Research on the Application of Numerical Simulation Technology in Mechanics of Materials Teaching

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Abstract

This paper discusses the current situation of mechanics of materialsteaching, proposes to introduce the finite element numerical simulation technology into mechanics of materials teaching, so as to closely combine the ANSYS software with mechanics of materials teaching, and shows its application through the finite element simulation examples of the key and difficult problems in teaching. This method enriches the teaching means, makes the mechanical concept more intuitive and visualized, reduces the difficulty of course learning, stimulates the students' interest in learning, deepens the students' understanding and understanding of the basic concepts and theories of mechanics, and cultivates the students' ability to analyze engineering problems by combining theory with practice, which is also of great help to mechanics of materials teaching for less class hours.

Keywords: *Mechanics of materials, teaching reform, ANSYS, numerical simulation, stress concentration, Saint-Venant's principle*

1 INTRODUCTION

Mechanics of materials course is an important professional basic course for engineering majors. At present, a relatively stable curriculum system has been formed and a lot of rich and valuable experience has been accumulated [6]. Large amount of calculation, complex theory, abstract concept and strong logicality are the characteristics of this course, which has high requirements for students' abstract thinking and mathematical knowledge. However, students in application-oriented undergraduate colleges are generally lack of mathematical skills, which leads to students' low interest in learning in ordinary classroom teaching and increases the difficulty of teaching [7]. At present, the course of mechanics of materials mainly relies on one-way teaching in the classroom, mostly in the form of filling the whole classroom, and the overall teaching effect is not very good. The teaching content of mechanics of materials mostly focuses on theoretical analysis, lacks the relevant teaching and practice of scientific calculation using modern technology, lacks the introduction of engineering application practice, and students' perceptual knowledge is not strong. Students mainly stay at the stage of applying formulas for manual calculation, which is difficult to deal with complex calculation problems in practice. Therefore, the actual teaching effect of this course has been affected [2]. The literature shows that the current mechanics of materials teaching mostly pursues the integrity of mechanics of materials theory [3] [4]. When basic mechanics is taught, the class hours used for formula derivation account for a large proportion of the total class hours. Teachers often spend a lot of class hours on teaching, but the effect is still poor. One of the main reasons is that students do not understand the concepts, formulas and their engineering applications. They do not understand the meaning of formulas deeply and do not master them well. They can only remember them simply and mechanically, and it is more difficult to flexibly use the knowledge they have learned to solve practical problems. Moreover, because the theoretical derivation process is complex and cumbersome, many students, especially those with poor mathematical foundation, can

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not help but feel afraid of difficulties. In order to overcome the above difficulties in mechanics of materials teaching and enable students to understand and master knowledge, in addition to the continuous reform of teaching contents and teaching methods, teaching methods should also be constantly updated.

In this paper, the finite element numerical simulation technology is introduced into mechanics of materials course. Through computer-aided analysis, the more abstract concepts in mechanics of materials are simulated, and the previously difficult knowledge is visually and visually displayed to the students in the form of graphics, so as to deepen the students' understanding and understanding of the key knowledge points of mechanics of materials, make them truly master the engineering significance of the formula, and significantly improve the teaching effect of mechanics of materials course.

2 TEACHING EXAMPLE OF MECHANICS OF MATERIALS BASED ON ANSYS ANALYSIS

ANSYS software is a large-scale general finite element software commonly used in engineering, which can carry out structural analysis, fluid, thermal, electromagnetic, etc. It is widely used in many research and technical fields such as civil engineering, machinery, materials, etc. Some colleges and universities have begun to explore its application in mechanics of materials teaching[1] [5] [8]. This paper uses ANSYS software to carry out numerical simulation calculation on some key points and difficulties in mechanics of materials teaching, so as to enable students to have a more intuitive and perceptual understanding, so as to deepen the understanding and mastery of knowledge and improve the learning effect.

2.1 Stress Concentration

Stress concentration is a common mechanical phenomenon in engineering. It refers to the phenomenon that the stress in the local range increases significantly due to the sudden change of geometric shape and overall dimension of the stressed component. The sharper the change of section size, the sharper the angle and the smaller the hole, the more serious the stress concentration. This concept is introduced because the cross-section of the member is continuous in the previous stress calculation, but there are always round, square, large or small notches on the member in engineering practice. Most students have only a vague understanding of this. They can only understand it mechanically from the formulas in the textbooks, but cannot correspond to the actual engineering problems.

Example analysis 1: There is a 100mm×100mm elastic thin plate with an elastic modulus of E=200GPa, and there is a circular hole with a radius of 5mm in its center, as shown in figure 1. The left and right ends of the thin plate are uniformly loaded, and the stress distribution of the thin plate after loading is calculated.

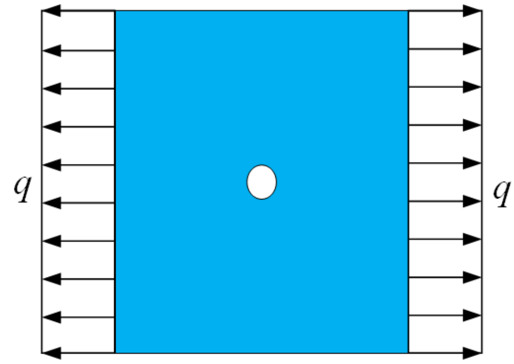

Figure 1: Uniformly distributed load on perforated thin plate.

According to the symmetry, 1/4 of it is modelled by ANSYS software, as shown in figure 2.

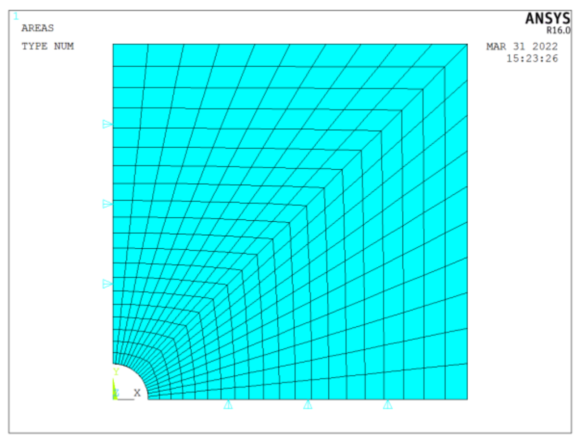

Figure 2: Finite element model of perforated thin plate.

The equivalent plastic stress nephogram calculated by numerical simulation is shown in figure 3. It can be seen that there is significant stress concentration at the edge of the circular hole. The maximum stress value is located at the upper or lower side of the hole edge, and the stress concentration factor is as high as 2.86. The stress values at the left and right sides of the round hole are obviously smaller than the average stress value, and the stress distribution in other parts is uniform. Through intuitive observation, students have a deep understanding of the stress concentration in the textbook. The stress concentration factor can be analyzed by changing the aperture size, and the stress concentration factor is different for different apertures. Therefore, in teaching, students can list cases of stress concentration, and further guide students to think about how to eliminate the phenomenon of stress concentration in engineering structures.

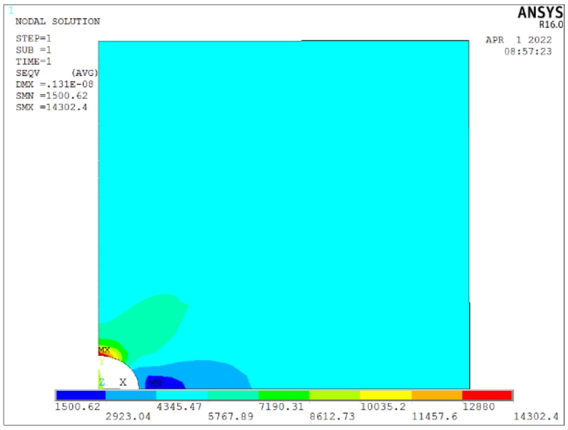

Figure 3: Equivalent plastic stress nephogram of perforated thin plate.

2.2 *Saint-Venant's Principle*

Saint-Venant's principle in the textbook of mechanics of materials points out that the distribution mode of force acting on the rod end only affects the stress distribution in the local range of the rod end, and the axial range of the influence area is about 1~2 horizontal dimensions of the rod from the rod end. Saint-Venant's principle is of great significance in practice and theory. In practical application, if we only care about the stress far away from the load, we can change the load distribution according to the needs of calculation or experiment and the principle of mechanical equivalence. Because there is no proof in the textbook, students are always vague about this principle, and cannot feel its real mechanical significance and engineering role.

Example analysis 2: There is an elastic bar with a size of 100mm×10mm, both ends are loaded with uniformly distributed force and concentrated force respectively, and the stress distribution of the bar after loading is calculated.

Use ANSYS software to model according to plane stress element, as shown in figure 4.

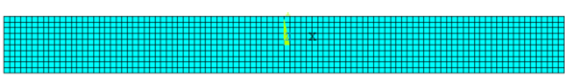

Figure 4: Finite element model of bar.

It can be seen from the numerical simulation that the stress distribution in the member is uniform under the uniformly distributed force, as shown in figure 5.

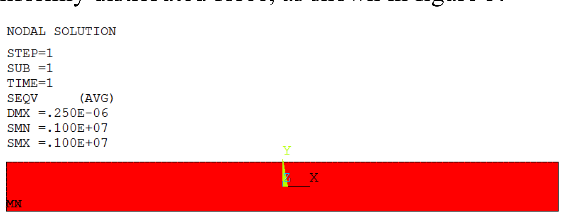

Figure 5: Equivalent plastic stress nephogram of bar under uniformly distributed force.

Change the uniformly distributed force into a concentrated force of equivalent size, and the stress nephogram is shown in figure 6. It can be seen that the stress distribution at the end is complex and obviously non-uniform. The stress concentration factor at the point where the concentrated force acts is as high as 9.52. Far away from the point where the concentrated force acts, the stress distribution is uniform.

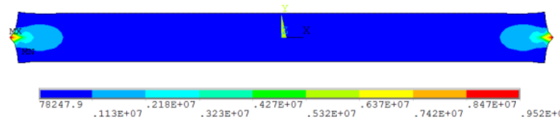

Figure 6: Equivalent plastic stress nephogram of bar under concentrated force.

In order to deepen the influence of the distribution mode of the force acting on the rod end on the stress distribution range at the rod end, a cross-sectional position with a transverse dimension away from the concentrated force is taken for analysis, as shown in figure 7. Students can find that the stress is approximately uniformly distributed, and the maximum stress concentration factor here is only 1.05. This shows that changing the distribution of the force system will only affect the stress distribution near the force system, while the stress in the area far away from the distribution of the force system will not be affected. The finite element simulation results intuitively show the meaning expressed by Saint-Venant's principle.

Through these nephograms, students can intuitively feel the principle of this local effect, rather than simply and mechanically memorize it. In this way, teachers can further guide students to think. For example, cutting metal wires with wire cutters can be explained by Saint-Venant's principle.

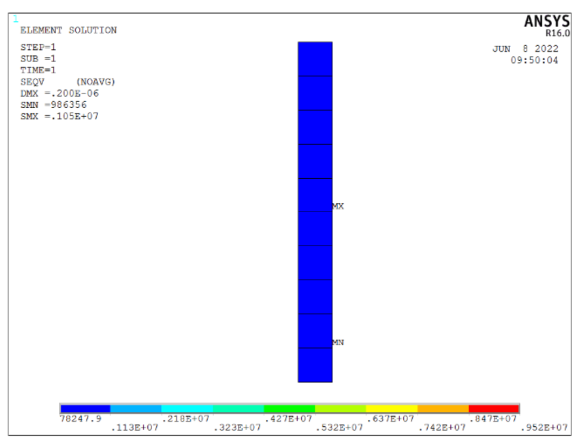

Figure 7: Equivalent plastic stress nephogram of a transverse dimension section from the rod end.

2.3 *Torsional Deformation of Circular Shaft*

When several basic deformations of the bar in the study of mechanics of materials are small deformations, that is to say, when the maximum stress of the rod is not greater than the proportional limit, the basic assumption of each deformation is established. Among several basic deformations, the cylinder torsion is relatively difficult to understand. The application of ANSYS software to simulate the torsion deformation of the cylinder rod under stress and show it to the students in the form of physical objects can deepen the students' understanding of this part of knowledge.

Example analysis 3: One end of a circular section equal straight bar is fixed, and the other end is subject to a torque. ANSYS software is used to analyze and simulate the deformation of the round shaft bar in the process of torque.

The ANSYS software is used for modelling, as shown in figure 8, and the torque is equivalent converted to the nodal force applied in the circumferential direction of the end face. Before torsional deformation, the grid lines on the surface of the circular shaft form many longitudinal lines in the direction parallel to the axis, form circular lines in the radial direction, and form many small rectangular grids on the outer surface of the circular shaft.

Figure 9 shows the deformation of the cylinder as a whole after the torque is applied to the upper end face of the circular shaft. It can be seen from the figure that the longitudinal line parallel to the axis before the torque changes to an oblique line after the torque, and the inclination degree is the same. The circumference distributed on the cylinder surface before the torque is still concentric after the torque. The small rectangular lattice on the outer surface of the circular axis becomes a parallelogram after deformation. Through this phenomenon, combined with the relevant knowledge behind, the plane hypothesis of torsion is derived. In this way, the deformation geometric relationship of the circumference after torsion, which is difficult to understand, is shown to the students in the form of graphics, so as to pave the way for the subsequent derivation of the torsional shear stress formula.

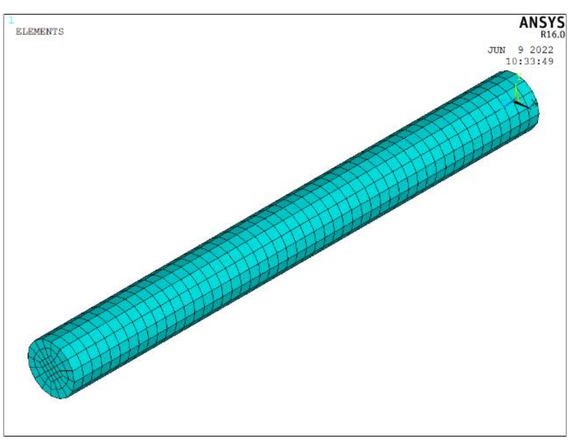

Figure 8: Finite element model of circular shaft member.

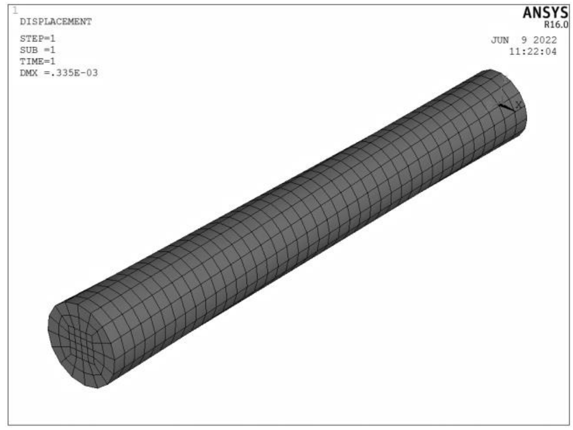

Figure 9: Mesh deformation diagram of a round shaft member after torsion.

Figure 10 is the cloud diagram of equivalent plastic stress of the round shaft member after torsion, and Figure 11 is the cloud diagram of equivalent plastic stress of the middle section of the round shaft member. It can be seen from the figure that the maximum stress occurs at each point around the cross section, and the stress at the center of the circle is approximately zero. The stress is proportional to the radius, and the tangential stress at each point on the circumference of the same radius is the same. This rule is completely consistent with the result calculated by the theoretical formula. Through the display of cloud chart, students' understanding of theoretical formulas is deepened.

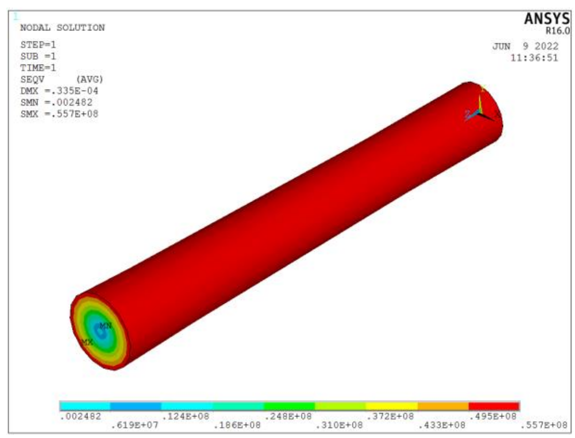

Figure 10: Equivalent plastic stress nephogram of a round shaft member after torsion.

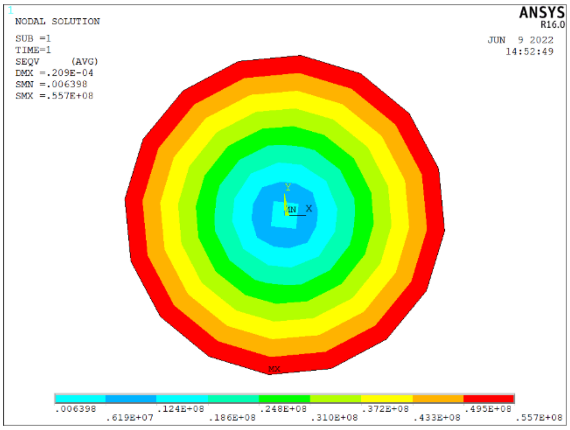

Figure 11: Equivalent plastic stress nephogram of middle section of circular shaft member.

3 APPLICATION EFFECT OF NUMERICAL SIMULATION TECHNOLOGY

Mechanics of materials itself is very abstract and theoretical, and often requires complex geometric and mathematical derivation. If the teaching is limited to pure explanation and derivation, the concepts and meanings in the above derivation process can only be digested by students after repeated thinking and imagination. It is easy for students to be afraid of difficulties and slack off, and the learning effect is not satisfactory. Finite element numerical simulation can transform abstract data into vivid graphics, which helps to reduce students' learning difficulties, improve students' analytical thinking ability, enhance students' perceptual knowledge of structure, and cultivate strong structural analysis ability. Through the finite element calculation and analysis, the original boring mechanical concepts and theories have been transformed into intuitive graphics with visual impact. The finite element calculation and analysis can be repeated many times, which can simulate some conditions that are difficult to achieve in the experiment, and has the advantages that the experiment does not have.

In the process of teaching practice, the author introduced the finite element numerical simulation technology into the course teaching of mechanics of materials, used the large-scale engineering software ANSYS to carry out finite element calculation on the key and difficult problems in mechanics of materials, formed corresponding cases, and appropriately supplemented the engineering concepts to show the students visually and intuitively, and the students responded well.

4 CONCLUSIONS

This paper discusses the current teaching situation and existing problems of mechanics of materials, and proposes to introduce the finite element numerical simulation technology into the classroom teaching of mechanics of materials in order to improve the teaching effect. The author organically combines the ANSYS software with mechanics of materials teaching, and verifies some important concepts through the finite element simulation examples of key and difficult problems, which can display the abstract theoretical knowledge in the form of graphics, help students better understand the physical meaning of mechanical concepts, improve their perceptual knowledge of mechanics and enhance their engineering practice ability.

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REFERENCES

[1] Chen, Y. Y. (2019).Application of ANSYS software in bending normal stress teaching of mechanics of materials. Henan Education (Higher Education). (07), 98-100.

[2] Kang, Y. M. (2016). Exploration of Saint Venant's principle teaching method combining theoretical analysis and numerical simulation. Shandong Industrial Technology. (05), 222-223.

[3] Liu, H., Zhou, S. C. (2022). Elementary discussion on basic assumptions of impact stress analysis in mechanics of materials. Mechanics in Engineering. 44 (01), 192-196.

[4] Li, Y. H., Wang, Y., Li,M. (2021). Discussion on the applicable scope of the small deformation assumption of planar triangular truss structure. Mechanics in Engineering. 43 (01), 100-104.

[5] Xu, B.,Yin, G. S.,She, B., et al. (2018). Teaching Method Research on Metarial Mechanics by FEA Method. Experiment Science and Technology. 16(01), 82-85.

[6] Zhang, H. W., Xi J., Xu, Y. M., et al (2016). Discussion on application of finite element numerical simulation in mechanics of materials teaching. Higher Education in Chemical Engineering. 33(02), 80-84.

[7] Zhang, X. A. (2017). Application case of finite element analysis in mechanics of materials. Agricultural Engineering. 7 (04), 174-177.

[8] Zhou, X. M., Sun, Z. (2019). ANSYS and teaching of mechanics of materials. Mechanics in Engineering. 41(2), 222-226.