Experimental Study on Static Behavior of Bamboo Paper Type I-Shaped Beam with Rectangular Shaped Stiffened Flange

Hongling Sun[1], Jie Pi[1,*], Jingyu Peng[1], Chao Hu[1], Gang Yang[1], Zhengchi Jiang[1]

[1]School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu, 610500, China.

Abstract

This experiment is an open-ended experiment of undergraduate. The mechanical properties of the I-shaped beam with rectangular stiffened flanges are studied by replacing the steel with bamboo paper. In the experiment, four different I-beams were hand-made from bamboo paper, which were general I-shaped beams, I-shaped beams with rectangular flanges, and two I-shaped beams with rectangular stiffened flanges. Microcomputer controlled electronic universal test was adopted. The test piece is tested by the method of concentrated force loading of the simply supported beam. It is concluded that the I-shaped beam with rectangular flange can significantly improve the bearing capacity of the I-beam and improve the overall stability of the I-beam. The I-shaped beam of the stiffened flange can further improve the mechanical property of the I-beam.

Keywords

Open-ended experiment of undergraduate; I-shaped beam; Mechanical property; I-shaped beam with rectangular shaped stiffened flange.

1. Experimental Background

Steel has many advantages such as high strength, light weight, low plasticity and recyclability. Compared with the traditional building structure, the steel structure has shorter construction cycle, better seismic performance, and can meet the requirements of large bay, beautiful appearance and other building, many advantages make the steel structure widely used in engineering construction. In order to effectively utilize materials and rationally utilize the strength of steel, beams are generally designed as open sections with high, narrow and thin wall thickness. Therefore, larger rotational radius and section inertia moment are obtained, so as to improve their flexural capacity, such as I-shaped steel, H-shaped steel and so on. But they also have poor twisting and lateral bending resistance. When the bending moment reaches a certain value, when a small lateral interference is imposed on the compression zone of the beam, the lateral bending with small stiffness will suddenly occur, and accompanied by torsion, the beam will also lose its bearing capacity and overall stability, and the stiffness of the material cannot be fully utilized. In order to further improve the overall stability of I-beam, a new type of cold-formed thin-walled steel beam, hollow flange beam HFB for short (see Figure 1) is proposed by Australian scholars. It consists of two closed triangular flanges with large torsional stiffness and a relatively flexible web. It is more developed and its cross section efficiency is higher. Compared with conventional thin-walled members with open section, the torsion stiffness of hollow flange beams increases significantly. Because of its simple processing and excellent performance, it has been applied in foreign countries in the past more than 10 years. Hollow flange beams have been widely used in light steel structures in Australia and some European and American countries. They are mainly used as flexural members and are widely used in portal frames, purlins and steel frames.

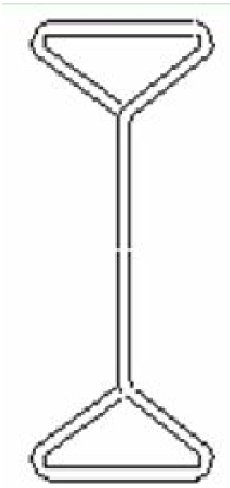


Fig 1. Hollow flange beam

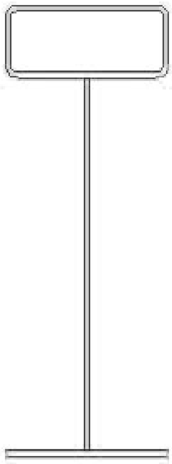


Fig 2. LHFB section form of new hollow flange beam

In China, a new type of I-shaped beam LHFB with rectangular steel tube as upper flange and strip steel plate as web and lower flange was created by Master Liu Renfeng of Harbin University of Technology in 2006. The rectangular steel tube flange beam is a new type of thin-walled beam based on the Australian empty flange beam. See Figure 2. The beam is welded directly from rectangular steel pipe and strip steel plate. It has the advantages of simple fabrication, section development, torsional stiffness and bending stiffness. Considering that the lower flange of the beam is mainly subjected to tension, there is no stability problem, so LHFB adopts uniaxial symmetrical section, compression flange adopts rectangular steel tube and tension flange adopts strip steel plate. When the bearing capacity is very small, the amount of steel is saved and the economic performance of the flange beam is improved.

This open experiment is based on a new type of I-beam LHFB transformation innovation, in the rectangular empty flange set stiffening ribs, thereby further enhancing the overall stability of the I-beam. The design and optimization of the new I-shaped beam can be determined by the test results.

2. Buckling Modes of Beams

There are three kinds of buckling modes of beams, namely flexural torsional buckling, local buckling and distortional buckling. The flexural torsional buckling can also be called lateral torsional buckling. When the beam bends in the main plane with large stiffness, if the beam does not have enough lateral stiffness or lateral support, the beam may buckle out of the load plane, that is, bending-torsion buckling. The load during buckling is much lower than the in-plane bearing capacity of the beam. The ideal slender straight beams remain elastic before buckling, which is called elastic buckling. The buckling process is generally divided into two stages: at first, the member is in a plane bending state; when the load reaches the branching point, the member will suddenly appear lateral deformation u and torsion angle. As the load continues to increase, the lateral deflection and torsion increase sharply, and the bearing capacity of the component is lost. Flexural torsional buckling includes lateral bending and twisting along the longitudinal axis. These two functions are coupled. When the beam is subjected to lateral bending, the bending moment M produces a partial torque Mu', which causes the beam to twist, and the torsion of the beam causes the bending moment M to produce a lateral moment M_. Inelastic buckling means that the ideal straight beam with medium slenderness may yield before the critical moment is reached. When buckling begins, most areas of the beam have been plasticized or strain-hardened, and the effective stiffness of these plastic and strain-hardened parts decreases, resulting in a decrease in the critical moment. Therefore, the inelastic buckling load will be much lower than the elastic buckling load. The flexural torsional buckling of simply supported beams has no change in the shape of the section, and the half wavelength of buckling is equal to the span of the beam.

For beams with the same cross section, local buckling occurs frequently when the span is small. That is to say, the compression flange and web have out-of-plane deformation, but there is no transverse deformation at the intersection of the flange and web. The local buckling half-wavelength is short and uniformly distributed along the span of the beam, forming a uniform wavy buckling in the beam section. After partial buckling of a certain part of the beam, the stress in the section can be redistributed, and it is possible to bear greater loads, but the strength and overall stability of the beam will be reduced, and the stiffness will be reduced. Usually, the flange and web of beams are used as force plates to calculate their buckling loads.

The buckling mode of beams is mainly related to the height thickness ratio of the web, the width to thickness ratio of the flange and the slenderness ratio of the beam. For medium-span beams with small flange width and large web thickness, web distortion will occur when bending and torsion buckling occurs, which is called lateral distortion buckling. Distortional buckling is a kind of buckling mode between bending-torsion buckling and local buckling, and web distortion will introduce some effects that have not occurred in elastic bending-torsion buckling. First, the web distortion reduces the effective torsional rigidity of the section. Secondly, there are different twist angles in the parallel upper and lower flange when buckling. Finally, the center of mass, the position of shear center and the direction of the principal axis are different from those of the pre-buckling section without distortion, which no longer conforms to the rigid peripheral assumption. The original symmetrical section will become an asymmetrical section after buckling. Therefore, the effective war page stiffness of the section will also decrease.

3. Experimental Study of Bamboo Paper Type I-Shaped Beam with Rectangular Shaped Stiffened Flange

3.1. Test Specimen Design and Processing

In terms of material selection, for two reasons, first of all, this experiment is an open experiment for undergraduates. Open experiment is an innovative experiment, which allows students to design experimental topics independently and draw up experimental schemes and technical routes in order to achieve the experimental objectives. In this process, students can deeply feel and understand the process of knowledge generation and development, learn and master the basic research methods of this subject, and cultivate students ‘scientific spirit and creative thinking ability, hands-on ability, as well as the ability to collect, process information, analyze and solve problems. Focusing on the process of experiment, the result is not too precise. Secondly, because of the limited funds, if the steel is used as the test object, the specimen production process is troublesome, and the material consumption is too large, the cost is relatively high, so bamboo paper is selected for the design and optimization of the new I-beam. The mechanical properties of bamboo paper are shown in Table 1. The characteristics of the material are that the along-grain strength is much higher than the cross-grain strength, the tensile strength is much higher than the compressive strength, and the modulus of elasticity is also high. At present, there is not a complete study of this material, including the characteristics of the original material and bonded material properties. However, this characteristic will seriously affect the design of the new I-shaped beam, which has not been systematically studied yet.

Table 1. Mechanical Properties of experimental bamboo paper

density	Tensile strength of parallel grain	compressive strength
0.8g /cm3	60MPa	30 MPa
Modulus of elasticity	environmental protection	tolerance
6GPa	E0	+0.03mm

This experiment mainly designed and processed 4 bamboo I-shaped beams. Including I-beam, rectangular tube flange I-beams, and two I-shaped beam with rectangular shaped stiffened flange. As shown in Figure 3.

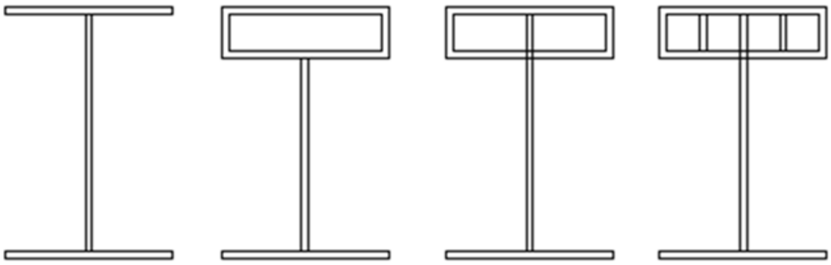


Fig 3. Four I-shaped beams

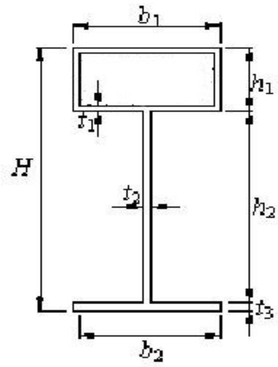


Fig 4. Size parameter of model

For example, the rectangular tube flange I-shaped beam is taken as an example to determine the size parameters of the model, as shown in the Figure 4. It includes the width and thickness of the upper and lower flange, the flange height of the rectangular tube, the thickness of the web, and the total height of the beam. The detailed parameters of the model are shown in Table 2.

Table 2. Geometric dimensions of experimental beams (mm)

Beam number	b1	b2	H	h1	h2	t1	t2	t3	span	Flange ribbed
1	20	20	30	0	30	0.7	1	1	200	no
2	20	20	30	10	20	0.7	1	1	200	no
3	20	20	30	10	20	0.7	1	1	200	yes
4	20	20	30	10/	20	0.7	1	1	200	yes

3.2. Test Loading Method and Apparatus

Microcomputer controlled electronic universal testing machine is used to test the mechanical properties of various non-metallic and composite materials. The professional design of automatic control and data acquisition system realizes the full digital adjustment of the system. The data acquisition, process control and post-processing of the test data are all completed by the computer. This equipment can automatically obtain tensile strength, peel strength and tear strength. The equipment is suitable for waterproof roll, wire, textile, rubber, ceramics, packaging industry, film, paper, plastic products and other manufacturing industries as well as product quality supervision departments at all levels, but also for teaching demonstration work in Colleges and universities.

As for the loading mode, if two-point loading method is adopted in the middle of the span, the pure bending state of the middle section can be simulated, but this not only requires higher loading equipment, but also requires the length of the beam to be lengthened, which brings difficulties to manual production, and also causes unnecessary waste. Therefore, according to the comprehensive consideration and comparison, the loading scheme of simple beam mid span concentrated force is adopted finally.

3.3. Loading Process and Failure Condition

Hydraulic jack is used in this experiment to carry out graded loading. Before each loading, alignment should be carried out first that is, calibrated by standard weight to ensure that jack, sensor and midpoint of beam span are collinear at three points. Preloading should be carried out before loading, so that the gap between the beam and the support and between the various loading devices can be eliminated, and the load-displacement curve can be ensured smooth and stable without sudden change. When loading, the loading speed should be strictly controlled to ensure that the speed cannot be too fast. The loading rate can be achieved by controlling the jack oil pump. When the member enters the plasticity, the loading rate should be reduced as far as possible, so that the component can fully develop plasticity. The destruction of the 4 components is shown in Figure 5. As can be seen from Fig 5, the I-beams with rectangular tube flange show obvious overall instability during loading, while the I-beams with rectangular tube flange do not show overall instability during loading, but local buckling of upper flange appears.

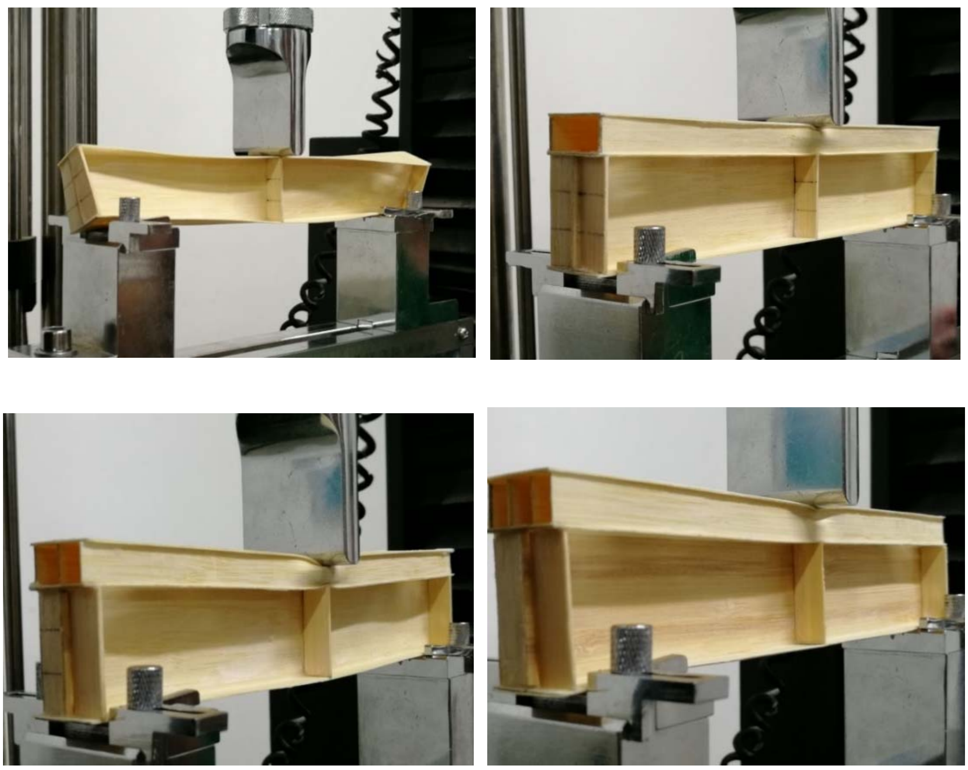
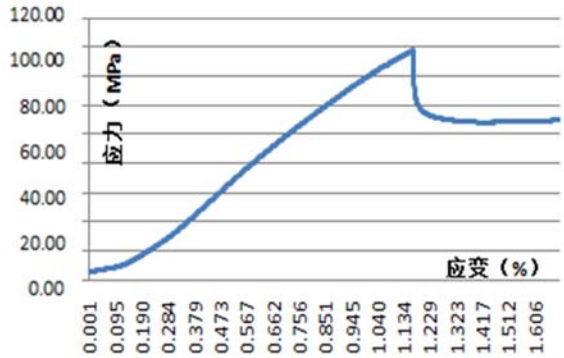
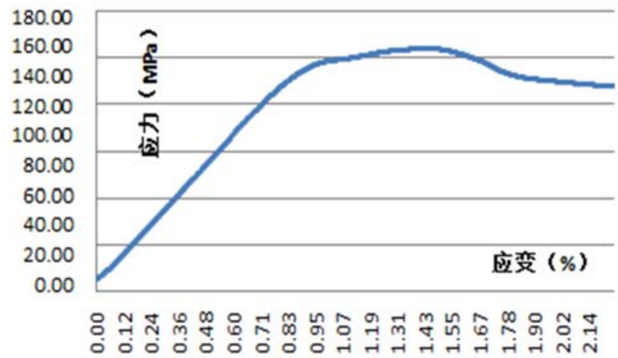


Fig 5. Destruction of components

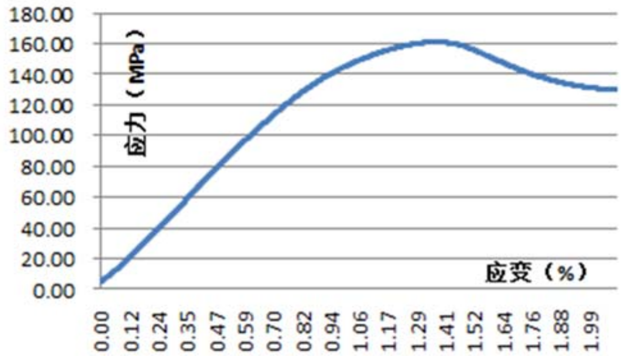
3.4. Experimental Data and Analysis



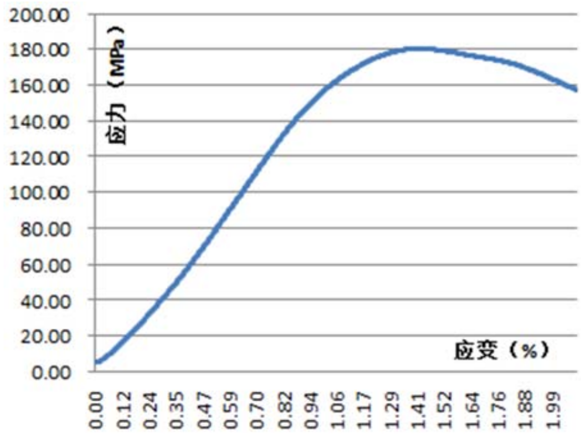
(a)



(b)



(c)



(d)

Fig 6. Stress-strain diagram of members

The stress-strain diagram of the experimental beam is sequentially drawn from the experimental data, as shown in Fig. 6. It can be seen from Fig. 6(a) that the No. 1 beam, the I-beam, has a maximum bending force of 0.1 ken and a bending strength of 1.2 MPa, and the line segment which suddenly decreases from the stress-strain diagram indicates that the I-beam has a lateral direction. The phenomenon of buckling indicates that the overall instability of the I-beam has occurred. It can be seen from Fig. 6(b) that the No. 2 beam, that is, the rectangular pipe flange I-beam, has a maximum bending force of 0.16 kN and a bending strength of 1.84 MPa, and the maximum bending force of the No. 1 I-beam is increased by 60%. The flexural strength increased by 53.3% because the rectangular tube flange significantly increased the torsional stiffness of the I-beam and the overall stability of the beam was greatly improved. It can be seen from Fig. 6(c) that the No. 3 beam is an I-beam with a stiffener in the rectangular flange, and the maximum bending force is close to the bending strength and the No. 2 beam, as shown in Fig. 6(d). The No. 4 beam is a three-strength ribbed I-beam with a maximum bending force of 0.18 kN and a bending strength of 2.11 MPa. The maximum bending force of the No. 1 I-beam is increased by 60%. The flexural strength increased by 53.3%. At the same time, the maximum bending force of the No. 2 beam increased by 12.5% and the flexural strength increased by 14.7% because the vertical stiffener in the rectangular flange improved the local stability of the flange. It also withstands part of the shearing force, so the carrying capacity has been improved to some extent.

4. Conclusion

Four different I-beams were made of bamboo paper and tested by a microcomputer controlled electronic universal testing machine. Under the scheme of concentrated load in the middle span of simply supported beam, four different I-shaped beams are obtained, and their stress-strain diagrams are given. Through the data and experimental phenomena, it can be concluded that ordinary I-shaped beams appear when bearing concentrated load in the middle span, because of their poor lateral flexural capacity, when the beams fail to reach the ultimate bearing capacity. The overall instability phenomenon makes the bearing capacity of beams lower. The I-beam with rectangular tube flange can greatly improve the lateral flexural capacity of the beam, and the bearing capacity of the beam is also significantly improved, and the material properties are fully utilized. For I-shaped beam with rectangular shaped stiffened flange, the local stability of the flange is improved on the basis of the rectangular tube flange I-shaped beam, and the bearing capacity of the beam is further improved.

In conclusion, I-shaped beam with rectangular shaped stiffened flange can effectively overcome the disadvantages of lateral instability of ordinary I-beam, significantly improve the bearing capacity of I-beam, and make full use of material properties.

References

[1] He Jia.Experimental study on static behavior of I-beam with rectangular steel tube upper flange[D].Harbin University of Technology, 2009.

[2] Chengbo.Experimental study on static behavior of I-shaped beam with rectangular concrete filled steel tubular upper flange[D].Harbin University of Technology, 2009.

[3] Liang Wenfeng.Experimental study on the overall stability bearing capacity of rectangular concrete filled steel tubular I-beam with upper flange[D].Northeast Petroleum University, 2016.

[4] Xu Jinfeng. Stability analysis of new type of flange beam [D]. Harbin Institute of Technology, 2005.

[5] Liu Renfeng.Static analysis of a new type of I-shaped beam with rectangular upper flange[D].Harbin University of Technology, 2006.

[6] Dempsey R. Structural Behaviour and Design of Hollow Flange Beams[C]// Institution of Engineers, Australia, 1990.

[7] Liu Renfeng, Wu Zhenyu.Effect of Web stiffeners on the LHFB bearing capacity of hollow flange beams [J].Journal of Harbin University of Technology, 2008, 40 (6): 855-859.