Soil Dynamics and Earthquake Engineering 90 (2016) 221–226

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Mechanical models for shear behavior in high damping rubber bearings

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A R T I C L E I N F O

Article history:
Received 25 August 2016
Accepted 25 August 2016

Keywords:
High damping rubber bearing
Mechanical model
Loading and unloading
Shear behavior
Nonlinear response
Base isolation

A B S T R A C T

High damping rubber bearings have been in use for seismic isolation of buildings worldwide for almost 30 years now. In the present work, a brief introduction to the process leading to their manufacturing is first given. Next, a series of novel 1D mechanical models for high damping rubber bearings is proposed, based on the combination of simple and well-known rheological models. These models are calibrated against a set of harmonic tests at strain amplitudes up to 200%. Extension of the models to bidirectional horizontal motion and to time-varying vertical loads is the subject of ongoing work.

1. Introduction

Natural rubber is obtained from a milky fluid (latex) extracted from the *Hevea brasiliensis* tree, also called by the Maya Indians *Caoutchouc*, which means "weeping wood" [1]. The name "rubber" was first used in 1770 by chemist Joseph Priestley, who observed that the material was very good for rubbing out pencil marks from paper [1]. In 1939, the term "elastomer" was introduced by Fisher for synthetic materials having rubber-like properties [2]. Natural rubber latex consists of chains of polysisoprene and the main disadvantage of this material is that it gets sticky when warm and brittle when cold [3]. In 1839, Charles Goodyear discovered that the addition of sulfur to natural rubber latex during heating creates crosslinks between the chains of polyisoprene, forming a super-molecule (vulcanization). In 1931, DuPont invented the popular synthetic polymer Duprene, which was later called Neoprene [4]. The material consists of chains of polychloroprene, crosslinked through vulcanization using metal oxides rather than sulfur. In order to improve their mechanical properties, fillers (mainly carbon black) are generally added to the rubber compound, accelerators are used to shorten the duration of heating during vulcanization, anti-ozonants are added to protect the material against ozone attack, and anti-oxidants are used to reduce ageing and to delay degradation due to exposure to oxygen [5].

Natural rubber pads were first installed in 1889 between the superstructure and the piers of a rail bridge in Melbourne, Australia. These were approximately 1.3 cm thick and were meant to absorb impact rather than to accommodate horizontal movement [2]. In 1954, French Engineer Eugene Freyssinet obtained a patent for his idea of reinforcing sheets of rubber with thin steel plates, see Fig. 1. By imposing steel plates between layers of rubber, a combination of vertical stiffness and horizontal flexibility was achieved [7]. In 1956, a vulcanization procedure was adopted to bond the thin steel plates to the rubber sheets [7]. Since then, multilayer rubber bearings have been used extensively in a variety of applications, including protection of buildings against earthquakes. Since rubber sheets provide very low damping, a lead plug

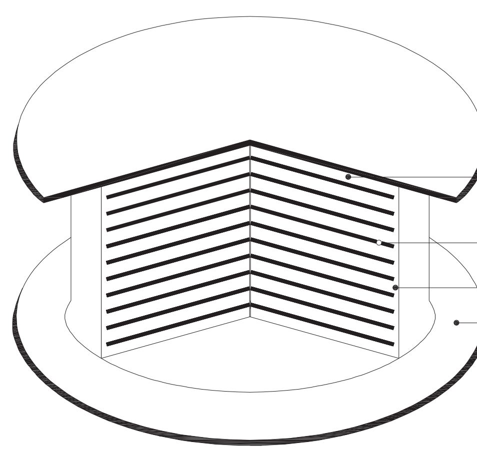

Fig. 1. High damping rubber bearing (HDRB) cross-section from [6].

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http://dx.doi.org/10.1016/j.soildyn.2016.08.035
0267-7261/

Table 1
Geometrical characteristics of HDRB.

External diameter (mm)	500
Diameter of steel plates D (mm)	490
Thickness of steel plates (mm)	3
Number of rubber layers	12
Thickness of single rubber layer T_{ri} (mm)	8
Total rubber thickness T_r (mm)	96
Cross section area A_r $\left(\text{mm}^2\right)$	188574.10
Total height (mm)	169
Primary shape factor S_1	15.31
Secondary shape factor S_2	5.10

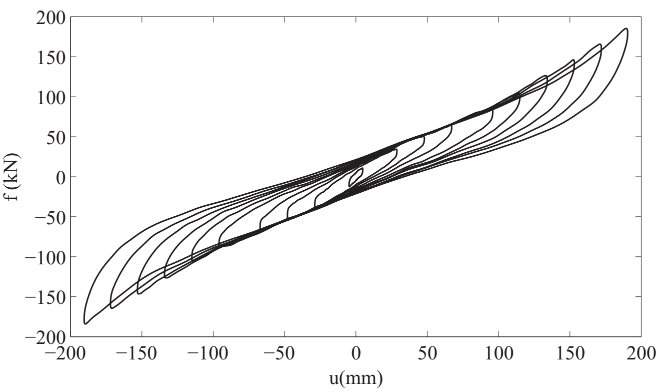

Fig. 2. Third cycle force-displacement response from harmonic tests on HDRB.

is sometimes inserted in the bearings to increase energy dissipation [8]. These bearings are referred to as Lead Rubber Bearings (LRB). An alternative way of increasing energy dissipation is to provide sufficient damping in the rubber sheets by using fillers, namely high damping rubber [8]. The first building using High Damping Rubber Bearings (HDRB) is the Foothill Communities Law and Justice Center, constructed in 1985 in the city of Rancho Cucamonga in Southern California.

HDRB exhibit high stiffness and damping at low shear strains, which minimizes the response under service and wind loads, and low shear stiffness with adequate damping capacity at the design displacement level. At higher displacement amplitudes they exhibit an increase in stiffness and damping, useful in limiting displacements under major earthquakes. Additional aspects must be considered when modeling the behavior of HDRB in the design of seismic isolation systems. A major one is creep, which makes the behavior of the devices rate dependent. Mechanical properties are also affected by manufacturing variations, contact pressure, loading and strain history, temperature, and ageing [5].

The ASCE/SEI 7 [9] regulation proposes the use of lower and upper bounds for the nominal properties of seismic isolation bearings. The use of upper bounds leads to lower values in the relative displacement of the isolators and to larger values of the force transmitted to the superstructure. On the other hand, the use of lower bounds leads to larger relative displacements for the isolators and lower forces for the superstructure, i.e., the opposite effect. The designer will alternatively use upper or lower bounds based on whether the safety of the superstructure or that of the isolator is being assessed. A general procedure for establishing the upper and lower bound properties of seismic isolators through the

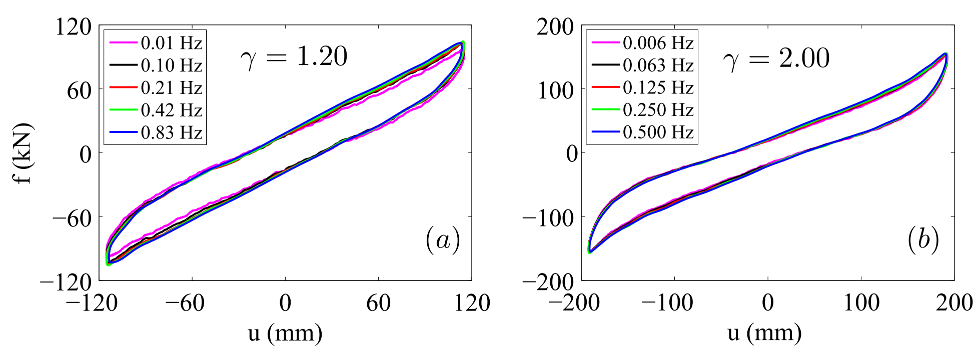

Fig. 3. Third cycle force - displacement graphs at different frequencies at shear strain amplitudes (a) $\gamma = 1.20$ and (b) $\gamma = 2.00$.

Table 2
Mechanical model classification.

Model				
1	2	3	4	5