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TECHNICAL FACULTY
"MIHAJLO PUPIN"
ZRENJANIN

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ZRENJANIN, June 2014

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CONTENTS

DATA PROCESSING OF RECORDED MOTION AT SEVEN-STORY HOTEL IN VAN NUYS, CALIFORNIA DURING NORTHRIDGE EARTHQUAKE 1994

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Abstract - In this paper, we present digital signal processing of recorded earthquake motions. The paper describes all the techniques used for the whole process of signal processing. From the measured displacements at the ground (first) floor and at the roof of typical seven-story building and their processing, we can get valuable information about the strong ground shaking and the structural response. In many cases, Fourier transform from time to frequency domain provides more information about the signal.

First, using FFT, we transform the measured displacements at basement and at the roof from time to frequency domain. The transformation at basement level, Fb(f), gives us valuable information about the frequency content of the strong ground motion. On the other side, the ratio of the Fourier transform at the roof and at the basement gives us so called transfer function, $H\square Fr\square f\square\square Fr\square f\square$, which reveals the natural frequencies of the building.

To accomplish the above tasks, we use the software Labview. Labview enables constructing graphical environment that represents design and analysis of a DSP system in a very minor compared to text – based programming environments. The graphical environment in Labview consists of VI (virtual instrument) which is represented by a Front Panel (FP) and Block Diagram (BD). The BD incorporates the graphical code and the FP provides the user – interface of the program. The Vis is modular and independent, which means they can be run by itself.

I. INTRODUCTION

A. The Building

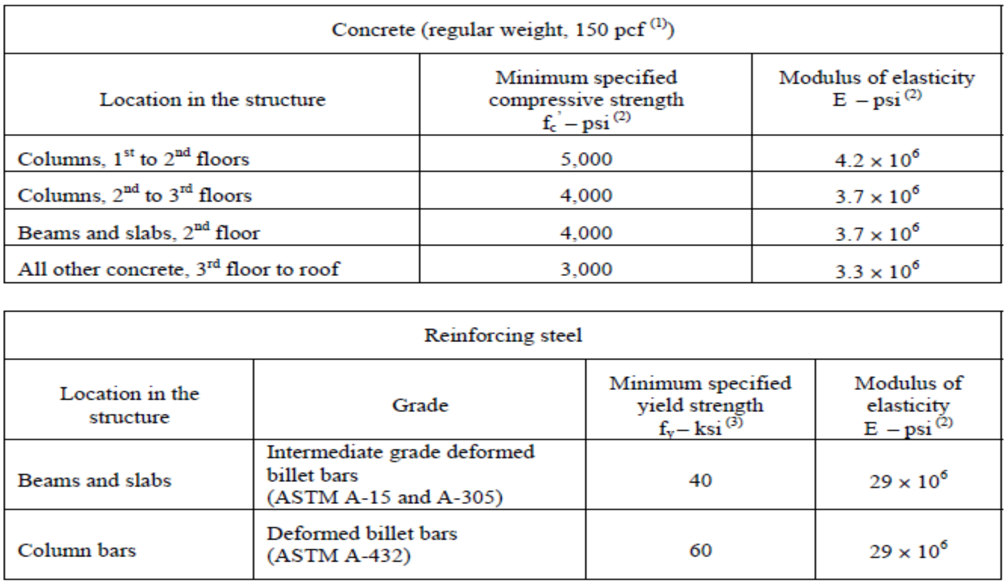
This seven – story hotel in Van Nuys (VN7SH), California is one of the most studied buildings is southern California [2]. It has been designed in 1965 and constructed in 1966. VN7SH is located in central San Fernando Valley of the Los Angeles metropolitan area.

The building is 18.9 × 45.7 m in plan. The typical framing consists of columns spaced on 6.1 m centers in the transverse direction and 5.8 m centers in the longitudinal direction. Spandrel beams surround the perimeter of the structure (Figure 1). Lateral forces in the longitudinal (EW) direction are resisted by interior column-slab frames and exterior column spandrel beam frames [4]. The added stiffness in the exterior frames associated with the spandrel beams creates exterior frames that are roughly twice as stiff as interior frames. The floor system is reinforced concrete flat slab, 25.4 cm thick at the second floor, 21.6 cm thick at the third to seventh floors, and 20.3 cm thick at the roof.

The building is situated on undifferentiated Holocene alluvium, uncemented and unconsolidated, with a thickness of < 30 m, and an age of < 10,000 years [4]. The average shear-wave velocity in the top 30 m of soil is 300 m/s, and the soil-boring log shows that the underlying soil consists primarily of fine sandy silts and silty fine sands.

The foundation system consists of 96.5-cm deep pile caps, supported by groups of two to four poured-in-place 61-cm-diameter reinforced concrete friction piles. These are centered under the main building columns. A grid of beams connects all of the pile caps. Each pile is roughly 12.2 m long and has a design capacity of over 444.82 × 103 N vertical load and up to 88.96 × 103 N lateral load.

TABLE 1. PROPERTIES OF THE CONSTRUCTION MATERIALS OF THE VN7SH BUILDING;
(1) POUNDS PER CUBIC FOOT
(2) POUNDS PER SQUARE INCH
(3) KIPS PERS QUARE INCH



Concrete (regular weight, 150 pcf (1))		
Location in the structure	Minimum specified compressive strength f_c' – psi (2)	Modulus of elasticity E – psi (2)
Columns, 1st to 2nd floors	5,000	4.2×10^6
Columns, 2nd to 3rd floors	4,000	3.7×10^6
Beams and slabs, 2nd floor	4,000	3.7×10^6
All other concrete, 3rd floor to roof	3,000	3.3×10^6

Reinforcing steel			
Location in the structure	Grade	Minimum specified yield strength f_y – ksi (3)	Modulus of elasticity E – psi (2)
Beams and slabs	Intermediate grade deformed billet bars (ASTM A-15 and A-305)	40	29×10^6
Column bars	Deformed billet bars (ASTM A-432)	60	29×10^6

B. The Earthquake Damage

The *M*L = 6.4 Northridge earthquake of January 17, 1994 severely damaged the building. The structural damage was extensive in the exterior north (D) and south (A) frames (figure 1) that were designed to take most of the lateral load in the longitudinal (EW) direction.

Severe shear cracks occurred at the middle columns of frame A, near the contact with the spandrel beam of the 5th floor (Figs. 1 and 2). Those cracks significantly decreased the axial, moment, and shear capacity of the columns. The shear cracks that appeared in the north (D) frame on the 3rd and 4th floors and the damage to columns D2, D3, and D4 on the 1st floor caused minor to moderate changes in the capacities of these structural elements. No major damage to the interior longitudinal (B and C) frames were observed, and there was no visible damage to the slabs or around the foundation. The nonstructural damage was also significant. The recorded peak accelerations in the building were 0.46g (L), 0.40g (T), and 0.28g (V) at the base, and 0.59g (L) and 0.58g (T) at the roof, along the longitudinal (L), transverse (T), and vertical (V) axes of symmetry (there were no sensors installed on the roof to measure vertical motions) [5].

During Northridge, earthquake five transducers have measured the longitudinal displacements over the seven floors.

The response of VN7SH was recorded by a 13-channel CR-1 central recording system and by one tri-component SMA-1 accelerograph, with an independent recording system but with common trigger time with the CR-1 recorder.

The simplicity, uniformity, and symmetry of the building geometry make this building ideal for testing and for calibration of different analysis methods. Instead of the common earthquake several damages, the Van Nuys damage is concentrated at the fourth floor, which makes VN7SH very important for any kind of numerical analyses.

We use digital signal processing via Labview to be known with the crucial characteristics of a seismic excitation like one in California 1994. In a study of the propagation of non-linear waves in a simple, uniform shear beam, caused by incident strong motion pulses, Gicev and Trifunac [2] found that for large ground displacement pulses the maximum permanent strains in the beam occur mainly at the interface of the beam with the soil, while for smaller amplitudes of pulses permanent trains occur closer to the top of the beam. They identified three zones of the permanently deformed beam: (1) a permanently deformed zone at the bottom; (2) an intermediate zone, which is not deformed at its bottom part and is deformed in the top part; and (3) a non-deformed zone at the top of the beam. They found that the occurrence and the development of these zones depend upon the dimensionless excitation amplitudes and the dimensionless frequency of the incident strong motion pulses, and in particular on the conditions that lead to the occurrence of the first permanent strain.

Gicev and Trifunac [2] have also showed that for excitation by near-field displacement pulses, failure can occur anywhere in the building, before the incident wave has completed its first travel from the foundation to the top of the building and back to the foundation.

For large and long strong-motion pulses, only zones 1 and 3 are present in the beam. For large amplitudes and short strong-motion pulses, all three zones can develop and are present. For smaller excitation amplitudes, only zones 2 and 3 exist in the beam.

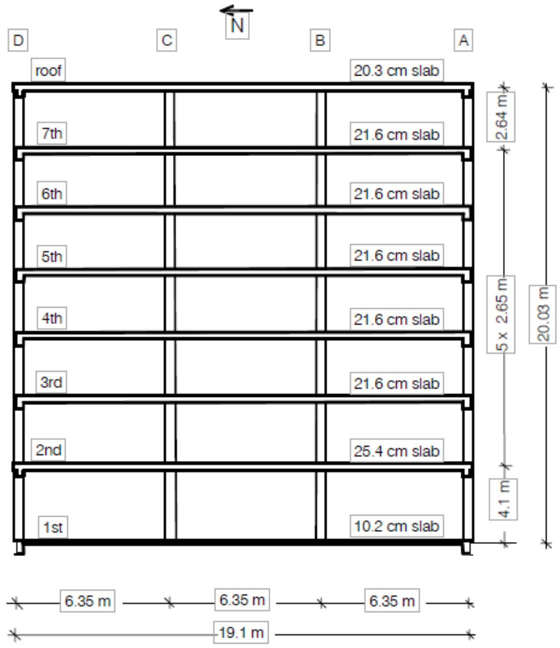


Figure 1. North – South section of the building.

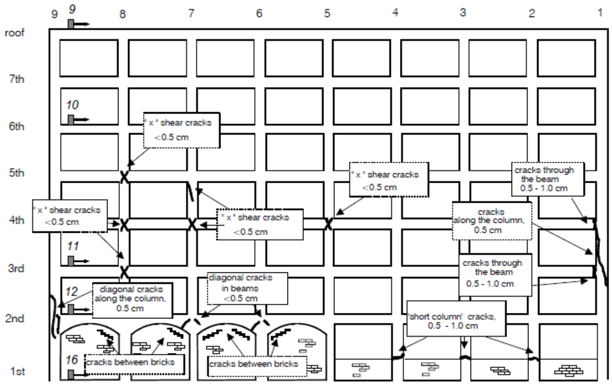


Figure 2. Observed damage at the north view of the building.

II. THE PHYSICS

A. Power Spectrum and Fourier Transform

Spectrum represents a relationship represented by a plot of the magnitude or relative value of some parameter against frequency. Any one of the physicals phenomenon has its own spectrum associated with it, the phenomenon is thermal, hydraulic, electromagnetic, seismic or other.

The Fast Fourier Transforms (FFT) is an algorithm for calculation of Discrete Fourier Transform (DFT) of an input data vector [6]. In fact, FFT is DFT algorithm wich reduces the number of computations needed for N points from $O(N^2)$ to $O(N \log N)$ where log is the base-2 logarithm using periodicity and property. There are several algorithms that can calculate FFT efficiently.

Every phenomenon also has his own quantities and in our case that is time and displacement from longitudinal wave caused by seismic excitation. The quantities are described in time domain, and for every function of time $f(t)$, an equivalent frequency domain function $f(\omega)$ can be found that specifically describes the frequency – component content (frequency spectrum) required to generate $f(t)$. With other words, the power spectrum answers the question “How much of a signal is at a frequency?” The periodic signal gives peaks at a fundamental and its harmonics. Another way to look at a signal is in discrete time domain, which puts series of values consecutively in time. One can tell something about the behavior of the signal at every moment of time, and make statements for its long – term behavior. However, it is difficult to say anything about how the long – term behavior is related to the short – term development of the signal. The Fourier transform views the signal as a whole. It swamps the dimension of time with the dimension of frequency. It can be thought as a combination of slow and fast oscillations with different amplitude. A very strong and slow component in the frequency domain implies that there is a high correlation between the large – scale pieces of the signal in time (macro – structures), while a very strong and fast, oscillation implies correlation in the micro-structures. Therefore, if we consider that our signal $f(t)$ represents values in every single moment of time, its Fourier transfer $f(\omega)$ represents the strength of every oscillation in a holistic way in that chunk of time. Each of the two signals is related to one another with the formula:

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-j\omega t}\, dt \qquad (1)$$

In our case Labview functions for FFT – based signals are the FFT, the Power Spectrum, and the Cross Power Spectrum. With these functions also can be created additional measurement functions such as frequency response, impulse response, coherence, amplitude spectrum, and phase spectrum. The Fourier transform analysis assumes the life of a signal from $-\infty$ to ∞. Because of that, when an analysis is carried out for a finite amount of time, it is either assumed that the signal is periodic or that it has a finite amount of energy. The true power spectrum of a signal has to consider the signal from $-\infty$ to ∞. However, we must consider that we are not always able to observe a signal that way or derive precise functions for it. Virtual instrumentation software is focused on the needs of the application and user defined. Applied mathematics is combined with real – time measurements, which reduce the time for innovation and importantly the time to market and/or time to commercialization of the final products and services that result from research and development using virtual instrumentation approach.

III. LABVIEW RESULTS

The measured displacements from the seismic excitations are longitudinal displacements in matter of time. We collect data from five instruments (channels) shown on Figure 2 (09, 10, 11, 12, 16). Channel 16 is at the basement of the building and channel 09 is at the roof of the building. Analog to this, the displacement is most significant at channel 09. We construct program in Labview to see graphically these displacements. The program has reader of the data files shown in figure 3.

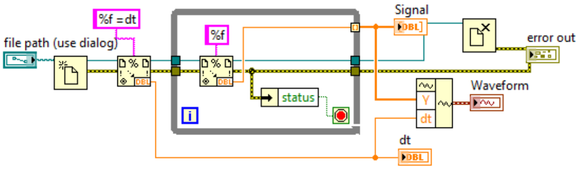


Figure 3. Block Diagram for data reader for each of the channel measurements

Important to mention is that the measurement is with time of 60 seconds and time step $dt = 0.02$. That mathematically gives 3000nd steps. The time step is defined at the start of each of the measurement files, so, we make a scan function to collect dt and through while-loop build a waveform.

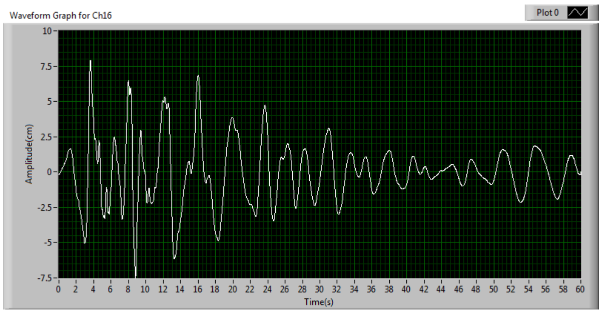


Figure 4. Displacement in matter of time for channel 16 (x-scale represent the time(s), y-scale represent the displacement (cm)).

If we analyze the waveform graph, we can see that in first 24 seconds the amplitudes are high and are going from 5 to 7.5 centimeters.

From the channel 16 to channel 09, the amplitudes are continuously growing and at channel 09, they are highest. So because we are interested mostly of that what is the difference between the basement channel and the roof channel, on figure 5 is represented the displacement at channel 09.

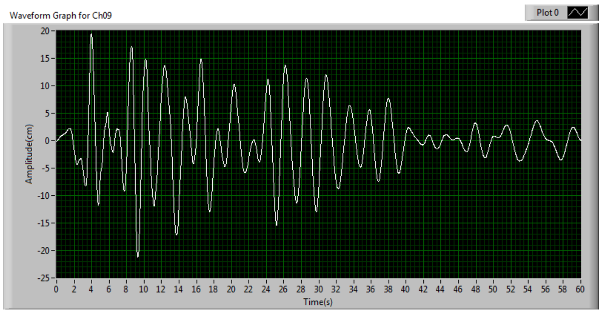


Figure 5. Displacement in matter of time for channel 09 (x-scale represent the time(s), y-scale represent the displacement (cm)).

From figure, 5 can be seen that the displacement is significantly bigger and from 0 to 38 second is between nearly 8 to 20 centimeters that gives us a clue that, metaphorically said, the roof of the building is shaking for 20 centimeters. Important to mention is that these displacements looked from seismic angle are far more complex, and are illustrated in [2].

Next processing that interests us in this paper is the FFT of these signals.

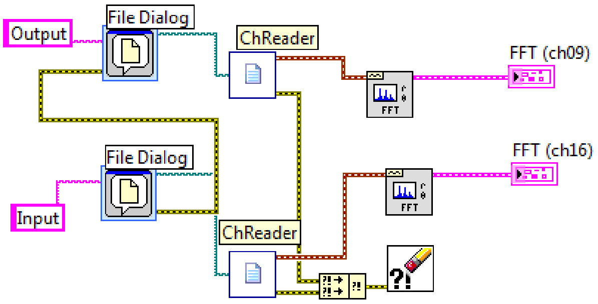


Figure 6. Blog diagram for simultaneously reading the two channels with FFT signal processing

On figure 6, one can see that there are two channel readers connected with FFT spectrum for magnitudes of the signals. There are also two file-dialog boxes connected on the channels, and two waveform graphs denoted as FFT(ch09) and FFT(ch16).

The figure 7 and figure 8 represent the FFT of the channel 09 and channel 16 consequently. Now if we take a close look at waveform graph of channel 09 (roof) we will see that for higher displacement we get higher magnitude. The highest peak is at nearly 0.43Hz at magnitude of 3.5.

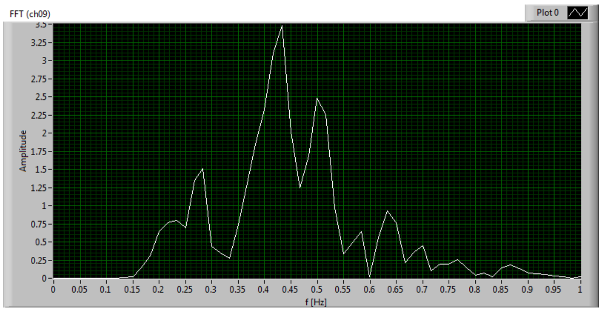


Figure 7. Waveform graph for FFT of channel 09 with x-scale frequency and y-scale magnitude.

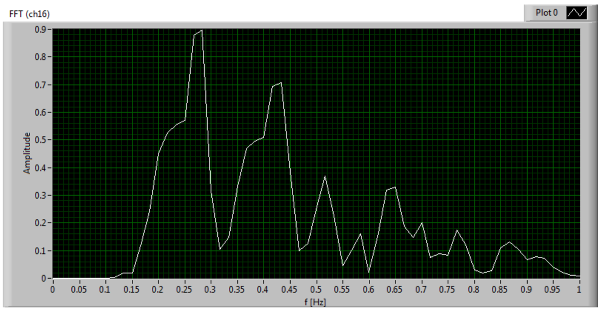


Figure 8. Waveform graph for FFT of channel 16 with x-scale frequency and y-scale magnitude.

The figure 8, waveform graph for channel 16 represent also FFT at displacements in the basement and proves that with smaller displacements there are smaller magnitudes, or, in case of ch16 we have 0.9 magnitude at frequency of 0.28Hz.

The transfer function represents the ratio of the output of a system to the input to the system, in the Laplase domain considering its initial conditions and equilibrium point to be zero. If we have an input function of $X(t)$, and an output function $Y(t)$, we define the transfer function $H(s)$ to be:

$$H(t) = \frac{Y(t)}{X(t)} \qquad (2)$$

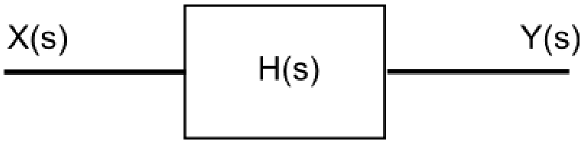


Figure 9. Input X(s) and output Y(s) of a transfer function H(s).

The transfer function of a system is the relationship of the system's output to its input, represented in the complex Laplace domain.

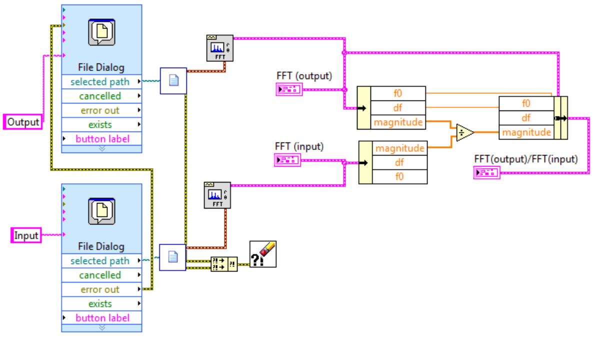


Figure 10. Blog diagram of H(t) transfer function via Labview

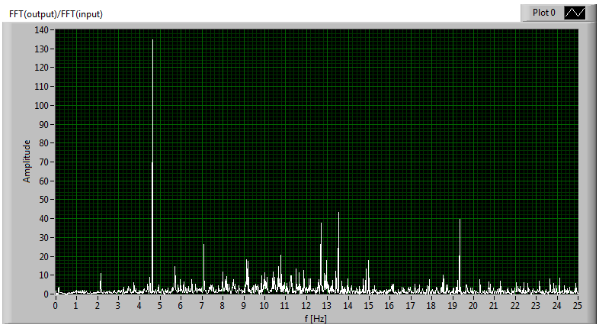


Figure 11. Waveform graph for H(t) transfer function

Figure 10 represent the block diagram for H(t) transfer function, the two channel readers gives the signals to FFT(magnitude) and we divide the output from the input in a waveform graph, figure 11. From the waveform graph, we can see what is like the impulse response of this particular building or the natural frequency of the building. The highest amplitude peak is at nearly 4.5Hz with is crucial in case of a seismic excitation with that proportions.

IV. CONCLUSION

For past three of four decades, scientists are giving efforts on predicting some natural disasters. The fact is that, we still do not know all of the characteristics of these natural excitations, but we can prepare better for them, if we know closely the effects of these disasters in matter of their power. In our case, we speak about seismic excitation that has result with damage to the VN7SH.

With power of numerical methods, mathematical transformations and software digital processing, we can be a little more aware of what kind of damage would be, in scenario like in California 1994. Every building has its own natural frequency. Sometimes it is very important to know this frequency because some buildings are used as fabriques that have some oscillating machines and it can be of crucial importance where in the building will these machines will be located.

Our purpose is to take measurements of the buildings and tell to their builders little more informations of that how will that building act in worst-case scenario.

Normally this field of investigation is improving more and more, with powerful tools like Labview which is used for these signal processing.

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