Research on Numerical Simulation of Laminated Rubber Bearing

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Abstract: Based on the test of laminated rubber bearing GYZ250*77 in the literature, the finite element analysis model of the bearing is established by using ANSYS analysis software. The bearing force can be calculated by considering different modeling methods and different load application methods, and the analysis results are compared with the test results. The results show that when the laminated rubber bearing performance is simulated and analyzed under vertical loads, the rigid zone loading method or the steel plate loading method should be selected according to the specific conditions, rather than the direct loading method; Both solid model analysis and plane model analysis can simulate the effect of vertical load on the laminated rubber bearing. The research results provide a reference for the numerical simulation analysis of the laminated rubber bearing.

1. Introduction

As an important part of the bridge structure, the bridge bearing is designed to reliably transfer the reaction of the superstructure to the pier and abutment and to complete the deformation required by the bridge structure, so that the quality of bridge bearing will directly affect the service life and structural safety of the bridge. At present, the laboratory tests are mostly used to evaluate the mechanical properties of bearings, and the numerical simulation analysis is seldom carried out, so that there are relatively less research data on the numerical simulation.

Based on the test of laminated rubber bearing GYZ250*77 in the literature [2], ANSYS analysis software is used to establish the finite element analysis model of the bearing in this paper. The bearing force can be calculated by considering different modeling methods and different load application methods, and the analysis results are compared with the test results.

2. Basic Theory

The behavior characteristics of rubber bearings are non-linear. However, in view of the simplicity and practicability, the linear elastic theory can also be used to analyze the mechanical properties of rubber bearings. There are at least four different linear elastic theories that can be used to predict the behavior characteristics of bearings in the compression tests. At present, the more mature constitutive models include polynomial model and Ogden model based on continuum mechanics theory, as well as the follow-up model based on statistical thermodynamics theory. In order to simplify the calculation, a Mooney-Rivlin model based on continuum mechanics theory is adopted.
3. Model building

The rubber and steel plate in the rubber bearing are always constrained together in the manufacturing and application process. For the purpose of the simplification of the model, the conode is used between the rubber and steel plate in the finite element model.

3.1 Planar model

Based on the geometrical shape and symmetry of the loading condition of the circular laminated rubber bearing under the axial compression, a planar model can be established for the finite element analysis. In the finite element model, PLANE182 element is used for rubber material. This element is a 2-D four-node solid structural element, and each node has two degrees of freedom and can be used as a plane element or an axisymmetric element.

The stress-strain constitutive relation of the thin steel plate in the bearing is described by the bilinear method. Its elastic modulus is 206 GPa and Poisson's ratio is 0.3. PLANE42 element is used in the finite element model.

Taking the laminated rubber bearing GYZ250*77 as an example, the finite element model is established. The thickness of the surface rubber and the middle rubber layers of the bearing GYZ250*77 is 4 mm and 8 mm, respectively, and the middle steel plate thickness is 3 mm. There is a total of 7 layers. The planar model is shown in Figure 1.

3.2 Solid model

In the solid finite element model, solid185 element is used for rubber material, which is used to construct the three-dimensional solid structure. The element is defined by 8 nodes, each of which has 3 degrees of freedom to move along the xyz directions. The thin steel plate in the bearing uses solid95 element, which has 20 nodes and each node has 3 degrees of freedom (XYZ directions). The solid model is shown in Figure 2.

4. Determination of Load Application Method

In the experiment of literature [2], the bearing is loaded by 10 MPa. In the finite element analysis, the plane model is analyzed by different loading methods to determine the appropriate loading mode.

Three different loading methods are used, which are introduced as follows.

(1) Direct loading

The 10 MPa uniform load is applied directly on the upper part of the planar model. The load application is shown in Figure 3.

(2) Rigid region loading

A point is found in the middle of the upper part of the planar model to form a rigid region with other upper joints. A concentrated force of 2,500 N is applied in the middle part of the planar model. The load application is shown in Figure 4.

(3) Additional steel plate loading

The bearing is usually clamped on the instrument by steel plate to apply pressure when the manufacturing test is conducted; therefore, a certain thick steel plate should be established in the upper part of the planar model, and the larger elastic modulus of the steel plate should be selected without considering the weight. The 10 MPa uniform load is applied on the steel plate. The load application is shown in Figure 5.
5. Analysis of Calculation Results

5.1 Planar model results
In the experiment of literature [2], the bearing is loaded by 10 MPa, and the vertical deformation is between 1.941 mm and 2.562 mm. According to the Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts (JTG D62-2004), the compressive deformation value is 2.3038 mm. After three different loading methods are adopted, the vertical deformation calculated is shown respectively in Figure 6.

The comparison of the test results, the normative calculated values and the finite element calculation results is shown in Table 1.
Table 1. Comparison of maximum vertical displacement of bearing center (unit: mm).

| Loading methods                          | Calculated values | Test values | Normative calculated values |
|-----------------------------------------|-------------------|-------------|-----------------------------|
| Direct loading method                   | 0.482             | 1.941–2.562 | 2.124                       |
| Rigid region loading method             | 2.131             | 1.941–2.562 | 2.124                       |
| Additional steel plate loading method   | 2.131             | 1.941–2.562 | 2.124                       |

From the Fig. 6, it can be seen that the deformation of the bearing with direct loading method is quite different from the other two loading methods. Because of the small constraints on both sides of the bearing, the maximum deformation value is 4.87 mm. The deformation of the rigid region loading method is consistent with that of the additional steel plate loading method, which conforms to the test bearing deformation in the experiment of literature [2].

It can be seen from the Tab. 1 that the maximum deformation of the bearing center by the direct loading method is 0.453 mm, which is quite different from the measured test values; the maximum displacement of the bearing center by the rigid region loading method and the additional steel plate loading method is 2.131 mm, which is within the range of the test value and is close to the normative calculated value (2.124 mm).

Therefore, the direct loading method is not applicable to the simulation analysis of the bearing by the planar model. The rigid region loading method and the additional steel plate loading method should be selected in accordance with specific conditions to apply the vertical load.

5.2 Solid model results

The calculation of vertical deformation of the bearing by the solid model is as shown in Fig. 7. The figure shows that the vertical deformation of the center position is about 2.31 mm.

The comparison of the test results, the normative calculated values and the finite element calculation results is shown in Table 2.

It can be seen from the table that the vertical displacement value calculated by the solid model is 2.31 mm, which is not different from the test value and the normative calculated value. The calculation by the solid model conforms to the actual bearing deformation.

Table 2. Comparison of maximum vertical displacement of bearing center (unit: mm).

| Model        | Calculated values | Test values | Normative calculated values |
|--------------|-------------------|-------------|-----------------------------|
| Solid model  | 2.31              | 1.941–2.562 | 2.124                       |

6. Conclusions
Referring to the test value of laminated rubber bearing GYZ250*77 in the literature, the finite element model is used to analyze. The conclusions are as follows.

(1) When the laminated rubber bearing performance is simulated and analyzed under vertical loads,
the rigid zone loading method or the steel plate loading method should be selected according to the specific conditions, rather than the direct loading method;

(2) Both solid model analysis and plane model analysis can be used to simulate the effect of vertical load on plate rubber bearings. In order to save time and capital, the analysis model should be selected according to the specific analysis purpose.

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