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Numerical study on the end rotation effect of elastomeric bearings on their mechanical behavior in flexible bridges

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ABSTRACT: When elastomeric bearings support the deck of long-spans or tall pier bridges, they experience end rotation and it can change the seismic performance of the whole isolated system. So far, the behavior of these bearings has been numerically modeled under individual actions (compression, shear, or bending) or combined compression and shear load. However, the effect of end rotation on the response of elastomeric bearings and its numerical model in combination with different load actions have not been considered well. In the current study, we used a two-dimensional mechanical model of elastomeric bearings that simulate the effect of end rotation in the combined action of pressure, shear and end rotation. The test results indicate that bearing rotational stiffness increases with the increasing vertical load but decreases with increasing shear deformation. Further, end rotation does not affect the critical displacement appreciably, but it significantly influences the critical shear force.

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1- Introduction

Elastomeric bearings, which consist of rubber layers interleaved with steel reinforcing plates, are one of the most popular seismic isolation systems. Various studies on the behavior of these bearings, assuming no rotation of the top/bottom supports, involved quasi-static and dynamic tests of bearings. Hakimian and Taghikhany carried out dynamic tests to investigate the behavior of the bearing under lateral cyclic displacement, constant axial load. It was shown the lateral stiffness of the bearing decreases with increasing axial load or lateral displacement [1]. Recent studies aimed to investigate the effect of rotation on the behavior of bearings experimentally or numerically. Crowder and Becker experimentally studied column-top isolation in a retrofit application and showed that, in the case of flexible columns, the endplate rotation due to the column's flexibility causes appreciable reduction in the lateral stiffness of the bearing [2]. Rastgoo Moghadam and Konstantinidis have performed FEA and experimental analyses to simulate the nonlinear behavior of elastomeric bearings under various boundary conditions. It was concluded that imposing rotation at the supports, depending on the rotation value and axial force, can appreciably influence the lateral behavior of a rubber bearing [3]. While finite element or experimental models are indispensable for developing a good understanding of the behavior of elastomeric bearings, both at the global and local level, they are computationally much costlier and less practical than simple mechanical models. The first two-spring simple mechanical model was proposed by Koh and Kelly, to study the stability of elastomeric isolators [4]. Ishii et al. extended the previous model by Yamamoto et al. [5] to account for the effect of rotation on the horizontal behavior of elastomeric bearings [6]. It was shown that end rotations do not affect the critical displacement. The main objective of this paper is to present the mechanical model extended by Ishii et al. furthermore evaluate its performance by comparing its predictions to the results of FEA and experimental data.

2- Mechanical Model

Figure1 shows the mechanical model for elastomeric bearings developed by Ishii et al. [6]. This model is developed for a two-dimensional system, and consists of a series of axial springs at the top, mid-height, and bottom of the bearing. Nonlinear hysteretic relationships are defined for each axial spring to simulate the compression and bending behavior of the bearings. Additional axial spring and a shear spring are located at the center of the mid-height layer. Used to FEM the model is divided into three parts of a-m, m-n and n-b. The relationship between incremental forces and incremental displacements of the a-m, m-n and n-b, respectively is

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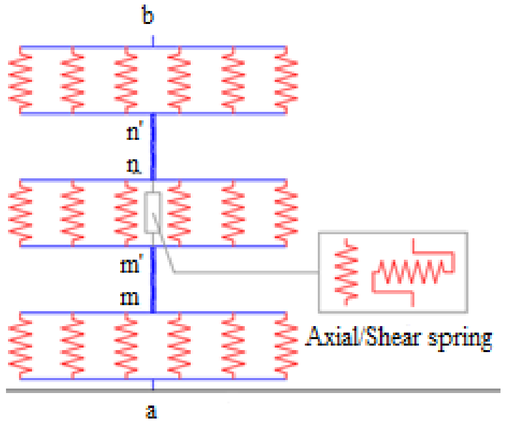

Fig. 1. Three layers multi-spring mechanical model

expressed as

$$\Delta^{am} f = {}^{am}k\, \Delta^{am} u \tag{1}$$

$$\Delta^{mn} f = {}^{mn}k\, \Delta^{mn} u \tag{2}$$

$$\Delta^{nb} f = {}^{nb}k\, \Delta^{nb} u \tag{3}$$

The relationship between incremental forces and incremental displacements of the overall bearing element is obtained from Equations (1), (2) and (3) as below,

$$\Delta^{ab} f = {}^{ab}k\, \Delta^{ab} u \tag{4}$$

Each spring in the multiple axial spring component represents an individual strip of the bearing's cross-sectional area, and is located at the center of gravity of the individual strip. The spring constant of each spring ${}_ik$ is calculated as

$${}_ik = \frac{{}_ie\,{}_ia\,{}_i\Phi}{l} \tag{5}$$

Where ${}_ie$ ${}_ia$ and l are the elastic modulus, the area of the strip and the fictitious computational length of the spring. The overlapping factor ${}_i\varnothing$ ${}_i\Phi$ is used to calculate the effective sectional area of multiple axial springs. The horizontal stiffness of the bearing is represented by the shear spring which is located at the center of the mid-height layer. The condition can be expressed as

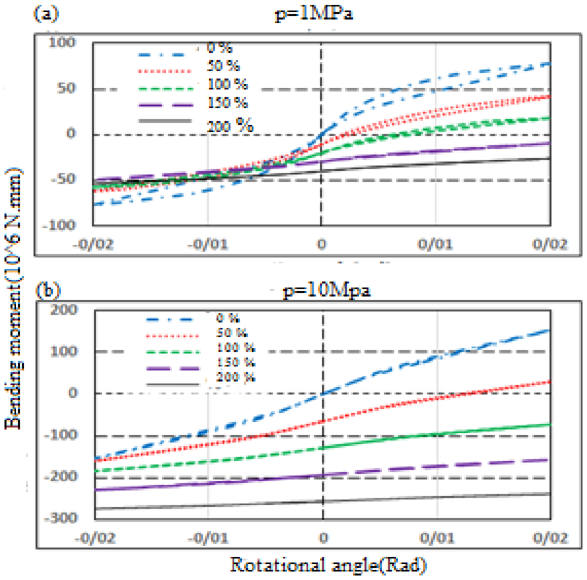

Fig. 2. Bending moment-rotational angle relationship

$$k_s = k_H = \frac{GA}{h_r} \tag{6}$$

Where G, A and h_r are the Shear modulus, the area is the cross-sectional area and the total thickness of the rubber pad. The incremental nonlinear analysis was conducted using an updated Lagrangian formulation and Newton-Raphson iteration method.

3- Results and Discussion

Figure 2 shows the result of the bending moment. Rotational angle relationship for the bearing with aspect ratio equal to 4. The rotational stiffness decreases with increasing offset shear strain and increases with increasing compressive stress. The bending moment at zero rotation is a result of the offset shear deformation in the bearing. Figure 3 shows the comparison of the FEA and the Exp with mechanical model (MM) results for the bearing with an aspect ratio equal to 4. The results showed that the mechanical model is able to simulate the effect of rotation on the lateral behavior of the bearing. The results showed that the rotation causes the hysteresis loops to shift up. As can be seen, the results in estimating the initial lateral stiffness are in a relatively good agreement.

4- Conclusions

This paper investigated the behavior and mechanical properties of the elastomeric bearings use to the simple mechanical models under combined applied loading, which included support rotation (it is prevalent in bridge applications). Static bending tests under various combinations of vertical load and shear deformation were performed to identify the mechanical characteristics of bearings. The results indicate that bearing rotational stiffness decreases with increasing

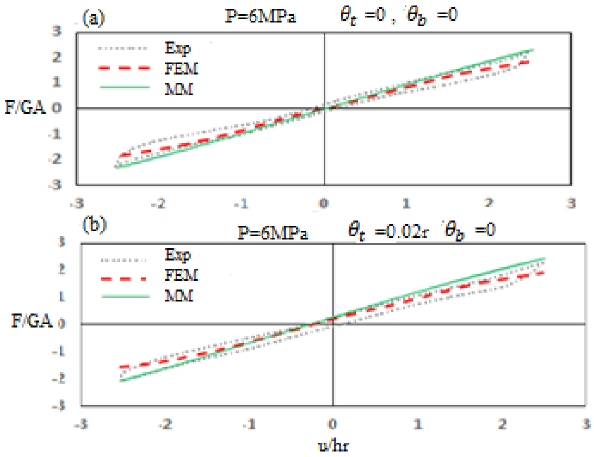

Fig. 3. Comparison of shear force-lateral displacement curves obtained FEA, Experimental and MM

offset shear strain, and increases with increasing compressive stress. The effect of support rotation on the lateral behavior of elastomeric bearings revealed that rotation causes the hysteresis loops to shift up. Increasing rotation angle and axial load accentuated this shifting. So, support rotation has a minimal effect on the critical displacement, but it does affect the critical shear force.

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