Name of the Scholar: Gaurav Rastogi

Name of the Supervisor: Prof. Khalid Moin

Name of the Co-supervisor: Prof. S. M. Abbas

Department and Faculty: Department of Civil Engineering, Faculty of Engineering and Technology

Title of the Thesis: **NON-LINEAR DYNAMIC ANALYSIS OF MULTI-STOREYED BUILDINGS USING FINITE ELEMENT APPROACH**

ABSTRACT

Seismic response of Reinforced Concrete frame structures has been one of the major topic of interest for past few years among the structural engineering researchers. The complex behavior of the Reinforced Concrete structures and their vulnerability to earthquake are the main cause behind this interest. Seismic response analysis is an art to simulate the behaviour of RC frame building structures subject to earthquake forces based on dynamics and analytical model of the RC frame building structures. The accurate analysis depends upon the proper modeling of the behaviour of materials, elements, joints and structures. This is very important to select an appropriate and simple model to properly obtain the purpose of the analysis. The behaviour of building structures when subjected to severe earthquakes may undergo nonlinear plastic deformations. Inelastic behavior of Reinforced Concrete frame structures plays a vital role in the current seismic design and re-qualification practice for Reinforced Concrete structure.

Multi-Storeyed buildings are analyzed with Linear and Non-Linear analysis. In Linear analysis the yielding of members is indirectly taken into account by either of the two considerations: by reducing the seismic demand on the structure by a response reduction factor proportional to the expected ductility of the structure or by permitting demands higher than capacity of members. This is not a true reflection. It has been seen in the past earthquakes that this criteria may be adequate for the regular structures, but for structures with some irregularity or special structures required to satisfy a particular performance level, this criteria is not sufficient and a non-linear analysis of the building is required. A severe earthquake causes tremendous forces on structures and it is not economically viable to design structures to resist elastically these high forces. At least some members in the structure must be allowed to yield to dissipate the energy. This yielding can damage the structure to some extent. Therefore the linear analysis may not reflect the true behaviour of the structure for earthquake forces. Still the linear analysis methods are widely used for earthquake analysis of structure due to the complexity of application of the non-linear methods.

In this study, linear and nonlinear analysis of 3, 6, 8 and 10 storey prototypes of Reinforced Concrete frame buildings and their 1:4 scale reduced are performed using computer program ETABS. Seismic response and nonlinear performance of prototypes and their 1:4 scale reduced models are studied and compared within the framework of comparison of Base shear, Storey moments, Time periods and formation pattern of Non linear Hinges. For scaling of the reduced scale models, similitude rules are followed. The results of prototype and their small scale models are found to be in the same fashion.

In this study an extensive research test program has been carried out to evaluate the cyclic or hysteresis performance of the RC frame building which is responsible for resisting the earthquake

load and deformation in the form of ductility by the formation of plastic hinges at the predefine locations. To understand the failure patterns and to interaction effects of infill walls and to update modeling aspects, a detailed experimental investigation is performed.

Considering the limitations of test facility available, a three dimensional 1:4 scale model of a 3 storey Reinforced Concrete frame building structure with brick infill walls at two upper floors is in accordance to the dimensional analysis and similitude rules by reducing the size and sections of a prototype building. Free Vibration Test is performed to obtain natural frequency, time period and damping ratio of the model by giving initial displacement to the model. Push over test under cyclic loading is performed with displacement control to experimentally observe the response of the Reinforced Concrete frame against lateral forces in the linear elastic and inelastic regions. The schematic diagram of test set up is shown in Figure 2. Cyclic loading is applied at roof level of the model through actuator with increments of 2.5 mm of displacement in each cycle. Load deformation curves in the form of hysteresis curves are obtained. The envelope of hysteresis curves along with the bi-linear idealization is presented as shown in Figure 3. Before and during the push over test under cyclic loading, the free vibration tests are also carried out at various stages of deformation and damage of the experimental model. The deformation and damage pattern of the experimental model is observed at various stages of load cycles. Damping ratios are calculated with the frequencies recorded from free vibration tests. Equivalent viscous damping ratios, ductility factor and cumulative energy dissipated are determined using the hysteresis curves. Storey profile and stiffness degradation have been plotted with respect to roof drift ratio.

Further in this study, the nonlinear analytical modeling of the same 1: 4 scale 3 storey Reinforced Concrete frame having equivalent struts for infill walls has been carried out using nonlinear analysis program SAP 2000. The values of plastic rotation of each component of the analytical model have been modified in different trials for the best matching of push over curves with load deformation curves obtained from experimental results.

Finally the nonlinear push over analysis of analytical model has been carried out using the modified parameters and keeping the loading pattern same as applied in Quasi Static Test. The push over curve is and superimposed with envelope of hysteresis curves obtained from experiments. The modifications of controlling nonlinear parameters have been done to match both the curves within an acceptable percentage of error.

The base shear - roof displacement curves and storey drift profile obtained from the results of Quasi Static Test under cyclic loading of the experimental model are used to update the nonlinear parameters of the analytical model in nonlinear ranges. The damage pattern and failure mode of the model obtained from the experimental results are tried to be validate with updated nonlinear analytical model.

Minor modifications in non-linear modeling parameters, such as plastic rotation and capacity of nonlinear hinges are proposed in the analytical model to closely match with the performance of the experimental model under cyclic loading testing and used in updating of nonlinear analytical 1:4 scale reduced RC frame model. Finally the non-linear modeling parameters based on the updated analytical 1:4 scale reduced model of RC frame building with infill masonry have been used to update the prototype of 3 storey model of RC frame building with infill masonry. The non-linear performance of prototype has been evaluated on the basis of updated analytical model. The results of the study shows that, using the computer programs for prediction of nonlinear behavior of RC structures without modification of non-linear modeling parameters or validation with experimental tests may lead to some erroneous results and hence it is proposed that these modifications are essential to predict the true behavior.