Region-Educational Research and Reviews, 2025,Volume 7, Issue 6
10.12238/rerr.v7i6.4211
ISSN Online:2661-4634
ISSN Print:2661-4626

# Innovative Practice and Exploration: Applying Finite Element Software to Empower Teaching in Pressure Vessel Courses

**Qiang Zhang, Yuchao Liu, Hengrui Zhang**

Air Force Logistics Academy, Xuzhou, Jiangsu, 221000, China

**Abstract:** Traditional instruction in gas cylinder courses predominantly relies on theoretical formulas and simplified models, which inadequately visualize complex stress distributions and failure mechanisms. This study bridges the theory-practice divide by integrating finite element software into pedagogy, systematically analyzing its functional mechanisms across theoretical instruction, project-based practical sessions, and innovation skill development. Empirical validation through teaching cases demonstrates significant enhancements in students' depth of theoretical comprehension and engineering application competence. Pedagogical practice confirms the approach elevates the course's visual accessibility, interactivity, and technological currency, establishing finite element technology as a transformative enabler for gas cylinder education.

**Keywords:** finite element software, gas cylinders, course instruction, applications

## 1. Introduction

Gas cylinders, as critical equipment for storing and transporting gases, are widely used across various industrial sectors. Cylinder-related courses cover multidisciplinary knowledge such as material mechanics and thermodynamics, aiming to equip students with professional skills in cylinder design, manufacturing, inspection, and safe operation. However, due to the complex structure and loading conditions of cylinders, traditional teaching methods struggle to provide students with a comprehensive and profound understanding of the relevant knowledge. Finite element software enables precise simulation of the mechanical properties and temperature distribution of cylinders. Through visual result displays, it helps students better grasp course content. Integrating finite element software into cylinder-related course teaching is not only an innovation in teaching methodology but also an essential requirement for adapting to the trends in engineering education and cultivating high-quality engineering talent.

## 2. Current Status and Problems in Cylinder-Related Course Teaching

### 2.1 Abstract Nature of Theoretical Teaching

The theoretical knowledge involved in cylinder-related courses is highly abstract and complex, encompassing interdisciplinary content such as material mechanics, elasticity theory, and thermodynamics. In stress analysis and strength design instruction, students must understand and master numerous theoretical formulas, such as thin-walled vessel stress formulas and the Fourth Strength Theory. Taking the calculation of hoop and axial stresses in cylindrical cylinders as an example, the formula derivation involves complex mechanical assumptions and mathematical operations. Relying solely on textbooks and teacher explanations, students find it difficult to intuitively connect these abstract formulas with the actual stress state of cylinders. Furthermore, stress distribution patterns under different working conditions, such as stress variations under coupled internal pressure and thermal loads, cannot be deeply understood through textual descriptions and static images alone. Students report difficulties comprehending stress analysis theories, leading to diminished motivation, superficial knowledge retention, and failure to achieve learning objectives.

### 2.2 Limitations of Practical Teaching

Cylinder-related courses are highly practical, yet the practical teaching component faces significant constraints. Firstly, cylinder experiments pose substantial safety risks. During pressure tests, burst tests, etc., improper operation or equipment failure can lead to explosions, leaks, and other serious accidents, endangering lives. Consequently, many universities have drastically reduced or eliminated such hazardous experiments. Secondly, the procurement and maintenance costs of experimental equipment are exorbitant. A complete set of cylinder testing equipment, including pressure testing machines and non-destructive testing instruments, can cost hundreds of thousands of RMB, with ongoing expenses for calibration and repairs. Limited teaching budgets prevent universities from providing sufficient equipment, drastically reducing students' hands-on opportunities and hindering their mastery of key skills like cylinder inspection and maintenance. Additionally, practical teaching content is often simplistic, focusing mainly on verification experiments (e.g., visual inspection, basic pressure testing), lacking comprehensive or design-oriented experiments, thus failing to cultivate students' innovative and practical abilities.

### 2.3 Monotonous Teaching Methods

Current cylinder-related course teaching predominantly relies on the traditional one-way "teacher lectures, students listen" model, with teaching tools limited to blackboards and simple PowerPoint presentations. Classroom interaction is minimal, placing students in a passive knowledge-receiving role with little room for active thinking or exploration. This approach fails to stimulate student interest or innovative thinking, resulting in low engagement. Simultaneously, course content updates slowly, often failing to incorporate new industry technologies and standards. For instance, despite the widespread application of composite materials in cylinder manufacturing and the industry trend towards new carbon fiber-wrapped cylinder design and manufacturing techniques, some courses still focus primarily on traditional metal cylinders, providing scant coverage of new materials and processes. This creates a disconnect between acquired knowledge and actual industry needs. Furthermore, the assessment system is overly simplistic, relying heavily on exam scores as the sole measure of learning outcomes, neglecting the evaluation of practical skills, innovation capabilities, teamwork, and overall competence, thereby hindering a comprehensive assessment of student achievement and teaching quality.

## 3. Advantages of Finite Element Software in Cylinder-Related Course Teaching

With the continuous advancement of engineering technology, finite element software has gained widespread application in the engineering field due to its powerful numerical simulation and analysis capabilities. Integrating finite element software into cylinder-related course teaching can effectively address the shortcomings of traditional methods, offering significant advantages and playing a crucial role in enhancing teaching quality and cultivating students' engineering practice abilities.

### 3.1 Visualizing Complex Mechanical Phenomena

Cylinder courses involve stress analysis under various working conditions (e.g., internal pressure, external pressure, temperature changes). These mechanical phenomena are abstract and challenging for students to grasp. Finite element software can establish 3D cylinder models, simulate various conditions, and vividly display mechanical parameters like stress, strain, and displacement through contour plots and vector diagrams. For example, when teaching internal pressure strength analysis, finite element simulation clearly shows stress distribution within the cylinder and the locations of maximum stress, enabling students to instantly understand and deepen their comprehension of relevant theories.

### 3.2 Enhancing Students' Practical Operation Skills

Traditional practical teaching relies mainly on physical experiments, which are constrained by equipment, space, and safety, limiting hands-on opportunities. Finite element software provides a virtual practice platform. Students can independently build models, set parameters, perform simulations, and process and discuss results on computers. This approach is safe, convenient, and allows students to experiment with different designs and conditions, fostering self-learning and practical operation skills. Using the software, students can safely simulate cylinder mechanical behavior and failure processes under hazardous conditions like overpressure, high temperature, and impact, avoiding the risks and costs of physical experiments. They can observe burst processes and crack propagation in virtual environments, deeply understand failure mechanisms, and master scientific safety assessment and prevention measures.

### 3.3 Facilitating Course Content Integration and Expansion

Cylinder courses cover knowledge from multiple disciplines. Finite element software application organically integrates this knowledge. When performing cylinder finite element analysis, students must comprehensively apply knowledge from material mechanics, elasticity theory, and heat transfer to build models and set parameters. Furthermore, the software allows for expanding course content by introducing advanced analysis methods like fatigue analysis and fracture mechanics analysis, exposing students to cutting-edge knowledge.

### 3.4 Close Alignment with Practical Engineering Applications

By participating in teaching projects based on finite element software, students gain engineering analysis experience, developing engineering thinking and competence. This teaching model, closely aligned with industry practice, effectively bridges the gap between academic education and actual enterprise needs, enabling graduates to adapt faster to workplaces and enhancing their employability. Moreover, students' proficiency with the software during their studies lays a solid foundation for learning and applying more complex engineering analysis techniques in their future careers.

## 4. Specific Application Paths of Finite Element Software in Cylinder-Related Course Teaching

### 4.1 Deep Integration with Theoretical Teaching

When teaching cylinder stress analysis and strength design, use software like ANSYS to build 3D finite element models. For a cylindrical cylinder, applying internal pressure loads allows stress distribution contour plots to visually demonstrate stress concentration at the neck and shoulder. Combine these plots with detailed explanations of how different structural parameters affect stress distribution, helping students understand the application logic of mechanical formulas in real engineering. For liquefied gas cylinders involving temperature changes during filling and use, utilize COMSOL software for thermo-structural coupling analysis. Simulate thermal stress distribution and deformation during temperature transients. Combine this with thermodynamic knowledge to systematically explain temperature's impact on cylinder material properties and structural stability, broadening students' perspectives.

### 4.2 Innovative Models for Practical Teaching

Establish a finite element analysis lab platform, guiding students to use software like ABAQUS for virtual experiments. For instance, assign tasks predicting cylinder fatigue life: students build models, set cyclic load parameters, observe fatigue crack initiation and propagation, and analyze the impact of load magnitude and cycle count on fatigue life, cultivating practical operation and data analysis skills. Collect real cylinder accident cases and use finite element software to recreate the accident process. Present simulation results in class, organize students to analyze causes (e.g., overpressure, material defects), and propose targeted preventive measures, reinforcing safety awareness and problem-solving skills.

### 4.3 Innovation Capability Cultivation System

Set open-ended research topics encouraging students to explore cutting-edge areas using finite element software. Examples include researching carbon fiber composite applications in cylinder design, analyzing their mechanical performance and economic benefits, or investigating the impact of new manufacturing processes (e.g., filament winding) on cylinder performance. Through independent literature review, modeling, and analysis, students hone research skills and innovative thinking. Integrate with competitions like the National Undergraduate Mechanical Innovation Design Competition or Engineering Mechanics Competitions, guiding students to optimize competition entries using finite element software. Solving real engineering problems and competing with peers further enhances their comprehensive abilities and innovation capacity.

## 5. Case Study of Finite Element Software Teaching Application

In mechanical engineering, cylinders are core equipment for storing high-pressure gases, making their structural strength and safety design critical in engineering practice. Traditionally, cylinder stress analysis relied heavily on formula derivation and 2D diagrams, making it difficult for students to intuitively understand mechanical behavior under complex conditions. To overcome this teaching bottleneck, a university's mechanical engineering program introduced ANSYS finite element software for teaching reform. "Stress Analysis of Cylinders under Internal Pressure" was selected as a pilot module for junior students. Based on the Pressure Vessel Design course and integrated with ANSYS simulation tools, the course aimed to cultivate students' ability to translate theoretical knowledge into engineering analysis skills while exploring a new "Theory-Simulation-Practice" trinity teaching model.

### 5.1 Building Theoretical Foundation

In the initial phase, the teacher systematically established the theoretical framework for cylinder stress analysis through lectures. Content covered cylinder structure, working principles, and core theories:

(1) Stress-Strain Relationships: Explained material elastic deformation characteristics via derivation of Hooke's Law and Generalized Hooke's Law.

(2) Strength Theories: Focused on the applicability of the Third and Fourth Strength Theories in cylinder design.

(3) Thin-Walled Vessel Formulas: Derived membrane stress formulas for cylindrical and spherical thin-walled vessels, comparing theoretical calculations with actual conditions.

Additionally, the teacher used industry cases (e.g., mechanical analysis of hydrogen cylinder explosion accidents) to emphasize the importance of stress analysis for engineering safety, stimulating student interest.

### 5.2 Software Operation Demonstration

Following theory, the teacher demonstrated ANSYS operation step-by-step via multimedia:

(1) Geometric Modeling: Created axisymmetric 2D or 3D solid models in ANSYS Workbench[1-2], explaining simplification principles.

(2) Material Property Definition: Input elastic modulus, Poisson's ratio, and yield strength of common cylinder materials, guiding students to understand their impact on results.

(3) Meshing: Meshed using tetrahedral or hexahedral elements, demonstrating the effect of mesh density on accuracy, emphasizing the need for refinement at the cylinder-head junction.

(4) Load & Boundary Condition Application: Applied rated pressure to the inner wall, constrained all degrees of freedom at the bottom end, explaining the rationale for constraint settings.

Engineering examples (e.g., meshing strategies for different pressure-rated cylinders) were interwoven to help students grasp the core logic of FEA.

### 5.3 Student Practical Operation

Students performed tasks on lab PCs:

(1) Model Construction: Built geometry and meshed based on given cylinder dimensions.

(2) Parameter Setting: Defined material properties, loads, and boundary conditions independently [3]; some modified pressure values for comparative analysis.

(3) Calculation & Debugging: Submitted jobs; if convergence issues arose, checked model parameters and mesh quality under teacher guidance and made corrections.

The teacher monitored, addressing common issues collectively and encouraging peer discussion to foster collaboration.

### 5.4 Results Discussion and Deepening

Post-calculation, the teacher organized seminars guiding multi-dimensional result analysis:

(1) Stress Contours: Identified stress concentration zones at cylinder-head junctions, comparing theoretical membrane stress with simulation results.

(2) Deformation Analysis: Observed radial and axial deformations, discussing the effect of increased wall thickness.

(3) Optimization Design: Proposed solutions (e.g., local thickening, reinforcement rings) to reduce stress concentration; students validated feasibility using simulation data.

Students were guided to compare results with standards, reinforcing engineering design thinking.

## 6. Conclusion

The application of finite element software in cylinder-related courses effectively addresses the dilemmas of traditional teaching, significantly enhancing teaching quality and student learning outcomes. Through deep integration into theory teaching, innovative practical teaching models, and an innovation capability cultivation system, the software helps students intuitively understand complex knowledge, master cylinder mechanical properties and failure mechanisms, and improve practical innovation abilities. Although challenges exist (e.g., software learning curve, insufficient teaching resources, need for teacher up skilling), strategies like optimizing teaching methods, strengthening resource development, and enhancing teacher competence can effectively resolve them.

Looking ahead, as finite element software technology evolves and teaching reforms deepen, its application in cylinder-related courses will become more extensive and profound. Further exploration into innovative integration of software and teaching, developing more high-quality models and methods, is needed to advance the high-quality development of these courses. Simultaneously, staying abreast of the latest FEA technology trends and promptly updating course content will ensure students access cutting-edge industry knowledge, boosting their employability and career development potential, thereby cultivating more high-quality professionals for the industry.

## References


[1] Luan, C. Y. (2013).Application and technical review of ANSYS workbench in pressure vessel analysis[M]. China water & power press.

[2] Cheng, X. Y., Feng, X. W., Li Z. G. (2011).Analysis of pressure vessel nozzles based on ANSYS/workbench [J].Oil & chemical equipment,14(2): 5-8.

[3] Liu, Y. C., & Wang, J. H. (2018).Application of ANSY Workbench in stress analysis of pressure vessel nozzles [J].Journal of mechanical & electrical engineering technology,47(11): 135-138.