Soil-Structure Interaction Effects at Three Mexico City Accelerograph Stations Which Recorded the 1985 Mexico Earthquake

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INTRODUCTION

Recent studies have shown that soil-structure interaction effects (SSIE) might occur at accelerograph stations (i.e. Bycroft, 1978, Crouse et al., 1984, 1989). The consequence of this is that the so called free field ground motions might be distorted in their frequency content and also in their amplitudes, particularly if the soils under the stations have low shear wave velocities (Vs) (Crouse et al., 1984, 1989).

The objective of this paper is to describe an experimental study carried-out to assess the posible existence of SSIE at Tacubaya (TACY), Viveros (VIV) and Tlahuac Deportivo (TLHD) accelerograph stations at Mexico City. These stations provided some of the ground motions recorded in Mexico City during the 19th of september 1985 earthquake (Mena et al., 1986). The results of the study are presented as follows: first we discuss about the properties of the soils at the three stations, as well as about the constructions characteristics of each of them. This is followed by a description of the experiment and of the processing of the information obtained during the tests. The results of the experiment and a discussion of the SSIE observed at the stations are presented in the final part of the paper.

SOILS AND STATIONS CHARACTERISTICS

The accelerograh stations under study are located on different types of soils. Station TACY is located in the hill zone of Mexico City, on a 200 m depth pre-Chichinautzin sedimentary layer (Suarez et al.,1987). A 22 m depth borehole situated nearby the TACY station showed that up to this depth there are several alternating thin layers of clays, limes and sands. The following variation with depth (D) of the number of blows (N) from SPT tests was found in this borehole: for a D equal to 0, 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, 20.0, 22.0m, there is an N equal to 0, 15, 51, 5, 0, 72, 196, 20, 320, 30, respectively (Suarez,personal communication, 1989).This is the only information available for the TACY stratigraphy.

Station VIV is located on the transition zone which separates the hill zone from the lake-bed (soft soils) of Mexico City. According to Suarez et al., (1987) at this site a thin soft layer material of about 10m covers a 450m layer of hard sediments. A 45m depth borehole situated at a distance of about 20m from the station showed that there are alternating layers of sand, gravel and sands, clay and lime at VIV. It also provided the following information about the parameter N: for a D equal to 0, 5, 10, 15, 20, 25, 30, 35, 40, 45 m, there is an N equal to 50 (10cm), 55, 20, 50 (10cm), and 50 (5cm) for the other depths,respectively. The quantity in brackets represents the number of cm (less than 30cm) which the SPT test device penetrated into the soil after applying the N blows. No other information is available for the soils at VIV.

The TLHD station is located on the aformentioned lake-bed zone and its soils consists of saturated clays with sand lenses overlying alluvial and glacial deposits. The thicknesses of the clays and sediments at TLHD are about 70m and 300m, respectively (Suarez et al., 1987). In situ measurements of Vs have been reported by Jaime et al. (1987) from a borehole located at a distance of 20m from the TLHD station. Their resuls showed that Vs decreases from a value of 90m/s for the first 5m of depth, to a value of about 65m/s from 5 to 35m of depth; from the latter depth downwards it gradually increases its value up to 150m/s at 65m of depth. After this depth the Vs value is equal to 480m/s.

The TACY station is at the basement of a building (made of brick and reinforced concrete) 2.65m underground. Its base is made of reinforced concrete and measures 1.40m by 0.60m of cross section and 0.45m high. The base rests directly on the building's floor system and it is located at one of its corners (Fig 1a). The accelerograph is protected by a 0.04 m thick steel hut of 0.45m by 0.65m plan dimensions and 0.45 high. The building plan dimensions are 12m by 7.5m and a total height (including the basement) of about 8m,and it is founded on several isolated concrete foundations which rest directly on the soil media. The larger sides of the building (i.e. the ones in the north-south direction) are at about 2 m of distance from two similarly constructed buildings. The one in the north side has 16m by 9m of cross section and a total height of 6m (including the 2.65m of basement), and the other construction has plan dimensions of 16m by 17m and the same height.

The VIV station is located in the gardens of an urban compound at about 35m from a highrise building. It consists of a box-like reinforced concrete base of 0.95m by 0.80m of cross section and a total high of 1.35m. The base is embedded 0.40m in the soil and the accelerograph is inside the base at the ground level (Fig 1b). The base walls are about 0.12m thick, except the one in contact with the soil media, which is 0.45m thick. It also has two metalic doors of 0.70m by 0.65m, as the one shown in Fig 1b.

The TLHD station is located in an open air sport center; its base is a reinforced concrete pedestal of 0.6m by 0.5m of plan dimensions and 0.5 high (Fig 1c). The pedestal is anchored an unknown depth in the soil media (probably less than one meter). Shelter to the base is provided by a brick and reinforced concrete construction of 2.54m by 2.54m plan dimensions and 2.50m tall (Fig 1c). The floor and roof of the shelter are made of 0.12m reinforced concrete slabs. There is a gap of about 0.04m between the foot of the pedestal and the floor slab. Incidentally, this type of shelter has also been used in some accelerograph stations at California and elsewhere (Crouse et al.1989).

FIELD TESTS AND DATA REDUCTION

The microtremor technique was used to study the SSIE at the stations. This technique consists in the measuring of the low amplitude ground motions induced by natural sources such as wind,waves, and also by man made type of sources, i.e. the traffic. The technique has proved to be very efficient to estimate the fundamental frequency of Mexico City soils (Lermo et al., 1987). To study the SSIE at the stations the tests consisted in the simultaneous recording of the velocities induced by Mexico City ambient vibration, at points located on the base and its vicinity, i.e. the latter provided the free field reference points. In Fig 1 the location of these points at each station are shown.

The measuring equipment consisted of two sets of seismographs with natural periods of 5 seconds and percentage of critical damping of 0.7. Each set was composed by one vertical and two horizontal Kinemetrics seismometers, linked to a DR-100 Sprengnether digital (in cassette) recording system (100 samples per second for each component). Each set recorded the vertical (V), north-south (NS) and the east-west (EW) velocity components of the station's bases and of the free field points. As the responses of the measuring systems were practically flat from 0.2 to 20Hz, this is the range of frequencies of interest for the tests (Chavez, 1989).

During each test one set of seismometers was located on points of the base (Fig.1a) and the other set was positioned at one of the reference point shown in Fig 1, then for a lapse of 2 minutes the simultaneous recording of the velocities for the vertical and horizontal components at both locations were obtained. This operation was repeated for all the points at each of the stations. The tests were carried out during the day,when the signal to noise ratio was adequate, accordingly with the experience derivated from Mexico City microzonation tests (Lermo et al., 1987).

The processing of the information obtained during the field tests was carried out as follows, the velocity signals recorded on cassettes were transferred to a Prime computer by using an interphase card. Then, the signals were visualized and a time window for each couple of components (V, NS, EW) corresponding to the base and to the reference point under consideration, was selected. The selection criteria was based on the signal to noise ratio observed for different time windows. The time window selected for all the signals was of 40.5 seconds. Once the time window was selected, the Fourier amplitude spectra of velocity for the components (V or NS or EW) recorded simultaneously at the base and at a particular reference point were obtained by using a Fast Fourier Transform code. The computed Fourier Amplitudes were smothed by averaging them in a band of one third of octave, and then they were corrected by using response curves of the corresponding measuring system (Chavez, 1989). The final part of the processing of the information was the computation of the Transfer Functions (TF) defined by the ratios obtained by dividing, for a given component, the Fourier amplitudes of the velocity recorded at the base by the corresponding of a particular free field reference point. In Fig 2 the average of the TF's in the NS, EW and V for the three stations are shown.

ANALYSIS OF RESULTS AND DISCUSSION

From the average TF's shown in Fig 2, it can be seen that there are SSIE in the TACY, VIV and TLHD accelerograph stations. These effects produce both, amplifications and reductions in the horizontal and vertical components of the signals recorded at the bases of those stations; this can be observed for practically the whole of the frequency range of observation, i.e. 0.2 to 20Hz. The effects at TACY are smaller than at VIV and TLHD.

The amplifications in the horizontal components are up to 1.3 times in 12Hz for TACY, 6 times at 20Hz in VIV, and 2.8 times at 8Hz in TLHD; and the reductions are of up to 0.6 times for 0.3 Hz in TACY, 0.35 at 0.9 Hz in VIV, and 0.15 times at 0.3Hz in TLHD. The average amplifications for the vertical components are 1.2, 2.3 and 1.3 for TACY, VIV and TLHD, respectively; and the reductions are of about 0.8 for the three stations.

The probable causes of the SSIE observed at each of the stations might be the following. In TACY it is likely that the location of the base (2.65m underground) plays a significant role on its observed TF's. Recent theoretical studies (Luco et al., 1987) have shown that SSIE occur when a structure is partially embedded in a layered soil media, regardless of the relatively large Vs of the considered layering, as it seems to be the case for the construction that hosts the station and for the type of soils on which it is founded. Another posible cause which might be also contributing to the SSIE at TACY station is the dynamic interaction between adjacent foundation phenomena, of the type studied recently by Lin et al. (1987). As it was mentioned above the host building is located between two constructions of very similar geometry, the same materials, but larger weight.

Concerning the SSIE at VIV station, they might be linked to the type of layering of its soil media, which, as mentioned above, is characterized by the presence of rather different materials alternating each other trough the depth. This type of cases were studied recently by Luco et al. (1987).

Finally in relation to the SSIE observed at TLHD, they might be due to two causes, one is the dynamic properties of the soil layers under the station which were discussed already, and the other is the type of shelter used at this station. This type of interaction effects have also been observed at the Differential Array Station (Crouse et al.,1989). This station has practically the same type of "heavy" sheltering as the one of TLHD, and also it is located on soils with relatively low Vs, which, as in the case of TLHD soils, show a sudden diminution of the Vs values at superficial depths. These investigators used harmonic and impulse response vibration tests to study the SSIE at the aformentioned station, and the TF for the horizontal component they found shows a remarkable similarity with the ones we found for the TLHD station for the frequency range from 8 to 20Hz (Fig 2a, b). Notice that we only used the microtremor technique to obtain the TF included in this figure.

CONCLUSIONS

Taking into account that the dynamic behaviour of the soils found under the Tacubaya, Viveros and Tlahuac Deportivo accelerograph stations are very likely to remain in their linear range type of behaviour when subjected to eartquakes, including the clays of TLHD (Romo et al., 1986), lead us to the conclusion that the soil structure interaction effects, observed for the microtremors, can be also generated during the earthquakes. Therefore, amplifications and reductions (depending on the frequency) of the signals recorded at those stations (mainly on the horizontal components) might occur.

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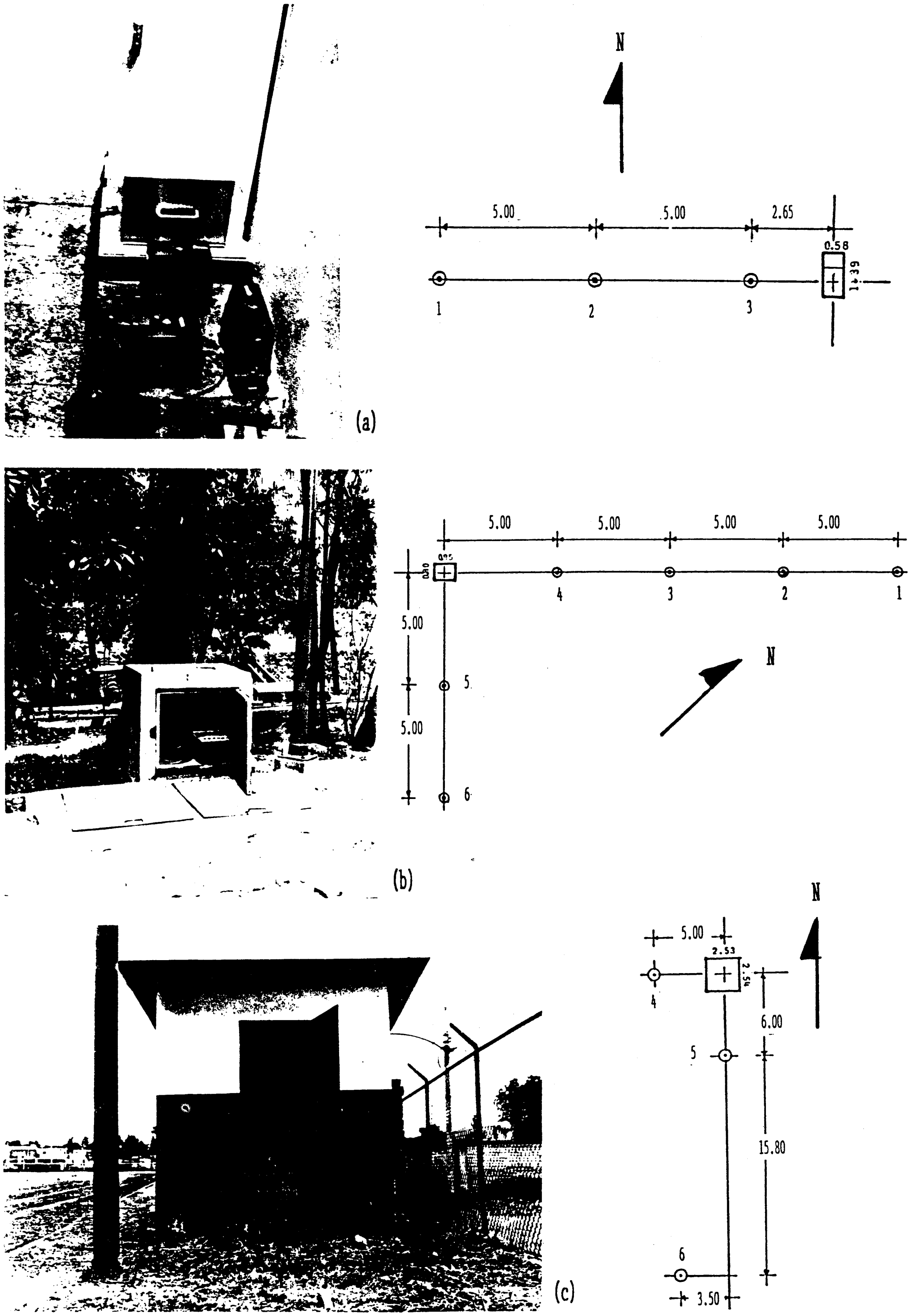

Fig. 1 Accelerograph stations and test arrays, (a) Tacubaya (TACY), (b) Viveros (VIV). Tlahuac Deportivo (TLHD). Distances in m.

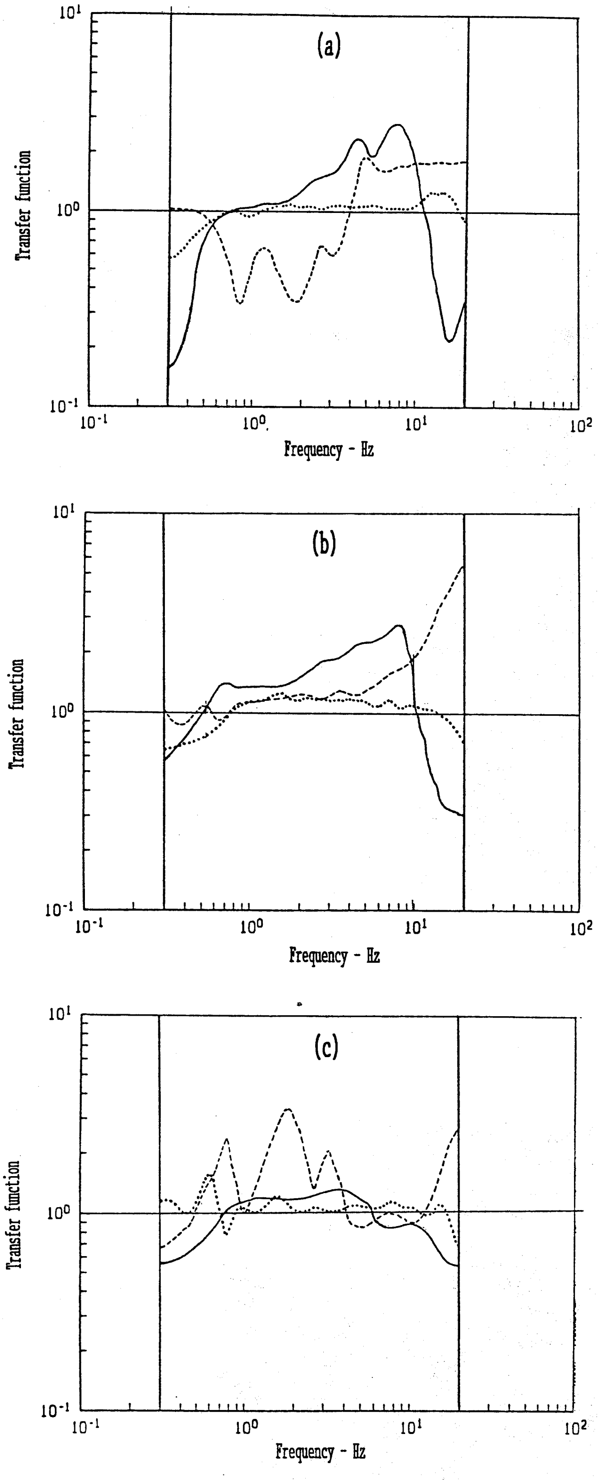

Fig. 2 Average transfer functions : (a) North-South component, (b) East-West component, (c) vertical component. Accelerograph station Tacubaya (....), Viveros (---), Tlahuac Deportivo (——).