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# Effects of amplitude-dependent damping and time constant on wind-induced responses of super tall building

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**Abstract**

Full-scale measurements of wind-induced responses of a 79-story tall building, Di Wang Tower, were conducted during the passages of several typhoons. The amplitude-dependent damping ratios of the super tall building were obtained from the measurements. A Monte Carlo simulation procedure was developed in this study to generate fluctuating along-wind and across-wind forces acting on this building. The wind-induced responses of Di Wang Tower were numerically evaluated in time domain on the basis of the generated fluctuating wind forces and the established finite element model of the building. The predicted dynamic responses of the building using the actual amplitude-dependent damping characteristics were compared to those computed with constant damping parameters assumed by the structural designers to evaluate the adequacy of current design practices and to investigate the effect of amplitude-dependent damping on the wind-induced responses. Finally, the effect of time constant on the wind-induced responses of Di Wang Tower was studied by comparing the time domain computational results with those from conventional spectral analysis method. Some of the research findings resulted from this combined experimental and numerical study are expected to be of interest and practical use to professionals and researchers involved in the design and analysis of super tall buildings.


*Keywords:* Tall building; Damping; Wind effect; Typhoon; Dynamic response; Full-scale measurement

## 1. Introduction

Di Wang Tower is located at northwest of downtown Shenzhen, Guangdong province, China, including 68-storey main office tower, plus 11-storey facility and refuge floors as well as top tower structures, as shown in Fig. 1a. Total, the main structure of the tall building is 79-story and is about 325 m high from ground level. There are two masts with 59 m high erected on the roof of the tower. The height from the ground to the top of the masts is about 384 m. Di Wang Tower was the tallest building in Mainland China when it was built several years ago. The lengths of the main building in *X*-direction (longitudinal) and *Y*-direction (transverse) are 68.55 m and 35.5 m, respectively. Therefore, the aspect ratio between height and transverse width is about 9, which means that it largely exceeds the relevant criteria laid down in the current design codes and standards in China. This implies that this tall building is a slender structure. As Shenzhen is located at the edge of the most active typhoon generating area in the world, this super tall building may be susceptible to severe vibration induced by typhoons. Therefore, there is a need for investigating its dynamic performance under typhoon conditions.

Natural frequencies and damping ratios are very important parameters which affect the dynamic response of structures under dynamic actions such as wind or earthquake excitation. The natural frequencies can be conveniently determined from conventional methods with reasonable accuracy. However, it is very difficult or impossible to determine structural damping ratio accurately prior to

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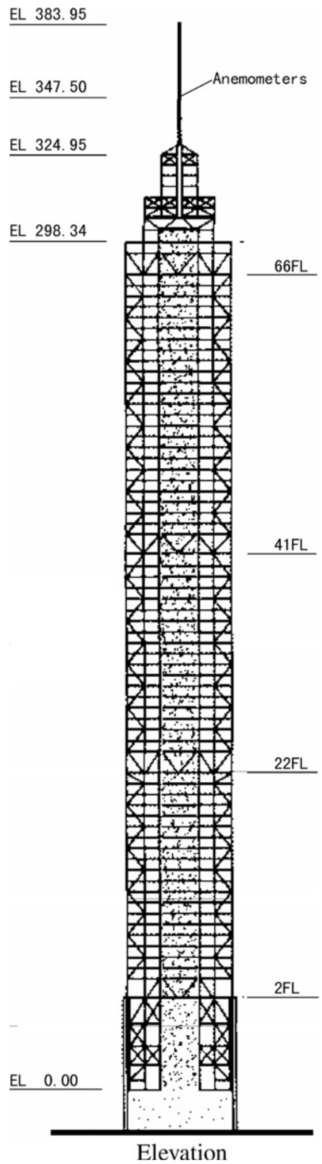


Fig. 1a. Overview of Di Wang Tower.

construction. Structural damping ratio is usually assumed to be constant value at design stage. However, the actual damping ratio is found to be a nonlinear parameter with amplitude-dependent property [9,28,12,13,17–19]. Little work has been done to examine and validate the assumptions made on structural damping of tall buildings. Over the last three decades, significant measurements of structural damping have been made throughout the world [9,28,23]. However, the majority of the previous measurements were made for buildings with 10–50 stories. There is a serious scarcity of damping data measured from super tall buildings (building height > 300 m), especially under strong wind excitations. Therefore, there is a pressing need to collect such a database.

Wind-induced responses of a tall building can be estimated in time domain [30,20,11] or frequency domain [5,22]. The damping ratio is usually treated as a deterministic value in dynamic analysis either in time domain or frequency domain. Li et al. [14] presented the first study in wind engineering to investigate the effects of amplitude-dependent damping on wind-induced vibration of a tall building in Hong Kong. However, in their study, the damping measurements were made under moderate typhoon conditions and the tall building was simplified as a five lumped mass system in the dynamic analysis. Obviously, it would be more meaningful to investigate such effects under larger vibration amplitude levels and a tall building should be modeled as a 3D multi-degree of freedom system. Therefore, further comprehensive studies are required on this research topic.

In this study, the damping database was accumulated from field measurements of wind effects on Di Wang Tower during the passages of Typhoons Sally, York, Imbudo, Dujuan and Compass. It was reported by the Hong Kong Observatory that Typhoon York was the strongest typhoon to hit Hong Kong and Shenzhen since 1983 and Typhoon Dujuan was the strongest typhoon to attack the Pearl River Delta region since 1979. This thus allowed us to obtain the damping data from the super tall building under severe vibration amplitudes induced by the strong typhoons, which provides a basis for further study on the effects of amplitude-dependent damping on the dynamic responses of the building.

The product of the natural frequency and damping ratio, which is related with time constant of a structure, indicates how long the structure takes to response to an action [10]. When a time constant becomes large then the response of a structure to wind action may be delayed. The reduction factor of root mean square (RMS) displacement response of a structure with long time constant can be as high as 20% compared with the results from conventional spectral analysis method [10]. The effect of time constant on the reduction of dynamic response of a tall building was studied by Jeary [10]. However, the structural system of the building was simplified as a single degree of freedom system and only a linear sway mode was considered in his study. As discussed previously, it is desirable to model a tall building as a multi-degree of freedom system and include more numbers of modes in the dynamic analysis for investigating the time constant effect on the dynamic responses of tall buildings.

This study, taking Di Wang Tower as an example, will address two important issues in dynamic analysis of tall buildings: the effects of amplitude-dependent damping and time constant on the wind-induced dynamics response of super tall building. First of all, the amplitude-dependent damping ratios are obtained on the basis of the full scale measurements of wind-induced vibrations of Di Wang Tower during several typhoons. Then an empirical amplitude-dependent damping model is established from the accumulated damping data. At the second stage, the time histories of fluctuating along-wind and across-wind forces are generated by the Monte Carlo simulation procedure developed from the weighted amplitude wave superposition