison of autocorrelograms of the two first modes of the soil for the CDAO N00E 1985 Mexico accelerogram and for Almendral S40Eº and Ventanas EW, Chile Central 1985 earthquake accelerograms showing the natural period and damping. Records were filtered around the period of the first and second modes of the soil

## CONCLUSIONS

Two techniques to estimate soil mode periods and dampings from accelerogram of large earthquakes have been presented: Autocorrelogram and Fourier spectra. Both techniques allow sometimes to measure up to the three first soil modes as well as modal dampings.

Autocorrelogram techniques also allow estimating vertical mode periods as well as their dampings.

Soil modal periods satisfy classic 1D model S-wave equation. $T_n = \frac{4H}{V_S(2n-1)}$

Application of these techniques require of time windows without important seismic wave arrivals in which free vibrations can be developed.

Soil damping estimation from autocorrelogram technique can be overestimated due to interference of small seismic wave arrivals and higher mode responses.

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