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Numerical Simulation Study on Shear Behavior of Hat-shaped Shear Connector

FENG Wen-xian[1, a], LIANG Xing-he[1,b] and ZHANG Xi[1,c]

[1] Faculty of Civil and Transportation Engineering, Guangdong University of Technology, Guangzhou, 510006, China

[a]fengwx@gdut.edu.cn, [b]liangxinghe555@foxmail.com, [c]xrkxixi@163.com

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Abstract: In order to verify the conclusion of push-out test and further analyze the influence of each parameter on the hat-shaped shear connector, a finite element analysis model of shear connector was established; To study the influence of the change of the diameter of the steel plate of the hat-shaped shear connector on the shear capacity of the hat-shaped shear connector, and to verify the test conclusion of the hat-shaped shear connector; (Concrete strength grade, diameters of perforated rebars and steel plate thickness) which is not taken into account in the experiment, and to verify the rationality of the calculation formula of hat-shaped shear connector.

Introduction

The shear connector is located on the interface between the corrugated steel web and the concrete slab, which is an important structural part of the corrugated steel web composite bridge. In the 1950s, Viest and THubrlimann [1] began to study the shear resistance of the stub shear connector. Later, Slutter and Driseoll [2], Ollgaard [3], Hawkins and Mitchell [4] et al. conducted a large number of model tests and finite element studies on the ultimate shear capacity of stub shear connectors. In 1987, Leonhardt et al. [5] proposed the PBL shear connector for the first time and studied its failure and shear capacity. In China, Zhang, Z. H. [6], Wang, W. A. [7], He, S. H. [8] et al. studied a large number of model tests and finite element studies on PBL shear connectors.

According to the domestic and international research situation, there are still many problems in the research of shear connector. It is necessary to study the new shear connector whose shear performance is better than the traditional shear connector. Therefore, in this paper the finite element model is established to analyze the shear capacity which can reduce the influence of the test error.

hat-shaped shear connector push-out test

Young-Ho Kim [9] proposed a hat-shaped shear connector to improve the traditional shear connector steel-concrete composite interface shear performance. In this study, a stud shear connector specimen, a PBL shear connector specimen and seven cap shear connector specimens were designed. The test process uses the shear connector entity to launch the test method, starting from the top of the steel beam. When loading, the test uses the displacement control of the loading method.

The test is limited by the number of models and the parameters, it is impossible to determine the influence of the concrete strength grade, the diameter of perforated rebars and the steel plate thickness on the mechanical properties of hat-shaped shear connector. Therefore, this paper will establish a reasonable finite element model, using ABAQUS to study the strength of concrete, the thickness of steel plate, the diameter of hole and the diameter of perforated rebars.

finite element model of hat-shaped shear connector

model arrangement

Model arrangement of hat-shaped shear connector is shown in Figure 1-2.

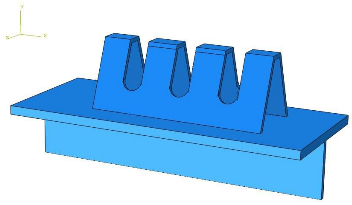

Fig.1 Hat shaped connector arrangement

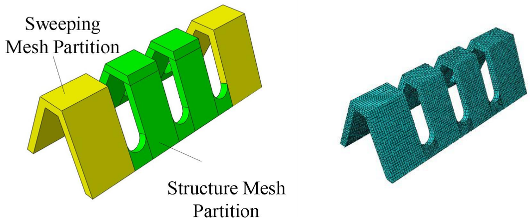

Fig.2 Mesh partition method

the constitutive relation of the material

The study of the shear connector involves three kinds of materials, the concrete, steel and steel bars. In order to understand the parameters that affect the shear capacity of the shear connector, it is necessary to determine the constitutive model of the three materials.

(1) constitutive model of concrete

This paper uses the finite element analysis software ABAQUS/Standard6.14 to model. The constitutive relationship of concrete compression, concrete material parameters derived from the design strength value.

(2) unit type

Concrete, I-beam and shear connector use C3D8R solid unit, which is 8-node hexahedral linear reduction unit.

(3) boundary conditions

In order to save the calculation time of the model, finite element model takes 1/2 structure. Applying a fully fixed restraint to the bottom of the concrete and a symmetrical constraint in the Y direction on the symmetry plane. The finite element model uses the displacement loading method.

(4) contact settings

For the exposure of the constraints imposed by the use of penalty function, tangential friction coefficient uses 0.25. The contact behavior uses a normal "hard" contact that allows separation.

the influences of parameter change

Combined with the literature [10,11], the shear strength of cap type shear connector is only considered the four key parameters of concrete strength grade, diameters of perforated rebars, steel plate hole diameter and steel plate thickness.

concrete strength grades

In this paper, C30 as the control point, comparing the shear bearing capacity of three kinds of shear connectors, and studying the concrete strength of its shear capacity. The shear bearing capacity of three kinds of shear connectors under different steel concrete strength grades is shown in Table 1.

Tab.1 Shear bearing capacity of three kinds of shear connectors under different steel concrete strength grades

shear connectors type	concrete strength grade	shear bearing capacity(kN)
Stud shear connector	C30	139.35
PBL shear connector	C30	184.27
hat-shaped shear connector	C30	231.43
hat-shaped shear connector	C40	287.83
hat-shaped shear connector	C50	332.41
hat-shaped shear connector	C60	388.46

As can be seen from the Table 1, for the same strength grade of concrete C30, the shear bearing capacity of stud shear connector, PBL shear connector and hat-shaped shear connector increased in turn. From C30 to C60, the shear bearing capacity of hat-shaped shear connector had increased from 231.43 kN to 388.46 kN, when bearing capacity increased by about 70%. This shows that the concrete strength level of this parameter changes, regardless of the shear bearing capacity of stud shear connectors, the PBL shaped connector and hat-shaped shear connector have a great influence.

steel plate hole diameter

In the study of shear connector, in order to prevent the shear connector in advance of the phenomenon of stress concentration, Chang' an University Feng Jianping et al [12] proposed that aperture diameter should not be too small. So, this section uses 40mm steel plate opening diameter as the control point. The shear bearing capacity of three kinds of shear connectors under different steel plate hole diameter is shown in Table 2.

Tab.2 Shear bearing capacity of three kinds of shear connectors under different steel plate hole diameter

shear connectors type	steel plate hole diameter(mm)	shear bearing capacity(kN)
PBL shear connector	40	184.27
hat-shaped shear connector	40	231.43
hat-shaped shear connector	50	347.83
hat-shaped shear connector	60	380.45

As can be seen from the Table 2, it can be concluded that the Steel plate hole diameter increases and the shear capacity of the shear connector increases. For the diameter of the same plate hole(40mm), the shear performance of the hat-shaped shear connector is improved by 26% compared with the shear strength of the PBL shear connector, the shear bearing capacity increased from 184.27kN to 231.43kN. For the same hat-shaped shear connector, the steel plate hole diameter is increased from 40mm to 60mm, and the shear bearing capacity increased from 231.43kN to 380.45kN. This shows that increasing the steel plate hole diameter can improved significantly the shear capacity of the hat-shaped shear connector.

diameters of perforated rebars

In this paper, 15mm perforated rebars are used as a control point, comparing the shear capacity of the PBL shear connector and hat-shaped shear connector. And then the hat-shaped shear connector be used as the research object. The effect of changing the diameters of perforated rebars on its shear capacity was studied. The shear bearing capacity of three kinds of shear connectors under different perforated rebars diameters is shown in Table 3.

Tab.3 Shear bearing capacity of three kinds of shear connectors under different perforated rebars diameters

shear connectors type	diameters of perforated rebars(mm)	shear bearing capacity(kN)
PBL shear connector	16	184.27
hat-shaped shear connector	16	231.43
hat-shaped shear connector	20	261.54
hat-shaped shear connector	25	295.71

As can be seen from the Table 3, in the case where the diameters of perforated rebars are the same (16mm), the shear capacity of the hat-shaped shear connector is better than that of the PBL shear connector. The shear bearing capacity of hat-shaped shear connector increased from 231.43kN to 295.71Kn, which has increased by about 30%. From numerical simulation, as the diameter of the perforated rebars increases, the shear bearing capacity of the hat-shaped shear connector also increases.

steel plate thickness

In this paper, 15mm steel plate thickness is used as a control point. And then the hat-shaped shear connector is used as the research object. The effect of changing the steel plate thickness on its shear capacity was studied. The shear bearing capacity of three kinds of shear connectors under different steel plate thickness is shown in Table 4.

Tab.4 Shear bearing capacity of three kinds of shear connectors under different steel plate thickness

shear connectors type	steel plate thickness(mm)	shear bearing capacity(kN)
PBL shear connector	15	184.27
hat-shaped shear connector	15	231.43
hat-shaped shear connector	20	258.16
hat-shaped shear connector	25	280.45

As can be seen from the Table 4, at the same steel plate thickness (15mm), the shear capacity of the hat-shaped shear connector is better than that of the PBL shear connector. The shear bearing capacity increased from 184.27kN to 231.43kN. For the same hat-shaped shear connector, the steel plate thickness increased from 15mm to 25mm. The shear bearing capacity increased from 231.43kN to 280.73kN, which has increased by about 20%. And when the steel plate thickness is increased from 20 mm to 25 mm, the shear bearing capacity increased by only 8%.

calculation of shear strength

Young-Ho Kim proposed the formula for calculating the shear capacity of hat-shaped shear connector:

$$Q_u = 0.867A_l f_c + 0.9A_v f_y + 2.608nd^2\sqrt{f_c} + 0.41b_f L_c$$

Among them： A_l represents shear connector cross-sectional area(mm^2)； f_c represents concrete compressive strength design value(MPa)； A_v represents the total area of perforated rebars(mm^2)； f_y represents the yield strength of perforated rebars(MPa)； n represents the number of hole； d represents hole diameter(mm)； b_f represents sheets-type steel beams-flange width(mm)； L_c represents the contacted length of concrete and I-beam steel beam flange(mm)。

（1） concrete strength grade

According to the first group of parameters of the finite element simulation scheme, when compared to different levels of concrete strength, finite element results and formula results of shear strength are shown in Table 5.

Tab.5 Comparison of finite element results and formula results of shear strength of different concrete strength grades

concrete strength grade	concrete compressive strength(MPa)	formula calculation results(MPa)	finite element analysis results(MPa)	relative error (%)
C30	11.9	426.30	449.35	-5.13
C40	19.1	502.75	535.30	-6.08
C50	23.1	544.27	572.43	-4.92
C60	27.5	589.43	624.73	-5.65

（2） steel plate hole diameter

According to the second group of parameters of the finite element simulation scheme, when compared to different steel plate hole diameter, finite element results and formula results of shear strength are shown in Table 6.

Tab.6 Comparison of finite element results and formula results of shear strength of different steel plate hole diameter

steel plate hole diameter(mm)	number of hole	formula calculation results(MPa)	finite element analysis results(MPa)	relative error (%)
40	3	426.30	449.35	-5.13
50	3	450.59	483.05	-6.72
60	3	480.29	507.87	-5.43

（3） diameters of perforated rebars

According to the third group of parameters of the finite element simulation scheme, when compared to different diameters of perforated rebars, finite element results and formula results of shear strength are shown in Table 7.

Tab.7 Comparison of finite element results and formula results of shear strength of different diameters of perforated rebars

diameters of perforated rebars(mm)	total area of steel(mm^2)	formula calculation results(MPa)	finite element analysis results(MPa)	relative error (%)
16	603.3	426.30	449.35	-5.13
20	942.6	548.45	577.13	-4.97
25	1472.7	739.29	775.42	-4.66

In this section, the calculation results of shear bearing capacity of the hat-shaped shear connector are compared with the finite element results, which is in different concrete strength grade, steel plate diameter, diameters of perforated rebars case. The analysis shows that, the results of finite element analysis are slightly larger than those of formula.

There are two possible reasons for this: ①The formula does not take into account the effect of the steel plate thickness on the shear capacity of the hat-shaped shear connector. ② Since the formula is based on the experimental data, there are many unavoidable errors in the experiment, which leads to the deviation of the formula calculation result and the finite element analysis result.

Conclusions

(1) Contrast with the push-out test, the test conclusion was verified： Hat-shaped shear connector can improve the shear strength of the traditional shear connector. The size of the hat-type

shear connector has a great influence on the shear capacity, whose carrying capacity increases with the increase of the hole size of the shear connector.

(2) The concrete strength grades and the diameters of perforated rebars have great influence on the shear capacity of hat-type shear connector, while the steel plate thickness has little effect on that.

(3) The calculated value of the shear capacity of the cap shear connector is different from that of the finite element analysis. The calculation formula of the calculation formula is conservative.

Acknowledgements

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