Experimental Study on Hysteretic Performance of Assembled Steel Energy-dissipating Hinge

Changgui Wei, Lianqiong Zheng, Guiyun Yan and Yongchao Ma

ABSTRACT

A new type of steel energy-dissipating hinge, which was used to connect prefabricated beam and column in the frame structure, was proposed to meet the seismic design demand of "strong connection". A steel energy-dissipating hinge was tested under cyclic loads to study its seismic performance and damping effect. The experimental results were presented in terms of failure mode, hysteretic curve, load-bearing capacity, stiffness and ductility. The test results show that the hysteretic curve of this kind of steel energy-dissipating hinge is full, strength degradation is not obvious and energy dissipation ability is strong, which indicate that this kind of steel energy-dissipation hinge has good bearing performance and hysteretic characteristics.1

INTRODUCTION

The steel structure has been widely used because of its high strength and good seismic performance. However, extensive brittle failure of the beam-column joints were observed in the 1994 Northridge earthquake and 1995 Kobe earthquake[1-2]. There is no plastic hinge to dissipate seismic energy, which does not accord with the design philosophy of “strong column and weak beam, strong joint and weak member”. After that, some new beam-column connections were proposed based on the idea of plastic hinge outward to improve the seismic performance of steel structure, such as strengthening the beam at the column face[3-4] and weakening the beam section at a proper distance from the column face[5-6]. The reduced beam

1 Changgui Wei, Lianqiong Zheng, Guiyun Yan, Yongchao Ma. Fujian Provincial Key Laboratory of Advanced Technology and Information in Civil Engineering, College of Civil Engineering, Fujian University of Technology, Fuzhou, China 350118
section (RBS) is a kind of weakened connection. A large number of studies have been carried out on reducing the beam flanges connection. However, research has seldom been conducted on reducing the beam web, at the same time, there is seldom research on the using of RBS joint in prefabricated structures. Therefore, this paper designs a new energy dissipating hinge which can be bolted in the prefabricated structure, and uses reciprocating bending energy dissipating hinge to connect the precast beam of the frame structure with the extended beam in the core area of the precast joint. It realizes the outer movement of the connecting joint of the traditional beam-column splicing, eliminates the weakness of stitching and protects the integrity of the core area of the joint. The detailed schematic diagram is shown in Figure 1.

![Figure 1. Frame diagram.](image)

![Figure 2. A general view of specimen.](image)

**EXPERIMENTAL PROGRAM**

**Specimen Design**

The specimen flange is made of dog-bone-weakening section. In order to prevent buckling of the flange, a curved stiffener is arranged under the flange. There is a T-shaped cross section with a variable cross section in the flanges. The hinge center is connected by a pin shaft to form a hinge mechanism during the test. The two ends are connected by opening plates for easy bolting with the loading device. The actual construction of the specimen is shown in Figure 2. The materials used in the components are all Q235B grade steel. Table I shows the average yield strength (fy), tensile strength (fu), elastic modulus (Es) and Poisson's ratio (μs) for all the steel used in the tests.
### TABLE I. STEEL MECHANICAL PROPERTIES.

<table>
<thead>
<tr>
<th>specimen</th>
<th>Elastic modulus $E$/MPa</th>
<th>Yield strength $f_y$/MPa</th>
<th>Yield strain $\varepsilon/10^{-6}$</th>
<th>Ultimate strength $f_u$/MPa</th>
<th>Poisson ratio $\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>155695</td>
<td>202.3</td>
<td>1236</td>
<td>356.3</td>
<td>0.285</td>
</tr>
<tr>
<td>2</td>
<td>156984</td>
<td>198.6</td>
<td>1165</td>
<td>350.2</td>
<td>0.281</td>
</tr>
<tr>
<td>3</td>
<td>165324</td>
<td>197.5</td>
<td>1265</td>
<td>354.3</td>
<td>0.286</td>
</tr>
<tr>
<td>average</td>
<td>159334</td>
<td>199.5</td>
<td>1222</td>
<td>353.6</td>
<td>0.284</td>
</tr>
</tbody>
</table>

Figure 3. Test set-up.

### Test Set-up

The experimental device includes the base, loading beam, hydraulic-servo actuator, reaction wall, articulated device and so on. Figure 3 shows the loading device diagram for this experiment. The upper and lower ends are connected by bolts. The base is anchored to the rigid floor by high-strength bolts. The actuator is anchored on the reaction wall by high-strength bolts. The actuator controlled by MTS. To prevent the external displacement of the loading beam, lateral support was arranged on both sides of the load beam. Lateral support welding on the reaction frame.

### Loading System

This test refers to the specification for seismic test of building (JGJ101-2015). The load is controlled by force before the yield of the member, and every stage of the load circulates once. After the member reaches yield, the displacement is used to control the loading, and the displacement increment of each stage takes the multiple of the yield displacement and circulates three times. The standard of stopping the test is stipulated: when the bearing capacity of the member drops to 85% of the ultimate bearing capacity or if the test cannot continue to carry out safely.
Measurements

The measuring layout point is shown in figure 4.

![Figure 4. Arrangement of instrumentation.](image)

EXPERIMENTAL RESULTS AND ANALYSIS

Experimental Phenomena And Failure Modes

At the beginning of the experiment, there was no obvious deformation. When the test load reaches a positive displacement of 60mm, a slight buckling occurs locally on the flank of the compression. Slight buckling also occurs on the other side of the 60mm when it is loaded in reverse. When loaded into 70mm, the buckling phenomenon is gradually obvious, and then every stage cycle increases the buckling degree of flange, and finally presents the half-wave failure mode. During the loading process, the specimen rotates around the pin shaft, and the connection between the pin shaft does not deform. The ultimate failure mode of the component is shown in figure 5.
Moment-Rotation Curve of Hinge Center

Hysteretic curve is the comprehensive embodiment of seismic performance of structures. The degree of satiety of the curve is closely related to the energy dissipation capacity of members. Figure 6 shows the moment-rotation curve of the specimen. The skeleton curve of the component is shown in figure 7.

![Figure 6. M-φ hysteretic curve.](image1)

![Figure 7. Skeleton curve.](image2)

From the hysteresis curve, we can see: in the early stage of loading, the hysteretic curve is basically in a linear cycle because the flange tension (compression) degree is not large, and the component is basically in the elastic stage. In the later stage of the test, the stiffness of the member decreases gradually and the rise tends to be gentle because the flange tension (compression) degree becomes larger, and the member enters the plastic stage.

Ductility Coefficient

The ductility coefficient of the component is shown in table II. In the table, $\phi_u$ is the ultimate turning angle. In this test, because the measuring range of the guide rod extender is not enough, the data can't be collected in the later stage of the test. The collected data have not shown a significant downward trend. So the limit angle is temporarily taken as the maximum angle of rotation measured. And $\phi_y$ is the yield angle. The yield angle is obtained by the energy method, that is, the angle at the intersection of the elastic phase of the skeleton curve and the tangent of the over-peak load.

It can be seen from the data in the table that the ductility coefficient of the component is very large, and these data are all in the degree of incomplete measurement. In the later stage of the test, the turning angle of the component will continue to increase, and the ductility of the component will be greater than...
the measured one. It shows that the components in this test have strong deformability.

**Energy Dissipation Capacity**

The area surrounded by the hysteretic curve reflects the energy dissipation capacity of the specimen. Take the cumulative area $E$ of the hysteretic curve when the horizontal load drops to the peak load 85 and the energy dissipation coefficient $E$ of the hysteretic curve when the horizontal load drops to the peak load as the representative value of energy consumption. Because the data collected in this experiment is incomplete, the last circle of data obtained is calculated. The energy dissipation coefficient of the component is shown in table III.

<table>
<thead>
<tr>
<th>TABLE II. DUCTILITY COEFFICIENT.</th>
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<tbody>
<tr>
<td>$\varphi_y$</td>
</tr>
<tr>
<td>specimen</td>
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<tr>
<td>-0.0031</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE III. ENERGY DISSIPATION CAPACITY.</th>
</tr>
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<tbody>
<tr>
<td>cumulative hysteretic area $E_p$ (KN·m)</td>
</tr>
<tr>
<td>specimen</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

1. The hysteretic curve of the new type of steel reciprocating bending energy dissipating hinge proposed in this paper is plump, and this hinge has larger energy dissipation capacity, the hysteretic curve is still in the rising stage, the ductility of the hinge is better, the strength degradation is not obvious, and the bearing capacity is higher.

2. The structure of the hinge is easy to assemble, and it is convenient to disassemble and assemble. The test of this hinge provides a basis for the study of its mechanical properties when it is used in joints.

3. The hinge has good mechanical performance, which can be used as the basis of theoretical analysis. The finite element software can be used to analyze a large number of parameters to quantify its performance.
ACKNOWLEDGEMENTS

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REFERENCES