PERFORMANCE BASED SEISMIC ENGINEERING AND RETROFIT OF MASONRY INFILLED REINFORCED CONCRETE FRAMES

by

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1 Reinforced Concrete frames
2. Seismic engineering

CERTIFICATE

This is to certify that the thesis entitled, "**Performance Based Seismic Engineering and Retrofit of Masonry Infilled Reinforced Concrete Frames.**" being submitted by **Arshad K. Hashmi** to the Indian Institute of Technology, Delhi for the award of degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirement for the degree of **Doctor of Philosophy**.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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(Arshad K.Hashmi)

ABSTRACT

More than 90 percent of multi-story buildings in urban India and, in general, Asia – Pacific region are constructed as reinforced concrete (R/C) frame structures with masonry infills for architectural, aesthetic, functional or economic reasons. One of the lessons learnt from experiences with past earthquakes is that abrupt changes in stiffness along the height of a building due to irregular distribution of masonry infill panels over the elevation of the building frame can unfavourably and sometimes catastrophically affect the seismic performance of the frame. Despite intensive worldwide research in the area of masonry infilled frame structures during the past few decades, displacement-based analyses of masonry infilled frames with explicit consideration of masonry infill panels as structural elements is far from common practice in earthquake resistant design, mostly due to the analytical complexity in modeling the infill panel realistically. The displacements are of particular interest from the viewpoint of performance-based design (PBD), an emerging paradigm for the next generation of standard codes of practice for earthquake resistant design (seismic design codes). The present study is based on analytical investigation of the effect of distribution of masonry infill panels over the elevation of planar masonry-infilled R/C frames on the seismic response of the frame subjected to earthquake ground motions implementing rational seismic analysis methods within the performance-based framework such as non-linear dynamic time-history analysis and non-linear static force-displacement (push-over) analysis using realistic and efficient computational models of structural models. The study focuses on masonry-infilled R/C frame building structures with vertical layouts of infill panels that are commonly constructed in the field and are particularly vulnerable to earthquakes, such as the layout in which the masonry infill panels are discontinued at the ground level to create an open story, commonly termed as a 'soft' and / or 'weak' story, at the base of the building for functional purposes such as providing parking spaces at the ground

level. In the event of a near-field (near-fault) earthquake, the seismic vulnerability of such buildings would be further multiplied due to the long period velocity pulses observed in near-field earthquake ground motions. Non-linear dynamic time history analyses of typical planar multi-bay multi-story masonry infilled R/C building frames with seismically undesirable and preferred distributions of masonry infill panels over the frame elevation is performed under the action of far-field as well as near-field earthquake ground motions to predict the extent of seismic damage and possibility of collapse of such structures in the event of design level as well as maximum credible earthquakes.

One of the objectives of the present study is to demonstrate rational displacement-based analysis methodologies within the performance based framework for accurately and efficiently predicting the global and local seismic demands and related intensity of seismic damage in practical masonry infilled multi-story R/C framed structures with seismically vulnerable distributions of masonry infill panels over the frame elevation under the influence of near-field earthquakes as well. "Push-over" or non-linear quasi-static analysis methods have gained significant popularity, as they can be employed to rationally assess the seismic performance of building structures while avoiding the complexities and difficulties associated with non-linear dynamic time-history analysis. A class of equivalent static analysis procedures that employ the pushover analysis in conjunction with the response spectrum concept for predicting the seismic demands on a building structure is popularly known as the capacity spectrum method. The present study also includes a theoretical evaluation of the effect of distribution of masonry infill panels over the elevation of planar masonry-infilled R/C frames on the seismic demands of near-field as well as far-field earthquakes using the capacity spectrum procedures.

The thesis also presents a potentially feasible approach for training artificial neural networks in performance based seismic design of masonry infilled reinforced concrete (R/C) frame structures without the supervision of a teacher (unsupervised learning). A counter-propagation neural network with the unsupervised learning paradigm is trained to output the performance based design dimensions and reinforcement of the R/C frame elements without the aid of teacher signals (i.e. target design outputs). The present study shows that, in principle, the counter-propagation network (CPN) can learn from the presented training patterns to solve the inverse problem of computing the design dimensions and reinforcement of the R/C frame members that are required to achieve the specified performance objective for a selected seismic hazard level in the absence of any feedback on the correctness of the design output (i.e. without any information on the errors in output activations of the network).

The thesis also presents the development of region-specific seismic performance and vulnerability curves for the populations of typical medium-rise masonry infilled R/C framed buildings constructed in the present decade in urban India considering the various commonly implemented seismically vulnerable distributions of masonry infill panels over the frame elevation. The seismic performance and vulnerability of the generic population of medium-rise masonry infilled R/C framed building structures in urban India is assessed through non-linear dynamic analysis of representative planar masonry infilled R/C frame geometries subjected to artificially generated earthquake ground motions that are compatible with the design response spectrum specified by the seismic code for the region. Seismic fragility curves are developed for the generic population of code-compliant medium-rise R/C framed building structures in urban India for the three important structural performance limit states of immediate occupancy, life safety and collapse prevention as defined by the global acceptance criteria specified by FEMA.

Performance based design (PBD) is an iterative exercise in which a preliminary trial design of the building structure is selected for a displacement-based analysis to assess the seismic performance of the trial design. If the selected trial design of the building structure does not conform to the desired performance objective, that characterizes both the seismic hazard level at the building site and the target performance level of the structure, the trial design is revised and the iterative trial-and-error process repeated until the revised trial design complies with the performance objective. In this context, development of a fundamental approach for performance based seismic design of masonry infilled frames with minimum number of trials is an important objective. The thesis proposes a plastic design procedure based on the energy balance concept for performance based design of multi-story multi-bay masonry infilled reinforced concrete (R/C) frames subjected to near-field as well as far-field earthquakes. The proposed energy based plastic design procedure was implemented for trial performance based seismic design of representative masonry infilled reinforced concrete frames with various practically relevant distributions of masonry infill panels over the frame elevation. Non-linear dynamic analyses of the trial performance based designs of masonry infilled R/C frames was performed under the action of near-field and far-field earthquake ground motions to investigate the efficacy and accuracy of the proposed energy based plastic design procedure in achieving the target performance levels under the action of near-field as well as far-field earthquakes taking into account the influence of the distribution of masonry infill panels over the frame elevation on seismic vulnerability of the frame.

Research results show that the prevalent force based seismic analysis methodology specified by the current generation of codes of practice for earthquake resistant design (seismic design codes) is inherently deficient in predicting or controlling the seismic drift demands and the related seismic damage in building structures particularly in the event of near-field earthquakes. In particular, masonry infilled reinforced concrete (R/C) framed building structures with seismically vulnerable distributions of masonry infill panels over the frame elevation even if designed in compliance with the current seismic design codes may not achieve the desired performance objective of life safety during severe earthquakes. The thesis also proposes a plastic analysis procedure based on the energy balance concept for seismic retrofit of multi-story multi-bay masonry infilled R/C frames using passive energy dissipation (PED) devices with the objective of achieving a target performance level of the retrofitted R/C frame for a given seismic hazard level at the building site. The proposed energy based plastic analysis procedure was implemented for developing performance based design (PBD) formulations for PED devices for application in seismic retrofit of existing moment resisting frame structures. The PBD formulations developed for PED devices were implemented for a trial performance based seismic retrofit of a representative code-compliant masonry infilled R/C frame with a 'soft' ground story using friction dampers as PED devices. An important objective of the present study is to demonstrate the efficacy and accuracy of the proposed energy based methods for performance based design of new masonry infilled R/C framed structures and performance based seismic retrofit of existing masonry infilled R/C frames using PED devices subjected to near-field as well as far-field earthquakes.

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