Journal of Wind Engineering & Industrial Aerodynamics 172 (2018) 256–266

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

Wind-induced vibration control of super-tall buildings using a new combined structural system

Houshyar Eimani Kalehsar, Nahmat Khodaie *

Engineering Department, University of Mohaghegh Ardabili, P. O. Box 56199-11367, Ardabil, Iran

ARTICLE INFO

Keywords:
Vibration control
Wind-induced response
Super-tall buildings
Along-wind
Crosswind

ABSTRACT

The excessive vibration due to wind loads is the main concern in design and construction of super-tall buildings. The present paper proposes a new structural system to reduce the wind-induced vibrations of super-tall buildings. The proposed structural system is a combination of an exterior tubular structure and an interior or core structure, and consists of two upper and lower parts. At the upper part, the exterior and core structures are isolated from each other. Damping devices are used in this part to limit the relative flexural motion between the exterior and core structures and control the wind-induced motions of the building by dissipating the vibration energy. In order to demonstrate the control effectiveness of the proposed structure, a numerical example of a super-tall building is presented, and the along-wind and crosswind responses are obtained using the frequency domain analysis of multi-degrees-of-freedom lumped mass models. The control performance of the proposed system is compared with that of the structure controlled by the tuned-mass-damper (TMD) system. The results demonstrate that the proposed control structure, which is a self-control structural system, can effectively reduce the wind-induced vibrations of super-tall buildings and improve occupant comfort during strong wind excitation.

1. Introduction

The population growth of large cities and limited construction areas has led to an increased demand for the design and construction of super-tall buildings. Structural design of high-rise buildings is often governed by the stiffness rather than the strength requirements. Developments in design technology, construction methods, and material qualities in civil engineering have resulted in more flexibility and insufficient inherent damping of super-tall buildings. The main concern for these buildings in strong wind events is the occupant discomfort, such as physical symptoms due to motion sickness or psychological responses like anxiety (Zhang and Roschke, 1999). It is necessary to limit such a wind-induced vibration to improve occupant comfort and structural safety of super-tall buildings. One simple parameter to estimate the lateral stiffness of a building is the drift index defined as the peak displacement at top of the building due to lateral forces divided by the height of the building (Smith and Coull, 1991). For the performance of the building envelope to be adequate, the drift index with a 20-year mean recurrence interval should not exceed 1/600 to 1/400, depending upon the type of cladding or glazing (Simiu, 2011). For high-rise buildings, the human comfort requirement is usually stated based on the wind-induced peak acceleration response. The allowable drift and peak acceleration are generally taken to be around 1/500 and 20 cm/s^2, respectively (Balendra, 1993).

Wind-induced vibration control of tall buildings has been the subject of many investigations in the recent decades. Tuned mass damper systems and tuned sloshing or liquid column dampers are the control systems studied to suppress the wind-induced vibrations of tall buildings (Varadarajan and Nagarajaiah, 2004; Moon, 2010; Roffel et al., 2012; Modi and Akinturk, 2002; Samali et al., 2004; Pirner and Urushadze, 2007). The basic concept of these devices is to increase the effective damping of the structures near a critical mode of vibration. For the TMD system, as a building gets taller and more massive, a heavier TMD mass is required and a longer stroke must be accommodated, thus raising significant safety concerns (Feng and Mita, 1995). New kinds of structural systems have been recently proposed that use a part or parts of the main structure as vibration absorbers to reduce the structural vibrations. The passive mega-sub controlled structure, introduced by Feng and Mita (1995), is one of these control systems. In this structural system, the mega-structure involves substructures, each containing several floors. The vibration energy of the mega-structures due to wind or seismic loads is transferred into the substructures, and the transferred energy is dissipated in the substructures. Zhang et al. (2005a) studied a new practical steel mega-sub controlled structure with reference to the conventional mega-frame, used in the Tokyo City Hall. Zhang et al. (2005b) suggested

* Corresponding author.
E-mail address: Nahmat.Khodaie@uma.ac.ir (N. Khodaie).

https://doi.org/10.1016/j.jweia.2017.10.029
Received 16 July 2016; Received in revised form 28 September 2017; Accepted 29 October 2017
Available online 21 November 2017

some changes in the configuration of the initially proposed mega-sub controlled structures. Zhang et al. (2009) carried out a parametric study of the structural characteristics that affect the response control of the mega-sub controlled structure. Limazie et al. (2013) investigated vibration control parameters of the passive mega-sub systems for a three-dimensional model of the structure subjected to an earthquake excitation. Makino et al. (2008) studied the effect of a large mass damper utilizing the building top floor weight isolated from a high-rise reinforced concrete building. Moon (2009) investigated the potential of the double skin façade (DSF) system as a structural vibration control device. In this system, the outer skin of the façade was modeled as a dynamic vibration absorber. Wang et al. (2011), and Liu and Lu (2014) studied the seismic performance of the tall buildings having the suspended segments regarded as vibration absorbers.

In this study, a new structural system is proposed to suppress the wind-induced vibrations of super-tall buildings. The general configuration and properties of the proposed control system are described in the following section. In order to demonstrate the control effectiveness of the proposed structure, a numerical example of a super-tall building is presented. The structure is modeled as a multi-degree-of-freedom lumped mass system, and the along-wind and crosswind responses are evaluated and compared for the following conditions of the example building using the random vibration method: (a) the uncontrolled structure; (b) the structure equipped with the TMD systems having different values of masses; (c) the proposed combined structural system. It is shown that the proposed structural system can effectively reduce the wind-induced motions of super-tall buildings and improve occupant comfort.

2. Structural forms of tall buildings and the proposed structural system

Ali and Moon (2007) divided the structural systems of tall buildings into two main categories based on the distribution of lateral-resisting systems: interior and exterior structures. The lateral load resisting systems for the interior and exterior structural systems are located within the interior and on the perimeter, respectively. Framed tube and trussed tubes are examples of exterior structures. The framed tube is formed by closely spaced columns tied together by deep spandrel beams around the perimeter of the building. In the trussed tubes, the inherent weakness of the framed tube due to the flexibility of the spandrel beams is compensated by introducing diagonal members, which resist shear forces. For the Outrigger-braced structures, the central core is connected to the perimeter columns by rigid horizontal cantilever outrigger girders or trusses. Under lateral loads, the rotation of the central core in the vertical plane is restricted through the outrigger by the axial forces in the perimeter columns. Super or mega-frames, tube in tube, and shear wall/shear truss are other structural systems of tall buildings.

For the proposed structure, the general configuration and the simplified analytical model are presented in Fig. 1. The proposed system is a combination of an exterior and an interior or core structure, and consists of two upper and lower parts. At the lower part, with high values of the internal forces and relatively small amplitudes of vibration, the external and core structures are connected to each other and resist the internal forces. While at the upper part, with relatively low internal forces and high vibration amplitudes, the exterior and interior structures

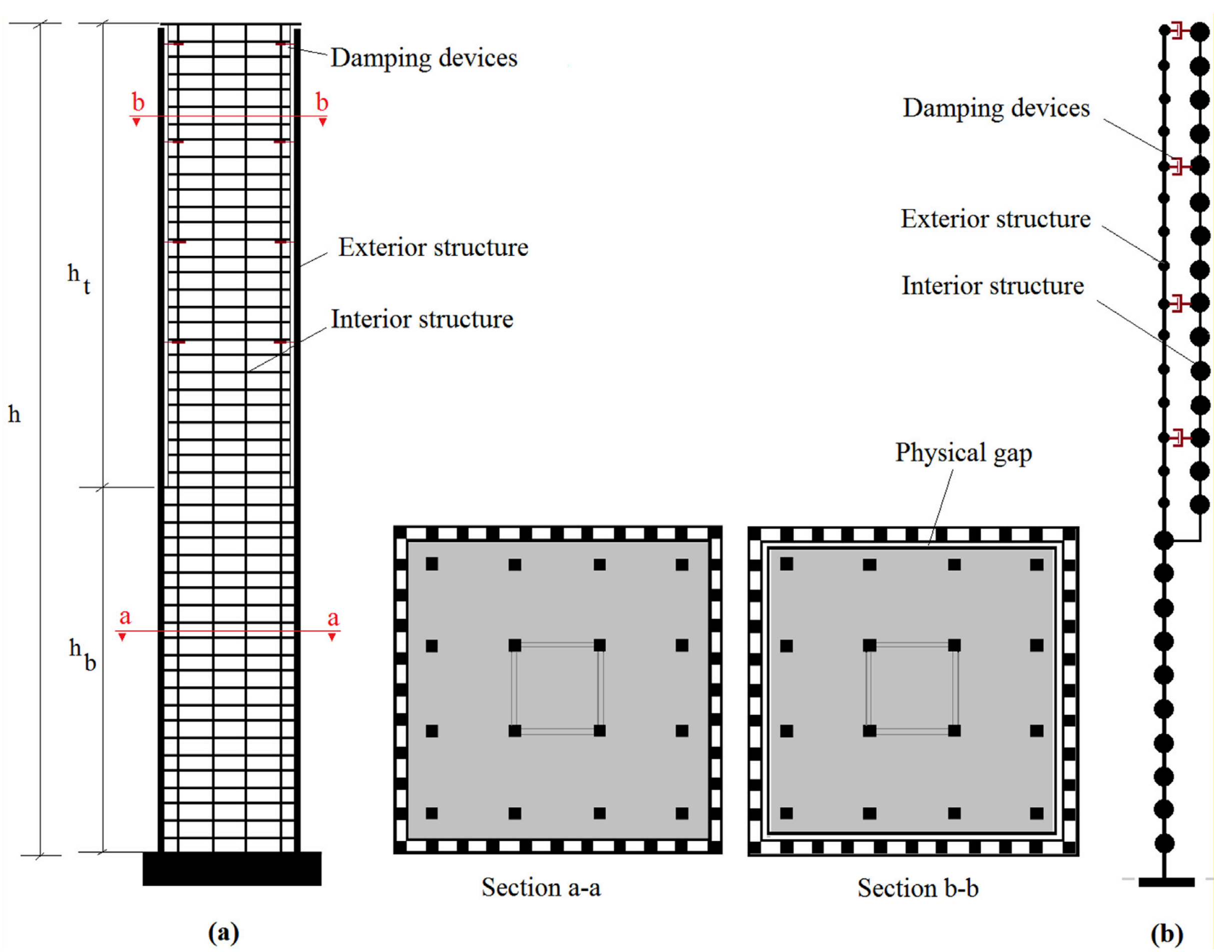

Fig. 1. The proposed structural system: (a) general scheme of the structure (b) simplified analytical model.