Mechanical performance analysis of U-shaped steel-concrete composite deep coupling beam

Yuan Zhiren\textsuperscript{1a}, Ding Jiayue \textsuperscript{1*}, Ren Wang\textsuperscript{1}, Fan Jianhong\textsuperscript{1}, Niu Junfei\textsuperscript{1}

\textsuperscript{1}Changchun Institute of Technology, Changchun, Jilin, China
\textsuperscript{1a}email: tm_yzr@ccit.edu.cn, \textsuperscript{1*}email: 475331212@qq.com,

Abstract: In this paper, semi-span simply supported beam is used to simulate the mechanical behavior and failure mode of U-steel reinforced concrete composite-deep coupling beam, and three U-steel reinforced concrete composite beams, with same height-span ratio of 1/3, were tested under one-point vertical concentrated loading in mid-span. The results show that the mid-span yield height exceeds 60\% of U-steel-concrete composite beams flange, and that the three of U-steel-concrete composite beam specimens are damaged, there is a critical oblique crack in the inner concrete of the beam that is roughly parallel to the line between the bearing center and the loading point. It is concluded that the failure mode of this type of U-shaped steel-concrete beam begins with yield at mid-span bottom and flanges of U-shaped steel, and ends with concrete shear failure.

1. Introduction

Steel-concrete composite beam can make full use of the respective advantages of materials, so that they have strong bearing capacity, good ductility and high economic benefits.

Therefore, a large number of scholars have done research on external girder - concrete beam. As Leskela in A concrete T - Section – Steel U – section Composite Beam full scale experiment was carried out for groove steel - concrete composite beams, the whole process of specimen stress analysis, and Section of the shear stress distribution is obtained, and then by pull-out tests to obtain the force between concrete and steel channel - slip curve, based on this, advances the double beam model of finite element analysis.

Based on previous research experience, this paper analyzes the failure performance of U-shaped steel-concrete composite beams. The research provides a reference for the structural design of U-shaped steel-concrete composite beams.

2. Testing survey

2.1. Test design

The U - shaped steel beam adopts the form of flange inversion. The stud is welded at the bottom of the U-shaped steel beam as an anti-slip component. When pouring concrete, the stud is directly embedded in the concrete. Through the stud, the steel plate and the concrete work together as a whole. At the same time, the angle steel is set on the side plate of the U-shaped beam to enhance the combination effect and prevent the local instability of the steel plate. The angle steel on both sides is connected with the steel plate to enhance the constraint effect on the concrete, as shown in Figure 1.

In this paper, the scale model is used to test. The specimen ST-1 and ST-2 are 1: 4 scale of the actual component. After the scale, the net span of the component is 1650 mm, the width is 600 mm, and the
height of the specimen is 500 mm. The concrete is C40 commercial concrete, the thickness of steel plate is 10 mm, and the steel plate is Q345 steel. In order to increase the combined effect of steel plate on concrete, reasonable structural connection is adopted, steel nails are uniformly distributed at the bottom of the steel plate, and 8 mm thick equilateral angle steel is set on the side of the steel plate. At the same time, the equilateral angle steel is welded by equal thickness steel plate strip. On the basis of ST-1, specimen ST-3 welded steel plates on both sides of the supporting end to simulate the connection between the coupling beam and the column in the actual building structure, so as to ensure that the concrete and the steel plate will not be separated due to the upwarping of the flange end of the U-shaped steel beam when the force is destroyed, so that the steel plate does not reach the ultimate bearing capacity, and the component will be destroyed.

![figure1 Detail drawing of specimen](image)

2.2. Table of specimen parameters

| Specimen number | Width (mm) | Span (mm) | Height (mm) | Ushaped steel |
|-----------------|------------|-----------|-------------|---------------|
| ST1             | 600        | 1650      | 500         |               |
| ST2             | 600        | 1650      | 500         |               |
| ST3             | 600        | 1650      | 500         | bar of 550*100*10 on both sides of specimen top |

2.3. Loading scheme

The specimen is supported on the pedestal and loaded symmetrically at one point. The half-span force of the specimen is used to simulate the force of the deep coupling beam.
2.4 Loading system
Formal loading adopts load control, graded loading, 300kN for each stage, loading rate 10kN/s, load-holding time 1 min between all levels of loads, displacement and strain are recorded in the load-holding process. When the load is greater than 3000kN, each stage is 300kN, the loading rate is 10kN/s, and the load-holding time between all levels is 3 min. Displacement and strain are recorded and the test phenomenon is observed.

3 Experimental phenomena and analysis

3.1 Failure modes of specimens
In the ST-1 and ST-2 tests, when the load reaches the ultimate load, the tensile bars near the top of the right supporting end face are pulled out with huge noise. The internal concrete is sheared and destroyed along the connection between the loading plate and the support, and the concrete is lifted up. The U-shaped outsourcing steel plate is jacked up in the folding part of the top surface, and the side steel plate at the edge of the support large deformation shear dislocation locally, and the structure cannot continue to load. At this time, the height of mid-span strain exceeding yield strain of side steel plate has reached 60% of beam height.

In the ST-3 test, with the huge noise, the tensile bar at the support end and the interface of the front steel plate were pulled open, and the concrete cracks were widened rapidly. The steel plate was bulging from the top to both sides. The test machine reading was no longer increased, and the specimen was declared to be damaged.

Figure 2 Coupling beam model
Figure 3 Semi-span simply supported beam

Figure 4 Details of destruction
Figure 5 Midspan Height-Strain Curve of Steel Plate
4. Conclusions
The static loading test was carried out on three groups of U-steel reinforced concrete-composite deep coupling beams to observe the failure phenomenon and analyze the failure mode. According to the work done, the following conclusions are drawn.

(1) During the working process of ST-1 and ST-2 specimens, the steel plates on both sides of the top and the concrete were obviously upwarped during the stress process of the specimens. The U-shaped outsourcing steel plate was top-opened in the folding part of the top surface, and the side steel plate at the edge of the support produced large deformation shear dislocation locally. The structure could not continue to bear the load. The maximum load that the specimens could bear was 4728kN and 4780kN.

(2) A 550 * 100 * 10 steel plate was welded on each side of the steel plate on the top of the ST-3 specimen, which effectively strengthened the connection between the top steel plate and the steel plate on both sides. The failure was due to the shear of the top steel plate and the side steel plate, and the maximum load that the specimen could bear was 5418kN, and the bearing capacity was significantly improved.

References
[1] Shun-ichi N. ASCE. Bending Behavior of Composite Girders with Cold Formed Steel U Section[J]. Journal of Constructional Steel Research, 2002(9): 1169-1176.
[2] Shun-ichi N. New Structural Forms for Steel/Concrete Composite Bridges[J]. Structural Engineering International, 2000(1): 45-50.
[3] ZHANG Li. Study on the Flexural Behavior of High Strength U-Shaped Steel-concrete Recycled Mixed Beams [J].Journal of Qi qihar University (Natural Science Edition), 2013,37(01):62-67.
[4] WU zhongyan, et al. Study on Flexural Behavior of U-shaped Steel-concrete T-shaped Composite Beams with Cold Bending [J]. Structural Engineer, 2018,34(04):121-131
[5] Jiang-huaiyan, Zhao Zhiqiang. Comparative analysis of flexural performance of U-shaped steel bar connection with wet joint of precast assembled plate [J]. Construction Technology, 2019,48(03):37-40,74