A MODIFIED RHEOLOGY MODEL FOR HIGH DAMPING RUBBER BEARINGS

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1. INTRODUCTION

The use of seismic isolation is one of the most effect ways to protect structures from destructive earthquakes. The application of rubber bearings for structures increased rapidly after Kobe earthquake in 1995 due to the needs of great seismic performance for bridge structures. Especially, High Damping Rubber Bearings (HDRBs) are one of most implemented types in Japan. However, even after years of practice, some of the important hysteresis behaviors of HDRBs are still left as difficult and complex issues.

Experimental observations (Bhuiyan et al , 2009 ; Dall'Asta and Ragni, 2006) show that mechanical properties of HDRBs are dominated by the nonlinear rate dependence. Since the simplified models in guide specifications (AASHTO, 2004; JRA, 2002) neglecting rate dependence do not furnish an adequate description of the dynamic behavior of HDRBs, a design model of HDRBs should take the rate-dependent behavior into account.

In this study, a hysteresis model of HDRBs is developed for bridge seismic design. For this purpose, a modified model is proposed from the rheology model of Bhuiyan et al. (2009). The model is proposed based on a simple modification of the rheology model (Bhuiyan et al, 2009).

2. A MODIFIED RHEOLOGY MODEL

The configuration of the new model can be presented by Fig. 1. The rate-independent equilibrium response is described by the first and second branches, while the rate-dependent overstress response is represented by the third branch. The total stress can consequently be expressed as follow

$$\tau = \tau_{ep} + \tau_{ee} + \tau_{oe} \quad (1)$$

where, τ_{ep} is the elasto-plastic stress in the first branch

$$\tau_{ep} = C_1^{(EQ)}\gamma_{a1} \text{ with } \begin{cases} \dot{\gamma}_{s1} \neq 0 & for \quad |\tau_{ep}| = \tau_{cr}^{(EQ)} \\ \dot{\gamma}_{s1} = 0 & for \quad |\tau_{ep}| < \tau_{cr}^{(EQ)} \end{cases} \quad (2)$$

τ_{ee} is the nonlinear elastic stress in the second branch

$$\tau_{ee} = C_2^{(EQ)}\gamma + C_3^{(EQ)}|\gamma|^m \operatorname{sgn}(\gamma) \quad (3)$$

τ_{oe} is the rate-dependent overstress in the dashpot D, it also is the sum of the stress τ_a in spring A_2 and the stress τ_b in spring B_2 as.

$$\tau_{oe} = \tau_a + \tau_b \quad (4)$$

where $$\tau_a = C_1^{(OE)}\gamma_{a2} \text{ with } \begin{cases} \dot{\gamma}_{s2} \neq 0 & for \quad |\tau_a| = \tau_{cr}^{(OE)} \\ \dot{\gamma}_{s2} = 0 & for \quad |\tau_a| < \tau_{cr}^{(OE)} \end{cases} \quad (5)$$

$$\tau_b = C_2^{(OE)}\gamma_b + C_3^{(OE)}|\gamma_b|^p \operatorname{sgn}(\gamma_b) \quad (6)$$

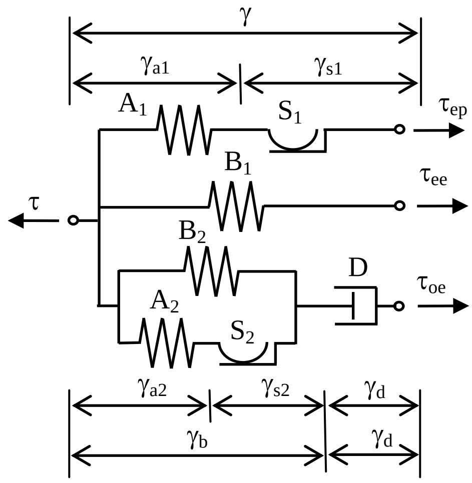

Fig. 1. Model of high damping rubber bearings

A nonlinear relation to represent the dashpot D is proposed as follow

$$\tau_{oe} = a|\dot{\gamma}_d / \dot{\gamma}_0|^n \operatorname{sgn}(\dot{\gamma}_d) \quad (7)$$

where $C_i^{(EQ)}$; $C_i^{(OE)}$ (i=1 to 3); $\tau_{cr}^{(EQ)}$; $\tau_{cr}^{(OE)}$; m; p, a and n are parameters of the model and determined from experimental data, and $\dot{\gamma}_0 = 1/\sec$.

3. PARAMETER IDENTIFICATION AND NUMERICAL SIMULATION

Multi-step relaxation (MSR) test was employed to identify the equilibrium response. The similar approach was also used by Bhuiyan et al. (2009); Lion (1996) to identify the equilibrium state of rubber materials. As shown in Fig. 2, the short prompting loading with constant strain rate of 5.5/s and a subsequent 1200 seconds deformation holding were repeatedly performed to the specimen. The equilibrium responses can be obtained by connecting all the asymptotically converged stress values at each strain level as shown by the solid lines.

The parameters for springs A_1, B_1 and slider S_1 were obtained by fitting the first and second branches of the model with the equilibrium response obtained from MSR test, the values of the equilibrium parameters are given in table 1.

In this paper, stress-strain relations obtained from dynamic simple shear (SS) tests with high strain rates of 8.75/s were used to identify the parameters for springs A_2, B_2 and slider S_2, as the dashpot D can be considered as locked under the high speed.

Keyword: High damping rubber, Rate dependence, Viscosity, Overstress.
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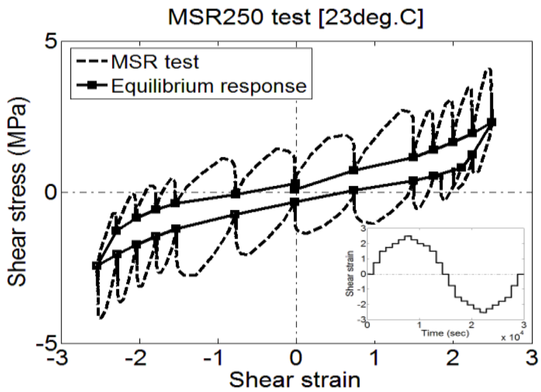


Fig 2: Equilibrium response obtained from MSR test

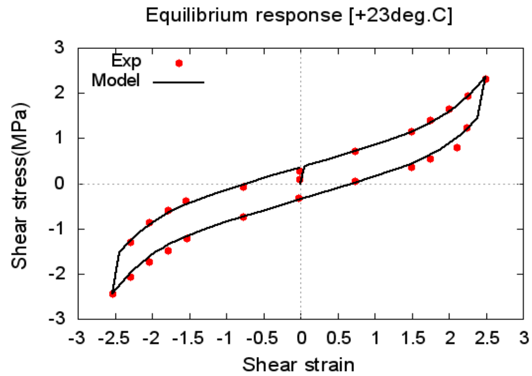


Fig 3: Identification of equilibrium parameters

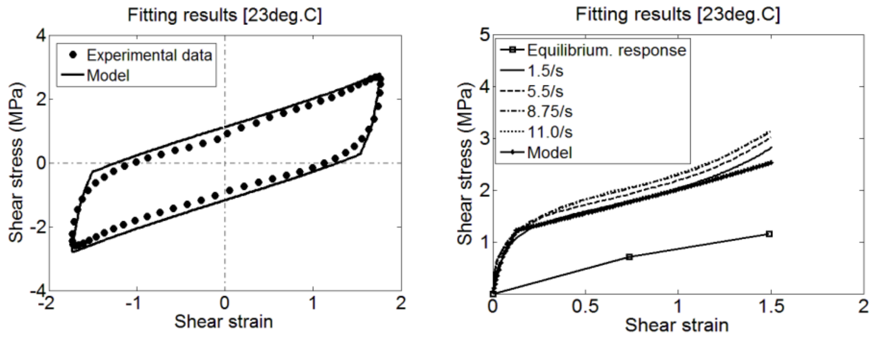
Table 1: Equilibrium parameters obtained from MSR tests

$C_1^{(EQ)}$ (MPa)	$C_2^{(EQ)}$ (MPa)	$C_3^{(EQ)}$ (MPa)	$\tau_{cr}^{(EQ)}$ (MPa)	m
7.12	0.486	0.0075	0.355	5.03

Table 2: Overstress parameters

$C_1^{(OE)}$ (MPa)	$C_2^{(OE)}$ (MPa)	$C_3^{(OE)}$ (MPa)	$\tau_{cr}^{(OE)}$ (MPa)	p	a (MPa)	n
5.89	0.35	0.056	0.755	1.45	1.45	0.36

Finally, the viscosity parameters of the dashpot D can be determined from the 2nd cycle of sinusoidal loading test in Fig. 4b. The overstress parameters are given in table 2. To evaluate the capability of the proposed model and the parameter determination procedure, the determined parameters in table 1, 2 were used in the model to simulate simple relaxation (SR) tests and MSR tests. The simulation results are very close with the experiments in Fig. 5.

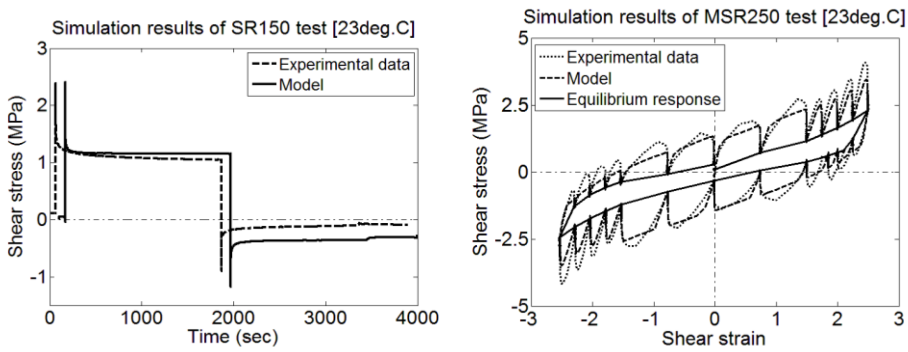


(a) (b)

Fig 4: Identification of (a) instantaneous parameters (b) viscosity parameters

4. CONCLUSION

On the basis of experimental results, a constitutive model is proposed to describe the mechanical behavior of HDRBs. The basic structure of the proposed model is to divide the total stress into a rate-independent equilibrium stress and a rate-dependent overstress. The model can adequately reproduce the equilibrium response and instantaneous response of HDRBs. The comparison of the simulations with the relaxation tests shows the sufficient capacity of the proposed model and the parameter identification procedure.



(a) (b)

Fig. 5. Numerical simulation of relaxation tests: (a) simple relaxation test (b) multi-step relaxation test

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