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NON-LINEAR MODEL OF HIGH DAMPING RUBBER BEARING

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SUMMARY

Among several methods of base isolation of structures, application of High Damping Rubber Bearings (HDRBs) seems to be one of the most promising. However, HDRB shows highly non-linear behavior which depends on shear strain and its rate. It can also be influenced by change of an axial load or temperature. In order to simulate the behavior of such a device accurately, a commonly used simple linear model is not recommended. The aim of this paper is to analyze a non-linear, strain rate dependent model of a high damping rubber bearing. A horizontal response of the device under specified vertical pressure is simulated by a non-linear elastic spring-dashpot. The parameters of the model are obtained by fitting the experimental data using the method of the least squares. In order to check its effectiveness, a simulation of behavior of two HDRBs is conducted. The results of the study show that the model considered is able to simulate the behavior of a bearing over a wide shear strain range. It can describe high stiffness properties for low amplitudes and hardening effect at higher strain levels.

INTRODUCTION

Base isolation has been recognized to be a very effective way of protecting structures from damage during earthquakes [1, 2]. The aim of the method is to extend a natural structural period in order to avoid resonance with the ground motion. Moreover by adding damping to the isolation devices more energy can be dissipated out of the structure. Among several methods of seismic isolation, application of High Damping Rubber Bearings (HDRBs) is one of the most effective. Various models are applied to simulate the horizontal behavior of HDRB. Due to its simplicity, a viscoelastic linear model is often used for the design purposes of isolated structures equipped with HDRBs [3]. In the model, the effective stiffness, K, and the equivalent damping ratio, ξ, are considered constant during the time of earthquake. These parameters are determined from the hysteresis loop of a bearing obtained for the design displacement, u, using formulas [4]:

$$K = \frac{F(u) - F(-u)}{2u}, \tag{1}$$

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$$\xi = \frac{\Delta W}{2\pi W}, \tag{2}$$

where $F(u)$ is a lateral force at displacement u, ΔW is an energy dissipated in each cycle (area enclosed by the hysteresis loop) and W is a strain energy induced in a bearing:

$$W = F(u) \cdot u. \tag{3}$$

In order to simulate the shape of the design hysteresis loop more accurately, bilinear and tri-linear models have also been applied [5].

In this paper, an accurate non-linear strain rate dependent model of HDRB is considered. In the model, the horizontal response of a bearing under specified vertical load is described by a non-linear elastic spring-dashpot element. The parameters of the model are obtained by fitting the experimental data using the method of the least squares.

MODEL FORMULATION

Because of properties of rubber, a high damping rubber bearing shows highly non-linear hysteretic behavior depending on shear strain and its rate. Its response can also be changed by axial pressure or internal temperature [6]. Moreover, the behavior of HDRB is different for various rubber compounds depending on additives used and the production process. This makes difficulty in defining the general model taking into account the shape factors and the properties of the bearing layers. Therefore in this paper, a model, which attempts to fit directly a set of experimentally obtained hysteresis loops for different shear strains (under specified vertical load) is considered. The model describes the behavior of a bearing by a non-linear elastic spring-dashpot element (see also [7]). The shear stiffness, K, and damping, C, coefficients at a given time, t, are obtained based on the actual values of displacement, $u(t)$, and velocity, $\dot{u}(t)$, using formulas:

$$K = a_1 + a_2 u^2(t) + a_3 u^4(t) + \frac{a_4}{\cosh^2\left(a_5 \dot{u}(t)\right)} + \frac{a_6}{\cosh\left(a_7 \dot{u}(t)\right)\cosh\left(a_8 u(t)\right)}, \tag{4}$$

$$C = \frac{a_9 + a_{10} u^2(t)}{\sqrt{a_{11}^2 + \dot{u}^2(t)}}, \tag{5}$$

where a_1-a_{11} are parameters of the model, which are obtained by fitting the experimental data using the method of the least squares. In the above formulation, value of a_1 sets the basic stiffness level which is modified by a_2 and a_3 for higher shear strains. Parameters a_4, a_5 control the stiffness close to the maximum displacements $\left(\dot{u}(t) \approx 0\right)$ and a_6-a_8 increase stiffness value in case of motions with lower amplitudes. Finally, parameters a_9-a_{11} change the value of damping in order to obtain the appropriate shape of the loops.

SIMULATION ANALYSIS

In order to check the effectiveness of the model defined by eq. (4-5), behavior of several HDRBs has been simulated. In this paper, however, the simulation results for two isolation devices are presented. In the first case, one of the high damping rubber bearings (Indonesian bearing H14) tested by Taniwangsa et al. [8] is considered. The analyzed bearing was excited with a frequency of 0.5 Hz under the axial pressure of 3.9 MPa. The experimental hysteresis loops for the device, together with the simulated ones for the optimized set of parameters: a_1=4.1051·10^5, a_2=-1.7238·10^3, a_3=-98.611, a_4=1.2261·10^5, a_5=5.0777, a_6=3.5740·10^5, a_7=6.9069, a_8=48.371, a_9=1.0169·10^4, a_{10}=8.0471·10^4, a_{11}=0.15621 are shown in Figure 1.

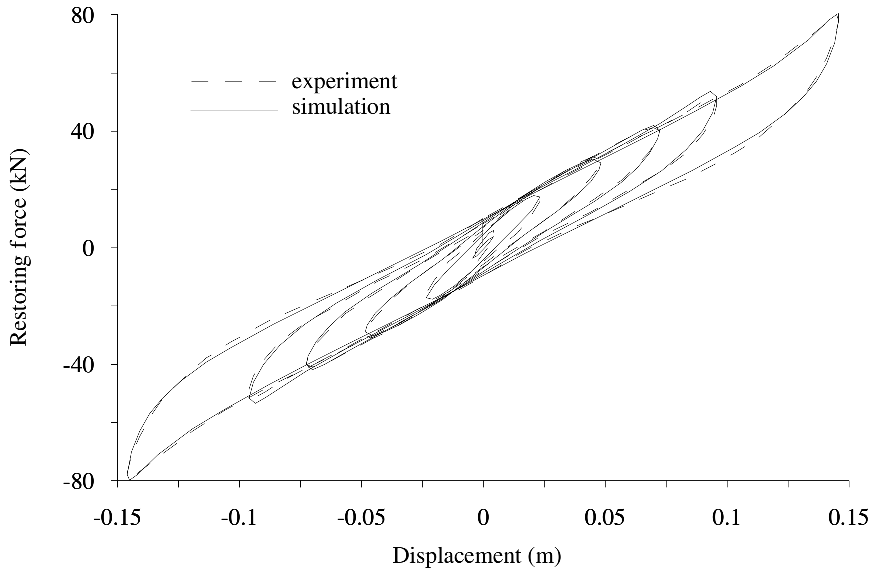

Figure 1. Experimental and simulated hysteresis loops for HDRB (case 1).

For the second case, the results of the experiment conducted on HDRB which was weighted with 12.5 tones and excited with constant frequency of 0.5 Hz are applied. This time, the optimized parameters of the model have been found to be: a_1=21.239, a_2=343.10, a_3=-876.70, a_4=51.829, a_5=4.3595, a_6=58.676, a_7=3.9664, a_8=91.482, a_9=1.5377, a_{10}=40.868, a_{11}=0.13985. The experimental and simulated hysteresis loops of the bearing are presented in Figure 2.

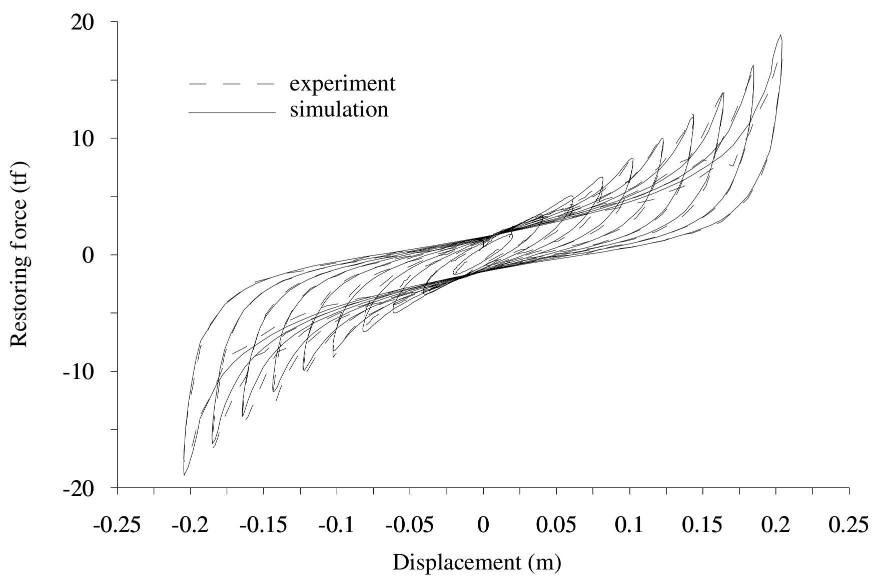

Figure 2. Experimental and simulated hysteresis loops for HDRB (case 2).

CONCLUSIONS

In this paper, a non-linear strain rate dependent model simulating the horizontal behavior of a high damping rubber bearing has been analyzed. The results of the study show that the considered model is capable to simulate the behavior of a bearing over a wide shear strain range. It can describe high stiffness properties in case of motions with low amplitudes. It can also precisely simulate the hardening of the device at higher strain levels. The simulation results confirm the effectiveness of the model.

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