Preliminary Identification of Dynamic Characteristics of a Unique Building in Chile following 27 February 2010 (M_w=8.8) Earthquake

M. Çelebi[1], M. Sereci[2], R. Boroschek[3] and P. Bonelli[4]

[1]USGS, Menlo Park, CA. USA 94025
[2]Digitexx Inc., Pasadena, CA., USA
[3]University of Chile, Santiago, Chile
[4]UTFSM, Valparaiso, Chile

Abstract. Following the 27 February 2010 (M_w=8.8) Offshore Maule, Chile earthquake, a temporary, real-time data streaming array comprising 16 channels of accelerometers was deployed throughout a recently constructed 16 story tall building with three additional basement stories in Vina del Mar, Chile. This building was not damaged during the mainshock; however, it is similar in design to many other buildings with multiple shear walls that were damaged but did not collapse in Vina del Mar and other parts of Chile. The temporary array recorded low-amplitude response of the building from aftershocks. The recordings provided dynamic response characteristics of the cast-in-place reinforced concrete building. Available dynamic charcateristics from mathematical modal analyses are compared to the observed responses. Distinct "major-axes" translational and torsional fundamental frequencies as well as frequencies of secondary modes are identified. Response data from each earthquake provide evidence of beating.

Introduction

During the reconnaissance mission organized by the Earthquake Engineering Research Institute to investigate the M_w8.8 Offshore Maule, Chile earthquake of 27 February 2010, a cooperative effort by the authors facilitated deployment of a temporary, real-time data streaming structural monitoring array comprising 16 channels of accelerometers distributed throughout a 16-story tall building (with 3 additional basement stories) in Vina del Mar, Chile. The building was chosen to understand the dynamic characteristics of a core-shear wall building, which is a typical construction type in Chile. This type of construction, in general, performed well during both the M 7.8 1985 Valparaiso and the recent 27 February, 2010, Offshore Maule events. Modal analyses performed during the design/analyses processes has yielded the first 6 modal periods as 2.01, 1.532, 1.14, 0.47, .0.31 and 0.27 seconds. The first two correspond to the fundamental modes in the NS and EW directions respectively.

The Building

A picture of the building and a typical plan view showing the distribution of shear walls and column lines are shown in Figure 1. Core shear walls are typically 35 cm thick, while the shear walls in the perimeter on the west and east edges are 30 cm thick, and the two in the south edge are 40 cm thick. Columns located on the column line intersections that do not have shear walls are typically 80cm x 80cm in plan. Such a distribution of walls and columns with non-coincidental mass and rigidity centers naturally is expected to cause torsional behavior. Furthermore, the basement foundation is a 100 cm-thick mat without piles. The combination of lack of piles, a thick mat foundation, and a stiff structural system situated on a sub-foundation of approximately 100 m-thick alluvial material[1] make this building an ideal target to study rocking effects, if present.

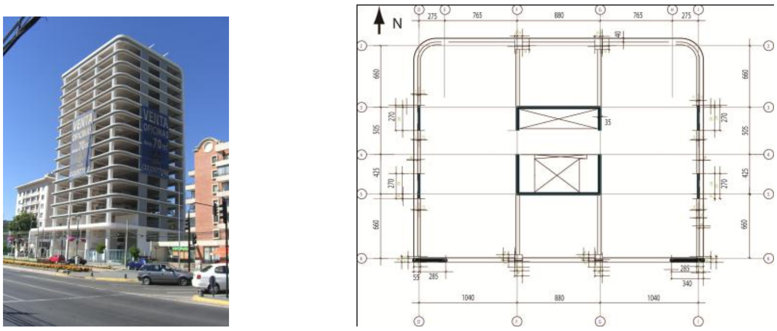

Figure 1. Left: General picture of the building. *Right*: Typical plan view shows distribution of shear walls and columns as well as dimensions and the axes system.

Temporary Instrumentation and Data

Figure 2 shows temporary deployment of an array of 16 accelerometers. Several sets of earthquake response data have been recorded by the array. Quick analyses

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[1] The site frequency has been computed to be approximately 1.5 Hz. Because of space limitations, computation of site frequency is not discussed in the paper.

of the data for response characterisitics indicated similar and repeatable results. Hence, in this paper, only one set will be presented and discussed.

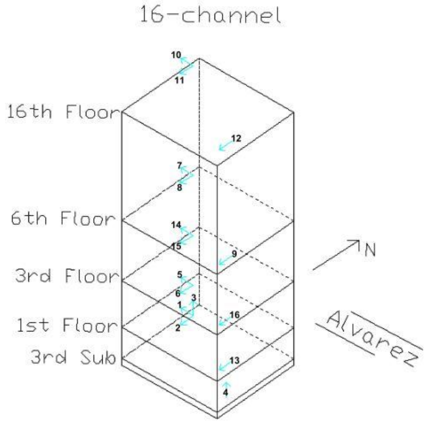

Figure 2. Schematic of temporary deployment of accelerometers.

Analyses of Data

Shown in Figure 3are acceleration time-histories of the response of the 16th floor [roof-level channels 10-12] of the building to an event that occurred at 06:03 AM local time on April 23, 2010 (M=5.9 located 65 km south of Concepcion and approximately 475 km south of Vina del Mar) To the right is an expanded 100-s interval of these records to better display the building behavior, which may include beating effects and low damping that most likely contributed to prolonged shaking. Amplitude spectra computed from the acceleration records are shown in Figure 4. The spectra show predominant peaks at several frequencies in the NS, EW and vertical directions. Clearly, in the low frequency range of 1Hz or less (the expected range of the fundamental frequencies), several peaks are clearly identifiable (e.g. EW frequency [period] of 0.84Hz [1.2 s], and NS frequencies [periods] 0.67, 0.84 and 1.05 Hz [1.49s,1.2s and 0.95s]). These significant frequencies and those of higher modes are seen in the amplitude spectra as well as being clearly identifiable in the plot of transfer functions in Figure 5a. In the EW direction, the transfer function, computed as the ratio of amplitude spectra of accelerations at the roof (CH10) to those in the basement (CH1), clearly indicates three distinct peaks at 0.84, 3.3 and 6.7 Hz (1.2 , 0.3 and 0.15 s) corresponding to the first three modes. It is noted that these frequencies are identical to those obtained from amplitude spectrum for torsional response represented by the difference of the two parallel NS motions (e.g., CH11 & CH12) as shown in Figure 5b. Thus, EW motions and torsional motions are coupled, and therefore the same frequencies appear in the transfer functions for the NS direction, as seen in Figure 5a. TheNS transfer functions also exhibit two additional peaks at 0.67 and 1 .05 Hz that do not appear in the spectra or transfer function for the EW direction; hence they are related only to the NS direction.

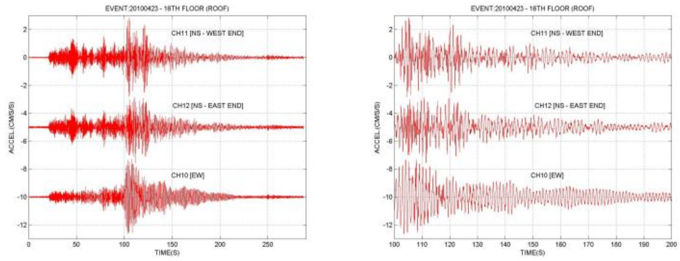

Figure 3. Acceleration time histories recorded at the roof level of the building.*Left:* the complete record. *Right:* expanded portion of record windowed beteeen 100-200 to display possible beating and low-damping associated with the building at this level of shaking.

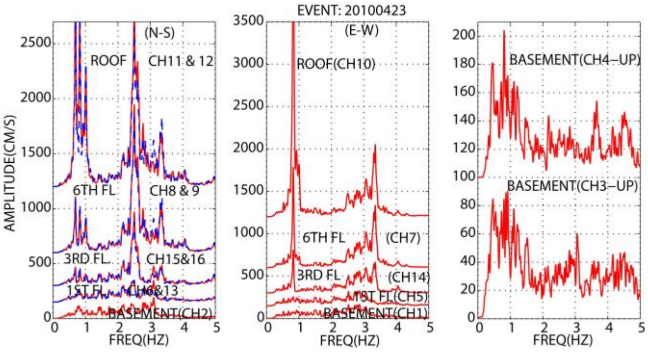

Figure 4. Amplitude spectra computed from accelerations recorded from all channels of the array.

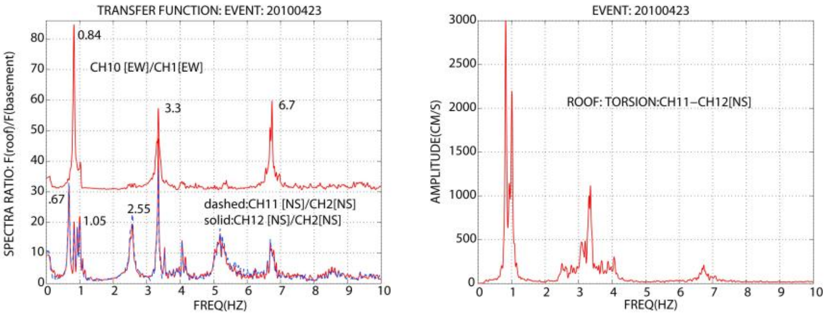

Figure 5. *Left*: Transfer function of EW and NS records at the roof with respect to corresponding records in the basement. *Right*: Amplitude spectra of differential acceleration from parallel channels in the NS direction to assess torsional response. These plots are made for 0-10 Hz horizontal axes to observe higher mode frequencies as well.

The challenge in identifying which one of the frequencies unique to the NS motions (0.67, 0.84 and 1.05 Hz) belong to what mode of vibration is made difficult by the fact that these frequencies are all in phase, as seen in Figure 6 displaying cross-spectrum, phase and coherency between CH12 (NS) at the roof and CH9(NS) at 6th floor (and similarly for other combinations that are not presented herein). However, as seen in Figure 7a and b, it is very likely that the frequency at 0.84 HZ is also the rocking frequency both for NS and EW directions, as identified by the auto-spectra, cross-spectra, phase angle and coherency plots for CH12(NS) and CH10 (EW), both at the roof, as compared to CH4 (UP) in the basement. This key figure illuminates the close frequencies that are about 1 Hz or less. So, it is safely concluded that 0.84 Hz is one of the important frequencies – the translational fundamental frequency in the EW direction, the torsional fundamental frequency, and also the rocking frequency in the EW and NS directions.

Thus, in the EW direction the apparent frequency ($1/f^2_{apparent}=1/f^2_{translational} + 1/f^2_{rocking}$) at 0.84 Hz is same as the rocking and translational frequency. In the NS direction, 1.05 Hz is the translational frequency and the apparent frequency is 0.67 Hz computed also by the relationship: $1/f^2_{apparent}=1/f^2_{translational} + 1/f^2_{rocking}=1/1.05^2 +1/.84^2$ that leads to $f_{apparent}$~0.67Hz which is consistently seen in the spectra and transfer functions.

An additional observation in the building response is the “beating effect”. As observed in other structures [1,2], low-level damping and nearly identical (or close) translational and torsional frequencies in structural system causes coupling and beating effect with a period $T_b=2T_1T_2 /(T_1-T_2)$. During the beating effect, repetitively stored potential energy during the coupled translational and torsional deformations turns into repetitive vibrational energy. Thus, for this building, in the NS direction, with T1=1/1.05Hz=0.95s, and T2=1/.84Hz=1.2s, then, $T_b=2T_1T_2 /(T_1-T_2)$ =2*.95*1.19 /(1.19-.95)=9.4s which is close to the observed/recorded motions seen in Figure 3.

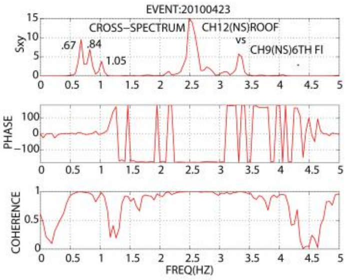

Figure 6. Cross-spectrum, phase angle and coherency plots of acceleration recorded by CH12(NS) at the roof and CH9(NS) recorded at the 6th floor.

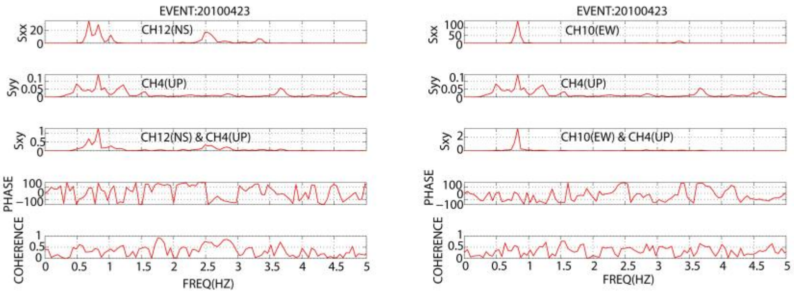

Figure 7. Auto and Cross Spectra, Phase angles and coherency plots for vertical motion (CH4) in the basement paired with horizontal motions: *Left*: Ch12(NS) at the roof and *Right*: CH10(EW) at the roof.

Conclusions

In the absence of widespread permanent accelerometer arrays in structures, which often is due to cost issues, an effective approach for non-destructive testing and extracting critical information on response characteristics is to deploy temporary arrays following large earthquakes to record significant aftershocks. This approach allows assessment of actual dynamic characteristics and significant modal behaviors that may not always be identified or accurately determined by mathematical models. In this preliminary study, the building exhibits frequencies attributable to translational, torsional, and rocking modes that are significantly different than those extracted from mathematical models. Furthermore, the beating effects are observed in the structure during the low-amplitude excitation generated by distant aftershocks almost two months after the main event. Assessment of critical damping ratios is left to future studies.

References:

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