Influence of Higher Modes on the Response of Irregular Tall Buildings

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Summary

Traditionally tall buildings are designed considering the dynamic response given only by the first three fundamental modes of vibration. This hypothesis is generally accepted for regular tall buildings with uncoupled modes of vibration as any error is generally considered to be known. However recent trends in the design of tall buildings have seen many proposals for structures with complex forms resulting in complex 3D modes and greater sensitivity to wind direction. In this paper the effects of mode truncation on the response of irregular tall building with complex 3D mode shapes is examined. The sensitivity of the errors to wind direction is also investigated.

Keywords: Tall buildings; structural response; modal analysis; time domain analysis.

1. Introduction

In the design of tall buildings the dynamic response is in general estimated by considering the first three fundamental modes of vibration. The errors inherent to this approximation have been the focus of some works over the years [1,2]. However in all these studies the buildings under consideration are of a regular geometric nature and present uncoupled mode shapes. Also the analysis is carried out considering only the alongwind and acrosswind response for wind blowing normal to one of the faces of the building. Recently the design of tall buildings has been characterized by a large number of proposals for buildings presenting irregular geometric forms. This has lead to a large number of structures characterized by 3D coupled modes of vibration and, high sensitivity of their response to the direction of the incident wind. In this paper the errors committed by mode truncation on the estimation of the response of irregular tall buildings is investigated. Also the sensitivity of the error to the incident wind direction is examined.

2. Analysis Framework

Wind tunnel tests on a rigid 1:500 scale model of the Bank of China building where carried out at the Boundary layer wind tunnel of the CRIACIV (Inter-university Research centre on Buildings Aerodynamics and Wind Engineering) in Prato Italy. Synchronous Multi-Pressure Sensing Systems (SMPSS) measurements were taken using 126 carefully positioned pressure taps located over the models various surfaces. These measurements were repeated with 10° increments from 0 to 360° for a total of 36 wind directions. A sampling frequency of 250Hz was adopted and 30s of data was recoded for each wind direction.

An equivalent dynamic system with 3 degrees of freedom per floor was used to model the response of the Bank of China building. The system was carefully calibrated so as to attain the same 3D fundamental mode shapes and associated frequencies as experimentally reported in literature for the actual building. The response analysis was carried out in the time domain with direct integration of

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the generalized equations of motion. In order to investigate the effects of mode truncation on the dynamic response the following parameter was considered:

$$\sigma_{R3}(\theta)/\sigma_{R15}(\theta) \tag{1}$$

where $\sigma_{R3}(\theta)$ is the Root Mean Square (RMS) of a particular response component R considering only the contribution of the first three modes for a wind direction θ while $\sigma_{R15}(\theta)$ is its counterpart considering the contribution of 15 modes.

3. Results

The results of this study show the importance of considering wind direction when estimating the errors associated with mode truncation. Examples are shown in Fig. 1 where the unstable nature of the top floor acceleration and base toque demonstrates the sensitivity of the response to wind direction. It was also evident the importance of modal correlation. Indeed mode truncation does not necessarily mean that a response component will be underestimated as can been seen for the base torque shown in Fig. 1.

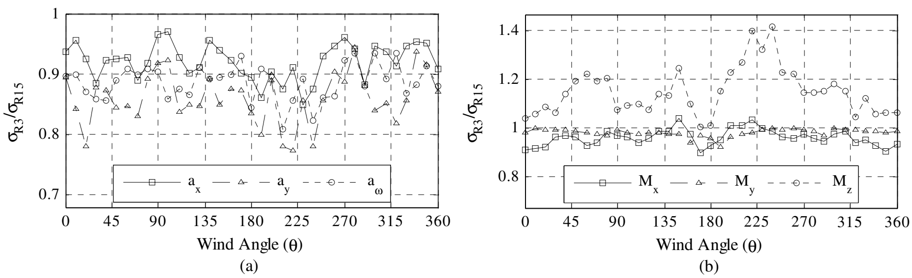

Fig. 1: Dependency of $\sigma_{R3}(\theta)/\sigma_{R15}(\theta)$ on wind direction: (a) top acceleration (b) base moments

Similar results to those shown in Fig. 1 were found for other response components such as the top floor displacements and shear forces with a maximum error of 50% and variations of 70%. The sensitivity of the torsional response was considerable with underestimates of top floor torque reaching 65%.

4. Conclusions

This study clearly demonstrated the susceptibility of irregular tall buildings to the influence of higher modes on their response. In particular it was seen that errors of up to 70% can be obtained in the estimation of the torsional response if higher modes are not considered. Also the importance of wind directionality on the errors committed by mode truncation was seen for all response components with the possible exception of the base bending moments. The important role played by mode correlation was observed by the presence of both over and underestimates due to mode truncation, sometimes accruing for the same response component by simply varying the incident wind direction.

5. References

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