Analysis of reinforced concrete structures with cracks based on finite element mode

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Abstract: Among the many factors that have a great impact on the quality of engineering structures, the quality problems caused by cracks are the most serious. The change of crack width and height with the change of time and the improvement of crack grades cause engineering quality problems. Safety. In this paper, the finite element model is established to analyze the cracked reinforced concrete structure, the process of finite element analysis is discussed, and the software design and empirical analysis are carried out. The test results verify the finite element model to analyze the application rationality of cracked reinforced concrete structure. The calculation visibility and accuracy are high.

1. Construct a finite element model of reinforced concrete

1.1 Bond and slip of steel and concrete

In the actual application process, the adhesion between the steel and the surrounding concrete will appear, which will directly cause serious nonlinear effects on the reinforced concrete structure[1]. It is also the main problem in the analysis of reinforced concrete structures, and this problem has great complexity and difficulty. Related studies have shown that the bond between the steel bar and the concrete joint will not only affect the bond slip of the reinforced concrete, but also affect the stress state of the concrete structure under the stress of the concrete, and also cause the development of concrete cracks. Certain influence. In order to further simulate the stress performance of concrete, the bond slip of steel and concrete should be fully considered in the process of modelling.

1.2 Linear elastic constitutive model

The linear elastic constitutive model is a relatively simple model with the simplest material constitutive model. In the online elastic constitutive model, the stress-strain relationship needs to be carried out according to Hooke's law. No matter whether it is loaded or unloaded,[2] it will exhibit a linear relationship, and the stress and strain correspond to each other one by one. The use of a linear elastic model is a simple and effective way. Although there are still some application problems in this model, it is still widely recognized and recognized in the industry because of its simple application.

1.3 Non-linear elastic constitutive model

The stress strains in the nonlinear elastic constitutive model still have a one-to-one correspondence, so the stress state will also be determined by the state of the strain, but the two are no longer proportional. The nonlinear single-row constitutive model is divided into a superelastic model and a subelastic model. In the superelastic model, the full-scale stress-strain relationship of the material is considered to be independent of the loading path[3].

It is more accurate for concrete materials that are subjected to proportional loading. When the material is unloaded, it cannot be adapted to the case of inelastic deformation. There are still some restrictive factors in theory, but since some simplified forms of concrete materials are widely used at present, they are gradually applied to nonlinear analysis.

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2. Reinforced concrete crack model

2.1 Traditional crack model

In the finite element analysis of reinforced concrete structures, two common crack models are the split crack model and the distributed crack model.

The split crack model assumes that the crack is formed along the boundary of the element and develops along the boundary of the element. After the concrete of the adjacent unit reaches the cracking condition[4], the original node is changed into two nodes at the crack. Separate crack models formed along the cell boundaries have certain advantages. If the main crack effect of the structure is studied, it is reasonable to use a single crack because the crack model expresses the discontinuity of the strain and makes the result closer to the actual situation, but this model also has great limitations. In this calculation, the model should be continuously re-divided into nodes, and the nodes are added. At the same time, the characteristics of the original overall stiffness matrix with narrow bandwidth are affected, which leads to the reduction of computer efficiency in the displacement calculation.

The basic assumption of the distributed crack model is that the cracked concrete also maintains some continuity, and the cracks are distributed in the unit in a "continuous" form. If the crack direction is taken as a local coordinate axis direction, it can be considered that the concrete in two orthogonal directions along the coordinate axis has different physical and mechanical properties. This method is easy to express the sudden drop in concrete strength along the tensile stress direction. In a distributed crack model, the cracks are not discrete or singular[5], but rather a plurality of mutually parallel slits that are spread throughout a unit. The main advantage of the distributed crack model is the ability to automatically generate cracks without the need to re-change the geometry of the unit; cracks can be formed in any possible direction without the need to pre-specify the direction of the crack. This makes the model more versatile.

2.2 Improved crack model

Based on the previous section, the basic crack model is improved in this paper, and a new model, namely the hybrid crack model, is established. The hybrid crack model is based on the distributed crack model to judge the new crack according to the direction of crack development, and avoids the model in which cracks appear in pieces[6].

The concrete unit is divided into a splittable unit and a non-cleavable unit. For the splittable unit, the maximum principal tensile stress strength criterion is used under each load. If the primary tensile stress reaches the ultimate tensile strength, it is called the cracking unit, and the stiffness matrix is adjusted according to the distributed crack. For the non-cleavable unit, no discrimination is made[7]. Only the distributed crack is used to adjust the elastic modulus and Poisson's ratio of the non-sedimentable unit, and the corresponding stress is released, so that the stress relaxation region around the control crack will not appear again in the subsequent loading. Cracking. In the initial case, all concrete elements are non-cleavable units and the first splittable units are determined by the stress state of the elastic stage. When these units are cracked, the next batch of splittable elements is given according to the direction of the crack, so that several crack zones can be clearly distinguished. As the stiffness of the crack zone decreases, the concrete stress on both sides of the crack relaxes, and finally the crack form is closer to the actual discrete form. The crack form thus calculated is closer to the test result than the distributed crack model. Ideally, with the redistribution of stress, the main tensile stress of the concrete between the fracture zones will not exceed the ultimate tensile strength.

The selection of the area affected by the crack is more important[8]. The crack mainly affects the units on both sides, so that they have stress release. In this paper, the crack spacing is the lateral dimension of the affected area. According to the phenomenon that the cracks of different natures may occur in the actual situation, the author believes that the effect of such cracks on the surrounding elements should be limited to the same cracks, and the cracking unit with a large change in direction in the crack affected area, It should be considered that its cracks are not affected. This improved fracture model is used herein to simulate a crack shape.

$$\omega = \frac{1+\gamma}{E}\sigma(1-D)^{-2} - \frac{\gamma}{E}(1-D)^{-1} tr\left[\sigma(I-D)^{-1}\right] \quad (1)$$

$$Y = \frac{1+\gamma}{E}\sigma^{2}(1-D)^{-3} - \frac{\gamma}{E}(1-D)^{-1} tr\left[\sigma(I-D)^{-1}\right] \quad (2)$$

Based on this, the constitutive relation of improved fracture model is established:

$$\{\sigma\} = [E*(D)]\{\varepsilon\}$$

$$[E*(D)] = \left[\begin{matrix} (\lambda+2D)(1-D_1)^2 & \lambda(1-D_1)(1-D_2) & \lambda(1-D_1)(1-D_3) \\ -D_2)\lambda(1-D_1) & (\lambda+2G)(1-D_2)^2 & \lambda(1-D_2)(1-D_3) \\ (1-D_3) & (1-D_3) & (\lambda+2G)(1-D_3)^2 \end{matrix}\right]$$

inside $\lambda = E(t)/(1+\mu)(1-2\mu)$,G is Shear modulus, $G = (E(t)/2(1+\mu))$, $E(t)$ is Elastic modulus, it is Time function, μ is Poissonby, D is Elastic damage of main strain direction.

3. Nonlinear finite element analysis process

The finite element analysis step (see Figure 1) involves not only the restart, unit life and death, and array. For the analysis of finite element, the first thing to do is to formulate the corresponding initial load analysis and correspondingly Backup and storage. Then proceed to the next step, that is, enter the processor to further analyze and process the calculation results, and extract and analyze the results. The second is to further analyze and process the results of the previous load calculations, and judge the actual situation to see if it can meet the required standards. Then, the next load needs to be directly carried out, and the modified model is used to perform the second load step analysis on the original basis of the analysis until the analysis is completed[9]. When the condition meets the requirements, the spring of the slot interface needs to be modified separately according to the tension softening relationship, and the parameters are saved, and then saved to the disk as an external file. Finally, you need to make the analysis type a restart and perform the corresponding operations.

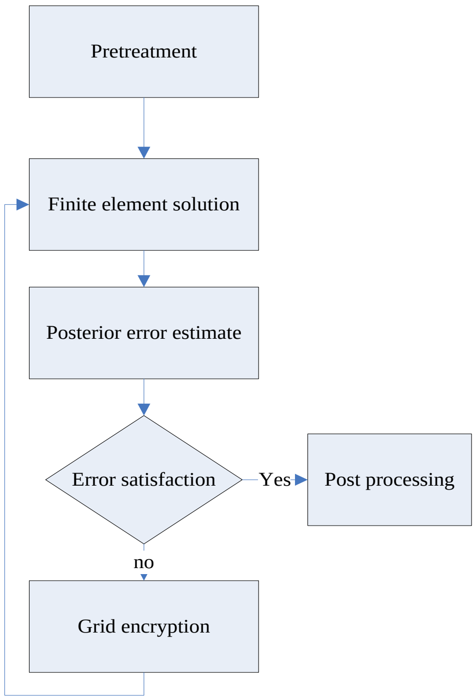

Figure 1 finite element analysis steps

Before the loading, the concrete is not cracked, so the thin layer unit is not set first (this is different from the discrete model). When the load increment method is used for calculation, when the main tensile stress at the Gauss point of a concrete unit reaches the concrete resistance At the time of tensile strength[10], it is considered that the concrete unit will produce cracks. At this time, a thin layer unit is set in the direction of the main tensile stress of the Gaussian integration point of the unit, and the mechanical behavior of the crack (including whether the crack is one-way or two-way, cracking and closing) And the first few cracks and closures can be simulated with a thin layer unit, draw and embed thin layer units, and call the combination unit class to calculate the stiffness matrix of the combined unit, the software finite element analysis main class will call the thin layer crack unit The class and the combined unit class are automatically analyzed, and then the calculation of the next load is performed. When the principal compressive stress at the Gaussian integration point of a concrete unit reaches the compressive strength of the concrete, it is considered that the concrete unit will be crushed, and the setting of the thin layer unit is the same as above, except that it is thin at this time. The layer crack unit will fail, and such discrimination is automatically performed by software.

Like the common distributed crack model, the thin-layer unit is considered to be an orthotropic medium based on the distributed crack model of the thin-layer crack unit[11], which can easily determine the position and orientation of the thin-layer unit and the stress and deformation of the thin-layer unit. . This model can automatically form new cracks without changing the grid map, and can also represent cracks in any direction, which can be used to study the problem of multi-crack development in reinforced concrete plane problems. In this way, the stress redistribution of the various elements (including concrete, steel bars and double spring bonded units) after crack occurrence can be automatically calculated by software.

After analyzing the stress-strain relationship of the steel bars near the crack and the relationship between the stress and the slip of the double spring bonding unit, the relationship between the darkening effect of the steel bar and the gripping force between the steel bar and the concrete can be obtained[12]. Using visualization technology, the whole process of reinforced concrete beams from loading to cracking, crack propagation and component failure can be obtained under load. It is more intuitive and realistic to reflect the influence of crack on structure, and the intuitiveness of discrete crack model is taken into account. The dual effects of the mechanical simulation of the simulated and distributed crack models.

4. Experimental analysis of finite element examples

(1) Prepare the Folium Class of the base class of the succession unit. The calculation, assembly, internal force and displacement calculation, unit state analysis, etc. of the element stiffness matrix are similar to the concrete plane 8 node isoparametric element. The difference is the processing of the visualization effect of the unit thin layer unit.

(2) Compiling a combination unit class, using the calculation of the stiffness matrix of the composite unit when a thin layer unit is embedded in a crack in a concrete unit, and this class also inherits the basic properties of the unit base class, otherwise it cannot be assembled into the total just.

(3) Add a pointer to the thin-level unit class in the finite analysis main class. When the concrete is cracked, the pointer calls the thin-layer unit class to automatically calculate and analyze[13].

(4) The thin layer unit is displayed by using visual technology and different color models. When loading by load increment method, the whole process of crack occurrence, crack propagation and component damage of reinforced concrete beam is shown.

The thin layer unit thickness t is much smaller than the unit plane feature size e (t+e), and part of the strain should be ignored. Immediate

$$\varepsilon_x^{'} = \varepsilon_y^{'} = \gamma_{xy}^{'} = 0 \tag{3}$$

And take $\varepsilon_x^{'} \approx \frac{1}{t}\Delta w^{'}, \gamma_{xy}^{'} \approx \frac{1}{t}\Delta v^{'}, \gamma_{xz}^{'} \approx \frac{1}{t}\Delta u^{'}$, the displacement array in the local coordinate system and the global coordinate system in the unit node displacement satisfies the following coordinate transformation relationship formula:

$$\{u^{'}v^{'}w^{'}\}^T = [T_0]\{uvw\}^T \tag{4}$$

In the middle

$$[T_0] = \begin{bmatrix} l_1, l_2, l_3 \\ m_1, m_2, m_3 \\ n_1, n_2, n_3 \end{bmatrix} \tag{5}$$

So you can build a finite element equation: $[K]^e\{\delta\}^e = \{R\}^e + \{R^0\}^e$

The example used is a set of two ordinary reinforced concrete specimens in the reinforced concrete deep beam test (the concrete strength grade is C40 main ribs using grade II steel bars. The beam section is used $b \times h$ as a rectangle and the protective layer is c=30mm, (as shown in Figure 2). Show) The material parameters of the specimen loading and section are: The parameters of concrete $C40\, f_c = 37.9N/mm^2$, $f_t = 4.45N/mm^2$, $E_c = 33.2kN/mm^2$, and steel grade II are $f_y = 445(660)N/mm^2$, $E_s = 1991.1(201.1)kN/mm^2$ [14].

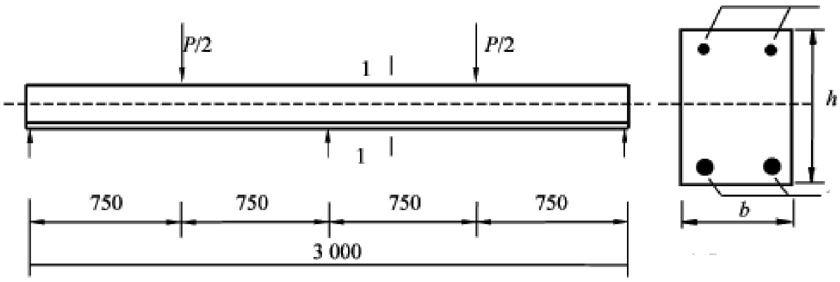

Figure 2 Test piece loading and section schematic

Comparing the deflection-load comparison of the two deep beams, the comparison test results show that the cracks in the structure are mainly concentrated in the bottom of the continuous deep beam at the middle support, the support and the span, with the load The increase of the number of thin-layer crack units increases, and the stress of the concrete unit is redistributed, realizing the simulation of stress redistribution. The cracks thus appearing (ie, the thin-layer elements) will continue to crack along the direction of the main tensile stress of the Gaussian integration point of their concrete, and no cracks will occur in a certain area around them, which is the actual situation of cracking of the reinforced concrete structure. (See Fig. 3) Through the vicinity of a certain crack, the stress-strain curve of the steel element can analyze the dark squeezing effect of the steel bar; the curve of the slip amount of the double spring bonding unit near the crack can be used to analyze the relationship between the steel bar and the concrete. At the same time, the program realizes the whole process of the occurrence of concrete cracks, crack propagation and component damage during the load increment process.

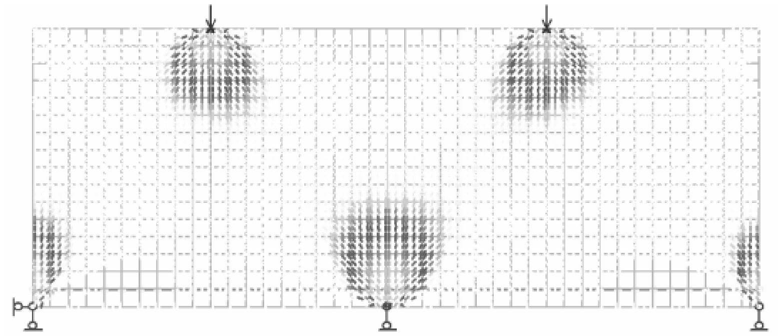

Figure 3 reinforced concrete crack expansion process

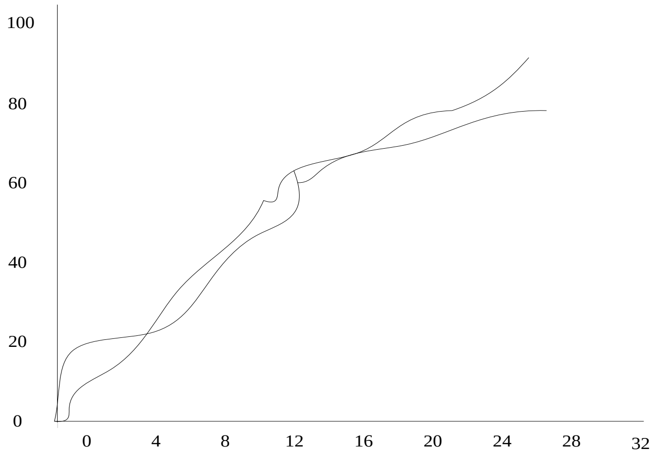

Fig. 4 Deflection-load comparison of the left cross of the beam

Note: The upper line is the test value; the lower line is the development software analysis value.

The purpose of establishing a stochastic model is to visually reflect the random nature of the occurrence and development of cracks on a component. The results of crack distribution obtained by finite element analysis based on stochastic simulation are closer to the actual situation because they reflect the influence of the random performance of the structural part. This has obvious effects on the stochastic characteristics of the simulated structure and the weak parts of the structure caused by randomness. It also provides ideas for the development of a complete reinforced concrete auxiliary test or simulation analysis software.

5. Conclusion

In the program test, the reliability of the nonlinear analysis of reinforced concrete and the validity of the work of random simulation of random variables are verified. In this paper, the Darwin-Pecknold model is used in the constitutive model. The concrete failure criterion is the bidirectional stress state failure criterion of Kupfer and Gerstle. The iterative method adopts the incremental iterative method. The deterministic model and the randomness model are considered in the mathematical model. The randomness is simulated by the Monte Carlo method. The reinforced concrete nonlinear finite element method has the characteristics of full-process simulation. For the widely used and complicated structure of reinforced concrete, it has the advantage that other methods can't match. The author explores the finite element method of reinforced concrete structure by stochastic simulation method and adaptive method, but there are still many problems to be further improved.

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