Finite Element Analysis of H-Steel Beam Bending Performance

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Abstract. Compared with ordinary I-steel, H-steel was equipped with good mechanical properties and structure superiority and occupied the dominant position in the steel manufacturing for a long time. H-steel is an important member in steel structure. The bending performance of H-steel attracted widespread attention. Because of constantly emergence of modern high performance steel, the design theory and manufacturing level of H-steel beam sprung up. All kinds of new varieties and new technologies emerged in endlessly. At present, people's awareness of bending performance of various H-steel beam remains to be further explored. Because of the restriction of test conditions and models’ number, the actual test date may be difficult to draw accurate conclusions. Therefore, a specific model of H-steel beam can be numerically simulated by using ABAQUS finite element software. The finite element method will provide more useful research data to bending performance analysis.

Keywords: H-Steel Beam, Bending Performance, Finite Element Analysis.

1. Introduction

With the modern construction of high-rise buildings and structures of complex shape demand continued to strengthen, the traditional structure with reinforced concrete and masonry materials can’t fully meet the current design objectives. Our country explicitly promote to use steel structure because of its characteristics of light weight, high strength, good seismic performance, high efficiency of construction process and cyclic utilization comparing to traditional structure. And the steel structure has been widely used in the construction of civil buildings, industrial plants and large public buildings for the rapid development of China’s steel industry. The application of steel structure is very wide, and there are many kinds of component types of steel structure. And the most common type is H-steel.

The development of H-steel in the developed country has been a long time, and it is a kind of widely used steel varieties. Hot rolled H-steel is as early as 1902 made by Luxemburg’s factory. Since then, H steel has been developed rapidly in the world. At present, Japan's H-steel production has accounted for nearly 8% of the national steel production, while the European and American countries of the H-steel consumption accounted for at least 4% of the total consumption of steel products [1]. Compared with developed countries, the development of H-steel in China was lagging behind. Until the late 1990s, mass production of H-steel began to appear in China. And then, with the development of China's industrialization process, H-steel developed rapidly, and gradually became one of the mainstream products in the steel structure building in less than 20 years.

2. The Advantages of H-Steel

H-steel was originally developed by I-steel, and was regarded as the optimization and improvement of the early I-steel. Ordinary I-steel rolling only cost a set of horizontal rolls. And there is slope in the inner surface of flanges, for the factors of production process. I-steel web is relatively high and flanges are narrow flange while there is large difference between the centric axis moment of inertia. This section properties makes ordinary I-steel pieces around the weak axis bending stability is relatively weak, if used alone, applied only in the web plane bending component. H-steel added a set of vertical rollers in rolling, and its rolling process and equipment are relatively complex. The flanges width of the H-steel is appropriately widened, which make the bending stiffness of main shaft close to...
the other. And in this way, the performance of steel has been fully played, and the bearing capacity of the components is effectively improved. The flanges of the H-steel are thick and parallel to each other, which facilitates the connection with other components. In addition, H-steel can also be used in the processing of recycled profiles, and can also easily be made into T-steel or honeycomb beam.

H-steel has both the rolling cross section and the composite cross section, and the section size can be designed according to the characteristics of the components and the actual needs of people. It has a very general adaptation range. Domestic production of the maximum cross section of H-steel height is 800mm, while more than the height can only be used in combination cross section. For the difference between maximum cross section and combination cross section, there are no specific specifications for the composite cross section, and by calculating the cross section size, the form can be more diversified. From the view of manufacturing process, the composite cross section can be divided into two kinds of different connection modes of welding and bolt connection. Because of the possibility of the connecting parts of the process error and the connection defect, the composite cross section has more product quality problems than the rolling section. Hot rolling H-steel has a small amount of processing capacity and short period, and it is suitable for the construction of high rise steel structure. But for the light steel structure workshop with portal frame, the use of composite cross section H-steel will be more conducive to solve the problem of variable cross-section portal rigid frame. In addition, the combination of the cross section has its own flexible and variable processing performance, when the time limit for the project is not strict and conditions permit, using the composite cross section H-steel can also achieve the purpose of saving steel.

H-steel is mainly used for industrial workshop crane beam, floor beams, and other high-rise steel structure building load-bearing frame system [2]. Because of the structural advantages of the H steel, the steel beam with the section of the steel has good mechanical properties. In order to improve the in-plane bending capacity of the beam in the maximum extent, the H-steel is generally chosen for narrow flange type (HN), and the size of beam is larger than flange width dimension. With the gradual popularization of high performance steel and the continuous improvement of the theory of steel structure design, the research on the flexural performance of H-steel beam is also much more deeply.

3. Research Status of Bending Resistance of H-Steel Beam

A large amount of literature indicates that the influence of the residual stress and initial imperfection on the structure of the bearing capacity of H type steel beam is analyzed. In 2006, Tang Xichun in Wuhan University of Technology [3] indicated that the residual stress had a large impact on limited bearing force of H-steel beam. Especially, the flange ends of the peak residual stress increased, while the residual stress reduced.

In order to reflect the concept of "strong weak member node" in the seismic design of steel, "Seismic Design of Buildings" put forward specific requirement about calculation of the connection of steel structure with lateral force component, which including the ultimate bearing capacity of rigid connection of beams and columns. In 2007, Xiang Jianyao [4] derived from the beam's plastic bending bearing capacity calculation formula, and further improved the H-steel beam full plastic bending bearing capacity of the theoretical system. The application of Q345 steel in steel structure building is very common, but it is lower than that of Q235 steel, and it is often difficult to meet the requirements of the formula. Therefore, he put forward to improve the ductility of steel, increased the thickness of flange and strengthened the constructing measures of the node and other technical measures, and finally, solved the Q345 steel plastic checking effectively.

With the continuous expansion of the scale of China's steel production, high performance steel is increasingly showing a variety of trends. In order to take advantages of performance of various types of steel in steel production, the conception that mixing different kinds of steels has been widely recognized. The design method took the crane beam in the engineering practice in complex stress characteristics into account, and compared with the web, the flange took use of higher strength steel, which reduced weight while improved the beam stability.
This type of steel beam is more economical than the homogeneous steel beam under the same condition, and it has high economic value. Currently, it’s common that there are more and more mixed steel girder design ideas in the production of industrial crane beam. In 2012, Qingdao Technological University, Wang Pengfei [5] took the a single axial symmetry I-beam which was common in crane beam as the object, analyzed the ultimate bearing capacity of bending steel in a multi-mix conditions, and then, compared it with homogeneous steel beam in the same conditions. And finally found the failure modes of steel beams bending torsion buckling critical moment of each section. They found that differences in multi steels mix steel I-beam and homogeneous beam in the limit bearing capacity is very small, but the former can obtain obvious economic benefits. The proposed method can effectively optimize the steel structure, and its advantages will be fully played in the development of steel structure in the future.

In recent years, many steel mixed design philosophy also contributed to the development of bridge engineering in our country, but people of high strength bridge study on mechanical properties of steel is still in initial stage. In 2011, in order to accurately assess the high performance steel plastic deformation capacity and safety reserves, Pan Yongjie’ team [6] from China Academy of Railway Sciences studied limited bearing capacity of Q500qE, high-performance I- steel beam. They believed that the Q500qE high performance steel in the test reflected a good plastic performance, and compared with Q345qD, it has the same security reserves basically. In 2012, Duan Lan’s team [7] from the Chang'an University studied the flexural behavior of high strength steel I-beam and found: For high strength steel I-beam mixed design, the matching range for strength of steel should be reasonable for flanges and web. When using HPS485W, high strength steel, the web should use the strength of not less than Q345. On the other hand, the wide flanges can improve the ultimate load of steel beam and anti-roll ability. However, with the increase of the width to thickness ratio of the flanges, the deformation ability of the steel girder in elastic stage correspondingly weakened.

The improvement of modern steel production level speeded up the development of new varieties of H-steel. High performance H-steel beams are used in railway, bridge and industrial and civil buildings frequently, but there is still a need for further research on the flexural properties of H-steel beams. Due to the fact that some of the test data may be limited by the number of test conditions and the number of models, it is difficult to obtain accurate and reasonable conclusions. Therefore, a large number of experimental data results need to be compared and checked by the use of finite element analysis.

4. Finite Element Analysis of H-Steel Beams Bending Performance

In the actual steel structure engineering, H-steel beam is the main bending member. Therefore, in the design, it should be carried out under the load condition of the bending performance analysis. In order to get the steel beam flexural status changes during the data and more accurately compare the flexural properties in the elastic and plastic two-stage, analyze H-steel beams ultimate load and deformation by the use of finite element software. Therefore, obtain the ABAQUS finite element software to create three-dimensional models of H-steel beams, then, use the model to complete its elastic-plastic bending performance under uniformly distributed loads analysis and conclude the stress and displacement of the most unfavorable joints of H-steel beam, and the curve of the displacement with time and the stress-strain curve. Through the comprehensive analysis of the finite element software, it is easy for design personnel who designed the H-steel beam to verify the reasonableness of the bending resistance in the elastic and plastic stage. And it’s also clear and intuitive to obtain the dynamic change process of the model can be obtained the dynamic changing process when the model is subjected to load.

4.1 Model Establishment and Calculation

This model selected the ordinary H-steel beam which is often used in actual engineering of steel structure; the span of the beam is 6m; at both ends of the hinge support, coming from the beam size is uniformly distributed load Q=3.5e5 N/m². In full consideration girder span and suffered load conditions, the high beam is set to 300mm, the corresponding web height is taken as 280mm,
thickness is 8mm, flange plate width is 200mm, and thickness is taken as 10mm. The calculation models and cross-sectional dimensions of H-steel beam is as shown in Figure 1 and Figure 2.

![Fig. 1 Calculation Models of H-Steel Beam](image1)

![Fig. 2 Cross-sectional Dimensions of H-Steel Beam](image2)

The material properties settings should be conducted after selecting the model size. The modulus of elasticity of the steel beam is 2.1 e11 N/m², the Poisson's ratio is μ=0.3, the yield strength is f_y=3.45 e8 N/m². After checking calculation, it is proved that the model size is reasonable, and it can guarantee the whole stability and local stability of the beam. Then the load and boundary conditions are defined, and the values of the load and the arrangement of the load and the constraints of the bearing are also required. The next step is the grid division, according to the actual size of the model and the accuracy of the solution to determine the size of the mesh. The smaller the size is, the more intensive the grid is, and the higher accuracy of the model will be, while more calculating time and quantity will take. After the completion of the grid, the model is completed, as shown in Figure 3. Then the finite element analysis of the flexural behavior of the elastic and plastic state of the model is carried out in the post processing step.

![Fig. 3 Mesh Model after Node Deformation](image3)

4.2 Post Processing of Model

After the finite element calculation of the model, the ABAQUS finite element software can generate the deformed mesh model and the stress pattern, as shown in Figure 4 and figure 5. From deformed grid model picture we can find that: At the middle of the cross, the obvious trend of the torsion is presented for bending moment caused by uniformly distributed load. In addition, the stress value of the node is relatively concentrated, which is the most unfavorable position in the span of the steel beam.
After the finite element software, it is concluded that the H type steel beam is the most unfavorable node of the structure, which is the first yield point under the corresponding load. From Figure 6 we can find that: when the operation is about 0.875, stress-time curve is going to a platform which indicates that H-steel beam in the condition of the worst areas has to yield, and enters into the plastic stage.

The displacement time relationship curve of the most unfavorable nodes in Figure 7 can be divided into three stages, the horizontal section, the turning section and the falling stage. The horizontal segment indicates that the steel beam did not yield in the elastic stage. The transition section indicates that the deflection of the cross section is increasing for a part of the steel beam going into plastic state. The falling stage indicates that the deflection changed dramatically for the whole section of the
H-steel beam gonging into the plastic stage. As shown in Figure 9 and Figure 8, the stress and strain of steel beam at the most unfavorable nodes can be explained by the time variation curve and the stress-strain curve.
5. Conclusion

H-steel beam is a common member in main bearing system of steel structure. With reasonable cross-section form, good mechanical properties and process ability, it gradually became the mainstream products of steel manufacturing. Compared with the ordinary I-steel, H-steel had many advantages. It also became the best substitute of traditional I-steel. Because of the continuous development of modern high performance steel manufacturing level, more and more advanced technology had been applied to process of H-steel. The current high strength H-steel beam can adapt to demand of engineering field bridge, railway, building, etc. However, compared with developed countries, steel industry developed relatively late in China. The awareness of H-steel and stress performance of new H-steel beam need further study. Currently, the technology of finite element analysis is an effective way to solve engineering problems. This method is very common in engineering research and makes up for many deficiencies of traditional testing methods. It provides the supplements and support of data for massive engineering tests. The study of H-steel beam bending performance is based on ABAQUS finite element analysis software. The detailed variable process of steel beam model is numerically simulated in elastic phase and plastic phase, and the following conclusions can be drawn:

1) The stress and strain status of H-steel beam on the condition of uniform load can be determined by taking advantage of postprocessor of finite element software. Summarizing from the diagram of stress moiré and stress-time curves in the result of postprocessor, the middle part of steel beam span is the most unfavorable position. This position yields in first time and brings about the plastic phase of member.

2) The process of deformation and failure is considered reasonable by analyzing stress of most unfavorable node, variation of strain-time curves and stress-strain curves. The study shows that H-steel beam is equipped with favorable bending performance.

References