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Dynamic Characteristics of Buildings from Signal Processing of Ambient Vibration

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Abstract. The experimental technique used to determine the dynamic characteristics of buildings is based on records of low intensity oscillations of the building produced by various natural factors, such as permanent agitation type microseismic motions, city traffic, wind etc. The possibility of recording these oscillations is provided by the latest seismic stations (Geosig and Kinemetrics digital accelerographs). The permanent microseismic agitation of the soil is a complex form of stationary random oscillations. The building filters the soil excitation, selects and increases the components of disruptive vibrations corresponding to its natural vibration periods. For some selected buildings, with different instrumentation schemes for the location of sensors (in free-field, at basement, ground floor, roof level), a correlation between the dynamic characteristics resulted from signal processing of ambient vibration and from a theoretical analysis will be presented. The interpretation of recording results could highlight the behavior of the whole structure. On the other hand, these results are compared with those from strong motions, or obtained from a complex dynamic analysis, and they are quite different, but they are explicable.

1. Introduction

Generally, the earthquake damages to buildings are related also to changes in time in the oscillation periods of buildings and to evolution of degradation, deformation and cracks that accumulate in the structural system and they can be important. The natural period of vibration is thus an important dynamic factor which defines how a building structure will have the response to a severe ground motions [1-3].

On the other hand, the recorded accelerograms allow to realize the destructive potential of earthquakes (frequency content, amplitude, duration) and to determine the nature of vibration and characteristics of vibration in buildings (spectral response, spectral amplitude Fourier).

The permanent microseismic agitation of the soil, as an ambient vibration, is a complex form of stationary random oscillations. The building filters the soil excitation, selects and increases those components of vibrations corresponding to its natural vibration periods. The possibility of recording these oscillations is provided by the latest seismic stations Geosig and Kinemetrics digital accelerographs. From signal processing (baseline correction, filtering the data etc.), integration of the corrected acceleration, in order to obtain velocity and displacement waveforms, computation of acceleration response spectra and others parameters are made.

2. Concept of dynamic structural characteristics from low intensity vibrations

Measurement of vibration periods can be made at any time during the operating period of the building and the ambient vibrations occur continuously. For the experimental determination of the vibration periods, oscillations of low intensity are simultaneously recorded at different points located on the same vertical or at the same level.

Determining the structural dynamic characteristics plays an important role in the following situations:

- a global appreciation of structural rigidity variation and global/local damage degree, if the measurements/records are made before and after a major seismic event;

- the establishing a correlation between the dynamic characteristics determined at low levels of stress, such as ambient / microseism sources, and those from severe earthquakes;

- the establishing a correlation between the increase of the vibration periods and the orientation of the building, or the local intensity, in the case of strong recorded seismic motions;

- the possibility of statistical interpretation and obtaining simple calculus relations for determining the period;

- obtaining an interval in which are the values of the periods obtained from vibrations with low amplitude, or microseismic vibrations with low intensities and ambient vibrations, compared to those determined from the recordings of severe earthquakes, as well as those obtained from a dynamic calculation;

- the knowledge of the fundamental period of the building is particularly important for estimating the seismic base shear force in seismic designing of structural systems.

For more accurate knowledge of the seismic signal arriving at the building, several accelerometers, placed under free-field conditions and in depth boreholes instrumented with accelerometers, are required to provide data on the spatial, horizontal and vertical variation of the seismic / microseismic motions.

In Romania, the permanent seismic monitoring of buildings is in accordance with two important Romanian Codes (Normative on the behaviour of buildings over time P130/1999 and The seismic design code P100-2013, Annex A- Seismic instrumentation of buildings) [4-6]. So, in the seismic design code, these provisions are set:

- in areas where the value of the design acceleration is a_g= 0.25g, buildings classified as class I of importance-exposure and buildings with above height of over 45 m, classified as class II of importance-exposure, will be seismically instrumented by digital accelerometers placed at the top level and in free field / at the base of the building and, optionally, in specific deep boreholes or in other positions in the building;

- the instrumentation, maintenance and operation are in the responsibility of the building owner and the records obtained during strong earthquakes should be available to authorities.

3. Some selected buildings, with different instrumentation schemes

In a complete building analysis, it is also necessary, besides the building design technical documentation, and of experimental data on in-situ investigations (e.g. accelerographic data).

Criteria for selecting buildings proposed to be monitored are numerous: seismic zoning of the territory; data on structural system and types of existing structural systems, depending on the material pre and post-1940; the effect of vibration other than from the seismic vibration; location-site; seismic stations and sensors, sensors position/location in a building; correlations between data obtained directly on the ground, analytical and from the instrumented buildings; the allocated budget etc. and should be applied taking into account the possibility of obtaining the agreement of the institutions, their owners.

3.1. Buildings where the selection criterion was applied to obtain data on ambient motions and structural response

The first two buildings are from an area where in 2016 large peak ground acceleration values were recorded at the Vrancea earthquake from 24.09.2016, with a local magnitude (M_L) of 5.3. The maximum values were recorded at a seismic station in Iasi and in vicinities, their values being 0.7…0.9 m/s^2.

Hotel-type building (recordings in 23_28.09.2016 period of time), Iasi. This building was constructed in 1969, with basement, ground floor and 13 levels, the height H= 48 m, and with a monolithic structure on reinforced concrete frames, figure 1. Sensors at basement, ground floor, level 5 and level 13.

Hospital-type building (recordings in 22_29.09.2016 period of time), Iasi. Building was constructed in 1972, with basement, semi Basement, ground floor and 6 levels, the height H = 28.9 m, variable height regime, structural system in reinforced concrete frames and with isolated foundations, figure 2. Sensors at basement, ground floor, level 3 and level 6.

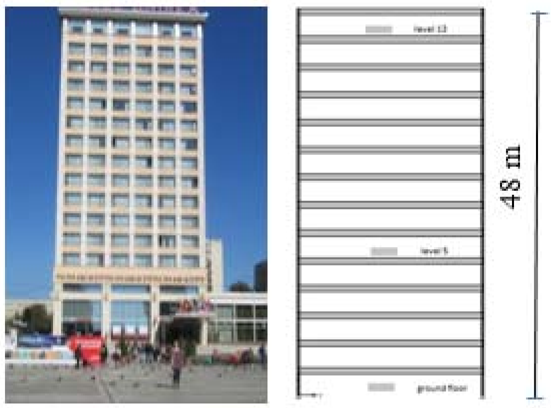

Figure 1. Hotel-type building, Iasi. Vertical layout of sensors.

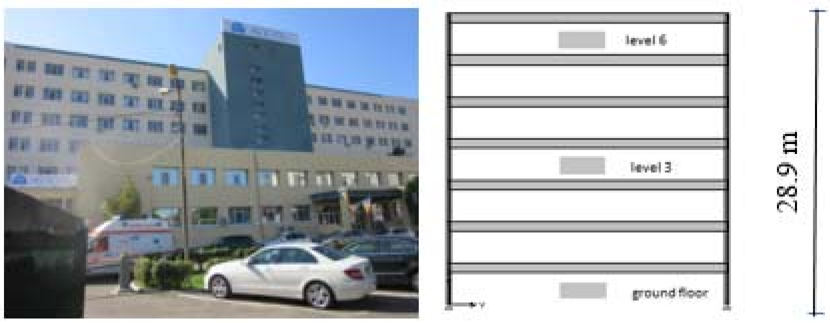

Figure 2. Hospital-type building Nicolae Oblu, Iasi. A vertical scheme for sensors setting

3.2. Buildings where the selection criterion was applied to fill in the data on a seismically expertised / instrumented building and at ambient vibrations

The third building is from Bucharest, an area of the country heavily affected by the Vrancea seismic source.

The seismicity of Vrancea is characterized by a source process and some spectral characteristics of this intermediate-depth source in a narrow epicentral and hypocentral region. Thus, according to some studies [7], for Vrancea source the following most important characteristics are considered:

- the frequency content of the Vrancea ground motions shows significant differences in source mechanisms, a directivity between events and an asymetric distribution of the ground motion;
- soil condition in Bucharest with long predominant period of ground vibration T =1.4-1.6s;
- the extent of the macroseismic effects etc.

Block of flats-type building, Bucuresti (recordings in 16_25.08.2016 period of time). This building is a complete example, possessing convincing technical information and that has often been instrumented at ambient vibrations or before/after serious earthquakes, figure 3. Sensors at basement, ground floor, level 5 and level 10.

Block of flats, section E, constructed in 1968, a structural system with Basement, Ground Floor, 10 levels and a Technical floor, homogeneously on height, with dimensions in plane 24.10x12.65 m, H=30.36 m, H_{level} = 2.75 m, III importance class (an ordinary building, importance factor is 1, according to P100-2013), figure 3. There are also reinforced concrete shear walls on two directions with highly developed areas in the ladder zone, with continuous foundations (bearings reinforced concrete and concrete blocks), brick walls from normal or hollow / vertical hollow bricks.

Figure 3. Block of flats-type building, Balta Alba Bucuresti. A vertical scheme for sensors setting

4. Structural dynamic characteristics from the processing of records and simplified calculation formulas

Determination of dynamic characteristics, also referred to as "modal parameters", is particularly important when trying to validate a finite element analysis or in case of monitoring the structure [1, 6, 7].

In order to get the domain of periods obtained from low amplitude/seismic vibration records with reduced intensities/ambient vibrations, compared to those determined from simplified calculation according to P100-2013/ Annex A, figure 4 and 5 and table 1, respectively figure 6 and table 2 are presented. In the simplified calculation relations, the effect of reducing the stiffness of reinforced concrete elements due to their cracking to severe seismic actions is not taken into account.

From the analysis of building records, the horizontal motions at basement, intermediary level and top are comparatively represented and the modal frequencies are identified from the top over basement spectral ratios or they can also be estimated from the Fourier amplitude spectra of top motion.

Acceleration time histories (from the ambient vibrations in Iasi city) and Fourier spectra (level 13, 5 and ground floor)

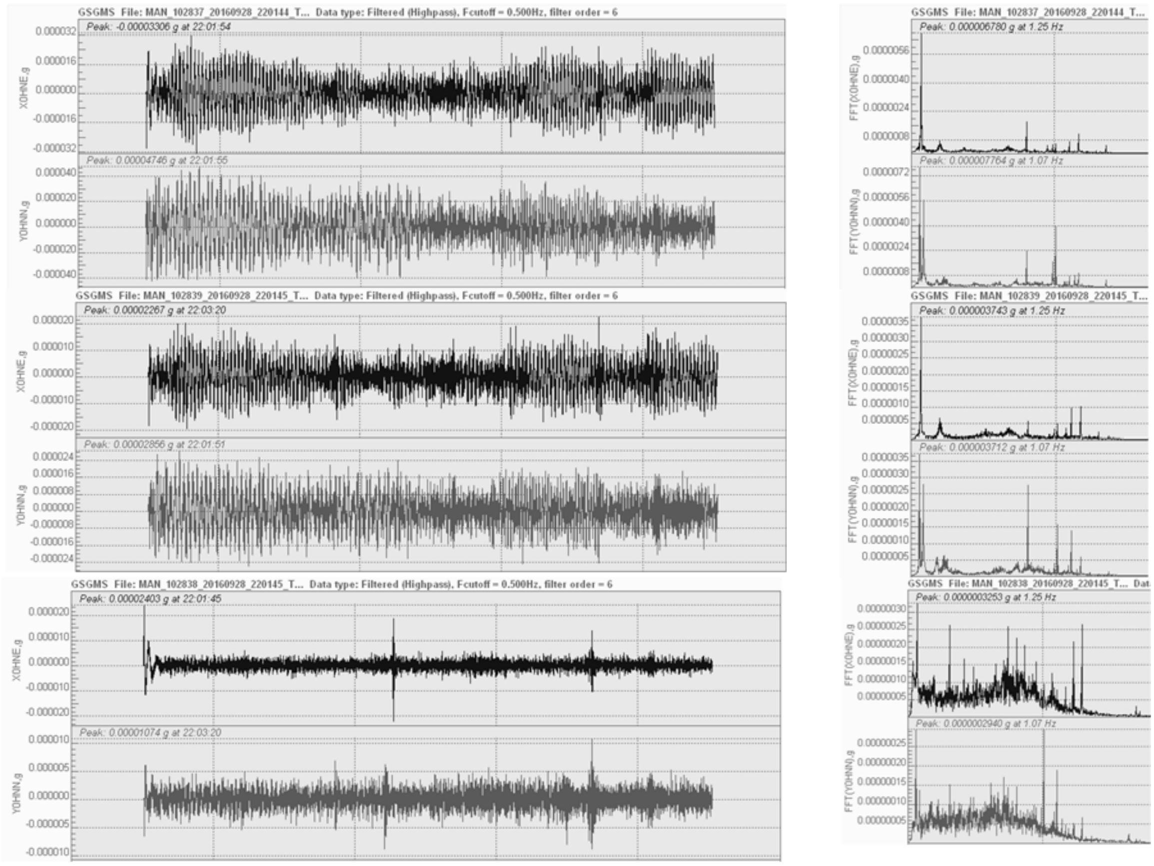

Figure 4. Acceleration records, hotel-type building. Vertical scheme for sensors setting (sensors at basement, ground floor, level 5 and level 13), predominant frequencies f_x=1.25 Hz (T_x=0.8 s); f_y= 1.07 Hz (T_y=0.9 s). It is noticeable the possibility of determining frequency also for the vibration mode 2

Table 1. Simplified formulas for estimating the fundamental period (Annex A, P100-2013) and the value of the vibration period for the experimentally determined vibration modes

Natural fundamental periods	
Type of structure, height $T_1 = C_t \times H^{0.75}$ C_t coefficient whose values are function of the structure type, H height	Experimental (2016)
*Hotel-type building, Iasi (*B+G+13 levels, H = 48 m)	
T_1= 0.92 s	T_{tr}= (0.80, 0.82) s T_{long}= (0.64, 0.93) s
*Hospital building, Iasi (*B+SB+G+6 levels, H =28.9 m)	
T_1= 0.63 s	T_{tr}= (0.45, 0.54) s T_{long}= (0.36, 0.53) s

Acceleration time histories (from the ambient vibration in Iasi city) and Fourier spectra (level 6 and 3)

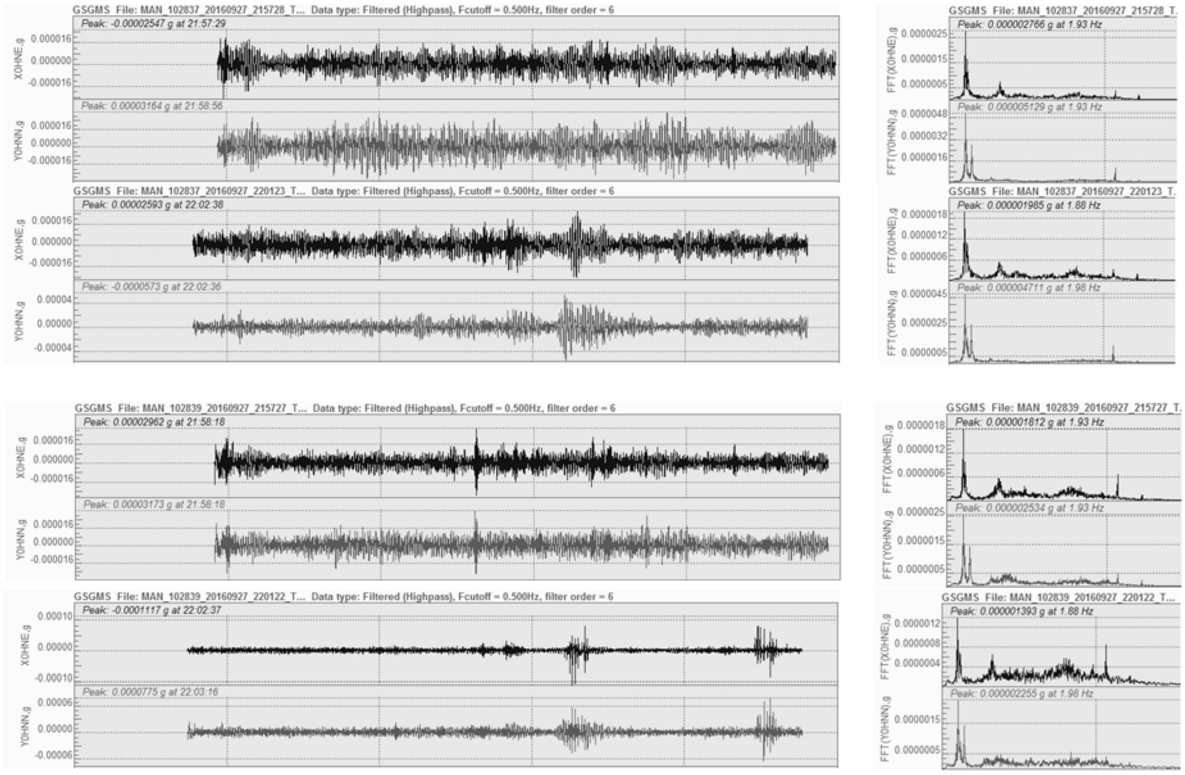

Figure 5. Acceleration records, hospital building. Vertical scheme for sensors setting (sensors at basement, ground floor, level 3 and level 6), predominant frequencies f_x= 1.88 Hz (T_x=0.53 s); f_y= 1.98 Hz (T_y=0.51 s). It is noticeable the possibility of determining frequency also for the vibration mode 2

Table 2. Simplified formulas for estimating the fundamental period (Annex A, P100-2013) and the value of the vibration period for the experimentally determined vibration mode

Natural fundamental periods with simplified formula and experimental data (low intensity vibrations)			
Type of structure, H, B dimensions $T = 0.07 \times \frac{H}{\sqrt{B}}$	Type of structure, height $T_1 = C_t \times H^{0.75}$ C_t coefficient whose values are function of the structure type, H height	Experimental (1984)	Experimental (2016)
*Block of flats building, Bucuresti (*B+G+10 levels, H= 30.36 m)			
T_{tr}= 0.60 s T_{long}= 0.43 s	T_1= 0.65 s	T_{tr}= 0.59 s T_{long}= 0.49 s	T_{tr}= (0.57, 0.59) s T_{long}= (0.48, 0.49) s

Acceleration time histories (from the ambient vibrations in Bucharest city) and Fourier spectra (level 10, 5 and ground floor)

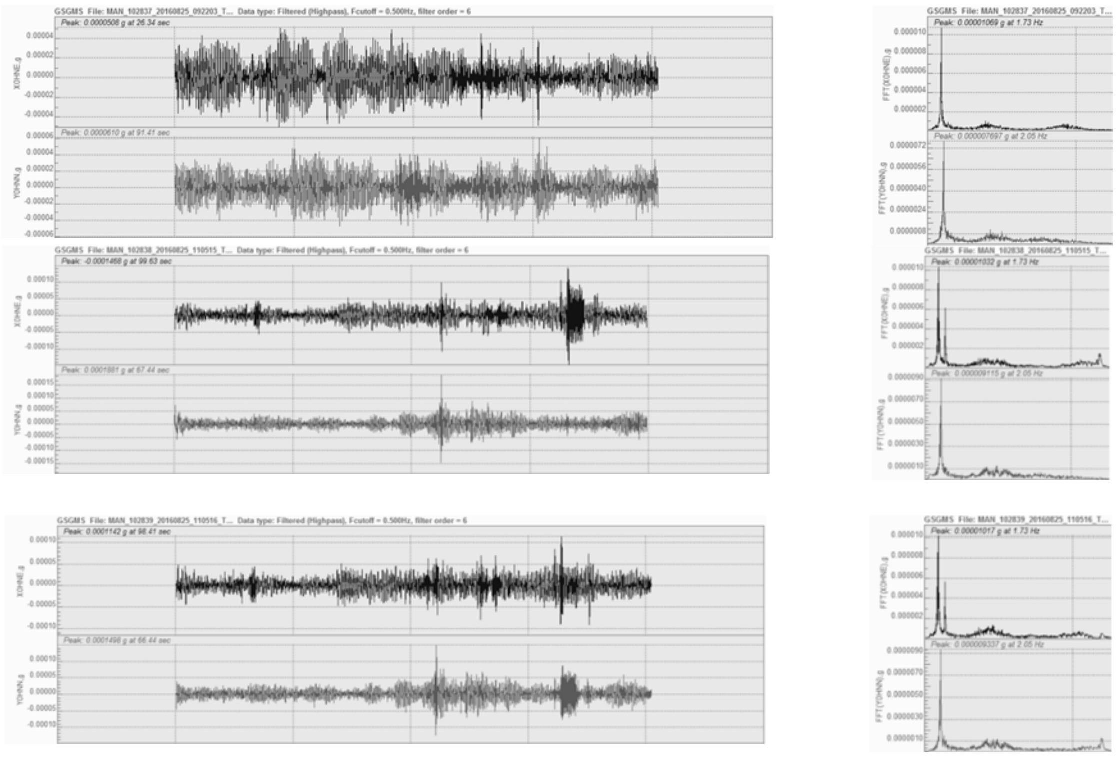

Figure 6. Acceleration records, block of flats building, Bucuresti. Vertical scheme for sensors setting (sensors at basement, ground floor, level 5 and level 10), predominant frequencies f_x= 1.73 Hz (T_x=0.58 s); f_y= 2.05 Hz (T_y=0.49 s). It is noticeable the possibility of determining frequency also for the vibration mode 2.

5. Results and discussions

For 3 selected buildings, applying some selection criteria, with different instrumentation schemes for the location of sensors (in free-field, at basement, ground floor, roof level), a correlation between the dynamic characteristics resulted from signal processing of ambient vibration and from a theoretical analysis were presented. The interpretation of recording results could highlight the behavior of the whole structure.

The ratio between transverse and longitudinal frequencies has the following values 1.17, 1.05 and 1.18, providing information about the relative stiffness in main directions of effort (transversal and longitudinal).

The values of the frequencies, obtained experimentally and theoretically, in these cases, are in a specific domain to each type of structural system, the calculated frequencies being generally higher, because not all non-structural elements to the lateral stiffness of the structure were taken into account.

In terms of spectral amplifications at the top levels of buildings, on predominant frequencies, values like on the order 8…26 times (hotel-type building), 1.5…2.1 times (hospital-type building) and 6…13 times (block of flats building) were highlighted.

6. Conclusions

The instrumental data obtained in-situ, before and after a major earthquake, along with visual observations, are contributing to a correct understanding of the importance and influence of various factors on the dynamic structural response, as possible changes in response that can be warning signs related on structural safety. In this context, determining the dynamic characteristics of structures, from ambient/microseismic vibration recordings, is one of the most important aspects of "structural health monitoring". Also, establishing criteria for selecting and monitoring of buildings represents an important milestone in a process more complex of dynamic modelling, theoretical and experimental analysis, depending on the nature of seismic/non-seismic source vibrations.

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