論文の要旨

題目　Study on Buckling-Restrained Steel Bar Dampers for Spine Frame Systems

（心棒架構における座屈拘束丸鋼ダンパーに関する研究）

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This study aims to reveal the applicability of "buckling-restrained steel bar dampers" as energy dissipaters for spine frame systems through experimental tests. The dampers are composed of round steel bar cores restrained by round steel tubes which are partially restrained by thin-plate elements called supporters.

Chapter 1 presents a brief literature review on buckling-restrained brace dampers and on spine frame systems. Afterwards, the dissertation objectives and outline are presented.

In Chapter 2, the application of round steel bars as cores for buckling-restrained braces (BRBs) is presented as a preliminary study of the proposed damper. The main objective is to reveal the applicability and restraining performance of a BRB composed of a steel bar core, restrained by inner round steel tubes and an outer square steel tube. The BRB is based on a previous research of the same authors (referred in the main text), aiming to simplify the assembly of end-connections by implementing solid steel sections (to which the core bar can be screwed).

Test specimens (2137 mm in length) were composed of round steel bars M20, buckling restrained by an inner round tube 31.8 × 5 (diameter × thickness) and an outer square tube 60 × 60 × 4.5. The two test specimens, T-1 and T-2, differed on the number of contraction allowance zones, two vs. four, respectively. The specimens were pin-connected and diagonally placed in a steel frame to which horizontal cyclic loads were applied. The loads were gradually incremented for each loading cycle every 0.5% story drift angle R, reaching amplitudes up to 3%. Test results were measured mainly through hysteretic performance diagrams and the ratio between the axial compression and axial tension of the damper (compression-to-tension ratio). Experimental test results revealed satisfactory performance for both specimens (which displayed stable hysteresis loops), particularly for the specimen with four contraction allowance zones (T-2). The compression-to-tension ratio was within acceptable limits (1.2 as per BCJ specification) through all the amplitudes for specimen T-2, and up to 2% amplitude for specimen T-1. These results exhibited the efficacy of increasing the number of core contraction allowance zones. Functionality and mechanical behavior of end-connections were satisfactory as visually confirmed after the test. Thus, applicability of the proposed BRB damper in the preliminary study was revealed. Additionally, a theoretical method for designing the proposed BRB in a simplified and optimal way was discussed.

In Chapter 3, the buckling restrained steel bar damper (based on the BRB design concept of the preliminary research of Chapter 2) was implemented to the side columns of a spine frame system as an alternative energy dissipater to Buckling-Restrained Columns (BRCs). BRCs require a large cross-sectional area to ensure sufficient axial stiffness. By contrast, design of the proposed damper aims to avoid the use of large cross-sectional area using thin plates called supporters. The supporters are attached to the spine frame column and strengthen the damper against global buckling. To assess the functionality and energy dissipation performance of the proposed damper, cyclic loading tests were conducted on 10 damper specimens on a scaled spine frame system. The dampers (which were attached to the spine columns) differed in their buckling length (controlled through the number of supporters used), the type of connection to the spine frame base (fixed or pinned), the number and location of contraction

allowance zones, and the total length of the damper. The spine frame specimen (height = 2363 mm and width = 800 mm) was pin supported at its base and composed of welded H-sections. The damper specimens, with lengths of 550 mm for one specimen and 1200 mm for the others, were mainly composed of ABR 400 round steel bars M20 with screw-ends and STKM 13A S round tubes with dimensions of 31.8 × 5 (diameter × thickness). Supporters partially restrained the dampers by using thin PL9 plates fixed to the spine column using bolts. The core bars were screwed to the upper and lower connections. The upper connections were fixed via bolting to the spine column, and the lower connection was bolted to the base through a pin or a fixed connection. For nine of the specimens, horizontal cyclic loads were applied to the spine frame for amplitudes up to $R = 3\%$. Among these nine specimens, seven used a single damper configuration (a damper in only one of the spine columns) to assess the optimal single damper configuration. Two specimens had double damper configuration (damper at both spine columns at the sides) to test the optimal single damper configurations. One specimen (the optimal single damper configuration) was subjected to 100 constant amplitude cycles with $R = 1\%$ to test the damper's fatigue capacity. Strain data of the buckling restrainer was recorded through strain gauges strategically located on the round tube surface of the specimens. For the test, special attention was placed on contraction allowance zones and on the supporter connection. The experimental test revealed satisfactory performance for dampers with two contraction allowance zones, at least one supporter at the center, and fixed connections at their base exhibit the most satisfactory performance, displaying full hysteretic loops until the final loading test amplitude of $R = 3\%$. These dampers displayed stable hysteretic performance and their compression-to-tension ratio was within acceptable limits (1.2 as per BCJ specification). Abrasion at the threaded part of the core bar (caused by the interaction between the round tube and bar thread during the loading test) was present at the lower contraction allowance zone. However, performance of the damper was not apparently affected. Functionality and mechanical behavior of the spine, the supporter and end-connections were satisfactory as visually confirmed after the test.

In Chapter 4, the proposed buckling-restrained steel bar damper was implemented into a real scale building example with spine frame systems to assess the practicality of application of the damper. The building example has the following dimensions (See main text): total height of 20.6 m, story heights of 4.6 m for first story and 4 m for other stories, plan dimensions of 32 m × 32 m with bays of 6.4 m in each direction. The implementation of the damper was notably influenced by the required damper length (10 m) to satisfy the strain demand which was considerably long in relation to the building's height (20.6 m), and by the required number of dampers to satisfy the expected strength demand (4000 kN). The implementation was also influenced by the required number of dampers to satisfy the strength demand (2000kN yield strength for each damper, with two dampers at each side of the spine column). Because the damper was considerably long, and the required number of dampers per column was more than one, the orientation of the spine frame H-sections was adapted to implement the proposed damper. This way, it was possible to extend the damper beyond the connection zones of the first stories, and to install the two dampers at each side of the column. Up to six supporters were necessary to partially restrain the damper. In contrast to the damper connections used for the test specimen in Chapter 2, welding was necessary for the supporters (instead of bolting) to avoid difficulty of installation and obstacle at the spine column web caused by connection. Welding was also necessary for the end-connections. Thus, for a building with dimensions and strength demand as in the design example, it is necessary that the proposed damper be set up and attached to the spine column at the assembly factory, where welding of the supporters and connections shall be performed.

In Chapter 5, conclusions of the research are presented. Overall, it can be concluded that the damper can be implemented as an energy dissipation system for spine frame systems. Depending on the damper length and its strength requirements, the damper can be attached to the spine column either by bolting at the construction field, or by welding at the assembly factory.