한국복합신소재구조학회 논문집 제6권, 제1호, 2015년 3월
J. Korean Soc. Adv. Comp. Struc. Vol. 6, No. 1, pp. 01-05, March 2015
DOI http://dx.doi.org/10.11004/kosacs.2015.6.1.001
ISSN 2093-5145(Print)
ISSN 2288-0232(Online)

지진 시 콘크리트 합성 빌딩 내 지진 거동의 스펙트럼 해석

Mosbeh R.Kaloop[1] · 최석준[2] · 허종완[3]

인천대학교 건설환경공학과 박사후과정[1], Leotek Co., Ltd., CEO[2],
인천대학교 건설환경공학과 교수[3]

Spectrum Analysis of Seismic Responses of a Building during an Earthquake

Mosbeh R.Kaloop[1] · Choi, Seok-Jun[2] · Hu, Jong-Wan[3]

[1]Post-Doc Fellow, Department of Civil Environmental Engineering, Incheon National University, Incheon, Korea
[2]CEO, 1 Leotek Co., Ltd., Incheon, Korea
[3]Professor, Department of Civil Environmental Engineering, Incheon National University, Incheon, Korea

Abstract: This study presents the design and implementation of a structural health monitoring system based on acceleration measurements which used to observe and investigate the structural performance of the administration building in Seoul National University of Education during an earthquake event. The frequency and spectrum are analyzed to assess the building performance during an earthquake shaking which took place on March 31st, 2014. The results indicate that : the vibration of the roof is more clear and dominant during the shaking, and the response of building during earthquake is so small and safe.

Key Words: Building, Structural health monitoring, Earthquake, Spectrum

1. INTRODUCTION

Structural Health Monitoring (SHM) is a recent field of research which appeared in the final decade of the last century. Recently, in building construction fields, changes to circulation-type production systems are strongly demanded. It is necessary to detect the structural performance adequately at each stage of a building's life cycle to use structures for a long time. Moreover, if available, instrumental measurements of shaking of a building or a nearby ground site, which means a SHM system, are very useful to decision makers (M. Gul et al., 2009).

Structural performance monitoring systems have not been adopted generally in buildings in South Korea. Nowadays, the National Disaster Management Institute (NDMI) in South Korea aims to investigate the structural performance and to mitigate the risk assessment by establishing different monitoring systems in the structures all around Korea. In addition, it aims to develop low cost monitoring applications which assess and support the health monitoring of structures. The development of monitoring tools is being driven not only by the evolving needs of engineers but also by the advent of data acquisition systems with certain software that can record, digitize, and process accelerations, integrate accelerations to obtain displacements in near real-time, and transmit both accelerations and displacements in real-time or near real-time (M. Celebi, 2013).

주요어: 건물, 구조 상태 모니터링, 지진, 스펙트럼

Corresponding author: Hu, Jong-Wan
Professor, Department of Civil Environmental Engineering, Incheon National University, Incheon, Korea
Incheon Disaster Prevention Research Center, Incheon National University, Incheon, Korea
Tel: +82-32-835-8463, Fax: +82-32-835-0775, E-mail: jongp24@incheon.ac.kr

Received February 16, 2015 / Revised March 6, 2015 / Accepted March 9, 2015

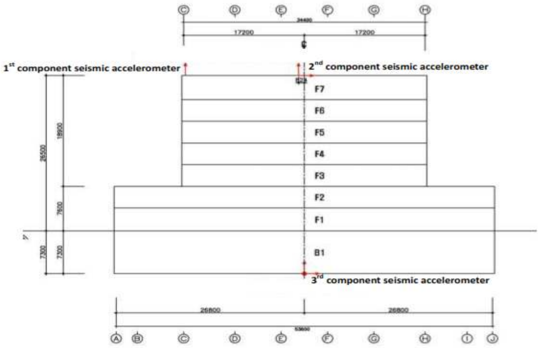
The structural responses under seismic motions are consequently random and spectrally non-stationary, and they should therefore be represented in stochastic manner by time-varying statistical quantities such as the evolutionary power spectral density function (V. Dinh et al., 2014; V. Kumar et al., 2014; H. Sohn et al., 2001). Wavelet analysis has been proven to be an effective signal processing tool for the detection and analysis of power signals; however, other signal processing tools such as Fourier transform, S-transform, time-time transform, higher-order statistics have also been used to find out other salient features (V. Kumar et al., 2014).

The response spectra has been presented, illustrating procedures that may be useful to professional engineers as an aid to design and evaluation of buildings and other structures. When earthquake ground motion data is available, the use of response spectra can be very useful in understanding how buildings perform and to identify deficiencies and damage potential (http://alum.sharif.edu/~tazarv/).

2. Building and SHM Description

The administration building in Seoul National University of Education, Seoul, South Korea is a 7-story building with total height of 26.5m in addition to a basement with depth 7.3m as shown in Fig. 1. The building is a reinforced concrete building which consists of reinforced concrete core and frames. The core was designed to resist the seismic and wind loads whereas the frames were designed to primarily carry the gravitational loads and part of the wind and seismic loads. The building has a rectangle plan with extensions in all directions as shown in Fig. 1.

(a) Elevation View



(b) Sensors Position

Fig. 1 (a) Elevation view and (b) Sensors Position for the Monitoring Building

The SHM system of the building is composed as illustrated in Fig. 2. Sensors are connected to the data acquisition device by a wire connection. Measured data are digitized in an analog-to-digital A/D converter and delivered through Bluetooth module and access point (AP) by a wireless connection. The collected data are stored in a secure digital (SD) memory and a personal computer (PC). The data acquisition device which is used in this research has one channel; each device was time synchronized by signal sender from PC at each time. PC stores data in real time and controls the sensor nodes (data acquisition devices). As a result of the feasibility measurements, the peak acceleration range of the building is about 3g. Therefore, the acceleration sensors were set with maximum amplitude of 4g. Data acquisition (DAQ) modules are prepared to measure the accelerations of each monitoring points of the building. All devices are set inside housing boxes to protect against wind and rain. The electric power was supplied from the building machine room.

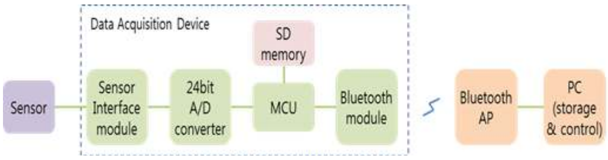
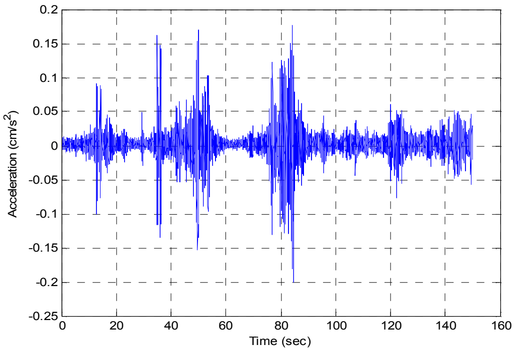


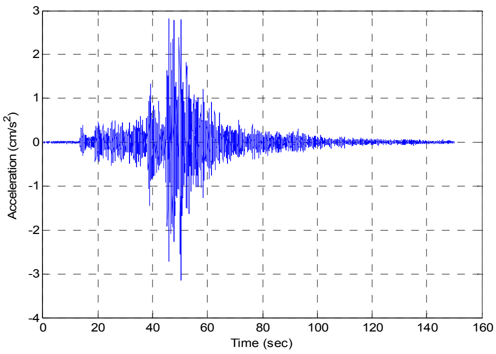
Fig. 2 Structural Monitoring System Components

3. Methods and Results

Fig. 3 illustrates the acceleration response (E-W component - Y direction) at the ground (free-field) sensor point before and during earthquake shaking, respectively. The earthquake shaking took place at 19:42 on March 31st 2014. Fig. 3(a) illustrates the noises before the earthquake; it can be seen that no effective acceleration occurred during the observation time. However, during the earthquake shaking, the peak acceleration exceeded 3Gal as illustrated in Fig. 3(b).



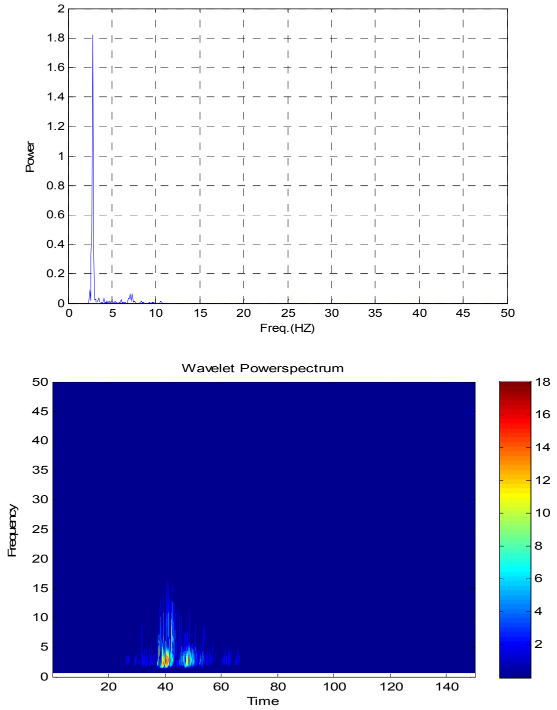
(a) Before the Earthquake



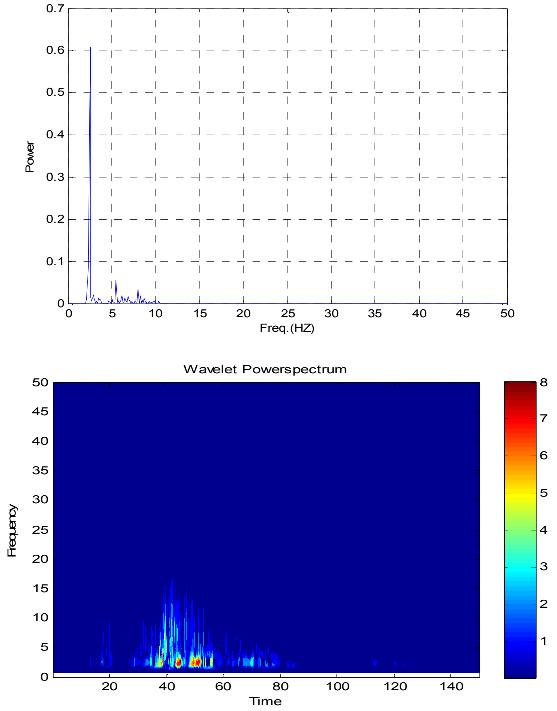
(b) During the Earthquake

Fig. 3 Acceleration Response Measurements at the Ground Point

The FFT (R. Sarica et al., 2003) and wavelet spectrum (M. Trauth, 2010) are used to calculate the dominant frequency and the frequency modes for the building. For the wavelet spectrum, the first step requires defining the number of scales for which the wavelet transform will be computed. The scales define how much a wavelet is stretched or compressed to map the variability of the time series at different wavelengths. Lower scales correspond to higher frequencies and therefore map rapidly-changing details, whereas higher scales map the long-term variations. Herein, the wavelet analysis for 120 different scales between 1 and 120 is used. The next step, the real or complex continuous db wavelet coefficients are computed. Then converts scales to pseudo-frequencies, using the db wavelet and a sampling period of accelerometer measurements. The frequency calculations based on the wavelet levels which are calculated at the previous section, and the wavelet spectrum for the acceleration response measurements are shown in Fig. 4.



(a) X direction

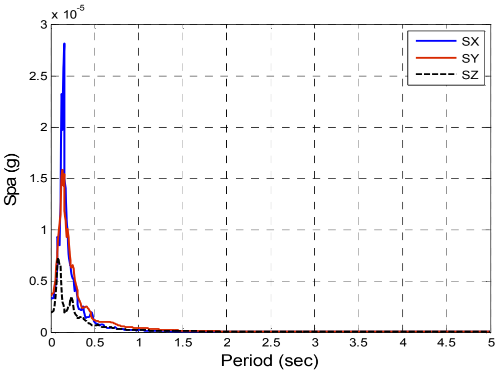


(b) Y direction

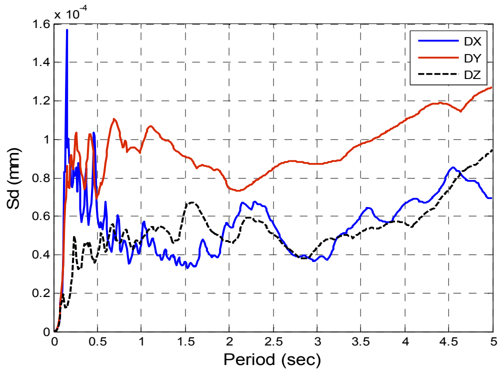
Fig. 4 First Ten Frequency Models and Wavelet Spectrum of Roof Point for X and Y Direction

It can be noticed, from Fig. 4, that the frequency modes are shown clearly at base and roof points, which are 2.54, 3.52, 4.70, 5.47, 6.84 and 8.20 Hz. The first and fourth modes are visible clearly at measurements of the roof point in X direction; while, the first, third, and sixth modes are more clearly visible in measurements in the Y direction. For the base point measurements, the vibrations modes are apparent clearly with low power spectrum density in both X and Y direction. From the comparison between the power spectrum density for the base and roof vibration, it can be concluded that the vibration of the roof is more clear and dominant during the shaking. The plots of the wavelet spectrum illustrate that the fundamental frequency mode is the dominant frequency with time at the base and roof points. Therefore, the vibration of building is occurred within the first frequency mode which implies that the behavior of the building during the earthquake shaking was elastic.

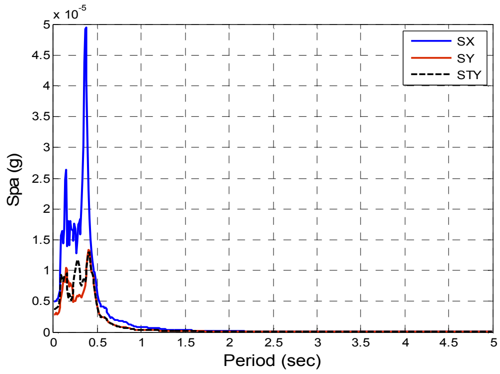
To design a structure against earthquake, one of the most recommended methods by design specifications is “response spectrum analysis” in which rather than time history analysis, maximum responses are estimated by this method. To do so, first, natural frequencies should be obtained by means of modal analysis of desired structure. Then, we need a curve which covers all the possible frequencies versus maximum responses called “response spectrum”. Specifically, this curve represents the maximum responses of several structures under an earthquake (http://alum.sharif.edu/~tazarv/). Response can be displacement, velocity or acceleration. However, for response spectrum analysis, displacement spectrum is of interest. Finally, for each mode maximum values responses of the structure can be obtained. Fig. 5 shows the elastic pseudo acceleration and displacement spectrum free and roof points monitoring.



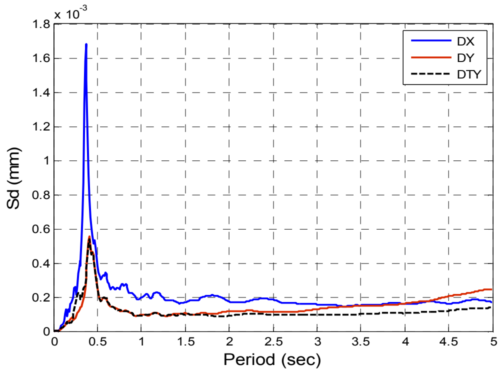
(a)



(b)



(c)



(d)

Fig. 5 Pseudo Acceleration Spectrum for (a) Free, Displacement Spectrum for (b) Free, (c) Roof (d) Roof Points

From this figure, it can be seen that the earthquake acceleration and displacement spectrum is effective in X, Y then Z directions, in addition, it can be seen that the spectrum of acceleration and displacement is so small so the effective of the earthquake can be neglected. Also, the response of roof point in X and Y are shown in Fig. 5 c, d. From this Fig, it can be seen that the response of building in X direction is higher than Y direction for mid and side points. In addition, it can be seen that the effective period time is about one second, while the maximum spectrum displacement is 1.7e-3 mm. it means that the response of building during earthquake is so small and can be neglected.

Summary

It is necessary to detect the structural performance adequately and properly at each stage of the life cycle of structures, which extends the lifetime of these structures. This study proposed a SHM system based on the acceleration response measurements to assess and investigate the structural performance of the administration building in Seoul National University of Education during the earthquake shaking which took place at 19:42 on March 31st, 2014. The conclusions drawn from the frequency and spectrum analysis illustrate the following: The vibration of the roof is more clear and dominant during the shaking and the wavelet spectrum can be illustrated the fundamental frequency modes with time more clear. In addition, it can be concluded that the vibration of building is occurred within the first frequency mode which implies that the behavior of the building during the earthquake shaking was elastic. From the acceleration and displacement spectrum can be concluded that the earthquake effect and building response are so small and safe affects on the building members.

ACKNOWLEDGEMENT

This research was supported by a grant (12-TI-C01) from Advanced Water Management Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

References

Celebi, M., (2013), “Seismic monitoring of structures and new developments,” Chapter 2, *Earthquakes and Health Monitoring of Civil Structures*, XII P, p. 331, Springer.

Dinh, V., basu, B., Brinkgreve, R., (2014), “Wavelet-based evolutionary response of multispan structures including wave-passage and site-response effects,” *J. Eng. Mech.,* 140, 04014056.

Gul, M., Catbas, F. N. (2009), “Statistical pattern recognition for Structural Health Monitoring using time series modeling” *: Theory and experimental verifications, J. Mechanical Systems and Signal Processing*. Vol. 23, pp. 2192-2204.

Kumar, V., Gawre, C. R., (2014), “Power quality analysis using wavelet transform *: A review, I.J. of Innovative Research in Science, Engineering and Technology*, Vol. 3, pp. 130-136.

Sarica, R., Rahman, M., (2003), “A wavelet analysis of ground motion characteristics,” *Proceedings of the U.S.-Taiwan workshop on soil liquefaction,* Taiwan,

Sohn, H., Farrar, C. R., (2001), “Damage diagnosis using time series analysis of vibration signals,” *Smart Materials & Structures,* Vol. 10, pp. 446-451.

Tazarv, R., (2003), “Elastic Response Spectra for Response Spectrum Analysis of Structures, available online at: http://alum.sharif.edu/~tazarv/

Trauth, M., (2010), “MATLAB Recipes for Earth Sciences,” Third Edition, Springer