Comparison of FEA for Different Type Element Models of Open Thin-Walled Member

Yonglan Xie\textsuperscript{1,2*}, Hu Qi\textsuperscript{1,2}, Bing Lin\textsuperscript{1,2}, Qingyu Zhang\textsuperscript{3}

\textsuperscript{1} China State Construction Engineering Corporation, Beijing, 101300, PRC
\textsuperscript{2} China Construction Engineering Research Institute Corporation Limited, Beijing, 100300, PRC
\textsuperscript{3} China Construction Integrated Housing Corporation Limited, Beijing, 100097, PRC
\textsuperscript{*}Corresponding author’s e-mail: xieyonglan@cscec.com

Abstract. Open thin-walled beam is widely used in civil engineering. The open-walled section model is significantly different from closed section model because the torsional stiffness is small. In order to select an appropriate analytical model for the open-walled section member, three different type element models (beam element model, shell element model and solid element model) for open-walled section members are adopted in ABAQUS/Standard and the low-frequency cyclic loading is used in the analysis process in this paper. The hysteretic curves and skeleton curves of the different element model are obtained using above method, and the bearing capacity, stiffness and the computation time are compared. The analysis results show that the results of three type element models are in good agreement, and the computational efficiency of the three type element models varies significant differences. Hence, it can be concluded that the accuracy of computation results can be guaranteed using those three type element models, and the beam element model has the highest computational efficiency.

1. Introduction
Open thin-walled member is widely used in civil engineering [1-2]. In open thin-walled members, the $b/t \geq 10$ and $l/b \geq 10$, where $t$ is the wall thickness and the $l$ is the length of the member, respectively [3]. In addition, the coupled bending and torsion often occurs in practice because the torsional stiffness of open thin-walled member is small [2-4]. Hence, the deformation is greatly influenced by shearing-stress when the cross-section is restrained and twisted [5-6]. In addition, the shell element, beam element and solid element are the most commonly used elements in finite element software [6]. In order to select an appropriate analytical model for the open-walled section member, three different type element models (beam element model, shell element model and solid element model) for open-walled section members are adopted in ABAQUS/Standard and the low-frequency cyclic loading is used in the analysis process in this paper. The hysteretic curves and skeleton curves of the different element model are obtained using above method, and the bearing capacity, stiffness and the computation time are compared. The next few sections are a detailed description of this paper.
2. Finite element models

2.1. Model design
In this paper, a special-shaped open thin-walled member is selected and the embedded restraint boundary at the end of member is used. The calculation diagram of the special-shaped open thin-walled member is shown in figure 1. The points and centroid coordinates of the special-shaped open-walled section are shown in figure 2. The beam element model, shell element model and solid element model are shown in figure 3, respectively. The element type and quantity of the different model in ABAQUS/Standard are shown in table 1. In order to avoid the shear locking, the reduced integral element S8R and C3D8R are used in shell element model and solid element model, respectively. In addition, the B32OS element is used in beam element model due to the warpage effect of open thin-walled section.

![Figure 1. The calculation diagram.](image1)

![Figure 2. The points and centroid coordinates.](image2)

(a) Shell element model  (b) Beam element model  (b) Solid element model

![Figure 3. The finite element models.](image3)

| Model               | Element type | Element quantity | Element average size |
|---------------------|--------------|------------------|----------------------|
| Shell element model | S8R          | 10988            | 10mm                 |
| Beam element model  | B32OS        | 14               | 200mm                |
| Solid element model | C3D8R        | 68544            | 4mm                  |

2.2. Material constitutive relation and Loading spectrum
In this paper, the steel in the finite element models is the commonly used Q345 type with yield strength of 345MPa, modulus of elasticity of 206GPa and Poisson’s ratio of 0.3. In addition, the yield stiffness is taken as 0.95% of the initial stiffness using the two-fold-line follow-up strengthening model in steel constitutive. The stress-strain relationship of the Q345 steel is shown in figure 4. In this simulation, displacement loading is used and the loading spectrum is shown in the figure 5 and the loading point is located in centroid of the middle of the span of the special-shaped open thin-walled member.
3. Results

3.1. Hysteretic curves
The bearing capacity and stiffness of different element model subjected to repeated loads can be reflected by hysteretic curve [7]. The hysteretic curve of different element models are shown in figure 6, respectively. It can be seen from the hysteretic curve of different element models that the hysteretic curve of different element models have good consistency. And the shape of the hysteretic curves are similar and full, only the bearing capacity has a little difference.

3.2. Skeleton curves
The skeleton curve can be obtained by connecting the peak load points of the first cycle under various loads in the hysteretic curve [8], and the skeleton curve of different element models are shown in figure 7.

The skeleton curve is a straight line in the early stage of loading. After the specimen yields, with the increase of displacement, the bearing capacity does not increase. It can be seen from the skeleton...
curves that the elastic computation results of different element models are highly consistent, and the elastic-plastic computation results show differences, but the overall results have little difference.

3.3. Comparison of failure modes
The failure of the special-shaped open thin-walled member begins with the yield position of steel. The development of the yield area of the special-shaped open thin-walled member can be obtained from the stress nephogram, and the stress nephogram of different element models are shown in figure 8, respectively.

![Stress nephogram of different element models](image)

(a) Shell element model

(b) Beam element model

(c) Solid element model

Figure 8. The stress nephograms of different element model.
It can be seen from the stress nephograms that the stress distribution of shell element model is in good agreement with the solid element model, however, the stress distribution of beam element model is rough and the stress distribution in each beam element can not be shown in detail.

3.4. Comparison of the results
The ultimate bearing capacity, initial stiffness, yield bearing capacity, yield displacement and computation time of the three element models are compared and the indexes are shown in table 2. The Park method is used to determine the yield point of the member [9]. The used CPU of the computer is Intel Xeon E5-2687W v2(x2) with 16-core 3.4GHz and 32 threads, and the used memory is 58GB.

Table 2. The comparison table of indexes for different models.

| Index                  | Shell element model | Beam element model | Solid element model |
|------------------------|---------------------|--------------------|---------------------|
| Ultimate bearing capacity | 157.1kN            | 139.2kN            | 144.9kN             |
| Initial stiffness       | 9.93kN/mm           | 9.56kN/mm          | 8.92kN/mm           |
| Yield bearing capacity  | 138.1 kN           | 136.3kN           | 122.6kN            |
| Yield displacement      | 24mm                | 28.3mm             | 21.1mm              |
| Computation time        | 49793s              | 8518s              | 105306s             |

It can be seen from table 2 that the ultimate bearing capacity, initial stiffness, yield bearing capacity and yield displacement of different models are in good agreement, however, the computation time of different models varies greatly. The computation time of beam element model is the shortest and solid element model is the longest.

4. Conclusions
The analysis results show that the ultimate bearing capacity, initial stiffness, yield bearing capacity and yield displacement of three type element models are in good agreement, and the computational efficiency varies significant differences. Hence, it can be concluded that the accuracy of computation results can be guaranteed using those three type element models, and the beam element model has the highest computational efficiency.

Acknowledgments
This research is supported by the Research and demonstration of standardization, sizing and industrialization of temporary facilities on construction site (Project No. 2016YFC0702102-02). The authors are grateful for this financial support.

References
[1] Wang, S., Ji, Y.L., Zhu, H.P. (2005) Geometric nonlinear finite element analysis of open thin-walled frame structures. Journal of Huazhong University of Science and Technology (Urban Science Edition), 22(1):78-80.
[2] Wang, X.F., Yang, Q. S. (2012) An elastic beam element with closed thin-walled cross section. China SciencePaper, (5):339-342.
[3] He, Z., Chen, J.F., Li, W., Yang, L.F. (2013) Torsional stiffness matrix of open thin-walled beam element considering torsional shear deformation. Journal of Guangxi University: Natural Science Edition, 7(5):795-800.
[4] Wen, H.J., Wu, X., Yang, L.J. (2007) Flexural-torsional bucking of thin-wall open compression members eccentrically connecting with multiple elastic supports. Journal of Water Resource and Architectural Engineering, 5(2): 31-34.
[5] Ren, Y.Z., Cheng, W.M., Yi, J.W., Cai, K. (2014) Research on analytical method and mechanic property of shear force at inflect point on batten plates in open thin-walled bar. Machine Design and Research, 30(5):72-75.

[6] Yang, L.F., Zhong, D.W., Li, G.Q. (1999) Analysis of restrained torsion of thin walled bar with open section by a new kind of finite element. Journal of Guangxi University: Natural Science Edition, 24(1):34-38.

[7] Yuan, X.X. (2015) Experimental study on seismic performance of concrete shear walls with slit and metallic dampers. Jiangsu University of Science and Technology.

[8] Wu, Y.B. (2011) The experimental study of-concealed bracings impact on seismic behavior of steel high-strength concrete low shear walls. Chongqing University.

[9] Park, R., Priestley, M.J.N., Gill, W.D. (1982) Ductility of square-confined concrete columns. Journal of the Structural Division, 108(4): 929-950.