Geofísica Colombiana | Nº. 7 | pp. 74-78 | diciembre de 2003 | Bogotá, D.C. | ISSN - 0121 - 2974

Application of neural networks to obtain the site response in Mexico city

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RESUMEN

Hemos implementado una red neuronal de tres capas escondidas con 40 neuronas por capa para ser usada como funciones de trasferencia suelo/roca en dos estaciones acelerométricas en Ciudad de México. La red fue entrenada con entrenamiento supervisado por medio de vectores de aceleración de entrada y salida (doce registros de cinco eventos sísmicos localizados en la costa de Guerrero y uno al sur de Puebla, 5,8 M 7,3), y probado con tres registros no tomados en cuenta en el entrenamiento de la red. Los resultados obtenidos en el dominio de la frecuencia son bastante buenos, encontrándose una amplificación sísmica entre 0,2 a 5 Hz para la zona de Lago (estación RMCS). En el dominio del tiempo obtuvimos resultados que no son coincidentes. Debido a los datos y a la complejidad del fenómeno, es necesario aplicar esta herramienta usando más registros de movimientos fuertes para entrenar la red neuronal, así el fenómeno puede ser aprendido mejor mediante una base de datos confiable.

PALABRAS CLAVE: REDES NEURONALES, RESPUESTA DE SITIO, CIUDAD DE MÉXICO

ABSTRACT

We have implemented a neural network of three hidden layers with 40 neurons each layer to be used as soil/rock transfer functions for two stations in Mexico City. The net was trained with supervised learning through input and output vectors of accelerations (twelve records, from five seismic events from Guerrero and Puebla, 5.8 M 7.3), and tested with three records not taken in account in the training. The results in the frequency domain are good, finding a seismic amplification between 0.2 to 5 Hz for the Lake zone. In the time domain we obtain results that are not coincident. Due to the data and the complex of the phenomena, it is necessary to apply this tool using more records for the training net, so the phenomena can be learned better through reliable database.

KEY WORDS: NEURAL NETWORKS, SITE RESPONSE, MEXICO CITY

INTRODUCTION

The modeling of site response and specially the determination of the capacity of amplification from strong lithologic contrasts have been an aspect of relevant interest for earthquake engineering in the past three decades. A wide variety of methodologies has been proposed and applied in searching to establish transfer functions soil/rock oriented to purposes of seismic microzonation and geotechnic. Some techniques were inspired in the capacity of coda waves or ambient tremors to denote changes of stiffness or attenuation of seismic energy, others were based in physical models under visco-elastic conditions in terrain with lateral homogeneity (Borcherdt, 1970; Su *et al.*, 1992; Field and Jacobi, 1993; Kato *et al.*, 1995; Su and Aki, 1995; Steidl *et al.*, 1996; Mucciarelli, 1998; Rielpl *et al.*, 1998; Cultera *et al.*, 1999).

Popular techniques such as Nakamura (Nakamura, 1989) and standard technique have been applied in Mexican cities to study the site effect (Lermo and Chávez-García, 1994; Chávez-García and Cuenca, 1996). Due to Mexico City was funded over soft soils (layers of clay surrounded by basaltic material), it was known the amplified seismic waves and its long duration effect (Sing and Ordaz, 1993; Lermo and Chávez-García, 1994). Singh

Manuscrito recibido para evaluación el 15 de abril de 2003.
Artículo aceptado para publicación por el Comité Editorial el 30 de octubre de 2003.

and Ordaz point out that the long duration of acceleration records in the Lake zone (called soft zone) is result of multipath from the source.

Recently, the use of artificial intelligence for purposes of site response has put of manifest the practical utility of genetic algorithm and artificial neural network for the simulation of transfer functions soil/rock and inversion of others geophysical variables (Anderson, 1990; Aguirre *et al.*, 2000; Moya *et al.*, 2000; Romo *et al.*, 2000; García *et al.*, 2000; Vargas *et al.*, 2002). In this work, we try to show the importance of neural network for seismic response proposes for the Lake zone in Mexico City.

DATA

Digital acceleration data associates to five earthquakes were selected from the Instituto de Ingeniería UNAM, the Centro Nacional de Prevención de Desastres (Cenapred) and the Mexican DataBase of Strong Motion. The units are gals and the series of time are 100 and 200 samples/sec depending on the local network and instrument. Four earthquakes used are located at the Mexican coast of Guerrero State and one at south of Puebla city (see Figure 1) covering principally three different azimuths. The accelerographic stations in Mexico City taken on count due to quality of the data are RMCS (called Roma "C" in surface on clay layers or lake zone) and Cena (called Cenapred over basaltic deposits). The station called CUP4 (called C. U. Patio 4 on similar basaltic deposits as in Cena) was used in the case when Cena not registered the events numbers 1 and 2 (see Table 1).

METHODOLOGY

In this work, we have tried to determine a non-analytic transfer function capable to predict seismic response under the soft formations/hard rock relation, which can consider non-linear aspects of that relation. For that reason, we have selected to train a neural network on the basis of spectral observations of the N-S, E-W and Z components for five seismic events.

Taking in consideration some conclusions mentioned by Vargas *et al.* (2002), who computed seismic amplification factor for the Armenian area (Colombia) using neural networks with acceleration data, pointing out that the simulations with any component must keep a similar tendency in the results. For this reason, from fifteen records (5 events with 3 components) we applied twelve records in the training phase and the others three for the evaluation phase.

The utility of neural network has seen limited its use for spectral analysis. Justly, the analysis on the time domain becomes a not very practical procedure due to the high computation demanding (Vargas *et al.*, 2002; García *et al.*, 2000). In our case, it was proposed that inversion of the spectral acceleration for RMCS station on soil of Mexico City with data of spectral acceleration from stations on rock (CUP4 and Cena) through the use of neural networks based on the following criteria:

1. Spectra of the events coming from the seismic zones of Guerrero and Puebla, principal seismic sources, recorded in Mexico City show components that rarely exceed the 5 Hz
2. The longitudes of data accelerographic for seismic events with 5.7< Mc < 7.3, generally not exceed their strong movements so far than 4 minutes. Figure 2 is one example of this situation.

For the 12 records of the training phase we applied Fast Fourier Transform (FFT) to spectral acceleration determination, with an analysis of 50 seconds beginning from S wave. The following step was used a neural network with supervised learning; the inputs are the spectral accelerations in the reference station (rock) and the output the spectral acceleration on other station (soil). That network must have capacity of generalization with certain detail the spectrum (training with 12 records), for that it is necessary a good number of neurons; it was selected a back-propagation topology (Johansson *et al.*, 1990) with three hidden layers of 40 neurons and activation functions [TanSigmod LogSigmod Linear]. The first two activation functions have the capacity of learning linear and non-linear patrons, while that the

Table 1. Earthquake of acceleration data analyzed in this work registered in RMCS (soil) and Cena (rock)

#	Date	Ti-meHh:mm:ss	Mag.Mc	Lat.N(°)	Lon.W(°)	Dist.(°) - Azi.	Location
1	10 December 1994	16:17:40.9	6.3	18.02	101.56	2.7 239	NW Guerrero
2	14 September 1995	14:04:30.5	7.3	16.31	98.88	3.1 176	South Coast Guerrero
3	15 June 1999	20:42:07.1	6.7	18.18	97.51	1.9 129	South Puebla
4	21 June 1999	17:43:05.5	5.8	17.99	101.72	2.7 241	NW Guerrero
5	29 December 1999	05:19:46	5.9	18.02	101.68		NW Guerrero

third scale magnitudes of output. The learning was based in the method of conjugated gradient (Hagan et al., 1996), a powerful algorithm with rapid capacity of error convergence.

Finally, we tried to invert the waveform using Inverse Fost Fourier Transform (IFFT) in the band 0.02 to 10 Hz with intervals of 0.02 Hz in the time domain. Figure 3 shows the fidelity of the recorder interloper versus the true one.

RESULTS AND DISCUSSION

It has been appreciated in several works of site response for Mexico City, the amplification due to the contrast soil/rock is important in low frequencies mainly between 0.2 to 5 Hz (Lermo and Chávez-García, 1994; Chávez-García and Cuenca, 1996). These observations detailed with the data of this work were simulated from the neural network. Figure 4 shows an example of the capacity of reconstruction of neural network with the learned information of 12 records. We see (top of Figure 4) a real amplification effect as product of soil/rock relation. However, we can obtain an simulated amplification effect similar to real one when we use as input for the net a spectra from the rock (bottom of Figure 4). This procedure allows us to considerate the neural network as a well approximation for infering empirical transfer functions soil/rock by means of its generalization capability.

To evaluate the inference capacity of the neural network with data unknown, we used 3 records on rock (not taken in account in the training phase) to establish what similar are the deduction of the net with respect to the true spectral accelerations on the soil. In the Figure 5, we can appreciate simulated and true accelerations that follow the same tendencies, the dominants period obtained are best coincident (0.02-5 Hz). Thus, it is clear that the neural network has a well behavior as a transfer function soil/rock with unknown data and it can be used for inferring spectra on soil from spectra on rock.

On the other hand, it looks attractive to use a net for infering the waveform on the soil from the waveform on the rock. Several tests were made to obtain a transfer function in the time domain that should reach this objective. Figure 6 shows real signal on the time domain (top) where we see different amplitudes as answer of the amplification effect of the soil. Similarly, we see the true and simulated records on the soil with the learned data. These results satisfy in the first instance our requirements with a little change of the wave-phase. However, when we use records not taken in account in training, the waveforms were very different (see Figure 7). This situation is answer of the very complex problem associated to lateral heterogeneity of soils, scattering and the structure of Mexican basin. Obviously, it is necessary to use more records for the training phase that can assure optima learning and permit obtain more reliable records.

CONCLUSION

We have used five triaxial accelerographic records to determine soil/rock transfer functions for two stations in Mexico City with neural networks. In this case it was used a topology with three hidden layers of 40 neurons by layer. The net was trained with supervised learning through input and output vectors of accelerations (12 records), and tested with three records not taken in account in the training. In the frequency domain the results were good and the net has a valuable behavior as reliable tool for studies of site response. However, in the time domain the results were not coincident. Due to the complex of the phenomena, it is necessary to use more records for the training net that can learn the nature of phenomena. We suggest to made more works on this sense where exit reliable databases that permit to show the great capacity of this technology for proposes of site response.

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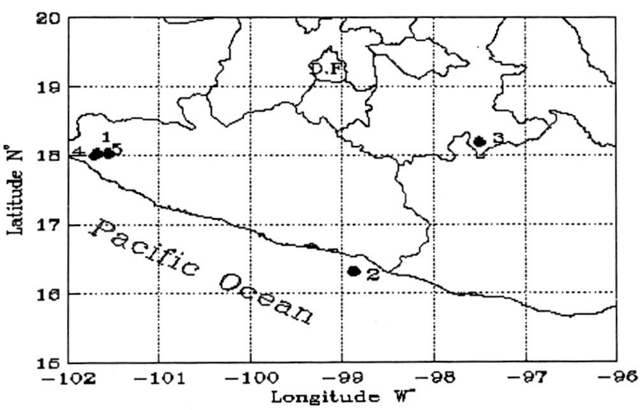

Figure 1. Five numbered earthquakes and location respect to **Federal** District (D. F.).

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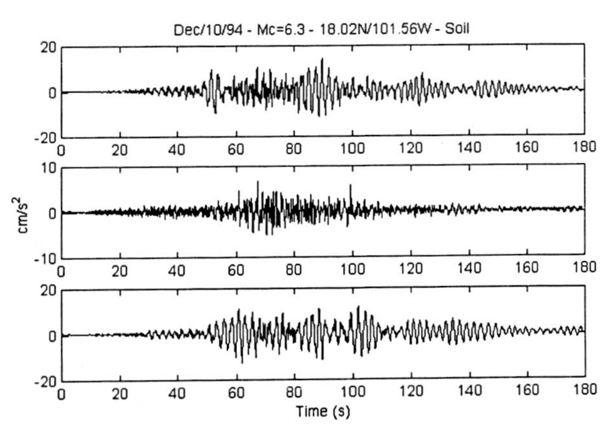

Figure 2. Event of December 10 of 1994 registered on soil for RMCS station.

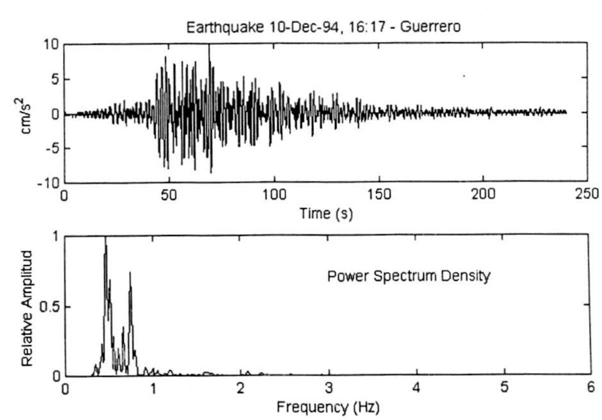

Figure 3. Signal in time (top) and frequency domain (bottom). Note the spectrum rarely exceed the 5Hz.

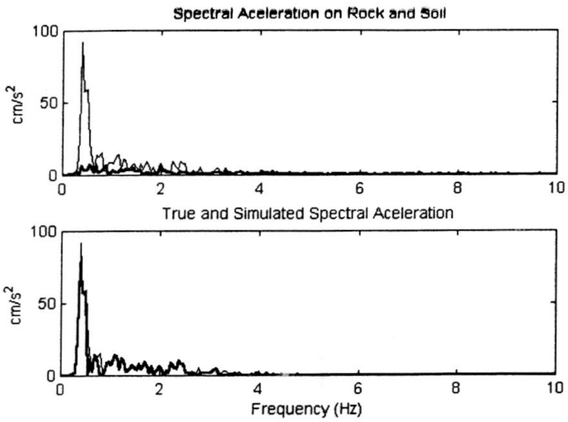

Figure 4. On the top, spectra of soil (soft line) and rock (heavy line). On the bottom, the true (soft line) and simulated (heavy line) spectral acceleration on soil, from learned data.

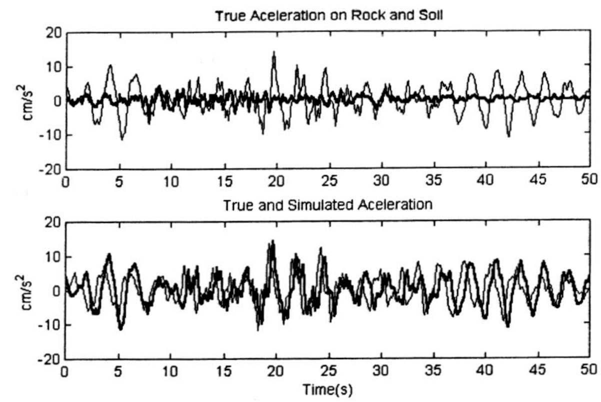

Figure 6. On the top, true acceleration on rock (heavy line) and (soft line) soil. On the bottom, true (soft line) and simulated (heavy line) acceleration for the same time window of soil.

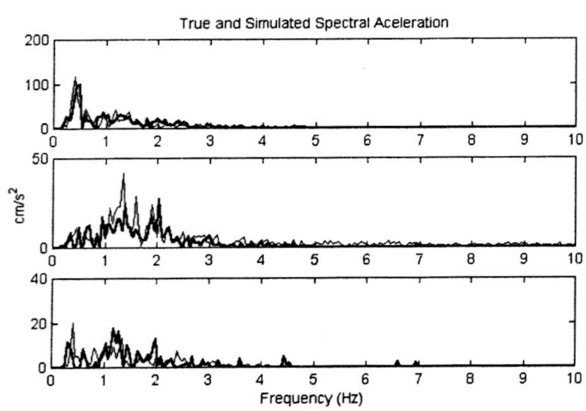

Figure 5. True (soft line) and simulated (heavy line) spectral acceleration on soil for three different records. The simulated data obtained from spectral acceleration on rock not taken in account in the training.

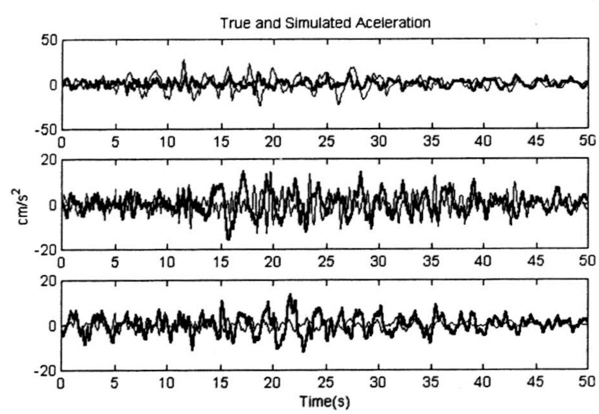

Figure 7. True (soft line) and simulated (heavy line) acceleration for three different events.