論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Study on Performance of Steel Moment-Resisting Frames Subjected to Multiple Earthquakes
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出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12004号, 授与年月日:2021年3月26日, 学位の種別:課程博士, 審査員:吉敷 祥一,元結 正次郎,河野 進,佐藤 大樹,西村 康志郎,山田 哲
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12004号, Conferred date:2021/3/26, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	建築学 系 / 都市・環境学 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of (Engineering)
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

At an earthquake event, a number of ground shakings with various intensities usually occur within a certain period of time. In addition, in several earthquake events all around the world, it is found that more than one strong ground shaking with almost equal intensity could occur within a short period of time. For example, in the 2016 Kumamoto Earthquake, two strong shakings occurred within a time interval of only 28 hours. That shocking event leads structural engineers and researchers to ask how safe are the buildings designed using current seismic codes in response to seismic sequence events. Since under this seismic sequence event, no structural repair could be done so that the structure itself should utilize its available capacity to sustain all the strong shakings. Until now, the influence of the multiple shocks to the building damage has not been specifically considered in any seismic design codes. For example, the current Japanese seismic design code ensures that a building will be able to sustain one severe earthquake without collapse; however, its performance to sustain multiple severe earthquakes needs to be clarified further. The main objective of this study is to comprehensively evaluate the actual seismic performance of SMRFs under multiple earthquakes. To achieve the objective, extensive numerical analysis and experimental tests are conducted.

Firstly, a numerical analysis is conducted using a non-deteriorated model. In this model, any deterioration effect is not considered. Instead, the main focus is the ductile fracture of beams because the application of the strong column weak beam concept is resulting in the beam members weaker than the column members. Various non-deteriorated SMRF models are analyzed by conducting a series of inelastic time-history response analyses that simulate the occurrence of multiple earthquakes. The damage of the structure under multiple excitations is evaluated by the cumulative damage at the beam end. Overall, it is found that the structure could maintain stable behavior under multiple excitations. Although in a few cases, it is found that the ductile fracture might occur or the ultimate state might be reached when the input intensity is larger than the design level, the performance of the structure is satisfying. By adopting the criterion of over 90% uncollapsed cases, the structure can resist up to five excitations with an intensity of peak ground velocity (PGV) 0.75 m/s or three excitations with PGV 1.0 m/s. Moreover, the beam-to-column connection test is conducted to further verify the reliability of the cumulative damage evaluation method under random cyclic loading. The loading history used in the test is created from the response analysis of the non-deteriorated model and simulating the occurrence of multiple earthquakes. By calculating the cumulative damage value of the test specimens, it can be verified that the reliability of the cumulative damage evaluation method is acceptable.

Secondly, the numerical analysis is conducted using a deteriorated model that considers the effect of strength deterioration due to local buckling of columns. Various deteriorated SMRF models are created for the analysis. These models are designed considering the combination of two main design parameters, i.e., the width-to-thickness ratio of the column member (D_c/t) and the column-to-beam moment capacity ratio (${}_cM_p/{}_bM_p$). Then, an inelastic response analysis that simulates the occurrence of multiple shocks is carried out. Overall, it is found that the performance of SMRFs under multiple excitations is lower than that of the non-deteriorated model because the weak story collapse is more likely to occur. The behavior of the structure can be divided based on whether the structure reaches the deteriorated stage or not. If the structure stays in the non-deterioration stage, then stable behavior can be achieved. In general, it is found that in the cases where the structure is having a non-deterioration margin of over 50% at the 1st excitation, the stable behavior can be achieved under five excitations. Moreover, to achieve the same criterion of 90% uncollapsed cases, a lower Dc/t value or a higher ${}_cM_p/{}_bM_p$ value is necessary. The combination of D_c/t and ${}_cM_p/{}_bM_p$ that can achieve the criterion are provided.

Lastly, to further verify the analytical result, a full-scale steel frame test is conducted. To simulate the occurrence of multiple earthquakes, one typical set of loading history that corresponds to one earthquake is created. During the test, multiple loading sets with various levels of intensities are loaded to simulate the occurrence of multiple earthquakes. Two specimens are tested in the experiment. The specimens are single-floor, one-span substructures of an intermediate story of typical current Japanese middle- or low-rise steel buildings. In addition to the test, an inelastic response analysis is conducted by matching the maximum story drift angle range ($SDAR_{max}$) with those of the loading sets used in the test. It is found that by limiting the $SDAR_{max}$ under multiple earthquakes to 4%, an acceptable performance can be achieved. From the test result, until loading set with $SDAR_{max}$ of 4%, the strength and stiffness of the steel frames barely deteriorate and only a small crack and local buckling are found at the beam end. A similar result is obtained from the response analysis, until the $SDAR_{max}$ of 4%, the cumulative damage at the beam ends are all less than 25% and the column is still in an early stage of deterioration.