A SIMPLIFIED RHEOLOGY MODEL OF NATURAL AND LEAD RUBBER BEARINGS FOR SEISMIC ANALYSIS

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INTRODUCTION

The concept of seismic/base isolation is in receipt of wide acceptance after the 1994 Northridge earthquake in California, USA and the 1995 Hyogoken-Nanbu earthquake in Kobe, Japan. Three types of laminated rubber bearings are widely used for this purpose: natural rubber bearing (RB), lead rubber bearing (LRB), and high damping rubber bearing (HDRB). Of these, HDRBs exhibit nonlinear rate-dependent hysteresis in addition to the static equilibrium hysteresis (Bhuiyan et al., 2009 and Hwang et al., 2002). On the basis of the experimental observations of HDRBs, an elasto-viscoplastic rheology model is developed by Bhuiyan et al. (2009) for seismic response analysis. The model is quite capable of representing the mechanical behavior of HDRBs. On the other hand, LRBs and RBs show relatively weak rate-dependent hysteresis in compared with HDRBs (Bhuiyan et al., 2008). Motivated by the experimental results, a rheology model is proposed for LRBs and RBs by simplifying the earlier rheology model of the authors (Bhuiyan et al., 2009). To the end, an experimental scheme comprised of cyclic shear (CS) test, multi-step relaxation (MSR) test and simple relaxation (SR) test was conducted in order to identify the viscosity and elasto-plasticity parameters. Using the experimental results, a mathematical expression of the rate-dependent stress response of LRBs and RBs is proposed. The proposed rheology model along with the identified parameters is verified with experimental results obtained using the sinusoidal loading test (0.5 Hz and 1.75 strain level). Furthermore, a seismic response analysis of a single degree of freedom (SDF) system is carried out to show the effectiveness of the proposed model for the level-2 earthquake ground motion.

EXPERIMENT

An experimental scheme comprising of cyclic shear (CS) test, multi-step relaxation (MSR) test and simple relaxation (SR) test was carried out on two RBs and two LRBs. All specimens confirm the ISO-2005 standard geometry (ISO, 2005). The CS and MSR tests were conducted to identify the rate-independent response parameters while a series of SR tests were carried out to identify viscosity parameters of the bearings. Four bearings namely RB1, RB2, LRB1, and LRB2 were used in the experimental scheme; however, due to space limitations, typical results of only two bearings (RB1 and LRB1) are represented and discussed herein. All the specimens were tested under shear deformation with a constant vertical compressive stress of 6 MPa.

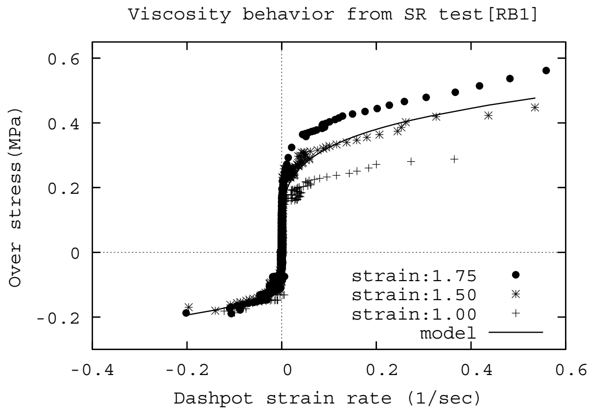

Fig.1. Typical rate dependent overstress of RB1

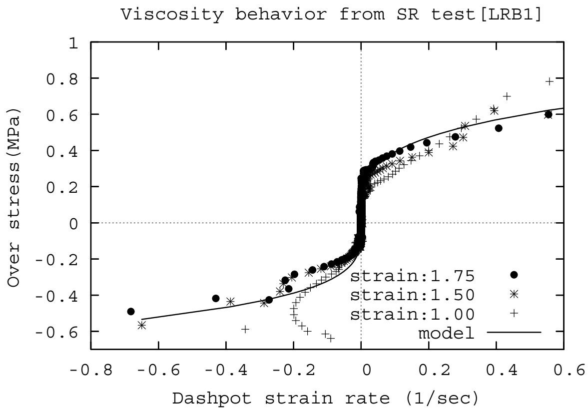

Fig. 2. Typical rate dependent overstress of LRB1

RHEOLOGY MODEL

The experimental results of the bearings exhibited from CS, MSR and SR tests' results have motivated the basic foundation of the proposed rheology model as shown in Fig. 3. The same construction procedure of the rheology model of the bearings as discussed in the earlier model is applied herein. Motivated by the experimental results as shown in Figs 1 and 2, the mathematical expression of the overstress is modified as presented in Eqs.(1E).

NUMERICAL SIMULATION

Figs. 1 and 2 show the typical rate-dependent overstresses of RB1 and LRB1, respectively. The gradient of the curves (Figs. 1 and 2) representing the viscosity of the bearings does not change with the strain levels of the relaxation tests of LRB1; however, some changes occur in RB1 (Fig.1), with small overstress and the dashpot strain rates. Similar observations were also obtained in other two bearings. Using a standard numerical procedure the viscosity parameters are determined (Table 1). Figs. 1 and 2 present the overstresses obtained using Eq.(1E) for RB1 and LRB1, respectively, along with experimental results at different strain levels. Figs. 4 and 5 illustrate the simulation results of RB1 and LRB1 showing good agreement with sinusoidal loading data.

SEISMIC RESPONSE ANALYSIS

In order to check the effectiveness of the proposed model, a seismic response analysis of an SDF system representing a bridge superstructure supported on rigid foundation is conducted. Standard numerical integration method is used to get the response by solving the equation of motion of the system and the differential equation governing the rate-dependent behavior of the bearings. For comparison, the bearings' responses are computed using the proposed model and the earlier model of the authors. The seismic responses of RB1 and LRB1 are presented in Figs.6 and 7 in which the stress responses are seen closely comparable.

Keywords: rheology, seismic response, bridge, simulation and hysteresis
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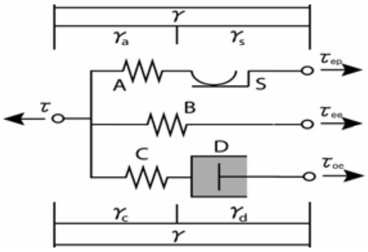

Fig. 3: Rheology model

$$
\begin{cases}
\text{Slider} \quad S : \tau_{cr} \\
\text{Spring} \quad A : \quad \tau_{ep} = C_1 \gamma_a \\
\text{Spring} \quad B : \quad \tau_{ee} = C_2 \gamma + C_3 |\gamma|^m \operatorname{sgn}(\gamma) \\
\text{Spring} \quad C : \quad \tau_{oe} = C_4 \gamma_c \\
\text{Dashpot} \quad D : \quad \tau_{oe} = A \exp\left(q|\gamma|\right) \operatorname{sgn}(\dot{\gamma}_d) |\dot{\gamma}_d|^n \\
\qquad \textit{with} \quad A = \frac{1}{2}(A_l + A_u) + \frac{1}{2}(A_l - A_u) \tanh(\xi \tau_{oe} \gamma_d)
\end{cases}
\tag{1}
$$

Table 1: Elasto-plasticity and viscosity parameters of RBs and LRBs for simulating the 4th cycle of sinusoidal loading data

	C_1 (MPa)	C_2 (MPa)	C_3 (MPa)	C_4 (MPa)	A_l (MPa)	A_u(MPa)	τ_{cr} (MPa)	m	n	ξ
RB1	1.95	0.799	0.005	0.40	0.10	0.06	0.13	7.80	0.23	1.20
RB2	2.05	0.883	0.006	0.40	0.10	0.07	0.11	7.23	0.24	1.20
LRB1	4.25	0.710	0.003	1.35	0.45	0.27	0.19	8.24	0.27	1.80
LRB2	4.18	0.779	0.010	1.35	0.35	0.20	0.23	6.68	0.30	1.90

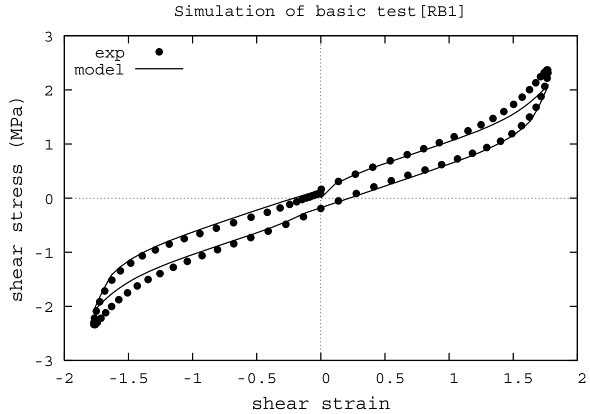

Fig. 4. Simulation results of RB1

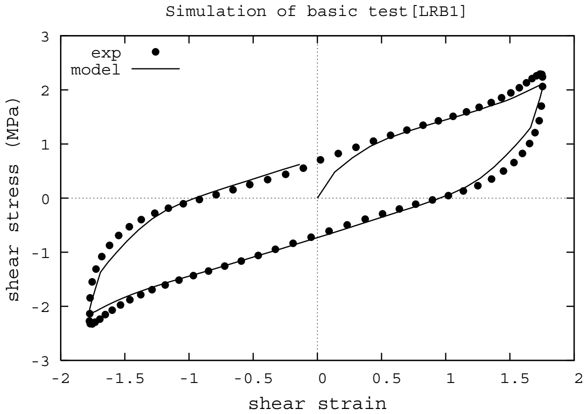

Fig. 5. Simulation results of LRB1

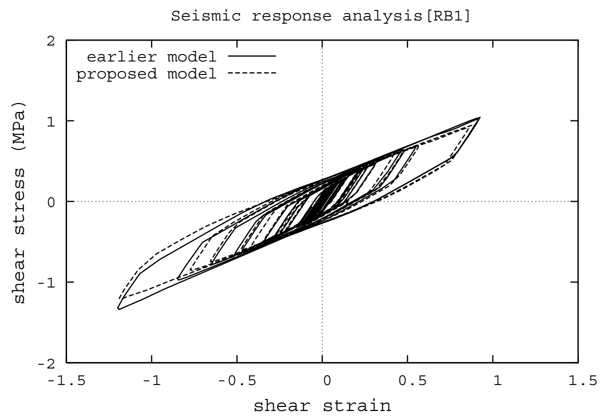

Fig. 6. Results of seismic response analysis using RB1

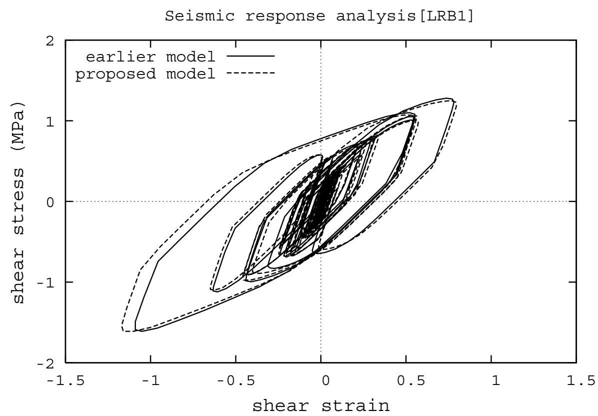

Fig. 7. Results of seismic response analysis using LRB1

CONCLUDING REMARKS

A simplified version of the rheology model based on the experimental observations of RBs and LRBs is presented for using in the practice of seismic design of highway bridges in Japan. The viscosity parameters can be identified from SR test data. The nonlinear viscosity in loading and unloading can be well identified and reproduced by the model. The comparison of numerical results with sinusoidal loading data has shown adequacy of the simplified model in predicting the mechanical characteristics of the bearings. In the simulation, the 4th cycle stress-strain responses are used to simply remove the softening behavior of rubber materials. Moreover, from the comparative assessment of the seismic response analysis of an SDF system it can be concluded that the simplified model instead of the complicated rheology model (Bhuiyan et al., 2009) can be suitably used for predicting the mechanical behavior of RBs and LRBs in seismic response analysis of bridges.

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