Engineering Structures 164 (2018) 230–242

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Determining dynamic characteristics of high rise buildings using interferometric radar system

M. Sofi[a,*], E. Lumantarna[a], A. Zhong[a], P.A. Mendis[a], C. Duffield[a], R. Barnes[b]

[a] Department of Infrastructure Engineering, The University of Melbourne, Parkville 3010, Victoria, Australia
[b] Papworths Construction Testing Equipment, Suite 2, Level 1, 949-951 Wellington St, West Perth 60005, Western Australia, Australia

ARTICLE INFO

Keywords:
Tall buildings
Field measurement
Non-contact sensor
Mode shapes
Dynamic analysis

ABSTRACT

Dynamic performance measurement of buildings using conventional contact sensors such as accelerometers, tilt meters and Global Positioning System (GPS) can be difficult due to accessibility restrictions, particularly during construction or retrofitting periods. This is one of the first studies using a non-contact microwave interferometry radar based system for dynamic measurement of high rise buildings. This paper presents results of a combined experimental and analytical approach to investigate modal properties of two high rise buildings in Australia. Dynamic properties of the buildings, namely Soul building and Zen Apartments, were investigated. The choices of the buildings were based on the different physical properties and plan layouts of the buildings. To capture the dynamic characteristics of the buildings, field measurements were carried out using an interferometric radar based equipment and compared with results from more conventional contact-sensors such as accelerometers and GPS. The building vibration test results were then correlated with the buildings' respective finite element modelling (FEM) simulations to test the capability of the radar in capturing mode shapes of the buildings. Finite elements software ETABS was used for this purpose. Results show that interferometric radar system has the potential as a non-contact instrument to be effectively used to measure the dynamic properties including mode shapes of high rise buildings.

1. Introduction

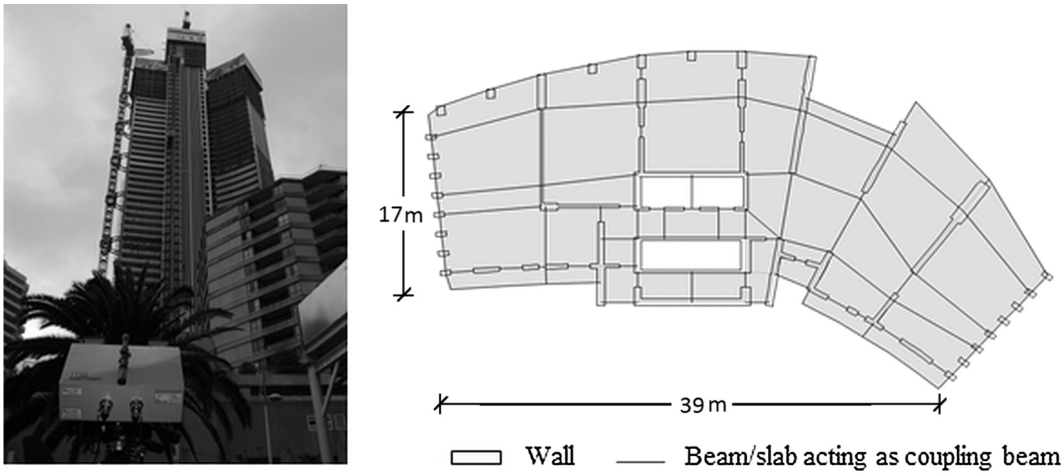
High rise buildings are becoming increasingly important features of most urban centres around the world. They are characterised by their slenderness and sensitivity to external actions such as wind, earthquake and service loadings. Resistance to lateral forces is a requisite for almost all building types and understanding the dynamic behaviour of tall buildings is imperative in order to be able to deliver effective design solutions that satisfy the requirements of stability, strength and serviceability. The design of tall buildings is governed by their dynamic performance.

Due to the growing concerns of increased extreme weather events, natural events and climate change, condition assessment and monitoring of buildings have gained increased interest. Any building failure could cause substantial damage to the property, amenity and even lead to eventual loss of life. It is very important that the building structural performance is monitored during its construction, retrofitting works particularly when the building is stripped for renovation, post-extreme events and at the end of its service life.

Various types of dynamic acquisition sensors have been developed over the past decades for the purpose of structural health monitoring. Depending on the method of application, those sensors are generally categorised into two groups: traditional contact sensors and more remote sensors. The most regularly used acquisition instrumentations in the dynamic testing of buildings are accelerometers [e.g., 1–4], tiltmeters and inclinometers [e.g., 5–8] which are categorised as contact sensors. They have a relatively low cost and high sensitivity [5,9]. The recent development of wireless communication has eliminated substantial efforts associated with the hardwiring of the sensors when used in a network to capture the global behaviour of structures. Recent advancement in Global Positioning System (GPS) has also allowed the technology to be used in the dynamic monitoring of structures [e.g., 10–15]. However, their mounting process is still considerably difficult and can be prohibitive in some cases. Construction managers and owners' corporations are often reluctant to provide easy access to the building for the installation of sensors. Other than concerns with safety, it is mostly inconvenient to install contact sensors which will require power input, wiring between sensors and data loggers without interfering with construction work. For these reasons alone, innovative remote sensing devices, which do not rely on physical contact with

* Corresponding author.
E-mail address: massoud@unimelb.edu.au (M. Sofi).

https://doi.org/10.1016/j.engstruct.2018.02.084
Received 30 April 2017; Received in revised form 21 January 2018; Accepted 26 February 2018



(a) Photograph of the building (b) Typical building plan

Fig. 1. The Soul building.

structures, have their own appeals.

The non-contact measurement techniques that can typically be employed for developing modal test data include digital image correlation, dynamic photogrammetry and three-dimensional laser vibrometry [16]. A recent addition to the list is radar based microwave interferometry to measure phase differences in electromagnetic waves, from which deflections, vibrations and resonant frequencies of structures can be measured from a distance.

As a relatively new technology, interferometric radar based system has been used across the world in the field dynamic monitoring of structures. The system has been used mostly for bridges as an integral part of long-term structural health monitoring programs. The capability of the radar based system in capturing the dynamic response of bridges has been investigated by some researchers [17–20]. Hakobyan et al. [17] examined the ability of the system in capturing the deformation of a pedestrian skywalk under static and dynamic loads. Studies have been conducted to test the accuracy of the system through a series of laboratory tests and field measurements of a concrete bridge [18]. Comparative studies based on field measurements using interferometric radar based system and accelerometers have been conducted on a cable-stayed pedestrian bridge [19]. A bridge health monitoring strategy has been proposed by Alani et al. [20] incorporating the use of interferometric radar based system to measure the deflection of the bridge under moving loads.

Only very limited number of publications to date have reported the use of such systems for measuring dynamic properties of buildings. The application of microwave remote sensing for the vibration measurements of masonry towers has been presented [19,21]. Several other studies [22–24] have also discussed the potential of using interferometric radar in dynamic structure monitoring of buildings. However, the studies have been mostly conducted on chimneys and towers [22,24] and structures with a very specific geometry [25,26]. When the interferometric radar has been used on a multi-storey building [27] results have been presented for a limited number of range bins. To the authors' best knowledge, there are no studies to date on the use of microwave interferometry radar on high rise buildings. This paper presents a study which explores the use of an interferometric radar based equipment, IBIS-FS, to obtain the dynamic characteristics of buildings that are more typical of high rise constructions in an urban area. Specifically, the results of natural frequencies and the corresponding mode shapes were measured and then compared to measurements from other sensors and results from computer modelling. The dynamic characteristics of buildings, namely, natural frequencies and mode shapes, have been used in structural health monitoring to detect deterioration of structures [28–31]. Two reinforced concrete high rise buildings in Australia: Soul Surfers Paradise in Gold Coast and Zen Harmony Apartment in Melbourne CBD, were selected for the study. The description of the case study buildings will be presented in Section 2. Field measurements using the interferometric radar based system and more conventional measurement systems, accelerometers and GPS, were conducted to capture the dynamic characteristics of the buildings (Section 3). Dynamic modal analyses were conducted on the two buildings (Section 4). Natural frequencies and mode shapes captured by the interferometric radar system were compared with those obtained from the other conventional measurements and dynamic modal analyses to test the capability of the system in capturing the dynamic characteristics of high rise buildings (Section 5).

2. The case study buildings

Two reinforced concrete buildings, namely Soul Surfers Paradise and Zen Harmony Apartment, were selected as the case study buildings. The two buildings feature significantly different characters in terms of design and construction.

2.1. Soul surfers paradise

The Soul building (Fig. 1) is a 77-storey building located in Gold Coast, Australia, that was constructed in 2010. The building houses four levels of retail precincts and 73 levels of apartment towers. The building height is 240 m and is currently stands as the ninth tallest building in Australia. The structural elements consist of reinforced concrete core, shear walls and columns that are linked by coupling slabs and header beams that are designed for the lateral loads. The reinforced concrete cores and shear walls are also designed to transfer the gravitational load and serve as internal partitions. The façade of the building mainly consists of a variety of glazing types. The building features vertical irregularities in the form of discontinuities of the structural elements due to the multiple functions of the buildings and vertical setbacks that occur progressively from level 62 to 77. The location of the structural elements and the plan geometries also cause plan eccentricities within the building. A typical floor layout is presented in Fig. 1(b). The floor to floor variations are presented in Section 4.

2.2. Zen harmony apartments

The Zen building (Fig. 2a) is a 50-storey residential/commercial