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Estimation of 3D coupled wind-induced inelastic response of eccentric base-isolated tall buildings

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SUMMARY:
This study investigates three-dimensional (3D) coupled inelastic responses of base-isolated tall buildings with eccentricity of mass and resistance and coupled hysteretic forces of base isolation system. A comprehensive parametric study is performed to explore the effects of base isolation, eccentricity of resistance center and biaxial interaction of hysteretic base restoring forces on time-varying mean and statistics of fluctuating building responses and their correlations. The results of this study help in developing improved understanding of performance of eccentric base-isolated tall buildings to strong wind.

Keywords: high-rise buildings, inelastic response, base-isolated tall buildings.

1. INTRODUCTION

Increasing number of base-isolated tall buildings have been constructed primarily for seismic design consideration in terms of comfort of occupants, functionality, non-damage to acceleration-sensitive contents and non-structural elements. However, reduction of building frequency by base isolation system may cause increase in wind-induced response. Several studies have addressed the uncoupled inelastic alongwind and crosswind responses of base-isolated tall buildings (Katagiri et al., 2011; Ogawa et al., 2016; Feng and Chen, 2019a and 2019b). The coupled wind-induced responses of base-isolated tall buildings with noncoincident centers of mass and resistance has not yet been extensively investigated, while several earlier investigations have addressed the coupled lateral and torsional elastic and inelastic responses of base-isolated low- and middle-rise buildings under seismic excitations (Nagarajaiah et al., 1993; Jangid and Kelly, 2000). Another important factor influencing coupled responses of base-isolated buildings is the interaction of hysteretic restoring forces of base isolation system in two translational directions. This study investigates 3D coupled inelastic responses of base-isolated tall buildings with eccentricity and coupled hysteretic restoring forces of base isolation system.

2. THEORETICAL FRAMEWORK

A multi-story base-isolated building with eccentricities of mass and resistance is considered. The upper building is modelled as a linear elastic shear building. The building displacements relative to base are represented in modal displacements using mode shapes of corresponding fixed-base building. The base isolation system contains hysteretic restoring forces in two principal directions. The relation of restoring shear forces and displacements are represented a biaxial Bouc-Wen hysteretic model. The relation of base torque and rotation is linear. The mean alongwind wind load is defined by a power law, while the 3D fluctuating story wind forces are represented in their cross power spectra. The wind load time histories are simulated from the cross power spectra of story forces using spectral representation method. The response time history is calculated by Runge-Kutta method.

The hysteretic restoring forces of base-isolation system are also represented by an equivalent linear model using statistical linearization approach. It leads to linear equations of building motion. Subsequently, the response variances and covariances are determined from spectral analysis.

3. INELASTIC BUILDING RESPONSE

A tall building with a height of 200 m is considered as an example. The eccentricity of C.R. at each floor is the same, i.e., $e_{xi}/r_i = e_{yi}/r_i = -0.40$, and the eccentricity of C.R. at base is $e_{bx}/r_b = e_{by}/r_b = -0.40$, where r_i = 8.1650 m and r_b = 8.1650 m are the radius of gyration. The yielding displacements of base isolation system in two translational directions are 0.025 m. The yielding restoring shear forces of the base isolation system are 2% and 3% of the total building weight in alongwind and crosswind directions, respectively.

The time histories of building base and top displacements with and without eccentricity at wind speed at the building top U_H= 40 m/s is shown in Figs.1 to 3. The base displacement exceeds the yielding displacement. The yielding causes the alongwind base displacement drift in the mean wind load direction in terms of time-varying mean around which the fluctuating component is observed. The drift continues until reaching the steady-state level, which is determined by the static wind force and post-yielding stiffness. Fig.4 shows the time-varying mean alongwind base displacement normalized by the corresponding steady-state mean value. The time-varying mean displacement grows faster at higher wind speed due to larger fluctuating response and more frequent yielding. The eccentricity leads to faster growth of time-varying mean displacement.

Figs.5 to 9 show the STDs of responses. The response of base-isolated building with and without eccentricity are higher than those of the fixed-base building at lower wind speeds due to reduction of natural frequency by base isolation system. But the responses of base-isolated building are lower at higher wind speeds, which is due to additional hysteretic damping caused by yielding of base. For base-isolated building with eccentricity, the reduction of torsional displacement is resulted from the reduction of coupled alongwind and crosswind responses. The base isolation system is more effective for inelastic response of building with eccentricity.

The eccentricity leads to increases in the STDs of alongwind and crosswind building top displacements. In the case of base-isolated building, the increase in hysteretic damping resulted from yielding of base in both alongwind and crosswind directions, particularly from the higher level of yielding in crosswind direction, reduces the STD ratio of crosswind to alongwind top displacement from 1.42 to 1.17. The decrease in the ratio of crosswind to alongwind displacements of base-isolated building leads to less increase in alongwind displacement due to eccentricity. The yielding further reduces the alongwind top displacement. As a result, the eccentricity has less effect on inelastic response of base-isolated building as compared to fixed-base building.

Figs.10 and 11 show the ratio of STDs of building top displacements with biaxial hysteretic force model of base isolation system to that with uniaxial model. For building without eccentricity, the biaxial interaction leads to increase in alongwind base displacement at high wind speeds. The response power spectral analysis indicated that this increase is a result of increase in low-frequency component and decrease in resonant component around the first modal frequency. The increase in the low-frequency alongwind base displacement does not affect upper building response. The biaxial interaction leads to faster growth in time-varying mean alongwind base displacement, while the steady-state value is not affected.

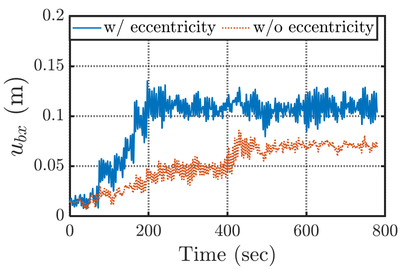

Fig.1 Alongwind base displacement

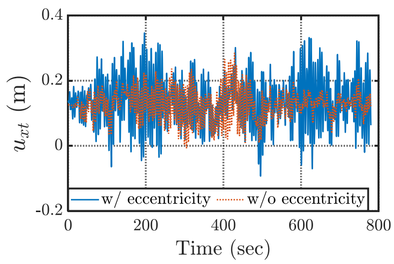

Fig.2 Alongwind top displacement

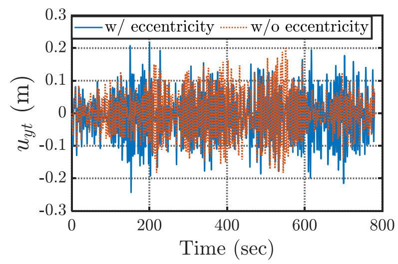

Fig.3 Crosswind top displacement

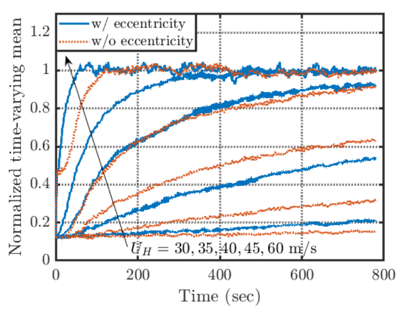

Fig.4 Normalized time-varying mean

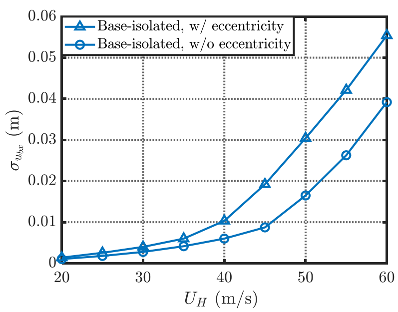

Fig.5 Alongwind base displacement

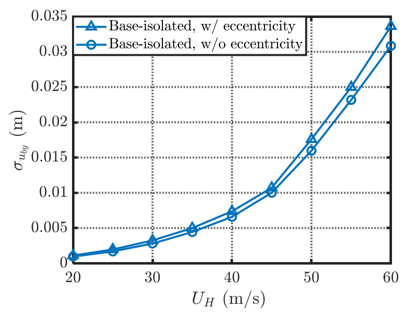

Fig.6 Crosswind base displacement

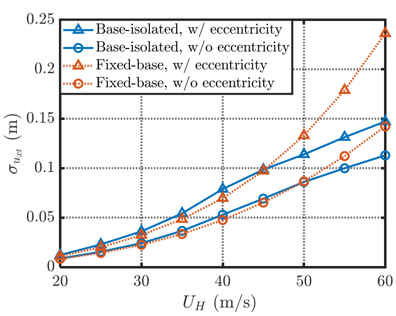

Fig.7 Alongwind top displacement

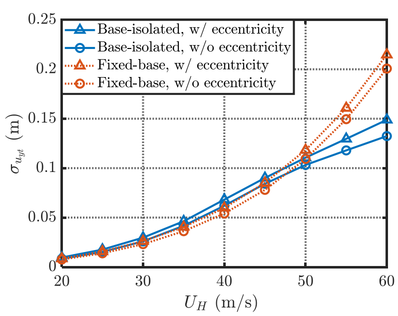

Fig.8 Crosswind top displacement

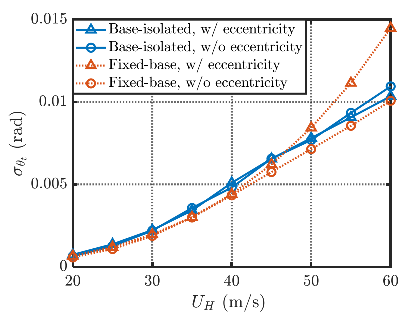

Fig.9 Torsional top displacement

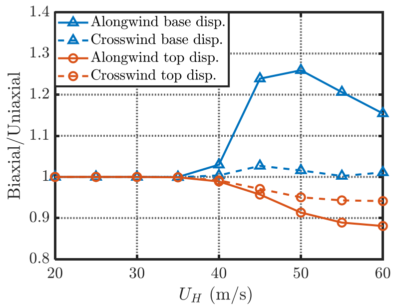

Fig.10 Biaxial interaction (w/o eccentricity)

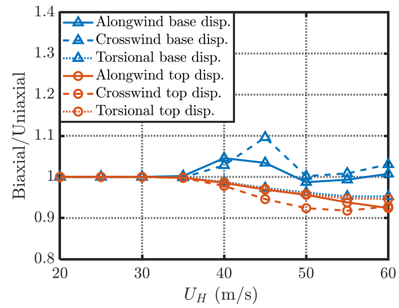

Fig.11 Biaxial interaction (w/ eccentricity)

The statistical linearization approach with a Gaussian distribution assumption is also used to estimate the STDs of fluctuating responses. It underestimates the alongwind and crosswind base displacements at high wind speeds and give good estimate of top displacements. The time-varying mean of base displacement can also be computed from response STDs and correlation coefficients. The analytical solution gives accurate prediction of time-varying mean response.

4. CONCLUSIONS

The influence of eccentricity is less on the inelastic response of based-isolated building as compared to the fixed-base building. The base isolation is more effective for building with eccentricity as compared to building without eccentricity. The biaxial interaction of hysteretic forces of base isolation system leads to increase of inelastic alongwind base displacement, primarily the low-frequency component, but decrease in resonant component of alongwind base displacement. The increase in low-frequency alongwind base displacement does not affect the upper building relative response. The building eccentricity and hysteretic restoring force model of base (i.e., uniaxial or biaxial model) affect the time-varying mean displacement. The Gaussian statistical linearization method underestimates the alongwind and crosswind base displacements at high wind speeds and give good estimate of top displacements.

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