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Improved equivalent viscous damping model for base-isolated structures with lead rubber bearings

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ABSTRACT

Nowadays, seismic isolation system has been widely applied in the world to mitigate damage risk of structures. Although maximum displacement demand can be obtained through nonlinear time history (NLTH) analysis, many approximate methods are frequently recommended in structural specifications to reduce the required computational time. One of the best-known methods is the equivalent linear (EL) method, in which the nonlinear response of isolator can be adequately modeled using a fictitious viscously damped elastic structure. In this paper, a comparison between existing expressions supplying the state of research is carried out and then, an improved expression is presented for equivalent linearization of structures supported on lead rubber bearings (LRB). Based on the concept of secant stiffness, the optimal damping ratios, which minimize the errors of maximum displacement between EL analysis and NLTH analysis, are calculated and averaged over 12 ground motions. Then, a rational model to estimate equivalent damping ratio is derived through statistic analysis of the optimal damping ratios. To examine the prediction accuracy of the proposed model, mean ratios of approximate to exact maximum displacement and root mean square error for different isolated period are calculated as evaluation indicator. Compared with other EL models, the newly proposed model predicts a displacement that is in better agreement with the one obtained through NLTH analysis.

1. Introduction

Seismic isolation, decoupling the structure from the ground, provides a very effective passive method of protecting structures against severe seismic events. The mitigation of seismic risk is primarily achieved through period shift and modification of mode shape to focus most of deformation at isolators. Various seismic isolators have been developed and used practically for anti-seismic design of structures during the last twenty years [1], including elastomeric bearings, frictional/sliding bearings and roller bearings.

Compared to other passive devices, the lead rubber bearings (LRB) (Fig. 1a) require minimal initial cost and maintenance [2]. The lead core is the crucial element of LRB, which provides the initial rigidity against minor earthquakes and exhibits nonlinear behavior to add hysteretic damping in the structure when subjected to severe earthquakes. Due to its wide applications, the present research study is focused on LRB bearing. For the sake of simplification, bilinear force–deformation behavior is generally assigned to LRB, which can be characterized by the initial elastic stiffness K_i, the yield displacement x_y, and the post-to-pre yield stiffness ratio α, as presented in Fig. 1b.

Due to the structural flexibility introduced by the isolation system, large deformation often occurs under a given earthquake ground motion. Therefore, predicting the maximum inelastic deformation demands becomes a very important step in the evaluation of seismically isolated structures. As well known, maximum inelastic deformation demand can be obtained through nonlinear time history (NLTH) analysis. However, solving of a system with a large number of degrees of freedom may require an exorbitant amount of time when time history analysis methods are used. Even for SDOF systems, the number of different loading cases needed to be solved may be quite large. In addition, in the preliminary stage of structural design, structural configurations are not completely defined. Thus, there will always be a need for good approximate methods of analysis of nonlinear systems [3].

Among the approximate methods, the equivalent linear (EL) method, which estimates the maximum displacement of an inelastic system by the maximum displacement of an EL system,

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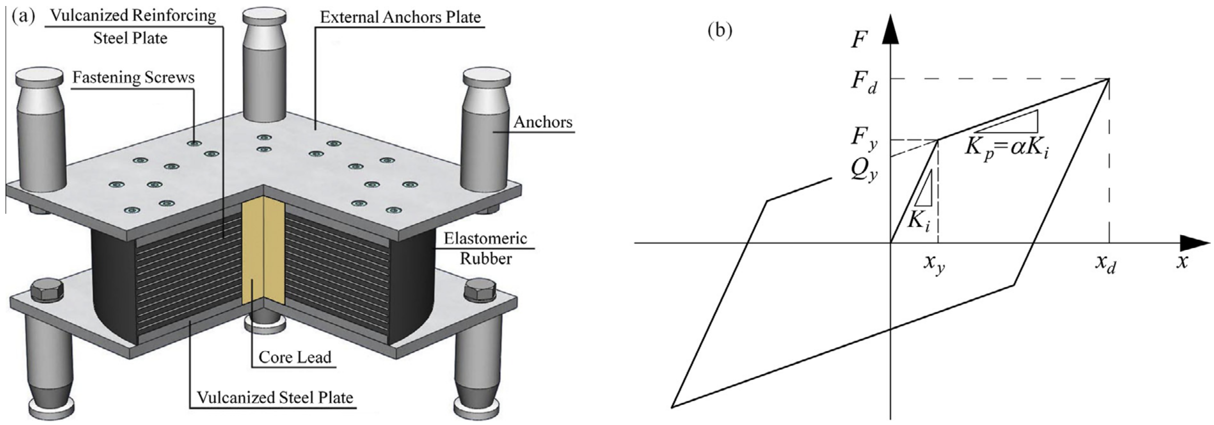

Fig. 1. (a) Lead rubber bearing (LRB) and (b) idealized bilinear hysteresis model.

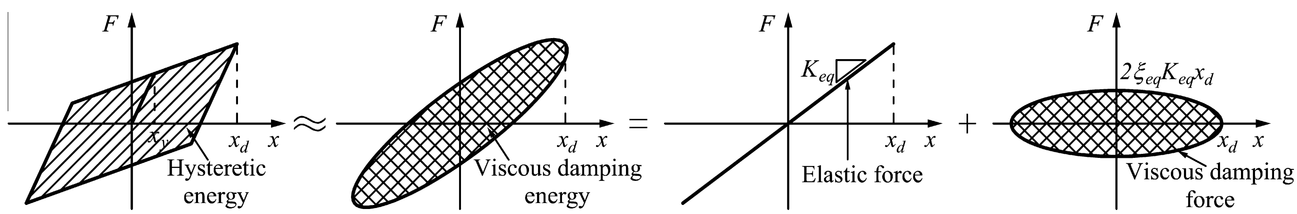

Fig. 2. Equivalent linearization of bilinear hysteretic behavior.

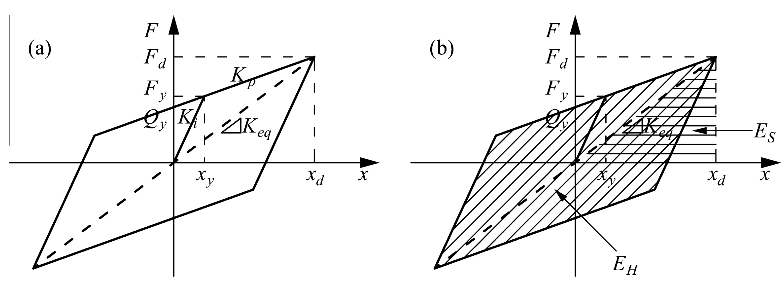

Fig. 3. R&H model: (a) secant stiffness and (b) equal energy dissipation principle.

Table 1
Recorded earthquake ground motions used in this study.

Date	Earthquake	M_s	Station name	R_{rup} (km)	Vs_{30} (m/s)	Com. (deg)	PGA (m/s^2)	PGV (m/s)	PGD (m)	Duration (s)
1966	Parkfield	6.2	Temblor pre-1969	16.0	527.9	205	3.504	0.215	0.038	30.3
1971	San Fernando	6.6	Castaic-Old Ridge Route	22.6	450.3	021	3.177	0.156	0.024	30.0
1972	Managua-Nicaragua-01	6.2	Managua-ESSO	4.1	288.8	090	4.131	0.214	0.060	26.0
1979	Imperial Valley-06	6.5	Compuertas	15.3	274.5	015	1.826	0.138	0.029	36.0
1980	Mammoth Lakes-01	6.1	Convict Creek	6.6	338.5	090	4.084	0.232	0.047	30.0
1980	Victoria-Mexico	6.3	Cerro Prieto	14.4	659.6	045	6.091	0.316	0.131	24.5
1983	Coalinga-01	6.4	Parkfield-Cholame 2WA	44.7	184.8	000	1.069	0.113	0.026	40.0
1989	Loma Prieta	6.9	Foster City-Menhaden Court	45.6	126.4	270	1.048	0.206	0.080	30.0
1992	Cape Mendocino	7.0	Petrolia	8.2	712.8	000	5.782	0.481	0.219	36.0
1994	Northridge-01	6.7	LA-Wonderland Ave	20.3	1222.5	095	1.101	0.087	0.018	30.0
1995	Kobe-Japan	6.9	Kakogawa	22.5	312.0	000	2.466	0.187	0.058	41.0
1999	Kocaeli-Turkey	7.5	Izmit	7.2	811.0	090	2.153	0.298	0.171	30.0

Note: M_s is the surface-wave magnitude of recorded earthquake; R_{rup} is the rupture distance to the horizontal projection of the fault; Vs_{30} is shear-wave velocities in the upper 30 m of the site profile; Com. is the horizontal component of the considered ground motions.

is the best-known. The equivalent stiffness K_{eq} and the equivalent damping ratio ξ_{eq} should be determined such that the maximum displacement responses of the two systems are approximately equal, as shown in Fig. 2.

When EL analysis is performed, it is obviously noted that the rational estimation of EL properties is crucial for the prediction accuracy. The main difference among the existing EL methods is the way in which the EL properties are determined. According to