The Affection of Transverse Stiffener for Elastic Buckling of Castellated Beam Web under Concentrated Load

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Abstract

This paper analyzed the elastic critical buckling load of castellated beam in different void-height ratio and length-height ratio using the finite element model ANSYS15.0. By comparing the critical load of castellated beams when setting stiffeners and not setting stiffeners, it can draw a conclusion that transverse stiffeners can significantly improve the anti-buckling capacity of castellated beams and provide a reference for an engineering design.

Keywords

castellated beam, elastic buckling, critical load, transverse stiffener

1. Introduction

Castellated beam is an open web girder which composed of H-beam by cutting, welding beam.Castellated beam section height h and the original beam section height H is known as the expansion ratio, generally from 1.2 to 1.7, the expansion of the commonly used ratio 1.5.The expansion of the ratio will increase section moment of inertia and section modulus, improving the beam stiffness and bearing capacity.This allows the beam to apply to a larger span and heavier load.Meanwhile reducing the weight of structure which can save a lot of steel.However after opening, the continuity of web plate was damaged whose main failure mode is local buckling on panel.Buckling leads to a sharp increase in deformation so components will be damaged before reaching its bearing capacity of the plastic,that will influence the properties of materials into full play. Referring to the method of improving the local stability of solid-web beams,we can set some transverse stiffeners on the web to divided it into small size of the rectangular area in the aspects of construction. By doing this, the sides of district which supported by the flange and stiffener can significantly improve the critical stress of web plate to make sure local stability.

In the past decades, a lot of research on castellated beam shear buckling have been made. Shanmugam.N.Echecked the failure of performance about plate with holes and bearing capacity by using finite element. N.C.Hagen has simulated a large number of finite element to determine the shear bearing capacity of the open web beam according to different hole shape, including rectangular and circular hole, and the location of stiffeners. He finally puts forward the suitable calculation formula of shear bearing capacity for opening web.Redwood puts forward a buckling coefficient k about the hole pitch and web thickness aimed at hexagonal hole.Aglan analyze the relationship between castellated beam's hole pitch and the buckling critical load with finite element method. Demirdjian puts forward the modified shear and moment buckling coefficient with correctional finite element model. Zhang Zhuo analyzes the local stability of web of castellated beam under the pure bending state and studies the web limitation of height-width ratio.Liang Jia studies the local stability of castellated beam under the pure bending state.

However,the real stress state of castellated beam is the result of combined shear and bending force.Most castellated beams use the structure requirements of solid web girders for reference to design the depth-thickness ratio of web and stiffener because no opinion theory and calculation method could be used.This paper references the checking rules about local stability of the web of solid-web beams under local lateral load to improve the local stability of the castellated beam web plate by setting stiffeners.

Our《Code for Design of Steel Structures》(GB50017-2003) mainly limits the ratio of depth-thickness of web local stability for the solid-web beams.When the ratio don't be satisfied,GB50017-2003 specification has used the tension field or web stiffeners to prevent the web local buckling while it does not mention the stability about opening webs. The latest exposure draft《Code for Design of Steel Structures》(GB50017-201X) takes the web with circle and rectangular holes into account to meet the requirements of overall stability,local stability and structure measures. The form of opening used in this article is hexagon. However, the Code does not give a specific stability calculation and structural requirements.Therefore,this paper references the requirements of castellated beam opening and setting in latest exposure draft GB50017-201X to confirm the value of hole space which is between $0.5h_0$ and $2h_0$.As, According to the opening web structure requirements and different opening forms of castellated beam,it has been analyzed under different hole ratios and aspect ratios with the finite element.This analysis will provide a guide for the research and application of hexagonal castellated beam.

2. Finite element modeling and verification

2.1 Description of models and boundary conditions

There are are two important parameters about castellated beam:void height ratio and length height ratio.This paper has build a finite element model of castellated beam which is simply supported to study the local buckling of web under different void height ratio and length height ratio according to the example of this article.The effective span of this beam is 4320mm, the thickness of panel are 5mm, 6mm, 7mm, the height of beam is 600mm,void height ratios are 0.425, 0.476, 0.520, 0.563, 0.606. It can be divided into two situation, first of which is setting stiffeners in every 1080mm, 720mm and 540mm, the second of which is not to place any at all.Under these two situations, the paper has analyzed the model beams with 4, 6, 8 holes. The elasticity modulus is 2.0×10^5Mpa and Poisson's ratio$\upsilon$is 0.3.

The boundary conditions of finite element are constraining lateral and vertical displacement in the cross point of lower flange on left side and web,only constraining vertical displacement in the cross point of lower flange on right side and web,constraining out-of-plane displacement near straight plate edges of web.Loading condition is applying vertical concentrated load in the upper flange at mid-span.

2.2 Element selection and meshing

According to the software of finite element analysis,we have build and meshed the finite element model as shown in Figure 1, 2, 3.

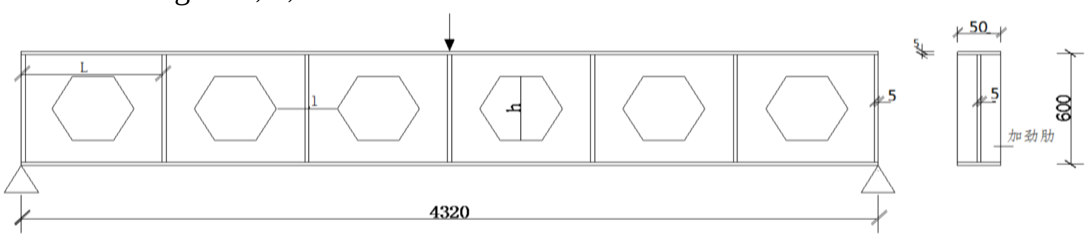

Fig. 1 Cellular beam model and cross-sectional size(Using six holes as an example) Unit: mm

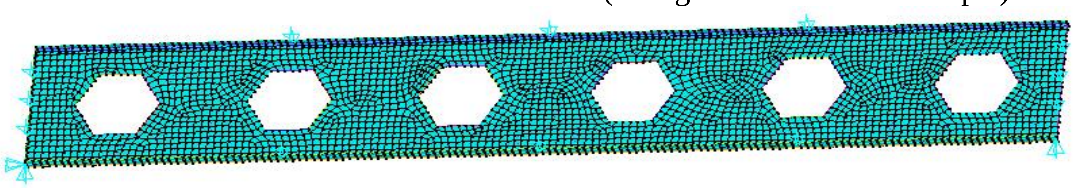

Fig.2 Element mesh of Beam model

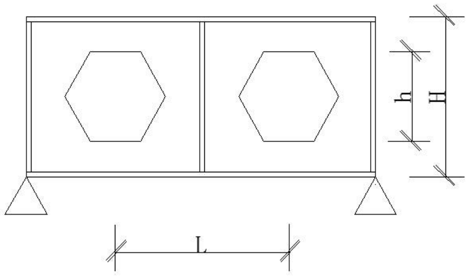

Fig.3 “Void height ratio” $\gamma = h / H$ and “length height ratio” $\alpha = L / H$

2.3 Model verification

We adopt the example which has been mentioned in section 2.1 to verify the rationality of the model in this paper.The critical loads of castellated beam which has 6 holes with void-height-ratio of 0.5, 0.6 and 0.7 under the concentrated are contrasted as follows:

孔高比	0.5	0.6	0.7
圆孔蜂窝梁[12]	118389	113855	116579
六边形蜂窝梁	104560	100610	104030

Table 1. Comparison of critical load (N)

It is clear from the comparison of critical load that the critical load of cellular beam is 13% higher than castellated beam.As listed in the《Design of Circular Hole Castellated Composite Beams》，the bearing capacity of cellular beam is 10%~15% higher than castellated beam which has been manufactured by the same void-height ratio and the same style I beam.This shows that the model is reasonable.

3. interpretation of results

3.1 The buckling displacement contrast of stiffened and un-stiffened web

When the void height ratio of castellated beam is 0.520,the buckling displacement figure of un-stiffened web shows as follow:

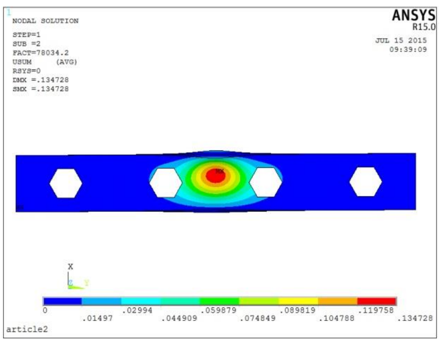

Fig.4 4holes (not set stiffeners)

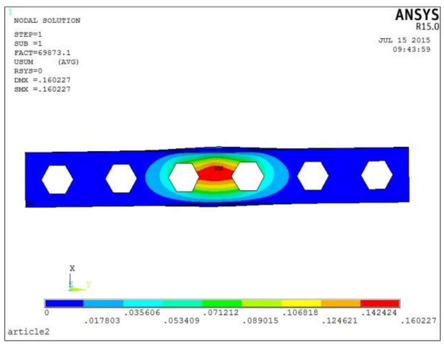

Fig.5 6holes (not set stiffeners)

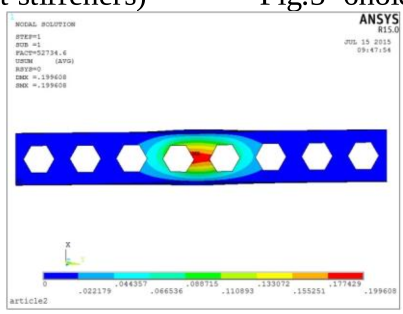

Fig.6 8holes (not set stiffeners)

When the void height ratio of castellated beam is 0.520,the buckling displacement figure of stiffened web shows as follow:

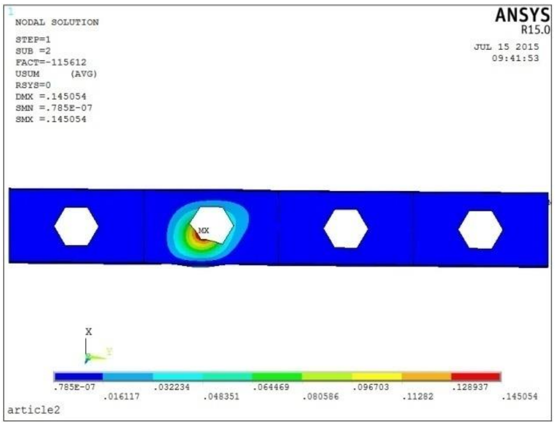

Fig.7 4holes (set stiffeners)

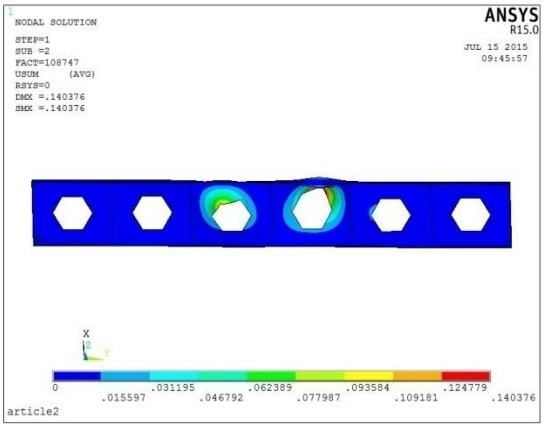

Fig.8 6holes (set stiffeners)

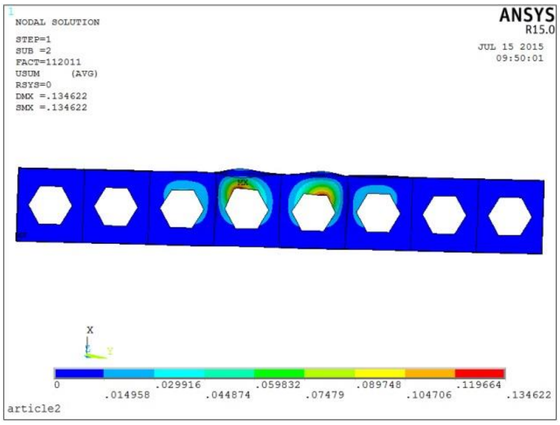

Fig.9 8holes (set stiffeners)

3.2 Analysis of Deformation Failure

As we can see from the un-stiffened buckling displacement figure, the maximum buckling displacements of castellated beam web with 4, 6, 8 holes presents to the mid-span of orifice plate. The main reason about buckling is carrying maximal bending moment and larger shear effect under the action of load. According to the variation of deformation displacements value, their ranges and values increase gradually from mid-span to both sides of web with the decrease of length-height ratio. Much of this is because the holes on the web may increase as the reduction of length-height-ratio. Meanwhile stiffness of castellated beam web will decrease. For this reason, ranges and values of deformation will have a bigger increase.

However, when we study the buckling modes of stiffened castellated beam web, we find that the buckling appeares in angle of holes on both side of mid-span. The reason is the transverse stiffeners restrain deformation of the web in the same place, meanwhile stiffness of web between holes increases significantly, so the weakness of buckling place has transferred to opening area. This phenomenon will cause stress concentration at opening web and hole angle. From the above, the maximum buckling displacement appears in angle of holes. With the decrease of the length-height ratio, range of deformation increases. The reason of this distribution is the stiffness of castellated beam web reduced with the decrease of length-height ratio and increase of holes. This leads to a bigger increase of deformation area and value. The deformation of castellated beam web with transverse stiffeners is much less than that without transverse stiffeners. This shows that transverse stiffeners can significantly improve the capacity of anti-buckling of castellated beam under concentrated load.

3.3 Interpretation of Result

By simulating the elastic buckling of castellated beam web under concentrated load according to the analysis of finite element software ANSYS, the critical buckling load of castellated beam web is summarized below as Fig. 10, 11, 12 with considering void-height ratio, thickness and number of the holes.

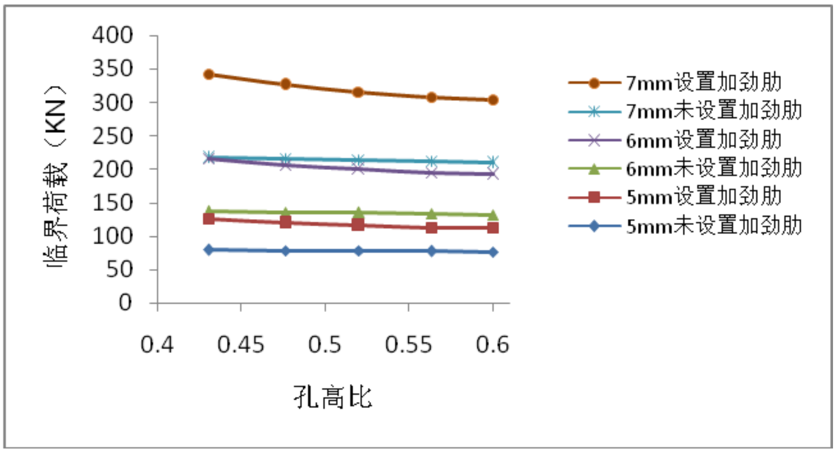

Fig.10 Critical load contrast(4 holes)

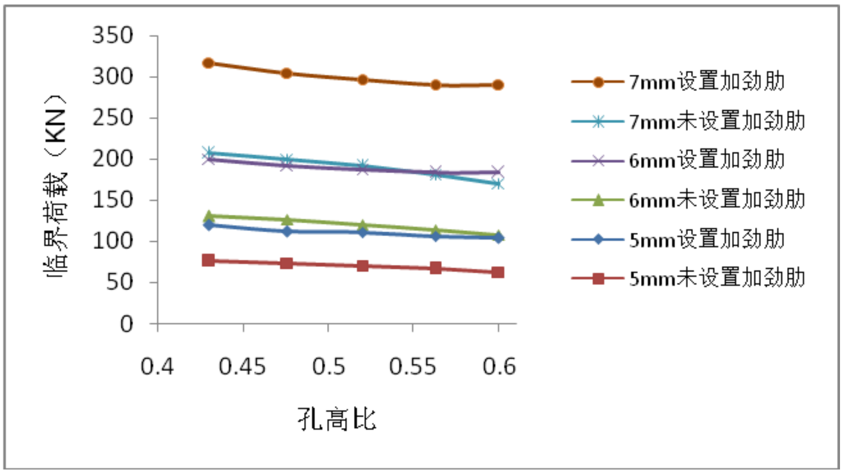

Fig.11 Critical load contrast(6holes)

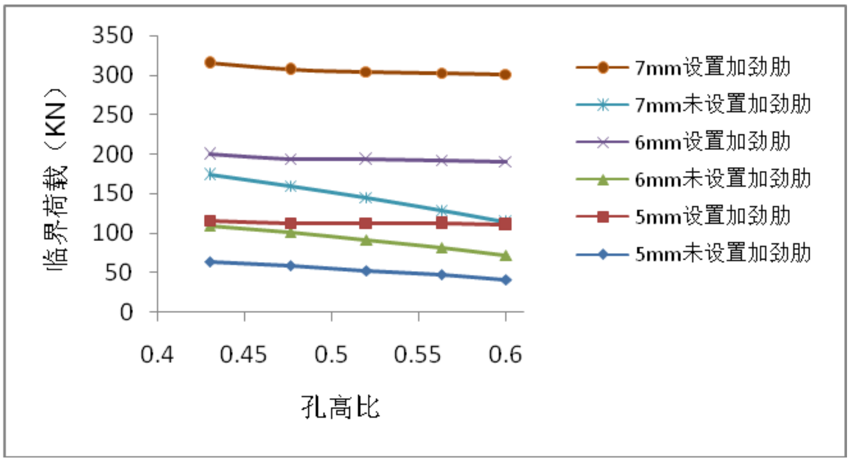

Fig.12 Critical load contrast(8 holes)

As we can see from the figures above, no matter how to change the value of void-height ratio or length-height ratio increase of thickness can obviously improve critical buckling load of castellated web. This is the main factor affecting the web buckling. When the whole thickness is constant, the critical buckling load of un-stiffened castellated beam web reduces with the increase of void-height ratio. And the reduction improves significantly with the increase of number of holes. The critical buckling load of stiffened castellated beam web slightly reduces with the increase of void-height ratio and number of holes. It can be found that setting stiffeners will significantly improve the critical buckling load of correspond un-stiffened castellated beam web by comparing it between stiffened and un-stiffened castellated beam. The range of increase can reach up to 60%~70%.This increase illustrates that setting stiffeners can significantly improve the capacity of anti-buckling load of castellated beam web under concentrated load.

By comparing the weight of steel, we take the minimum of void-height ratio 0.425 as an example to calculate the side length of hexagonal hole that is 149.68 mm. We set transverse stiffeners which size is 25.5mm×5mm×600mm between each holes continuously. The weight of steel is showed at Tab2 which has compared between stiffened castellated beam and un-stiffened solid beam(length of steel beam is 4320mm,flange size is 50mm×5mm,web size is 600mm×5mm)by taking size of Figue1 as an example.

Table2. Comparison table of weight of steel for castellated beam with stiffener and solid beam without stiffener

腹板重量(kg)		加劲蜂窝梁	未加劲实腹梁
开孔数	四孔	95.25	101.74
	六孔	91.74	101.74
	八孔	88.23	101.74

We can see from Tab2 that the weight of steel of stiffened castellated beam is less than the un-stiffened solid beam with the same size and length. The weight of steel is further reduced with increasing number of holes. In conclusion, setting transverse stiffeners can save steel for maintaining a steady state.

4. Conclusion and Suggestion

In this paper, it is analyzed the situation of castellated beam in different void-height ratio and length-height ratio with and without stiffener by using the finite element software. The influence of stiffeners of castellated beam to local buckling can be summarized as follows:

Buckling of castellated beam under concentrated load occurs in mid-span. The maximal displacement of web without stiffeners occurs at the bridge pier right under the load. And its buckling deformation is the combination of bending and shear buckling. The maximal displacement of web with stiffeners occurs at the bridge toe near the both side of concentrated stiffener and its buckling deformation is depending on the bending buckling.

The deformation of castellated beam with stiffeners is much smaller than that without them. And they will improve the buckling stiffness of castellated beam.

When void-height ratio is same and length-height ratio is not same, it is not obvious about the improvement of critical load with the increase of length-height ratio. It can be perceived that critical load will be improved twice by comparing the critical load between stiffened and un-stiffened web. This shows that transverse stiffener can significantly improve the buckling bearing capacity of castellated beam under concentrated load.

When void-height ratio is not same and length-height ratio is same, setting stiffeners will improve the critical buckling load from 50% to 130%.This shows that transverse stiffener can significantly improve the buckling bearing capacity of castellated beam in different void-height ratio.

With the increase of void-height ratio, transverse stiffeners will improve the buckling bearing capacity significantly. With the increase of length-height ratio, the effect of transverse stiffeners is smaller than castellated beam with lower length-height ratio. In this case, setting stiffener is more effective for lower length-height ratio.

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