

# Experimental Study of Local Buckling of Castellated Steel Beams Under Pure Bending

Wenting Ji<sup>1</sup>, Lianguang Jia<sup>1</sup> Yuhang Wang<sup>1</sup> Chen Chen<sup>1,2</sup>

<sup>1</sup> School of Civil Engineering, Shenyang Jianzhu University, No.9, Hunnan Road, Hunnan District, Shenyang City, Liaoning, P.R. China

<sup>2</sup> Country Garden Neimenggu Regional company, Xincheng District, Huhehaote City, Neimenggu, P.R. China

**Abstract.** In order to investigate the buckling performance of castellated beams, three hexagon-hole castellated beams with different depth-thickness ratio and stiffeners setting were tested under pure bending. By observing and comparing the failure mode and the relationship of moment-curvature, the local stability and overall performance of beam webs were studied. The experimental results show that under pure bending, the buckling mainly occurs in the bridge plate above the openings and pier plate among the openings. Reducing the depth-thickness ratio of the web and setting stiffeners can improve the web buckling performance and the overall performance of castellated beam.

## 1. Introduction

With the characteristics of light weight and high strength and convenient crossing of pipelines, castellated steel members are widely used in multi-story buildings and large-span space structures<sup>[1-3]</sup>. Because of the web openings, the castellated beam is divided into the bridge plate and the pier plate, which change the stress distribution mode of the original solid-web section<sup>[4-5]</sup>. The stress distribution mode becomes much more complicated<sup>[6]</sup>.

The castellated member is machined on the H-shaped section web. The opening holes increased the dislocation welding and weaken the capacity of the plate. So that web is more likely to be local instability<sup>[7]</sup>, which leads to the loss of the bearing capacity of the castellated beams. Therefore, the design of the local stability of the castellated beams webs is particularly important. However, due to the opening of castellated beam webs, stressing state is difficult to apply directly to the design<sup>[8-9]</sup>. How to make the design method of castellated beams accurate and simple has become the focus of scientific researchers.

At present, the researches of castellated member are mostly concentrated on overall performance<sup>[10-11]</sup>, while the research on local buckling of the castellated webs is relatively few. In this paper, we apply experimental research to research the pure bending and buckling of castellated beam web with hexagonal openings.

## 2. Material and methods

### 2.1. Testing Program

Three castellated beams were tested under two point loads in this experiment, including FWL-1, FWL-2 and FWL-3. There are 3 hexagon openings on the H-Beam. Openings of castellated beams were



created by cutting the web directly. The opening ratio of castellated beam is 60%. The dimensions of each tested beam is listed in Table 1. And Figure 1 shows the schematic of tested beams.

Loading points were chosen at 1/4 and 3/4 of the castellated beam to make two point bending tests. To avoid the local buckling failure caused by concentrated force at the loading point, two stiffeners are set near the loading point and support of beam. Compared with the inner web, the outer web is more likely to buckle due to bending and shearing. Therefore, the thickness of the outer web is 10mm, which is greater than the inner web. This prevents the outer web from buckling earlier than inner web.

Table 1. The parameters of castellated beams.

| Experimental model | Beam Height×Flange Width×Flange thickness /mm | Outer web thickness | Inner web thickness | Beam length/mm | Whether the stiffener between holes is set |
|--------------------|-----------------------------------------------|---------------------|---------------------|----------------|--------------------------------------------|
| FWL-1              | 500×250×14                                    | 10                  | 5.0                 | 3424           | no                                         |
| FWL-2              | 500×250×14                                    | 10                  | 5.5                 | 3424           | no                                         |
| FWL-3              | 500×250×14                                    | 10                  | 5.0                 | 3424           | yes                                        |

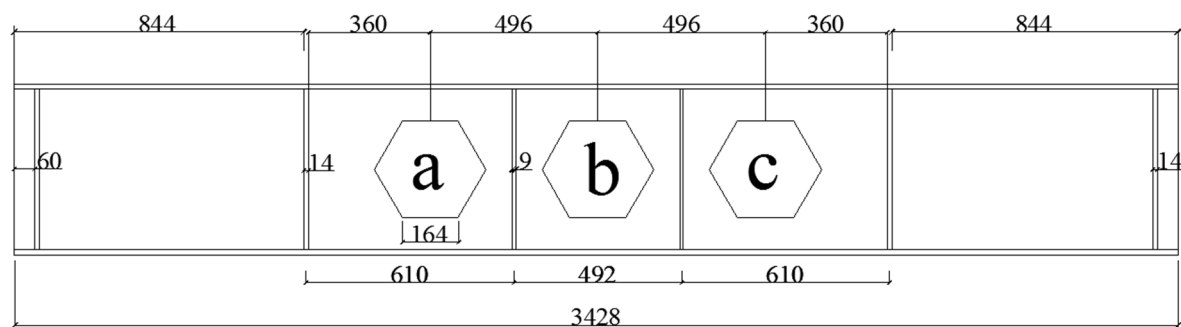


Figure 1. Schematic of castellated beam specimen.

## 2.2. Materials quality testing

The type of steel used in the test piece is Q345. Three steel samples were made according to the specifications and then the stretching experiment was performed. Material of samples is the same as the material of test specimens. The result of materials quality testing is shown in Table 2.

Table 2. Mechanical properties of steel.

| Thickness of steel | $f_y$ (N/mm <sup>2</sup> ) | $f_u$ (N/mm <sup>2</sup> ) | $E$ (10 <sup>5</sup> N/mm <sup>2</sup> ) |
|--------------------|----------------------------|----------------------------|------------------------------------------|
| 5.5mm              | 333                        | 550                        | 2.013                                    |
| 10mm               | 452                        | 619                        | 2.000                                    |
| 14mm               | 389                        | 544                        | 2.017                                    |

## 2.3. Instrumentation and Loading

Details of the test loading device are shown in Figure 2. The load was applied by a testing machine of 10000kN capacity. The test specimens were placed on supports at 60mm from both ends. Lateral bracing were placed on both sides of beams near the stiffeners. Distributive girder distributed static load on the

loading points. The contact surface between lateral bracing and beam uses acrylic plates to reduce friction.

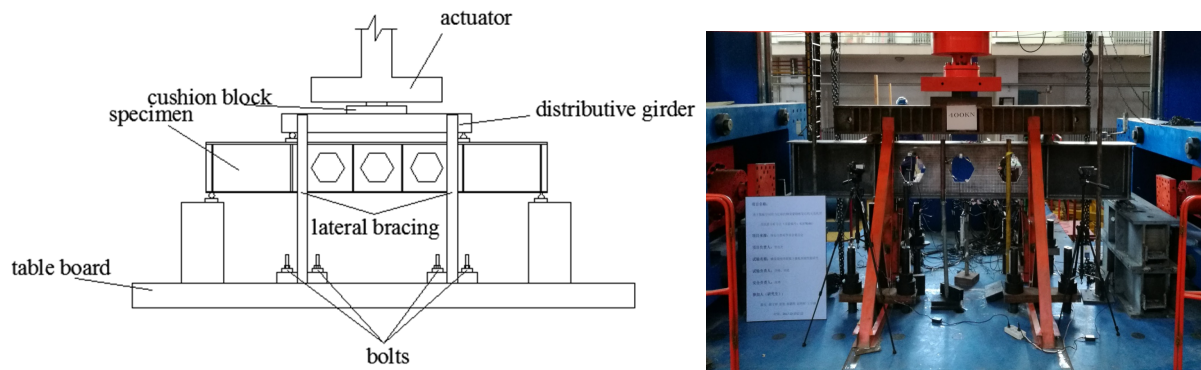


Figure 2. Details of test device.

After the start of the test, pre-loading is used to check the stability and reliability of the device, and the data of each measurement point are normal. At the load control stage, each stage load is 200kN, and the loading speed is 30kN/min. Between each stage load, there is 3min to observe experimental phenomena. When specimen is yielded, loading speed is changed to 1mm/min. Then keep loading until bearing capacity drops to 85% of the limit load.

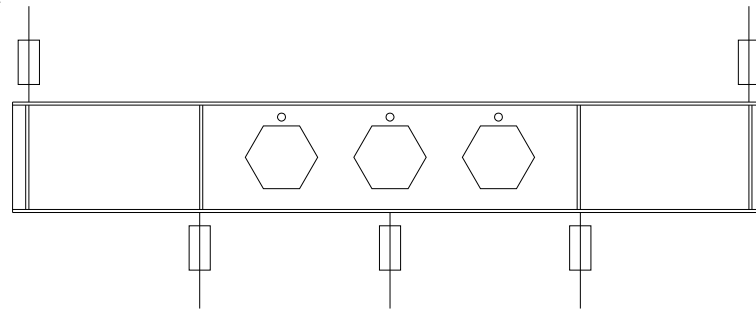


Figure 3. Layout of displacement meter.

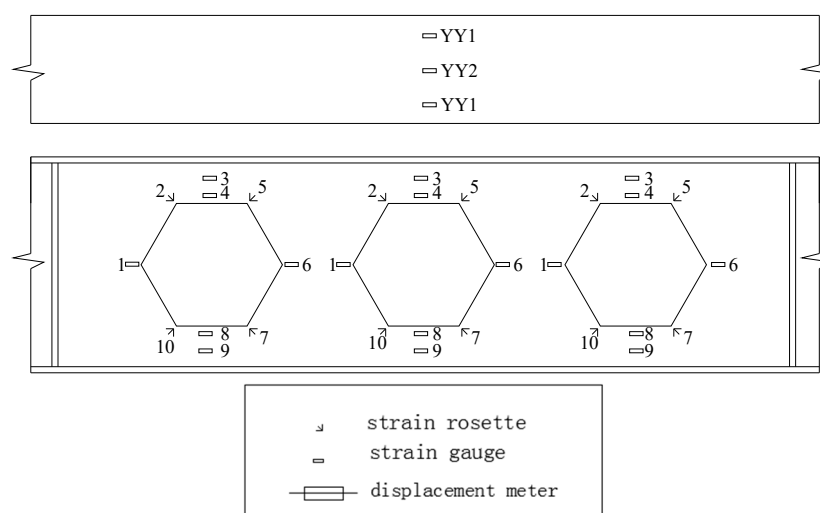


Figure 4. Arrangement of strain gauges.

Layout of displacement meter and strain gauges is shown as Figure 3 and Figure 4. The measurement content include: (1) Displacement and load at mid-span of castellated beam. (2) Displacement at loading

points of castellated beam. (3) The stress distribution around the opening of the webs. (4) The stress distribution on the upper flange. (5) Displacement deviating from the middle plane of the webs. (6) The deformation conditions and failure mode of castellated beam.

### 3. Result and discussion

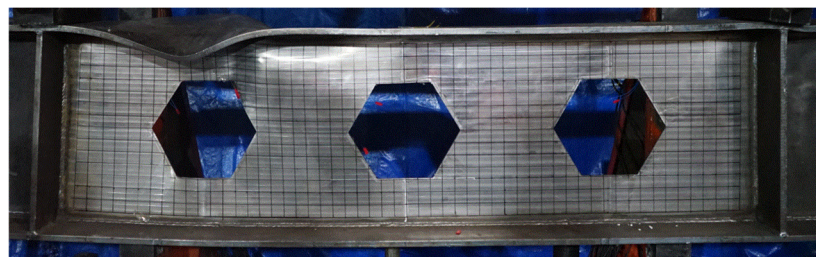
The failure modes of specimens are slightly different. Webs of FWL-1 and FWL-2 yielded first, and the buckling deformation mainly occurs in the C-hole bridge plate, hole angle and pier part. For FWL-3, because of the action of stiffeners, the flange yielded first, then the web buckling happened. Deformation mainly occurred in a hole of the bridge plate and hole angle part. In order to verify whether the position of support have an influence on distribution of beam, changed the position of the left and right support. The experimental results show that the position of the buckling was related to the types of the support. Experimental phenomena are shown in Figure 5. Experiment results summary is in the Table 3.

Table 3. Experiment results summary.

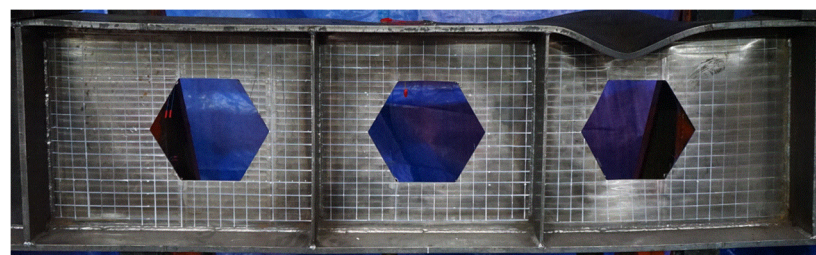
| Experimental model | Yield moment (kN • M) | Ultimate moment (kN • M) | The point yield first | The point Failure first |
|--------------------|-----------------------|--------------------------|-----------------------|-------------------------|
| FWL-1              | 653.99                | 786.93                   | b-hole bridge plate   | b-hole bridge plate     |
| FWL-2              | 659.54                | 810.6                    | b-hole bridge plate   | b-hole bridge plate     |
| FWL-3              | 641.19                | 790.77                   | Upper Flange          | a,b,c-hole bridge plate |



(a) Experimental deformation diagram of FWL-1.



(b) Experimental deformation diagram of FWL-2.



(c) Experimental deformation diagram of FWL-3.

Figure 5. Experimental phenomena.

Figure 6 is the moment-curvature curve. At the initial stage of loading, the specimen is in elastic stage and load control loading stage. The specimen has good performance in elastic stage. The curves of the three specimens are basically same in this stage. When the specimen is yielded, it becomes the displacement control. In the test the ultimate flexural capacity of the FWL-1 is 786.93kN·M. The ultimate flexural bearing capacity of FWL-2 is 810.6kN·M. The ultimate flexural capacity of FWL-3 is 790.77kN·M. By reducing the depth-thickness ratio of web and setting lateral stiffener, the ultimate flexural capacity and ductility of the beam are improved. It can be seen from descending stage of the curve that FWL-1 occurs buckling failure because post-buckling capacity increase obviously. FWL-2 is the strength failure because the value is falling slowly after peak value. The post-buckling capacity of FWL-3 is improved slightly.

It can be seen from the curve that reducing the depth-thickness ratio of webs has a large impact on the buckling performance and integral performance of castellated beams. Setting lateral stiffeners can also improve it.

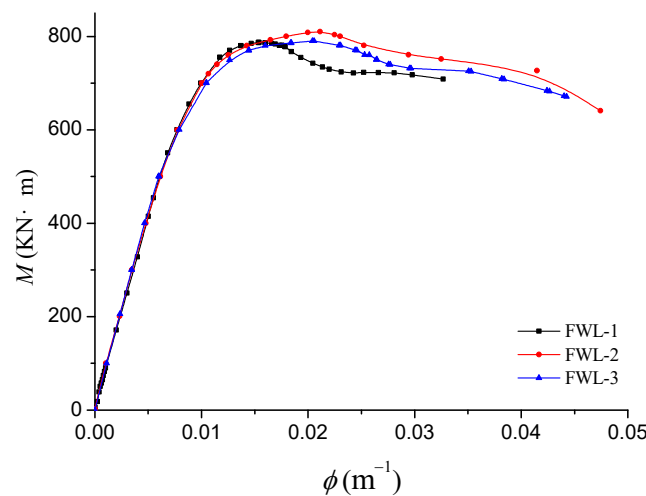


Figure 6. Experimental moment-curvature curve.

#### 4. Conclusion

From the results of experimental study the following items were concluded:

- (1) Under pure bending, buckling mainly occurs in the part of the bridge plate above the openings and pier plate among the openings. The upper hole corners were outward. The deformation mainly occurs around the openings near the loading points.
- (2) Reducing depth-thickness ratio of the web has good effect on improving the buckling performance of webs and the integral performance of castellated beams.
- (3) By setting lateral stiffener, the buckling behavior of the pier plate and web is improved.

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