NONLINEAR VISCOSITY OF HIGH DAMPING RUBBER BEARINGS: EXPERIMENTAL INVESTIGATION AND RHEOLOGY MODEL

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INTRODUCTION

Use of base isolation technique is widely increasing as an innovative aseismic design approach to be employed in bridge structures. High damping rubber (HDRS) bearings, in this case, are widely accepted as the base isolation device due to having the inherent rate-dependent damping property along with other inelastic properties. The current practice of design of the base isolation bearing is to use the bilinear model to characterize the force displacement hysteresis loop (JRA 2002). However, the mechanical behavior of rubber bearing is very complicated due to having the inherent rate dependent hysteresis property. In this regards, in the recent past, some hysteretic models have been proposed to model the hysteresis behavior of HDRS bearings. However, these models are subsequently incapable of representing the mechanical behavior of HDRS bearings adequately. To address these behaviors of HDRS bearing and implement into the seismic analysis of bridge, a phenomenological rheology model based on the experimental investigations is proposed in this study. Furthermore, the proposed rheology model along with the parameters identified in this study is verified with experimental results obtained using the sinusoidal loading test (0.5 Hz and 1.75 strain level), which is different from that used in the parameter identification.

EXPERIMENT

An experimental scheme comprising of cyclic shear (CS) test, multi-step relaxation (MSR) test and simple relaxation (SR) test was carried out on three different HDRS bearings. All specimens confirm the ISO-22762-1 standard geometry. The mechanical behavior of HDRS bearings as observed from experiments may be conveniently subdivided into three groups such as the nonlinear elastic response, rate dependent overstress response and the time independent elastoplstaic responses. The typical shear stress-strain responses, obtained from the experimental results of CS test as presented in Fig. 1, exhibit the different rate dependence in loading and unloading while Fig.2 shows the rate independent response as obtained from MSR test results. The rate dependent behavior in loading and unloading may be attributed to the different viscosity property inherently occupied in HDRS bearings. The overstress-dashpot strain rate ($\tau_{oe}-\dot{\gamma}_d$) calculated from MSR test data is shown in Fig.4, which represents the different overstress response in loading and unloading reflecting the experimental phenomena of CS test results (Fig.1). Moreover, a rate dependent hysteresis behavior of the bearing is also demonstrated in Figs. 1.

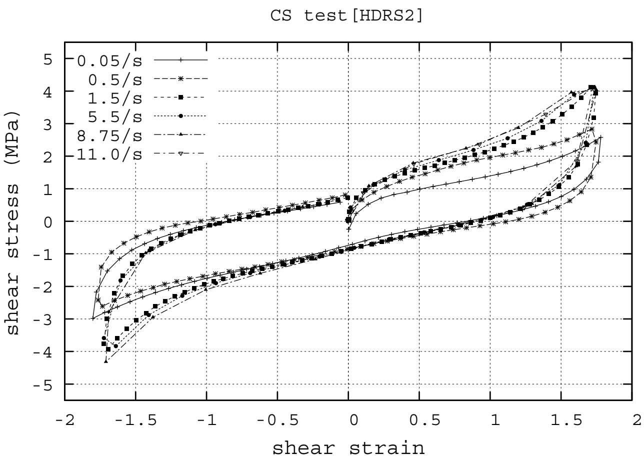

Fig.1. Typical rate dependent behavior exhibited in HDRS2

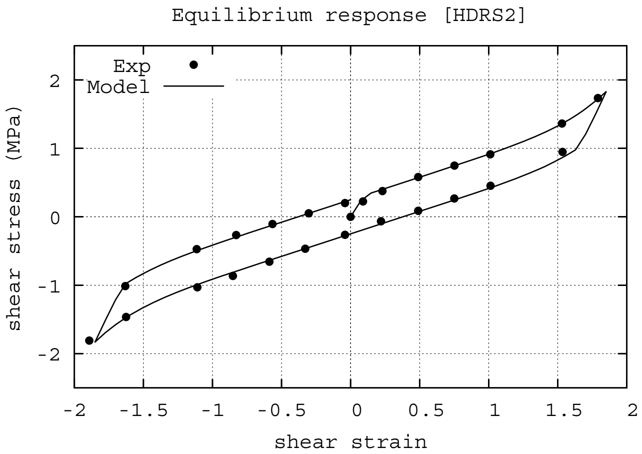

Fig. 2. Rate independent response of HDRS2

RHEOLOGY MODEL

The experimental results of HDRS bearings exhibited from CS test, MSR test and SR test results have motivated the basic foundation of the proposed rheology model as shown in Fig. 3. The rheology model is constructed by adding a slider with one spring in parallel with the original the Maxwell 3-paramer solid model. This model is structured by taking the rate dependency along with the equilibrium hysteresis of rubber bearing into account. In the model, the first branch comprising of a spring (Element A) and a slider (Element S) represents the elasto-plastic response; the second branch of a spring (Element B) represents the elastic equilibrium response and these two branches together constitute the rate independent effect of rubber bearing. On the other hand the third branch consisting of a spring (Element C) and dashpot (Element D) represents the overstress resulting from the rate dependent effect of bearings.

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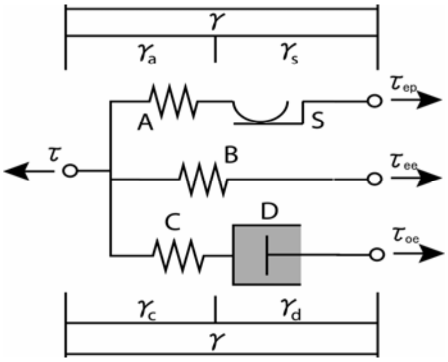

Fig. 3: Rheology model

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\left\{
\begin{array}{lll}
\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) & & (1) \\
\text{Spring} \quad C: \quad \tau_{oe} = C_4\gamma_c & & \\
\text{Dashpot} \quad D: \quad \tau_{oe} = A_l \exp(q\|\gamma\|) \operatorname{sgn}(\dot\gamma_d)|\dot\gamma_d|^n & \text{loading} & \\
\qquad\qquad\qquad\quad \tau_{oe} = A_u|\dot\gamma_d|^n \operatorname{sgn}(\dot\gamma_d) & \text{unloading} &
\end{array}
\right.
$$

As motivated by the experimental observation as shown in Fig. 4, the loading and unloading condition is determined by a mathematical quantity of $\frac{d}{dt}|\gamma_d|$; $\frac{d}{dt}|\gamma_d| > 0$ for loading and $\frac{d}{dt}|\gamma_d| < 0$ for unloading.

PARAMETER IDENTIFICATION

The rheology model as shown in Fig. 3 constitutes two categories of parameters such as time independent elastic parameters and time dependent viscosity parameters. Time independent elasticity parameters corresponding to elements A,B,C and S are determined from CS and MSR test results whereas the time dependent viscosity parameters corresponding to element D are determined from SR and MSR test results. The parameters determined in this way are shown in Table 1. (Please refer to Bhuiyan et al., 2007 for details)

Table 1: Elasticity and viscoelasticity parameters

	C_1 (MPa)	C_2 (MPa)	C_3 (MPa)	C_4 (MPa)	A_l (MPa)	A_u(MPa)	q	m	n
HDR-S2	2.50	0.6573	0.0062	3.25	0.350	0.24	0.412	6.72	0.24

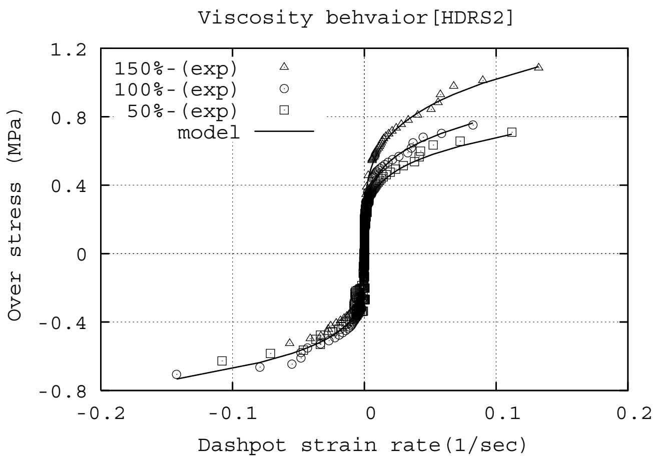

Fig. 4. Rate dependent response of HDRS2

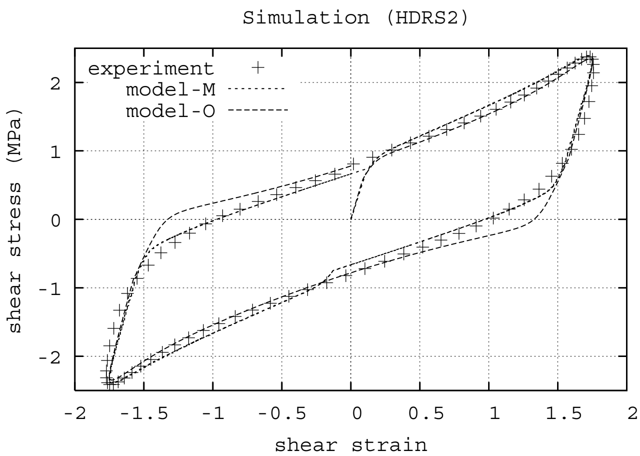

Fig. 5. Simulation of the 4th cycle stress-strain response of HDRS2

NUMERICAL SIMULATION

Figures 2 and 4 represent, respectively, the rate independent and rate dependent behaviors of HDRS2 that are well simulated by the rheology model in loading and unloading. Furthermore, the different viscosity behavior of HDRS bearing in loading and unloading is well described by the rheology model. Fig. 5 shows the simulation and experimental results of shear stress-strain response obtained using sinusoidal loading test. Here, it is noted that “model-O” corresponds to the model proposed by the authors (Bhuiyan et al., 2007) considering the same viscosity in loading and unloading and “model-M” to the modified model as presented in (Eq. (1)). A better agreement between the experiment and the model is clearly observed in Fig. 5.

CONCLUSION

To overcome the limitation of the current bilinear model as being practiced in the design of highway bridges in Japan and other countries, a rheology model is proposed by taking the nonlinear rate dependence and equilibrium hyteresis into account in addition to the nonlinear elasticity behavior of HDRS bearing. The rate dependent behavior of HDRS bearing cannot be overlooked in the analysis and design of base isolation bearings. The different viscosity behavior in loading and unloading should be considered to have a rational dissipation behavior of HDRS bearings. Moreover, temperature dependent behavior of HDRS bearings would be the future task to incorporate into the proposed model.

REFERENCES

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