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SEISMOLOGY

Determination of Local Site-Specific Spectra Using Probabilistic Seismic Hazard Analysis for Bitlis Province, Turkey

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ABSTRACT

In this study, site-specific earthquake spectra for Bitlis province in Lake Van Basin has been obtained. It is noteworthy that, in probabilistic seismic hazard assessment, as a first stage data from geological studies and records from the instrumental period were compiled to make a seismic source characterization for the study region. The probabilistic seismic hazard curves for Bitlis were developed based on selected appropriate attenuation relationships, at rock sites, with a probability of exceedance 2%, 10% and 50% in 50 year periods. The obtained results were compared with the spectral responses proposed for seismic evaluation and retrofit of the building structure in Turkish Earthquake Code, Section 2. At the end of this study, it is apprehended that the Code proposed earthquake response spectra are not sufficient for the performance evaluation of the existing structures and the current estimations show that the potential seismic hazard research of the Turkey is underestimated in the code. Therefore, site- specific design spectra for the region should be developed, which reflect the characteristics of local sites.

Keywords: Site-specific, earthquake spectra, site response analysis, codes, probabilistic.

Determinación de espectros de sitio específico locales a través del análisis probabilístico de amenazas sísmicas para la provincia de Bitlis, Turquía

RESUMEN

En este estudio se obtuvieron espectros de terremoto de sitio específico para la cuenca del Lago de Van, en la provincia de Bitlis, al este de Turquía. La primera fase del trabajo consistió en una evaluación probabilística de riesgo sísmico donde se compilaron los estudios geológicos y registros del período instrumental para hacer una caracterización de fuente sísmica en la región de estudio. Las curvas de amenaza sísmica para la provincia de Bitlis se desarrollaron con base en las relaciones de atenuación apropiada seleccionadas en los sitios rocosos, con una probabilidad de exceso de 2 %, 10 % y 50 % durante 50 años. Los resultados obtenidos se compararon con las respuestas de espectro propuestas para la evaluación sísmica y modernización de estructuras contempladas en el Código de Terremoto de Turquía, en la sección 2. En la parte final de este trabajo se comprende que las respuestas de espectros de terremoto propuestos en el código no son suficientes para la evaluación de desempeño de las estructuras existentes y que las estimaciones actuales muestran que la investigación de amenazas potenciales sísmicas en Turquía está subestimada en el código. Por lo tanto, el diseño de espectros de sitio específico para la región se debe desarrollar, ya que permitiría conocer las singularidades locales.

Palabras clave: Sitio específico, espectros de terremoto, análisis de respuesta de sitio, códigos, probabilística.

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Introduction

Seismic hazard analysis of the earthquake-prone Eastern Anatolia region of Turkey has become more important due to its growing strategic importance as a global energy corridor and closer integration with the European Union. In this study, Bitlis province is selected as the study area. The town of Bitlis has a population of 70,000 (including the surroundings) as of the year 2000. The town is located 15 km from Lake Van along the steep slopes of the Bitlis River valley at an elevation of 1,400m.

The seismicity of Bitlis has been evaluated using a performance-based earthquake engineering approach in this study. Performance-based earthquake engineering seeks to improve seismic risk decision-making through assessment and design methods that have a strong scientific basis and that reveal options in terms that enable stakeholders to make informed decisions. Given the inherent uncertainty and variability in seismic response, it follows that a performance-based methodology should be formalized on a probabilistic basis. The framework has four main analysis steps: Hazard analysis, structural/nonstructural analysis, damage analysis, and loss analysis. The first assessment step entails a hazard analysis, through which one evaluates one or more ground motion Intensity Measures (IM). For standard earthquake intensity measures (such as peak ground acceleration or spectral acceleration) is obtained through conventional probabilistic seismic hazard analysis. Typically, IM is described as a mean annual probability of exceedance, which is specific to the location and design characteristics of the facility (Moehle and Deirlein, 2004).

In performance-based design and assessment method, it is possible to determine in quantities the damage levels that may arise from the design ground motion within the system structural system elements. It is checked whether this damage stays under the acceptable damage levels for each related component. Acceptable damage limits are defined in a way to be consistent with the foreseen performance targets at various earthquake levels (Aydınoğlu, 2007; Doran et al. 2011; Kutanis and Boru, 2014). Site-specific design spectra for the region have great importance to determined building's performance under an earthquake hazard. According to Section 2 of the Turkish Earthquake Code (TEC'07), the demand spectra used to determine seismic performance of an existing building based on a probability of exceedance of 10% in 50 years (Fig 1).

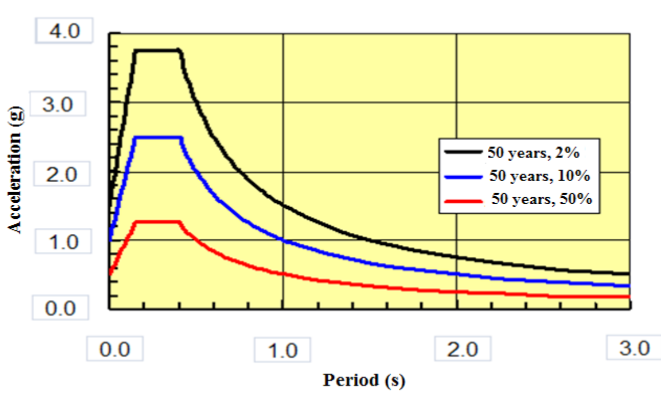

Figure 1. The earthquake spectrum curves for different exceedance probability

The assessment procedure aims to estimate the earthquake force demand at which the building would sustain the performance objectives. Demand spectrum, which is used in determining the performance of the building's system, shows the maximum response that a building gives against seismic activities during an earthquake (İlki and Celep, 2011). The assessment calculations were done based on a simple technique called the "equivalent displacement rule". The equivalent displacement approximation is based on the assumption that inelastic spectral displacement is the same as that which would occur if the structure remained perfectly elastic (ATC-40, 1996). For the flexible structures, where the natural vibrational periods are greater than the corner periods, this rule yields acceptable results. In other cases, particularly in short period (rigid) structures, where the natural vibrational periods are shorter than the corner periods, the displacements obtained from this approximation method might be significantly different from the actual results (Fig. 2 and Fig. 3). In such cases, elastic spectral displacement is modified by multiplying it by a spectral displacement amplification factor (C_{R1}) to obtain inelastic spectral displacement.

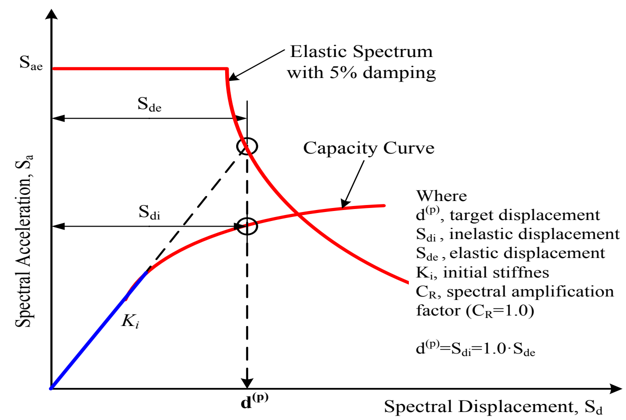

Figure 2. Equivalent Displacement Rule: Flexible structures

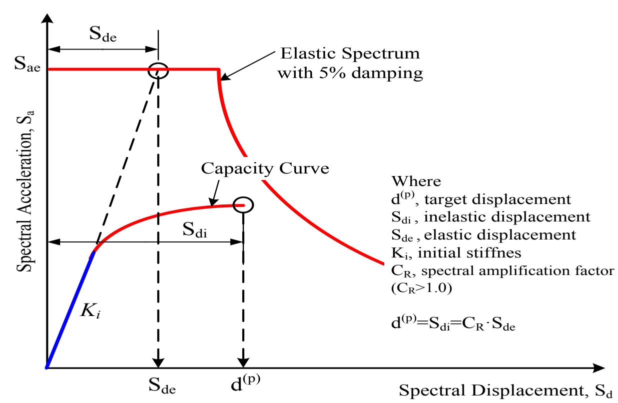

Figure 3. Equivalent Displacement Rule: Rigid structures

2. Local Geology

Soil conditions change the characteristics of surface seismic response. It is a known fact that this may cause damage to the existing structures built on these grounds (Borcherdt, 1990). The Lake Van Basin, which contains Bitlis, is located in the region known as the Bitlis Thrust Zone. It is a collapsed tectonic basin which is related to the Eastern Taurus region (Özkaymak et al., 2003). Orogenic movements have occurred in the field until the third phase of Miocene. Volcanic and tectonic events have caused many faults to form, as well as depressions and large lakes in this period (Facenna et al., 2006; Köse, 2004). Metamorphic rock in the region belonging to the Bitlis Massif include the Upper Cretaceous Ahlat-Adilcevaz mélange and Ahlat conglomerate, Miocene Adilcevaz limestone, Pliocene-Quaternary volcanic rocks and alluvial deposits from the surface in Bitlis and surrounding region (Report 1, Report 2). A geological map of Lake Van Basin is shown in Figure 4.

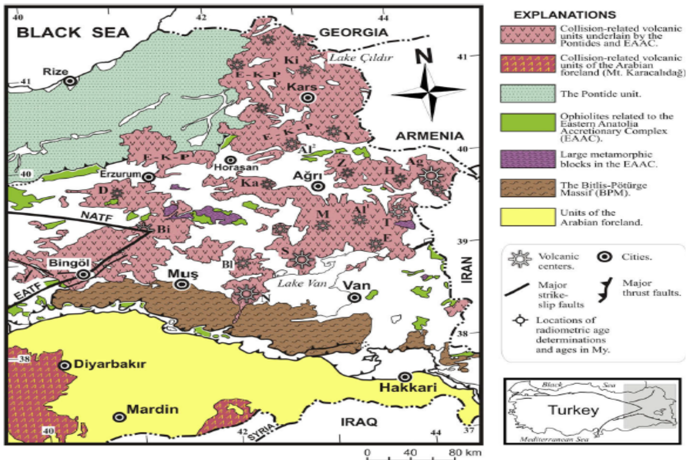

Figure 4. Geological map of the Lake Van region. N – Nemrut Volcano, S – Süphan Volcano near the lake (Litt et al., 2009).

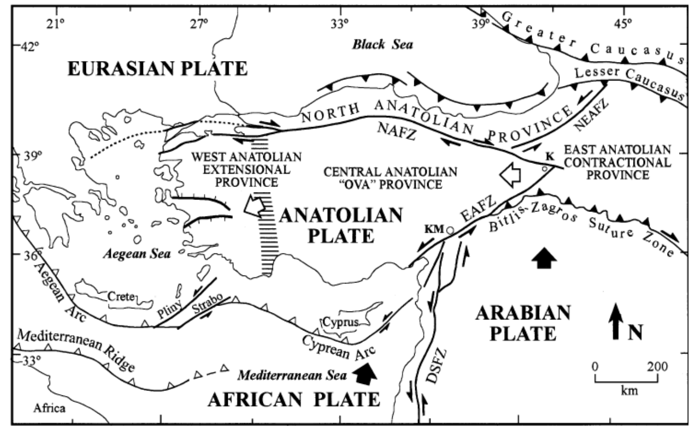

Figure 5. Tectonic map of Turkey including major structural features (from Bozkurt, 2001)

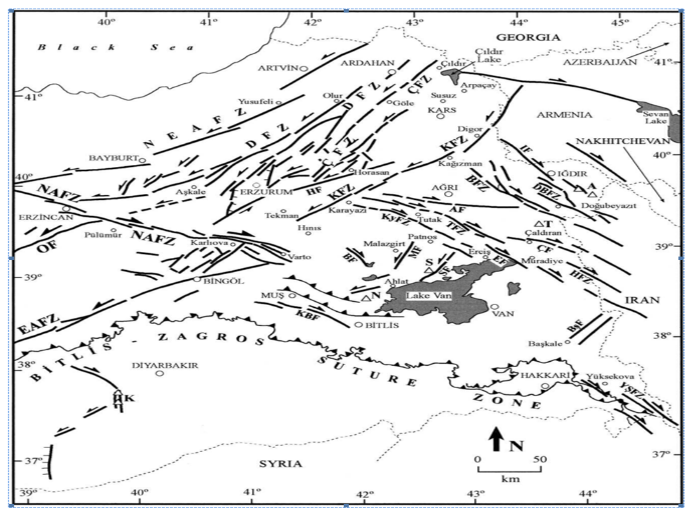

Figure 6. Active faults of Eastern Anatolian Province (Bozkurt, 2001).

3. Tectonic Setting and Seismicity of Bitlis and Surrounding Areas

The general tectonic setting of Eastern Anatolia is mainly controlled by the collision of the northerly movable Arabian plate against Anatolian plate along a deformation zone known as Bitlis Thrust Zone (Fig. 5). The collision leads to the westward extrusion of the Anatolian plate along the two notorious transform faults with a different sense of slip, the dextral North Anatolian Fault, and the sinistral East Anatolian Fault zones, which join each other in Karlıova Triple Junction (KTJ) in the Eastern Anatolia (Fig. 5). In the eastern side of KTJ: however, the collision deformation is largely accommodated within the Eastern Anatolian Block through distributed NW-SE trending dextral faults and NE–SW trending sinistral faults representing escape tectonics, and shortening of the continental lithosphere along the Caucasus thrust zone. East–west trending Mush-Lake Van and Pasinler ramp basins constitute other conspicuous tectonic properties within the Eastern Anatolian border (Şengör et al. 1985; Barka and Kadinsky, 1988; Mc Clusky et al. 2000; Reilinger et al. 2006; Utkucu et al. 2013). The East Anatolian Fault Zone is a 550 km-long, approximately northeast-trending, sinistral strike-slip fault zone (Fig. 5) that comprises a series of faults arranged parallelly, sub-parallelly or obliquely to the general trend. The Bitlis Suture is a complex continent-continent and continent-ocean collisional boundary that lies north of fold-and-thrust belt of the Arabian platform and extends from south-eastern Turkey to the Zagros Mountains in Iran (Homke, 2007; Bonnin et al. 1988; Piper et al. 2008; Stern et al. 2008 and Lyberis et al. 1992). The area to the east of Karlıova triple junction is characterized by an N–S compressional tectonic regime (Fig. 6). Conjugate strike-slip faults of dextral and sinistral character paralleling to North and East Anatolian fault zones are the dominant structural elements of the region. Some of these structures include Ağrı Fault, Bulanık Fault, Çaldıran Fault, Erciş¸ Fault, Horasan Fault, Iğdır Fault, Malazgirt Fault, Süphan Fault, Balıklıgölü Fault Zone, Başkale Fault, Çobandede Fault Zone, Dumlu Fault Zone, Hasan Timur Fault Zone, Kavakbaşı Fault, Kağızman Fault Zone, Doğubayazıt Fault Zone, Karayazı Fault, Tutak Fault Zone, Yüksekova–Şemdinli Fault Zone and the Northeast Anatolian Fault Zone (Fig. 6) (Bozkurt, 2001). Aydemir et al. (2014) investigated the faults and possible structural elements that may have caused the devastating earthquake that occurred on October 23, 2011. This potential extended fault zone starting from the Nemrut Mountain in the west may exist through to the east of Lake Van (Aydemir et al. 2014).

The faults are seismically active and form the source for many earthquakes. Some of the major earthquakes in the 20th Century are 13 September 1924 Pasinler (M = 6.8), 1975 Lice (M = 6.6), 24 November 1976 Çaldıran (M = 7.3), 1988 Van (M= 5.0), 2000 Van (M=5.7), 23 October 2011 Van (M=7.2) and 09 November 2011 Van (M=5.6) earthquakes.

The examination of historical and instrumental earthquakes in Bitlis and its surroundings proves that this region is constantly under the influence of micro and macro earthquakes. Thus, Bitlis remains under an enormous influence of micro and macro earthquakes (Işık et al., 2012). Therefore, its buildings must be constructed, especially in Lake Van Basin where earthquake resistant design has always been neglected, according to earthquake codes.

4. Seismicity Parameters

On any given fault within any particular region, earthquakes occur at irregular intervals in time, and one of the primary activities in seismology has long been the search for meaningful patterns in the time sequences of earthquake occurrence (Dowrick, 2003). Among some recurrence laws have been proposed, in this study, Gutenberg and Richter's law was used because there is no available evidence to determine whether the Gutenberg –Richter or some other recurrence laws are correct. During any given interval in time, the general underlying pattern or distribution of size of events is that first described by Gutenberg and Richter (1944), who derived an empirical relationship between magnitude and frequency of the form

$$\log N = a - b.M \quad (1)$$

where N is the number of shocks of magnitude at least M per unit time and unit area, and a and b are seismic constants for any given region (Dowrick, 2003).

In a seismic hazard modeling study of Bitlis, recurrence rates are estimated by using historical and digital records. After the compilation of collected data, a plot of "M" against "log N" was constructed and the best-fit line of the form of Eqn. 1 was determined by regression analysis (Fig. 7). In probabilistic seismic hazard analysis, beside magnitude–frequency relationship that is calculated for Bitlis province as logN = 5.6247 – 0.7794 M.

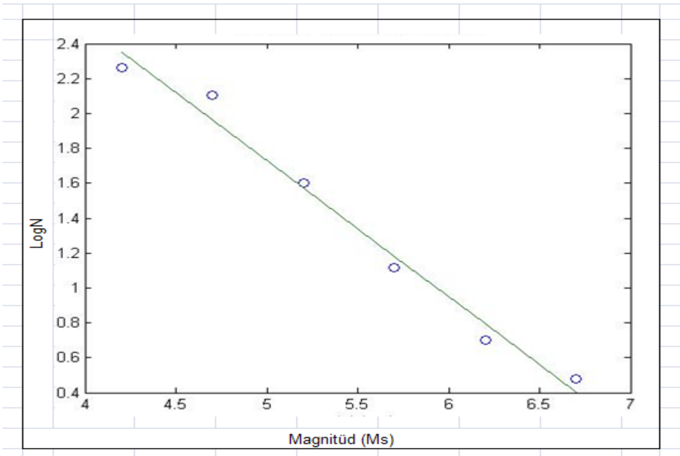

Figure 7. Gutenberg-Richter magnitude–frequency relationship for earthquakes from Bitlis and surrounding data

5. Site-Specific Design Spectra for Bitlis Province

The seismic hazard analysis approach is based on the model developed originally by Cornell (1968) who quantified it regarding the probability of exceedance of the design level peak ground acceleration (PGA). The procedure for conducting a probabilistic seismic hazard analysis includes seismic source characterization, size distribution and rate of occurrence determination for the source, ground motion estimation and, lastly, probability analysis. In the current study, since the neotectonic faults are not identified in the research area clearly, earthquake sources are characterized as area source zones. Area seismic sources are often defined where specific fault data are not known, but seismicity does exist. Area sources assume that the rate of occurrence is uniform throughout. Therefore, every location within the area has equal probability that an event will occur (EZ-FRISK; Anton and Gibson, 2008).

All seismic sources, that can generate strong ground shaking in Bitlis and surroundings, are classified into 7 areal seismic zones (Fig. 8): (1) Bitlis-Zagros Suture Zone; (2) Northern Bitlis thrust fault zone (Dhont and Chorowicz, 2006); (3) Kavakbaşı Fault zone; (4) Malazgirt fault zone; (5) Ahlat and surrounding fault zone; (6) Suphan Fault zone ; and (7) Southern Van faults (Erçek fault, Kalecik fault, Edremit fault and Southern Boundary fault (Utkucu, 2006).

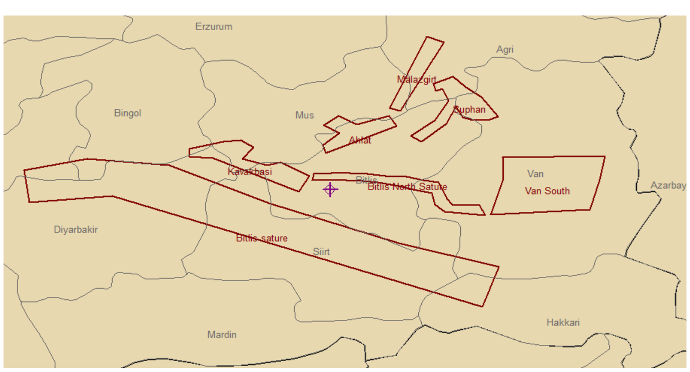

Figure 8. Earthquake areal zones (Bitlis Suture, Van South, Bitlis North Suture, Kavakbaşı, Ahlat, Malazgirt and Suphan) in Bitlis and surroundings

In Eastern Anatolia region, previously recorded strong ground motion acceleration records are limited. Therefore, in the current analysis, worldwide applicable three empirical attenuation relationships are utilized to perform the seismic hazard analysis. Attenuation relationships for rock sites employed in this study are Abrahamson-Silva (1997), Ambraseys et al. (2005), Boore et al. (1997), Campell (2003) and Idris (2008) (Fig. 9).

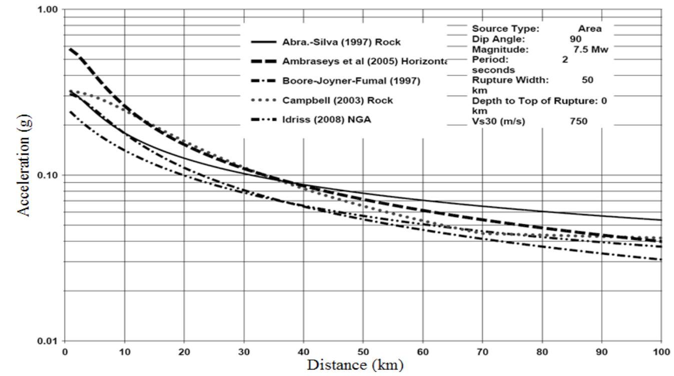

Figure 9. Abrahamson-Silva (1997), Ambraseys et al. (2005), Boore et al. (1997), Campell (2003) and Idriss (2008) attenuation relationships for rock sites.

After the compilation of the seismic hazard analysis data, the procedure for conducting a probabilistic seismic hazard analysis, by using EZ-FRISK (McGuire, 1995). The software was employed to produce the PGA as a function of return periods (Fig. 10) and uniform probability response spectra for selected return periods (Fig. 11). The results of probabilistic seismic hazard analysis for Bitlis are presented regarding spectral responses at 5% damping for the return periods of 72, 474.6 and 2474.9 years (Fig. 11). The results are compared with the spectral responses proposed for seismic evaluation and retrofit of building structure in Turkey Earthquake Code (2007) Section 7.

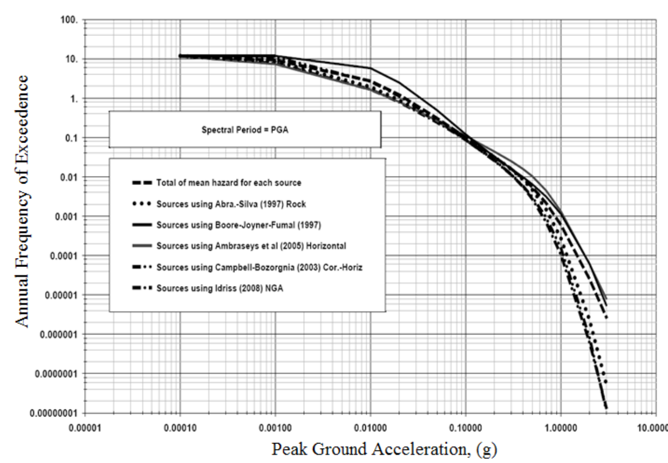

Figure 10. Peak ground acceleration (PGA) at Bitlis with varying return periods.

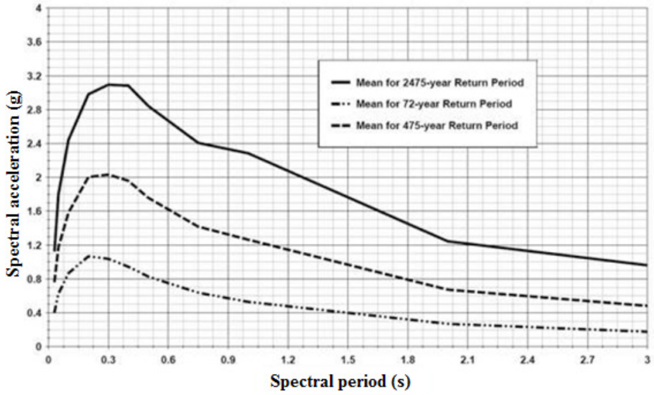

Figure 11. Spectral responses at 5% damping for the return period of 72, 474.6 and 2474.9 years

The results of probabilistic seismic hazard analysis revealed peak acceleration values for a typical rock site as 0.76g for 50% probability of exceedance in 50 years, 1.61g for 10% probability of exceedance in 50 years and 2.68g for 2% probability of exceedance in 50 years. The obtained results are compared with the spectral responses proposed for seismic evaluation and retrofit of building structure in Turkey Earthquake Code, Section 7 (Fig. 12).

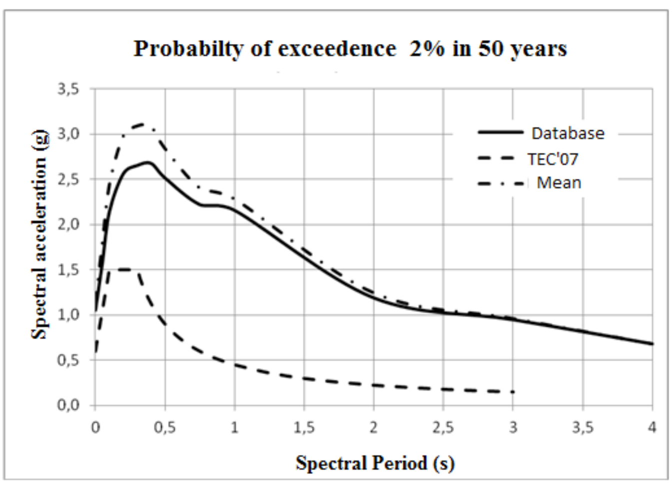

Figure 12a. Comparison of spectral responses at 5% damping for the return period of 2474.9 years in Bitlis

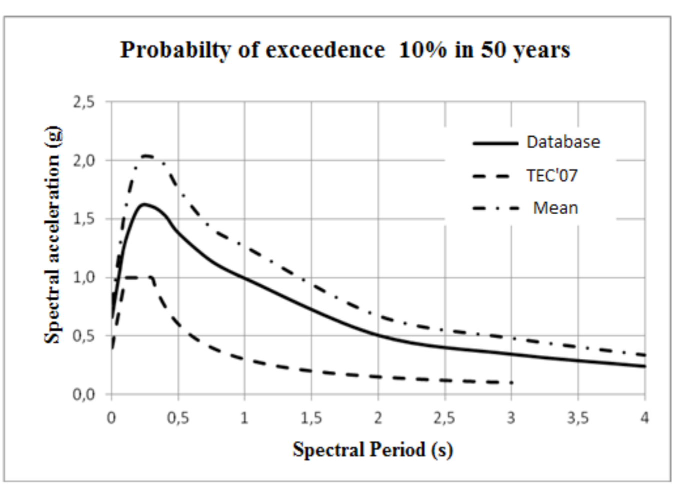

Figure 12b. Comparison of spectral responses at 5% damping for the return period of 474.6 years in Bitlis

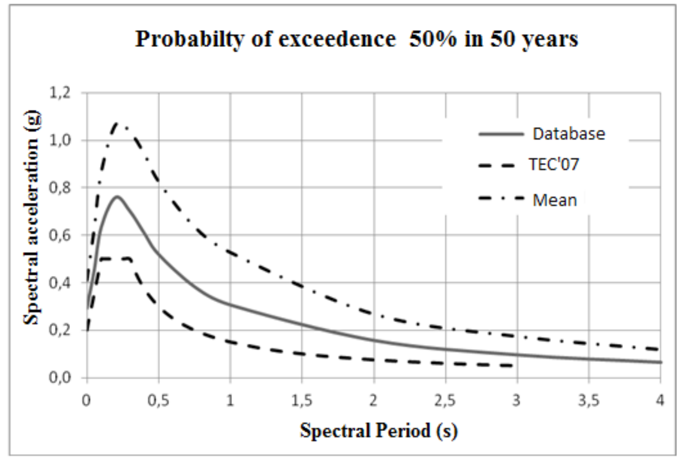

Figure 12c. Comparison of spectral responses at 5% damping for the return period of 72 years in Bitlis

6. Results and Conclusions

By utilizing available data and the use of improved methods, a probabilistic seismic hazard of Bitlis province in Turkey was determined. As a first step of the performance-based earthquake engineering, it is well understood that the Code proposed spectra are not sufficient to represent earthquake demand in the performance evaluation. The results of this work will form the basis for the replacement of the existing earthquake design spectra in the assessment of earthquake performances of the existing buildings in Bitlis province. In this study, since active faults are not identified clearly, regional areas were used as an earthquake source zones. Future work will increase the resolution of the seismotectonic model by adding specific active faults. The obtained results are compared with the spectral responses proposed for seismic evaluation and retrofit of building structure in Turkish Earthquake Code, Section 7, and the amplitude and frequency range was different from each other (Fig.13).

Using the response spectrum obtained from probabilistic seismic hazard analysis will make obtained data for Bitlis and other regions which are under a threat of earthquakes.

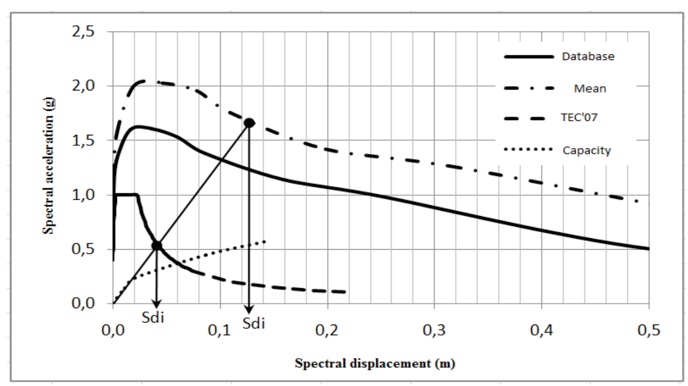

Figure13. Comparison of demand displacement of the earthquake

Therefore, site- specific design spectra for the region should be developed, which reflect the characteristics of local sites.

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