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Abstract

Base isolation is widely considered as an efficient technique to improve seismic performance of buildings. The most desirable performance of base-isolated buildings, where structural and nonstructural damage is reduced or even eliminated is achieved when the superstructure remains essentially elastic and seismic pounding with adjacent structures does not occur. While field evidences and previous studies indicate that the desirable performance of base-isolated buildings can be assured under far-fault ground motions, their performance under near-fault ground motions containing long-period pulses is of increasing concern. Current design codes do not explicitly take into account the effects of near-fault ground motions on buildings. Extreme nonlinear response of the superstructure and seismic pounding with adjacent structures are two potential consequences of strong near-fault motions acting on base-isolated buildings. Nonetheless, previous studies focused on evaluating the performance of base-isolated buildings subject to near-fault motions have been carried out under several restrictions and accordingly lack in sufficiently addressing these issues. This thesis presents a comprehensive study of base-isolated buildings subject to design and beyond-design level shaking of near-fault and far-fault ground motions.

The study is first focused on assessing base displacement demands imposed by various types of ground motions on base-isolated buildings, and evaluating the accuracy of the equivalent lateral force (ELF) procedure of ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. Here nonlinear time-history analyses (THA) are conducted on isolation systems with rigid superstructure and a wide range of design parameters, subject to bidirectional excitation of maximum considered earthquake level ground motions. The effects of procedure for scaling ground motions (weighted scaling versus spectral matching) and the specification of response spectrum (geometric mean versus maximum direction spectrum) are also investigated. The results indicate that the near-fault pulse-like motions impose base displacement demands that could be up to 90% larger than those under far-fault non-pulse-like motions. The displacement demands are also found to be highly sensitive to the adopted scaling methodology. It is found that the ELF procedure of ASCE 7 provides reasonably good or conservative estimates of isolation system displacement demands provided that non-pulse-like motions are selected and spectral matching is used for scaling. Finally, formulae are proposed that provide better estimates of displacement demands than those provided by current provisions of ASCE 7.

A comprehensive analysis of base-isolated buildings using rigorous nonlinear THA requires (i) an appropriate approach to model viscous damping in the superstructure and (ii) contact elements for seismic pounding simulation. Accordingly, test results of a reduced-scale three-story base-isolated reinforced concrete (RC) building previously tested on a shaking table are utilized for the first time to evaluate many different commonly used damping ratios and approaches of modeling viscous damping based on three-dimensional

finite element analyses (FEA). The issue is investigated for both the nonlinear direct-integration and nonlinear modal THA. For nonlinear direct-integration THA it is found that 1% stiffness-proportional damping, where the coefficient multiplying the stiffness matrix is calculated from the frequency of the base-isolated building with the post-elastic stiffness of the isolation system is appropriate. For nonlinear modal THA, it is found that frequency-dependent damping where zero damping is assigned to the frequencies below the fundamental frequency of the superstructure for a fixed-base condition and 5% damping is assigned to all other frequencies, is more appropriate, than 5% constant damping. For simulation of seismic pounding in symmetric buildings under unidirectional excitation, a modified Kelvin-Voigt (MKV) impact force model which does not have the limitations of the conventional Kelvin-Voigt model is developed and validated using available experimental data. The MKV model is then extended to develop a novel contact element capable of simulating seismic pounding including friction and is useful for the analysis of symmetric buildings under bidirectional excitation and asymmetric buildings under unidirectional or bidirectional excitation. These newly developed impact force and contact element models are then implemented in finite element program OpenSees and will be made available for general use in the near future.

Representative nonlinear direct-integration THA are then carried out on a typical base-isolated RC building, designed using nominal properties of isolators, subject to unidirectional excitation of design earthquake level ground motions. Seismic pounding with retaining walls at the base, and for the first time floor-to-column pounding with an adjacent fixed-base building is investigated using various separation distances and earthquake ground motions. Unlike most of the previous studies, three-dimensional nonlinear FEA using fiber beam column elements and considering material and geometric nonlinearities for the superstructure as well as the isolation system, are considered in all the representative analyses performed in this study. It is found that the superstructure of the building remains essentially elastic unless pounding occurs accidently and that seismic pounding with retaining walls at the base is more critical than that with the adjacent building. Finally, extensive nonlinear direct-integration THA are carried out, for the first time on a typical base-isolated RC building, designed according to the contemporary practice of using bounding values of isolator properties, subject to bidirectional excitation of a suite of design and maximum considered earthquake level ground motions. Elastic response of the superstructure is confirmed under design earthquake level shaking. Furthermore, it is found that the building damage is acceptable under maximum considered earthquake level far-fault non-pulse-like motions, but severe damage occurs under maximum considered earthquake level near-fault pulse-like motions, yet collapse is avoided. Seismic pounding with retaining walls at the base is very likely under maximum considered earthquake level near-fault pulse-like motions, even though the required minimum separation distance from retaining walls estimated from the ELF procedure is maintained. Such pounding could initiate collapse and cause dramatic increase in floor accelerations only at the base level. Adverse effects of seismic pounding are found to be concentrated in the immediate vicinity of impact i.e., at the first story. Additional analyses carried out on the same building under unidirectional excitation for comparison purposes revealed that the inter-story drift ratios under bidirectional excitation could be up to 84% larger than those under unidirectional excitation, highlighting the importance of considering bidirectional excitation in numerical analyses.

This study reveals that excellent performance of base-isolated buildings designed according to the contemporary practice can be assured under any type of design earthquake level shaking. Nonetheless, near-fault pulse-like ground motions that represent maximum considered earthquake level shaking possess great risk to the safety of such buildings. It is shown that considering unidirectional excitation instead of bidirectional excitation can provide highly unconservative estimates of seismic demands. A comprehensive time-history analysis of base-isolated buildings must include nonlinear response of the superstructure and seismic pounding with retaining walls at the base. This study has led to the development of tools and methods for modeling viscous damping and seismic pounding that are necessary to conduct such analyses.