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Development and Testing of Low-Disturbance Seismic Retrofit Method for Steel Column Bases Using Induction-Heating Bending Members

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1. Introduction

In Japan, many industrial buildings have been constructed from the late 60s to early 90s, before the collapse of the bubble economy. These rich building stocks are mostly steel structures and facing close to their life span, legally 34 years. Besides, construction materials prices have increased due to the international situation and the pandemic. Therefore, sustainable development of structures such as extending the lifespan of existing industrial buildings using retrofit techniques becomes increasingly important.

This study aims to propose a new retrofit method that combines the advantages of curved members to overcome the typical column retrofit method's weaknesses.

2. Curved Members

In structural design, the main reason for using curved members in building structures is often for aesthetic purposes. However, structural efficiency, flexibility, and functionality provided by curved members such as arches and horizontally curved members also serve as attractive options for both architects and structural engineers. Although curved members are often used in buildings, their usages for the lateral load-resisting system are very few. Furthermore, the structural behavior of curved members can be much different from straight members. Vertically curved members in structures are subjected to combined axial compression and in-plane flexural loads, while horizontally curved members need to resist both flexural and torsional moments. Previous studies and specifications mainly focused on the elastic behavior of curved members while the research on plastic behavior is limited. In addition, curved members can be formed by many bending processes which have different effects on their behavior.

3. Proposed Retrofit Techniques

As shown in Figure 1, the retrofit system consists of 2 induction heating bending channel steels that lean against the existing column. Two curved members are connected to each other by high-strength bolts connection with steel plates. The end plates are tied with anchor rods on the foundation and covered by new concrete.

The design concept is to use the characteristic of curved members to achieve the behavior with a controllable yielding region. Moreover, the eccentricity

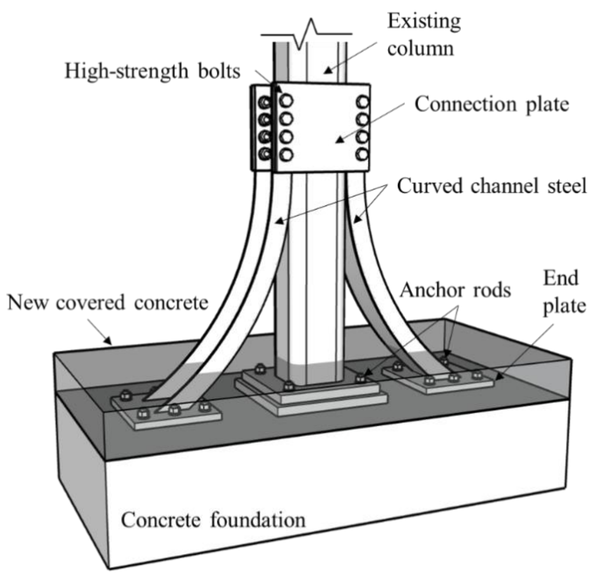

Figure 1. Schematic of the proposed curved member retrofit system

provided by the curved member itself has the feature that lateral stiffness is uncoupled from the yield strength. This behavior indicates that the strength-stiffness relationship of the retrofit system can be controlled by geometric parameters and can also avoid severe loss of strength due to buckling. Design targets for the retrofitted column base consist of behavior having (a) enhanced strength, stiffness, and improved ductility, (b) the enlarged plastic rotation capacity to reduce the seismic demand for the column base, (c) minimal disturbance to the structure during and after adopting this retrofit method, as illustrated in Figure 2.

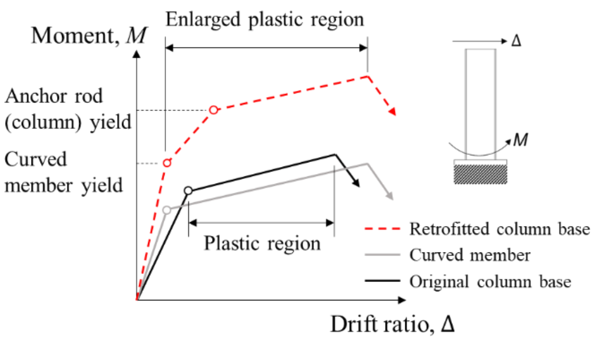

Figure 2. Comparison of strength backbones of original and retrofitted column base

4. Performance Evaluation

To first examine the mechanism, performance, and design targets of the proposed curved member retrofit method, numerical models of column bases, curved members, and retrofitted column bases were developed using OpenSees framework and ABAQUS. The behavior of curved members and their influence on the frame system were evaluated by the fundamental and static pushover analysis.

The analytical results show that the proposed curved member retrofit method provides enhanced strength and stiffness for column bases. Improved ductility is achieved by the enlarged plastic region with plastic strength corresponding to the early yielding of the curved member and the delayed yielding of the anchor rods at the column base. The plastic rotation capacity of the retrofitted column base has been increased by 36%. The design target of minimal disturbance to the structure was analytically verified by adopting the retrofit method to a four-story steel moment-resisting frame which was designed for a hospital facility. The analytical results indicate that the natural period of the 4-story SMRF with retrofit has 6% reduction and a space occupancy rate of 16% in a single span compared to the original one, which implies that the proposed retrofit system won't increase much seismic demand on the overall frame system. In addition, an experimental program of the a prototype specimen conducted at the DPRI structural laboratory confirmed a stable cyclic behavior with very limited strength degradation.

5. Conclusions

The study concluded several remarks as listed follows: (1) The proposed retrofit method has been analytically verified to achieve the design targets; (2) The mechanics of induction-heating bent specimens have been experimentally verified as having great ductility, limited strength degradation, controllable yielding region, and feasibility in practical application. (3) The initial distortion and poor precision of the cold-formed bending specimen resulted in early local buckling and strength degradation.

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