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A Multi-step approach to generate response-spectrum-compatible artificial earthquake accelerograms

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ABSTRACT

Time history records are essential for nonlinear dynamic analysis to determine the response of structures. Considering lack of enough earthquake records, generation of artificial earthquake records and spectrum-matched records are the best method in this regard. This study is motivated by real life applications of designing new structures or evaluating the performance of current ones in Afghanistan where two structures are to be designed and built to withstand earthquakes. In this paper, design response spectrum and time history records are generated for two sites located within the city of Kabul, Afghanistan. The Probabilistic Seismic Hazard Assessment (PSHA) results are employed initially to produce the required parameters and data. Then, the generalized nonstationary Kanai-Tajimi model is applied to simulate the ground acceleration time history using the identified characteristics of the site from preliminary ARMA (Auto Regressive Moving Average) analysis and the site-specific analysis. The response spectrum is developed and iteratively compared to the ARMA model and the site-specific spectrum until a satisfactory match is achieved. Finally, the time domain description of the spectrum-compatible artificial earthquake record is developed exploiting inverse FFT of the design response spectrum. The total errors in spectral matching generated accelerograms are compared to results from a commercially available software. Results demonstrated the effectiveness and robustness of the adapted approach.

1. Introduction

Acceleration time-histories of earthquake ground motions are required for assessing nonlinear structural performances as well as the response of soil deposits under seismic loading. This consideration is significant when unusual building configuration exits. Moreover, the nonlinear dynamic analysis is sensitive and greatly affected by the characteristics of ground motion used as seismic input. The presences of non-linear finite element analysis tools with recent computational power are improving analysis philosophy to a non-linear and displacement based method. Additionally, modal analysis uses real ground motion time-series in theory, but in practice, it employs real average and smoothed design response spectrum that is identified by nearly most international design building codes, e.g. International Building Code IBC2012 [1]. Non-linear analysis based displacement and performance design are evolved to new efficient and practical methods. These approaches need reliable and general sets of seismic time-series wave documented after seismic activity. Due to lack of representative recorded ground motion data, artificial ground motions are often generated.

In the last decade, many researchers, Kaveh and Mahdavi [2], Banerjee et. al. [3], Rizzo et. al. [4], Kost et. al. [5], Silva and Lee [6] and Mukherjee and Gupta [7], have proposed different methodologies to generate legitimate and accurate spectrum-compatible earthquake ground motions. Others scaled the Fourier or wavelet amplitudes or phases of an actual earthquake record to generate a compatible response spectrum with a target design spectrum. Various researchers [8–10] proposed methods of matching response spectra of real accelerograms by adding wavelet functions in the time domain to generate spectrum-compatible artificial earthquake records. Hilbert–Huang Transform (HHT) is signal-processing method that retains the non-stationary features of real earthquake records. The HHT method is adopted by Ni and his co-authors who generate spectrum-compatible unidirectional or tri-directional earthquake ground [11–14].

In this paper, a new multi-step approach is proposed to generate spectrum-compatible earthquake ground motions from a specific seismic design response spectrum using few real accelerograms. This set of spectrum-compatible earthquake ground motions is produced by using the ARMA [15] and Kanai-Tajimi [16] models. First, the site-specific parameters and data are produced using PSHA approach.

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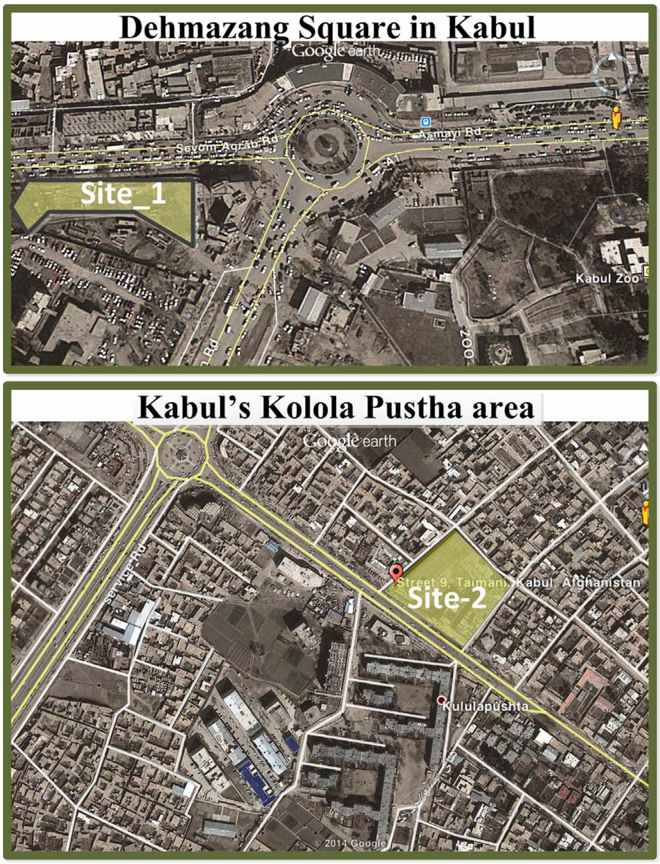

Fig. 1. Aerial view of Site-1 and Site-2.

Table 1
Coordinates of Site-1 and Site-2.

Corner	Site-1: Average Elevation 1807 m		Site-2: Average Elevation 1792 m	
	Lat. (°)	Long. (°)	Lat. (°)	Long. (°)
1.	34.51044	69.15042	34.54134	69.15138
2.	34.51036	69.15222	34.54210	69.15241
3.	34.50993	69.15212	34.54144	69.15313
4.	34.51017	69.15128	34.54066	69.15248
5.	34.51019	69.15051		
6.	34.50992	69.15036		
7.	34.51000	69.15012		

Second, the characteristics of the site are identified using ARMA analysis. Third, the generalized non-stationary Kanai-Tajimi model is applied to simulate the ground time history records using the results of both PSHA and ARMA. The design response spectra based on Kanai-Tajimi model as well as PSHA and ARMA methods are smoothed and averaged to generate site-specific design response spectra. Finally, several accelerograms are generated iteratively and compared to the site-specific spectra until a satisfactory match is achieved to generate spectrum-compatible accelerograms.

This study is inspired by real life applications of designing new structures in Afghanistan. Due to lack of representative strong motion data recorded in Afghanistan, synthetic ground motions required. Six artificially generated earthquake accelerograms are developed and properly tuned for the two sites in Kabul Afghanistan. These records are generated with specific PGAs and frequency ranges filtered to fit the conceivable frequencies and amplitudes that any structure built in these sites will experience.

2. Site description and PSHA results

The two sites are located within the city of Kabul, Afghanistan, referred to here as “Site-1 and Site-2”. Fig. 1 shows an aerial view of Site-1 and Site-2, respectively. Site-1 is situated at the heart of the busy district of Dehmazang Square in Kabul, which is planned to host the Azizi Millie Palace. Meanwhile, Site-2 is located within the heart of Kabul's Kolola Pustha area and it is planned to contain Azizi Star residential and business complex. The coordinates for the two sites are given in Table 1.

The authors and co-researchers [17] performed PSHA for the selected sites within the city of Kabul, Afghanistan. Results of the study were reported and submitted to the consultant in an unpublished report [17]. The report presents an assessment of earthquake hazards and the ground motion levels for the two Kabul sites determined using a PSHA with seismic sources within 300 km circles. The assessment includes the estimation of the severity of ground shaking on bedrock conditions (i.e. Vs=760 m/s) at the two sites using a probability of exceedance of 10%, 5% and 2% in 50 years of exceedance (i.e., a 475, 975, 2475 years of return period) as shown in Fig. 2. Earthquake hazards analysis using a PSHA approach for the two selected sites indicated that ground motion values of both sites are having comparable PGA values for a probability of exceedance of 10% in 50 years ranges between 0.1290–0.1860 g and 0.1280–0.1760 g for Site-1 and Site-2, respectively. These numbers indicate similar ground motion values between the two sites since the distance between the two locations is less than 3.5 km. In an attempt to provide a more conservative PGA estimation, the study suggests a value of not less than the highest PGA value estimated for a firm rock boundary (Vs≥760 m/s). A summary of PGA values for both sites of the different estimated return periods is given in Table 2 for different attenuation equations.

3. Earthquake time histories

For engineering design and analysis purpose, two approaches are available to get time histories records: real ground motion records or synthetic ground motions. The real ground motion sources are available from sufficient and reliable monitoring earthquake centers.

Many centers around the world are cataloguing and gathering records of ground motions that are made gradually available to design engineers. Available archives can be utilized to find records corresponding to source type, distance to rupture, geologic and local soil conditions, earthquake magnitude, etc. These accelerograms are used to generate special response spectra with different damping values, period ranges, for nonlinear inelastic systems [18]. In this study reliable ground motion are obtained from IRIS (Incorporated Research Institutions for Seismology) [19], founded in 1984 with support from the National Science Foundation.

Several time history records are available neighboring the studied sites. In this regards, selected historical records are obtained and prepared to generate the design response spectra for Site-1 and Site-2. The recorded time history for both sites are described in Tables 3, 4. The data files were downloaded for the Hindu Kush region [19], Afghanistan (Lat/Long 36.47130/70.92510, Magnitude 6.2) earthquake at depth 196.5 m on 2009-10-22 19:51:28 and Afghanistan (Lat/Long 36.46580/70.71640, Magnitude 6.0) earthquake at depth 202.4 m on 2009-10-29 17:44:31. These two events distance around 270 km from both sites as can be estimated from the coordinates. Five different stations recorded the seismic events at the Hindu Kush region are shown in Tables 3, 4. For example, the station EIWX name is Colaiste Bridge and situated in Wexford Ireland at Lat/Long 52.50/−6.56. Similar information can be found at IRIS website.

For the case of the city of Kabul, Afghanistan, the selected ground motions shown in Tables 3, 4 vary in their duration and PGA values. Hence, it is difficult to rely on these records to develop the response