Experimental Studies on Hysteretic Behavior of Buckling-restrained Metallic Connecting Plate of Hinge

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ABSTRACT

The buckling-restrained metallic connecting plate was as a part of assembled joint of steel plastic-deformation controllable hinge, its hysteretic behavior was the key to plastic energy dissipation of assembled joint of steel plastic-deformation controllable hinge. In order to investigate the hysteretic behavior of buckling-restrained metallic connecting plate, quasi-static reciprocating experiment of two specimens of buckling-restrained metallic connecting plate were carried out. The hysteretic force-displacement curves, skeleton curve, failure modes, ductility and energy dissipation were analyzed. The results show that the buckling-restrained metallic connecting plate has reasonable failure modes and higher hysteretic behavior, ductility and energy dissipation capacity.

INTRODUCTION

A large number of studies have shown that the connection and joint of prefabricated components are the weak points of the assembled structure, which is also the focus of the research on seismic performance of the prefabricated structure and the premise and basis for the study of the overall seismic performance of the structure [1-4].

The buckling-restrained metallic connecting plate, as a connecting member for a fabricated energy consuming hinge is an important part of the steel plastic-deformation controllable hinge and its assembled joint (Figure 1), whose mechanical properties are also the key to the force transmission and plastic energy dissipation. In

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order to make a deep research on the hysteretic behavior of the buckling-restrained metallic connection, quasi-static reciprocating test of two specimens of buckling-curves, skeleton curve, failure modes, ductility and energy dissipation were analyzed.

THE GENERAL SITUATION OF THE EXPERIMENT

Experimental Component Overview

The experimental object is two buckling-restrained metallic connecting plate, the structure of which is shown in Figure 2. There is a slight gap between the inner core plate and the restraining steel sleeve, and the lubricating oil is filled to ensure that the inner core plate and the steel sleeve can slide relative to each other. The inner core plate is a rolled steel plate with the yield strength of 235MPa, and the inner core plate is attenuated by an elliptical hole. The steel sleeve is made of steel with the yield strength of 235MPa by protective welding.

Experimental Device And Method

EXPERIMENTAL DEVICE

Experiment on hysteretic behavior of buckling-restrained metallic connecting plate was completed on a 100 ton SANS microcomputer controlled electro-hydraulic servo tension and compression test machine, as shown in Figure 3. The horizontal-push clamp is a disc type clamp with a diameter of 140 mm. The end of the specimen is connected to the experimental device through the clamp, and the contact surface between the specimen and the clamp is the entire surface of the clamp, so the effective length is 370 mm.
LOADING SCHEME

The loading system is as follows: According to the requirements of the Code for Seismic Testing of Buildings (JGJ101-2015) [5], the loading procedure adopts the load-displacement double control method. Before the specimen is yielded, the load is controlled and graded according to $0.25F_y$, $0.5F_y$, $0.7F_y$. $F_y$ is the calculated yield bearing capacity of the specimen. After the specimen is yielded, the displacement control is adopted, and the multiple of $\Delta y$ is used to control loading until the specimens are destroyed, and $\Delta y$ is the yield displacement of the test piece. In addition, according to the load control, each stage of the load is cycled once; according to the displacement control, the cycle is 3 times. In the experiment, both components are pulled first and then pressed.

EXPERIMENTAL RESULTS AND ANALYSIS

Experimental Phenomena And Failure Modes

Due to the error in the production of E-6-100, there is no gap between the inner core plate and the restraining steel sleeve, so that it cannot slide relative to each other. Under the above loading system, the inner core plate exhibits obvious buckling in the unconstrained non-yield section when the displacement amplitude of 2.7mm. The bearing capacity decreased rapidly during the tension of the displacement amplitude of 4.5mm, and the experiment ended.

The bearing capacity of the specimen E-10-100 decreased rapidly during the tension of the displacement amplitude of 3.9mm, and there is no obvious sound. It is judged that the buckling-restrained metallic connecting plate to crack in the middle portion, and the experiment is ended.

Cut the confined steel sleeve of the specimen, and the failure mode of the inner core plate is as shown in Figure 4. Obvious cracks appeared in the middle of inner
core plate in E-10-100. From the thickness direction of the inner core plate, obvious necking can be observed in the section where the fracture and crack are located.

**Analysis of Experimental Results**

**FORCE-DISPLACEMENT CURVES**

The force-displacement curve of the two test pieces measured in the experiment is shown in Figure 5. It can be seen from Figure 5 that the E-6-100 has buckling in the unconstrained non-yield segment during the loading process with a displacement amplitude of 2.7 mm due to the error in the production, but the strengthening phenomenon after buckling is obvious. It also shows that the buckling-restrained metallic connecting plate is a good energy-dissipation member. The force-displacement curve of E-10-100 is very full, and the strength and stiffness of specimens are basically not degraded. There is no obvious pinch phenomenon occurred before the specimen was cracked. Therefore, it is explained that the buckling-restrained metallic connecting plate to have good energy dissipation capability. All the specimens were first pulled and then pressed. From the force-displacement curve, it can be seen that there is obvious tension-compression asymmetry in each specimen.

**FORCE-DISPLACEMENT SKELETON CURVES**

According to the Code for Seismic Testing of Buildings (JGJ/T 101-2015) [5]: The skeleton curve should be determined by the envelope which formed by the peak value of the first cycle of loading at each stage of the force-displacement curve. Therefore, the skeleton curves of the two specimens were obtained and compared. The results are shown in Figure 6. It can be seen from Figure 6 that the skeleton curves of the two specimens are S-shaped, indicating that specimens were in the elastic stage at the initial stage of loading. At this time, the stiffness of each specimen is not significantly degrade. As the load increases, the stiffness of each specimen decreases, the slope of the skeleton curve decreases, and the specimen enters the strengthening stage. The ultimate bearing capacity of the specimen is

![Figure 5. Force-displacement curves.](image-url)
closely related to the thickness of the inner core plate. There was no obvious descending stage when the specimen was pulled, and no degradation occurred. When pressed, E-10-100 has no obvious descending stage, E-6-100 bearing capacity has degraded, and the descending stage is obvious. Therefore, the thickness of the inner core plate is an important parameter for analyzing the bearing capacity of the buckling-restrained metallic connecting plate.

ENERGY DISSIPATION CAPABILITY

By calculating the area surrounded by the force-displacement curve under various loads, the cumulative hysteretic energy under various loads is obtained. The cumulative hysteretic energy of the two specimens is compared, and the result is shown in Figure 7. The load-displacement curves of the two specimens in this experiment are relatively full, and the enclosed area is large, and the energy dissipation capability is good. It can be seen from Figure 7 that the energy dissipation capability of the specimen has a certain relationship with the thickness of the inner core plate.

DUCTILITY FACTOR

According to the relevant provisions of the Code for Seismic Tests for Buildings (JGJ/T 101-2015) [5], the ductility factor of the specimen is calculated according to Equation 1. The calculation results of the ductility factor of each specimen in this experiment are shown in Table I.

\[ u = \frac{\Delta u}{\Delta y} \]  

(1)

Where \( \Delta u \) is the ultimate deformation of the specimen, \( \Delta y \) is the yield deformation of the specimen.

It can be seen from Table I that the ductility coefficient of each specimen is greater than 7, indicating that the buckling-restrained metallic connecting plate has
good ductility. Comparing E-6-100 with E-10-100, it is found that the ductility coefficient of the two specimens is not much different, indicating that the thickness of the inner core panel is not the influencing factor of the ductility of the specimen.

### TABLE I. DUCTILITY FACTOR.

| Specimen number | $\Delta y$ | $\Delta u$ | $u$ |
|-----------------|-----------|-----------|-----|
| E-6-100         | 0.62      | 4.68      | 7.5630 |
| E-10-100        | 0.56      | 4.07      | 7.2617 |

### CONCLUSIONS

The experimental and analytical results show that:

1. The buckling-restrained metallic connecting plate has a good failure mode: The inner core plate is cracked in its middle part, that is, its failure control section.
2. The force-displacement curve of the buckling-restrained metallic connecting plate is full and the hysteretic behavior of the specimen is good.
3. The ductility coefficient of the buckling-restrained metallic connecting plate is greater than 7, and it has good ductility.
4. The energy dissipation of the buckling-restrained metallic connecting plate is large, and the energy dissipation capability is good.

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