ANALYTICAL AND EXPERIMENTAL STUDY OF REAL MASONRY BUILDINGS

M. I. Enrique CRUZ GÓMEZ[1]

SUMMARY

Using small vibration produced by human and car transit, frequencies and modal shapes corresponding to ten masonry structures of five levels located in Mexico City were determined. The mechanical properties of the masonry used in the structures construction were obtained in the laboratory. Two analytical models, frame-panel and wide-column, were developed. In both of them, the soil influence in the frequencies and modals shapes according to local code, NTC of design against quake of the RDF-87, were made. The experimental results were compared against the analytical models, good correlation was found for the buildings based on hard soil. With the same experimental technique it was not possible to get frequencies and vibration modes for buildings based on soft soi

INTRODUCTION

During the earthquake of September 19th 1985, Mexico City, which is located about 350 km from the epicenter, was the most seriously damaged city. The damage was related by both, the type and deep soil compressible located in the city. Other factors that influenced the damage were the intensity, quake duration and the relative big number of cycles of high amplitude with resembling periods between them. The movement gain was also extraordinary. The buildings with masonry walls stood in a very good manner the earthquake of September 1985. The damages were only in low quality constructions and previous damaged buildings; even though the natural periods of those structures are in spectrum zone where the ordinates are little, they are not reduced dramatically by ductility and were superior than the design. We can suppose that the security of those constructions is big, so that they were protected of failure. This earthquake provoked most of the reviews of the earthquake design aspects: from seismic actions to design requirements [1, 2, 3].

The structures studied belong to a popular housing building, made of masonry walls, block or brick concrete, that belong to five neighborhoods in Mexico City: Gutiérrez Najera, Zapote III, Brahams, 5 de Mayo and Ranchito. The first two places are built on hard soil and the rest of them over soft soil.

Objectives:

Motivated by these considerations, an extensive research stage was carried out to determine the natural frequencies and structure vibration modes.

The first problem, from the analytical point of view, to obtain the dynamic characteristics, is the postulation of a model without being too complicated that reflects acceptably the main characteristics. Secondly the results of the research must be compared with the results of the models to examine its components. Thus, the objectives of the research come out. They are:

a) Determine experimentally, the dynamic characteristics of the considered structures.

b) Establish the influence of the interaction soil-structure on the dynamic characteristics.

[1] *Department of Mechanical Engineering ITESM, Campus State of Mexico State of Mexico, Mexico*

c) Calibrate the mathematical model used, to obtain the structures' dynamic characteristics, determining the relative importance of both, the structural and not structural elements on them.

Contribution and importance of the work.

One of the most used structural system in Mexico is the masonry walls; however, these structures have not been studied in detail and do not count with a proper model to be analyzed. This was obvious after the 1985 earthquake; that is why it is important to analyse the natural frequencies of these structures, and look for models that justify the frequency and help to design these structures in the finest wa

METHODOLOGY

the record and analysis of the forced, free or environmental vibration is required [6]. In this research, both free and environmental vibration were used by creating them from the wind, car and human transit. The advantages of this method are: they do not interrupt the normal function of the building, the electronic tool is easy to convey and a small staff is required. The disadvantage is that the acceleration is too small (approximately 0.01 gal), requiring the use of special equipment.

Six concrete brick and three concrete block wall piles were built. With three pieces each, joined by a mortar, cement, lime and sand in 1:0.25:3.5 volumetrical proportion. The joins thickness were 1.5 cm. Finally they were tested after 50 days of construction.

The secant module was calculated between 0 and 30% of the maximum strength, fixing the last because of slenderness [1]. The values found were 39167 kg/cm^2 to block and 48230 kg/cm^2 to brick.

Mathematical model.

A mathematical model was created in order to obtain the dynamic characteristics of the structures and to compare them with the values that were gotten experimentally. The most important step is the proper model selection. The easiest solution is making several analysis modifying the model and examining the parameters sensibility establishing their relative importance. The soil-structure interaction is a principal problem; that is why the model was studied on hard and soft base. For the last one the NTC of RDF-87 code was used [3, 5].

Two different model criteria were used: The first one was represented by frames and panels; on the second one, the walls were considered as wide columns. To calculate the frequencies, the Super Etabs program was used [4].

Frame-panel model.

The first buildings modeled were Gutierrez Najera's neighborhood, which are on hard soil, made of concrete blocks without supplement, water tanks. Later, the supplement was added to represent Zapote III's buildings. The live load on inside floors was estimated on 40 kg/cm^2 and on the roof was considered void . The rigidity module was considered 30% of elasticity module value. The concrete used on the structures has 200 kg/cm^2 strength. The elasticity module was used to low stress levels [6]. The result is shown on table 1.

Wide column model.

Gutierrez Najera's structures were modeled, without supplement, with a wide column criterion in order to have an alternative model and to distinguish the differences between structure's dynamic characteristics with respect to frame-panel criterion. The result is shown on table 2.

Soil-structure model.

The frame-panel model was used to represent the structures on soft soil. The following changes took place: the brick instead the block wall, foundation box was annexed, the supplement was set and a fictitious floor was added below the foundation to simulate the angular rigidity. The equivalent rigidities were gotten with the speed of the shear wave of 67 m/s, wich is a representative value of the ground in question. The rigidities gotten were: Kx=25556 t/m and Kr=1845495 t-m/rad, Kx=25556 t/m and Kr=555490 t-m/rad, to the longitudinal and transversal directions respectively . A variation was considered by taking in mind the lateral rigidity a velocity of the shear wave of 115 m/s due to the rigid crust in the city. The results are shown on table 3.

EXPERIMENTAL AND ANALYTICAL RESULTS COMPARISON

The equipment used to determine the structures dynamic characteristics consist about: systron donner servoacelerometers, 4310 pattern, cables signal conditioners and HP-3582A spectra analyzer with two channels. The servoacelerometers, which are transductors that transform the captured signals into a electrical proportional signal to the acceleration, they were stuck with screws over acrylic plates to the structure with epoxic resin on the selected points. The servoacelerometers are connected with cables to the conditioner, in which the signal is amplified and filtered in order to get a proper signal noise relation. Then, the signal was analyzed using a spectra analyzer, which process each servoacelerometer signal by means of the fast Fourier transform, practically obtained in real time the power spectra of such signal. The two signal plugged simultaneously to the analyzer are compared to obtain its coherency at different frequencies and the transfer functions in phase and magnitude. The signals' spectra were copied directly of the screen, taking note of the characteristic values of each spectrum.

Sensors' location.

In order to obtain the natural frequencies of the structures and the ground, eight measure points were selected: three of them on the roof, diagonally located, one on the geometric center, the other two in the opposite corners. Two near of the geometric centers of the second and fourth levels, two of them in the lower floor in opposite corners and corresponding to the roof points, the last point on ground, outside of the structure. The points located near of the geometrical centers were useful to compare the effects of movement amplification on the building. The surface point on the ground was used to measure the ground's natural periods and to estimate the soil-structure interaction.

Test results of the environmental vibrations.

In the buildings built over hard soil (Gutierrez Najera and Zapote III) was observed that in the first place the flexion frequencies were greater, due to its lower mass, since they do not have supplement, formed by the water tanks. Torsion frequencies do not have much difference because the supplement is near the rigidity center. The results are shown on tables 4 and 5.

In the buildings built over soft soil there was not any magnified spectral value, even though they were physically pushed by two people. The main excitation source of these buildings is the local traffic that produces waves, that is thought are Rayleigh waves, due to vertical movements were up to 3.5 times bigger than horizontals. The spectra obtained from the roof, lower floor and ground were very similar, being noticed in all the structures the main frequencies of the ground. Only the torsion frequencies were obtained, the rest were not possible to identify due to the characteristics of ground, the structures and the excitation. The frequencies of soft soil are indicated on table 6.

Mechanical Properties.

One important parameter to obtain the mathematics model is the elasticity module of masonry. For that reason it was experimentally obtained. The material was taken directly from the work place. Due to the few pieces of materials that we had (35) it was not possible to determine with great accuracy that value, but it was considered representative.

For the structures over hard soil, with the frame-panel model taken as reference, the frequencies values obtained were from 5 to 10% different from the experimental tests. The experimental values show that the structures over hard soil are a little bit more rigid in the longitudinal direction than in the transversal direction. The frame-panel criterion indicate the opposite result, table 1. Correlation for the first vibration mode of the buildings built over hard soil is good as it shown in tables 1 and 4. The wide column criterion taken as reference, have a difference from 10 to 15% in the frequencies of the first mode; in this case the longitudinal rigidity is bigger than the transversal, as was indicated experimentally, tables 4 and 5. When the influence of the ground is introduced, frequencies values are reduced more than 100% with respect to the obtained in hard soil, table 3. The objection to obtain experimentally the frequencies in soft soil seems to be due to the structure moves almost rigid body with present excitation on the environmental vibration. This could be noticed on the similarity of the power spectra obtained from different structures' points and observing that the transference function does not show any important peak, having in the other hand high values of the coherence in most part of the specter. The studied buildings are very rigid, which can notice in their frequencies. This is due to, between other factors, to the high density of the walls; which is 24.4 cm/m^2 in the longitudinal direction and 34.9 cm/m^2 in the transversal direction.

CONCLUSIONS

possible, except for those of torsion. This was due to the analysis assumption, that the excitation must be a random stationary process that have relatively plane spectrum, in order to respond all the modes, it can not be done. It seems that the torsion modes does not look affected by the type of soil, because the value found on hard and soft soil was similar. A great uniformity of the rigidity of the structures was experimentally observed because in all the buildings built over hard soil the rigidity of the transversal direction was a little bit lower than the longitudinal one. With the frame-panel criterion it was established, that by neglecting wall connection which are in adjacent span in the analysis direction point out significant differences in the frequencies.

Even in the wide-column modelation was found a bigger difference between the experimental values, we can observe that the relationship between the frequencies of longitudinal flexion to transversal one is more similar to the experimental. Here the small wall played a very important role. The analytical models indicate that the kind of wall piece, block or concrete brick, does not influence the natural frequencies for these structures, because the best bricks properties versus the block are compensated with the biggest weight. The rigidity module value was left uncertain but was supposed equal to the 30% of the elasticity module. The soil-structure interaction in the determination of the natural frequencies, was demonstrated because their values were reduced more than 100%.

Table 1. Building based on hard soil. Model frame-panel

REFERENCE MODEL	COMPONENT	FREQUENCIES [Hz]	
		FIRST MODE	SECOND MODE
Coupling wall Small wall Effective length Material properties for small stress Beam-slab coupling	Longitudinal Transversal Torsion	5.40 5.43 6.88	17.20 17.28 22.40

Table 2. Building based on hard soil. Model wide-column

REFERENCE MODEL	COMPONENT	FREQUENCIES [Hz]	
		FIRST MODE	SECOND MODE
Transformed section Small wall Effective length Material properties for small stress Beam-slab coupling	Longitudinal Transversal Torsion	6.03 5.72 7.55	20.18 20.21 25.25

Table 3. Building based on soft soil. Frame-panel model

MODEL	COMPONENT	FREQUENCIES [Hz]	
		FIRST MODE	SECOND MODE
Kx, Kr Vs=67 m/s	Longitudinal Transversal	2.07 1.28	6.23 5.62
Kx, Vs=115 m/s Kr, Vs= 67 m/s	Longitudinal Transversal	2.38 1.33	8.94 8.75

Table 4. Experimental frequencies. Gutierrez najera

BUILDING	FREQUENCIES [Hz] FIRST MODE			FREQUENCIES [Hz] SECOND MODE		
	LONG	TRANSV	TORS	LONG	TRANSV	TORS
1	5.54	5.40	7.06	19.6	21.8	......
2	5.36	5.08	6.90	19.6	22.0	......
3	5.48	5.16	7.12	......	......	......
AVERAGE	5.46	5.21	7.03	19.6	21.9	......

Table 5. Experimental frequencies. Zapote iii

BUILDING	FREQUENCIES [Hz] FIRST MODE			FREQUENCIES [Hz] SECOND MODE		
	LONG	TRANSV	TORS	LONG	TRANSV	TORS
A	4.88	4.58	7.12	19.6	17.4	......
B	5.16	4.64	7.20	......	......	......
AVERAGE	5.02	4.61	7.16	17.4	17.4	......

Table 6. Soil frequencies. Soft soil

PLACE	COMPONENT, FREQUENCIES [Hz]		
	LONG	TRANSV	VERTICAL
BRAHAMS	2.56	2.64	2.40
EL RANCHITO	3.36	2.64	1.76
5 DE MAYO	2.40	2.56	1.68

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