EXPERIMENTAL INVESTIGATION OF LAMINATED RUBBER BEARINGS AT LOW TEMPERATURES

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INTRODUCTION

It is now widely accepted among the practicing engineers that the laminated rubber bearings can be reliably used in the base isolation system of aseismic design of bridges and buildings. The base isolation system protects superstructures by reducing the energy transmitted to them through the dynamics of the system. Different types of rubber bearings with or without lead plug have been successfully used in this system for the last few decades. A lot of experimental investigations have been done to explore the mechanical behavior of laminated rubber bearings. The experimental observations have shown that the mechanical behavior of laminated rubber bearings is dominated by rate-dependent hysteresis with strain hardening (Bhuiyan et al., 2007; Hwang et al., 2002). Moreover, Mullins softening behavior is also noticed in the experimental observations. In this regard, many analytical models have been proposed to simulate the mechanical behavior of laminated rubber bearings (Abe et al., 2004 and the references therein.). In practice of seismic design for bridges in order to simulate the hysteresis loop of rubber bearings, a bilinear model is currently used in some specifications especially in Japan (JRA, 2002).The bilinear model and other rate-independent models cannot reproduce the viscosity behavior (rate-dependent hysteresis) of rubber bearings. In addition, most of the previous models are deficient in theoretical background and thereby the parameter identification procedure loses the physical meaning.

The earlier work of the authors (Bhuiyan et al., 2007)was devoted to develop a rheology model capable of reproducing the rate-dependent hysteresis behavior with strain hardening of rubber bearings at room temperature (23 ^{o}C). A schematic presentation of the proposed rheology model is shown in Fig.1, in which the stress component is conceptually decomposed into three branches in parallel: a nonlinear elastic stress response, a rate dependent overstress and a rate independent elasto-plastic stress response. The temperature dependent mechanical behavior of rubber material was first investigated by Gough and Joule in 1805 (Treloar, 1975).They concluded that due to the entropy elasticity property of rubber, the elastic response changes with the absolute temperature of the material. Moreover, in the recent past, several experimental investigations of thermo-mechanical behavior of rubber materials have been conducted by some authors (Lion, 1997; Khan and Lopez-Panies et al., 2002 etc.). The conclusions from these experimental investigations have been made that the rate-independent behavior of rubber material is weakly dependent on the temperatures, whereas the rate-dependent behavior is very sensitive to the ambient temperature of the material. Some authors carried out experimental studies (Hwang et al., 2002 and Oshima et al., 1998) of the temperature dependence of rubber bearing based on sinusoidal loading tests,

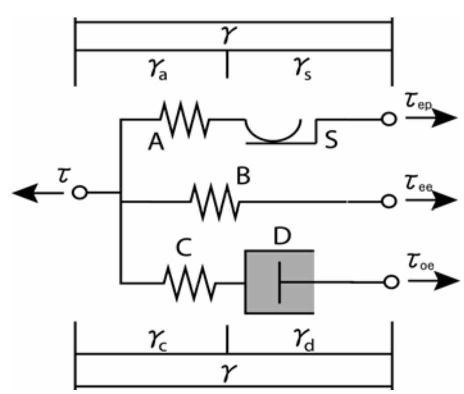


Fig.1. Rheology model

which have not provided sufficient information of thermo-mechanical behavior. In the present study, a large scale experimental scheme is being conducted to investigate the thermo-mechanical behavior of rubber bearings at different temperatures ranging from -30^{0}C to +40^{0}C. Although the main objective of the work is to propose a thermo-rheological model considering all thermo-mechanical characteristics of rubber bearings, as the first step, some experimental results are presented in this paper to discuss the necessity of considering the temperature dependence in the rheology model.

EXPERIMENTAL INVESTIGATIONS

As the main objective of the current work is to have deep understanding of the thermo-mechanical behavior of rubber bearings, an experimental scheme comprised of multi-step relaxation (MSR) test, cyclic shear (CS) test, simple relaxation (SR) test and sinusoidal test is proposed in this study. Each test of the scheme has a specific objective: MSR and CS test are being conducted to identify the rate independent elastic responses and SR test is being carried out to determine the viscosity behavior of rubber bearings. The experimental scheme is conducted on seven specimens of three different types of rubber bearings. The specimen's geometry confirmed the ISO standard geometry as shown in Fig.2. The dimensions of the specimens are presented in Table 1. All specimens are tested under shear deformation with a constant vertical compressive stress of 6 MPa. This mode of deformation is the most relevant one for the application of base isolation. Each test is carried out with new specimen using a computer-controlled servo hydraulic testing machine. The displacement is applied along the top edge of the specimen and the force response is measured by two load cells. All data are recorded using a personal computer.

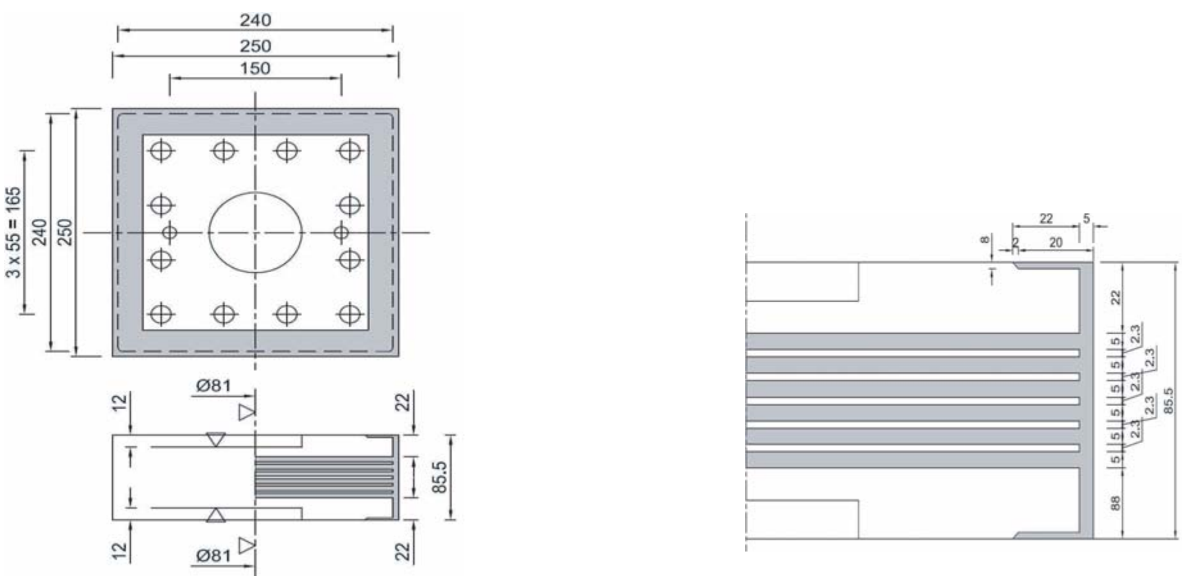
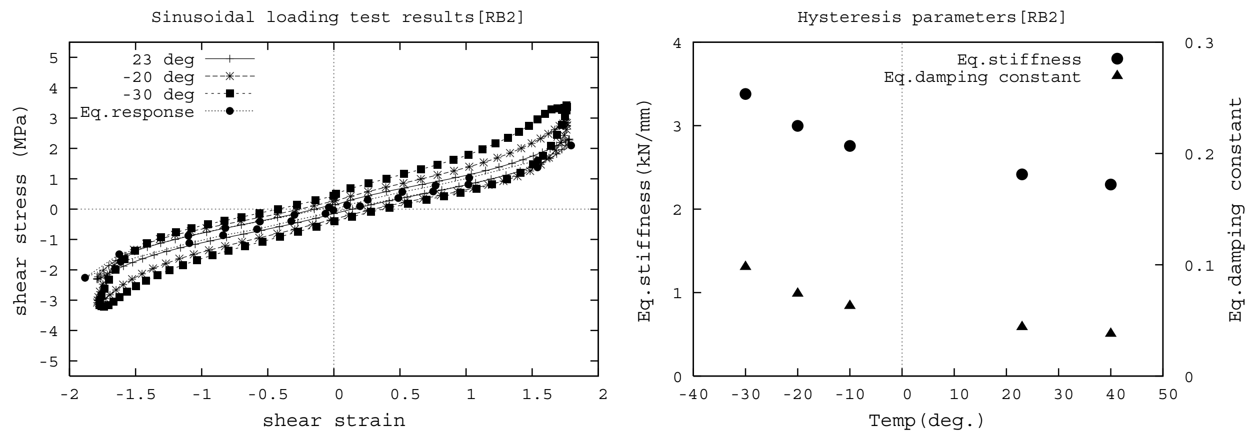


Fig.2. Size of laminated rubber bearing used in experiment (a) Plan and side view [mm] (b) Detail of side view [mm]

The usual methods are used to control the desired temperature of the specimen in the laboratory. In this paper, the experimental results of three specimens as obtained using sinusoidal loading tests are considered for discussion. The sinusoidal loading corresponds to a strain history at absolute amplitude of 1.75 and 0.5 Hz. The shear stress-strain response along with the equivalent stiffness (k) and equivalent damping constant (β) of each specimen at each temperature are computed and discussed to explain the future direction of the work. The following formula are used in order to compute k and β : $k = \frac{F_{max} - F_{min}}{\delta_{max} - \delta_{min}}, \beta = \frac{\Delta W}{2\pi W}$,where, W: elastic energy and ΔW: total hysteresis energy of the bearing, F_{max}, F_{min}: maximum and minimum force and δ_{max}, δ_{min}: corresponding deformation experienced by the bearing at F_{max} and F_{min}, respectively.

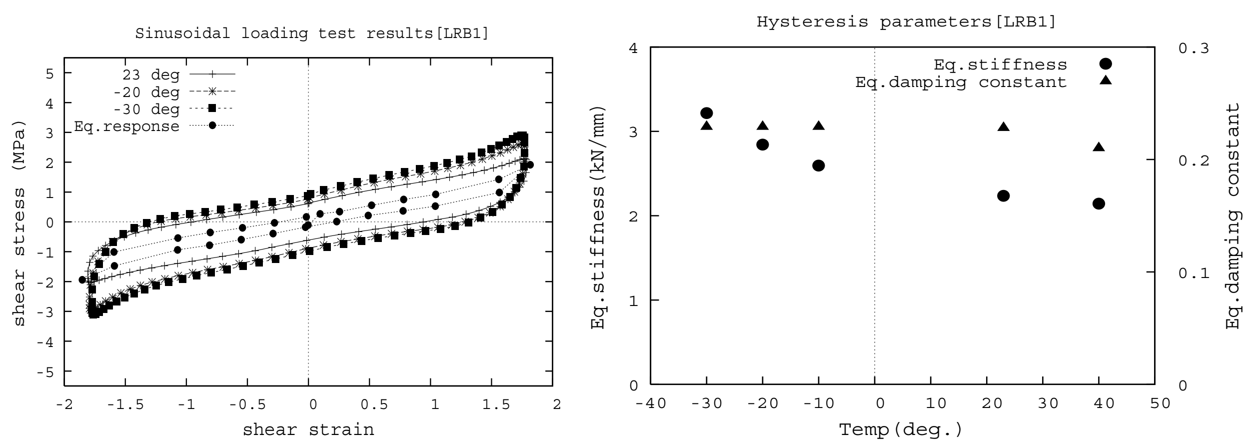
Table 1 Dimension of laminated rubber bearings

Type of bearing Abbreviated designation	High damping rubber bearing			Natural rubber bearing		Lead rubber bearing	
	HDRS1	HDRS2	HDRS3	RB1	RB2	LRB1	LRB2
Cross-section (mm^2)		240X240		240X240		240X240	
Number of rubber layers		6		6		6	
Thickness of one rubber layer (mm)		5		5		5	
Thickness of one steel layer (mm)		2.3		2.3		2.3	
Diameter of lead plug (mm)		-		-		81	
Nominal shear modulus (MPa)		1.2		1.2		1.2	



(a) (b)

Fig.3. Shear stress-strain response of RB2



(a) (b)

Fig.4. Shear stress-strain response of LRB1

RESULTS AND DISCUSSIONS

The experimental results of shear stress-strain responses, two seismic parameters (equivalent stiffness and equivalent damping constant) of three specimens at different temperatures are presented in Figs. 3 to 5. The equilibrium hysteresis (23 ^{0}C) of each specimen is also attached for the comparison. To simply ignore the Mullins effect of the specimen, the 4th cycle stress-response of sinusoidal loading is considered in this study. The interested readers are referred to Bhuiyan et al. (2007) for the details of equilibrium hysteresis of rubber bearings. Fig. 3(a) presents the shear stress-strain responses of RB2 specimen and Fig. 3(b) shows the equivalent stiffness and equivalent damping constant of the same specimen at different temperatures. From these figures, it has been clearly seen that hysteresis behavior and the seismic parameters are significantly affected by temperature variations.

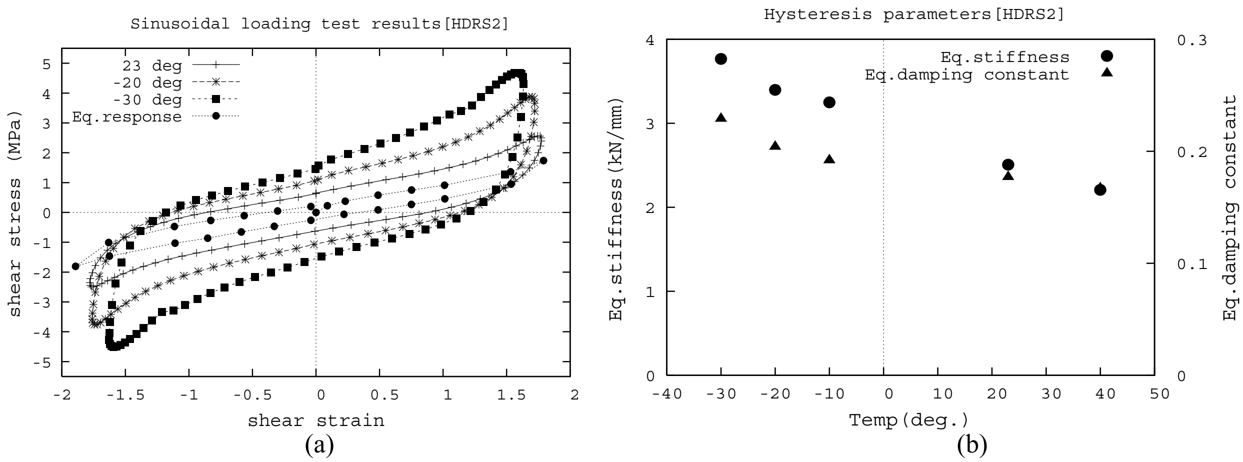


Fig.5. Shear stress-strain response of HDRS2

This typical behavior of the rubber bearing can be attributed to the temperature induced viscosity property occupied in the rubber material. The similar phenomena have also been observed in LRB1 and HDRS2 specimens as illustrated in Figs. (4) and (5), respectively. However, the damping property of LRB1 is comparatively less affected by temperature variation. While comparing among the three specimens it has been observed that the HDRS2 shows more temperature dependence than the other two specimens.

CONCLUSION

In this paper, some experimental results obtained using sinusoidal loading tests are presented. On the basis of experimental observations of different rubber bearings, it can be said that the temperature dependent viscosity behavior should be considered while constructing a rheology model. In this sense, the currently available bilinear and other rate-independent models cannot be suitably applied to address this phenomenon. In this regard, the rheology model proposed by the authors would be extended to incorporate the temperature dependence of rubber bearings. To the end, the goal of this work is to construct a rheology model capable of reproducing the thermo-mechanical properties of rubber bearings.

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