

Teaching Reform of Advanced Steel Structure Course Based on Accident Cases -Taking the Joint Design as an Example

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Abstract

The construction measures of steel structure joints have an important impact on the overall steel structure, the safety of the joint itself and the seismic performance of the structure. In the teaching of the node chapter of Advanced Steel Structure Course for undergraduates majoring in civil engineering, the focus is on teaching the calculation and design method of nodes, and only introductory explanations are given for the construction measures of nodes, and the students' learning effect is not satisfactory. This paper analyzed the current situation of teaching in the chapter of steel structure joints. Based on three engineering accident cases caused by improper joint construction measures, a case teaching idea was proposed. On this basis, the critical issues of teaching in this chapter and the application of cases were investigated. This paper aims to provide some reference opinions for the teaching reform of engineering-related courses, and to provide reference for the construction of practical teaching based on improving students' learning interest and autonomous learning ability.

Keywords: case teaching, advanced steel structure, engineering accident, teaching reform, teaching design

1. Introduction

Steel structure has the advantages of high industrialization, low emission, short construction period and environmental friendliness. With the proposal of the dual carbon goal and the improvement of social requirements for environmental protection, steel structure buildings that can be prefabricated in factories and assembled on site are gradually popularized.

To realize on-site assembly, steel structures usually use joints to connect beam-column and other components. According to different force forms and site conditions, different connection methods, e.g., bolted joints, welded joints and cast joints, can be used (Shen, Z., Chen, Y., Chen, Y., & Zhao, X., 2018). According to the different stiffness of the joints, it can be divided into hinged joints, rigid joints, semi-rigid joints and other types. In the existing steel structure design methods, the joints are usually regarded as rigid joints without volume or freely rotatable hinged joints, and then the overall structure design is carried out. In addition to the structural safety requirements, the joint design should meet the seismic performance requirements of the engineering structure. The Technical Regulations for Steel Structures of High-rise Civil Buildings (JGJ 99-2015) requires that under the action of strong earthquakes, the steel structure node domains must be able to form effective plastic hinges, dissipate the vibration energy, and improve the seismic performance of the structure (JGJ99—2015). The stiffness, deformation and energy dissipation capacity of the joints need to be achieved through construction measures such as stiffeners and connecting lugs.

To sum up, the construction measures of steel structure joints have an important impact on structural safety and disaster resistance. The importance of the joint design chapter in the teaching process of Advanced Steel Structure by civil engineering teachers has become increasingly prominent. Therefore, based on the OBE orientation (Hu, J., 2021), it is necessary to propose a teaching method that is more efficient and easier to enhance students' interest in autonomous learning.

2. Existing Teaching Status and Reform Ideas

2.1 Current Situation of Teaching of Steel Structure Joint Chapter

The existing course on Advanced Steel Structure for undergraduates majoring in civil engineering focuses on the design and calculation methods for the strength of welded and bolted joints. The teaching process is usually

based on cramming teaching by teachers and passive learning by students. Undergraduates majoring in civil engineering can master the mechanical performance analysis of rod system structures after studying the pre-courses, e.g., Material Mechanics and Structural Mechanics. In these courses, the nodes are usually simplified to rigid or hinged points, and they serve the overall design calculation of the structure. However, for studying the joint design chapter, the students need to break away from the concept of rod structure and carry out mechanical analysis and design calculations of space systems. Therefore, students' interest in learning is usually low, which generally reflects that the concept of this chapter is difficult to grasp and the learning effect is not satisfactory.

In addition, the existing undergraduate teaching only focuses on the design of the steel structure joint itself, and does not introduce the influence of the mechanical properties of the joint on the overall safety and disaster resistance of the structure. However, in the students' cognition, the node is only a point, and it is difficult to understand the influence of the mechanical properties of the joint on the overall performance of the steel structure through extended learning after class. Since the construction measures of steel structure joints are only configured according to the requirements of the specification, there is no need to design them according to calculation. Students are less familiar with the mechanical mechanisms such as the mechanical properties of the joint domain and the force transmission path. In the existing teaching methods, it is difficult for students to grasp the influence of structural measures such as stiffeners and connecting lugs on the mechanical properties of the joints.

2.2 Teaching Reform Ideas for Joint Chapters

The steel structure usually guarantees the consistency of the structure and the calculation model through reasonable joint construction measures. The construction measures of the steel joints are the basis for the simplification of the overall calculation model of the structure, which is related to the safety of the entire engineering structure during construction and service, as well as the safety of people's lives and properties. In the existing steel structure design methods, the stiffness of the joints can be effectively adjusted and the stress state of the joints can be optimized through various forms, e.g., stiffeners, connecting lugs and bolt arrangements. When the stiffness of the column foot joint changes, from the fixed column foot to the hinged column foot, the steel structure may be transformed from a bent frame system with reasonable mechanical performance to a structure with hinged top and bottom, resulting in engineering safety accidents. Under the combined action of multiple factors such as plate, bolt, weld stress and holes, the joint is in a complex stress state, which is brittle and prone to damage. Besides, because of the complex structure of the nodes, it is difficult for ordinary analysis or calculation to consider the stress state inside the nodes. When the stiffeners in the nodes are not properly set, the structure may be damaged due to the interaction between the plates. Under the action of earthquake, the seismic displacement of the structure causes the reciprocating deformation of the joints. When the ductility or deformation capacity of the joints is insufficient, the steel structure is prone to earthquake damage at the joints. The joints entering the plastic state can cause the dynamic characteristics of the overall structure to change and reduce the structure. seismic performance.

Based on the analyses of the existing teaching situation, this paper aims to guide students to fully understand the importance of joint measures. Before the formal teaching of the joint chapter, three cases of engineering structure accidents caused by improper design of joint construction measures are introduced. On this basis, the influence of the joint construction measures on the structural safety is expounded, and solutions are proposed (Figure 1). The cases aim to guide students to think: (1) How do joint construction measures affect the form of the structural computational mechanics model? (2) What safety hazards will be caused by improper design of joint construction measures? (3) When designing steel structures, what joint construction measures can be taken to improve structural safety? Through the teaching of this case course and subsequent joint chapters, students' interest in learning about structural measures of steel structure joints is stimulated, and students are guided to explore the influence mechanism of structural measures of joints on structural mechanical properties.

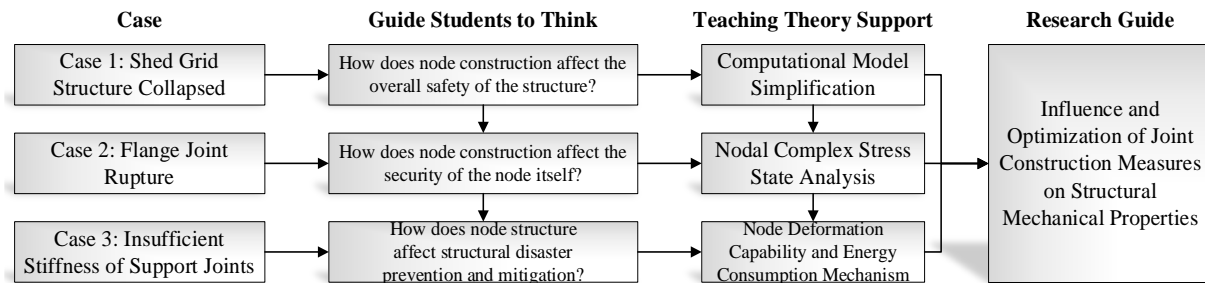


Figure 1. The Overall Idea of Case Teaching in the Node Chapter of Advanced Steel Structure

Besides, teaching is carried out based on engineering accident cases, and the serious damage to people's lives and properties caused by unqualified projects is described to stimulate students' professional sense of responsibility. Based on analyzing the causes of engineering accidents, the cases guide students initially establish a sense of professional ethics and engineering responsibility, and make them fully learn the details of accident cases and the analyze painful lessons to understand the importance of following professional norms, and feel the importance of the responsibility of civil engineers.

3. Case Introduction and General Knowledge

3.1 Case Introduction

In September 2021, a project collapsed during the construction of a steel frame, causing many casualties and bad social impact (He, C., & Ding, F., 2021). In the 2008 Wenchuan earthquake, the metal flange of a high-voltage transformer bushing ruptured, causing oil leakage in the transformer and power outages in the regional power grid, which brought inconvenience to earthquake relief and post-disaster reconstruction (He, C., Xie, Q., & Zhou, Y., 2019). In 2019, a 1100kV UHV gas insulated switchgear (GIS) bushing failed to pass the seismic performance test due to the improper joint design on the steel supporting frame, which causes great economic losses for the manufacturer (He, C., Xie, Q., Yang, Z., & Xue, S., 2019).

By comparing the design drawings, on-site photos, and design calculation models of the steel frame, when the design model of the steel frame is simplified, the column bottom joint should be considered as a rigid connection. However, the joint construction measures taken by the designer only meet the requirements of the hinged joint. The improper design of the structural measures of these joints increase the internal force of the structural members and reduces the stability of the members, which is one of the main reasons for the collapse of the steel frame (He, C., & Ding, F., 2021). Through the mechanical calculations and analyses of the damaged transformer flange joints in the Wenchuan earthquake, it was found that the design defects of the stiffeners of the joints caused the flange bottom plate to be subjected to huge punching action under the earthquake, and then cracked and caused structural failure (He, C., Xie, Q., & Zhou, Y., 2019). After the shaking table test, the seismic response of the UHV GIS bushing was analyzed, and it was found that the improper setting of the ear plate of the beam-column joint of the steel support changed the dynamic characteristics of the support and reduced the overall seismic performance of the structure (He, C., Xie, Q., Yang, Z., & Xue, S., 2019).

3.2 General Knowledge

3.2.1 Influence of Joint Construction Measures on the Overall Safety of the Structure

When designing a steel structure, it is necessary to simplify the structure to a mechanical mode, such as member structure, plate, and shell structure, etc. Besides, in the simplified models, the joints are usually simplified to points with different mechanical characteristics (e.g., rigid connection, semi-rigid connection, hinged connection, etc.). However, the mechanical characteristics of the joints need to be guaranteed by reasonable construction measures.

When the mechanical characteristics of the joints in the calculation model are inconsistent with the characteristics of the actual engineering joints, the assumptions of the calculation model may be invalidated, resulting in inaccurate structural calculation results, and even endangering the overall safety of the structure. Steel structure joint construction measures have an important impact on the overall safety of the structure. Therefore, ensuring the consistency of joint mechanical characteristics and calculation models through reasonable joint construction measures is one of the key issues in steel structure design.

3.2.2 Influence of Construction Measures on the Safety of the Joint Itself

In the design of steel structures, the beams, columns, and other components can usually be assumed to be two-dimensional members. The force model is clear, and the theoretical research is relatively deep. The existing calculation and analysis methods can accurately predict the safety of beam and column components. However, steel structure nodes are often connected with multiple members, and the welds and bolt holes openings on the joints are dense, which is in a complex stress state. Existing simplified theoretical methods cannot accurately predict parameters such as the joint strength. In the structural design, the design concepts of strong joints and weak members are usually adopted, and the safety requirements for joints are relatively high. Because the joint construction measures do not need to be designed by calculation and other methods, it is generally impossible to obtain the mechanical response of the joint accurately in the design process. When the structural measures of the joints are not designed properly, structural measures such as stiffening rib plates may cause damage to the strength of the joint itself, further affecting the structural safety.

3.2.3 Influence of Construction Measures of Joints on Structural Disaster Resistance

Under the action of dynamic disasters such as earthquakes and typhoons, the joints are often subjected to reciprocating loads and degeneration. When the construction measures of the joints are unreasonably designed, failure modes such as insufficient deformation capacity of the joints are prone to occur, which reduces the safety of the structure under disasters. When the joint construction measures are reasonable, the hysteresis and energy dissipation capacity of the node can be greatly improved, which is beneficial to improve the disaster resistance level of the structure. On the other hand, when the design of the construction measures of the joints is unreasonable, the changes of the dynamic characteristics of the joints under small earthquakes may cause the changes of the overall dynamic characteristics of the structure and reduce the overall indicators such as the seismic and wind resistance performance of the structure.

3.3 Case Teaching Structure

From the clues of the cases, the case course mainly expounds the influence of the joint construction measures on the mechanical properties and safety of the steel structure, and focuses on the influence of the simplified model of the column foot joint on the overall safety of the steel frame, the influence of the arrangement of the flange joint stiffeners on the safety of the joint under complex stress state, and the influence of the beam-column joint on the seismic performance of the structure. From the perspective of theoretical connotation, the case course takes three accidents caused by improper setting of joint construction measures as the overall framework, and focuses on the research on the impact of joint construction measures on the safety of engineering structures. The importance of joint construction measures is discussed. Therefore, taking the analysis of engineering accident joint construction measures as an example, the case teaching content of joint construction measures is constructed.

Teachers can flexibly apply the teaching reform content of this case according to the teaching objectives (purpose) or the specific arrangement of the course. According to the main line of case course proposed in this paper, the corresponding case teaching structure is extracted for teachers' reference in the process of case teaching.

4. Critical Teaching Issues and Case Application

4.1 Influence of Joint Construction Measures on the Overall Structure

In the process of learning, students usually pay attention to the overall calculation of the structure and ignore the impact of local construction measures on the overall mechanical properties and engineering safety of the structure. In the mechanical model of steel structure, the wrong assumption of the joint form may cause serious accidents such as the overall collapse of the structure. In this paper, the case teaching of the collapse accident of the steel frame in the literature is used to guide students to learn the knowledge of the influence of the joint construction measures on the overall structure (He, C., & Ding, F., 2021). The students should analyze the collapse accident of the steel frame, compare the design model and drawings, and determine whether the column foot joints should be set as rigid joints or hinged joints. Using the rigid connection and hinged assumptions of the column bases, the overall mechanical model of the grid frame is established, and the internal force of the members of the frame under different boundary conditions of the column base should be analyzed, and the influence of different boundary conditions on the overall mechanical properties of the grid frame will be judged. The stiffness of the column foot with different joint construction measures is compared and analyzed, and the joints are classified according to rigid joints, semi-rigid joints, and hinged joints. The case can guide students to analyze and summarize the influence path and influence mode of the joint construction measures on the overall

calculation diagram of the structure, and learn the method of judging the overall safety of the structure by the joint construction measures. This case corresponds to the reasonably simplified knowledge of the structural design model, and the relationship between the knowledge mechanism and the case application is shown in Figure 2.

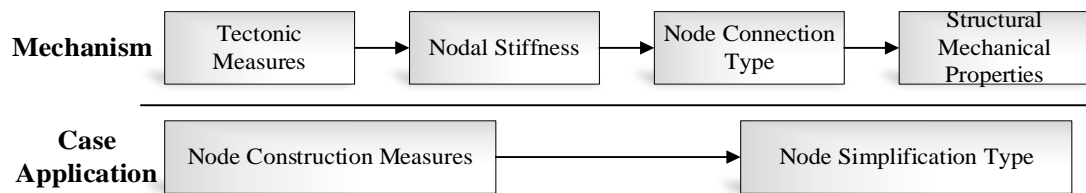


Figure 2. Case idea: Influence of Node Construction Measures on the Overall Structure

4.2 Influence of Construction Measures on the Safety of the Joint Itself

Based on the afore mentioned case studies and analyses of the influence of joints on the overall mechanical properties of the structure, students usually have a good grasp of knowledge such as the distinction of joint types and the setting of construction measures. However, overemphasizing the influence of construction measures on the overall structure may lead to neglect of the safety of the joints themselves, resulting in local damage and overall failure of the structure. By guiding students to analyze the construction measures, e.g., the stiffeners, of a high-voltage transformer bushing flange joint in He et al’s paper (2019), combined with the failure phenomenon of the joint in the engineering field and in the test, the stress state of the joint under the corresponding construction measures was analyzed. Besides, by analyzing the improved construction measures and effects of the joints in the case, the influence of the construction measures such as stiffeners on the joints of transformer flanges on the safety of the joints can be discussed. According to the engineering accident case of the transformer bushing flange joint, students will be guided to explore the relationship between the strength of the joint itself and its structure, master the principles and methods of optimizing the mechanical properties of the joint through structural measures, and understand the relationship between the joint strength and the overall mechanical properties of the structure. This case corresponds to the complex stress state distribution and optimization knowledge of the joints in a structure. The relationship between knowledge mechanism and case application is shown in Figure 3.

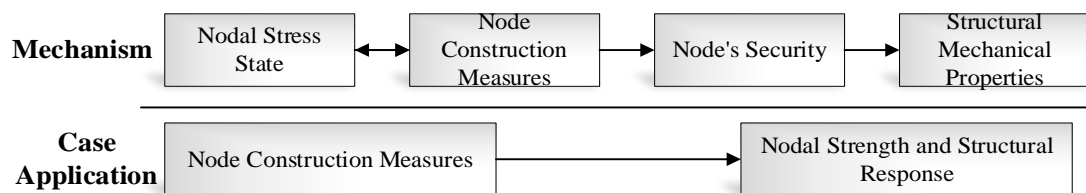


Figure 3. Case Idea: Influence of Node Construction Measures on Node Security

4.3 Influence of Joint Construction Measures on the Performance of Structural Disaster Prevention and Mitigation

The afore mentioned case analysis can enable students to understand the impact of joint construction measures on the strength of the joint itself and the safety of the structure. However, the joint construction measures have a great influence on the hysteresis performance and energy dissipation capacity. Taking the shaking table test and earthquake failure of a UHV GIS bushing in the literature as an example, the reasons for the bushing failure in the seismic qualification tests can be analyzed in the course, and the effects of the beam-column joint construction measures of this type of bushing support on the dynamic characteristics and impact of seismic performance were discussed (He, C., Xie, Q., Yang, Z., & Xue, S., 2019). In addition, according to the improved beam-column joint construction measures and bushing response, the influence mechanism of the joint construction measures on the bushing energy dissipation capacity and seismic response can be deeply explored. According to the earthquake failure case of this of the GIS bushing, the students will be guide to explore and

summarize the influence of joint construction measures on structural disaster prevention and mitigation capabilities through structural tests, numerical simulations, theoretical analysis, and other methods. The students will also reveal the relationship mechanism between joint construction measures and structural disaster resistance capabilities. This case corresponds to the influence of joints on the performance of structural disaster prevention and mitigation knowledge. The relationship between the knowledge mechanism and the case application is shown in Figure 4.

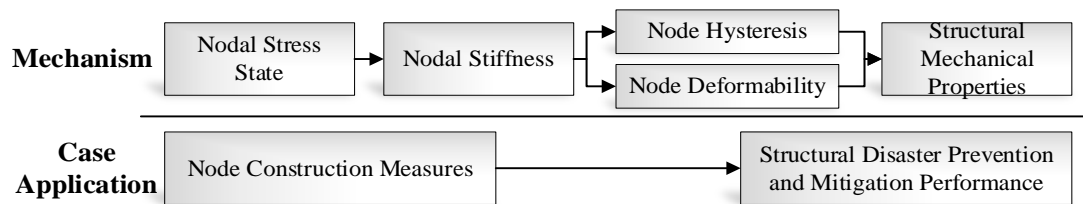


Figure 4. Case Idea: Influence of Node Construction Measures on the Performance of Structural Disaster Prevention and Mitigation

5. Conclusion

Before studying the chapter of steel structure joint design, undergraduates majoring in civil engineering have mastered the calculation method in structural mechanism. However, the mechanical properties of steel structure joint domain and structural mechanism are quite different. Teaching practice shows that students are generally not good at the chapter on steel structure joint design, especially for knowledge such as the joint construction measures. Since there is no need of calculation on the design of the joints, it is difficult for students to grasp the design mechanism. In order to enhance students' interest in this chapter and fully realize the important influence of joint construction measures on the overall safety of the structure, the safety of the joint itself, and the seismic performance of the structure, based on the engineering accident cases, this paper proposes a teaching method for the joint chapter in the Advanced Steel Structures. The case teaching method in the joint design chapter analyzes the mechanisms between the relevant cases and the corresponding knowledge, which can effectively improve the students' learning initiative and deepen the students' understanding of the corresponding knowledge. In addition, the use of engineering accident cases can effectively carry out ideological and political education in courses, cultivate students' awareness of engineering responsibility, and achieve the effect of moisturizing things without sound.

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