Finite element analysis of reinforced concrete beams with openings in the abdomen and strengthened with steel sleeves based on ANSYS

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Abstract. The finite element software ANSYS is used to calculate the ultimate bearing capacity of ordinary beam and circular hole beam, and the results are compared with the test values made by predecessors. The value of shear transfer coefficient between cracks of reinforced concrete beam with circular hole in the abdomen in ANSYS finite element simulation is summarized. The coefficient is used to simulate the circular hole beam strengthened by steel sleeve, and it is pointed out that the steel tube is used to reinforce the circular hole beam. The effect of tube reinforcement on the bearing capacity of circular hole beam is not obvious.

1 Introduction

In the construction of reinforced concrete buildings, openings are often needed in the beams due to the installation of ventilation, air conditioning, and water pipes. The opening of the beam has a great influence on the mechanical performance of the beam. After the opening, the main tensile stress and shear stress of the concrete around the hole will increase greatly, and the stress concentration will appear at the hole opening, and the local stability of the concrete near the hole will obviously decrease [1]. There are many researches on this kind of situation. Wang Xinling et al. [2] carried out experimental analysis on the simply supported beam with opening in the middle span under concentrated load, and obtained that the bearing capacity of the continuous beam is related to the area and location of the opening, and gave the limiting conditions of the opening and design suggestions. Liu Xiaochun [3], Wang Peng [4], Yang Yuhua [6] and Cai Jian [7] carried out a large number of experimental studies, and summarized the influence of various factors on composite beams. Liu Shizhong [8], Jiang Jiaohe [9], Wang Dongsheng [10], Li Yiqiang [11], Luo Ruden [12], Zhu Mingqiao [13] etc. simulated and analyzed the simply supported concrete beam and the concrete beam with simply supported square hole in the abdominal wall by using the ANSYS finite element simulation software, which verified the effectiveness of the ANSYS analysis, and discussed these problems, such as the finite element model, the selection of constitutive relations and parameters, and the convergence of solutions. The ANSYS finite element analysis of

concrete beams with circular holes in the abdomen is less, but there are more beams with round holes in the engineering. One of the reasons is that the hexahedral solid element has eight nodes, the mesh generation requirements are strict, and the element shape difference can not be too big, otherwise it is easy to cause inaccurate calculation, and the opening of circular hole will increase the difficulty in this respect; on the other hand, after the abdominal opening, the oblique crack damage characteristics of the beam will be different from that of the complete simply supported beam, so the parameters selection of the concrete is different. It must be applied and further research is needed. Finite element analysis is convenient for modeling and it is of great significance to determine the modeling parameters.

2 Finite element analysis

2.1 Material parameter setting

In this finite element model, separate composite model is used for reinforcement and concrete, and SOLID65, link80 and solid185 are used to simulate concrete material, reinforcement and casing respectively. SOLID65 element has the characteristics of cracking and crushing, which is often used to simulate concrete, and many parameters need to be set in the simulation process.

In order to compare with the test results, the strength and elastic modulus of concrete and reinforcement in this model are similar to the test values. The concrete material model adopts the multilinear isotropic strengthening model, namely concrete + miso model. The uniaxial compression stress-strain relationship is shown

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in Fig. 1 (a), and the maximum compressive strength is 37.3mpa. Because the numerical calculation is easy to not converge in the stage of stress drop, the concrete falling section is not considered. The tensile strength of concrete is 2.07mpa, and the elastic modulus is 3.0×10^4 mpa. The willam Warke five parameter strength criterion is adopted for concrete material, and the failure surface of concrete is controlled by five parameters. Among these five parameters, the shear transfer coefficients of crack opening and closing are uncertain, and different values have great influence on the simulation results. In this paper, several groups of

different numerical values are used to investigate the influence of different coefficients on the model, so as to determine the best coefficient value of circular hole beam. Turn off the crushing switch (i.e. set the uniaxial compressive strength value to - 1).

The reinforcement material model adopts bilinear isotropic strengthening material property (curve), that is, elasticity is linear, and plasticity is also linear. Hpb300 steel bar is used as reinforcement. Refer to the test value, the elastic modulus is 2×10^5 Mpa, the yield strength is 300mpa, and the ultimate strength is 463mpa. The stress-strain curve is shown in Fig. 1 (b).

Figure 1(a). Stress strain curve of concrete under uniaxial compression

Figure 1(b). Stress strain curve of steel bar

2.2 Setting of the criteria for convergences

In order to accelerate the convergence and improve the calculation accuracy, the modified Newton Raphson iterative method is used to solve the problem, and the following measures have been taken:

- Geometric large deformation, automatic time step and linear retrieval options are set to on.
- Control mesh generation, which has a great influence on the results. The element size should be controlled at about 50 mm. If the element is too large or too small, it will affect the calculation results.
- The load is linearly increased. In order to avoid local brittle failure of concrete, the concentrated load is input by uniformly distributed load in the small area in the middle of the span.

- The rigid cushion block is set at the support of concrete beam to avoid the stress concentration and early failure of concrete.

- The convergence criterion based on force is adopted, and the convergence accuracy is relaxed to 5%.

2.3 Building of the model

Referring to the test parameters of Yang Yuhua [6] of South China University of technology, three groups of tests of ordinary beams without openings and circular hole beams with opening diameters of 80mm and 100mm are selected as comparison. The detailed dimensions are shown in Figure 2, and the thickness of concrete cover is 25 mm.

Figure 2. Size of concrete beam model and its circular hole location.

3 Analysis of simulation results

In the process of simulation, the linear loading method is adopted, and the ultimate calculation result is the ultimate bearing capacity of the beam because the decline section of concrete strength is not considered. Because the shear transfer coefficient $C1$ of open crack and $C2$ of closed crack have great influence on the calculation results, this paper selects several representative numerical simulation and compares them with the test results, as shown in Table 1. In comparison, it is found that for ordinary beams, $C1 = 0.40$, $C2 = 0.90$ groups and $C1 = 0.40$, $C2 = 1.0$ groups are close to the measured ultimate bearing capacity, which is consistent with the research results of Luo Ruden [12], indicating that the

modeling in this paper is correct. For beams ① and ②, $C1 = 0.30$, $C2 = 1.0$ groups are close to the measured bearing limit values. The reason for this phenomenon is that the initial crack width of ordinary beam is relatively small, the crack development is relatively slow, the bite force between concrete materials basically does not disappear, and the shear resistance is better. However, for beams with circular holes, due to the appearance of concentrated stress at the hole edge, inclined cracks appear relatively early, and the cracks are relatively concentrated and the width is large, which is prone to cable-stayed failure, and the bite force between concrete materials is small. Therefore, the shear transmission coefficient $C1$ of open crack should be taken as a small point.

Table 1. Comparison of calculation results of different parameters (in kN).

Test	$C1=0.45$ $C2=1.0$	$C1=0.40$ $C2=1.0$	$C1=0.35$ $C2=1.0$	$C1=0.30$ $C2=1.0$	$C1=0.40$ $C2=0.9$	$C1=0.35$ $C2=0.9$	Measured limit value
Ordinary beam	380.0	399.3	331.1	265.0	400.4	220.9	395
Beam ①	343.7	263.4	296.5	296.5	255.5	273.7	312
Beam ②	397.3	372.1	269.7	266.0	376.8	235.1	250

Note: Beam ① is a beam with a hole diameter of 80mm, and beam ② is a beam with a hole diameter of 100 mm.

In the engineering construction, the fire pipeline and HVAC pipeline are usually embedded, and the decoration construction is usually directly drilled in the beam. With the embedded method, the pipe and concrete can be effectively bonded together. And the decoration hole is often no steel pipe protection. In order to study the interaction between steel pipe and beam and the

protection effect, steel casing with thickness of 6 mm is added at the hole position, and its influence is studied. The relevant calculation results are shown in Table 2, in which the simulation results of common beam are $C1 = 0.40$, $C2 = 1.0$ group, beam ① and beam ② are simulation values of $C1 = 0.30$, $C2 = 1.0$ group.

Table 2. Comparison of load values between simulation and experiment at different stages (in kN).

Ordinary beam	Test piece	Beam①	Beam②	Reinforcement ①	Reinforcement ②
The opening load of a normal crack	91 (90)	88 (80)	85 (80)	89	88
The opening load of a normal crack	190 (190)	70 (120)	76 (110)	139	161
The load during a failure	399 (395)	296 (312)	266 (250)	328	326
Deflection	5 (4)	4 (5)	3 (3)	4	4

Note: The test value is shown in the bracket; the casing pipe ① is the beam with the steel casing with the hole diameter of 80mm, and the casing pipe ② is the beam with the steel casing with the hole diameter of 100 mm.

The first normal crack and inclined crack calculated by ANSYS software appear earlier, and their values are far less than the experimental values. The main reason is that the cracks observed by the naked eye are usually relatively wide. Therefore, the crack load of normal crack and inclined crack calculated here is the load value corresponding to 0.914×10^{-3} mm lateral displacement in displacement nephogram. Although the crack load value corresponding to the test value can not be obtained

accurately, it can be seen from the simulation results that the crack load of steel casing reinforced circular hole beam is similar to that of ordinary beam under the same crack width observation condition, and the cracking load and ultimate bearing capacity of inclined crack are both greater than that of unreinforced beam, but less than that of ordinary beam, which indicates that the reinforcement effect of steel casing is not significant.

4 Conclusion

- For beams with circular opening, the shear transfer coefficient $C1$ with open crack and $C2$ with closed crack are $C1 = 0.30$ and $C2 = 1.0$

- respectively, which are close to the measured bearing limit value, and can be used to simulate and analyze the circular hole beam.
- Using steel casing to strengthen the round hole beam has a certain effect, but the effect is not significant.

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Acknowledgments

I would like to thank Lin Longbin and Feng Zhengwei for their warm help and for the efforts of scholars in the same industry.

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