Study on Modeling Method of Reinforced Concrete Pier Based on OpenSees

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Abstract. In this paper, the method of model established on reinforced concrete pier based on OpenSees was studied, and the parameter sensitivity analysis to OpenSees was carried out according to the test data. On the basis of introducing the related material model and element type, how to determine material model and element division as well as section meshing were studied, and the method of model established both reasonable and effective was given. The model of concrete material which can improve the convergence of calculation and the model of reinforced materials which can simulate elastic and reinforced plastic stage accurately were given in this paper. The results show that the distributed plastic beam-column element based on displacement can get higher calculation precision. At the same time, the bridge pier structure should be meshed sufficient number of elements and grids to meet the requirement of calculated accuracy.

1. Introduction

The full name of OpenSees is an Open System for Earthquake Engineering Simulation(The word of OpenSees means Open System for Earthquake Engineering Simulation. It is funded by the National Natural Science Foundation (NSF), led by the Pacific Earthquake Engineering Research Center (PEER) of the Western University Coalition and developed by the University of California, Berkeley. A series of projects have shown that OpenSees has good nonlinear numerical simulation accuracy and has been recognized by many researchers at home and abroad[1-2]. OpenSees is a finite element software based on fiber model[3]. The fiber model divides the component section into a series of discrete fibers[4] to consider the force characteristics of the cross section. The fiber model is based on the following assumptions:

(1) The beam-column element section always stays a flat section during the whole section deformation process, which accord with flat section assumption, regardless of the shear and torsion and the influence of concrete cracking on cross section deformation.

(2) For the fiber in the section, it is assumed that a single fiber is in a uniaxial stress state. Therefore, concrete and reinforcement can respectively adopt concrete and steel under uniaxial constitutive relations, the stiffness and stress of the fiber can be obtained according to the constitutive relationship. By integrating the section, the stiffness and internal force of the section can be obtained. In the actual calculation process, the fiber and section stiffness are calculated by strain. Therefore, the fiber model can well reflect the degradation of stiffness and strength, the coupling action between P-M-M during component deformation. The fiber model has a good simulation effect for nonlinear reaction.

(3) It is considered that the reinforcement and the concrete are fully bonded in the reinforced concrete beam-column, and the influence of bond slip and shear slip is ignored. When using the fiber...
model need divide more evenly, but but the number of fiber should not be too much. The calculated results tend to converge once the quantity of discrete fibers reaches a certain number. The fiber model uses the uniaxial stress-strain relation of the material to get the stiffness matrix of the macroscopic section or component, which has higher calculation accuracy and smaller calculation amount.

2. Material Simulation

OpenSees provides a variety of concrete and steel materials for finite element simulations. There are commonly three kinds of reinforcement and four kinds of concrete for the finite element modeling of reinforced concrete piers concerned in this paper. For concrete materials, the Concrete01 model does not consider the tensile strength of concrete. Concrete02 and Concrete03 considered the tensile strength of concrete. The former considered that the tensile softening segment of concrete presented linear change, while the latter considered that the tensile softening segment of concrete presented nonlinear change. In Figure 1, taking the simulation of a pier as an example, the comparison investigate the influence of concrete-material constitutive models such as concrete-01, Concrete02, Concrete03 and ConfinedConcrete01 on the force-displacement skeleton curve of the pier. The results show that the calculation results of the first three constitutive models are consistent both in the elastic section and in the strengthened section after yielding, but the result obtained by using ConfinedConcrete01 is far from the above three curves. It can be concluded that the tensile strength of concrete is relatively small compared with the compressive strength, which has limited influence on the mechanical behavior of materials. Therefore, when using OpenSees to model, whether to consider the tensile strength of concrete has little effect on the result. However, the convergence of Concrete02 and Concrete03 models considering the tensile strength of concrete is worse than that of Concrete01.

![Figure 1. Influence on calculation results of concrete constitutive models](image)

For steel reinforcement, the Steel01 material model is a Kinematic hardening model, which can consider the impact of material anisotropy. The unidirectional tension constitutive curve is a model of double line. The Steel02 material unit is based on the Giuffre-Menegotto-Pinto model, which can be modified to take into account the isotropic effect, and the model considers the Bauschinger effect. Unidirectional tensile constitutive is also a double broken line model. The Hysteretic Material model takes into account the pinching of reinforcement under Hysteretic stress, the damage accumulation with ductility and energy dissipation so as to provide the corresponding input coefficient. The unidirectional tensile constitutive model is a trilinear model.

For reinforced concrete piers, the tensile strength of concrete is tiny compared with the compressive strength, the treatment method of softening section of concrete tensile strength has little influence on the hysteresis curve of the pier. Gu Zhengwei et al. [5] also verified this conclusion. Since both Steel01 and Steel02 are double broken line models, there is no significant difference in the simulation of reinforcement properties, but Steel02 has better convergence in finite element calculation. For the same material Hysteretic Material and Steel02, there is no significant difference between the elastic and plastic strengthening segments of the simulation unit. However, due to the
limitations of Steel02, which does not take into account material softening, the descending section of the unit hysteresis curve cannot be simulated. The Hysteretic Material provides multiple parameters, which can simulate the softening segment of the Material well to reflect the strength degradation of the structure.

To sum up, Concrete01 and Hysteretic Material are recommended for simulating reinforcement and concrete respectively in the pseudo-static test of bridge piers.

3. Elements Selection

Distributed plastic beam-column element in OpenSees include nonlinearBeamColumn and dispBeamColumn. The stiffness of nonlinearBeamColumn is allowed to change along along rod length. The resistance and tangent stiffness matrix of the whole element are obtained by determining the section resistance and section stiffness matrix of each section control section and by integrating along the length according to the Gauss-Lobatto integral. DispBeamColumn allows the stiffness to vary along rod length. First, the displacement of the element rod end is obtained by calculating the node displacement, and the deformation of the concerned section is calculated by using the displacement difference function. Then the corresponding section resistance and section stiffness matrix are obtained through the force-displacement relation of the section. Finally, based on the Gauss-Legendre integral method along the rod length to calculate the resistance and tangent stiffness matrix of the whole element.

In the actual calculation, the existing research results and modeling experience has shown that for pier bearing prophase, the calculation results of nonlinearBeamColumn and dispBeamColumn were similar, but in the later period, dispBeamColumn on the plastic area of cross section curvature fitting accuracy is higher, and the convergence speed is faster. Therefore, this paper adopts dispBeamColumn to modeling analysis.

4. Element Division and Mesh Generation

Element division refers to the number of elements divided along the pier height. The plastic deformation of the low pier mainly occurs in the pier bottom under lateral force. The element length in this region has significant influence on the calculation accuracy. The stress and deformation of the pier top are relatively small, so the element division has little influence. The elements are uniformly divided along the pier height for the convenience of modeling. In Figure 2, the simulation of a bridge pier is taken as an example to show the influence of the number of elements divided on the calculation results. At the beginning of structural loading and before yielding, the number of element divisions had little influence on the skeleton curve. After yielding, the calculation results of different element divisions were slightly different. When the number of element is 2, the calculation result has a large deviation. As the number of elements increases, the results tend to converge, and there is little change when the number of elements reaches 6 or above. But the more elements divided, the more time it takes to compute. Therefore, a element number of 5–8 can be considered as a more accurate calculation result.

![Figure 2](image1.png)  ![Figure 3](image2.png)

**Figure 2.** Influence on calculation results of number of elements meshed  
**Figure 3.** Influence on calculation results of number of fibers meshed
Mesh generation refers to the number of fibers divided on the cross section. The larger the number of fibers, the more accurately the strain and stress changes at different positions of the cross-section can be simulated, but the calculation amount is greatly increased, which also brings about the convergence problem. Figure 3 shows the comparison of the calculation results of dividing core concrete into different fiber counts. It can be seen from the figure that, the number of cross-sectional fiber divisions has almost no effect on the structural force-displacement skeleton curve at the beginning of structural loading and before yielding. After yielding, the results of cross-section fibers tend to be different, especially in the later loading stage. It can be seen from the figure that the calculated results tend to converge when the cross-section is divided into more than 8 fibers parallel to the lateral force direction. Therefore, it is recommended that core concrete be divided into 8 fibers in the longitudinal direction of section.

The strain difference between the material fibers perpendicular to the force direction is not large for a rectangular section, so the fiber division perpendicular to the force direction has little influence on the result. Dividing the cross-section into strips of fibers only in the direction perpendicular to the force can increase the calculation speed.

5. Accuracy Validation of Modeling Method

Based on the above analysis, four test piers were selected for finite element verification of the modeling method. Concrete01 was used to simulate the concrete, where the cross-sectional core concrete was improved with a confined concrete improvement model calculated using the Kent-Park model; Hysteretic Material was used to simulate the reinforcement; and dispBeamColumn was used for elements modeling. The four test piers selected in this paper are all derived from the pier data in the "Pseudo-static test of Chenglan Railway". The specific test parameters are shown in Table 1.

| Model number | Sectional Dimension (mm) | Effective Height (mm) | Reinforcement ratio | Stirrup Reinforcement ratio | Axial compression (kN) | Axial load ratio | Shear span ratio |
|--------------|--------------------------|-----------------------|--------------------|----------------------------|-----------------------|----------------|-----------------|
| C1           | 720×420                  | 840                   | 0.61%              | 0.12%                      | 120                   | 0.99%          | 2.0             |
| D1           | 720×420                  | 630                   | 0.93%              | 0.12%                      | 120                   | 0.99%          | 1.5             |
| E1           | 720×420                  | 840                   | 0.93%              | 0.12%                      | 240                   | 1.98%          | 2.0             |
| G1           | 720×420                  | 840                   | 0.93%              | 0.15%                      | 120                   | 0.99%          | 2.0             |

As shown in Figure 4~7, OpenSees model of the bridge pier according to the parameters suggested in this article can get good simulation results. The simulation results of the bearing capacity of each specimen and the declining process of load-bearing capacity after the elastic-plastic stage are in good agreement with the experimental data.
6. Conclusions

The method of model established on reinforced concrete pier based on OpenSees was studied in this paper. And the parameter sensitivity analysis to OpenSees was finished. On the basis of introducing relevant material models and element types, how to determine material model and element division as well as section meshing were studied. The method of model established both reasonable and effective was given as follows:

(1) For simulating concrete materials, based on the parameter analysis in OpenSees, Concrete01, Concrete02 and Concrete03 model can more accurately simulate the material constitutive relation of concrete, and the calculation results are similar. In order to improve the convergence of computations, it is recommended to use the Concrete01 model to simulate concrete materials.

(2) For simulating reinforcement materials, compared with Steel01 and Steel02, the Hysteretic Material can not only simulate the elastic and plastic strengthening segments of the element well, but also simulate the falling segment of the hysteretic curve by considering material softening.

(3) For elements selection, the higher calculation accuracy and the better convergence can be obtained by using dispBeamColumn.

(4) For the elements division and mesh division, model parameter analysis shows that a higher calculation accuracy can be obtained by dividing about 5 elements along the height for bridge pier simulation, and the numbers of section fibers can be divided into 5-8 and try to keep the fibers in two dimensions with the same length, so that good convergence results can be obtained.
(5) The test results of four piers in the pseudo-static test of Chenglan Railway are selected to verify the accuracy of the modeling method in this paper. The results show that the material model and element model proposed in this paper can achieve better numerical simulation results.

7. References

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