A RHEOLOGY MODEL FOR RUBBER BEARING IN SEISMIC RESPONSE ANALYSIS OF BRIDGE

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1. INTRODUCTION

In base isolation, the devices are required to possess flexibility and high damping in order to extend the natural periods and reduce the displacement response of structures, respectively. In current practice of the design of highway bridges in Japan, bilinear model has been employed for seismic analysis of rubber bearing. However, the mechanical behavior of rubber bearing is very complicated due to having the inherent viscoplastic property. In this regard, the current model cannot represent explicitly the inherent complex properties i.e. viscoplastic properties of rubber bearing. To address the complex behavior of rubber bearing and implement into the seismic analysis of bridge, a rheology model based on the experimental investigations has been proposed in this study. The scheme of the study comprises of parameter identification of the proposed model along with verification with experimental results.

2. RHEOLOGY MODEL

The rheology model is an extended version of the Maxwell 3-paramer model by adding one slider with a spring in parallel to the original model. The rheology model has been proposed by taking the rate dependency along with the equilibrium hysteresis into account. In the model shown in Figure 1, the first branch comprised 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 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.

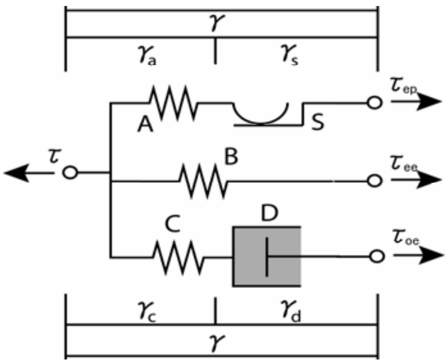

Figure 1: Rheology model

$$\begin{cases} \text{Slider} \quad S: \tau_{cr} \\ \text{Spring} \quad A: \quad \tau_{ep} = C_1 \gamma_a \\ \text{Spring} \quad B: \quad \tau_{ee} = C_2 \gamma + C_3 |\gamma|^m \gamma \\ \text{Spring} \quad C: \quad \tau_{oe} = C_4 \gamma_c \\ \text{Dashpot} \quad D: \quad \tau_{oe} = A\exp\left(q\|\mathbf{B}\|\right)\mathrm{sign}\left(\dot{\gamma}_d\right)|\dot{\gamma}_d|^n \end{cases} \tag{1}$$

$$\|\mathbf{B}\| = \sqrt{2 + 2\gamma^2 + (1+\gamma^2)^2}$$

3. PARAMETER IDENTIFICATION

The expressions of the different stress components in terms of some parameters that are to be determined from the experiments are shown in Equation 1. Three mechanical tests have been conducted such as cyclic relaxation tests (CR test) to determine the parameters of Element A, B and S, simple relaxation tests (SR test) to determine the parameters of element D and simple shear tests (SS test) to determine the parameters of element C (Figure 1). Table 1 presents the elasticity and viscosity parameters that are determined in this study.

Table 1: Elasticity and viscoelasticity parameters

	C_1 (MPa)	C_2 (MPa)	C_3 (MPa)	C_4 (MPa)	A (MPa)	q	m	n
HDR-S2	10.57	0.6573	0.0062	3.25	0.350	0.117	5.72	0.224

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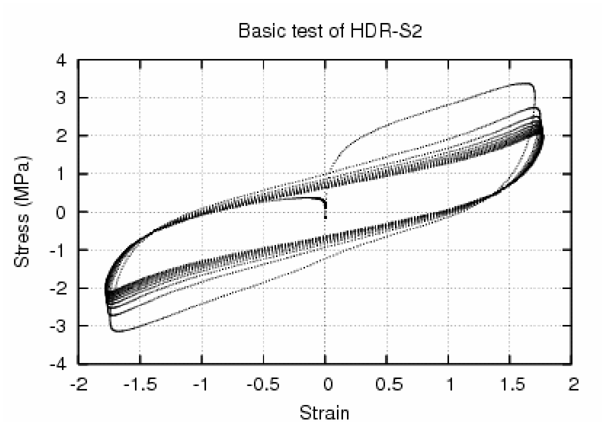

Figure 2 Stress-strain response of HDR-S2 at virgin state

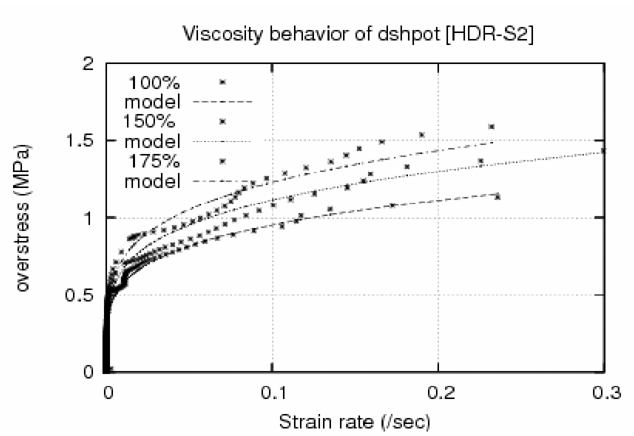

Figure 3 Overstress-strain rate response of HDR-S2

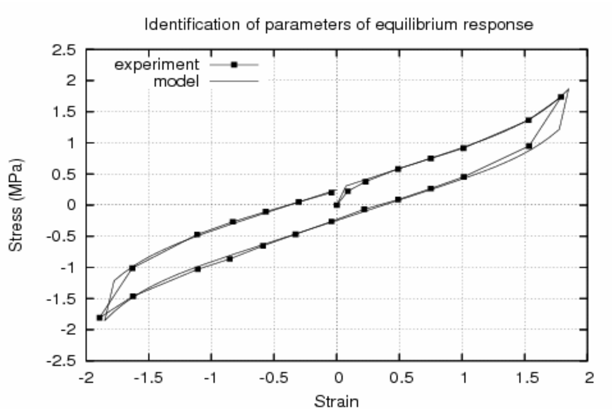

Figure 4 Equilibrium response of HDR-S2

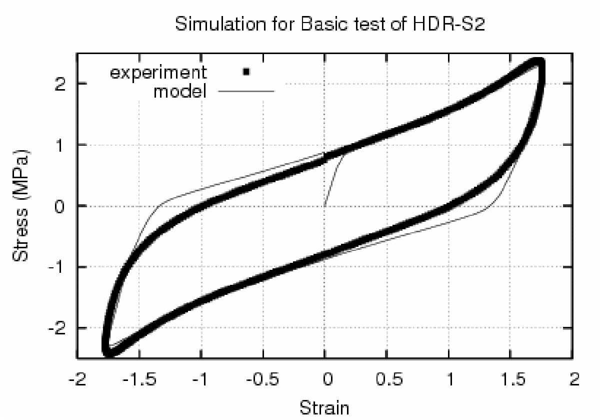

Figure 5 Simulation of 4th cycle stress-strain response of HDR-S2

4. EXPERIMENT

In this study, three types of rubber bearing (HDR, NR and LRB) were experimentally investigated. Two types of each of NR and LRB and three types of HDR bearing were used in this study. Only the experimental result of HDR-S2 has been stated here and all others are skipped owing to the page limitation. The experimental observation of HDR-S2 in the virgin state has been shown in Figure 2. The Mullins (Mullins 1969) softening effect has been clearly observed from Figure 2. Disregarding the Mullins effect the simulation has been done for the 4th cycle of stress-strain response in this study.

5. NUMERICAL SIMULATION

Figure 3 shows $\tau_{oe} - \dot{\gamma}_d$ relationship obtained from the relaxation test. The parameters of element D (Figure 1) have been determined using overstress-strain rate response relation (Equation 1(e)). Figure 4 shows the equilibrium responses obtained from the experiment and the proposed model (Equation 1(b), (c)). A good simulation result of equilibrium response has been observed in Figure 4. However, a good simulation of the 4th cycle-stress-strain response with slight overestimates at certain strain levels has also been observed in Figure 5.

6. CONCLUSION

To overcome the various limitations of the current bilinear model as being practiced in the design of highway bridges in Japan, a rheology model has been proposed by considering the nonlinear rate dependence and equilibrium hyteresis in addition to the nonlinear elasticity behavior of rubber bearing. The proposed model adequately presents the equilibrium response of rubber bearing with a slight overestimate in equivalent damping. Accordingly, the present work has suggested for improving the nonlinear viscosity model by modifying the mathematical expression (Equation 1(e)). In addition, the authors also feel the need to consider the temperature dependency of model parameters especially parameters relating viscosity in further study.

7. REFERENCES

Mullins,L ., Softening of rubber by deformations. *Rubber Chem. Technology*, Vol. 42, pp. 339-362, 1969