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Wind-induced responses and dynamics characteristics of an asymmetrical base-isolated building observed during typhoons

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ABSTRACT

Responses of an asymmetrical base-isolated building during the passage of Typhoon Roke 2011, Typhoon Guchol 2012 and a *bomb cyclone* strong-wind event on April 3, 2012 were investigated in this paper. Wind-induced accelerations of the building were recorded by dense array permanent monitoring system and analyzed in detailed by spectra analysis, time-frequency wavelet analysis and system identification. Results of analysis revealed that wind-induced responses of the buildings were dominated by the first mode which is the fundamental flexural mode coupled with torsion of the upper stories. Building responses demonstrated non-linear characteristics of natural frequencies, damping ratio and mode-shapes. Natural frequencies of fundamental modes decreased with the increase of acceleration amplitude, with the maximum reduction of 8–10% of natural frequencies observed during the peak wind speed. Damping estimates of the fundamental modes increased with the increase of accelerations, while characteristics of mode-shapes were also found to be dependent on the wind speed. Further analysis revealed that non-linear characteristics of building responses are related to isolator deformations caused by wind-induced static force.

1. Introduction

Base isolation is a popular seismic mitigation technique for buildings and has been applied to more than 150 tall buildings with the height of 60 m or more (Takenaka et al., 2004). As the number of base-isolated tall buildings increases, consideration for wind-resistant design has become more significant than before. Unlike earthquake, wind load has two different main characteristics, namely, long duration of excitation and having static component (mean force). Because of isolator characteristics, natural period of a base-isolated building is longer than ordinary building resulting in larger wind-induced displacement of the upper story.

There have been some studies on the behavior of base-isolated buildings subjected to wind excitation. Most of them focus on modeling building response to wind excitation (Kareem, 1997; Chen and Ahmadi, 1992; Henderson and Novak, 1989), addressing the serviceability aspect of wind-induced vibration (Liang et al., 2002) and comparing wind-induced response and earthquake response of base-isolated building (Vulcano, 1998). Several studies have experimentally investigated behavior of isolator component especially creep behavior that becomes an important consideration for relatively long duration of wind excitation (Takenaka et al., 2004, 2009; Kochiyama et al., 2004). Result of the study is included in the design guideline for wind effect of base-isolated building (Japan Society of Seismic Isolation JSSI, 2009).

Despite the efforts to investigate wind-response of base-isolated building through modeling and simulation, there have been very few studies that are based on real observation of full-scale base-isolated building especially due to strong wind excitation (Yasui et al., 2002; Sato et al., 2012). As comparison, there have been numerous studies on the wind-response of tall conventional fixed base buildings under strong wind events such typhoons (Campbell et al., 2005; Li et al., 2000, 2003). Based on these studies, several conclusions are obtained such as the amplitude-dependent characteristics of damping and natural frequency (Li et al., 2000, 2003), and comparison between predicted and measured wind-induced response of conventional fixed base tall buildings (Jeary and Ellis, 1983). Recently, more base-isolated buildings have been instrumented with permanent monitoring system to observe their performance during large earthquake. The monitoring system can also be used to capture the wind-induced responses during strong wind or typhoon.

The objective of this study is to investigate wind-induced responses and dynamic characteristics of a base-isolated building from full-scale structural responses recorded during the passages of typhoons. At first the paper outlines measurement program and describes the main characteristics of typhoon-induced building responses in detailed using temporal, spectral and time-frequency wavelet analysis. Further,

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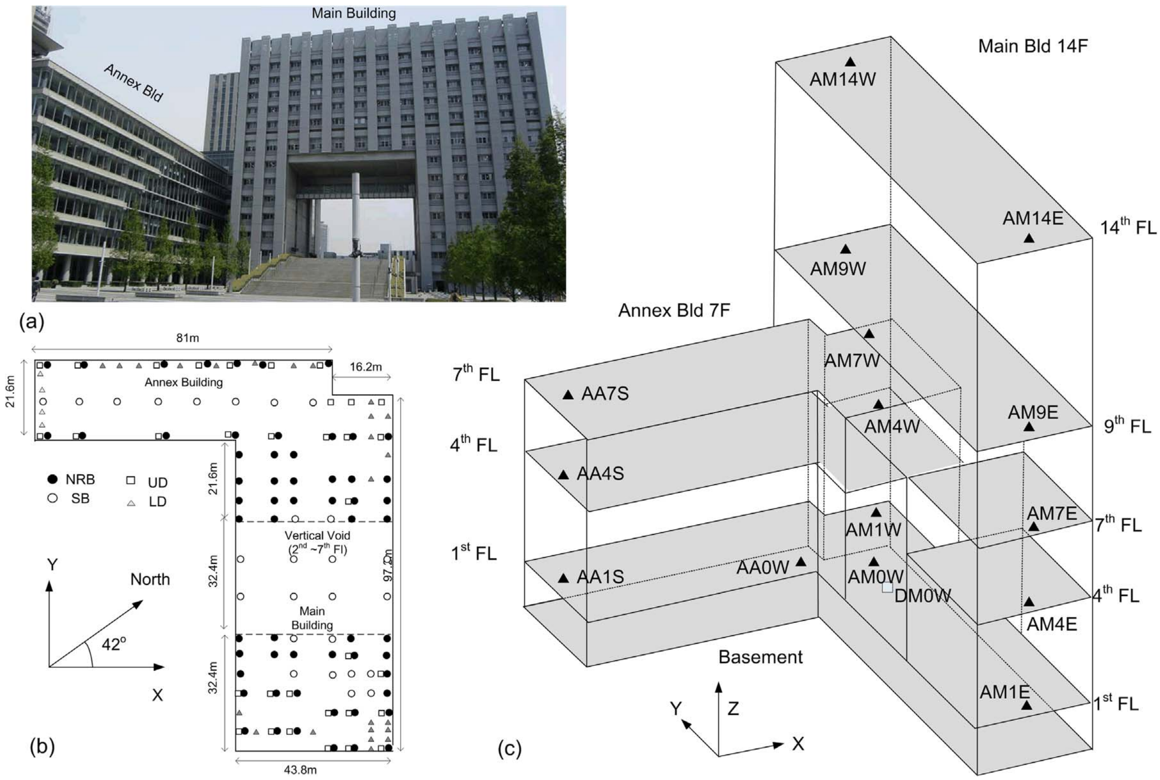

Fig. 1. (a) Photo of SIT Building, (b) dimension, orientation and building's plan view with layout of isolators at basement level, (c) Layout and location of monitoring system (note: NRB: natural rubber bearing, SB: sliding bearing, LD: lead damper and UD: U-shaped steel dampers).

dynamic characteristics of the building obtained from system identifications are described with respect to wind speed and direction. Finally, the paper provides discussions on interpretation of the results and compares the results with design condition and observations from seismic records.

2. Description of base-isolated building and monitoring system

The object structure is a mid-rise asymmetrical base-isolated building named SIT Building located in Tokyo-Bay area. The building consists of two parts: fourteen-story main building (M) and seven-story annex building (A) (Fig. 1). Both buildings are of braced steel frames and connected at the corner by elevator shaft forming an L-shaped asymmetric structure. Dimension of the main building is 97.2 m long, 43.2 m wide and 67.5 m high with 19 bays in longitudinal direction and 6 bays in transverse direction. Annex building is 81 m long, 21.6 m wide and 31.2 m high with 16 bays in longitudinal direction and 3 bays in transverse direction. The main building has vertical opening in the middle, starting from the second to the seventh floor, which divides the building into the west section (MW) and east section (ME). Concrete slab connects both buildings at the basement level and on top of the slab the isolation systems are placed.

The main building's orientation and axis direction are depicted in Fig. 1.(b). The building orientation is such that the x-axis deviates 42° clockwise from the north. Due to its unique shape, the building has significant eccentricity. The eccentricity ratio is defined as the distance between center of stiffness and center of mass with respect to building length in the corresponding direction. The ratio is presented separately for each floor and each building section in x- and y-directions. The eccentricity in y-direction is generally larger than in x-direction for annex and main building; and the eccentricity ratios in some floors are larger than 10%.

The building is base isolated with total of 146 units of isolator and damper system consisting of 59 units of natural rubber bearing (NRB), 26 units of sliding bearing (SB), 28 units of lead damper (LD) and 33 units of U-shaped steel dampers (UD) (Fig. 1). Detail explanation of the isolation system is given elsewhere (Siringoringo and Fujino, 2015a).

A permanent monitoring system consisting of 21 triaxial accelerometers and four displacement-meters is deployed on the building since 2010 as shown in Fig. 1(c). The sensors nomenclature is organized as follow, the first index denotes sensor type (A: accelerometer and D: displacement-meter), the second index represents the building (M: main and A: annex building), the third index represents story level, and the last index shows location of the sensor in the floor (i.e. S: South, E: East and W: West). Horizontal accelerations were oriented in the x and y directions per building as opposed to the commonly used North-South (NS) and East-West (EW) directions. The x-axis coincides with the main building's weak axis, while the y-axis coincides with the main building's strong axis. To avoid confusion, the terms x-axis and y-axis according to Fig. 1. will be used throughout the paper.

Eighteen accelerometers are placed on the building and three on the ground outside the building. It should be mentioned, however, that displacement-meters that measure relative displacement between basement and the first floor are activated by an underground trigger that functions only when ground motion with acceleration larger than 5 cm/s^2 occurs as in the case of earthquake. These sensors were not triggered by typhoon-induced vibration; therefore, in this paper we present analysis only from acceleration responses of upper stories. The accelerometers are the servo type with resolution of 0.01 cm/s^2 and measurement range $\pm$2000 cm/s^2. Sensor network is connected to a GPS controller unit to provide global reference position and to synchronize time recording with 4 ms maximum delay time among sensors (Siringoringo and Fujino, 2015a). The monitoring system records building accelerations at 100 Hz sampling frequency and stores the data in a server for further analysis.

Wind records were provided by Edogawa weather station, the closest weather station located approximately 2 km southeast of the building, since onsite wind measurement system was unavailable on