

Inelastic seismic energy spectra for soft soils: Application to Mexico City



Pablo Quinde^{a,*}, Eduardo Reinoso^a, Amador Terán-Gilmore^b

^a Instituto de Ingeniería, UNAM, Ciudad Universitaria, Coyoacán 04510, México D.F, México

^b Departamento de Materiales, Universidad Autónoma Metropolitana, Av. San Pablo 180, Col. Reynosa Tamaulipas 02200, México D.F, México

ARTICLE INFO

Article history:

Received 14 January 2016

Received in revised form

12 July 2016

Accepted 7 August 2016

Keywords:

Seismic energy spectra

Inelastic input energy

Hysteretic energy

Energy reduction factors

ABSTRACT

Earthquake databases are not sufficiently complete, particularly for soft soils. Also, there are few and oversimplified formulations that allow an understanding of the relation that exists between the elastic and inelastic energy demands for this type of soils. A study on energy reduction factors aimed at establishing inelastic input and hysteretic energy spectra for narrow-banded motions is presented. Unlike previous works, in this study elastic input energy spectra are used as input for energy functional forms that allow the formulation of inelastic energy spectra. For this purpose, over 250 seismic records recorded in soft soils are used. The energy reduction factors yield inelastic energy spectra that capture in a reasonable manner the energy content of narrow-banded ground motions, and yield a better characterization of inelastic energy demands.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

For several years, research has been aimed at providing transparency to building regulations, seeking to update design methodologies so that the engineer can understand and assess the expected seismic response and performance of earthquake-resistant structures. In soft soil sites, a particular item of interest is the inelastic hysteretic behavior undergone by structures and its relationship with their structural performance. A specific aim within this context is to provide the designer with tools to control seismic demands in such a manner as to control plastic energy dissipation and thus, structural damage.

Several methodologies have been proposed to model and characterize strong ground motions. Currently, the most accepted is the *Probabilistic Seismic Hazard Analysis (PSHA)*, which considers ground motion parameters such as pseudo-acceleration (S_a), pseudo-velocity (S_v) and peak ground acceleration (PGA). Current seismic design methodologies usually formulate their design requirements in terms of the control of the maximum displacement demand. Nevertheless, several researchers have discussed the shortcomings of current formats in regards to the characterization of the expected performance of structures subjected to long duration ground motions [1–7].

One alternative to current *strength-maximum deformation* formats is an energy-based seismic design approach that considers

ground motion characteristics that can better represent the destructive potential of narrow-banded motions, such as duration and frequency content. Energy parameters can be used to characterize strong ground motions. Particularly, it is possible to establish reasonable approximations of inelastic energy demands (input and hysteretic energy) from elastic input energy spectra through relatively simple models [2,8–11]. Then, damage models can be used to establish improved estimates of structural performance for long duration motions.

Housner [21] and Uang and Bertero [10] introduced energy concepts for structural seismic design. After that, several researchers have considered the balance between both, the demand and supply of energy. One way of studying inelastic energy demands is through the use of energy reduction factors (ERF), which are based on a similar concept than that of strength reduction factors. While the ERF for input energy is usually defined as the ratio of elastic input energy (E_i) to that related to a given ductility demand ($E_{i\mu}$); the hysteretic energy ERF corresponds to the ratio between hysteretic energy (E_H) and $E_{H\mu}$ (both referred to the same ductility demand). Research regarding inelastic energy demands, and input and hysteretic ERFs, has been carried out by Fajfar and Vidic [14], Lawson and Krawinkler [15], Terán-Gilmore [2], Decanini and Mollaioli [9] and Arroyo and Ordaz [24,25]. In their studies, the influence of ductility, soil characteristics, structural period and hysteretic behavior were analyzed. However, earthquake databases presented in their works are not extensive enough, particularly for soft soils. In this paper, it will be understood as soft soil that corresponding to sites with a ground period (T_g)

* Corresponding author.

E-mail address: pquindem@ingen.unam.mx (P. Quinde).

equal or larger than 1 s. In addition, there is little data related to inelastic input ERF, in such a manner that oversimplified models for hysteretic ERF are commonly used.

The main objective of this work is to study and develop expressions to estimate input and hysteretic ERFs for soft soils. For this purpose, a strong motion database of more than 250 records is used. The ERF were established from elastic input energy-based functional forms in order to reduce the error in the estimation of energy demands.

2. Energy-based design

Energy-based seismic design should consider that the energy introduced by the ground motion to the structure should not exceed the capacities of its corresponding storage and energy dissipation mechanisms ([2,10]).

Seismic energy demands will be approached next from the perspective of the response of single-degree-of-freedom (SDOF) systems. Particularly, the equation of motion of a SDOF system subjected to ground motion can be formulated as:

$$m\ddot{x}(t) + c\dot{x}(t) + fs(x, \dot{x}) = -m\ddot{x}_g(t) \quad (1)$$

$$m\ddot{x}_t(t) + c\dot{x}_t(t) + fs(x, \dot{x}) = 0 \quad (2)$$

where x_g is the ground displacement; x , the displacement of the system relative to the ground; m and c , the mass and viscous damping coefficient of the system, respectively; and fs , its restoring force. $\ddot{x}_t(t)$ corresponds to the total acceleration, defined as $\ddot{x}_t(t) = \ddot{x}_g(t) + \ddot{x}(t)$. While Eq. (2) considers the absolute motion of the system; Eq. (1) corresponds to its relative motion. The formulation developed herein is based on relative motion. From here on, relative input energy will be referred simply as input energy.

Integrating Eq. (1) with respect to x , and knowing that $dx = \dot{x}dt$, an energy balance equation can be formulated [10]:

$$\frac{m\dot{x}^2}{2} + \int c\dot{x}^2 dt + \int fs(x, \dot{x})\dot{x}dt = - \int m\ddot{x}_g\dot{x}dt \quad (3)$$

$$E_k + E_D + E_S + E_H = E_I \quad (4)$$

where:

$$E_k = \int m\ddot{x}(t)dx = \frac{m\dot{x}^2}{2} \quad (5)$$

$$E_D = \int c\dot{x}^2 dt = 2\xi\omega \int \dot{x}^2 dt \quad (6)$$

$$E_S + E_H = \int fs(x, \dot{x})dx = \int fs(x, \dot{x})\dot{x}dt \quad (7)$$

$$E_I = - \int m\ddot{x}_g\dot{x}dt \quad (8)$$

In the previous equations, E_k is the kinetic energy per unit mass; E_D , the viscous damping energy per unit of mass; ξ , the percentage of critical damping; and ω , the natural frequency of the system. $E_S + E_H$ are the energy demands per unit mass associated to the restoring force. Particularly, while E_S is the elastic-strain energy, E_H represents the hysteretic energy dissipated through inelastic behavior. Finally, E_I is the input energy introduced to the system by the ground motion.

Usually, it has been considered that E_I , E_H and E_D are the most relevant parameters in terms of the energy balance and structural performance of earthquake-resistant structures.

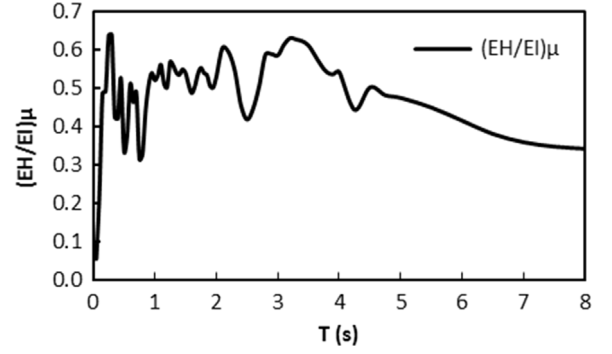


Fig. 1. Hysteretic energy and input energy ratio $(E_H/E_I)_\mu$ for $\mu = 2$. Station CDAO, earthquake April 25, 1989.

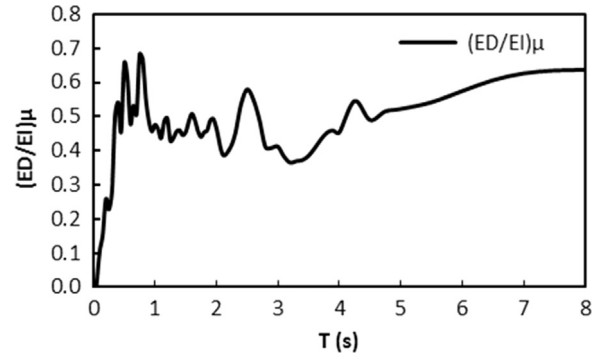


Fig. 2. Damping energy and input energy ratio $(E_D/E_I)_\mu$ for $\mu = 2$. Station CDAO, earthquake April 25, 1989.

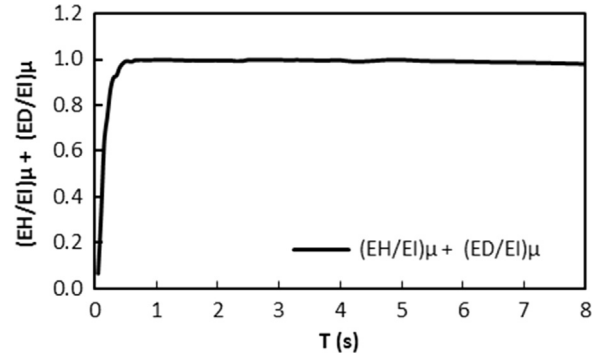


Fig. 3. Seismic input energy approximated by the sum of the $(E_H/E_I)_\mu$ and $(E_D/E_I)_\mu$ ratios.

First, the relationship between elastic and inelastic input energy demands will be considered through energy spectra. Figs. 1 and 2, derived from elasto-perfectly-plastic behavior and 5% of critical damping, show that for short periods and a given value of ductility, the ratio of the hysteretic energy to input energy, as well as that of damping energy to input energy, exhibit an unstable behavior and a tendency to increase. As illustrated in Fig. 3, with the exception of the energy demands corresponding to short periods, the input energy can be fully characterized by the sum of the hysteretic and damping energies.

3. Strong motion database

Soft soils with ground periods equal or larger than 1 s are considered. A large portion of the territory of Mexico City is located over the ancient Texcoco Lake, in such a manner that its sites overlay mostly soft soils. The records used herein have been

Download English Version:

<https://daneshyari.com/en/article/4927403>

Download Persian Version:

<https://daneshyari.com/article/4927403>

[Daneshyari.com](https://daneshyari.com)