

## Analysis on Behavior of web buckling of Hexagonal Castellated Beams with Transverse Stiffeners Under Uniform Loads

Hao Deng<sup>1, a\*</sup>, WanLi Pu<sup>2, b</sup>, TongLin LI<sup>3, c</sup>, Danyang Chen<sup>4, d</sup>

School of civil engineering and architecture, Southwest Petroleum University, Chengdu, China

School of civil engineering and architecture, Southwest Petroleum University, Chengdu, China

School of civil engineering and architecture, Southwest Petroleum University, Chengdu, China

School of civil engineering and architecture, Southwest Petroleum University, Chengdu, China

<sup>a</sup>496916723@qq.cm, <sup>b</sup> 623462158qq.com, <sup>c</sup> 449599268qq.com, <sup>d</sup> 963209433qq.com

**Keywords:** Castellated beam, Web Local buckling, Critical buckling load, Transverse stiffener

**Abstract:** This paper is concerned with a way to improve the anti-buckling performance of castellated beams. The finite element package ANSYS 15.0 is used to model castellated beams. Numerical simulations are carried out to provide data for the development of the critical load of web local buckling of hexagonal castellated beams with different “void height ratio” and hole numbers, with and without transverse stiffeners and I-members without web openings in this paper. Results are presented in terms of critical buckling capacity and distribution of transverse web deformations of castellated beams and I-members. Based on the comparison of the numerical data, a reference of improving the anti-buckling ability of castellated beams is presented for an engineering design.

### Introduction

Castellated beams are varieties of girders with generally circular or hexagonal web openings, distributed along the beams with regular intervals. The presence of opening in the web affects significantly the buckling resistance of the beams [1]. In order to prevent the local buckling of the web, it's a good way of setting transverse stiffeners on the web. A considerable amount of research has been directed during the past 50 years, towards the study of the behavior of castellated beams. N. C. Hagen [2,3], carried out numerical simulations to determine the ultimate shear capacity of steel girders with web openings with rectangular and circular shape. Z. Zhang [4] studied the web local stability of castellated beams under pure bending state. J. Liang [5] analyzed the web local stability of castellated beams under pure shear state.

The latest draft standard for examination Code for Design of Steel Structures (GB50017-201X) puts forward stipulations of opening circular holes and rectangular holes and presents that castellated beams should guarantee the overall and local stability as well as detailing requirements. In this paper, the opening of web is a regular hexagon beam. The paper carries out the FEA analysis with different “void height ratios” and hole numbers and gets the critical loads. The critical loads were evaluated by an eigenvalue buckling analysis [6], yielding effect was not considered. Because of the slenderness of the beam webs, it was assumed that the beams would fail by plastic buckling before yielding will occur in the web-post.

## Materials and Finite element modeling

The beams considered in this study are simply supported at the left-hand end with a symmetry support and the right-hand end with a vertical support and loaded with a uniform load at the central line of the flange, the upper and lower web/flange junctions and also the left-hand end and the right-hand end are restrained only for the translation in the x direction to simulate the lateral bracing of the castellated beam, since the overall lateral torsional buckling is not considered in this study. Fig. 1 depicts model considered. The webs, flanges intermediate and stiffeners were modeled by four-node of shell181 element. Regular meshing was employed for all components of the castellated beam, shown in the Fig. 2. The dimensions of “void height ratio” are 0.425, 0.476, 0.520, 0.563 and 0.606, respectively, with and without stiffeners. And “void height ratio” means the rate of the height of holes to the height of beams. The intervals of holes are 1080mm, 720mm and 540mm, with four, six and eight holes, respectively. Young’s modulus  $E$  was set to 206GPa and Poisson’s ratio  $\mu$  was set to 0.3.

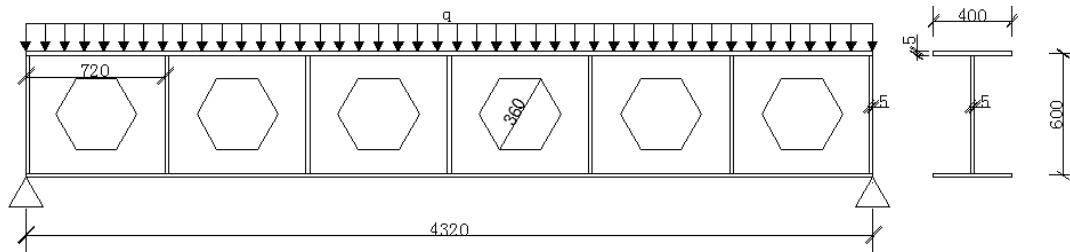


Fig. (1). Calculation model

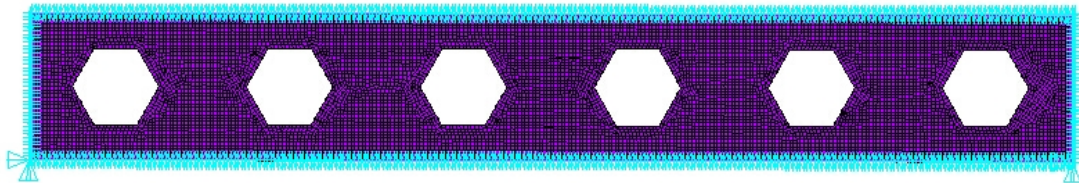


Fig. (2). Meshing and boundary conditions

In order to check the validity and the degree of accuracy of the proposed finite element model, carried out models by Y-F Zhang [6] when it opens six holes and is the same expansion ratio of beams, with the “void height ratio” are 0.425, 0.520 and 0.606. Critical loads compares as follows:

**Table [1]. Comparison of critical loads (N/m)**

Circular hole	39688(0.425)	33321(0.520)	28079(0.606)
Hexagon hole	35278(0.425)	29867(0.520)	24536(0.606)

With the same type of steel and the same expansion ratio of a beam, the capacity of a circle castellated beam is higher 10% to 15% than that of a hexagon castellated beam [7]. As seen from the comparison of obtained critical loads, critical loads of circle castellated beams are higher about 12% than those of hexagon castellated beams. These data show that the proposed finite element model can fairly predict the critical load.

## Results

### The contrast of displacement diagram of buckling

The web buckling deformations for castellated beams with “void height ratio” are 0.520 with six holes are depicted in Fig.3-4.

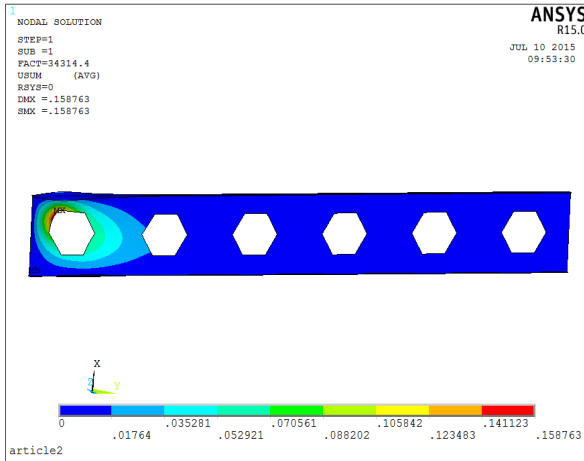


Fig. (3). 6 holes (not setting stiffeners)

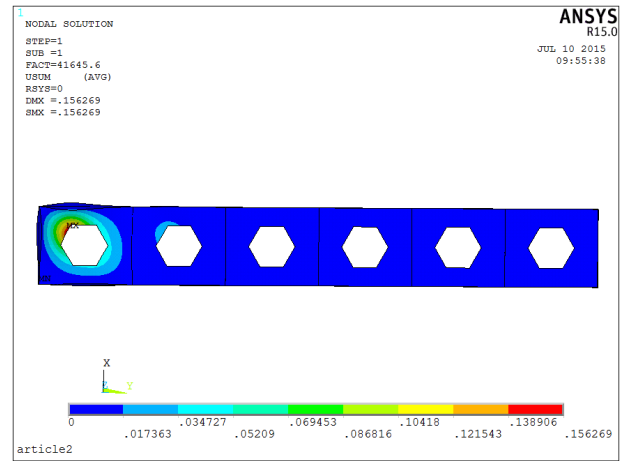


Fig. (4). 6 holes (setting stiffeners)

As is shown the above web buckling deformations for castellated beams, the maximum buckling positions occur at the end of beams. It means that under the uniform loads, castellated beams fail from shear stress, when they are subjected to web local buckling, with and without stiffeners.

With stiffeners and holes, their deformations are smaller than those without stiffeners. It indicates that setting stiffeners can constrain the local buckling of castellated beams.

### The contrast of critical loads

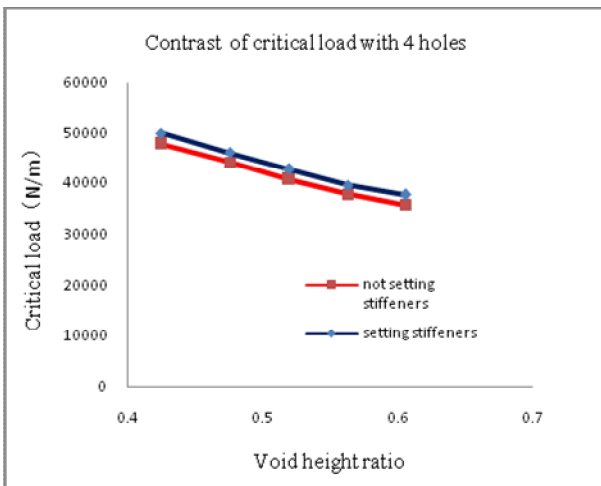


Fig. (5). Contrast of critical load with 4 holes

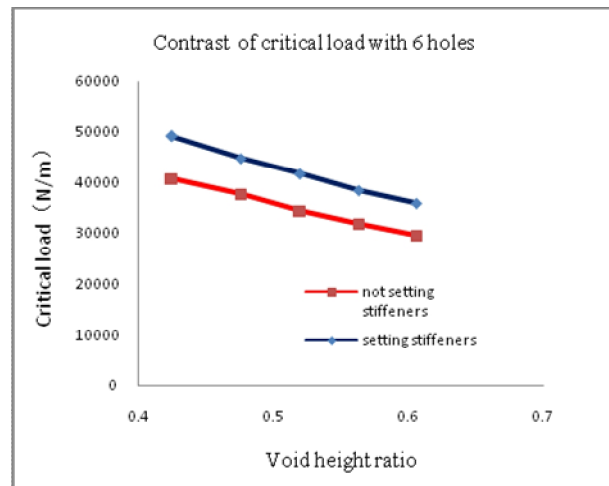
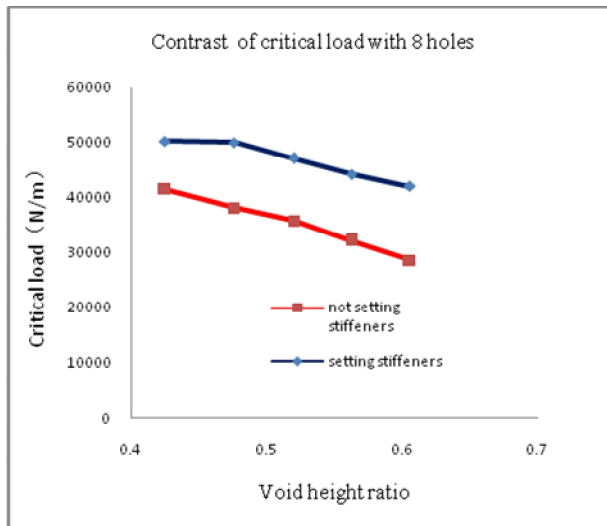


Fig. (6). Contrast of critical load with 6 holes



From the above data, with different “void height ratio” and holes, the buckling critical loads with stiffeners are larger than those without stiffeners, with an average increase of about 5% with four holes as well as with an average increase of about 20% with six holes, and with an average increase of about 20% to 40% with eight holes.

Fig. (7). Contrast of critical load with 8 holes

### The comparing I-members with castellated beams

In order to compare the results of castellated beams with those for I-members without web openings, it takes the same dimensions with the above castellated beams but without web openings. The corresponding deformations are depicted in Fig. 8-9 and critical loads in four kinds of conditions are shown in Table 2:

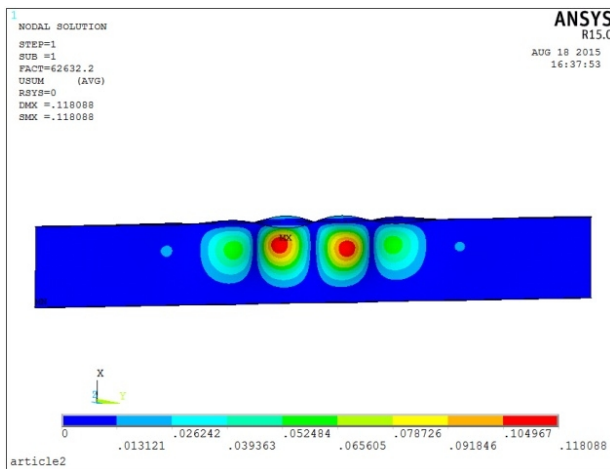


Fig. (8). Not setting stiffeners

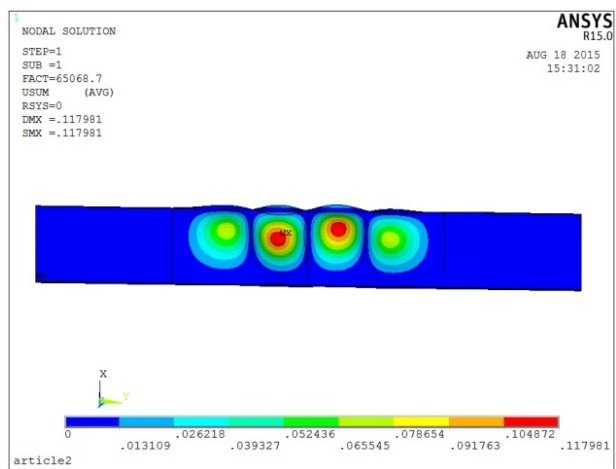


Fig. (9). Setting stiffeners (about 4 holes)

From the above deformations, the positions of local buckling are different from those of castellated beams. They occur in the mid-span with main buckling deformations, and it presents they are mainly subjected to bend buckling because of the interaction of a larger moment and a smaller shear.

Table [2]. Comparison of critical loads (N/m)

About stiffeners	Not set	set ( 4 hole )	set ( 6 hole )	set ( 8 hole )
Critical loads	63347	65069	67119	67547

As seen from the results of the above data about I-members, the critical loads of I-members are larger than those of castellated beams with the same dimensions about 20% to 40 %. The main rea-

sons are the web is discontinuous and stress concentration exists. But for the castellated beams, with proper stiffeners setting in the web, the critical loads can be 80 percent of the same I-members beams. This shows setting stiffeners can effectively improve the critical capacity of castellated beams compared with I-members.

## Summary

Numerical simulations have been carried out to determine the local buckling capacity of castellated beams and I-members. The paper considered “void height ratio” and hole’s numbers, with and without stiffeners. The objective of simulations was to establish a data base that could be used to improve the anti-buckling of castellated beams. The simulations confirmed that some conclusions as follows:

Under the uniform load, the buckling position of hexagonal castellated beams occurs at the first hole near the end of the beam and the maximum deformation occurs at the corner of the holes’ upper part, while the I-members occur in the mid-span.

With different holes opening, the improvement of critical load with stiffeners can increase from 10% to 40%. It shows that stiffeners can effectively improve the anti-buckling stiffness of castellated beams.

Comparing the deformations and critical loads of castellated beams and I-members, it show that on the approximately same buckling conditions, Castellated beams with stiffeners can more useful than I-members in functions. Setting stiffeners is a good way for castellated beams application.

## References

- [1] M.R. Soltani, A. Bouchair, Nonlinear FE analysis of the ultimate behavior of steel castellated beams, *J. Sci. Common* 70(2012) 101-114.
- [2] Hagen, N., Larsen, P., & Aalberg, A, Shear capacity of steel plate girders with large web openings, Part I: Modeling and simulations. *J. Sci. Common* 65(2009) 142–150.
- [3] Hagen, N., & Larsen, P, Shear capacity of steel plate girders with large web openings, Part II: Design guidelines. *J. Sci. Common* 65(2009) 151–158.
- [4] Z. Zhang, Local stability of web of castellated beams under uniform moment, M. S. thesis, Harbin Institute of Technology, Harbin, China, 2006.
- [5] J. Liang, Local stability of web of castellated beams under pure shear state analysis, M. S. thesis, Hunan University, Hunan, China, 2013.
- [6] Y-F. Zhang, Overall stability and local stability analysis of castellated beams, M. S. thesis, Central South University, Hunan, China, 2008.
- [7] J-K. Liu, X-D. Shao, Design a honeycomb composite beam with circular openings, M. S. thesis, Hunan University, Hunan, China, 2008.