論文の要旨

題目　Study on Buckling-Restrained Knee Brace Damper with Round Steel Core Bar

（丸鋼芯材を用いた座屈拘束方杖ダンパーに関する研究）

Togtokhbuyan Munkhunur

The study follows two main key phases: assessment of spreading plasticity in improved-scallop RMC using the proposed damper; assessment of the cyclic performance of the proposed slender damper with the cover tube. Based on the key phases, this dissertation has been structured in the following chapters:

Chapter 1 starts with a background of the strengthening methods of the steel beam-to-column connections used in steel construction and gives brief explanations of the yield mechanisms of the beam-to-column connections when a knee brace is implemented on them. In addition, the problem statement, the research objectives, and the scope of the dissertation are presented in this section.

Chapter 2 presents preliminary studies beginning with a literature review of the historical development of the research process on the knee brace systems and summarizing further research on the energy dissipation capacities of the different configurations of knee braces used for beam-to-column connections. This section also discusses the recent studies on applications of a steel bar used as an energy dissipator for beam-to-column connections.

Chapter 3 examines the performance of the spreading plasticity around the beam end using the proposed steel core bar BRKB dampers for the improved-scallop RMCs. In this regard, the beam-to-column connection subassembly specimens with two different lengths of the proposed dampers were tested. Their results are compared with the result of the reference specimen (no-brace beam-to-column connection subassembly). The discussion then considers the relationships between load and global relative rotation, strain distributions of upper and lower flanges of beams, and visual inspection of plasticity behavior of both beams and dampers for each specimen. This chapter reveals that the shorter damper has shown a high satisfaction for the spreading plasticity around the beam end in stable conditions (no damage). As against, for the longer brace, a noticeable bending behavior with minor thread failure was observed in the upper exposed section of the core bar after the cyclic loading tests. Based on the discussion on the comparison of the behavior of spreading plasticity for each specimen, an extensive numerical analysis was conducted in the following chapter 4.

Chapter 4 presents the extensive numerical studies using finite element analysis to examine the additional design criteria for the proposed shorter dampers. Specifically, to this end, the one-directional one-way loading analysis provided by ANSYS was employed in this section. The analysis results exhibit good agreement with the laboratory testing results. In addition, the percentage of the difference between the FE analysis and test results in each specimen for the relationship between load and global relative rotation is less than 7% regarding each peak value of the cyclic loadings. Moreover, detailed descriptions of the FEA parameters and results are provided in this chapter.

Chapter 5 examines the energy dissipation capacities of the proposed novel slender cover tube BRKB dampers using weld-free beam-to-column connections. Since chapter 3 revealed that noticeable damage was inspected in the exposed portion of the steel core bar for the longer BRKB damper, the number of contraction allowances were provided by the cover tube in this novel slender BRKB damper. Specifically, by increasing the number of contraction allowances, undesirable failure mechanisms that are global instability and local buckling of the restrainer ends can be suppressed effectively because the more uniform plastic deformation of the core bar can be achieved longitudinally. To examine the energy dissipation capacities of this new damper, two series of test programs, such as compression and cyclic loading tests, were carried out, and their results are discussed and summarized in this chapter. In addition, this new damper can be applied in weld-free beam to column connection to overcome the struggle in weld quality assurance in the RMC.

Chapter 6 summarizes the conclusions of this entire study within two subsections and offers suggestions for further inquiry investigations because future research is highly needed to extend this study. As a result of the first phase of this study, the following conclusion can be drawn.

Relative to the beam length, shorter BRKBs provided better results in terms of dispersing plasticity along the beam during the numerical and experimental studies. Based on the extended numerical analysis, it was determined that a small-diameter steel core bar (M16) for BRKBs was less effective for design purposes. Despite the thickness of the tube restrainer $t = 1$ models, all M22 steel core bar BRKB models with SF < 1 exhibited excellent ability to spread plasticity along the beams. However, a small safety factor cannot satisfy the stability requirements of the BRKBs. In contrast, in the M22 steel core bar BRKB models with SF > 1, yielding was initiated in the beam and brace simultaneously without failure of the brace, and plastic hinges were widened significantly along the beam, producing satisfactory behavior. Accordingly, it was concluded that the theoretical safety factor (value of at least one) of the proposed BRKBs could be achieved for design purposes. The half clearance between the screw section of the steel core bar and restraining tube $c_s/2$ should be controlled in the range of 1 to 2 mm for the models used in the case study.

Moreover, the second phase of this study summarizes the following conclusions. By increasing the number of contraction allowances, undesirable failure mechanisms that are global instability and local buckling of the restrainer ends can be suppressed effectively because the more uniform plastic deformation of the core bar can be achieved longitudinally. In other words, the adoption of several contraction allowance zones with the proper design of the cover tubes for the proposed dampers significantly improves the performance of the proposed dampers. The study revealed that the damper stability capacity is governed by the insertion length of the cover tube, l_{in}, and ratio of the section modulus of the cover tube against the buckling restrainer, R_{ct}.

In addition, the last section of this dissertation contains several appendices with the comparative numerical studies in which the effect of the typical knee brace on the spreading plasticity at the beam was contrasted with the proposed design plasticity mechanisms. Meanwhile, the more precise drawing schemes of the test setups with geometric explanations are attached to this dissertation. For example, Appendix A summarizes that TKBs` less stability or excessive strength and stiffness cause stress concentration in the beam end or induce plastic strain energy concentration outside of the knee brace portion at the beam, respectively. When slender BRKBs are used for RMCs, KB yielding followed by beam end plasticity is spread both inside and outside the KB areas.