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Bearing Capacity Analysis of CFRP Strengthened Steel Plate with Hole under Axial Tension under Load

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Abstract. In view of the CFRP reinforcement with a central holed plate under load, the ABAQUS software is used to simulate the axial tension of the component, which provides the theoretical basis for the application of CFRP reinforcement with the central holed bearing steel plate under the load, and establishes the numerical model of the CFRP reinforcement with the center holed plate under the load. Under the condition of equal stiffness, the influence of the different load percentage of CFRP on the bearing capacity of the holed steel plate under non load and the bearing capacity of the holed plate under the load is analyzed. The simulation results show that, for the condition that the holed steel plate reinforced with CFRP is not considered under the load, the yield load and the ultimate load of the holed steel members reinforced by the CFRP reinforcement can be obviously improved. And then the finite element simulation of the holed steel plate with CFRP reinforcement under the load is carried out. We can conclude that the ultimate load of reinforced components decreases with increasing loading level.

1. Introduction

Surface hole exists widely in various common structures. When the initial hole in the component is small, it has little influence on the bearing capacity of the structure, but the hole is easy to expand under the action of large load. If it is not found in time, it will cause unreparable damage to the structure at the end^[1]. In the traditional steel structure reinforcement methods, there are welding and sticking steel plates. These methods also have their shortcomings. The higher temperature in the welding process will affect the structure and property of the structure, increase the brittle fracture properties of the structure, and the large amount of the steel plate reinforcement can increase the volume of the component. And the new components will produce stress concentration. Therefore, it is feasible to reinforce the steel plate with central hole by fiber composite CFRP. CFRP has good acid resistance, alkali corrosion resistance and convenient maintenance. After strengthening, it does not increase the weight of the original structure. The tensile strength of the material is very high. After reinforcement, the bearing capacity of the component is greatly improved. At present, Abushaggur and ED Damatty and others^[2] have tested the steel beam with GFRP. GFRP is attached to the flange surface of the steel beam, and the fourth point bending method is used. The test results show that the failure mode of steel beam is that GFRP produces fracture failure and GFRP layer produces stratification. There is no peel failure between GFRP and adhesive layer, and the yield strength and



ultimate load of reinforced beams increase by 23% and 78% respectively. S.C.Jones and others^[3] conducted fatigue tests on reinforced specimens with edge cracks and central cracks, analyzed the factors such as CFRP type, CFRP length, and other factors before and after crack propagation. The final test results were not ideal and their dispersion was larger. Based on the current research situation at home and abroad, many scholars have carried out theoretical research and analysis on the CFRP reinforced components under the load, and all of them have obtained good reinforcement effect by CFRP. However, the reinforcement analysis is carried out for the holed members with axial tension, up to now, no literature has been found on carrying out systematic analysis of load carrying capacity of components using different load percentages as variables. Systematic analysis is carried out based on the variables described. Only the steel plate with holes under load is strengthened by CFRP, without considering the failure of reinforcement at both ends of the steel plate.

2. The establishment of a finite element model

2.1. The establishment of a finite element model under non load

In the process of establishing the finite element model, the bearing capacity of the reinforcement component under the axial tension load is mainly considered. The geometric parameters and material parameters of the model are shown in table 2, table 3. In the model, the element type of steel plate is analyzed by solid element C3D20R^[4], that is, twenty nodes, two times hexahedron elements, and reduction integral. CFRP is analyzed by shell element S8R^[5], that is, the thick shell with eight nodes, and the integral is reduced. The structure control technology is adopted in the grid division technology. The end plate is loaded at the end of the component, and the rigid connection is adopted to the fixed end of the model. The six degrees of freedom of U1, U2, U3, UR1, UR2 and UR3 are restrained, and the loading way is loaded on the U1 direction of the loading end. From the literature [6], it is known that at the initial stage of loading, the bonding performance of the steel plate and the CFRP is good, the failure stage of the specimen has a larger yield deformation. When the phenomenon of CFRP and steel part disengagement occurs, the bearing capacity of the component has not been greatly affected. Therefore, the failure form of the steel plate and the CFRP separation is not considered in the process of establishing the model. Tie constraint is used between the steel plate and the fiber material; that is, it is assumed that there is no slip or shear failure between the steel plate and the CFRP in the finite element simulation, so the joint between the CFRP and the steel plate is connected by a common node without considering the thickness of the rubber layer^[7]. In the model analysis, the initial notch on the steel plate is usually used to simulate the actual damage of the component, and the mesh division of the reinforced component with the initial hole is shown in Figure 1, and the CFRP mesh is divided as shown in Figure 2.

Table 1. CFRP material parameter table

Performance parameters of CFRP				
carbon fiber cloth model	tensile strength/MPa	modulus of elasticity/GPa	ultimate tensile rate/%	thickness/mm
UCP-300	3970	235	1.7	0.165

Table 2. Steel plate material parameter table

performance parameters of steel plate			
steel number	yield strength/MPa	modulus of elasticity/GPa	ultimate tensile rate/%
Q235	235	206	>26

Table 3. CFRP material anisotropy parameters table

E1(GPa)	E2(GPa)	Nu	G12(GPa)	G13(GPa)	G23(GPa)
CFRP					
198	3.18	0.3	5	5	2.5

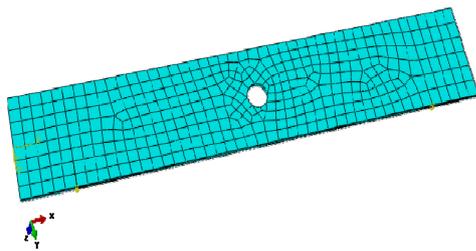


Figure 1 Finite element model diagram with holed plate

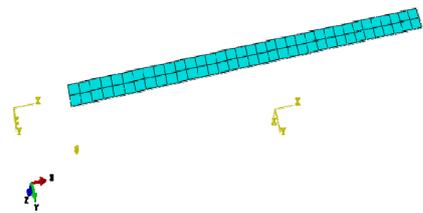


Figure 2 CFRP grid partition

2.2. The establishment of constitutive relation model

2.2.1 The establishment of constitutive relation of steel plate

For the establishment of the constitutive model of steel plate, the stress and strain values in the steel material test^[8] are used as the input of the constitutive relation in the software.

2.2.2 The establishment of constitutive relation of CFRP cloth

In the process of software simulation, the constitutive relation of CFRP cloth is set as linear elastic relationship^[8], and input elastic modulus, Poisson's ratio and ultimate tensile strain parameters are involved in the software.

2.3 Establishment of finite element model for axially loaded steel sheets strengthened with CFRP sheets under load

When the steel members are strengthened under the condition of loading, the strain of CFRP cloth will lag behind the steel member. This is the main difference between the load bearing reinforcement structure and the unloading reinforcement component. If a general method is used to establish the model of CFRP cloth and steel beam, the steel plate and CFRP will be subjected to joint stress. Therefore, in order to realize the phenomenon of stress and strain lag in the simulated CFRP cloth, the function of CFRP is not considered at the beginning of the stress of the component, only the steel plate is subjected to tension; after that, the role of the reinforced CFRP cloth is considered on the basis of the steel plate deformation, so that the reinforced components are subjected to two times loads and finally the force is shared. In software ABAQUS, we adopt the technology of "Model Change"^[8] to realize the above phenomena. In the analysis process, we activate the corresponding structural unit of CFRP material in time.

3. Comparison and analysis of the results of finite element model

3.1. Comparison and analysis of finite element results under non load

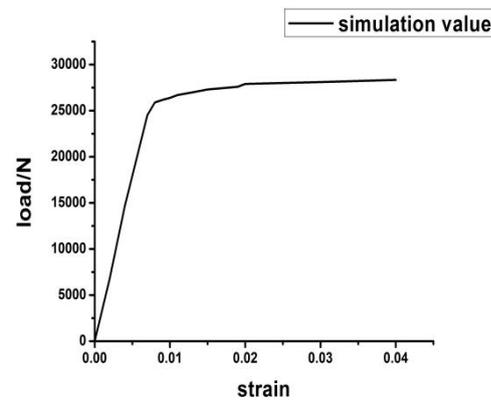
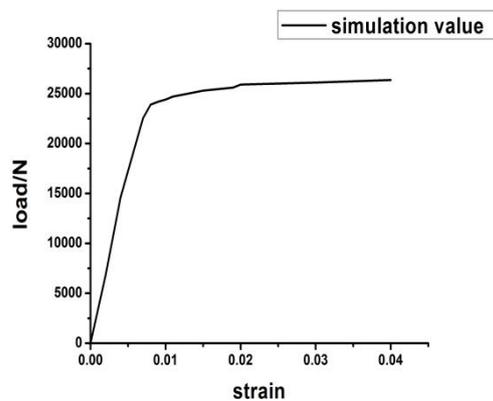


Figure 3 Load strain curve of unreinforced hole plate Figure 4 Load and strain relationship of CFRP with hole members

It can be seen from Figure 3 that when the component is in the elastic stage, the relationship between the load and the strain is linear linear. When the load reaches about 24.1kN, the component enters the yield stage. The slope of the load and strain decreases gradually, which is close to the gentle trend. When the load is about 26kN, the deformation of the component is very large and the bearing capacity reaches the limit. The hole at the steel plate first appeared to be damaged.

As shown in Figure 4, the CFRP reinforced hole member is compared with the unreinforced hole member. The yield load and the ultimate load of the member are increased. The yield load of the component in Figure 3 is about 24.1kN, and the yield load of the member in Figure 4 is about 26kN. The yield load is increased by about 7%, and the ultimate load is increased by about 8%. The results of the finite element calculation show that when the tensile load reaches 26kN, the yield deformation of the reinforced component occurs. At this time, the yield is mainly due to the stress concentration at the hole zone, and the final steel plate yields and the strain increases sharply. At this time, the CFRP material plays a role to bear a greater tensile stress.

It can be seen from Figure 3 and Figure 4 that the yield limit and ultimate load of CFRP strengthened steel sheet with hole are all improved, and the effect is remarkable. Based on this model, we can analyze the effect of CFRP reinforcement under load and the effect on load bearing capacity of members.

3.2. Variable analysis of axial tensile steel plate with hole strengthened by CFRP cloth under load

3.2.1 The impact of the holding level

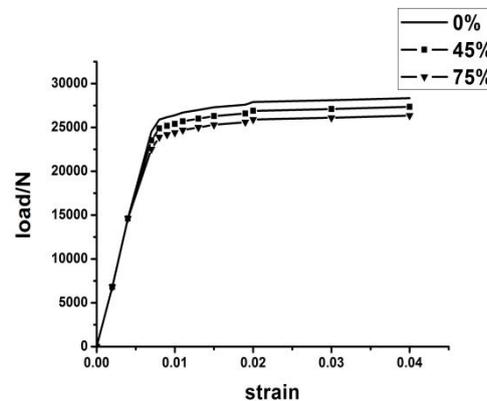


Figure 5 Load strain relationship of steel plates with hole under different load percentages

Using the finite element method, the axial tensile steel plate of the CFRP reinforcement with a hole under the load is established, and the relationship between the load and strain of three hole members under different loading levels is analyzed and calculated respectively. Using the unified reinforcement parameters, the percentage of load changes is 0%, 45% and 75% respectively, and the final finite element analysis results are shown in Figure 5. From Figure 5, as the percentage of the load increases, the ultimate load of the component decreases. When the percentage of the load is 45%, the comparison of the ultimate bearing capacity at 0% decreases by about 6%; when the load percentage is 75%, the comparison of the ultimate bearing capacity with 45% decreases by about 7%. It can be seen that the decrease of the ultimate bearing capacity increases with the increase of the load percentage, and with the increase of the load percentage, the yield strength of the component also decreases, the yield strength is 26KN at 0%, the yield strength is 25KN when the load is 45%, and the yield strength decreases by 4%. When the load is 75%, the yield strength decreases to 23.7KN.

4. conclusion

(1) For the non loaded steel plate with hole, the comparison between the CFRP reinforcement and the unreinforced, the CFRP cloth can enhance the ultimate bearing capacity and yield strength of the tensile member with the hole, the yield load increases about 7%, and the ultimate load increases by about 8%.

(2) For the axial tensile holed steel plate, the curve analysis of the non-load component and the load component was carried out. The ultimate load capacity of the load component was smaller than that of the non-load component, which was reduced by about 7%. The curve analysis of the load component was carried out, the ultimate bearing capacity of the component decreases with the increase of load percentage.

The influence of the residual stress is not considered in the model establishment. This factor can be taken into account. And after that, we can carry out experimental research on related problems. The adhesive layer of CFRP will be affected by temperature^[9], which is not considered in modeling.

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