CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 CONCLUSIONS

Various issues related to response of the building subjected to multicomponent earthquake excitation are addressed in this study, with emphasis only on two translational & torsional component. In view of accurate determination of torsional response of symmetric and asymmetric buildings, modal combination rule is formulated on the basis of stationary random vibration theory. The proposed rule requires the SV (spectral velocity) ordinates of the input ground motion. However SV curve corresponding to seismic hazard at the site under consideration is not always available. To overcome this limitation of the proposed rule, new approximation for SV for 5% damping is developed by regression analysis of 172 earthquake ground motions. It is shown that the proposed approximation performs consistently better than the other conventional approximations.

By computing the displacement, shear-force and bending moment responses at various storey levels of five five-storey symmetric and asymmetric example buildings excited by five real accelerograms with widely differing frequency contents, it is shown that the proposed modal combination rule with proposed approximation for SV, gives better agreement with the exact time-history solutions compared to CQC rule and proposed modal combination rule with SV=PSV approximation.

The proposed formulation is also able to determine the amplitudes of all the significant response peaks. It is shown that the predictions show very good agreement with time history solutions for first six peaks. These predictions are comparable with the time history results even for higher order peaks. The higher order peaks in the linear response are useful in a simple estimation of a damage measure during the inelastic response. (Sadhu, 2008).

One of the objectives of this study is to quantify the contribution of torsional response due to the torsional component of ground motion accurately. However torsional time-histories are not readily available, hence a new approach is developed to generate optimum torsional time-histories from recorded translational timehistories. The increase in
displacement responses due to torsional ground motion in various cases of five storey and ten storey symmetric and asymmetric example buildings are determined. The conclusions of this study can be summarized as follows

1) The building resting on soil is subjected to greater torsional excitations than the building resting on the rock during an earthquake.

2) The increase in response of symmetric buildings due to torsional excitation is very small (1.13 to 3.83 %) for higher values of the ratio \( \Omega > 0.7 \). In that case the accidental eccentricity coefficient, \( \beta \), lies between 0.01 and 0.022. These values are very low as compared to the recommendations of Indian seismic code (IS 1893, 2002). It has recommended the value of \( \beta \) as 0.0five.

3) In general, the increase in responses (due to torsional excitation) of ten storey buildings is more than that of five storey buildings.

4) It is observed that for low values of \( \Omega \) (\( \Omega < 0.7 \)) the in response of symmetric buildings is substantial (24.63 to 41.84\%) and the accidental eccentricity coefficient \( \beta \) lies between 0.062 and 0.075. The codal provision is not adequate for such buildings.

5) In case of unsymmetric buildings the values of \( \beta \) are found to be smaller than that of symmetric buildings. This indicates that effect of torsional excitation on the response of symmetric building is smaller than that of symmetric buildings.

6) For higher values of the ratio \( \Omega \) the codal provision for accidental eccentricity is conservative where as for low values of the ratio \( \Omega \) the codal provision is inadequate. Hence the value of \( \beta \) should not be constant, it should depend on the following structural characteristics
a) symmetry or asymmetry of the building
b) the ratio, \( \Omega \), of uncoupled torsional frequency to uncoupled translational frequency

Another objective of this study is to review various issues related to maximum response of the building subjected to multicomponent (bidirectional) ground motion. The responses of the five storey (5 cases) and ten storey (5 cases) example buildings subjected to two horizontal components of 5 example ground motions are determined. New procedure to determine maximum response without using principal components is also proposed. The responses obtained by various combination rules and proposed method are compared with
critical responses to evaluate their performances. The conclusions of this comparative study can be summarized as follows

1) The 30% rule overestimate or underestimate the critical response, with the largest overestimation of 27.96% and largest underestimation of 10.28%.

2) The SRSS rule overestimate the critical response, with the largest overestimation of 36.54%.

3) The RotI100 spectrum underestimates the response, with largest underestimation of 13.26%.

4) The principal component underestimates the response, with largest underestimation of 18.54%.

5) The Rot100 spectrum overestimate the critical response, with the largest overestimation of 9.36% only (Average overestimation is 0.93%). It do not underestimate the response in any case.

6) Presently, in the seismic design of buildings it is believed that the response obtained by principal components are maximum. However in this study it is revealed that, this response is exceeded by the critical response in 76% of the cases under consideration. Where as RotI100 response is exceeded by the critical response in 64% of the cases.

7) Following drawbacks are noticed in using principal components in this study.
   a) The two available recorded time-histories in orthogonal directions may not be properly synchronized.
   b) The orientation of the principal axes is not actually constant during strong motion.
   c) Even if it is assumed that orientation of the principal axes remains approximately constant with time during the strong motion phase of the ground motion, the different definitions of strong motion duration yield different durations, leading to different principal directions for a given earthquake.
   d) If minor principal component does not coincide with the vertical direction, the critical response is underestimated.
In view of these drawbacks of principal components an alternative approach to determine largest response of the building subjected to bidirectional ground motion, without using principal components, is suggested.

The design response spectrum should be developed on the basis of Rot 100 spectrum instead of response spectrum of recorded components. Applying Rot 100 spectrum along only one structural axis will directly give largest response (over all possible orientations) along that axis. This approach is very convenient and accurate as compared to other prevailing methods, in which responses along both the axes of the building are required to be determined.

The proposed Rot100 spectrum method is also applicable for irregular structures. In that case the responses should be obtained by applying Rot100 spectrum along both X and Y axes separately and greater of the two responses should be taken in to account. This way reasonably accurate results can be obtained without combining the responses in two orthogonal directions. Applicability of Rot100 response spectrum method for irregular structures is an improvement over prevailing methods.

7.2 Recommendations for future work

As an extension of the present study, following investigations are recommended

1) To develop attenuation relationships for Rot100 spectrum.
2) To obtain better relationship between higher order peaks in the linear response and damage measure during the inelastic response.
3) To study the inelastic torsional response of the buildings to seismic forces.