

PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR THE K. ÇEKMECE SITE IN TURKEY USING ENERGY- AND STRENGTH-BASED GROUND MOTION PARAMETERS

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ABSTRACT:

Probabilistic seismic hazard analysis (PSHA) studies for the K. Çekmece site in Turkey have been performed using two ground motion parameters – the conventional spectral acceleration, S_a and an energy-based parameter with units of acceleration, A_i , which is derived from input energy. This energy-related acceleration parameter is used since it is expected to provide more useful information regarding damage potential compared to conventional strength-related parameters (e.g., response spectral ordinates). Uniform hazard spectra for three different return periods are presented for the K. Çekmece site including site effects. Finally, the uniform hazard spectra based on the strength-based parameter are compared with design spectra based on the Turkish building code.

Keywords: Energy, strength, probabilistic seismic hazard analysis, uniform hazard spectra.

Introduction

The main purpose of seismic hazard analyses is to estimate the levels of ground shaking that are associated with different probabilities (return periods) and to develop rock, stiff soil, or soft soil ground motions for use in design for specified return periods. Traditionally, quantitative descriptions of ground shaking have been expressed in terms of strength-based ground motion parameters such as spectral acceleration, S_a . In this study, in addition to such strength-based parameters, we employ an alternative ground motion parameter derived from the input energy demand that a structure experiences. We refer to this parameter as an input energy-equivalent acceleration, A_i . Such energy-based parameters are worth considering for use in seismic hazard studies because they can provide useful information related to damage potential; they convey some indication of the cyclic nature of the loading and the duration of the ground shaking which a strength-based parameter such as spectral acceleration does not. In addition, similar to spectral acceleration, input energy (used to define A_i) is a frequency-dependent measure that relates to the response of a single-degree-of-freedom with a specified natural frequency and damping, as well as to the character of the ground motion. An input energy response spectrum

represents the peak input energy demand for different natural periods and for a given damping.

Results from the PSHA studies for the K. Çekmece site are presented in the form of hazard curves expressing the probability of exceedance of different levels of the strength- and energy-based ground motion parameters. Soil amplification effects are included in the PSHA studies using available information of the shear wave velocity profile for the site. Uniform hazard spectra are presented including site effects. Finally, comparisons of strength-based uniform hazard spectra with the design spectra based on the Turkish building code are presented.

Ground Motion Parameters

Traditionally, strength-based parameters (such as spectral acceleration (S_a) or velocity (S_v) or even peak ground acceleration) have been used to understand the effect of ground motion on structures with different natural period and damping values. Not as extensively studied are energy-based ground motion parameters and models describing their attenuation.

A transformation of the equation of motion for a single-degree-of-freedom system into an energy balance equation can be easily accomplished by integration over the entire duration of the ground motion. The integration is done with respect to relative displacement (u) of the mass with respect to ground (Sarı and Manuel, 2002, Uang and Bertero, 1988). The input energy, E_i , represents the maximum value of the work done by the base shear acting through the foundation/ground displacement (u_g), and is obtained by It is convenient to define parameters with units of velocity that relate to the input energy. Thus, an input energy-equivalent velocity, V_i , was defined by Uang and Bertero (1988), where $V_i = (2E_i/m)^{1/2}$. In the present study, in order to make direct comparisons with the conventional strength-based parameter (spectral acceleration, S_a), we employ an input energy-equivalent acceleration, A_i , equal to $(2\pi/T)V_i$, as was defined by Sarı and Manuel (2002). Note that an input energy response spectrum can be developed in the same manner as is done for conventional response spectra that yield spectral acceleration, for example. For a given ground motion record, a single-degree-of-freedom system with a specified period and damping is analyzed for its peak input energy and this is used as the input energy response spectrum ordinate. Such a period-dependent energy-based parameter (or a quantity derived from it, such as A_i) may be used in PSHA studies. This is exactly what is done here.

Ground Motion Attenuation

Studies comparing observed strength and energy demands from ground motions recorded during the Kocaeli earthquake with empirical attenuation models for the Western United States (WUS) suggest that there are similarities in the observed levels of motions except possibly in the near field (see Sarı and Manuel, 2002). Because recordings from shallow crustal earthquakes in an active tectonic region (California) were used to develop the Western U.S. models and a similar tectonic regime exists in Turkey, these

similarities are not surprising. As such, we believe that Western U.S attenuation models may be employed in PSHA studies for Turkey.

For the strength-based PSHA calculations, the attenuation relationships proposed by Boore et al (1997) and Sadigh et al (1997) are used for spectral acceleration and peak ground acceleration. An additional relationship for peak ground acceleration proposed by Campbell (1997) is also used. The attenuation model by Chapman (1999) for elastic input energy-equivalent acceleration, A_i , is selected for use in the energy-based PSHA calculations. Whenever more than one attenuation relationship is used for a ground motion parameter, the alternative models are assigned equal weights in the PSHA calculations.

Probabilistic Seismic Hazard Analysis Model

Quantification of the seismic hazard at a site involves the characterization of seismic sources, the compilation of seismicity data, and the use of ground motion attenuation models. In this study, researchers at the Kandilli Observatory and Earthquake Research Institute in Turkey carried out the source characterization leading to a description of eleven fault segments that make the northern portion of the North Anatolian Fault system, along with the required seismicity data needed as input for the PSHA studies. The fault segments were modeled in such a way that only characteristic events assumed to rupture the entire segment were considered. The magnitudes of these events on the segments were either 7.4 or 7.5 and their recurrence rates ranged from 159 to 286 years based on slip rate data and on past earthquakes. We assume a homogenous Poisson process to model the occurrences of characteristic earthquakes on each of the eleven segments of the northern portion of the North Anatolian fault system.

Numerical Studies

Seismic Hazard Curves

Seismic hazard curves based on the WUS attenuation relationships are shown in Figure 1a and 1b. In Figure 1(a), the seismic hazard curves are based on peak ground acceleration as well as spectral acceleration at different natural periods. In Figure 1(b), hazard curves are presented for the input energy-equivalent acceleration. Note the monotonically decreasing trend of hazard with increasing period in the case of the energy-based parameter (Figure 1(b)) which is in contrast to the hazard curves for spectral acceleration.

Soil Amplification of the K. Çekmece Site

Soil amplification coefficients to adjust spectral acceleration levels for site class effects at short periods (S_s) and at 1 second (S_1) are presented in the NEHRP Provisions (BSSC, 2001). Amplification of motions in a soil column is larger for lower levels of input excitation; also, softer soils experience greater amounts of amplification. The K. Çekmece site class is classified as site class D (Rathje et al, 2002).

The amplification of input energy-equivalent acceleration for different site classes has not been studied. Accordingly, here, this amplification is studied so that site effects may be included in the PSHA studies where A_i is used as a ground motion parameter. The SHAKE91 software is used to calculate the required amplification factors. The response of the K. Çekmece soil profile available from Rathje et al (2002) is studied by considering 64 different input bedrock motions. These input motions considered to be site class A ground motion recordings are applied at the top of the bedrock. A database of the 64 strong ground motion records from different earthquakes around the world, which was used in the soil amplification calculations, is presented in Table 1.

A flowchart describing the procedure for calculating the soil amplification factors is shown in Figure 2. As is indicated in the figure, response spectra for both energy- and strength-based parameters are calculated for both input (bedrock) motions and output (site class D) motions. The ratio of input energy-equivalent acceleration and spectral acceleration levels from the output motions to corresponding levels for the input motions at a specific period yields the amplification factor for that parameter at a specified level of shaking and period. Results of soil amplification calculations for the K. Çekmece site are classified broadly for short and intermediate periods. To define the amplification factors for spectral acceleration, specific levels of spectral acceleration are given in NEHRP Provisions (BSSC, 2001). These same levels are used here. A study of how spectral acceleration and input energy-equivalent acceleration (A_i) vary was performed to help determine levels of A_i that could be used to report soil amplification for energy demands. Figure 3 shows how S_a varies with A_i .

Results from the soil amplification studies are summarized in Table 2. The amplification factors to adjust input energy-equivalent acceleration for site class D at short periods and at 1 second are presented. Amplification factors for spectral acceleration are also shown in the table. Comparing the energy- and strength-based parameters, it is seen that at short periods, soil amplification factors are similar but at intermediate periods, energy-based parameters are amplified by smaller amounts for the site class D studied here.

Uniform Hazard Spectra including Site Effects

Uniform hazard spectra based on spectral acceleration and input energy-equivalent acceleration for the K. Çekmece Site (considering NEHRP site classes A&B and D separately) are presented in Figures 4 and 5, respectively. The spectra are shown for three different return periods corresponding to 1%, 2%, and 5% probabilities of exceedance in 50 years. The results are based on the PSHA studies carried out using Western U.S. attenuation models. For site class D, the uniform hazard spectra were calculated using the amplification factors given in Table 2.

In Figure 6, we compare the uniform hazard spectra with design spectra based on the Turkish building code. Comparisons are shown for site classes A&B and D separately. Design spectra from the 1997 Turkish building code for two importance factors, 1.5 (used for hospitals, power plants, etc.) and 1.0 (used for residential buildings) are compared with the uniform hazard spectra.

For the rock/stiff soils sites (site classes A&B), the design spectra for the higher importance factor ($I=1.5$) are conservative at short periods but for longer periods, they yield lower motions than indicated by the uniform hazard spectra. For the softer soil (site class D), except for a narrow intermediate frequency range, the design spectra generally lie above the uniform hazard spectra corresponding to a 2% probability of exceedance in 50 years.

Conclusions

Probabilistic seismic hazard studies have been performed for the K. Çekmece site. Strength- and energy-based ground motion parameters have been used. Soil amplification factors are proposed based on the analysis of the response of the K. Çekmece soil profile subjected to 64 different bedrock motions. For energy-based parameters, such amplification factors have not been studied before and at intermediate periods, amplification was found to be less than is the case for spectral acceleration.

Design spectra from the 1997 Turkish building code were compared with uniform hazard spectra including site effects. For the site class D conditions, the design spectra generally were above the uniform hazard spectra corresponding to a 2% probability of exceedance in 50 years.

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Table 1. Database of strong motion records used in the development of amplification of energy demands due to site effects.

Earthquake No	Earthquake Name	Earthquake Date	Number of Recordings
1	Cape Mendocino	04/25/1992	1
2	Chi-Chi, Taiwan	09/20/1999	30
3	Coyote Lake	08/06/1979	1
4	Hollister	11/28/1974	1
5	Kocaeli, Turkey	08/17/1999	3
6	Landers	06/28/1992	4
7	Loma Prieta	10/18/1989	8
8	Lytle Creek	09/12/1970	1
9	Morgan Hill	04/24/1984	1
10	N. Palm Springs	07/08/1986	2
11	Northridge	01/17/1994	7
12	San Fernando	02/09/1971	1
13	Whittier Narrows	10/04/1987	4
TOTAL			64

Table 2. Soil amplification factors for NEHRP site class D as a function of excitation level for spectral acceleration, S_a , and input energy-equivalent acceleration, A_i .

Soil amplification factors for different spectral acceleration (S_a) levels – site class D					
Short Period	< 0.25g	0.50g	0.75g	1.00g	> 1.25g
	1.6	1.4	1.2	1.1	1.0
Intermediate Period	< 0.10g	0.20g	0.30g	0.40g	> 0.50g
	2.4	2.0	1.8	1.6	1.5
Soil amplification factors for different input energy-equivalent acceleration (A_i) levels – site class D					
Short Period	< 0.50g	1.00g	1.50g	2.00g	> 2.50g
	1.6	1.4	1.3	1.2	1.2
Intermediate Period	< 0.20g	0.40g	0.60g	0.80g	> 1.00g
	2.1	1.8	1.8	1.2	1.0

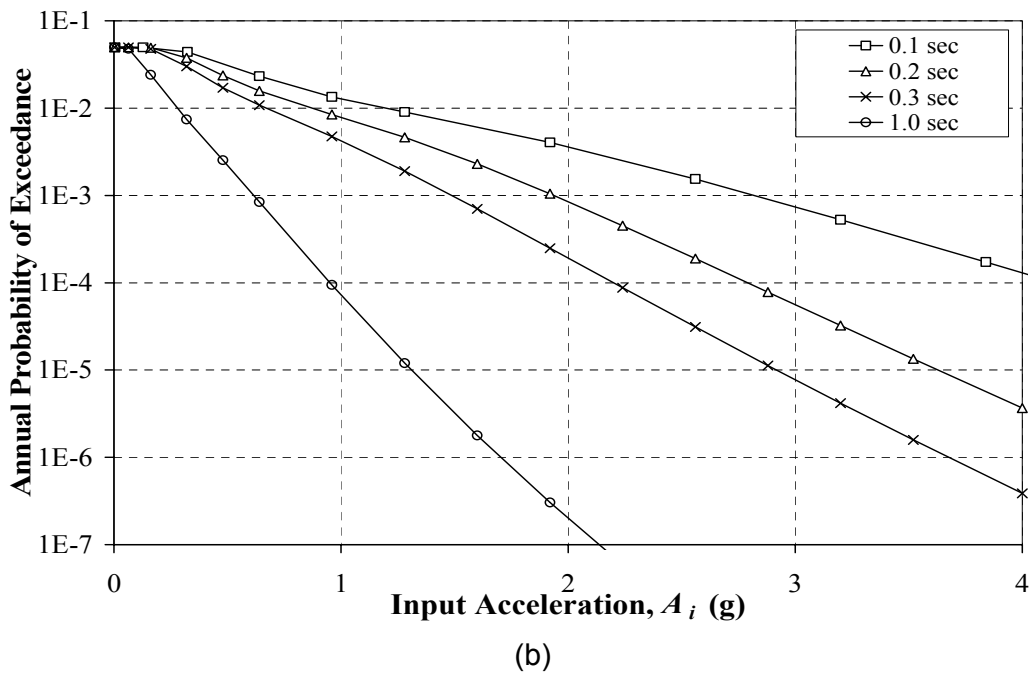
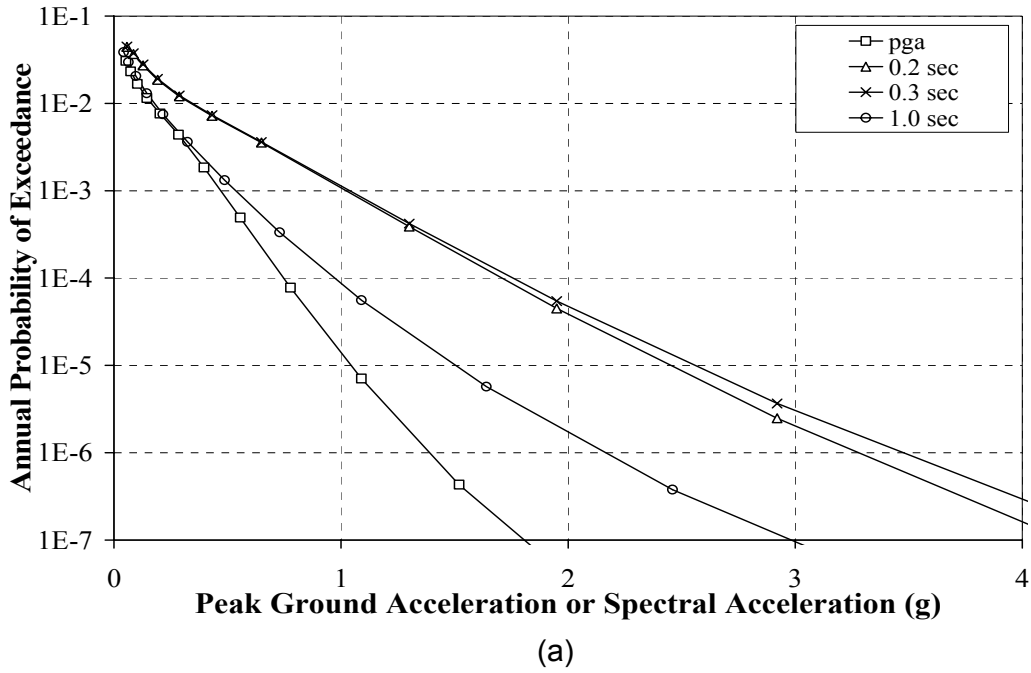


Figure 1. Seismic hazard curves for the K. Çekmece site using (a) strength-based ground motion parameters (pga and S_a), and (b) an energy-based ground motion parameter (A_i).

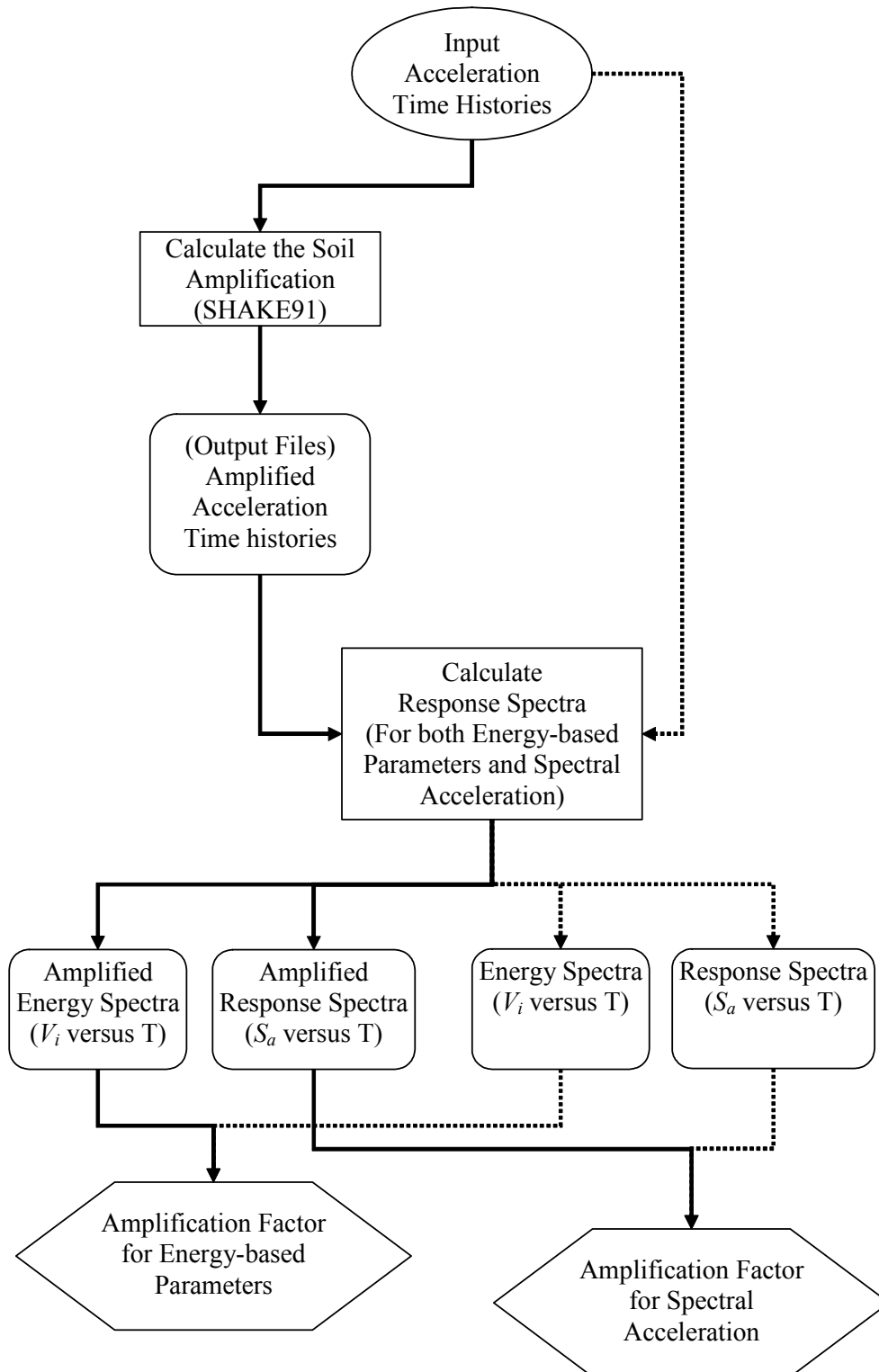
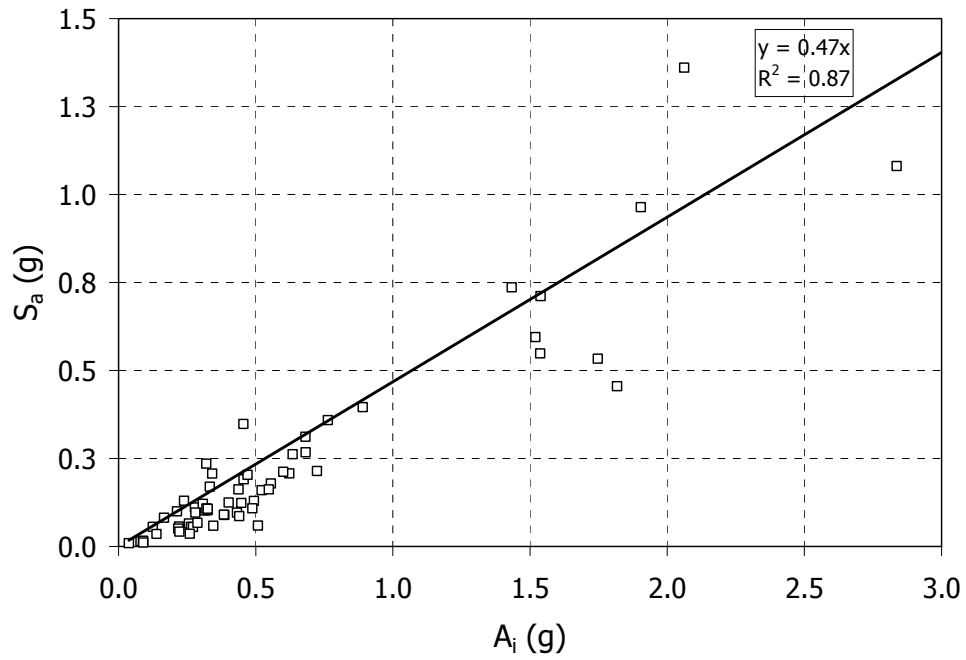
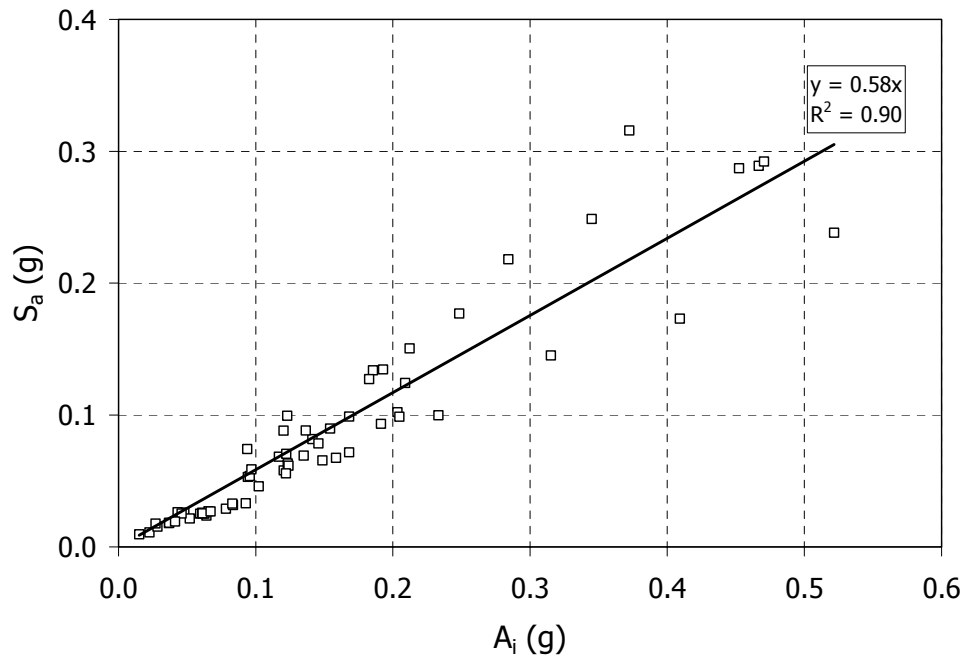


Figure 2. Flowchart describing procedure for calculation of period-dependent soil amplification factors.



(a)



(b)

Figure 3. Relation between spectral acceleration and input energy-equivalent acceleration at natural periods of (a) 0.2 seconds, and (b) 1.0 seconds.

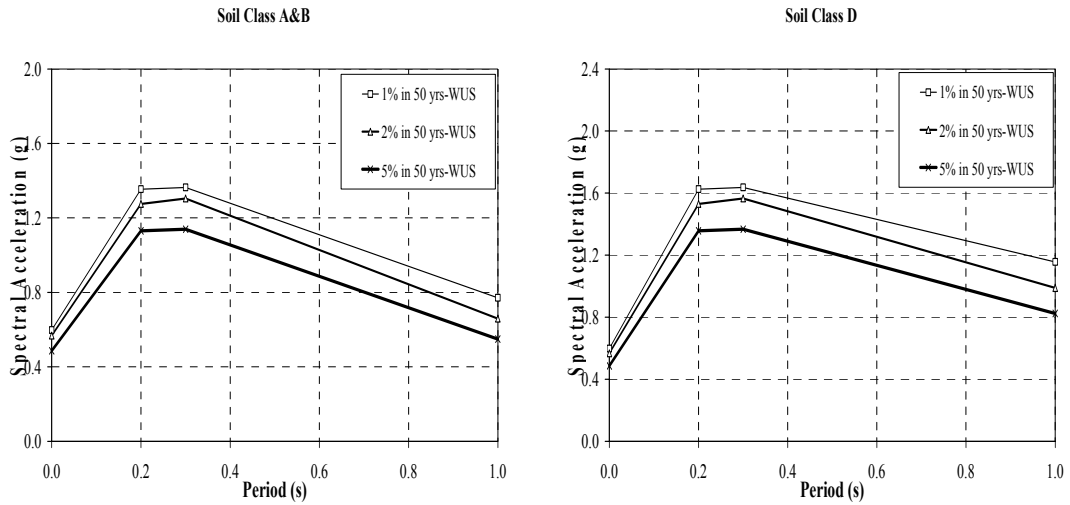


Figure 4. Comparison of uniform hazard spectra based on spectral acceleration for the K. Çekmece Site considering site classes A&B and D, respectively.

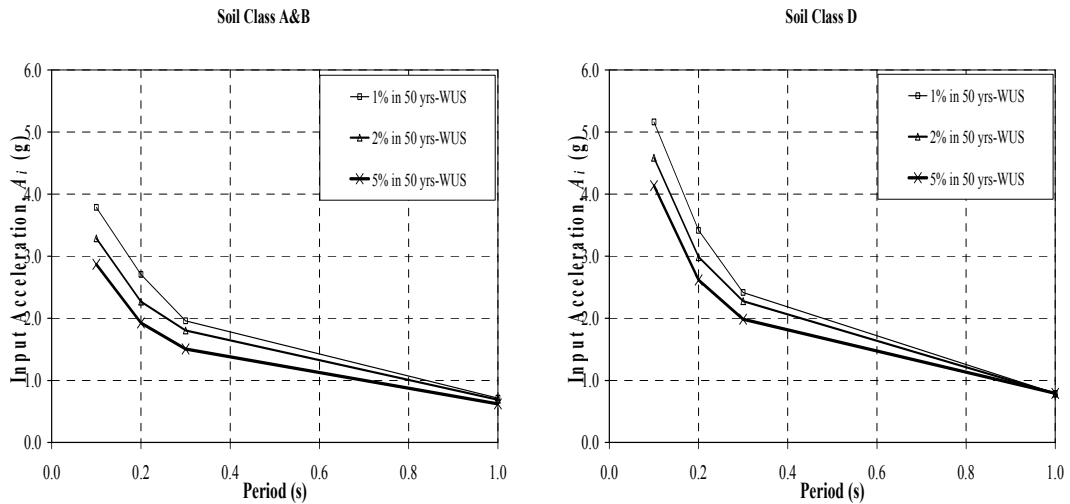
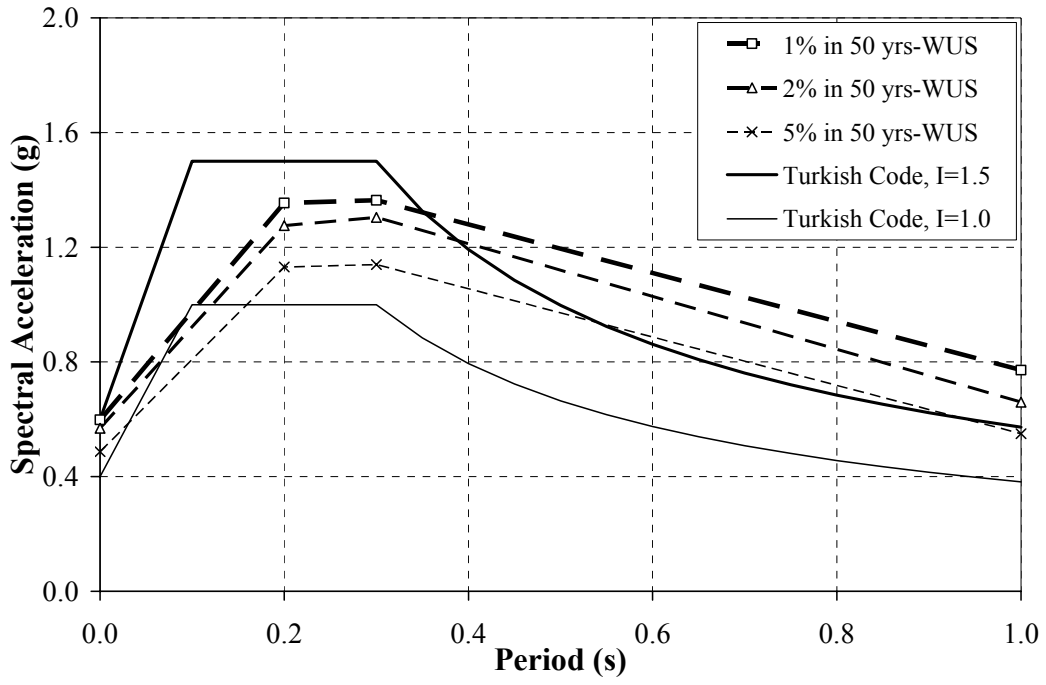
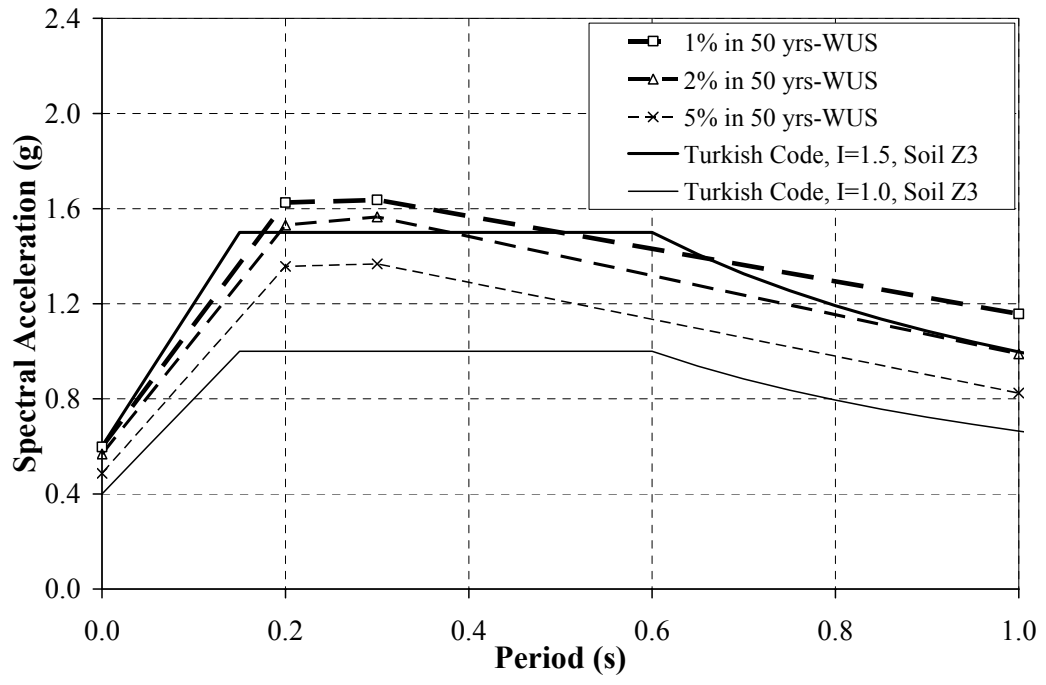


Figure 5. Comparison of uniform hazard spectra based on input energy-equivalent acceleration for the K. Çekmece Site considering site classes A&B and D, respectively.



(a)



(b)

Figure 6. Comparison of uniform hazard spectra for the K. Çekmece Site considering (a) site classes A&B, and (b) site class D, with the Turkish building code.