Applied Soft Computing 47 (2016) 357–369

Contents lists available at ScienceDirect

Applied Soft Computing

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

A new method for modification of ground motions using wavelet transform and enhanced colliding bodies optimization

A. Kaveh*, V.R. Mahdavi

Centre of Excellence for Fundamental Studies in Structural Engineering, Iran University of Science and Technology, Narmak, Tehran 16, Iran

ARTICLE INFO

Article history:
Received 24 May 2015
Received in revised form 9 March 2016
Accepted 17 June 2016
Available online 21 June 2016

Keywords:
Spectrum-compatible ground motions
Wavelet transform
Response spectrum
Enhanced colliding bodies optimization

ABSTRACT

In this paper a simple and robust approach is presented for spectral matching of ground motions utilizing the wavelet transform and an improved metaheuristic optimization technique. For this purpose, wavelet transform is used to decompose the original ground motions to several levels, where each level covers a special range of frequency, and then each level is multiplied by a variable. Subsequently, the enhanced colliding bodies optimization technique is employed to calculate the variables such that the error between the response and target spectra is minimized. The application of the proposed method is illustrated through modifying 12 sets of ground motions. The results achieved by this method demonstrate its capability in solving the problem. The outcomes of the enhanced colliding bodies optimization (ECBO) are compared to those of the standard colliding bodies optimization (CBO) to illustrate the importance of the enhancement of the algorithm.

1. Introduction

Recent aseismic code regulations recommend the use of linear or non-linear dynamic time history analyses for design of irregular, high rise and important structures due to the increased capabilities of the commercial software to account the potential inelastic behavior of structural systems under seismic time histories. These acceleration time histories can be achieved either by using a set of real recorded earthquake accelerograms associated with historical seismic events, or utilizing an ensemble of numerically simulated earthquake signals. In the latter approach, one can make pure artificial records and filter them according to the site characteristics or to reconstruct the real record so that its spectrum fits the target standard [1,2]. Obviously finding suitable methods for reconstructing or modifying realistic ground motions become important challenging problems.

The main objective of the reconstruction/modification of ground motions is to modify a given recorded ground motions such that these response spectrums become compatible with a specified design spectrum. For this purpose, various time or frequency-domain methods are used. The time-domain methods manipulate only the amplitude of the recorded ground motions, while the frequency-domain approaches operate the frequency contents and phasing of actual ground motions in order to match with the design spectrum. During the last two decades a number of researches are performed on this problem employing the frequency-domain methods. Gupta and Joshi [3] and Shrikhande and Gupta [4] used the phase characteristics of recorded accelerograms. Conte and Peng [5] directly modeled the evolutionary power spectral density function of the ground motion process. Recently, many researchers have focused on modifying the recorded ground motions using wavelet [6–10]. For example, Hancock et al. [6] utilized wavelet and Mukherjee and Gupta [7] developed an iterative wavelet-based method for spectral matching. Cecini and Palmeri [8] proposed an iterative procedure based on the harmonic wavelet transform to match the target spectrum through deterministic corrections to a recorded accelerogram. As will be mentioned in the coming sections, these works achieved iterative approaches to obtain the sought spectrum-compatible accelerograms. These methods do not necessarily fulfill the requirements of the code regulations.

In this paper an approach is utilized to modify the real ground motions such that these response spectrums become compatible with the European Code (CEN. Eurocode-8 [11]) for elastic spectrum regulations. For this purpose, the wavelet transform is used to decompose the ground motions to several levels and each level covering a special range of frequency, and each level is multiplied by a variable. Subsequently, an optimization algorithm is employed to calculate the variables to minimize the error between response and target spectrums, while the requirements of the code regulation are considered as constrains of the optimization process.

* Corresponding author.
E-mail address: alikaveh@iust.ac.ir (A. Kaveh).

http://dx.doi.org/10.1016/j.asoc.2016.06.021

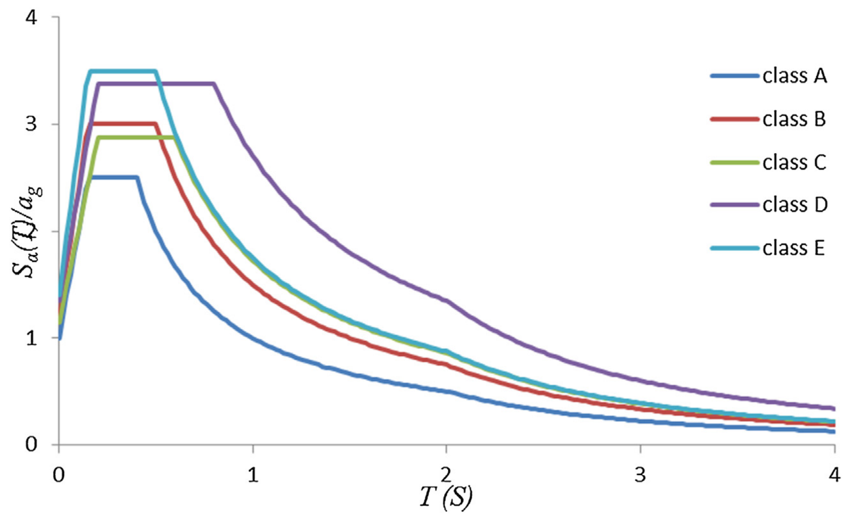

Fig. 1. Elastic response spectra for different site soil classes, based on the EC8.

Optimization algorithms can be divided into two categories: 1. Deterministic; 2. Stochastic. Deterministic algorithms are mostly gradient based methods, and the stochastic algorithms consist of heuristic and meta-heuristic methods. These optimization techniques which mimic stochastic natural phenomena have emerged as robust and reliable computational tools compared to the conventional gradient-based methods in solving complex problems. The stochastic nature of such algorithms allows exploration of a larger fraction of the search space than in the case of gradient-based methods. Since the objective function of this work (the difference between design spectrum and average response spectrum of modified ground motion) is non-smooth and non-convex, the gradient-based optimization methods can be trapped in local optima. Thus, a recently developed metaheuristic algorithm is utilized to optimize this objective function. Some algorithms based on natural evolution phenomenon are developed by Eberhart and Kennedy [12], Dorigo et al. [13], Erol and Eksin [14], Kaveh and Talatahari [15], Sadollah et al. [16], and Kaveh and Mahdavi [17]. Enhanced colliding bodies optimization (ECBO) is an improved version of the recently developed meta-heuristic algorithm so-called colliding bodies optimization (CBO) [18]. Simple formulation and the need for no parameter tuning are the main characteristics of this algorithm.

2. Spectral matching problem according to Eurocode-8

2.1. Standard design spectrum in Eurocode-8

The elastic acceleration response spectrum, $S\alpha(T)$, for oscillators with 5% ratio of critical damping and natural period T, is defined by the European seismic code provisions (CEN 2003) [11] as:

$$S_a(T)=\begin{cases}\alpha_g S(1+\dfrac{1.5T}{T_B}) & 0\le T\le T_B\\ 2.5\alpha_g S & T_B\le T\le T_c\\ 2.5\alpha_g S(\dfrac{T_C}{T}) & T_C\le T\le T_D\\ 2.5\alpha_g S(\dfrac{T_C T_D}{T^2}) & T_D\le T\le 4s\end{cases} \quad (1)$$

where S is the soil factor; T_B and T_C are the limiting periods of the constant spectral acceleration branch; T_D defines the beginning of the constant displacement response range of the spectrum, and a_g is the design ground acceleration on type A ground, which is defined according to the seismic hazard. In this study, a_g is chosen as 0.35 g.

Table 1
Values of the parameters describing the recommended Type I elastic response spectra.

Ground type	S	T_B (S)	T_C (S)	T_D (S)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.2	0.6	2.0
D	1.35	0.2	0.8	2.0
E	1.4	0.15	0.5	2.0

The values of the periods T_B, T_C and T_D and the soil factor S describing the shape of the elastic response spectrum depend on the ground type. In Table 1, the specific values that determine the spectral shapes for Type 1 spectra are listed, and the resulting spectra is normalized by a_g and plotted in Fig. 1.

2.2. Spectra matching requirements based on Eurocod-8

According to Eurocode-8, seismic ground motions can be classified depending on the nature of the application and on the information actually available by natural, artificial, or simulated accelerograms. These seismic ground motions should reflect some important seismological parameters in local seismic scenarios and should match the following criteria: (1) a minimum of 3 accelerograms should be used; (2) mean of the zero period spectral response acceleration values should not be smaller than the value of $a_g S$ for the site in question; and (3) in the range of periods between $0.2T_n$ and $2T_n$, where T_n is the fundamental period of the structure in the direction where the accelerogram is applied; no value of the mean 5% damping elastic spectrum calculated from all time histories should be less than 90% of the corresponding value of the 5% damping elastic response spectrum.

Moreover, the code requires the consideration of the maximum effect on the structure, rather than the mean effect if less than seven non-linear time history analyses are performed.

3. Wavelet transform

Wavelet transform provides a powerful tool to characterize local features of a signal. Unlike Fourier transform, where the function used as the basis of decomposition is always a sinusoidal wave, other basis functions can be selected for wavelet shape according