

論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Improved Seismic Design Procedures and Analysis Methods for RC Moment Resisting Frame Buildings with Viscous Dampers
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出典(和文)	学位:博士(学術), 学位授与機関:東京工業大学, 報告番号:甲第11660号, 授与年月日:2020年9月25日, 学位の種別:課程博士, 審査員:WIJEYEWICKREMA ANIL,廣瀬 壮一,岩波 光保,佐々木 栄一, BUI QUOC TINH
Citation(English)	Degree:Doctor (Academic), Conferring organization: Tokyo Institute of Technology, Report number:甲第11660号, Conferred date:2020/9/25, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	要約
Type(English)	Outline

Thesis Outline

Title: Improved Seismic Design Procedures and Analysis Methods for Reinforced Concrete Moment Resisting Frame Buildings with Viscous Dampers

The doctoral thesis entitled “Improved Seismic Design Procedures and Analysis Methods for Reinforced Concrete Moment Resisting Frame Buildings with Viscous Dampers” has the objectives: (i) propose a non-iterative alternative design methodology for the seismic retrofit of reinforced concrete moment resisting frame (RC-MRF) buildings with viscous dampers, (ii) develop new equations for the inelastic displacement ratio and inelastic velocity ratio for buildings with damping systems for near-fault ground motions to be used in the direct displacement-based design (DDBD) procedure, (iii) propose correction factors to calculate the peak velocity from the design velocity of the viscous dampers in the DDBD procedure, and (iv) evaluate the performance of RC-MRF building with viscous dampers by using the conditional mean spectrum (CMS). The contents of the thesis are summarized as follows:

Chapter 1 - Introduction: Background and motivation of the research, a detailed literature review of previous related studies, and research objectives are discussed.

Chapter 2 - An alternative design method for the seismic retrofit of RC-MRF buildings with viscous dampers: A non-iterative design methodology is proposed to calculate the viscous damper characteristics (peak relative viscous damper displacements, peak viscous damper forces, and viscous damper constants) to retrofit RC-MRF buildings, to achieve a prescribed target performance level. The methodology consists of four step. In short, the response indicators of the unretrofitted building are calculated using nonlinear response history analysis (NLRHA); viscous damper characteristics are calculated by estimating the peak viscous damper forces in terms of supplemental viscous damping and peak story shear forces of the unretrofitted building; and currently available expressions are used for the displacement profile of the retrofitted building and the equivalent single degree of freedom (SDOF) system displacements, to calculate the supplemental viscous damping. The proposed design methodology is applied for 4-, 8-, and 12-story RC-MRF buildings, and it is shown that the retrofitted buildings satisfy the target performance.

Chapter 3 - Inelastic displacement and inelastic velocity ratios for buildings with damping systems for near-fault ground motions: Equations for inelastic displacement ratio and inelastic velocity ratio are proposed for SDOF systems in terms of viscous damping ratio, displacement ductility, and elastic period for near-fault ground motions with fling step and forward directivity. Total number of analyses conducted are 36,456. The proposed equations are applied in DDBD procedure to calculate design values for equivalent SDOF systems with damping. The design values using the proposed expressions show better results than the conventional DDBD procedure.

Chapter 4 - Peak velocity of viscous dampers for direct displacement-based design (DDBD) of RC-MRF buildings: Damper velocity correction factors are proposed along the height to calculate the peak velocity of viscous dampers from the design velocity of viscous dampers to design RC-MRFs with linear viscous dampers (LVDs) using the DDBD procedure. The damper velocity correction factor is proposed using the results of NLRHA for a set of RC-MRFs with LVDs, which are designed using the DDBD procedure. In addition, the DDBD procedure is then used to design RC-MRFs with nonlinear viscous dampers (NLVDs) making use of the proposed damper velocity correction factor, by calculating the NLVD characteristics using the equal energy (EE) dissipation approach or the equal power (EP) consumption approach. When the damper velocity correction factor is used, the design LVD forces and design NLVD forces are close to the NLRHA results, and the maximum value of peak inter-story drift ratio (IDR) along the height of the RC-MRF from NLRHA is close to the design IDR limit. There is no significant difference in the peak story shear forces whether the damper velocity correction factor is used or not.

Chapter 5 - Performance of buildings with different methods used to distribute viscous damper constants: The responses of the RC-MRFs are compared when different methods are used to distribute the viscous damper constants. The 4-, 12, and 20-RC-MRFs were used from Chapter 4, which were design using the DDBD procedure (standard method). The total peak viscous damper forces calculated from the DDBD procedure is kept constant, and viscous damper constants are distributed to proportional for story mass (SM), design story shear force (SS), or design inter-story drift ratio (IDR) in each story. In addition, viscous dampers with the same damper constant are distributed in the top half of the building (THD) and bottom half of the building (BHD). The NLRHA results indicate that there is no significant difference in peak IDR, peak floor displacements, peak story shear forces, and sum of the peak viscous damper

constants when using the standard method, and when viscous damper constants are proportional to SM, SS, and IDR. When the damper constants are distributed using THD and BHD it is not possible to control the response indicators of the stories where dampers are not installed.

Chapter 6 - Performance assessment of RC-MRF buildings with viscous dampers using the conditional mean spectrum (CMS): The NLRHA results obtained using ground motions scaled to the CMS and the uniform hazard spectrum (UHS) are compared. The retrofitted 4-story RC-MRF with LVDs discussed in Chapter 2 is used. Conditional mean spectra are constructed by using a target period close to the fundamental period, twice the fundamental period, and second mode period. The building response is maximum when the target period of the CMS is close to the fundamental period of the buildings and the responses are close to the results obtained using UHS.

Chapter 7 - Conclusions and recommendations: Conclusions of the research which will be useful for improving seismic design of RC-MRF buildings with viscous dampers are presented, and recommendations for future research are outlined.