Soil Dynamics and Earthquake Engineering 104 (2018) 346–364

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

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

Influence of ground motion characteristics on the optimal single concave sliding bearing properties for base-isolated structures

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ARTICLE INFO

Keywords:
Seismic isolation
Single concave sliding bearings
Non-dimensional form
Optimal isolator properties
Frequency characteristics of seismic input
PGA/PGV ratio

ABSTRACT

This study examines the influence of ground motion characteristics on the optimal friction properties of single concave sliding bearings employed for the seismic isolation of structural systems. The evaluation of the optimal properties is carried out by considering a non-dimensional formulation which employs the peak ground acceleration (PGA) and the peak ground acceleration-to-velocity (PGA/PGV) ratio as ground motion parameters. A two-degree-of-freedom (2dof) model is employed to describe the isolated system and two different families of records representative respectively of near fault and far field seismic inputs are considered. Following the nondimensionalization of the equation of motion for the proposed ground motion parameters, it is shown that the non-dimensional responses obtained for the two types of seismic inputs are similar. This result confirms that PGA/PGV is a good indicator of the frequency content and of other characteristics of ground motion records, helping to reduce the scatter in the response. Regression expressions are also obtained for the optimal values of the friction coefficient that minimizes the superstructure displacements relative to the base as a function of the abovementioned ground motion parameter and of the dimensionless system parameters. These expressions can be used for the preliminary estimation of the optimal properties of isolation bearings with a single concave sliding surface or double concave sliding surfaces with equal friction coefficient.

1. Introduction

Isolation systems have been extensively implemented for many years to protect structural and non-structural building components from earthquakes, and their effectiveness has been demonstrated by a significant number of experimental and numerical studies [1,2]. The three basic features common to different isolation devices such as high-damping rubber bearings, lead rubber bearings and concave sliding bearings are horizontal flexibility, necessary to shift the vibration period of the structure away from resonance, energy dissipation capacity, necessary to reduce the displacement demand, and high stiffness at small displacements, required to limit movements due to wind and service loadings.

Concave sliding bearings offer some advantages over other bearings, such as the ease of installation, the reduction of displacements at serviceability, the isolation period independent from the system mass [3–13]. In single or double concave sliding bearings, flexibility is achieved by employing a large radius of curvature of the sliding surface, while the energy dissipation capacity and resistance to service loads depends on the friction between the sliding surface and the slider.

In recent years, increasing research efforts have been devoted to search for the optimal properties of concave sliding bearings. The earliest works have employed equivalent spring and damper models to describe the isolation bearing behavior [14,15]. Other studies have introduced more advanced models including bi-linear hysteretic ones or models accounting for variation of friction to represent the sliding bearing response [16–20]. These studies provide information useful for the choice of the radius of curvature and friction properties of concave sliding bearings, showing in general that a high energy dissipation capacity for the isolation system, helpful to reduce the isolator drifts, may increase significantly both the inter-storey drifts and absolute accelerations of the superstructure, thus compromising the benefit of base isolation. Thus, there exists a particular value of the friction coefficient for which the absolute accelerations or the displacements of the building attain the minimum value. More recent studies have proposed design methodologies for concave sliding bearing based on reliability criteria or even life-cycle cost considerations [21–25].

While many of these researches have pointed out that the optimum isolation properties are significantly dependent on the ground motion characteristics, very few have analyzed explicitly the relation between the

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http://dx.doi.org/10.1016/j.soildyn.2017.09.025
Received 15 February 2017; Received in revised form 27 June 2017; Accepted 24 September 2017
Available online 13 November 2017
0267-7261/

Nomenclature

Latin upper-case letters

D	Generic response parameter
$GM(D)$	Sample geometric mean of D
N	Total number of samples
R	Radius of curvature of the single concave sliding bearing
T_b	Fundamental period of the isolated system
T_g	Representative period of the ground motion input
T_m	Predominant period of the ground motion
T_s	Period of the superstructure

Latin lower-case letters

a_0	Seismic intensity measure
c_b	Bearing viscous damping constant
c_i	Regression coefficients
c_s	Superstructure inherent viscous damping constant
d_k	kth percentile of D
d_i	i-th sample value of D
$f_b(t)$	Single concave sliding bearing resisting force
$f(k)$	Function used to estimate the kth response percentile
g	Gravity constant
k_b	Single concave sliding bearing stiffness
k_s	Superstructure stiffness
m_b	Mass of the base floor above the isolation system
m_s	Mass of the superstructure
t	Time instant
u^*	Transition displacement from the second to the last slope of the force-displacement curve of the DC sliding bearing
$\ddot{u}_g$	Horizontal seismic input
u_b	Isolator (horizontal component) displacement relative to the ground
u_s	Displacement of the superstructure relative to the isolation bearing
$u_{b,\max}$	Peak isolator displacement
$u_{s,\max}$	Peak superstructure displacement

Greek upper-case letters

Π^*	Normalized transition displacement (DC sliding bearing)
Π_γ	Mass ratio
Π_μ	Normalized friction coefficient
Π_μ^*	Normalized friction coefficient corresponding to $\mu_{\max}$
$\Pi_{\mu,\mathrm{opt}}^*$	Optimal value of Π_μ^*
Π_{tr}	Normalized ratio between the circular frequency corresponding to the transition slope and the circular frequency representative of the ground motion input
Π_{ω_g}	Normalized ratio between the isolator circular frequency and the circular frequency representative of the ground motion input
Π_{ω_s}	Isolation degree
Π_{ξ_b}	Normalized viscous damping inherent to the isolator
Π_{ξ_s}	Normalized viscous damping inherent to the system

Greek lower-case letters

α	Exponent characterizing the dependency of friction on velocity
$\beta(D)$	Dispersion of D
γ	Mass ratio
$\lambda(\tau)$	Non-dimensional function of time describing the seismic input time-history
μ	Coefficient of sliding friction
$\mu_{\max}$	Maximum value of friction coefficient attained at large velocities of sliding
$\mu_{\min}$	Minimum value of friction coefficient attained at zero velocity
ψ_s	Normalized superstructure displacement
ψ_b	Normalized isolator displacement
ψ_{u_b}	Normalized peak isolator displacement
ψ_{u_s}	Normalized peak superstructure displacement
$\sigma_{\ln}(D)$	Sample lognormal standard deviation of D
ω_b	Fundamental circular frequency of the isolated system
ω_g	Circular frequency representative of the frequency content of the ground motion input
ω_s	Circular frequency of the superstructure
ω_{tr}	Circular frequency corresponding to the transition slope
ξ_s	Damping factor of the superstructure
ξ_b	Damping factor of the isolated system

Mathematical operators

sgn(·)	sign function
$\dot{}$	First order time derivative operator
$\ddot{}$	Second order time derivative operator
ln(·)	Natural logarithm of (·)

Acronyms

DC	Double Concave
FF	Far Field
IM	Intensity measure
NF	Near Fault
PBEE	Performance-Based Earthquake Engineering
PGA	Peak ground acceleration
PGV	Peak ground velocity
SC	Single Concave
dof	Degree of freedom

optimal concave sliding bearing properties and the ground motion frequency content. In fact, studies on this issue are rather limited and focused on systems different from those considered in this study. Inaudi and Kelly [26] analyzed a building isolated by exhibiting a visco-elastic behavior, and showed that the effect of high-frequency content in the excitation is to decrease the optimum viscous damping. Dicleli and Buddaram [27] studied the effect of the frequency characteristics and intensity of the ground motion on the performance of bridges with bilinear isolators. The results of their extensive parametric study demonstrated that the choice of the seismic ground motion according to the characteristics of the bridge site is crucial for a correct design of the isolators. Similar conclusions have been drawn in the context of isolated bridges by [28,29].

A recent work of [30] has evaluated the optimal friction of single concave sliding isolators for three different sets of artificial records representative of different soil conditions. However, the proposed non-dimensional formulation employed only the spectral acceleration at the fundamental period of the undamped base-isolated structure as ground motion parameter. This parameter does not provide any description of the frequency content of the ground motion and thus it does not allow to unveil the relation between the optimal single concave sliding isolator properties and the seismic input characteristics.

This work aims to further advance the study of [30] by proposing an alternative formulation for investigating the influence of the ground motion characteristics on the optimal isolator friction properties. For