Application Research of Modeling and Simulation Technology in the Design of Skills Competition Entries

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ABSTRACT

In the process of preparing for the skills competition, the students encountered the problem that the entries could not be tested for safety. In order to solve the students' problems and speed up the design and production progress of the entries, the research team adopted the method of finite element modeling and simulation. The students and teachers divided the work. Geometric model modeling and data analysis are completed by students, while finite element modeling and simulation calculation are completed by teachers. The Mises stress nephogram obtained by simulation calculation provides data support for the design of the entries. In addition, in the process of problem solving, the students' analysis ability and data processing ability have been improved and exercised. The technique and skills competition is an important part of the vocational education system. Finite element modeling and simulation can provide solutions for the design of skills competition entries, which should be explored by more scholars.

Keywords: *simulation, modeling, finite element simulation, skills competition, vocational education.*

1. INTRODUCTION

Vocational education and general education are two different types of education with equal importance. In recent decades, vocational education has provided strong talent support for China's economic and social development. With the acceleration of industrial upgrading, all industries have put forward higher training requirements for skilled talents, and the importance of vocational education is becoming more and more prominent [1]. Because vocational education is positioned to cultivate skilled application talents, participation and preparation of various skills competitions have become an important supplement to campus education (Wang 2014). In 2019, nine departments including the Ministry of Education issued the "Vocational Education Quality Improvement Action Plan (2020-2023)", which clearly stated that vocational colleges should "play the leading role of promoting education and learning through competitions" [4].

The skills competition has effectively promoted the integration of industry and education and has become an important thrust for the development and reform of vocational education. Skills competition is an important platform for students to improve their comprehensive quality in vocational colleges. It not only promotes the deepening of education and teaching reform, but also strengthens the relationship between the government, industry, enterprises and vocational colleges [12]. The skills competition has a complete standard system, a competition environment closer to the real production scene, and a fair and just evaluation mechanism, and is the most direct way for vocational colleges to test the talent cultivation quality [10]. Integrating the content of the technique and skills competition into classroom teaching, on the one hand, can speed up teaching reform and build an education model for real job ability training; on the other hand, can enable teachers to improve professional theory and practical skills around the actual operation of enterprises, and promote the construction of "double-teacher" teaching staff [11].

In recent decades, various technique and skills competitions have been highly valued by vocational colleges, and the number of participating teams and students has increased significantly. Taking the Henan Provincial Competition of the "Internet+" College Student Innovation and Entrepreneurship Competition as an example, up to 288,000 students from 98 vocational colleges signed up in 2021 [2].

As we all know, compared with ordinary undergraduate schools, vocational colleges lack experimental equipment, which affect the design and

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production of the skills competition entries. With the improvement in computing ability of computers and the popularization of simulation software, simulation technology has been greatly developed in many fields, such as metallurgy [9], transportation, medical treatment [3][6], military, and education [7]. However, the application cases of simulation technology in skills competitions are few and should be paid enough attention. This paper makes a related attempt.

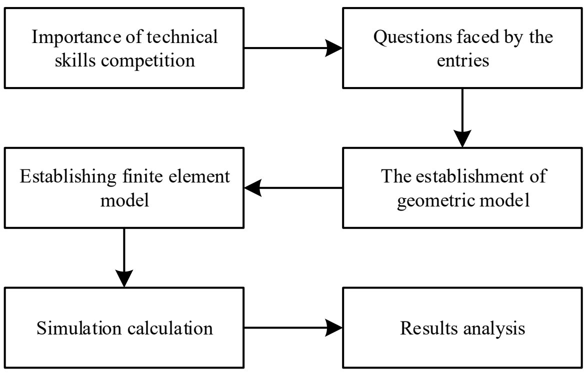


Figure 1: The research logic diagram of the paper.

In order to improve the safety of skills competition entries, students hope to do mechanical experiments. However, the school has no relevant experimental equipment. The research team proposed the solution of finite element modeling and simulation. With the joint efforts of students and teachers, the mechanical analysis was successfully completed, which provided data support for the design of the work. In the process of solving the problem, problem analysis ability and data analysis ability of the students have been improved. The research ideas of this paper are worth being applied to more fields of vocational education. The research logic of this paper is as shown in Figure 1.

2. PROBLEMS ENCOUNTERED

In order to participate in the "Internet +" College Student Innovation and Entrepreneurship Competition 2022, some students of Beijing Polytechnic formed a participating team. After a period of preparation, the participating team designed an entry of an "Unmanned Disaster Rescue Vehicle". The application scenario of the entry is: at the disaster scene, the unmanned rescue vehicle enters the dangerous area to transport emergency rescue materials (such as medicines). It can be seen from the above application scenario that the load capacity of the rescue vehicle is an important parameter of the entry.

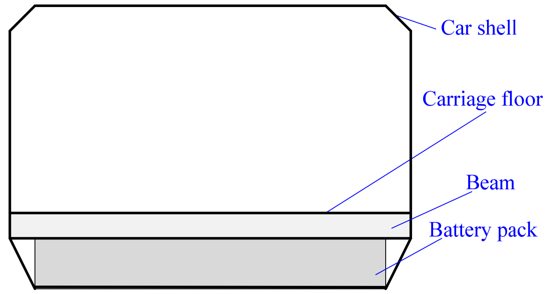


Figure 2: Cross section of students' entry.

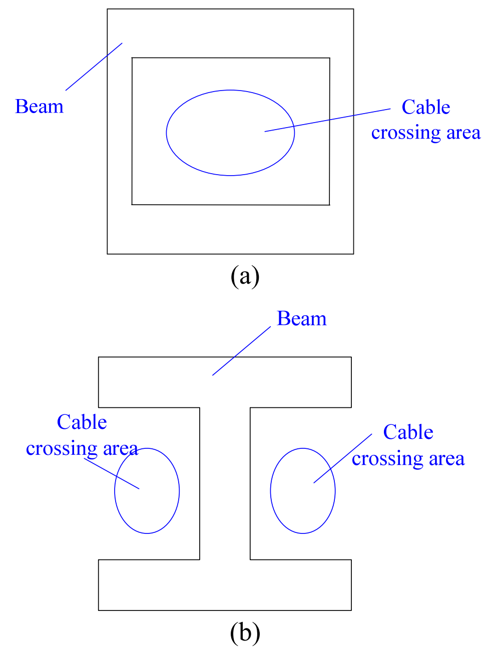


Figure 3: Geometric model of the two beams: (a) hollow beam; (b) H-beam.

Figure 2 is a sectional view of the entries in the skills competition. As shown in Figure 2, the upper part of the rescue vehicle is a loaded carriage. Materials to be transported can be placed on the carriage floor. The lower part of the loaded carriage is a battery pack. The loaded carriage is separated from the battery pack by a load-bearing steel beam. Obviously, an overweight load will cause severe bending deformation of the beam, which in turn will press the battery pack and cause an accident. In addition, the beam is not solid because multiple cables pass through the beam. According to the requirements of the entries, the students designed two different cross sections of the beam, as shown in Figure 3. Figure 3 (a) is a hollow beam, which can pass through the cables in the middle (the area marked by the blue ellipse). Figure 3 (b) shows the H-beam. Both sides of the H-beam web can pass through the cables (two blue elliptical areas in the figure).

In order to ensure the reliability of the entries, the team members hoped to carry out a three-point bending mechanical experiment to test the bending resistance of both beams. The students' solution and test requirements were recognized by the research team. Unfortunately, the school did not have relevant experimental equipment. In order to solve students' problems and promote the progress of the entries, the research team considered using finite element software for modeling and simulation calculation.

The research team introduced the basic finite element theory to the students. In order to establish a more accurate model for bending performance simulation, it is necessary to establish a geometric model. In order to improve the production process of the entries, the teachers and students have carried out a division of tasks. Students are responsible for the establishment of geometric models and data processing, including part size design, data processing with coordinate diagrams, and writing experimental reports. The teachers are responsible for the establishment of the finite element models and simulation calculation.

3. MODELING

3.1. Geometric Model

The establishment of geometric model is the basis of finite element modeling. The students looked up a lot of relevant materials in spare time. Finally, the students determined the specific dimensions of the beam and the three-point bending test requirements, and formed the geometric model diagram as shown in Figure 4.

The parameters are as follows: The length of the H-beam to be simulated is L=100 mm and height H=10 mm. The indenter and the two supports have the same structure, with diameter D=20 mm and axial length z_1=10 mm. The indenter is tangent to the upper surface of the beam at the center of the beam. The two supports are tangent to the upper surface of the beam. The distance between the axis of the two supports and both ends of the beam is s=10 mm (as shown in Figure 4).

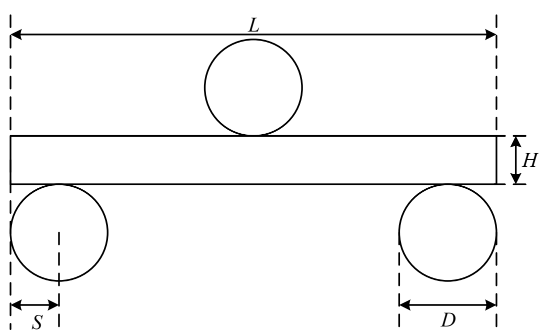


Figure 4: Geometric model of the three-point bending test.

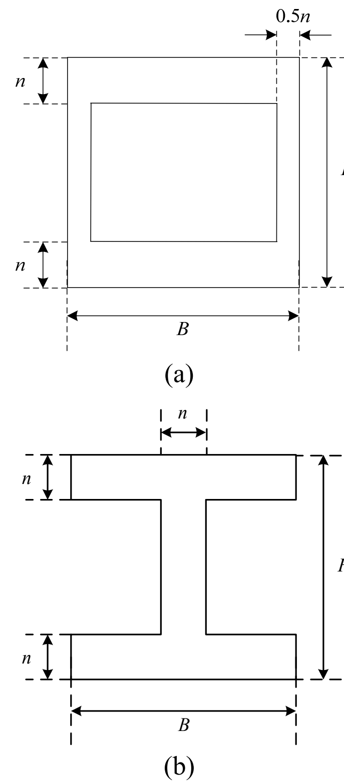


Figure 5: Cross section of the two beams: (a) hollow beam; (b) H-beam.

The geometric dimensions of cross-section of the both beams are shown in Figure 5, in which n=2 mm and B=10 mm (B=z_1). According to the data in Figure 5, the cross-sectional areas of the two beams are equal.

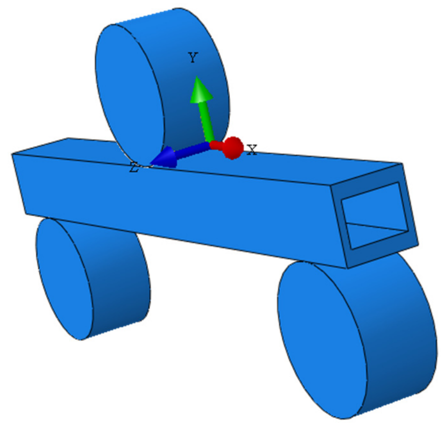
The test parameters of the students are as follows: the reduction amount H ranges from 1 mm to 6 mm, and the step factor is 1 mm. The data to be measured are as follows:

(1) The stress/strain distribution of the two beams corresponding to each reduction amount and stress concentration.

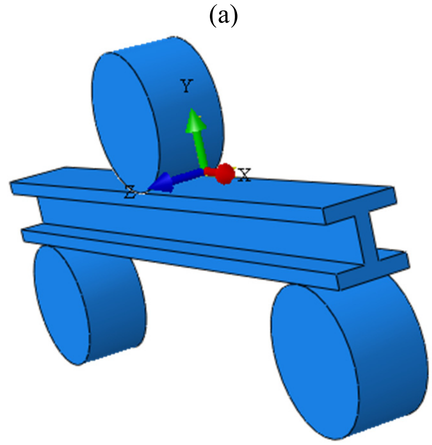
(2) Maximum Mises stress data of the two models corresponding to different reduction displacement.

3.2. Finite Element Model

According to the above dimensions, the finite element models are established by the research team using ABAQUS software. Except for different cross sections, the settings of the two models are basically the same.



(a)



(b)

Figure 6: Finite element models and the coordinate system: (a) hollow beam; (b) H-beam.

The indenter and the two supports are designed to be rigid without regard to the setting of its material properties. The material property of the H-beam are set as follows: density of the material ρ=7.9×10^3 kg/m^3, elastic modulus E=210 GPa, and Poisson's ratio λ=0.3. The plastic deformation of the beam are set as: σ_1=418 MPa, ε_1=0; σ_2=500 MPa, ε_2=0.0158; σ_3=606 MPa, ε_3=0.0298; σ_4=829 MPa, ε_4=0.25; σ_5=932 MPa, ε_5=0.55; σ_6=1040 MPa, ε_6=0.85.

Except for different cross sections, the settings of the two models are basically the same. In the ABAQUS software, "Element type" of each part is selected as C3D8R. "Approximate global size" of the beam is set as 1 mm, and the supports and indenter are set as 2 mm. In order to set "Load" and "Boundary condition" more reasonably, operation points RP-1 (0, 40, 5), RP-2 (-40, -40, 5) and RP-3 (40, -40, 5) are created. Three special points are defined and bound to three rigid bodies in the model. The indenter is set as a "Rigid body" and bound to the point RP-1. Similarly, the left support is set as a "Rigid body" and bound to the point RP-2, and the right support is set as a "Rigid body" and bound to the point RP-3. In "Interaction", the friction coefficient is set to μ=0.2. In "Boundary condition", all six degrees of freedom on the RP-2 and RP-3 are constrained. RP-1 is constrained to move only in the Y-axis to realize the pressure on the normal direction of the beam. In order to ensure the convergence of the model calculation, the left surface of the beam (surface x=-50 mm) is constrained to move only in the X-axis and Y-axis, and the other four degrees of freedom are constrained.

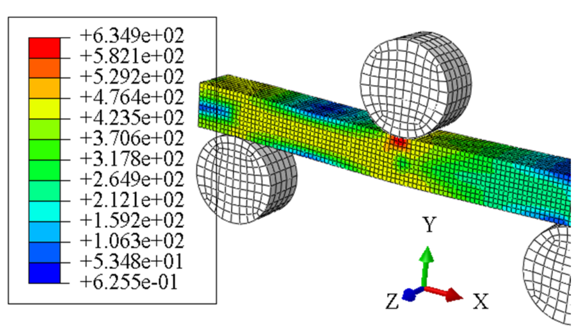
The time of the "Step" command was set to t=1 s, and the "H-output" command was set to T=10 times. The finite element models are shown in Figure 6.

4.SIMULATION CALCULATION AND ANALYSIS

According to the experimental needs of students, loading was set up in the software. The pressure of the indenter was set along the negative Y-axis direction. The deformation behavior of the two beams under different displacements was simulated. The displacement of the indenter is 1~6 mm and with a step factor 1 mm.

4.1. Simulation Results

When the displacement of the indenter is small, the Mises stress nephogram calculated by the model is shown in Figure 7. Figure 7 (a) shows the hollow beam's Mises stress nephogram with a reduction displacement H_1=1 mm. Figure 7 (b) shows the H-beam's Mises stress nephogram with a reduction displacement H_1=1 mm. As can be seen from Figure 7, the deformation of the two beams is not particularly obvious on the whole. The maximum Mises stress of both beams appears below the indenter. The maximum Mises stress value of hollow beam is 634.9 MPa, while the Mises stress value of H-beam is 595.2 MPa. In comparison, the stress distribution of H-beam is uniform, while the stress concentration of hollow beam is more obvious. In short, the performance of H-beam is slightly better.



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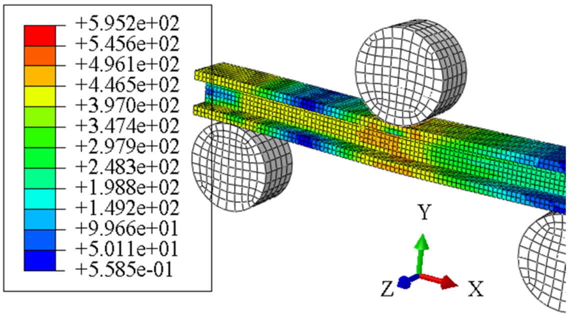


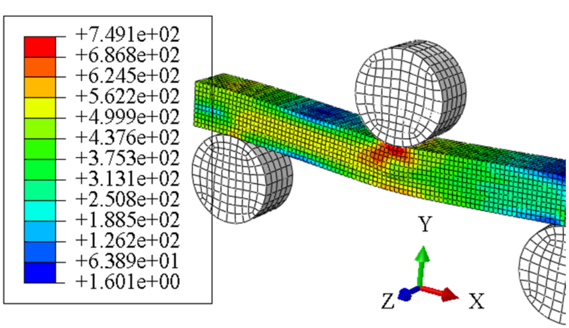
(b)

Figure 7: Mises stress nephograms of the finite element model of 6 mm reduction: (a) hollow beam; (b) H-beam.

Similarly, Mises stress nephograms of the finite element models with displacement of 3 mm were obtained, as shown in Figure 8. Figure 8 (a) shows the hollow beam's Mises stress nephogram with a reduction displacement H_3=3 mm. Comparison Figure 7 (a), the bending degree of the hollow beam increases with the increase of pressure, so does the Mises stress at the same part of the beam.

Figure 8 (b) shows the H-beam's Mises stress nephogram with a reduction displacement H_3=3 mm. Comparison Figure 7 (b), the bending degree of the H-beam increases with the increase of pressure, so does the Mises stress at the same part of the beam. The maximum Mises stress of both beams appears below the indenter. The maximum Mises stress value of hollow beam is 749.1 MPa, while the Mises stress value of H-beam is 714.4 MPa. In comparison, the stress distribution of H-beam is uniform, while the stress concentration of hollow beam is more obvious. In short, the performance of H-beam is slightly better with 3 mm reduction.

Mises stress nephograms of the finite element models with displacement of 5 mm were obtained, as shown in Figure 9. Figure 9 (a) shows the hollow beam's Mises stress nephogram with a reduction displacement H_5=5 mm. Comparison Figure 7 (a) and Figure 8 (a), the bending degree of the hollow beam increases with the increase of pressure, so does the Mises stress at the same part of the beam.



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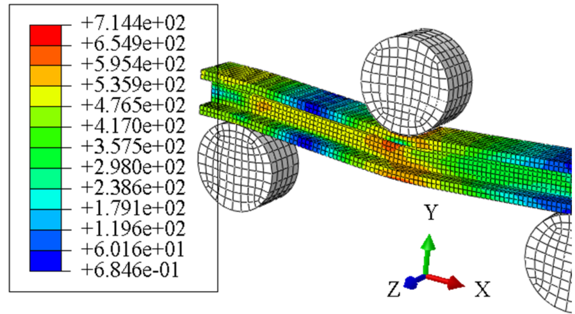


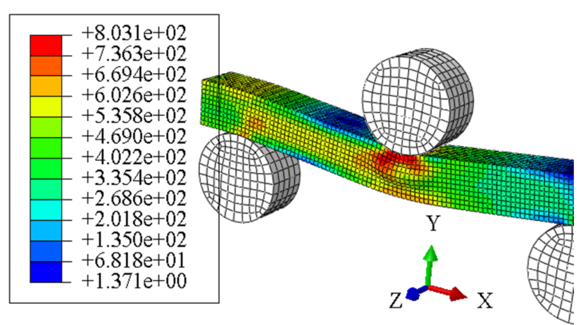
(b)

Figure 8: Mises stress nephograms of the finite element model of 6 mm reduction: (a) hollow beam; (b) H-beam.

Figure 9 (b) shows the H-beam's Mises stress nephogram with a reduction displacement H_5=5 mm. Comparison Figure 7 (b) and Figure 8 (b), the bending degree of the H-beam increases with the increase of pressure, so does the Mises stress at the same part of the beam.

Compared with Figure 9 (a) and Figure 9 (b), the deformation of hollow beam is more serious. It can also be seen from Figure 9 (a) that the beam under the indenter is distorted. For a clearer analysis, microscopic observations were made in the area below the indenter of Figure 9 (a), as shown in Figure 10. As can be seen from Figure 10, some elements are concave and some elements are convex. Obviously, the external force applied to the beam has exceeded the required limit.

The maximum Mises stress of both beams appears below the indenter. The maximum Mises stress value of hollow beam is 803.1 MPa, while the Mises stress value of H-beam is 795.5 MPa. In comparison, the stress distribution of H-beam is uniform, that is, more regions are bearing the role of external load, while the stress concentration of hollow beam is more obvious. In short, the performance of H-beam is much better after reducing 5 mm.



(a)

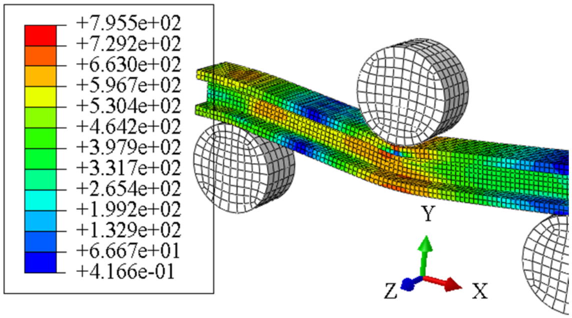


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Figure 9: Mises stress nephograms of the finite element model of 6 mm reduction: (a) hollow beam; (b) H-beam.

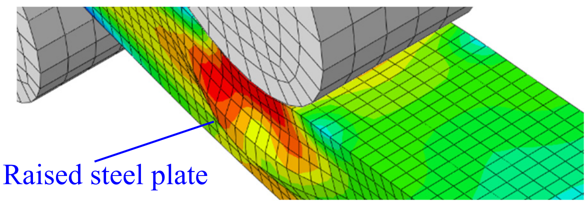
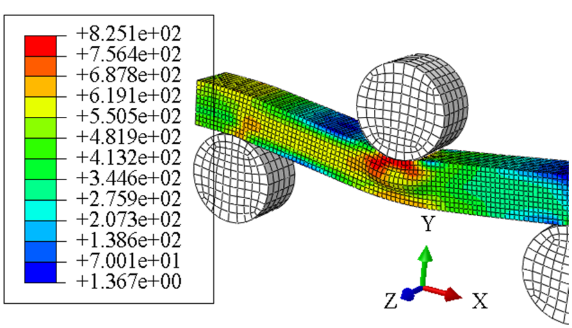


Figure 10: Mises stress nephogram of the local deformation the hollow beam.

Similarly, Mises stress nephograms of the finite element models with displacement of 6 mm were obtained, as shown in Figure 11. Figure 11 (a) shows the hollow beam's Mises stress nephogram with a reduction displacement H_6=6 mm. As can be seen from Figure 11 (a), the distortion of the area below the indenter is more obvious. Figure 11 (b) shows the H-beam's Mises stress nephogram with a reduction displacement H_6=6 mm. Compared with Figure 11 (a), the deformation of H-beam is small, and so is the maximum Mises stress. The maximum Mises stress value of hollow beam with 6 mm reduction displacement is 825.1 MPa, while the Mises stress value of H-beam is 812.4 MPa.



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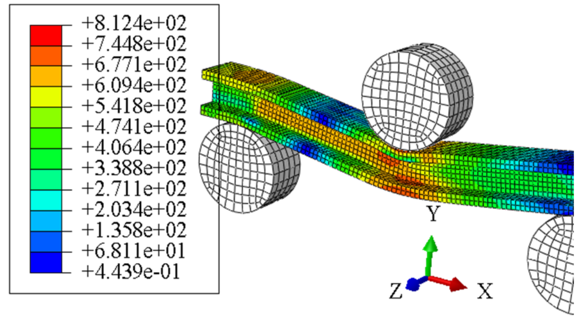
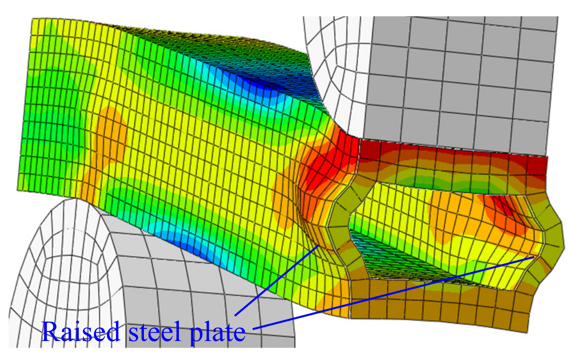


(b)

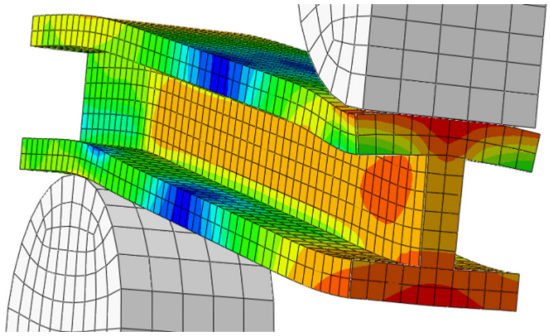
Figure 11: Mises stress nephograms of the finite element model of 6 mm reduction: (a) hollow beam; (b) H-beam.

In order to more clearly compare the deformation behavior of the two beams, the micro observation was carried out under the indenter of the two beams. In ABAQUS post-processing module, the "View cut" command is used to segment the model along face x=0. The micro morphology of the two models with x<0 were observed, as shown in Figure 12. Figure 12 (a) shows the cross-sectional deformation of the hollow beam with 6 mm reduction displacement. As can be seen from Figure 12 (a), the deformation and distortion are very serious. The two vertical steel plates bulge outward, and the stress concentration at the contact with the indenter is very serious. Obviously, the applied external load has exceeded the limit of the hollow beam. Figure 12 (b) shows the cross-sectional deformation of H-beam with 6 mm reduction displacement. Compared with Figure 12 (a), it can be seen that the bending resistance of H-beam is better. With the same displacement pressed by the indenter, the deformation of the cross section of the H-beam is much smaller.

In short, the deformation and stress distribution of the two beams under different external loads are analyzed. All Mises stress nephograms and data show that the performance of H-beam is better. Compared with the hollow beam, the stress distribution concentration of H-beam is not obvious with a small reduction displacement of the indenter. Compared with the hollow beam, the H-beam has less distortion and deformation with a big reduction displacement of the indenter.



(a)



(b)

Figure 12: Microscopic observation of cross section: (a) hollow beam; (b) H-beam.

The maximum Mises stress with different reduction displacement of the indenter is counted. The statistical results are shown in Figure 13. It can be seen from Figure 13 that the maximum Mises stress of the two model shows an increasing trend with the increase of displacement. However, the increase gradually decreased. This is because with the increase of reduction displacement, the beam has large-scale plastic deformation, which delays the increase of stress. Under the action of equal reduction displacement, the maximum Mises stress of H-beam is smaller than that of hollow beam. This shows that the bending resistance of H-beams commonly used in engineering is indeed very superior. The final suggestion is that the skills competition entry should use H-shaped steel beam instead of hollow steel beam.

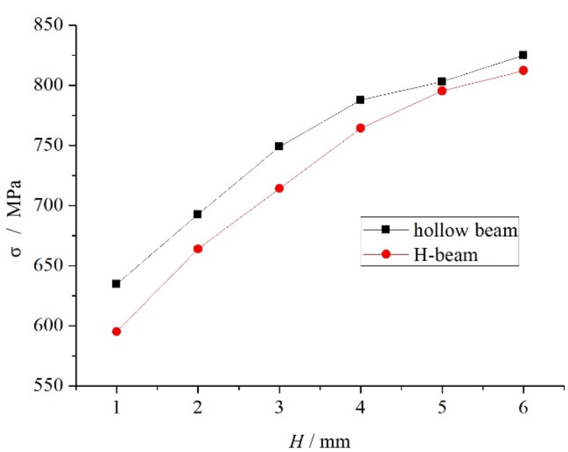


Figure 13: Variation of maximum Mises stress with reduction.

4.2. *Results Analysis*

As above, with the joint efforts of students and teachers, the finite element models were established. The finite element models were simulated on the computer, and the Mises stress nephograms and related data were obtained. Stress nephograms and data well solved the students' problems.

During the whole problem-solving process, the students have done a lot of work, and their abilities in all aspects have also been exercised and improved.

Under the guidance of the teachers, the students completed these tasks:

J1: Access to relevant information, and determining the specific dimensions of the test specimen.

J2: Determining specific needs for test data.

J3: Some simple diagrams are drawn (Figure 1, Figure 2 and Figure 3).

J4: Processing the data. The students completed the wireframe and text annotation in Figure 12 (a). Figure 13 is drawn by the students using the "Origin" software based on the simulation data.

J5: Writing a test report. Similar to J4, students completed project reports under the guidance of the teachers. The report contains figures, tables and formulas, which provide necessary data support for the skills competition entries.

In order to further study the growth of the students, the research team conducted a questionnaire, and the survey questions are as follows:

Q1: Does the simulation result solve your problem?

Q2: Has your problem analysis ability been improved?

Q3: Has your data analysis ability been improved?

Q4: Has your drawing ability been improved?

The statistical chart of the questionnaire is shown in Figure 14. All the five students answered "yes" to the above questions. During the period of solving problems, students' abilities in many aspects have been exercised and improved.

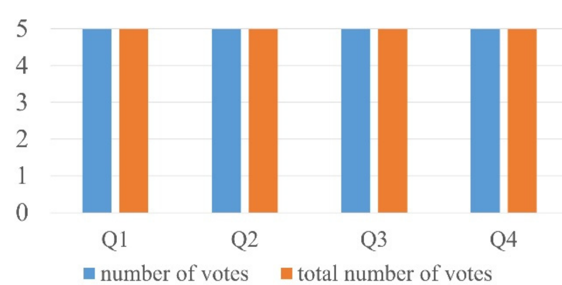


Figure 14: A questionnaire about ability improvement.

Through the solution of this problem, the students have mastered the basic methods and steps of analyzing and dealing with problems. In the future work, they can deal with similar problems. Similarly, the students have mastered the ability of data processing and can use "Origin" software to sort the data into a standard data graph.

In addition, the students' knowledge has been expanded. The students learned about the basic theory of finite element and the basic principles of ABAQUS software.

In particular, two students in the participating team are very interested in simulation technology and ABAQUS software. They made it clear that they would learn ABAQUS software in the future. Students like to learn new knowledge and have the courage to explore new technologies, which teachers are happy to see. From this point of view alone, the research team's efforts are valuable.

In conclusion, the problem faced by the entries was solved through the simulation technology, and the design and production progress of the entries was accelerated. In the process of solving problems, the students' various abilities have been exercised and improved.

5. CONCLUSION

In view of the problem that mechanical experiments cannot be performed, the research team proposed a solution to modeling and simulation. With the joint efforts of the participating team members and the research team, the problem was solved. The main conclusions of this paper are as follows:

(1) Simulation technology can be used in the design of skills competition entries.

(2) It is very necessary to force students to participate in the problem-solving process. Students' ability of problem analysis and data processing can be significantly improved in the process of participation.

The application field of finite element modeling and simulation technology is very wide, and scholars in vocational colleges should pay attention to it.

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