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Research on the teaching model of dynamic structural behavior simulation in structural engineering teaching by combining finite element method

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ABSTRACT

In order to improve the teaching effect of dynamic structural behavior simulation in structural engineering teaching, this study develops a dynamic structural behavior simulation teaching model combined with the finite element method to explore the effect of its application in teaching. This paper first introduces the process of applying the finite element method to simulation teaching and the steps of structural engineering system development. After that, it introduces the common structural engineering analysis functions under ANSYS software and its application in various aspects of structural engineering teaching. Then the construction process of the dynamic structural behavior simulation teaching model is briefly described, and the finite element principle is combined with the actual engineering problems through the integration of case teaching to realize the deep integration of theory and practice. Finally, the teaching model of dynamic structural behavior simulation is constructed and the teaching evaluation system after applying the model. The results of teaching practice show that more than 95% of the students maintain a positive attitude towards the use of the model in this paper. Under the teaching mode of the simulation model visualizing dynamic behavioral characteristics, the average grade of students in the experimental group was significantly higher than that of the control group by 14.96 points, and the difference between the grades of students in the two classes was significant (P=0.000). It can be seen that the use of the model can improve the students' understanding of dynamic structural mechanical behavior and the application of finite element analysis tools, which provides an efficient platform for combining theory and practice for structural engineering teaching.

Keywords: finite element method, ANSYS software, simulation teaching model, structural engineering

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1. Introduction

Virtual simulation technology, mathematical reasoning and scientific experiments are known as three ways to understand the laws of nature in modern teaching [1]. Virtual simulation teaching is a kind of practical teaching method similar to "project teaching", which is different from the traditional teaching methods, the most important feature of this method is to use virtual simulation technology to simulate the actual experimental scenarios, so that students can carry out independent learning and innovative experimental design in a dynamic situation [2-5]. This technology is characterized by low cost, high efficiency, repeatability, etc. Relying on computer technology, it highly restores the real experimental environment and experimental objects, provides a friendly and open platform for students to carry out independent experiments, and makes up for the shortcomings of practical teaching [6-9]. The virtual simulation teaching method enables students to have a deeper understanding of the relevant theoretical knowledge, stimulates the enthusiasm of students to learn the theoretical courses, and cultivates the ability of students to conduct scientific research and solve practical engineering problems [10-11]. At the same time, due to the difficulty of opening and resource sharing of physical laboratories, promoting virtual simulation experimental teaching is the future trend of innovative experimental teaching methods [12-13].

Structural engineering is a theoretical and logical course, the traditional text teaching makes students lack the ability to turn abstract into concrete, and it is difficult to understand the essence of structure exactly, how to solve this problem, there is an urgent need to induce a new method [14-17]. Since the simulation experiment of structural engineering has the characteristic of intuitive image, if the simulation experiment of structural engineering can be integrated with the teaching of structural engineering, this problem existing in the teaching of structural engineering may be solved effectively.

Some scholars design the innovative training program of structural engineering teaching around the virtual simulation experimental project, aiming to strengthen the innovation ability and comprehensive quality training of engineering professionals. Literature [18] after practical investigation shows that the construction of virtual simulation experimental teaching platform realizes the improvement of students' engineering quality by enhancing the effect of practical teaching, which meets the market demand for high-quality talents. Literature [19] proposed a combination of online and offline practical teaching mode based on Simdroid virtual simulation platform, with concrete structure as the teaching goal and students as the teaching center, which effectively improves the teaching effect while enhancing the fun of experimental teaching. Literature [20] explored the application of virtual reality technology in engineering teaching, and through the development of related teaching applications, engineering tasks, construction sequences, and structural shapes can be displayed in detail, providing strong interactivity for course teaching. Literature [21] constructed modular resources of course materials with visualization, interactivity, scalability and optimization characteristics, and combined them into a virtual simulation system for teaching, which provided a new path of modular teaching for engineering education. Literature [22] developed a new teaching mode based on engineering simulation practice teaching platform, with the help of virtual reality technology to fully meet the requirements of experimental practice teaching in the new situation, and effectively improve the level of training of applied talents in engineering specialties. Literature [23] shows that the traditional teaching mode is difficult for students to understand the complex spatial layout of structural engineering, while virtual reality tools can visualize the spatial structure, help students understand the complex deformation patterns of structural components, and improve the quality of teaching. Literature [24] points out that the combination of project-based teaching methods and virtual reality technology can promote effective communication and the realization of the expected goals of the students, and thus improve the learning effect and problem solving ability of students in the context of engineering education. Literature [25] describes the advantages of virtual simulation teaching system in engineering and technology education, which can reproduce the real scene in the virtual information system, and greatly improve the learners' motivation through vivid virtual teaching resources and simulation teaching methods, which is of positive significance for promoting the learning effect of engineering and technology students.

This paper first introduces the process of how to successfully apply the finite element method model to structural engineering teaching, and then analyzes the analysis function of ANSYS software in structural engineering teaching and its application in engineering teaching. On this basis, a dynamic structural behavior simulation teaching model was constructed. By combining the finite element principle with actual engineering problems through the case teaching method, a fusion case teaching model based on the finite element method is proposed, including the principle fusion and exercise fusion, to help students better understand the application of the finite element method in dynamic structural engineering analysis. A simulation teaching model of dynamic structural behavior and a simulation teaching effect evaluation system matching this model are further constructed. Finally, the teaching effect of dynamic structural behavior simulation of this model in structural engineering teaching is evaluated.

2. Construction of Simulation Teaching Model for Dynamic Structural Behavior in Structural Engineering Teaching

2.1. Development of a Simulation Teaching Model for Dynamic Structural Behavior

To successfully apply the finite element method simulation teaching model to structural engineering teaching, the following steps need to be followed:

1) Led by the departmental leaders, convene all the teachers to carry out the professional teaching seminar, and they will determine the simulation model needed for structural engineering teaching and the specific requirements for the simulation model after discussion.

2) Establish a simulation model development project team, which is responsible for the establishment of the simulation model library. The project team should formulate a detailed development plan and development program for the simulation model library, and the development program should determine the modeling simulation software required for each model.

3) Establish the simulation model library. The project team can use self-development and outsourcing methods to complete the establishment of the model library, model development can also rely on the simulation software in the existing model library or request software vendors to provide more case models.

4) After the simulation model library is built, prepare a tutorial on the application of the model library. Well-prepared tutorials are conducive to teachers to better organize teaching activities, improve the quality of teaching, and receive the expected teaching results.

5) Simulation model in the teaching of various professional courses in the specific application of the main teachers to demonstrate, explain the way, in the case of intellectual property rights can also be handed over to the students to practice on their own, but also as a learning task requires students to imitate the design.

6) Improvement of teaching model library. With the updating of teaching content, the model library needs to be updated accordingly. The development of each specific model is an important task and must be guided by certain methodology.

On the basis of the steps of structural engineering system simulation, this paper proposes that the development of simulation models should follow such steps:

1) Set up goals and conduct research to have a comprehensive and in-depth understanding of the system under study, describe the problem as clearly as possible, and clarify the goals of simulation and the scope of the system involved.

2) According to the simulation goal, logically sort out the system, identify some mathematical problems involved in the model, establish a mathematical model, and design appropriate

mathematical algorithms, heuristic algorithms or artificial intelligence algorithms according to the characteristics of the mathematical problems.

3) Establish the system simulation model. The characteristics of the simulation system are analyzed, and appropriate modeling methods are selected to build the model, such as entity flow diagram modeling method, activity cycle diagram modeling method, Petri net modeling method, system dynamics modeling method, MAS modeling method, etc. Then the model is realized in the simulation software, in which it may be necessary to compile certain procedures.

4) Model running and result checking. Check whether the results are reasonable, analyze and process the simulation results, and correct them if problems are found.

5) Using the statistical analysis function that comes with the software, the simulation results are statistically analyzed and output through statistical charts.

2.2. Application of ANSYS software in teaching structural engineering

2.2.1. ANSYS Analysis Functions in Structural Engineering. ANSYS structural [26] analysis is powerful, unit library and material library is very rich, almost can simulate any form of structural engineering. It can reflect the deformation, stress distribution, internal force, self-oscillation frequency, vibration mode, load coupling, time-course response and other characteristics of the structure more accurately. The commonly used functions for structural engineering analysis are as follows: Structural Static Analysis: Used to analyze the structural stresses of a structure.

Structural static analysis: It is used to solve the internal force and deformation caused by multiple loads. Static analysis is very suitable for solving problems where the effects of inertia and damping on the structure are not significant.The static analysis in ANSYS program can not only perform linear analysis, but also non-linear analysis, such as plasticity, creep, expansion, large deformation, large strain and contact analysis.

Structural dynamics analysis [27]: Structural dynamics analysis is used to solve the effect of time varying loads on a structure or component. Unlike static analysis, dynamic analysis takes into account time-varying force loading and its effect on damping and inertia.Types of structural dynamics analyses that can be performed in ANSYS include transient dynamics analysis, modal analysis, harmonic response analysis, and random vibration response analysis.

Structural Nonlinear Analysis: Structural nonlinearities cause the response of a structure or component to vary disproportionately with external loads.ANSYS programs can solve static and transient nonlinear problems, including material nonlinearities, geometric nonlinearities, and unit nonlinearities.

2.2.2. Application of ANSYS in teaching structural engineering. Structural engineering courses are characterized by extensive knowledge, formula symbols, empirical and practical.The powerful analysis functions of ANSYS software can all be applied to the teaching activities of structural engineering. The common structural forms in the teaching of structural engineering are steel structure, concrete structure, masonry structure and wood structure, etc. The common basic structural components are plate, beam, column, wall, rod, arch, cable and foundation, etc. In the teaching of structural engineering, ANSYS can be used in the teaching of structural engineering. In the teaching of structural engineering, the mechanical properties of structural engineering under load can be analyzed through static analysis function or nonlinear analysis function, etc., and the stress and strain distribution of basic components and deformation can be displayed in the form of colorful cloud diagrams. In addition, it can list the counterforce, countermoment, nodal force and moment, and so on.

In the teaching of structural engineering system, ANSYS software can be used to model and analyze and calculate the whole structural system, which can be used for both static load analysis and structural dynamics analysis, such as transient dynamics analysis, modal analysis, harmonic response analysis and so on. Similar to the analysis of basic components, the analysis of the structural system can also be shown in the form of color cloud diagrams of the structure of the stress, strain distribution, deformation and so on.

ANSYS software can also calculate the intrinsic frequency and vibration mode of the structure, which enables students to visualize the definition of structural vibration mode by observing the vibration state of the structure at the intrinsic frequency. In addition, in the structural engineering seismic related courses, ANSYS can calculate the structural response of the structure under different kinds of dynamic loads through harmonic analysis and transient dynamic analysis, so that the students can intuitively understand the location of the weak or soft layer of the structure, grasp the significance of the structural flat elevation regular arrangement on the seismic effect, and understand the significance of the seismic effect amplification through the whip-tip effect of the protruding parts of the top of the building by observation. The students will be able to visualize the location of the weak or soft layers of the structure and grasp the significance of the regular arrangement of structural elevation on the seismic effect.

2.3. Dynamic structural behavior simulation teaching model construction

1) Teaching needs analysis. Determine the teaching objectives: such as understanding the concepts of resonance, vibration attenuation, modal analysis and so on.

2) Simulation tool selection and development environment construction. Software platform selection: this paper chooses ANSYS finite element analysis software, the software function is more comprehensive, can be used for the simulation of complex structures.

Open source tools: this paper selected CalculiX tool, this tool is not only low cost and suitable for teaching secondary development.

Development environment configuration: the use of integrated modeling, solving and post-processing tool chain, and build a parametric input interface.

3) Parametric construction and dynamic simulation parameter design. Parametric modeling module:

(1) Geometry parameterization: define the structure size and mesh density, etc. through scripts.

(2) Material and load parameterization: support dynamic inputs of damping ratio and load type mentioned in this paper.

Dynamic simulation framework:

(1) Pre-processing: Generate a finite element model containing matrix mass and damping matrix, etc.

(2) Solver Configuration: Set the time step, integration method, and criterion for convergence.

(3) Post-processing: extract the displacement and stress time course curves, and generate the modal vibration animation and spectrogram.

4) Instructional Case Development and Validation. Case design principles:

(1) Gradual transition from single-degree-of-freedom systems to multi-degree-of-freedom complex structures.

(2) Include typical “free vibration, forced vibration, resonance, impact response” and other dynamic behavior coverage.

Example case: Simulation of impact response of cantilever beams.

Verification: Compare the simulation with theoretical or experimental data to verify the accuracy of the model.

5) Integration of Interactive Teaching Functions:

(1) Visualization and Interaction Design

Real-time animation: demonstrate the structural vibration process, such as displacement cloud, deformation animation, etc.

Parameter sensitivity analysis: students adjust the damping ratio through the slider and observe the change of vibration decay rate.

Modify the load frequency to verify the resonance conditions.

Data comparison tool: superimpose simulation curves and theoretical solutions, and mark key differences, such as phase delay and amplitude error.

(2) Teaching aid function:

When the mesh division is unreasonable or the time step is too large leading to dispersion, it automatically prompts modification suggestions.

Embedded simulation process description to reduce the threshold of software operation.

6) Model Verification and Teaching Evaluation. Model verification method:

(1) Verify the stability of the results by network refinement.

(2) Verify the balance between kinetic energy, potential energy and dissipated energy.

Teaching Effect Evaluation:

(1) Compare the students' test scores before and after using the model, such as the improvement of the score rate of dynamic problems.

(2) Collect students' evaluation of the simulation model's intuitiveness and ease of use, such as students' views on animation-assisted understanding.

3. Integration of case studies

3.1. Integration of fundamentals

Tension and compression of engineering structures is one of the classical contents of structural engineering courses, and bars subjected to tension or compression are often encountered in engineering practice, such as bridge steel cables, internal combustion engine connecting rods, etc. Now, we take a rectangular cross-section beam in tension as an example, and teach the method of integration of finite element and basic theoretical knowledge. For tensile bars, the basic stress and strain relationship equation is:

$$\sigma = F / A \tag{1}$$

$$\sigma = E\varepsilon \tag{2}$$

In order to explain the image of stress, strain knowledge points, can be established before the class finite element model, its basic parameters for the beam rectangular cross-section 25mm × 15mm, length 3000mm, one end of the fixed constraints to limit displacement and rotation, one end of the application of 5000N tensile force.

Instructing students to analyze can be found, the cloud appears uneven distribution of stress phenomenon, you can try to book knowledge of St. Venant's principle to explain the explanation, and further analyze the size of the uniform distribution of stress region, found that the value of the numerical and strain relations to solve the value of consistency, can be verified the accuracy of the numerical analysis of the finite element, but also to guide the students in the analysis of the solution. In order to expand the knowledge point stress concentration, the 3D model can be modified to a finite element model [28-29], set the same constraints and loads, and calculate to obtain the cloud diagram. The cloud diagram shows that the stress concentration phenomenon occurs in the region of cross-section change, and students can be instructed to analyze the reason for this situation, and teach students to carry out the selection of beams, the change in the cross-section of the bar will lead to stress concentration and reduce the safety of mechanical components.

3.2. Integration of practice problems

Teachers in the classroom teaching exercises, due to the mechanics of materials mathematical formulas, calculations and other characteristics are likely to cause the calculation of the derivation process is time-consuming, students are difficult to understand because of the abstraction, and exercises can be expanded poor phenomena. Now take the textbook example as an example, teaching the integration of finite element and textbook practice problems. Textbook examples are shown in Figure 1.

Example of cast iron beam cross-section for T-shaped, cross-section size and load as shown in the figure below, the permissible tensile stress of cast iron is 40MPa, the permissible compressive stress is 200MPa. Try to calibrate the strength of the beam.

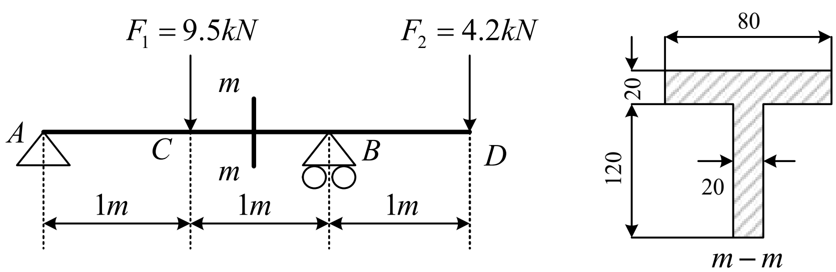

Fig. 1. Textbook examples

Positive stress calibration of beam bending is one of the important knowledge points of the mechanics of materials, and engineering practice is closely linked to the bending of the member, calibration of the positive stress is calculated as:

$$\sigma = \frac{My}{I_z} \tag{3}$$

A three-dimensional model with an I-beam as the object of study is built according to the example problem. Inputting the cross-section parameters, important parameters such as cross-section S, Iz and so on can be easily obtained, simplifying the time-consuming and labor-intensive calculations that students have to do in the classroom. The calculation results and cloud diagrams are obtained by analyzing and solving the cross-section shape and 3D finite element model. The finite element calculation analysis shows that the most dangerous section, section B, reaches the maximum tensile and compressive stresses, and the deformation trend is obtained very intuitively, which is easy for students to understand.

Through the basic theoretical knowledge of the same analysis can be obtained at the B cross-section of the most dangerous cross-section, the use of formulas to check the safety of its tensile and compressive stresses, respectively, the results obtained from the calculation and the finite element model analysis is completely consistent with the finite element model analysis, which verifies the correctness of the finite element analysis. That is:

$$\sigma_t = \frac{M_R y_1}{I_z} = \frac{4.2\times10^3 N.m\times52\times10^{-3} m}{7.63\times10^{-6} m^4} = 28.6MPa \tag{4}$$

$$\sigma_{ò} = \frac{M_B y_2}{I_z} = \frac{4.2\times10^3 Nm\times88\times10^{-3} m}{7.63\times10^{-6} m^4} = 48.4MPa \tag{5}$$

In order to further strengthen the students' understanding of knowledge, different loads can be applied to the I-beam to extend the training, so that the students will do the practice problems, want to do the practice problems, and enjoy doing the practice problems, in order to solve the actual problems of engineering to lay a foundation.

4. Evaluation system of simulation teaching effect based on finite element method

4.1. Course Input Evaluation Metrics for Virtual Simulation Instruction

In the process of constructing the virtual simulation experimental teaching model, the teaching system needs to be constructed based on the specific conditions of the course. The evaluation index system of virtual simulation teaching of structural engineering constructed in this study is shown in Table 1. After screening, this paper finally determines "simulation teaching support, practical teaching content and simulation system" three primary indicators and "simulation technology support, scene simulation simulation, etc." 14 secondary evaluation indicators. Calculating the weights of the indicators, it is found that the weight of "practical teaching content and simulation analysis" in the first-level indicators is greater than 0.43, and in the second-level indicators, the weight of "practical content knowledge framework and scene simulation" is greater than 0.1, and the weights of the rest of the second-level indicators are less than 0.1. Therefore, in this paper, we should pay more attention to the changes of these two indicators in the course input evaluation index system of virtual simulation teaching.

Table 1. The evaluation index of virtual simulation teaching of structural engineering

Primary indicator	Composite weight	Secondary indicator	Composite weight
A: Teaching support	0.128	A1 Virtual simulation facility preparation	0.0317
		A2 Organizational security	0.0348
		A3 Simulation technical support	0.0615
B: Practice teaching content	0.4365	B1 The rationality of the selection of structural engineering simulation cases	0.0918
		B2 Practice content knowledge framework integrity	0.1015
		B3 The compatibility of practical content and theoretical knowledge	0.0814
		B4 The focus of the practice is highlighted	0.0668
		B5 The consistency of the practice content and the teaching goals	0.095
C: Simulation analysis	0.4355	C1 Scenario simulation	0.116
		C2 System ease of use	0.0631
		C3 System reliability	0.0702
		C4 Operational repeatability	0.0958
		C5 Use convenience	0.0581
		C6 Scoring function	0.0323

4.2. Teaching Process Evaluation Indicators for Analog Simulation Teaching

The teaching effect evaluation indexes of virtual simulation teaching are shown in Table 2. In this paper, four first-level indicators of "teaching plan, simulation teaching resources utilization, classroom effect and teacher competence evaluation" and 11 second-level indicators of "simulation teaching program and student participation" are selected. In the evaluation index of teaching process, the weights of the four first-level indexes are relatively uniform, and their values range from 0.211 to 0.2839. Among the secondary indicators, the participation rate of the simulation system experiment has the highest weight (0.1567), followed by student participation (0.1267), followed by teaching language organization and expression ability (0.1102) and operation demonstration and guidance (0.1008); the weight of the rest of the secondary indicators is lower than 0.1. Comprehensively, in the process of the actual teaching and learning simulation, the various links are relatively more important. At this time, teachers should focus on the teaching process, the simulation model assisted by the students' learning effect on structural engineering knowledge.

Table 2. Evaluation index of teaching effect of virtual simulation teaching

Primary indicator	Composite weight	Secondary indicator	Composite weight
A: Teaching plan	0.2546	A1 The method of evaluation of simulation teaching is reasonable	0.0425
		A2 Connect with the theoretical course	0.044
		A3 Simulation teaching program	0.0872
		A4 Simulation teaching content execution situation	0.0809
B: Simulation teaching resource utilization	0.2505	B1 The participation rate of the simulation system experiment	0.1567
		B2 Important knowledge point online examination	0.0938
C: Classroom effect	0.2839	C1 Student participation	0.1267
		C2 Teaching coherence	0.0689
		C3 Teacher input	0.0883
D: Teacher evaluation	0.211	D1 Teaching language organization and expression ability	0.1102
		D2 Operational presentation and guidance	0.1008

4.3. Teaching Effect Evaluation Indexes of Virtual Simulation Teaching

The teaching effect evaluation indexes of virtual simulation teaching are shown in Table 3. In this paper, six primary indicators of “teaching objectives, teaching results, teaching satisfaction, student ability, student competence and course development” and 16 secondary indicators of “realization of teaching objectives and teaching innovation ability” are selected. The first-level indicators of teaching effectiveness evaluation show that the importance of student ability and teacher ability is higher, with weights of 0.2251 and 0.2755 respectively; followed by teaching achievement and teaching satisfaction, with weights higher than 0.1; and the teaching objectives and curriculum development are lower than the other indicators, with weights below 0.1. Among the secondary indicators, content satisfaction has the highest weight value (0.1123), and the rest of the indicators have weights below 0.1. Taken together, the weights of the teaching evaluation indicators are relatively more evaluative, and the results of the evaluation are more generalizable.

Table 3. Evaluation index of teaching effect of virtual simulation teaching

Primary indicator	Composite weight	Secondary indicator	Composite weight
A:Teaching target	0.0941	A1 Achievement of teaching goals	0.0503
		A2 Content completion	0.0438
B:Teaching results	0.1202	B1 Structural engineering learning	0.0732
		B2 Practice teaching results report	0.047
C:Teaching satisfaction	0.1953	C1 Content satisfaction	0.1123
		C2 Employer satisfaction	0.083
D:Student capacity	0.2251	D1 Understanding of structural engineering concepts	0.0965
		D2 Academic achievements in structural engineering courses	0.0613
		D3 Students' understanding of structural engineering	0.0673
E:Teacher capacity	0.2755	E1 Practical teaching ability	0.0537
		E2 Teaching innovation ability	0.0724
		E3 Teaching reflection ability	0.0814
		E4 Teaching management ability	0.068
F:Curriculum development	0.0898	F1 Course sustainability	0.0476
		F2 The sharing of the course	0.0422

5. Application effect of structural engineering simulation teaching modeling

1) Application process of teaching model. After the construction of the dynamic structural behavior simulation teaching model based on the finite element method is completed, a comparative method is used in the teaching application stage, and 40 students in one class (Class 1) and 40 people in another class (Class 2) are selected for the control test. Among them (class 2) students were taught in the traditional way using physical objects combined with PPT presentations. (The students of (class 1) are taught by using the dynamic structural behavior simulation teaching model system based on the finite element method constructed in this study.

The actual teaching process is as follows:

Using the dynamic structural behavior simulation teaching model for demonstration teaching, first using the method of lecture demonstration, the teacher uses the virtual model to explain the function, structure, principle, and related knowledge of each component, so that the students can grasp the necessary theoretical knowledge points, the key points of which were analyzed and explained. The students showed a stronger desire to learn about the dynamic structural behavior simulation teaching model, and while operating the model, they were able to memorize and understand the relevant knowledge of structural engineering.

The evaluation encompassed theoretical knowledge questions, including theoretical questions (15 questions of 30 % marks), self-assessment (10 % marks), and mutual assessment (10 % marks), and was done by using a questionnaire.

2) Results and Analysis. The questionnaire students use the virtual simulation teaching model, the students reflect good.

In this paper, the use of dynamic behavioral simulation teaching model in structural engineering teaching, whether the three-dimensional model in the system can arouse your interest in learning, whether the three-dimensional model display is clear and understandable, whether the operation of the virtual simulation model is interesting, whether you will be able to skillfully operate the virtual simulation system for learning, and whether students will still use the system for learning after class. The results show that more than 95% of the students are very positive about the use of the model in this paper, and only less than 5% have a negative attitude towards the use of the learning model in this paper.

Finally the results were analyzed by t-testing the results of independent samples of class 1, which was taught using the virtual simulation teaching model, and class 2, which was taught using traditional PPT. First look at the basic descriptive statistics. The results of the Student Learning Achievement Survey are shown in Figure 2. From the graph we can see that the means of class 1 and class 2 are 78.42 and 63.46 respectively and the standard deviations are 5.44 and 6.47 respectively. From this information, it can be seen that the mean value of class 1 is 14.96 higher than that of class 2, which indicates that class 1 has a better effect of using virtual simulation in teaching, and the test scores are improved significantly. It can be seen that the use of the model in this paper has effectively improved the students' understanding of the dynamic structural mechanical behavior and the application of finite element analysis tools in teaching structural engineering.

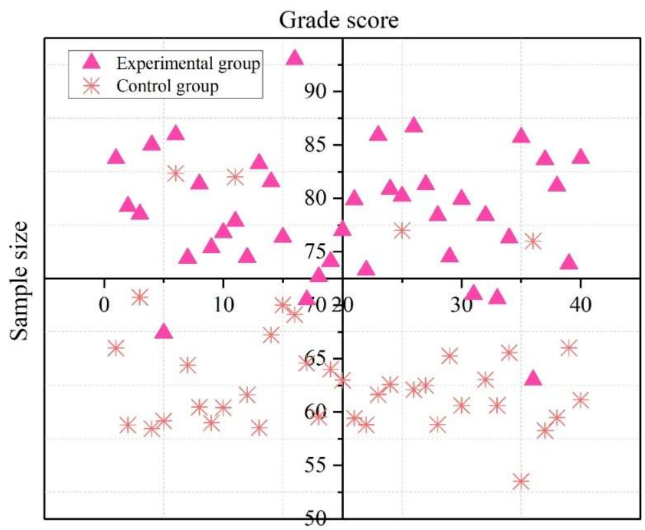

Fig. 2. Student achievement survey results

The results of the independent samples t-test to test the effectiveness of teaching are shown in Table 4. Then look at the results of the T-test for the 2 classes. The first step is to first analyze to see if the two variances are equal, mainly to see that the F value of 2.357 corresponds to a Sig value of 0.1563 which is much greater than 0.05, and it can be assumed that there is no significant difference in the overall variance between class 1 and class 2. The second step looks at the assumption of equal variance in the column of the T value of 6.4782 corresponding to the Sig of 0.000 is less than 0.005, contrary to the original hypothesis, indicating that there is a significant difference between the performance of class 1 and class 2 using the virtual simulation teaching model. Synthesizing the whole teaching process, the main thing is that the use of the virtual teaching model of structural engineering can stimulate students' interest in learning and improve their motivation to learn. Some students have some poor learning, not poor intelligence, but more likely lack sufficient interest in learning. So it creates a good learning atmosphere, thus promoting students to study tirelessly and get good grades. The experimental results prove that the application of the simulation model in structural engineering teaching can significantly improve students' understanding of complex dynamic structures, which provides a strong support for structural engineering teaching.

Table 4. Test results of the independent sample T of the test teaching effect

	Levene test of the variance equation	T test of the mean equation

		F	Sig.	t	df	Sig. (double)	Mean difference	Mean value	95% confidence interval of the difference	
									Upper limit	Lower limit
Appraisal performance	Let's say the variance is equal	2.357	0.1563	6.4782	72.687	0.000	8.472	4.315	6.7402	29.387
	Let's say that the variance is not equal			6.6541	70.452	0.000	7.0942	3.084	6.5014	34.7356

6. Conclusion

Aiming at the teaching demand of dynamic structural behavior simulation in structural engineering teaching, this paper develops a dynamic structural behavior simulation teaching model based on the finite element method, and constructs a teaching evaluation system supporting the model to explore the application effect of the model in structural engineering teaching. The results show that it is more necessary to pay attention to the process of teaching in structural engineering teaching, especially the teacher's language organization and expression ability (0.1102) as well as the process of operation demonstration and instruction (0.1008) when utilizing the simulation teaching model. Students' satisfaction with the application effect of the simulation teaching model proposed in this paper is as high as 95%, and the use of the teaching model in this paper can significantly improve students' academic performance, making the difference between the experimental class and the control class significant (P=0.000 less than 0.05). It can be seen that the method of this paper can significantly students' understanding of dynamic structural behavior and analytical ability, which provides a new teaching method and tool for teaching structural engineering.

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