Cyclic Behavior of Replaceable Steel Coupling Beams

Xiaodong JI
Associate Professor
Tsinghua University
Beijing, China
jixd@tsinghua.edu.cn

Yandong WANG
Graduate Student
Tsinghua University
Beijing, China
jltxwyd008@163.com

Qifeng MA
Graduate Student
Tsinghua University
Beijing, China
maqf@foxmail.com

Jiaru Qian
Professor
Tsinghua University
Beijing, China
qianjr@tsinghua.edu.cn

Summary

For improving the resilience capacity, a replaceable steel coupling beam is developed, which comprises a central "fuse" shear link connected to normal steel segments at its two ends. This paper presents a series of quasi-static tests used to examine seismic behavior of the replaceable steel coupling beams with various types of connections between shear link and normal segments. The end plate connection with shear key and high-strength bolts showed advantages. The inelastic deformation was found to concentrate in the shear link, while the normal segments remained intact. The replacement of shear link was also demonstrated after the coupling beams experienced the deformation corresponding to the maximum considered earthquake (MCE). The coupling beams reached the inelastic rotation of 0.06 to 0.08 rad, and the fuse shear links underwent the inelastic rotation of 0.15 rad. The overstength factor of very short shear links could reach a value of 2.0.

Keywords: replaceable steel coupling beam; seismic behavior; connection; replaceability; inelastic rotation capacity; shear link

1. Introduction

This paper presents a type of replaceable coupling beam comprises a central "fuse" shear link connected to permanent steel segments at its two ends (see Fig. 1). Inelastic deformation concentrates in the "fuse" shear link during a severe earthquake, while the normal segments remain elastic. The shear link can be replaced readily after being damaged as removable connections are employed at its two ends.

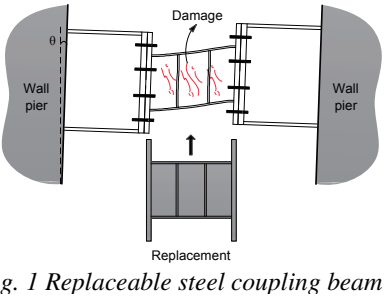
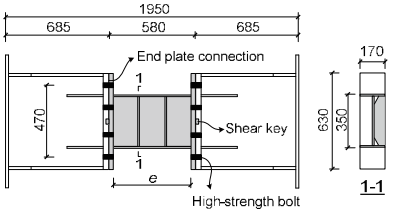


Fig. 1 Replaceable steel coupling beam

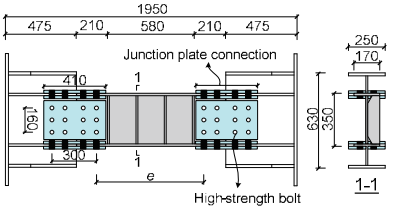
2. Experimental Program

A total of three specimens, with various types of connections, were designed and tested (see Fig. 2). The normal segments of all specimens were I-shaped steel. The shear links of Specimens CB1 and CB2 were built-up I-shapes, while that of CB3 was double channel-shapes. Specimens CB1 adopted end plate connection, where a shear key transfers the shear force and high-strength bolts transfer the bending moment. Specimen CB2 used junction plate connection. For Specimen CB3, the double channel steels were connected to the webs of normal segments by high-strength bolts. All links were designed to yield in shear. The strengths of normal segments and connections were designed to be higher than the maximum shear strength of shear link.

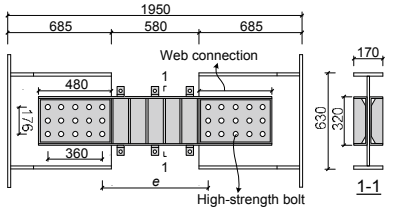
Fig. 3 shows the test setup and instrumentation. In Phase I loading, the specimen was loaded to 0.02 rad rotation, approximately the demand for coupling beams under MCE. Afterwards, the shear link was replaced. In Phase II loading, the specimen with reinstalled shear link was loaded till failure.



(a) CB1



(b) CB2



(c) CB3

Fig. 2 Test specimens.

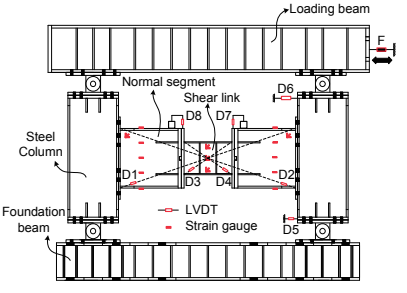
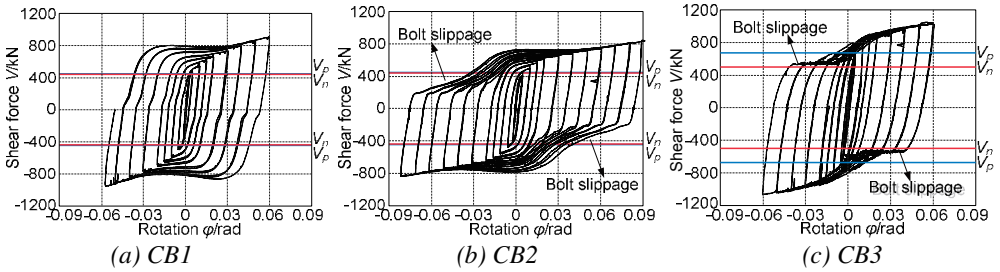


Fig. 3 Test setup and instrumentation.

3. Experimental Results

In Phase I loading, "fuse" links yield in shear for all specimens. In Phase II loading, Specimen CB1 showed very stable hysteretic loops under large inelastic rotation (see Fig. 4). Specimens CB2 and CB3 exhibited pinching behavior due to bolt slippage after 0.03 rad rotation. Two types of failure modes were observed in shear links, i.e., flange-to-end plate weld fracture and web fracture.

The ultimate rotation of coupling beams was no less than 0.06 rad for all specimens, significantly larger than the rotation capacity of RC coupling beams. The I-shaped shear links of Specimens CB1 and CB2 with a length ratio of 0.7 had an inelastic rotation capacity of approximately 0.15 rad and an overstrength factor of 2.0. The double channel-shaped shear link of Specimen CB3 with a length ratio of 1.24 had an inelastic rotation capacity of 0.12 rad, and an overstrength factor of 1.5.



(a) CB1 (b) CB2 (c) CB3

Fig. 4 Hysteretic loops of shear force versus rotation of specimens in Phase II loading.

The replacement of the shear links was conducted by two workers after Phase I loading. The replacement for Specimen CB1 was most rapid, only 0.4 h. The replacement of Specimens CB2 and CB3 took over 2h, because of installation of a large number of high-strength bolts.

4. Conclusions

Replaceable steel coupling beams were developed and tested in this paper. All specimens showed large inelastic rotation capacity of 0.06 to 0.08 rad. The inelastic deformation concentrated in the "fuse" shear link. The end plate connection with shear key and high-strength bolts was found to be superior in both strength and rapid replacement.