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Teaching Reform and Practice of 'Finite Element Method in Civil Engineering'

-- An Application-Oriented Teaching Exploration for Civil and Hydraulic Engineering Graduate Students

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Abstract: Graduate students in civil and hydraulic engineering often have relatively weak foundations in mechanics and mathematics. To address this, teaching reform strategies for the course '*Finite Element Method in Civil Engineering'* are proposed. These strategies include reducing theoretical derivations, strengthening practical applications, focusing on fundamental concepts and difficulties analysis, integrating engineering case studies and project-based teaching, and encouraging students to apply the finite element method to their research projects. The goal is to enhance graduate students' engineering analysis skills and practical problem-solving abilities. Practice shows that this reform significantly improves teaching effectiveness and lays a foundation for students' future professional development. This paper details the specific measures, implementation pathways, and outcomes of the reform, providing a reference for optimizing similar courses.

Keywords: Teaching Reform; Finite Element Method; Civil Engineering.

1. Introduction

The finite element method is a crucial numerical analysis technique in civil engineering and a powerful tool for solving complex structural engineering problems. Its core idea involves discretizing a continuum into elements, assembling the global system, and solving discrete equations, providing an efficient means for engineering design and analysis. However, traditional teaching often overemphasizes theoretical derivations and mathematical formulas, making it difficult for students with weak mathematical backgrounds to grasp the core concepts.[1] This leads to decreased interest and even aversion to learning. In response, based on years of teaching practice, an application-oriented teaching model is proposed for students with limited mechanics and mathematics backgrounds.[2] The approach aims to improve course effectiveness by 'reducing theory, enhancing application, focusing on core concepts, and emphasizing practice.' Meanwhile, by incorporating engineering cases and project-based learning, students' engineering thinking and innovation capabilities are cultivated, nurturing high-quality applied talents for the civil engineering industry.

2. Analysis of the Current Learning Situation in Civil and Hydraulic Engineering postgraduate education

2.1. Relatively Weak Mathematical and Mechanical Foundations

Students in civil and hydraulic engineering often lack sufficient knowledge in mechanics and mathematics, facing understanding barriers in areas such as partial differential equations, elasticity theory, and functional analysis. Surveys indicate that over 60% of students find it challenging to comprehend matrix operations and variational principles, leading to reduced learning motivation and difficulty in constructing a holistic framework for finite element analysis. Additionally, students lack the ability to integrate theoretical knowledge with engineering practice.[3]

2.2. Issues in Traditional Finite Element Teaching

Course content is predominantly theoretical, with theoretical explanations accounting for up to 70% of class hours. Due to the limited total class hours (typically only 32 hours), instructors cannot thoroughly cover related knowledge, leaving students feeling that the course is overly abstract and incomprehensible. Classroom examples often involve simplified models, leaving students unsure how to tackle complex real-world engineering problems during actual research. Abstract theoretical content and high difficulty levels result in student frustration, insufficient classroom interaction, and uneven homework quality. Students often resort to rote memorization of formulas to pass exams without truly mastering the core concepts of finite element analysis [4].

3. Teaching Reform Strategies and Practice

3.1. Reduce Theory, Enhance Application – Adjusting the Proportion of Teaching Content

Streamline Theoretical Content: Compress theories such as elasticity and functional analysis to 20% of class hours, focusing instead on the core ideas of the finite element method (e.g., discretization, element analysis, global assembly). Use animations and engineering examples to help students build intuitive understanding.

Problem-Oriented Teaching: Use practical engineering problems (e.g., bridge deformation analysis, building structural optimization) as starting points to guide students through finite element analysis steps. For example, when explaining mesh generation, use the discretization of beams

on elastic foundations to compare results under different mesh densities, emphasizing the "balance between discretization accuracy and computational efficiency."

Introduce Simplified Cases: Design basic models such as cantilever beams and simply supported beams. Compare hand calculations with software analysis results to validate the rationality of finite element outcomes, helping students understand the link between theory and practical application.

3.2. Focus on Basic Concepts and Strengthen Foundations

3.2.1. Element Types

Compare the characteristics and applicable scenarios of bar, beam, plate, and solid elements, using engineering examples (e.g., truss structures modeled with bar elements, floor slabs analyzed with shell elements). Demonstrate the impact of different element types on analysis results through software modeling.

3.2.2. Degrees of Freedom and Constraints

Use animations to demonstrate the constraint methods for nodal degrees of freedom (displacement, rotation), distinguishing boundary conditions such as fixed ends, hinged supports, and sliding supports. For example, use cases like three-hinged arches and continuous beams to explain the modeling of hinged connections.

3.2.3. Load Application and Result Extraction

Demonstrate the application of concentrated loads, distributed loads, and thermal loads using software like ANSYS or ABAQUS, along with the interpretation of stress and displacement contours. Focus on extracting key data (e.g., maximum stress locations, deformation amounts) for engineering evaluation. The plotting of internal force diagrams (axial force, shear force, bending moment) is critical in civil engineering and varies across different finite element software.

3.3. Overcome Difficulties with Methodological Guidance

3.3.1. Local Coordinate Systems

Use comparative teaching to explain how loads and constraints are defined in local coordinate systems. Through hands-on software modeling, compare analysis results in global and local coordinate systems, helping students flexibly use local coordinates to obtain accurate results.

3.3.2. Handling Complex Boundary Conditions

Design step-by-step exercises, progressing from simple constraints (fixed ends, free ends) to complex scenarios like spring constraints and contact analysis. For example, in problems involving beams on elastic foundations, introduce spring elements to simulate soil constraints and analyze the impact of soil stiffness on settlement through parameter adjustments.

3.3.3. Error Analysis

Add a special topic on "Reliability Assessment of Finite Element Results," covering methods such as mesh convergence analysis and element distortion checks, fostering a rigorous attitude toward engineering analysis.

3.4. Encourage Practice and Integrate Research Projects

Integration with Research: Senior graduate students in civil engineering often use various finite element programs in their research, addressing diverse problems such as steel joint design, bridge design, and reinforcement effect evaluation of existing buildings. Encourage students to learn from senior peers, assisting them in applying finite element methods to research projects while transforming theoretical knowledge into practical solutions.

Peer Review: Incorporate peer evaluation in project practice, encouraging students to assess each other's model rationality and depth of result analysis, promoting collaboration and reflection.

4. Implementation Results and Evaluation

4.1. Grade Improvement

After the reform, students' scores on application-oriented questions in final exams increased from 65% to 82%, with significant enhancement in complex problem-solving abilities. The pass rate reached 100%, and overall grade distribution showed a normal curve, indicating clear improvement in teaching effectiveness. Students' mastery of finite element analysis steps is shown in Figure 1.

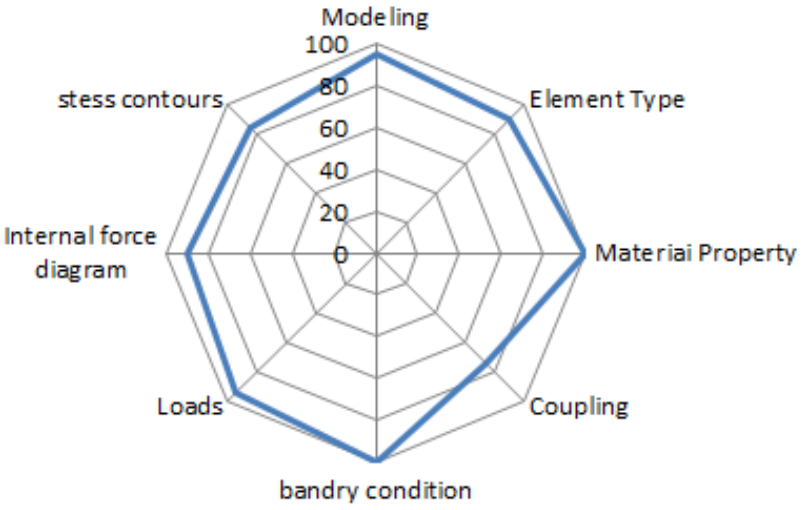


Fig 1. Mastery of finite element analysis steps

4.2. Enhanced Practical Skills

Students frequently won awards in the Liaoning Provincial Graduate Numerical Simulation Competition, with some summarizing project results into high-level papers published in academic journals. Graduate feedback indicates that finite element analysis skills have become a core competency in their careers.

4.3. Positive Feedback

Questionnaires show that 90% of students found the course highly practical, while 85% developed a strong interest in finite element analysis. Students generally reported that ‘project practice truly helped understand the application value of the finite element method.’

4.4. Improved Teaching Effectiveness

Classroom interaction increased by 40%, with a significant rise in student-initiated questions and discussions.

5. Conclusion

Teaching practice has demonstrated that in the finite element method course for civil engineering graduate students, streamlining complex theoretical derivations, strengthening practical engineering application, and focusing on in-depth analysis of fundamental concepts and key challenges can effectively enhance students' engineering analysis skills and practical problem-solving abilities. The reform concepts and specific strategies adopted in this course can provide a valuable reference for optimizing the teaching of similar engineering courses.

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