Experimental Study on Crack Resistance of Beam-column Eccentric Joints of Reinforced Concrete Frame Based on Computer Finite Element Analysis

Na Wang\textsuperscript{1,\*}, Hongxia Liu\textsuperscript{2}, Panpan Yi\textsuperscript{3}
\textsuperscript{1,2,3}Wuchang University of Technology, Hubei, China, 430223

\*E-mail: 914941610@qq.com

Abstract. With the rapid progress of urbanization in China in recent decades, reinforced concrete frames have played an irreplaceable role in urban development and improvement of living environment, it can be said that our surrounding environment, there is no place where reinforced concrete cannot be seen. At present, our living standard and living environment have been greatly improved, which has brought us a stronger demand for environmental safety and beauty. In this paper, the crack resistance of the eccentric joints of reinforced concrete frame beam-column is studied by using computer finite element analysis.

Keywords: Computer Finite Element Analysis, Reinforced Concrete, Crack Resistance

1. Introduction

The reinforced concrete frame joint is the weak part of the structure earthquake resistance. Under the strong earthquake action, the core area of the frame joint is subjected to complex force, and the damage of the joint has become one of the main reasons leading to the collapse of the whole frame. In recent years, due to the need of building facade or the requirement of using function, the eccentric joints of beam and column appear in large numbers, which makes the transmission path and force mechanism of the core area of the node more complicated. Due to the importance of the eccentric joints and the difficulty of repairing after the cracks appear, especially for some particularly important buildings, as well as serious corrosion environment or underwater construction (construction) structures need to strictly control the structure without cracks, it is necessary to calculate the crack resistance in the core area of the eccentric joints\textsuperscript{[1-3]}. Therefore, in this paper, the crack resistance of eccentric joints is studied from the angle of crack resistance, and the practical calculation formula is put forward.
2. Research significance of crack resistance of eccentric node

Reinforced concrete frame joint is a weak link in the seismic resistance of the structure. Under the strong earthquake, the core area of the frame joint is subjected to complex force, and the damage of the joint has become one of the main reasons for the damage of the whole frame. In practical engineering, due to the need of building facade or the requirement of using function, there exists the phenomenon that the axis of beam does not coincide with the axis of column. Under the action of horizontal seismic force, the eccentric joints of reinforced concrete frame are subjected to bending moment, shear force, axial force and torque, which makes the transmission path and force mechanism of eccentric joints more complicated. It is found in many large earthquakes at home and abroad that the effective width of the node is reduced and the bearing capacity is reduced due to eccentricity, which leads to the destruction of the eccentric node and even the collapse of the whole frame. Due to the importance of the joint site and the difficulty of repairing after cracking, the crack resistance calculation of the frame joint must be carried out for some particularly important buildings, as well as for the building (construction) in a corrosive environment or underwater, and the need to strictly control it without cracks. The test results show that the length and width of the joints develop rapidly, especially under the repeated action of load. The width can reach 0.3 m. joints that have already cracked, in fact, have often reached or exceeded the normal use limit state. Therefore, for the general industrial and civil buildings in seismic areas, in addition to the node strength should be calculated, but also according to the mode intensity of the frame node crack resistance check calculation, has guaranteed that in the case of small earthquakes, the frame without repair or only a little repair can continue to work properly. Many scholars at home and abroad have carried out experiments on different types of frame joints, studied the stress mechanism of the joints and how to improve the seismic performance of eccentric joints and improve their bearing capacity. However, there are few researches on the crack resistance of frame beam-column eccentric joints, and there are few papers in this field. Therefore, the research on crack resistance of frame eccentric joints becomes an urgent task to be solved.

3. Computer finite element analysis

3.1. Computer finite element concept

The basic idea of finite element method is to discretize the continuous solution region into a group of finite elements which are connected together in a certain way. The approximate function assumed in each unit body is used to represent the unknown field function to be solved on the full solution domain in pieces. The approximate function in a unit is usually expressed by the numerical value of the unknown field function and its derivative at each node of the unit and its interpolation function, so that a continuous infinite degree of freedom problem becomes a discrete finite degree of freedom problem. Once these unknown quantities are solved, the approximate values of the in-field functions of each unit can be calculated by interpolation function and the approximate solutions on the whole solution domain can be obtained[4].

The finite element divides the objects of the entity into different sizes, types and regions, pushes down the force equations of each element according to the requirements of different fields, combines the elements of the whole system and forms the system equations, and finally solves the system group. With the continuous development of finite element method, the method has the following
characteristics: (1) the whole system is discretized into finite elements. (2) A set of linear simultaneous equations is transformed into a set of equations by using the principle of energy minimization and the general culvert numerical theorem. (3) Concise process. (4) Discrete processing of the whole region requires a large amount of data output space and computer memory, and time-consuming solution. (5) Linear and nonlinear. (6) The problem of infinite region is difficult to simulate.

3.2. Computer finite element principle and process

Finite element method is an effective method for engineering calculation, that is, a complex elastomer is divided into a continuum of finite particle elements. In statics analysis, in order to combine finite elements in any type into an analytical system based on force method, displacement method, or mixing method, a set of characteristic matrices is required, i.e., the element inherent matrix, and the element John out matrix. For example, the generalized total strain field $\{E\}$ is expressed as:

$$\{E\} = [T_{Ed}] \{d_{ma}\} \quad (1)$$

Where $\{d_{ma}\}$ is the deformation variable and $[T_{Ed}]$ is the stress.

In order to obtain the strain field with the element deformation variable, the equation is usually assumed:

$$\{U_m\} = [T_{ue}] \{Q_{ma}\} \quad (2)$$

Formula $\{U_m\}$ generalized displacement of a local coordinate system. $\{Q_{ma}\}$ vector of deformation variables for generalized elements including zero strain or rigid body term. Different functions appropriately that the total strain field of equation (1).

The deformation variable $\{d_{ma}\}$ and variable $\{Q_{ma}\}$ by equation:

$$\{d_{ma}\} = [T_{da}] \{Q_{ma}\} \quad (3)$$

By directly linking the principle of virtual deformation to the $j$ independent deformation variables, we can get:

$$d_{ma} : F_{ma} : \int_B [E]^T \{a\} d\tau \quad (4)$$

Where the letters are in turn the $j$ independent element deformation variable. The corresponding $j$ is total strain field. The function corresponding to the stress $E$, and the volume of the element.

If a supposed to independent deformation variable, then there is a linear equation like (4).

Through the above formulas, it is not difficult to see that the above set of formulas are characterized by large amount of data, large amount of calculation, and no errors are allowed in the intermediate link.

Earlier, the level of development of computer technology was still very limited, people first based on the technical achievements of the time in other languages to write a number of finite element calculation applications, to provide a good interface for engineering calculation, and to create the basic theory of finite element and its method steps to be reflected in the operation of the computer to achieve
the calculation of the required large structural software. There are three ways to transfer information between modules, one is the common data storage area, the other is the combination of calling parameters, and the third is the file system\textsuperscript{[5-6]}. The information transfer of the first two is carried out in the main memory, which is suitable for both the common information of most modules and the small amount of information transmission.

3.3. Establishing computer finite element model

After the entity model is established, the grid is carried out. The establishment of the gridded finite element model has three steps are required: (1) the data of the establishment and selection of the unit to establish the unit includes the type of unit, geometric size, material properties and the coordinate system where the unit is formed, as shown in Table 1. (2) Setting the parameters required for the establishment of the grid will determine the size and shape of the grid and affect the correctness and economy of the analysis. According to the actual conditions, the grid division should be reasonable and not too thin and too thick. If the grid is too fine, good results will be achieved, but the grid is too dense and too thin, which will take up a lot of analysis time. The volume unit uses solid95 unit, the unit side length is 75 mm, each cross frame node model has about 4000-5000. (3) Grid generation. The solid model grid can be divided into free grid and corresponding grid. In this paper, free grid is used. Compared with the corresponding grid, the establishment of the solid model is simple and has no more restrictions.

| Group | test-piece | Beam (mm*mm) | Pillar (mm*mm) | Eccentricity mm | Width mm | ƒc (N/mm²) | Ev (N/mm²) | Model unit |
|-------|------------|--------------|----------------|----------------|----------|------------|------------|------------|
| 1.    | JM1        | 150*350      | 350*250        | 0              | 0        | 23.65      | 3.55*10⁴   | solid95    |
|       | JM2        | 150*350      | 350*250        | 33             | 0        | 23.65      | 3.55*10⁴   | solid95    |
|       | JM3        | 150*350      | 350*250        | 67             | 0        | 23.65      | 3.55*10⁴   | solid95    |
|       | JM4        | 150*350      | 350*250        | 100            | 0        | 23.65      | 3.55*10⁴   | solid95    |
| 2.    | JE         | 150*350      | 350*250        | 100            | 0        | 25.32      | 3.15*10⁴   | solid95    |
|       | JW1        | 150*350      | 350*250        | 100            | 50       | 25.32      | 3.15*10⁴   | solid95    |
|       | JW2        | 150*350      | 350*250        | 100            | 100      | 25.32      | 3.15*10⁴   | solid95    |
|       | JW3        | 150*350      | 350*250        | 100            | 150      | 25.32      | 3.15*10⁴   | solid95    |
|       | JW4        | 150*350      | 350*250        | 100            | 200      | 25.32      | 3.15*10⁴   | solid95    |

Table 1. Model geometric dimensions, material characteristics, element definitions

4. Analysis of results

According to the crack development of the core area and the analysis of the unit force, each specimen takes two faces, which are close to the eccentric side and far away from the eccentric side, and four representative unit nodes are taken in the center of the core area of each surface node. Table 2 Stress values of core nodes under computer software (N/mm²).
Table 2. The calculation results shows that with the increase of eccentric distance

The stress near the eccentric side is greater than the stress away from the eccentric side, which indicates that the greater the eccentric distance, the worse the crack resistance of the joint; with the increase of axillary width, the stress near the eccentric side is gradually close to the stress away from the eccentric side, which indicates that the addition of axils at the end of the beam improves the crack resistance of the eccentric joint and verifies the test results[7].

5. Conclusion

In this experiment, the plane frame is studied, which is different from the space frame with floor slab in the actual engineering. It is necessary to study the space effect of the eccentric joint by using the test which simulates the actual force of the eccentric joint more closely. with the diversification of structural forms and the development of composite materials, the addition of carbon fiber, high strength adhesive and other materials to the joints, or the combination of steel structure and so on, to improve the crack resistance of eccentric joints will need further experimental study.

References

[1] Wang Jingfeng. Experimental study on crack resistance and three-dimensional finite element analysis of eccentric joints of reinforced concrete frame beam-column [D]. 2002.

[2] Kang Guozheng. ANSYS principle of large finite element program: structure and use. Chengdu: Southwest Jiaotong University Press, 2004.7

[3] Zhao Hongtie. Crack resistance of reinforced concrete beam-column joints [J]. Journal of
[4] Guo Huiying, Kang Gu Yi. Effect of axial pressure on seismic performance of joints and shear strength of frame side joints. Structural engineer supplement. 2000.

[5] Huo Zhongsheng. Application of Computer Finite Element Analysis to Innovative Experimental Teaching [J]. Experimental Science and Technology, 2003(01):82-83 104.

[6] Liu Bingkang, Huang Shenjiang, Zhou An, et al. Experimental Study on Seismic Performance of Eccentric Joint of Reinforced Concrete Frame [J]. Journal of Architecture, 1999, 20(5):50-58.

[7] Wang Jingfeng, Liu Bingkang. Experimental study on crack resistance of eccentric joints of reinforced concrete [J]. Architecture, 2003(12):32-35.