Design of Experimental Seismic Tests with Didactic Approach

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SUMMARY
In-depth understanding and knowledge of structures behavior due to external dynamic loads is eagerly needed to mitigate the expected damage produced by the vibrations produced by earthquakes. Currently, seismic design study is of interest among the engineers/seismologists, and investigations have been evolving to become complex task. An straightforward way for better understanding the dynamic behavior of a structure, is by using didactic material and by doing small scale laboratory experiments, which allows diminishing economic risks, costs in addition to the saving time, increasing the knowledge through experimental/empirical observations and measurements. Experimentation is an effective method to introduce basic concepts of structural dynamics like frequencies, or normal modes in which the structures vibrate. In this work, a set of experimental tests realized in laboratory with small scale prototypes, are presented. Those experiments are part of the courses on soil response/behavior and structural analysis of the Autonomous University of Baja California (UABC) and are conducted on the laboratory of Earthquake Engineering and Structural Dynamics. The conducted tests included: 1) a vibratory table designed and constructed by one of the coauthors and 2) an equipment of measurement of vibration with four uniaxial accelerometers. Through the completion of the experiments, the topics of resonance, damping, and soil liquefaction, which are within the branches of earthquake engineering and engineering seismology were studied.

1. INTRODUCTION

The potential adverse effects of an earthquake on the persons are determined by the quality of the buildings in which they live or work. In spite of the technological advances and the experiences of previous seismic crises, enormous accumulation of population in big cities, the improvised and urgency on having built, and the unfavorable behavior of some buildings, do nothing but increase the number of victims caused by the earthquakes, particularly in needy regions or in development nations.

The vulnerability or seismic behavior of buildings is a parameter that not only can be used, but is indispensable to evaluate, so the engineers who construct should have a well rounded knowledge in engineering seismology/earthquake engineering allowing to achieve safe and secure buildings during and after the occurrence of an earthquake.

The work in laboratory contributes to learn the theoretical concepts and empirical knowledge. The Laboratory of Seismic Engineering and Structural Dynamics is physically located on the Ensenada Campus of the Autonomous University of Baja California (UABC). It is part of the School of Civil Engineering infrastructure of the Faculty of Engineering, Architecture and Design. UABC and CICESE have combined human and material resources to integrate and support this laboratory from its creation in the year 2001 up to the date, the accomplishment se four thesis, 23 presentations in national and international conference meetings, an article in scientific magazine (Huerta et al., 2009) and a book (Díaz et al., 2011), and more in progress works. The equipment is described later.

1.1. Shake Table

The School of Civil Engineering at UABC, bought a shake table designed and constructed by Flores (2012, co-author this paper). The table consists of: (i) a platform of 68.5 cm of height on which two electrical DC-current (Direct Current) motors of self-propelling use are fastened, (ii) an electrical power source, and (iii) a perpendicular axis to the plate, in which a pulley and a mechanical system (based in pulleys) are mounted. All mechanical components are protected by a metallic box proving safety to the users. The system is connected to an perforated aluminum plate of 30- by 30-cm with 25 holes (with internal thread) to hold the specimens to study. The height of the table is 1m ± 3 cm, adjustable by means of levelers located in the bases of the legs. In the frontal part is the panel that indicates the current-voltage at which the table works, as well as a knob with adjustable graduated scale that controls the distance and speed at which the plate moves (see figure 1.1 and 1.2). The motors are connected in series to a source of adjustable power from 0 to 20 volts of DC. From the engines a band goes up to the principal pulley of the axis with two grooves to every band. The axis is connected to a mechanism of mesh with a pivot which transforms the cyclic rotation of the motors into unidirectional movement, controlled by a lever that modifies the amount of the plate displacement. The speed at which the plate moves is controlled by the voltage applied to the motors. The table has a maximum displacement of ± 22 mm (Espinoza et al., 2010 a).

Figure 1.1. Shake Table. Left side an isometric, and to the right plant view.

Figure 1.2. In the photograph of left three accelerometers connected to the table,
and in the photograph of the right the regulator of voltage, the signal conditioner and the laptop.

1.2. Measurement Equipment 1

It has basically the following components: (i) the accelerometers, computer, recorder, cables, amplifier and batteries. The system 1 (see figures 1.3 and 1.4) has 4 triaxial FBA Episensor accelerometers (specifications in the table 1.1) and a 16 bits recorder of six channels, (specifications in the table 1.2). With this system configuration induced and ambient vibration studies on: (i) free-field sites, (ii) buildings, (iii) dams, (iv) bridges, etc. have been conducted.

(a) (b)

Figure 1.3. (a) Accelerometer Episensor Model FBA ES-T and (b) 16 bits Recorder.

Figure 1.4. Recorder and laptop for the capture of information of vibration

Table 1.1. Specifications of the triaxial Episensor accelerometers model FBA ES-T

Bandwidth	DC-200 Hz
Sensitivity (X, Y, Z)	20 V/g
Full scale range	±0.25 g
Voltage to the range to total scale	20 V

Table 1.2. Specifications of the recorder

Type of storage	Solid state memory
Analogical digital converter	16 bits
Maximum range of voltage	±2.5 v
Types of filters	Butterworth of 6 poles, and Bessel
Filters	5, 15 or 50 Hz
Gain	1, 10, 100 or 1000
Sampling rate	50, 100 or 200 samples/s

1.3. Measurement Equipment 2

The measurement equipment 2 of vibration measurements (Espinoza et al., 2010) consists of a set of sensors (4 accelerometers 340A66 of PCB Piezotronics), a card of signal acquisition, an amplifier of signals and a portable computer (sees figure 1.5). The signal amplifier is four channels Piezotronics's PCB442A101 with amplification factors of X1, X10 and X100. The data acquisition card is the USB NI6229, with 32 input channels and a frequency of 200000 samples per second (Miranda et al, 2010).

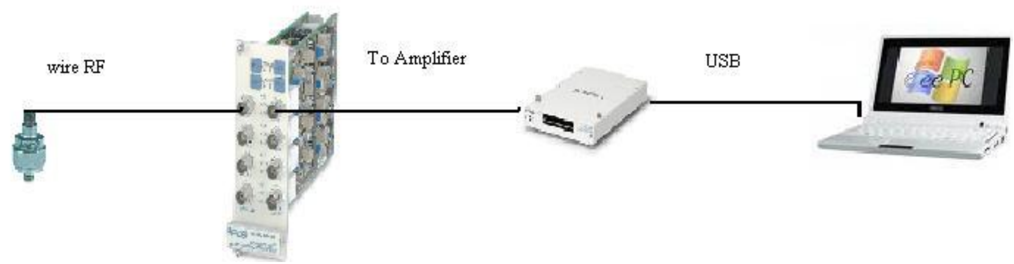

Figure 1.5. System of Measurement. PCB accelerometer,
four channels 340A66 Amplifier PCB442A101 Piezotronics, and the DAQ NI6229 of NI.

2. THREE OF THE PRACTICES REALIZED IN THE LABORATORY

2.1. Fundamental Period

Objective: Measure/estimate the fundamental vibration period of a structure.

Background: All systems (structures) oscillate, being the most important the fundamental vibration mode. The time of oscillation of the fundamental vibration frequency is so called the fundamental period of the system and is used principally in structural analysis and design forces in accordance with the construction codes.

In a study of a reinforced structure, conducted by Muriá-Vila and González (1995), changes of the fundamental period were clearly evident and associated with changes of the structure stiffness, which may occur after an earthquake if the structure is damaged and/or after a the structure is reinforced, increasing the fundamental mode vibration frequency when the structure becomes less flexible (Figure 2.1).

Structural model: A wood structure was build representing a slab and four columns (Figure 2.2), one of the columns was replaced by a damaged column (Figure 2.3).

Measurements and results: the equipment 1 was used for measuring accelerations in the horizontal axis in time series of 15 seconds, placing the accelerometer in the slab, with the damaged and the healthy columns successively. The obtained Fourier's spectrums from both measurements were compared between them and it was observed that the fundamental frequency of the structure with the healthy column is approximately 10 Hz, while the frequency value with the damaged column is 6-7 Hz (Figure 2.4).

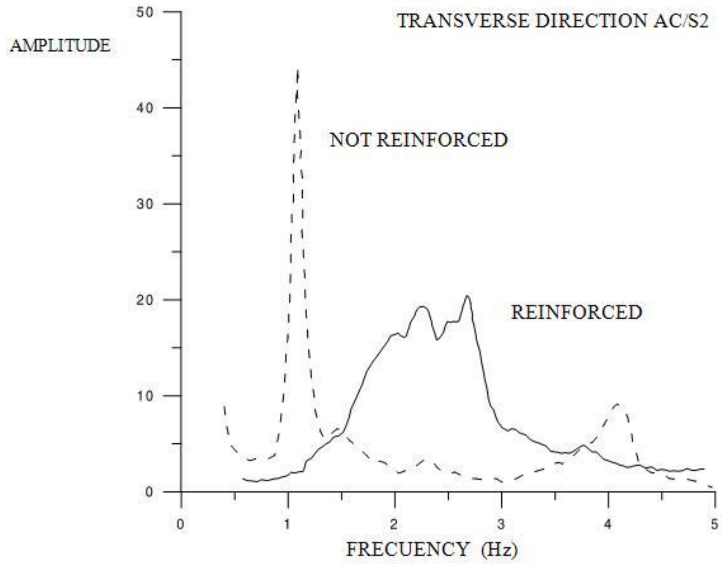

Figure 2.1. Comparison of transfer functions obtained in a test using ambient vibration, before and after the reinforcement of a 8-floor building. There are related the signals measured in the transverse direction in AC - center of the roof - with S2 - basement (Muriá-Vila and González, 1995).

Figure 2.2. Structure used to measure vibration. The accelerometer is placed in the center.

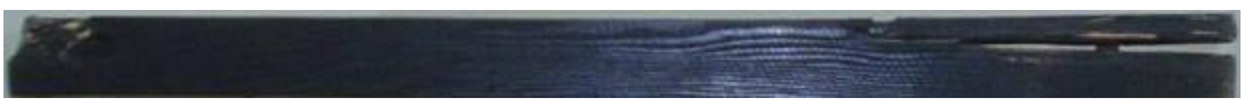

Figure 2.3. Column in horizontal position damaged in the ends, being the base the section of the right.

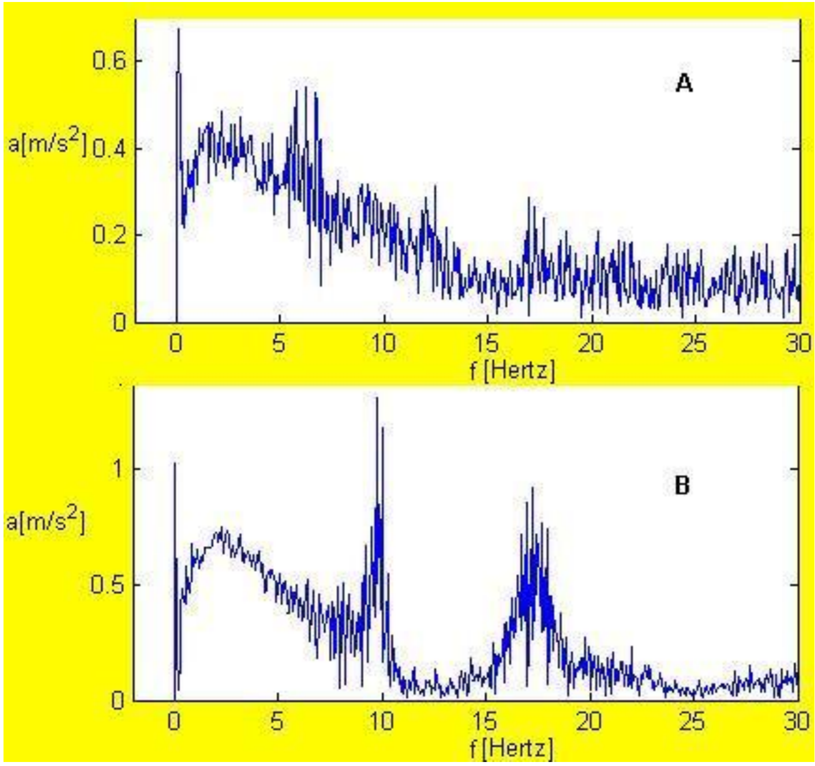

Figure 2.4. Fourier's spectra of the measured accelerations.
A) damaged column, B) healthy column (Ortiz et al., 2005).

2.2 Damping

Objective: Measure experimentally the vibration frequency of a structure with and without damping

Background: The use of the traditional design of structural systems using the deformation of his resistant elements in the non linear range for the dissipation of energy has been decreasing in the last years due to the development of new design procedures that use control systems with which it is possible to diminish the response of the buildings before seismic solicitations and the use of devices that modify in an active or passive way the dynamic properties of the structure.

The control systems mentioned above can be grouped in one of the followings: 1) Active (AMD or Active Mass Damper), 2) Semi-active, 3) Hybrid (HMD or Hybrid Mass Damper), and 4) Passives, they are classified in a) Seismic Isolation, b) Tuned (TMD or Tuned Mass Damper).

The tuned mass damper is a device placed in the structures to diminish the response before seismic solicitations. This device is a mass placed generally in the high portion of the building. Some authors do distinction in the nomenclature if the mass is a solid (TMD) or if the mass is a liquid (TLD), nevertheless the physical principle of the device and his response is the same.

A wood model of five-floor structure (50x50x200cm) with braces in one direction (Figure 2.5) was constructed. In the low part of each of the four columns a sponge is fixed in order that it acts as damper. In a different test from the previously described, a cylindrical device (10- and 20-cm in diameter and length respectively) with oil inside was placed in the top portion of the structure and an accelerometer was placed directly on each of the levels (Espinoza et al., 2011).

Data was obtained from each one of the two different tests: 1) with free vibration and 2) on a shake table. The vibration was recorded with the instruments described with measurement equipment 2. The structural response was measured with and without the damper.

Figure 2.5. Photograph of the structure on the shake table.

Free vibration: The structure is fixed at the base and a horizontal distance stretches in one of the levels (6.2 cm in the level 5 or 2 cm the level 1) using a cable that is released just after initiated the data acquisition. The experiment is repeated placing the accelerometer (see Figure 2.6) at each structure level (floor). Later, the Fourier's spectrum (Figures 2.7 and 2.8) were computed.

Results: The graphics with the obtained information from the measured data shows the structure response to free vibration, showing clearly that the accelerations increase from 0.03 (level 1) up to little bit more than 0.08 m/s^2 (level 5), these values decrease up to the half with the use of the device TMD. Having processed the information in terms of Fourier's spectra, the spectral amplitudes clearly diminish in the low frequencies band, about the fundamental mode (Figures 2.7 and 2.8).

Figure 2.6. Photograph of the accelerometer placed in the structure.

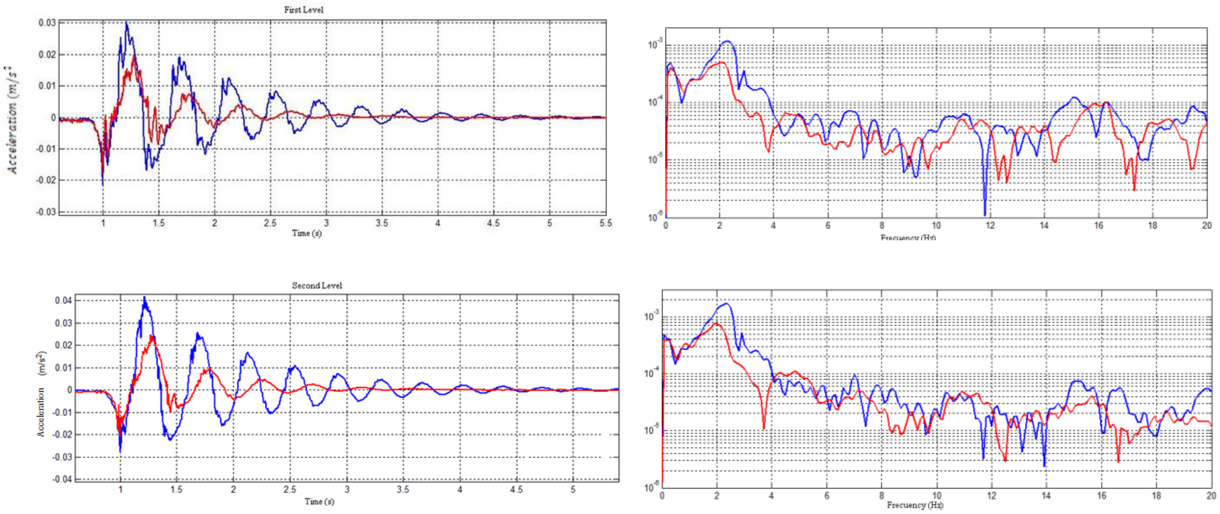

Figure 2.7. The graphs of the left side are acceleration (m/s^2) in the time domain, and their respective frequency domain representation are shown on the right. In the top part, there is the information of the first level and in the low part the second level. In blue color the information when the structure does not have the device and of red color when the damper is placed.

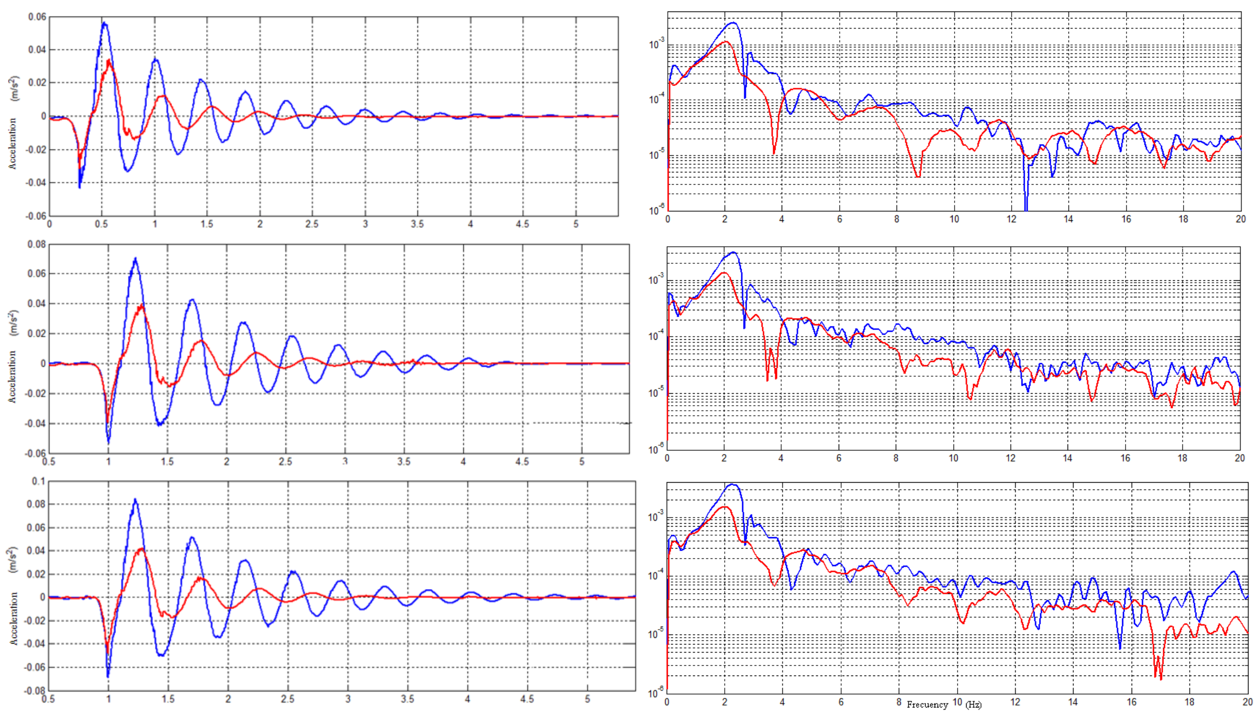

Figure 2.8. The graph of the left side is the acceleration (m/s^2) depending on the time and to the right Fourier's spectra of the acceleration. In the top part there is the information of the third level, in the low part the fifth level and in way the quarter. In blue color the information is when the structure does not have the device and of red color when the damper is placed.

2.3 Liquefaction

Objective: Determine the water quantity in a soil sample at which it liquefies and measure the applied vibration.

Background: Liquefaction effect is a physical phenomenon that occurs in the soils during earthquakes. It consists of the elevation of the water that saturates the soil, rising to the surface, diminishing the resistant capacity of the area which becomes liquefied. The liquefaction takes place in certain types of soils affected by earthquakes developing high pressure in a short time interval (without drainage), producing loss of resistance to the shear strength and degradation of the soil, manifested as if it were liquid. This phenomenon provokes damage in foundations, breaks of banks and land-slides. The soils capable to loss great part of his resistance during dynamic solicitations are the fine grain sands as well as sands and slimes badly graduated. The other one necessary conditions in order that liquefaction takes place, is that shallow (near surface) groundwater level and low degree of compaction (Gonzalez de Vallejo, 2003; Day, 2002). There are several methods to mitigate this phenomena, between them are: (i) to place drainages, or (ii) man-made soil/site compactation (Cooke y Mitchell, 1999).

Information gathering in laboratory: A sample of dehydrated sand was placed in a container on the shake table, water was added, and a vibration is applied to it. In figure 2.9, a photograph of the sample placed on the shake table is provided. The system 2 was used to measure the vibration in order to obtain the acceleration applied and the time duration of it. The observation and data was documented checking for when liquefaction occurs or do not occurs, during the process of adding successively portions of water until the soil liquefies (Espinoza et al., 2010 b).

Figure 2.9. Photograph of the sample on the shake table.

3. RESULTS

There is a set of practices that allow the students to obtain a better understanding of the earthquakes and its effects in the structures. With a proper vibration measurement system, it is possible to goes from the qualitative to the quantitative analysis and description of the phenomena, which is fundamental in engineering.

In this work we presented three tests; one over of the fundamental period, other on the damping, and the last one on soils. All three as examples of what is realized in the laboratory since its conception, and analyzed the wave propagation phenomena within the field of seismic engineering using simplified physical models as the way to characterize the seismic response of the structures as they are under external loads causing torsion, changes in stiffness, bracing and soil degradation between others.

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