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Wind Induced Vibration Characteristics and Model Updating of Canton Tower Structure

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Abstract

Acceleration responses of Canton Tower are measured under weak and strong wind excitations. The power-spectral-density and the vertical correlations of the structure responses under different level of wind loads are compared. The frequencies and mode shapes of the structure are identified according to the power-spectral-density (PSD) of the accelerations. The lumped mass model considering 53 concentrated mass nodes is updated based on the identified modal results.

Keywords: high-rise structure; wind induced vibration; feedback system; vertical correlation; model updating

1 Introduction

Canton Tower, which used to be named as Guangzhou New TV Tower, is a tower used for broadcasting and sightseeing. The height of the tower is 600m, which consists of a 450m-high main tower and a 150m-high antenna. The main tower is a shear-flexural structure, composed of inner reinforced-concrete (RC) core tube and the steel frame outside, where the steel frame is composed of inclining columns of concrete filled steel tubes, steel ring beams, and steel braces (Figure 1).

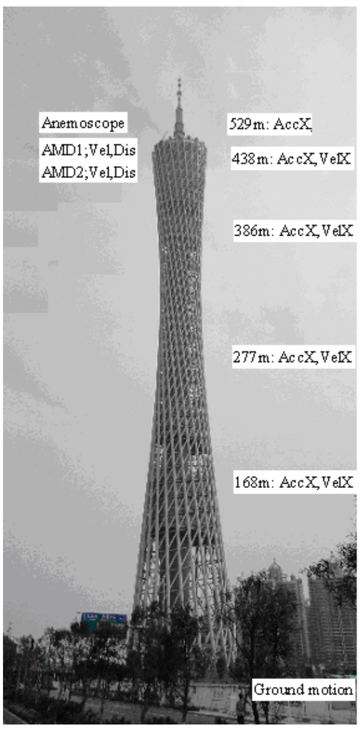

Figure 1. Sensors on Canton Tower

Figure 2. Calculation sketch of the structure

The tower is discretised with a 53-degree-of-freedom (DOF) lumped mass model considering 53 concentrated mass nodes, as shown in Figure 2. The original physical parameters, mass matrix and stiffness matrix, are obtained based on the three-dimensional finite element model. In the following sections, the lumped mass model will be updated based on the measured responses of the structure under wind excitations.

Ni (2012) developed the structural health monitoring (SHM) benchmark problem using Canton Tower. Then many researchers have studied the model updating methods based on the benchmark problem (Chen and Huang, 2012; Chung et al, 2012; Lei et al, 2012).

This paper introduces the feedback subsystem for active vibration control of Canton Tower. Analyse the characteristics of the wind induced vibration. The simplified model of the structure is also updated according to the identified modal results based on the measured dynamical responses.

2 Feedback Subsystem

The tower is so slender, with long natural period and low damping, that it is very sensitive to wind excitations. Moreover, the tower locates in Guangzhou, on the coastline of the South China Sea, where strong winds and typhoons occur frequently every year. Therefore, studying the vibration control of the tower is remarkably significant. Two active mass driver (AMD) systems were installed on the top of the main tower to suppress the wind induced vibration of the structure.

A feedback subsystem is installed on the structure to measure the structural responses for AMD controller. The feedback system consists of sensors, transmission and data acquisition devices (Figure 3).

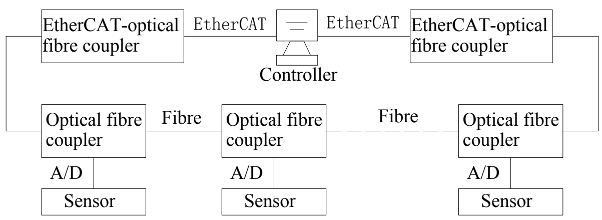

Figure 3. Feedback subsystem for AMD control system

Multiple sensors, such as accelerometers and velocity transducers, are installed on the structure to feedback the vibration of the structure, as shown in Figure 1. As the structure is very slender, the sensors adopted must have good low-frequency characteristics and high sensitivities. The frequency response range of the sensors are 0Hz(DC) ~ 100Hz. The sensitivities of accelerometers and velocity transducers are about 5mV/gal and 5V/(m/s) respectively.

The sensors are placed at the heights of 168m, 227m, 386m, 438m and 529m. The controller of AMD is positioned on the floor with height of 438m. As the transmission distance is too long from the sensors to the controller, optical fibres are adopted to transmit the signals instead of metal wires, which would make the signals decay significantly.

3 Dynamic Responses under Typhoon NESAT and Gentle Breeze

3.1 Dynamic Responses

Figure 4 and 5 show the accelerations and velocities of Canton Tower structure under gentle breeze with the wind speed of about 2.5m/s.

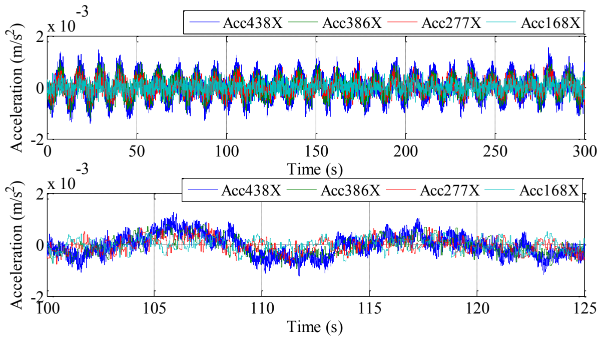

Figure 4. Accelerations of Canton Tower under gentle breeze

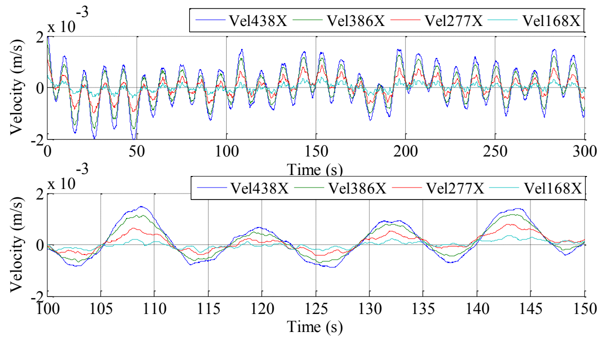

Figure 5. Velocities of Canton Tower under gentle breeze

Typhoon Nesat (international designation: 1117) was the most powerful tropical cyclone to directly impact China since 2005. Figure 7 shows the acceleration records when Typhoon NESAT (Figure 6) was passing by. The maximum wind speed recorded by the anemometer on the top of Canton Tower was about 24m/s.

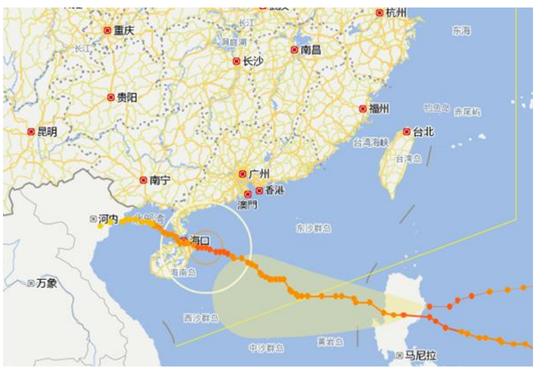

Figure 6 The path of Typhoon NESAT (the least distance from the central of the typhoon is about 428 km)

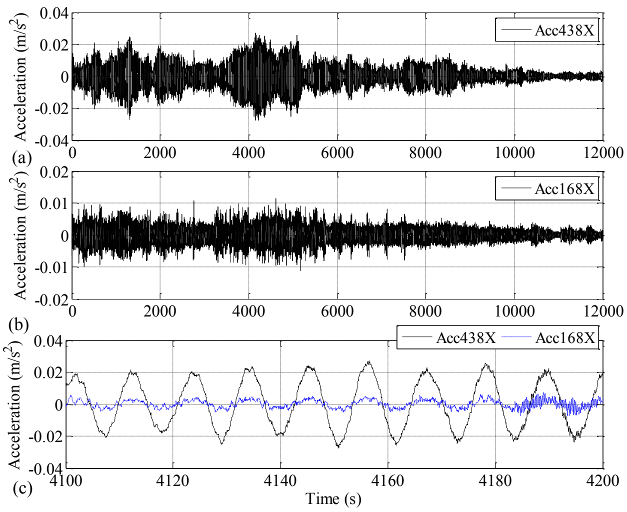

Figure 7. Accelerations of Canton Tower under the influence of Typhoon NESAT

3.2 Power Spectural Density

The power-spectral-density (PSD) of the accelerations is calculated as shown in Figure 8. The PSD of the accelerations of the structure under gentle breeze is also given to be compared with that under the influence of NESAT.

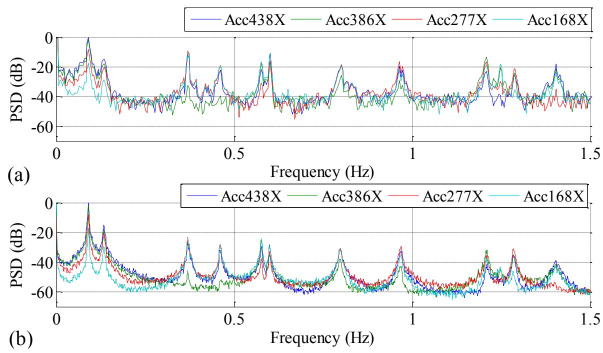

Figure 8. Power-spectral-density (PSD) of the accelerations of the structure: (a) under gentle breeze excitation; (b) under the influence of Typhoon NESAT.

Results given in Figures 8 and 9 show that:

- the vibration of the structure under wind excitation is mainly in the first order of mode;.
- the proportion of the first mode is more significant under strong wind excitation than that under the gentle breeze (as shown in Figure 9).

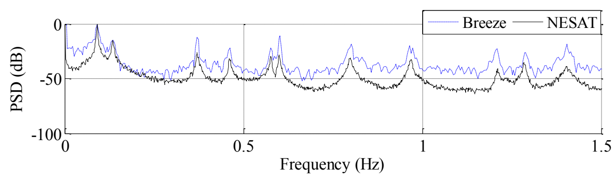

Figure 9. Comparison of the acceleration PSD under gentle breeze and under NESAT

3.3 Vertical Correlation of the Structure Response

The vertical correlations of the structure responses under gentle breeze and that under the influence of Typhoon NESAT are compared as shown in Table 1-4.

Table 1. Vertical correlations of accelerations under gentle breeze

168m	1			
277m	0.2081	1		
386m	0.0593	0.2038	1	
438m	0.0533	0.2753	0.5584	1
	168m	277m	386m	438m

Table 2. Vertical correlations of accelerations under NESAT

168m	1			
277m	0.7122	1		
386m	0.5997	0.8971	1	
438m	0.6157	0.8789	0.9631	1
	168m	277m	386m	438m

Table 3. Vertical correlations of velocities under gentle breeze

168m	1			
277m	0.9399	1		
386m	0.8387	0.9595	1	
438m	0.8167	0.9446	0.9956	1
	168m	277m	386m	438m

Table 4. Vertical correlations of velocities under NESAT

168m	1			
277m	0.9807	1		
386m	0.9450	0.9866	1	
438m	0.9359	0.9811	0.9980	1
	168m	277m	386m	438m

The comparisons of Table 1-4 show that:

- The vertical correlations of the structure responses (velocity and acceleration) under strong winds are much bigger than that under gentle breeze. The reason is that the proportion of high frequency response under strong winds is much less than that under weak winds.
- Under the same wind case, the vertical correlations of the velocity .responses are much bigger than that of the acceleration responses. That is because the proportion of high frequency response in accelerations is much higher than that in velocities.

4 Model Updating of Canton Tower Structure

The frequencies and the mode shapes of structure are identified by using the acceleration records under Typhoon NESAT. According to the obtained frequencies and mode shapes of the structure, the 53-node model of the structure is updated by using a weighted optimization method. The objective vector of the optimization is

$$P = \begin{bmatrix} \frac{f_{01}}{f_{m1}} & \frac{f_{02}}{f_{m2}} & \frac{f_{03}}{f_{m3}} & \frac{f_{04}}{f_{m4}} & \frac{f_{05}}{f_{m5}} & \frac{f_{06}}{f_{m6}} & C_{mx1} & C_{mx2} & C_{mx3} & C_{mx4} \end{bmatrix}^T \quad (1)$$

where f_{0i} and f_{mi} $(i = 1, 2, \cdots, 6)$ respectively denote the ith order frequency calculated with the updated model and that obtained according to the measured responses. C_{mxj} $(j = 1, 2, \cdots, 4)$ denotes the cross correlation coefficient of the ith order mode shapes obtained with the updated model and the measured responses.

Appropriate weight coefficients w_i $(i = 1, 2, \cdots, 10)$ are adopted for different frequencies and mode shapes. The optimizing objective function of the least square fitting is

$$\min J = (P-1)^T W_m (P-1) \quad (2)$$

The natural periods and the mode shapes of the updated model of the structure agree well with the measured results, as shown in Table 5 and Figure 10.

Table 5. Natural periods of the modified model

Mode	Natural period (s)		Relative error (%)
	Measured	Modified model	
X-1	11.1074	11.0645	0.3864
X-2	2.7196	2.7304	0.3961
X-3	1.7361	1.7482	0.6989
X-4	1.2483	1.3043	4.4872

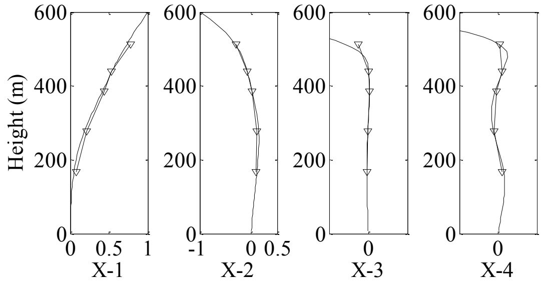

Figure 10. Mode shapes of the updated model compared with the measured results

Conclusions

Field measurements of the acceleration responses of the structure under wind excitation show that the vibration of the structure under wind excitation is mainly in the first order of mode. The proportion of the first mode is more significant under strong wind excitation than that under the gentle breeze.

The vertical correlations of the structure responses under strong winds are much bigger than that under weak winds. Under the same wind case, the vertical correlations of the velocities are much bigger than that of the accelerations.

The lumped mass model of the structure is updated according to the identified frequencies and mode shapes utilizing the measured responses of the structure. The natural periods and the mode shapes of the updated model of the structure agree well with the measured results

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