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Parametric Analysis of Laminated Rubber Bearings with Frictional Sliding

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Abstract. The behavior of laminated rubber bearings with frictional sliding was studied by finite element method. The results showed that by using the coulomb friction model better reflect the sliding bearing energy dissipation effect, but it cannot consider the static and dynamic friction transition relationship of the initial slip to the slip state and the change of friction coefficient caused by heating or wear. Therefore, it cannot reflect the degradation of the strength before the initial loading and the hardening phenomenon under the large displacement. The energy dissipation of the bearings was independent of the applied vertical force, and increased with the shear deformation. With the increase of the rubber layer thickness, the equivalent viscous damping ratio and the horizontal equivalent stiffness will decrease. For the change of bearing width, the equivalent viscous damping ratio has little effect on the change trend. The influence of the thickness of the rubber layer and the width of the support on the change trend of the sliding characteristics were too indistinct to describe the variation trend and impact of the bearing sliding characteristics.

Keywords: Analysis, Laminated Rubber Bearings, Frictional Sliding

INTRODUCTION

In the medium and small span bridges, the Laminated rubber bearings (hereinafter referred to as bearings) are usually used to connect the upper and lower structures, under the earthquake load, the inertia force generated by the superstructure will be transferred to the pier through the bearing, and the horizontal force transferred by the bearing can control the damage degree of the substructure. Rubber bearings played an important role in the previous earthquake damage. The failure modes of bridge structures in Chi-Chi earthquake were discussed by reference [1], it was found that the damage location of the upper structure and the bearings is accompanied by the damage mode of the minor damage of the substructure. In the literature [2], the bridge that destroys the bearing in the Wenchuan earthquake is analyzed. Through the numerical simulation analysis and the shaking table test account for the reason why the displacement rate of the main girder is higher and the pier is less. The results showed that the frictional sliding of the bearings can protect the destruction of the substructure, and the support plays the role of "fuse". So the seismic design of small and medium span bridges can use friction slipping of bearings [3].

In view of the important role played by the friction slipping of the support in the seismic design of bridges, foreign and Taiwan scholars have done a lot of research Steelman and others[4-6] are carried out a large number of bearing tests and the parameters of friction, stiffness and damping ratio were analyzed. And put forward the related computation model. Gordon and others used finite element analysis method to establish the support analysis model and the test results are used to verify the parameters. However, the research results of rubber bearings in mainland China are mainly concentrated in the construction of seismic isolation, after the earthquake in Wenchuan, although many scholars have realized the importance of the friction sliding of the support in the bridge seismic, but there is little research on it.

In order to study the influence factors of the friction and slip characteristics of the support, the 2D plane strain model of Abaqus is used to analyze the parameters on the basis of experimental study on seismic performance of friction sliding under different compressive stresses. Firstly, by comparing the finite element analysis results and the test results, the rationality of the finite element analysis model is demonstrated, and the geometric parameter analysis model is established. In rubber layer is the same case, the influence of the bearing slip characteristics is analyzed by changing the rubber layer thickness and bearing width on laminated rubber bearings. The analysis results can be used to guide the next step of the test and theoretical analysis to study the establishment of a reasonable mechanical model of the bearing for the seismic design and analysis of the bridge structure.

NUMERICAL SIMULATION OF FRICTION AND SLIDING CHARACTERISTICS OF BEARINGS

In the analysis of the model involves super elastic properties of rubber materials, geometrical non-linearity and contact nonlinearity. In this regard, Abaqus can choose the appropriate load increment and convergence criteria, and constantly adjust the values in the analysis process, to ensure the exact solution [9]. In this paper, the Abaqus is used to simulate the friction sliding characteristics of the test support.

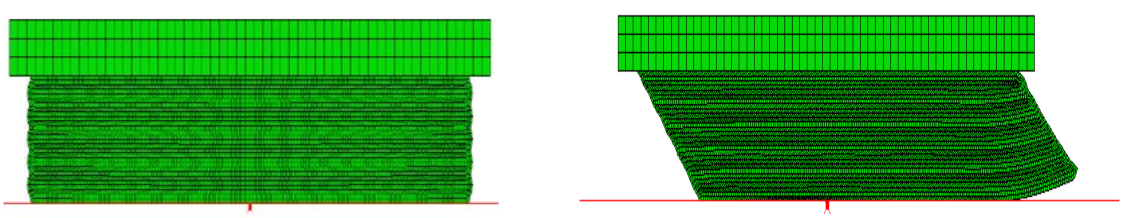
Selection of materials and units

It is different with small deformation materials such as steel bars and concrete, rubber has a lower shear modulus, a large deformation occurs under the action of the load and rubber is almost incompressible material. In ABAQUS, simulate the stress reaction of rubber by defining the super elastic material and Hybrid unit. This can be a better solution to the volume of rubber material self-locking problem. The characteristics of rubber material can be defined by Mooney-Rivlin model, the relevant test data of rubber materials supplied by the manufacturer of the bearing and parameters obtained by ABAQUS calculation: C_{10}=0.53， C_{01}=0.12, at the same time, take D1=0 as an incompressible material. Moreover, take into account the computational cost of the 3D entity and the fine division. In this paper, the plane strain model is simplified by using 2D, the rubber layer is defined as a 4 node and bilinear plane strain solid element, namely CPE4H, which satisfies the plane strain assumption [7].

For the inner bearing and top anchor plate of bearing, it will not enter the plastic stage under the test load, so the use of simple linear elastic material to define: $E=2\times10^5$MPa，V=0.3。The 4 node plane strain nonconforming element is adopted, namely CPE4I.

Analysis of hysteretic curve with frictional sliding

The hysteretic curve is the comprehensive reflection of the seismic performance of the structure, and is also the main basis for the analysis of the seismic performance of the structure. The horizontal force displacement hysteresis curves under different compressive stresses are compared with experimental results, as shown in Figure 2, the dashed line is the result of finite element analysis, the solid line is the test results. The results show that the calculated curves are in good agreement with the experimental curves, which indicates that the finite element model can well reflect the characteristics of horizontal shear deformation and hysteretic energy dissipation under load. The deviation is that the Coulomb friction model is used in the finite element analysis, which cannot reflect the degradation of the initial sliding strength and the hardening phenomenon under the large displacement.



（a）P=8MPa The vertical deformation （b）P=8MPa,Shear strain =200%,

Fig.1 2D Plain strain mode

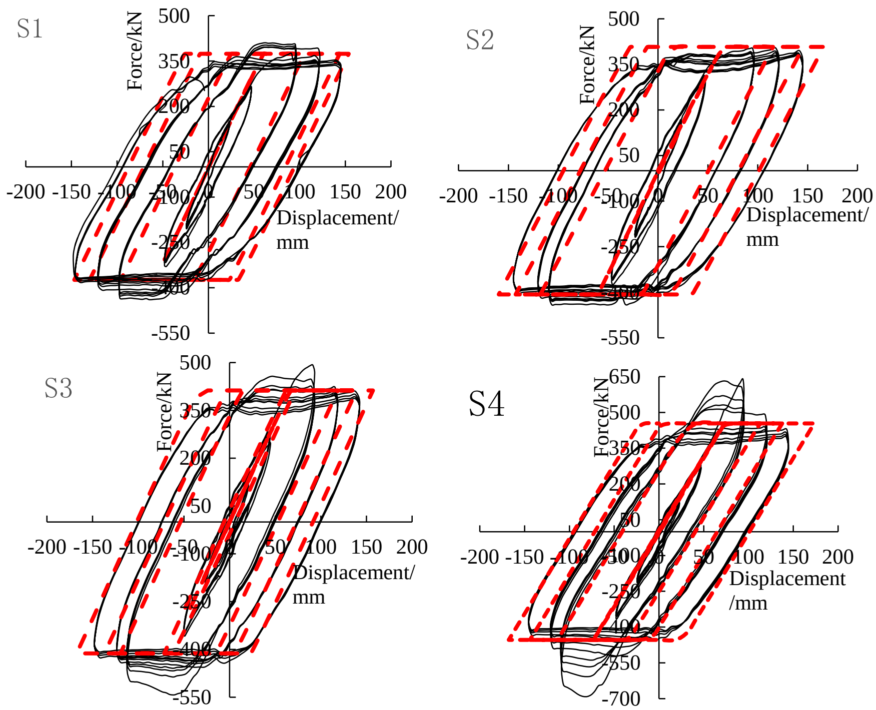


Fig.2 Comparison between FEM analysis and test results

Table 1 Model parameters

No.	Type	Thickness of single layer/mm	Number of rubber layer	Total thickness of rubber /mm	Shape factor	Pressure/MPa
S4	GJZ 500×550×78	9.8	5	48	13.4	10
S5	GJZ 500×550×90	12.5	5	62.5	10.5	10
S6	GJZ 500×550×110	15	5	75	8.7	10
S7	GJZ 400×500×78	9.8	5	48	11.7	10
S8	GJZ 300×500×78	9.8	5	48	9.8	10

PARAMETER ANALYSIS

The comparison between the hysteresis curve and the equivalent viscous damping ratio shows that the finite element model is reasonable. On the basis of the analysis model, the model with different thickness and different width is set up to further analyze the influence of the geometric shape coefficient on the friction and slip characteristics of the support. The parameters are shown in Table 3. In the analysis model of rubber layer thickness and width, the parameter of material, boundary conditions and solving process of the model are consistent with the reference model.

Figure 3 shows the equivalent viscous damping ratio of the bearing with different rubber layers under the same horizontal displacement. It can be seen from the figure that the equivalent viscous damping ratio decreases with the increase of the thickness of rubber layer in the same shear deformation. Although the thickness of rubber layer increases, it will produce relatively large shear deformation, at this time, the support is not easy to slip, and the energy consumption under the same displacement is less than the relatively short bearing.

Figure 4 shows the relationship between the thickness of the different rubber layers and the horizontal equivalent stiffness when the vertical compressive stress is 10 MPa. When the same shear strain is applied, the horizontal equivalent stiffness decreases with the increase of the thickness of the rubber layer. When the shear strain is larger, the decrease degree is slower than the shear strain. Such as γ was 200% fell by 45%, and dropped by 35% when γ was 250%. Since the shear strain reaches 200%, the reaction of the support is shown as slip.

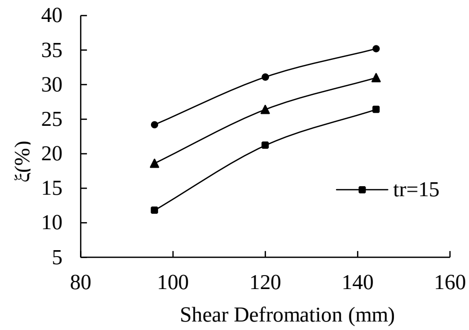


Fig.3 The influence of rubber layer thickness on EQVD ration

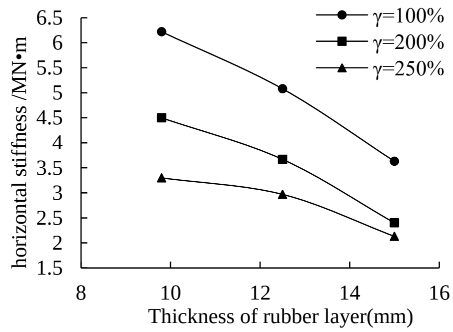


Fig.4 The influence of rubber layer thickness on the equivalent stiffness

CONCLUSION

(1) By using the coulomb friction model better reflect the sliding bearing energy dissipation effect, but it cannot consider the static and dynamic friction transition relationship of the initial slip to the slip state and the change of friction coefficient caused by heating or wear. Therefore, it cannot reflect the degradation of the strength before the initial loading and the hardening phenomenon under the large displacement.
(2) The energy dissipation of the bearings was independent of the applied vertical force, and increased with the shear deformation.
(3) With the increase of the rubber layer thickness, the equivalent viscous damping ratio and the horizontal equivalent stiffness will decrease. For the change of bearing width, the equivalent viscous damping ratio has little effect on the change trend.
(4) The influence of the thickness of the rubber layer and the width of the support on the change trend of the sliding characteristics were too indistinct to describe the variation trend and impact of the bearing sliding characteristics.

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REFERENCES

[1] Kuo-Chun Chang, Chih-Hung Lu, and Kuang-Yen Liu. Displacement-based Design for Highway Bridges with Function Bearing System [R]. Taiwan: NATIONAL CENTER FOR RESEARCH ON EARTH- QUAKE ENGINEERING.2011(in Chinese)
[2] Li Chong, Wang Kehai, Li Yue, el at. Experimental Study on Seismic Performance of Laminated Rubber Bearings with Friction Slipping [J]. Journal of Southeast University (English Edition), 2014, 44(1):162-167(in Chinese)
[3] J.S. Steelman, L.A. Fahnestock et al. Shear and Friction Response of Nonseismic Laminated Elastomeric Bridge Bearings Subject to Seismic Demands [J]. Journal of Bridge Engineering, 2013,18:612-623.
[4] Ian Buckle, Satish Nagarajaiah, and Keith Ferrell. Stability of Elastomeric Isolation Bearings: Experimental Study [J]. Journal of Structural Engineering, 2002,128:3-11.
[5] Sarvesh Kumar Jain, Shashi Kant Thakkar. Experiment Investigations on Laminated Rubber Bearings [J]. Bulletin of Earthquake Engineering, 2005,3:129-136.
[6] Gordon P. Warn, and Jared Weisman. Parametric finite element investigation of the critical load capacity of elastomeric strip bearings [J]. Engineering Structures, 2011,33:3509-3515.
[7] Huma Kanta Mishra, Akira Igarashi, and Hiroshi Matsushima. Finite element analysis and experimental verification of the scrap tire rubber pad isolator [J]. Bulletin of Earthquake Engineering, 2013,11:687-707.
[8] Wang Lu, Ou Jin, Wang Shu-guang, el at. Nonlinear Finite Element Analysis of Elastic Sliding Bearing Based on ABAQUS [J]. Journal of Nanjing University of Technology(Natural Science Edition), 2010,32[4]:49-53(in Chinese)
[9] Li Zhijun, Ge Fei, Xu Xiuli, el at. Finite Element Simulation and Experimental Study of Property for Elastomeric Pad Bearing [J]. Journal of Southeast University (Natural Science Edition), 2013,43(6):1299-1304(in Chinese)
[10] Dassault Co. Ltd. ABAQUS Theory Manual [M]. Version 6.9.1. France: Dassault Co. Ltd. 2009.