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EXPERIMENTAL STUDY OF THE SOIL-STRUCTURE INTERACTION EFFECTS ON THREE DIFFERENT KINDS OF ACCELEROMETRIC BASES

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ABSTRACT

An experimental study of the soil-structure interaction effects was conducted for three types of bases for accelerometric stations located on intermediate soil of Mexico City. The response analysis of the bases to ambient and forced vibration led to identify the best type of base for the soil considered in the study.

KEYWORDS

Accelerometer; ambient vibration; Arias intensity; coherence; Fourier spectra; peak acceleration; interaction; transfer function.

INTRODUCTION

After 1985 Michoacan's earthquakes, several institutions installed more than a hundred accelerometric stations in Mexico City in order to study the seismic behavior of the soil. Most of them are free-field ground stations, which usually consist of a concrete base where the accelerometer is fixed. A cabinet is placed on the base to protect the accelerometer and auxiliary equipments. During an earthquake the soil's natural movement is disturbed near a structure due to the soils-structure interaction effect. Some authors have established that these effects also are generated by accelerometric stations and the main factors that affect those effects are: foundation geometry, deep and weight of the base and also the geotechnical properties of the soil.

Taking into account the mechanism of the soil-structure interaction it is recommended, in practice, the selection of the minimum size for the base, in addition to a light-weight cabinet, but both guarantying the operation, maintenance and security conditions of the station. Because of the installation of the Universidad Autonoma Metropolitana (UAM) accelerometric network, it became necessary to carry out an experimental study of the soil-structure interaction of three differents types of accelerometric stations in order to select the best for the UAM network. In this report the results of the first stage of the project for intermediate soil in Mexico City are shown.

ACCELEROMETRIC STATIONS

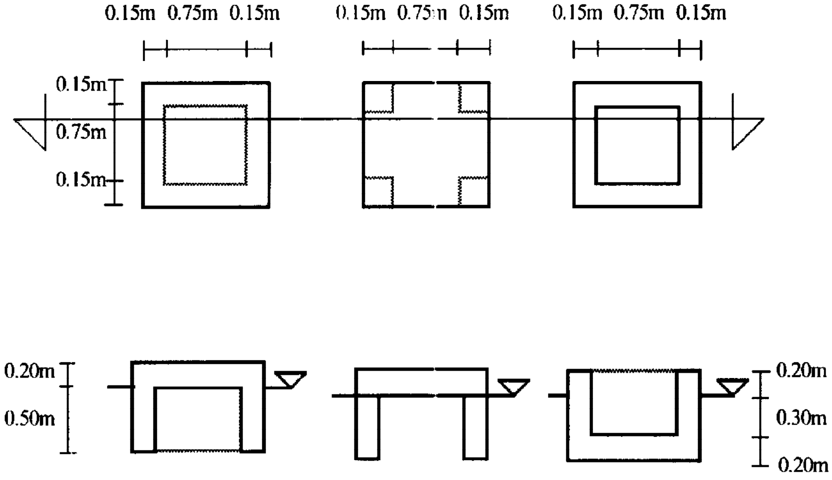
Three different types of reinforced concrete bases were built in the UAM Azcapotzalco Campus (Fig. 1); two of them with similar characteristics to those commonly used in Mexico (bases A and C). Base B is a light-weight option. A geometry description of each type is listed below:

Type "A" base: This is a 1.05m x 1.05m x 0.20m concrete slab, seated on a 0.15m wide and 0.50m deep underground perimetral beam. Its total weight is 1180 kg and the accelerometer level is located 0.20m above the ground level. (Fig. 1)

Type "B" base: This is also a 1.05m x 1.05m x 0.20m concrete slab, but it is fixed to four 0.15m x 0.15m x 0.50m deep concrete posts. The base weight is approximately 640 kg and the accelerometer level is also 0.20m over ground level (Fig. 1).

Type "C" base: This is a 1.05m x 1.05m x 0.20m concrete slab, with a 0.15m x 0.50m perimetral beam, but in this case the accelerometer level is 0.30m under ground level. Its weight is 1180 kg (Fig. 1).

The bases are located in grass open areas, and the two nearest structures are both four-story buildings, one of them 30m to the north and the other 25m to the west. The bases are aligned in east-west direction and spaced 3m between their centers. The soil is basically formed by three layers: the first is a middling compact 4.5m-thick sand layer; the intermediate is a high plasticity, soft and high compressible 5.0m-thick clay layer, and the deepest is again a middling compact sand deposit.



Type "A" base Type "B" base Type "C" base

Fig. 1. Bases for the accelerometric stations studied

EXPERIMENTAL METHODOLOGY

Ambient vibration

Ambient vibration measurements were conduced using a Kinemetrics SSR-1 digital recorder, which is able to record 200 samples per second with 16 bits resolution and six simultaneous channels. Three Kinemetrics WR-1 seismological sensors and two Kinemetrics FBA-11 accelerometric sensors were also used. During the measurements, a digital low-pass Butterworth filter was used to eliminate those frequencies above 15 Hz. A WR-1 sensor was located on each base and the FBA-11 sensors were directly located on the soil's surface between the bases; the measurement direction was normal to the common axis of the bases, in the horizontal plane (Fig. 2). With this arrangement 12 events were registered, each one of 30sec duration with five channels registering simultaneously. Ambient vibration measurements were also conducted in order to determine the fundamental period of the soil.

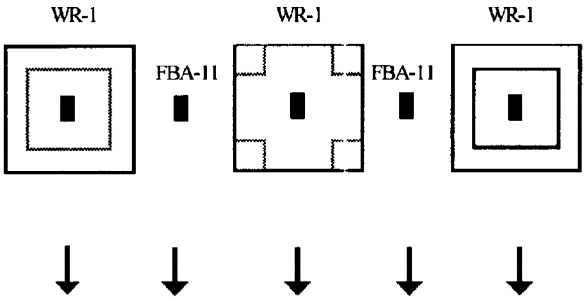


Fig. 2. Ambient vibration case

Forced vibration

Forced vibration measurements were effectuated using five Kinemetrics SSA-2 triaxial accelerometers, 1g full scale, with 200 samples per second and 12 bits resolution. On each base, an accelerometer was fixed, while the other two were located directly on the soil's surface (Fig. 3). To obtain a simultaneous trigger, the accelerometers were interconnected. Forced vibration was induced by using a pneumatic gasoline earth-compacting, machine with selectable speed, which permitted to establish two frequency cases: The first, named high frequency (+/- 60Hz), obtained at maximum speed, and the second, named low frequency (+/- 5Hz) obtained with the lowest speed. The compactor was located at two differents distances of the bases: 10m and 5m (Fig. 3); hence, four different conditions were carried out, according with the position of the vibration machine case (10m and 5m) and its frequency (high and low). For each condition 12 events of 30sec each were registered.

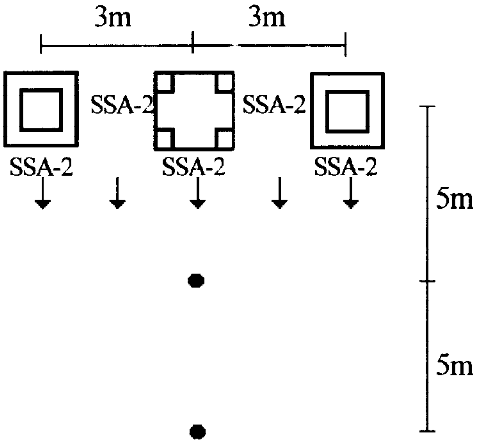


Fig. 3. Forced vibration case

SIGNAL ANALYSIS

The events were processed using the Seismic Workstation Software (Seismic, 1989). Three stages were followed to obtain the accelerograms: common format conversion, acceleration units conversion and, finally correction, filtering and accelerogram integration. Filtering was conducted using the Ormsby band-pass filter, whose limits were fixed according to the bandwidth of interest: 1.0 to 10.0Hz; the fundamental frequency of the soil, 1.67Hz, is included in this range. The acceleration response spectra were obtained from the accelerograms from 0.1 to 1.0sec. Fourier spectra defined from 1.0 to 10.0Hz were also obtained, and, finally, Arias intensities (Arias, 1969) were calculated. Arias intensity represents the dissipated energy per unit weight, for a single degree of freedom system with viscous damping. Spectra and Arias intensities were calculated for 12 events and then the average spectrum and Arias intensities average were calculated. In the case of the forced vibration, only the normal direction to the common base axis was considered, because in this direction appeared to be the greatest accelerations.

RESULTS

The criterium used in this study was to compare the signals registered on the bases with the signal registered on the soil, which was considered as the reference signal. The established comparisons and their results are as follow:

Correlation coefficient between Fourier spectra

The correlation coefficients were obtained between each base and soil spectra for both, ambient and forced vibration. In tables 1 and 2 it is observed a better behavior for base B than either A or C. Higher correlations are generally shown for high frequency as well as for the 5m distant source.

Correlation coefficient between acceleration response spectra

Correlation coefficients between acceleration response spectra were also obtained for each base and the soil's response spectra. Results are shown in tables 1 and 2 for ambient and forced vibration; it can be observed that base B had the best behavior in ambient vibration, while in forced vibration the behavior of all bases was satisfactory.

Arias intensity ratio

Arias intensity ratios were obtained also for the bases and the soil. In tables 1 and 2 results from ambient and forced vibration can be seen. In ambient vibration the best behavior is shown by base B, while with base C a low ratio was obtained. Bases A and B generally amplified the response, while base C damped the response when the source was at 10m. Amplifications were generally greater at high frequency. There is not a clear tendency of the results in relation to the source.

Peak acceleration ratio

The peak acceleration values was determined for each event of forced vibration and the ratios to and the corresponding soil acceleration values were obtained. These results are displayed in table 2. Base C had the lowest ratios, while base B showed ratios slightly greater than those of base A. There was no relation between frequency and peak acceleration ratios; on the other hand, ratios are greater with the source at a distance of 10m. All cases show ratios lower than the unit; this means that all bases filter the peak acceleration value.

Table 1. Results obtained with ambient vibration

Type of Base	Correlation Coefficient between Fourier Spectra	Correlation Coefficient between Response Spectra	Arias Intensity Ratio
Base A	0.84	0.77	0.65
Base B	0.98	0.86	1.00
Base C	0.83	0.67	0.21

Table 2. Results obtained with forced vibration

Event	Correlation Coefficient between Fourier Spectra	Correlation Coefficient between Response Spectra	Arias Intensity Ratio	Peak Acceleration Ratio
Base A, High Frequency at 10m	0.263	0.969	1.170	0.487
Base A, Low Frequency at 10m	0.581	0.943	1.400	0.690
Base A, High Frequency at 5m	0.623	0.945	0.580	0.440
Base A, Low Frequency at 5m	0.853	0.990	1.160	0.340
Base B, High Frequency at 10m	0.797	0.975	1.190	0.590
Base B, Low Frequency at 10m	0.851	0.958	1.330	0.760
Base B, High Frequency at 5m	0.801	0.993	1.880	0.590
Base B, Low Frequency at 5m	0.876	0.990	1.640	0.580
Base C, High Frequency at 10m	0.222	0.971	0.530	0.270
Base C, Low Frequency at 10m	0.249	0.975	0.640	0.480
Base C, High Frequency at 5m	0.632	0.976	1.040	0.120
Base C, Low Frequency at 5m	0.571	0.967	1.070	0.100

Transfer functions

Transfer functions, TF, were obtained for 1.0 to 10.0 Hz range. TF is defined as the ratio between Fourier spectra on each base and the corresponding soil spectra. Ambient vibration transfer functions can be seen in Fig. 4. Base B revealed the lower distortions; with maximum amplifications of about 1.6, maximum damping of 0.5 and a general tendency near unit. Bases A and C generally showed TF lower than unit, with minimum values of 0.1 in extreme frequencies. The ratios grow for bases A and C in the central range of frequencies (2 - 4 Hz). In Fig. 5 transfer functions for forced vibration are shown, and it is clear that in general there is a better behavior for base B, with amplifications less than 1.8, damping greater than 0.5 and a global tendency permanently around unit. Base A shows a slightly damped tendency for most of the events, while base C shows an attenuated behavior, with ratios less than unit in all cases. There is no influence of the frequency in transfer functions, but it was found that greatest ratios are presented at 10m distance.

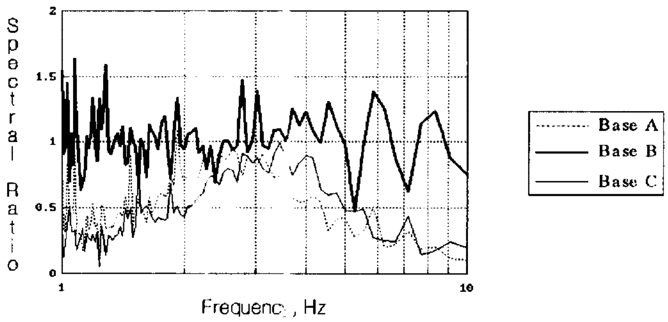
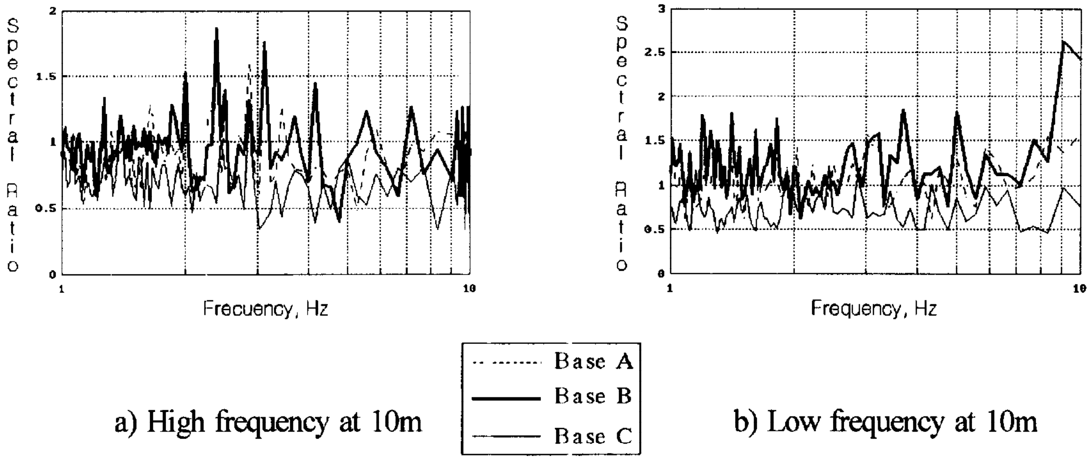
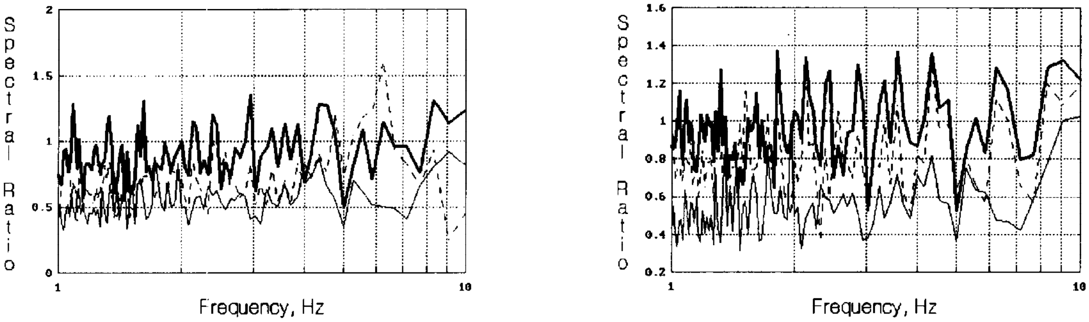


Fig. 4. Transference functions in the case of ambient vibration



a) High frequency at 10m

b) Low frequency at 10m



c) High frequency at 5m

d) Low frequency at 5m

Fig. 5. Transference functions in the case of forced vibration

Coherence functions

Coherence functions were obtained between each base and the soil's signal. Coherence function measures the extent to which a y(t) signal may be predicted from an other x(t) signal by an optimum linear least squares relationship in frequency domain (Bendat, 1989). MAC\RAN signal analysis software (USS, 1990) was used to obtain coherence functions from 1 to 10Hz range. From coherence functions for ambient vibration (Fig. 6) it can be seen that bases A and B are similar because coherence functions for this bases are satisfactory from 1 to 3Hz and from 6 to 10Hz. Base C shows the poorest behavior in all frequencies. High frequency cases produce higher coherence values than low frequency cases; furthermore, distance effect does not seem to affect coherence values. The poor behavior observed from 3 to 6Hz in forced vibration could be explained by dynamic characteristics of the equipment used to produce vibration (Fig. 7).

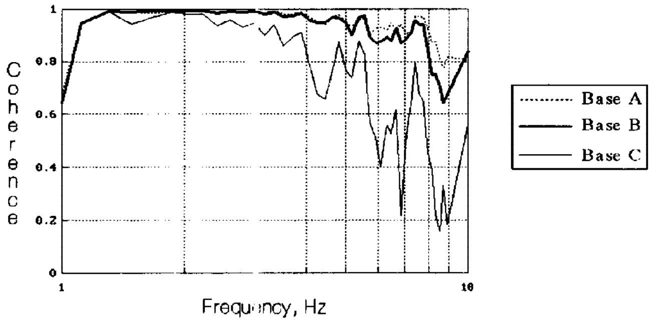
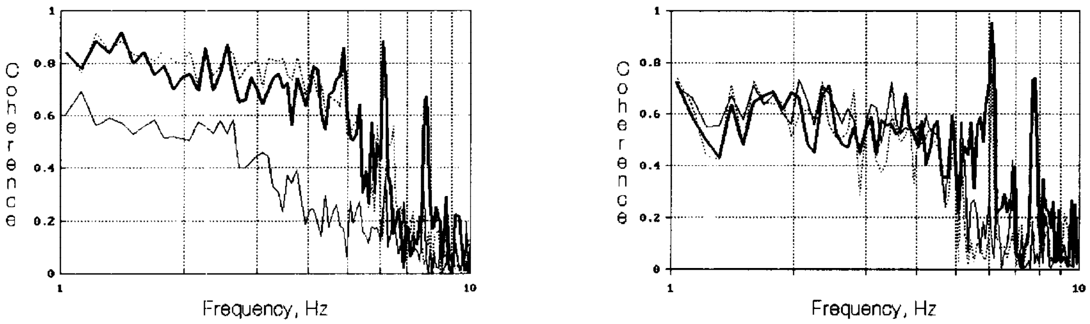
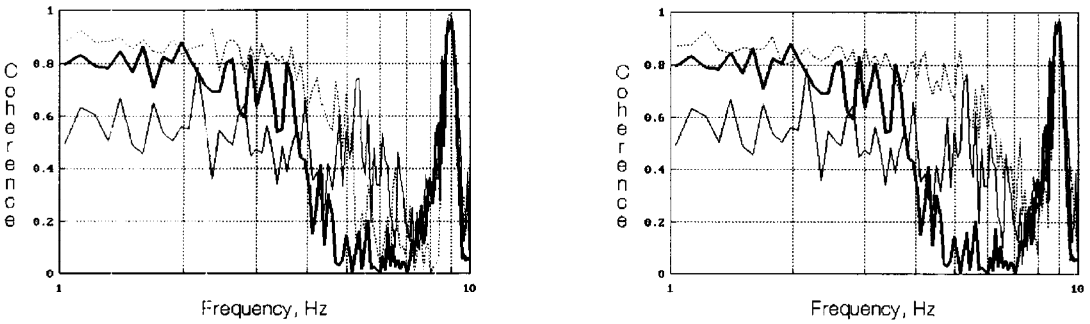


Fig. 6. Coherence functions obtained with ambient vibration



a) High frequency at 10m

b) Low frequency at 10m



c) High frequency at 5m

d) Low frequency at 5m

Fig. 7. Coherence functions obtained with forced vibration

CONCLUSIONS

Soil-structure interaction effects exists in the three types of bases studied. Those effects were evident in the amplifications and deamplifications observed in transfer functions and reaffirmed by coherence functions. Correlation coefficients between Fourier spectra and acceleration response spectra, Arias intensity ratios and peak acceleration ratios led to identify the degree of importance of those effects on the bases. It has also been determined that distortions founded in Fourier spectra are not generally important for bases A and B and that acceleration response spectrum obtained in all cases practically were not affected. The greatest distortions were observed in parameters such as the Arias intensity ratios and peak acceleration ratios, mainly in base C, in which the greatest damping effects were observed. The type of vibration, ambiental or forced, modifies the degree of the effects of the soil-structure interaction, as it was observed in each of the parameters compared: the correlation between Fourier spectra is better in ambient vibration than in forced, while correlation between acceleration response spectra is higher in forced vibration. The same happens with Arias intensity ratios. The base behavior related to frequency and distance of the excitation is generally higher for high frequency and 5m distance. Responses of bases A and B are satisfactory from 1.0 to 3.0 Hz according to the results. In this frequency range are placed the most common structures and the studied soil's natural frequency. In general terms, base B shows the best behavior, nevertheless, considering that differences between bases A and B are not important and taking into account that weight and geometry of base A supply the best security conditions, base A was selected to be used in the UAM accelerometric network.

Theorical and experimental studies of the behavior of accelerometric stations in Mexico City are recommended in order to determine the more convenient conditions of geometry, weight, cabinet and foundation according with soil's conditions. Finally, experimental studies of this type are recommended in operating accelerometric stations in order to take into account real seismic vibrations because it was found in this work, the type of vibration affects directly the behavior of an accelerometric station.

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