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The October 23, 2011 Van, Turkey Earthquake (Mw=7.2)

PROBABILISTIC ASSESSMENT OF THE SEISMIC HAZARD FOR THE LAKE VAN BASIN

Introduction

The seismic hazard in Van Lake region is retrieved from the study of probabilistic assessment of seismic hazard in Turkey conducted for the Ministry of Transportion Turkey, aiming the preparation of an earthquake resistant design code for the construction of railways, seaports and airports (DLH, 2007).

Methodology of PSHA

The general methodology of calculating probabilistic seismic hazard is well established in literature (Cornell 1968). The method involves two separate models: a seismicity model describing a geographical distribution event sources and the distribution of magnitudes, and an attenuation model describing the effect at any site given as a function of magnitude and source-to-site-distance. The seismicity model may comprise a number of source regions, the seismicity of which should be expressed in terms of a recurrence relationship of events with magnitudes greater or equal to a certain value. The attenuation model relates the earthquake intensity (i.e. the effect of it, as a general term) at a site to magnitude, distance, source parameters and site conditions.

For forecasting seismic occurrences numerous models have been developed. The simplest stochastic model for earthquake occurrences is the Homogeneous Poisson Model, which is used in this study. For the earthquake events to follow that model, the following assumptions are in order:

1. Earthquakes are spatially independent;
2. Earthquakes are temporally independent;
3. Probability that two seismic events will take place at the same time and at the same place approaches zero.

Obviously for the above assumptions to be applicable to a data set, it should be free of fore- and aftershocks. This has been achieved in our study by removing all the dependent events from the earthquake catalogue.

The recurrence relationship of the events is expressed with the help of the empirical relationship first defined by Gutenberg - Richter: $\log N = A - bM$ where N is the number of shocks with magnitude greater or equal to M per unit time and unit area, and A and b are seismic constants for any given region. The source regions may be described as lines representing the known faults or areas of diffuse seismicity, so that M may be related to unit length or unit area. The value of N will also generally be found assuming that M has upper and lower bounds M1 and Mo.

Using an application of the total probability theorem the probability per unit time that that ground motion amplitude a* is exceeded can be expressed as follows (McGuire, 1993):

$$P[A > a^* \text{in time t}]/t = \sum_i v_i \iint G_A|_{m,r}(a^*) f_m(m) f_r(r|m) dmdr$$

where $P[I \leq i|m,r]$ is the probability that the maximum effect I is less than i. Given m and r, $f_m(m)$ is the probability density function for magnitude, and $f_r(r|m)$ is the probability distribution function for distance. $f_r(r|m)$ is dependent on the geometric nature of the source.

Seismic Source Zonation

A seismic source zone is defined as a seismically homogenous area, in which every point within the source zone is assumed to have the same probability of being the epicenter of a future earthquake. An ideal delineation of seismic source zones requires a complete comprehension of the geology, tectonics, paleoseismology, historical and instrumental seismicity, and other neotectonic features of the region under study. However, it is not always possible to compile detailed information in all these fields for the majority of the world. Thus, frequently, seismic source zones are determined with two fundamental tools; a seismicity profile and the tectonic regime of the region under consideration. Although seismic source zonation is a widely used methodology to determine earthquake hazard, it is not the only approach. Since delineation of the seismic source zones still remains rather subjective, researchers (e.g. Frankel, 1995) are suggesting other methods for evaluating seismic hazard, in order to eliminate the subjectivity of this procedure. This is particularly important in areas where the tectonic structure is very fragmented and the seismicity is diffuse. Whereas in most regions of Turkey, the seismicity is relatively well documented, major faults are often well defined and the source zones are fairly obvious. Hence it is considered adequate to use the conventional method of seismic source zonation for Turkey in this study.

The seismic source zonation used in this study is essentially based on the seismic source zonation model of Turkey developed within the context of a project conducted for the Ministry of Transportion Turkey, aiming the preparation of an earthquake resistant design code for the construction of railways, seaports and airports (DLH, 2007), which was an updated version of the GSHAP (1999, Erdik et al. 1999) and TEFER (2000) models. The main improvement of the DLH model when compared to the previous two models (the GSHAP and TEFER models) was the representation of main fault traces (such as the North Anatolian and the East Anatolian Faults) with linear sources. In order to account for the spatially more diffuse moderate size seismicity around these faults, widths of at least several kilometers were assigned to the zones even if the associated faults were well expressed on the surface. In the new model however, earthquakes with magnitude > 6.5 have been assumed to take place on the linear zones, whereas the smaller magnitude events associated with the same fault have been allowed to take place in the surrounding larger areal zone. In addition to these zones, background zones have also been used in this model.

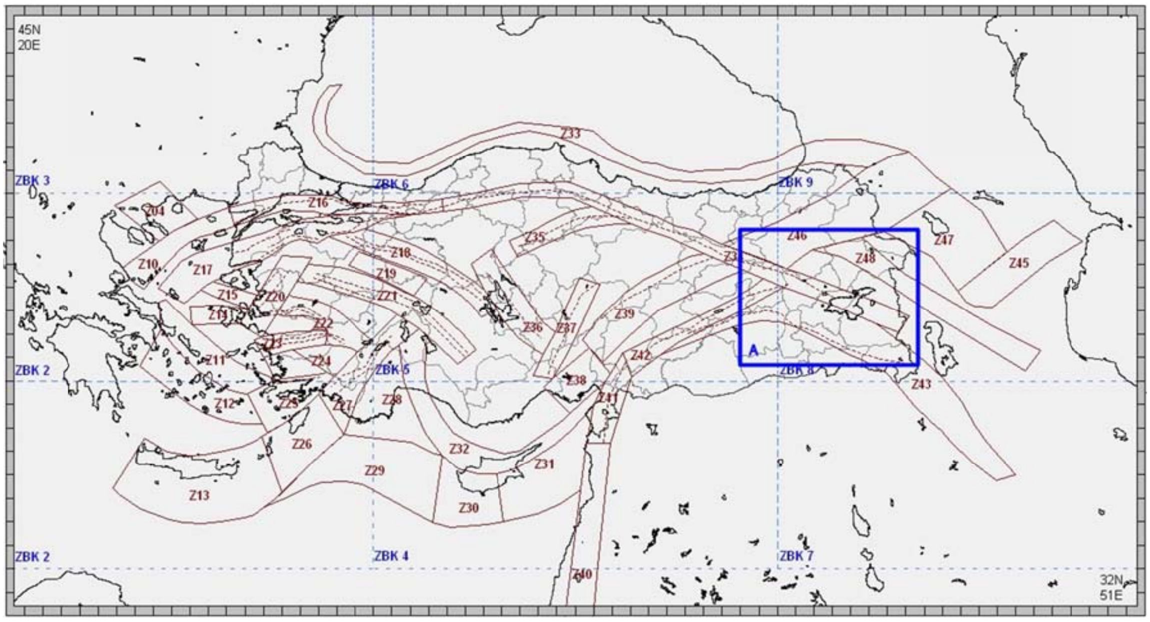


Figure 1. Source Zonation model used in the study of DLH (2007)

Earthquake Recurrence Relationships

The empirical recurrence relationship for earthquakes (Gutenberg and Richter Model. Richter, 1954) is as follows:

$\log N = a + b\,M$

where N is the number of the earthquakes above the magnitude M in a given region and within a given period and a and b are regression constants. The Gutenberg-Richter recurrence model has been extensively used in many seismicity studies and has also been confirmed to hold for micro-earthquakes. The coefficient a is a constant that is dependent on the location and time of the sample used and b represents a constant thought to be characteristic of the region.

The earthquake catalogues are often biased due to incomplete reporting for smaller magnitude earthquakes in earlier periods. Thus to fit the recurrence relationship to a region, one should choose among using

(1) a short sample that is complete in small events or

(2) a longer sample that is complete in larger events or

(3) a combination of the two data sets to complete the deficient data thereby obtaining a homogeneous data set.

A direct attempt to fit these data to a regression relationship may result in quadratic or higher order expressions to accommodate the inherent bias and inhomogeneity of the data. In the method used in this study, an artificially homogeneous data set is simulated through the determination of the period over which the data in a given magnitude group are completely reported (Stepp, 1973).

The computed recurrence parameters as well as the maximum magnitudes associated with the source zones are presented in Table 1.

Table 1. Source Zone Information

Source Zone No	Fault Name	Mechanism	a	b	M_{min} - M_{maks}
Z34 Outside Zone	North Anatolian Fault Zone (NAF)	Right Lateral Strike Slip	5.0	0.8	5.0 – 6.7
Z34 Inside Zone					6.8 – 7.9
Z39 Outside Zone	Goksun Fault ı	Left Lateral Strike Slip	2.7	0.7	5.0 -6.9
Z39 Outside Zone					7.0 – 7 .5
Z42 Outside Zone	East Anatolian Fault Zone(EAF)	Left Lateral Strike Slip	4.6	0.9	5.0 – 6.7
Z42 Inside Zone					6.8 – 7.9
Z43 Outside Zone	Bitlis_Zagros Fault Zone	Thrust	4.7	1.0	5.0 – 6.6
Z43 Inside Zone					6.7 – 7.0
Z46	North East Anatolian Fault Zone	Left and Right Lateral Strike Slip	5.6	1.1	5.0 - 7.7
Z47	PambaSevan Fault Zone	Right Lateral Strike Slip + Thrust	3.9	0.9	5.0 - 7.3
Z48	Tebriz Fault Zone	Right Lateral Strike Slip	4.4	1.0	5.0 - 7.3

Ground Motion Prediction Equations

Owing to the geological and geo-tectonic similarity of Anatolia to the California (strike slip faults similar to North, Northeast and East Anatolian Faults), the following ground motion prediction equations currently being used for the assessment of earthquake hazard for the Western US was utilized:

1. Average of Boore, Joyner and Fumal (1997), Sadigh et al.(1997), and Campbell (2003) for Peak Ground Acceleration (PGA)

- Average of Boore et al. (1997), Sadigh et.al. (1997) and Campbell (1997) for Spectral Acceleration (Ss and S1)

Hazard Results

The present analysis has been conducted for return periods of 475 and 2,475 years corresponding to 90% and 98 % probabilities of non-exceedence in 50 years respectively. The selected ground motion parameters of analysis were the Peak Ground Acceleration (PGA), the Spectral Accelerations (SA) at periods of 0.2 sec and 1 sec. A grid size of 0.05° by 0.05° was used. The earthquake location uncertainty was taken as 10 km. The standard deviations in the attenuation functions were taken as given in the associated papers. The results are presented in Figure 2 through Figure 7 in form of the mean of the log normally distributed results obtained from computations with the above attenuation relationships in bedrock conditions.

The sub-province based hazard result is also presented in Table 2.

Table 2. Hazard results for Tabanlı, Erciş, Muradiye and Van-Merkez districts

		72	475	2475
Epicentral Location (Tabanlı)	PGA	0.23	0.43	0.64
	SA(T=0.2s)	0.51	0.94	1.42
	SA(T=1.0s)	0.14	0.28	0.46
Erciş	PGA	0.12	0.22	0.34
	SA(T=0.2s)	0.27	0.49	0.76
	SA(T=1.0s)	0.09	0.16	0.26
Muradiye	PGA	0.1	0.18	0.29
	SA(T=0.2s)	0.26	0.41	0.65
	SA(T=1.0s)	0.075	0.14	0.22
Van - Merkez	PGA	0.27	0.47	0.7
	SA(T=0.2s)	0.59	1.04	1.56
	SA(T=1.0s)	0.15	0.31	0.51

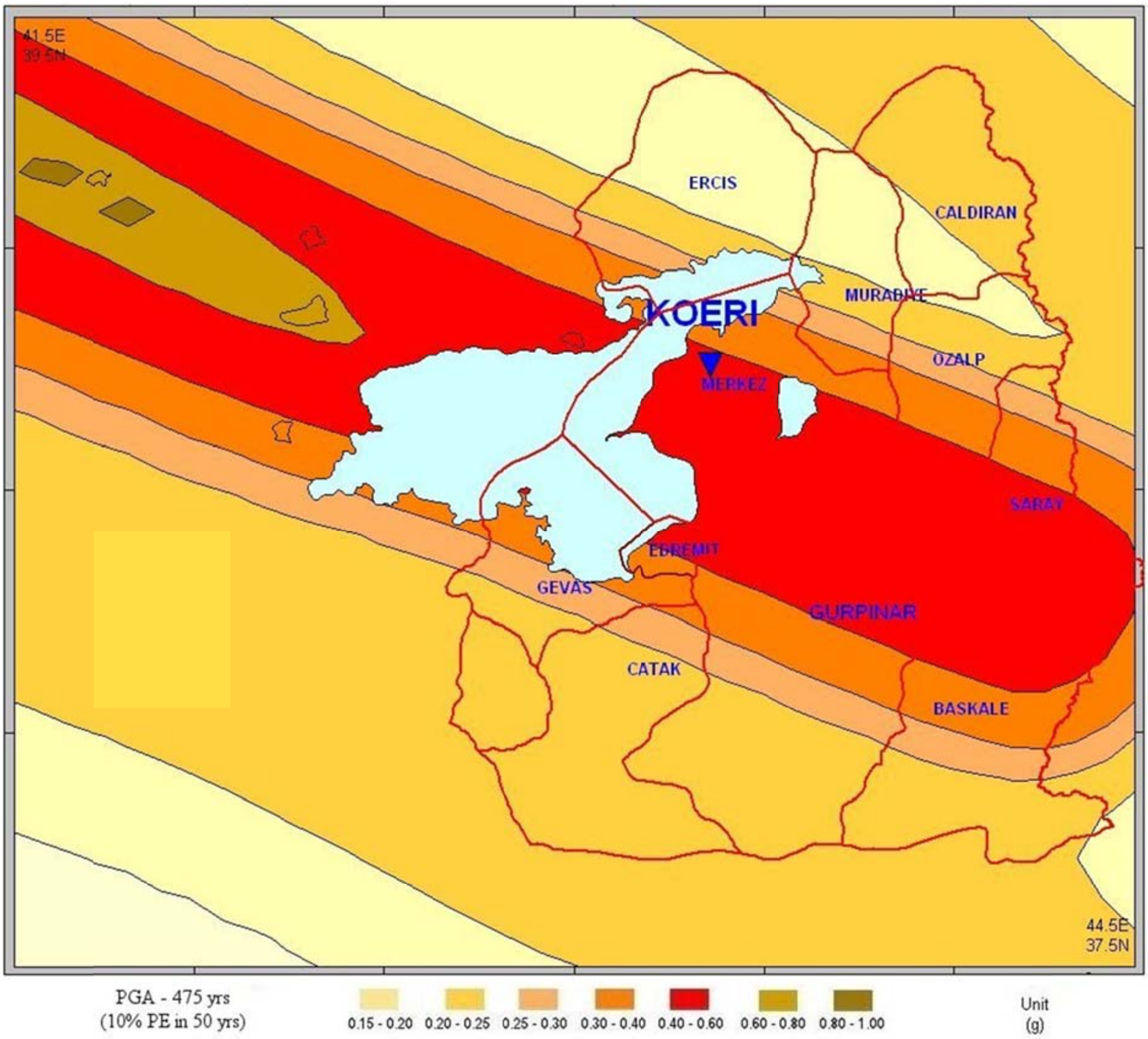


Figure 2. PGA for 10% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

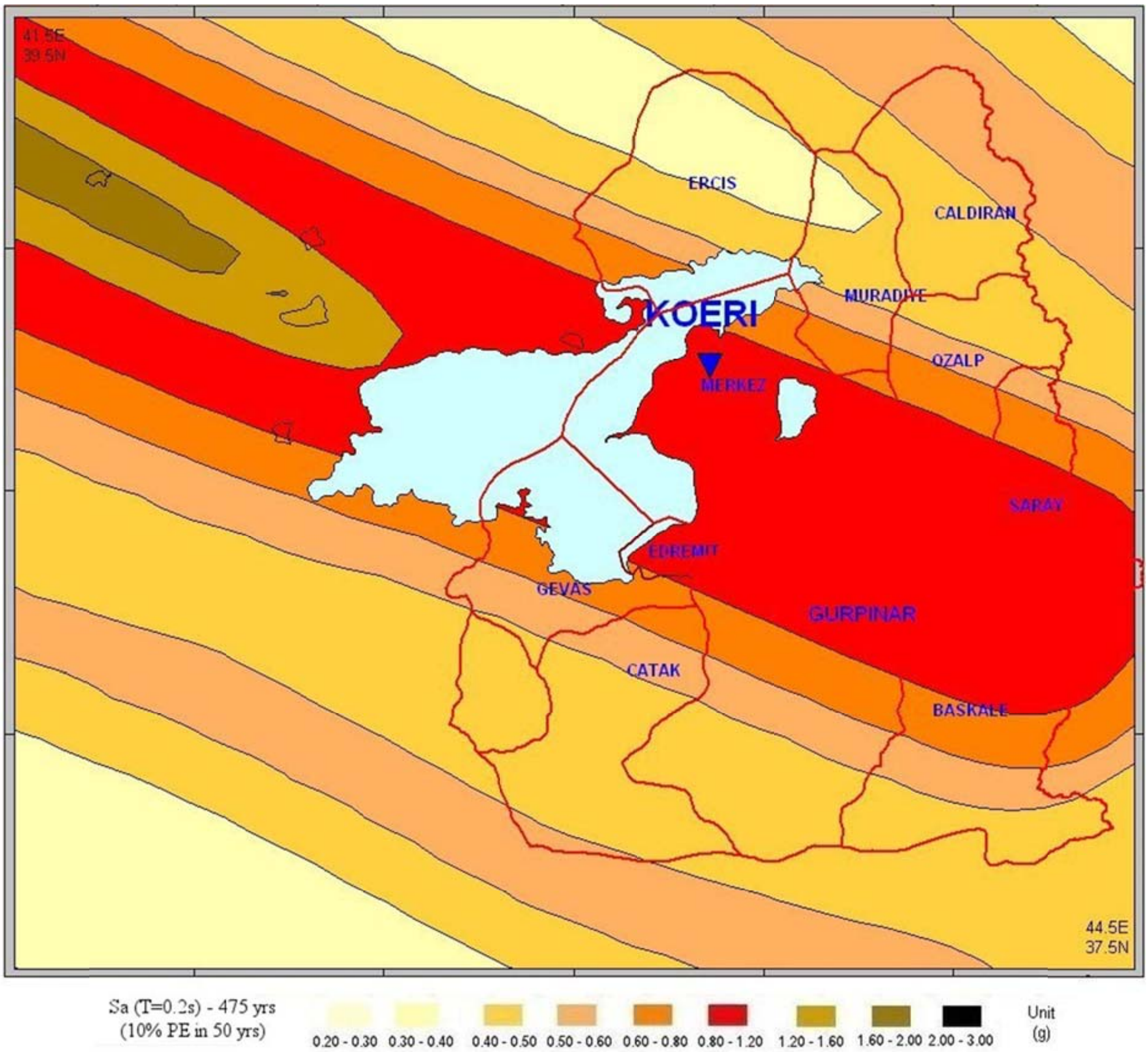


Figure 3. SA (T=0.2s) for 10% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

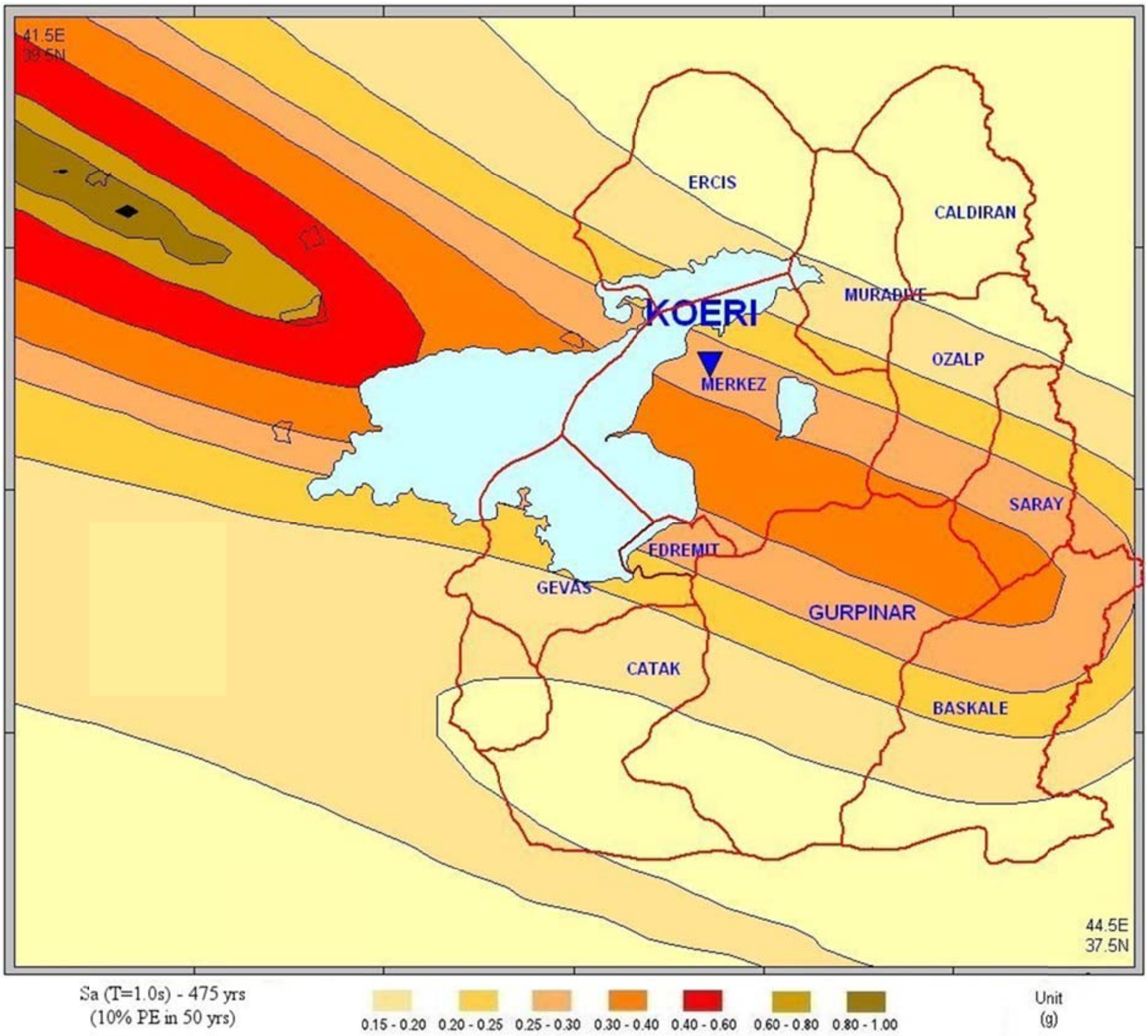


Figure 4. SA (T=1.0s) for 10% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

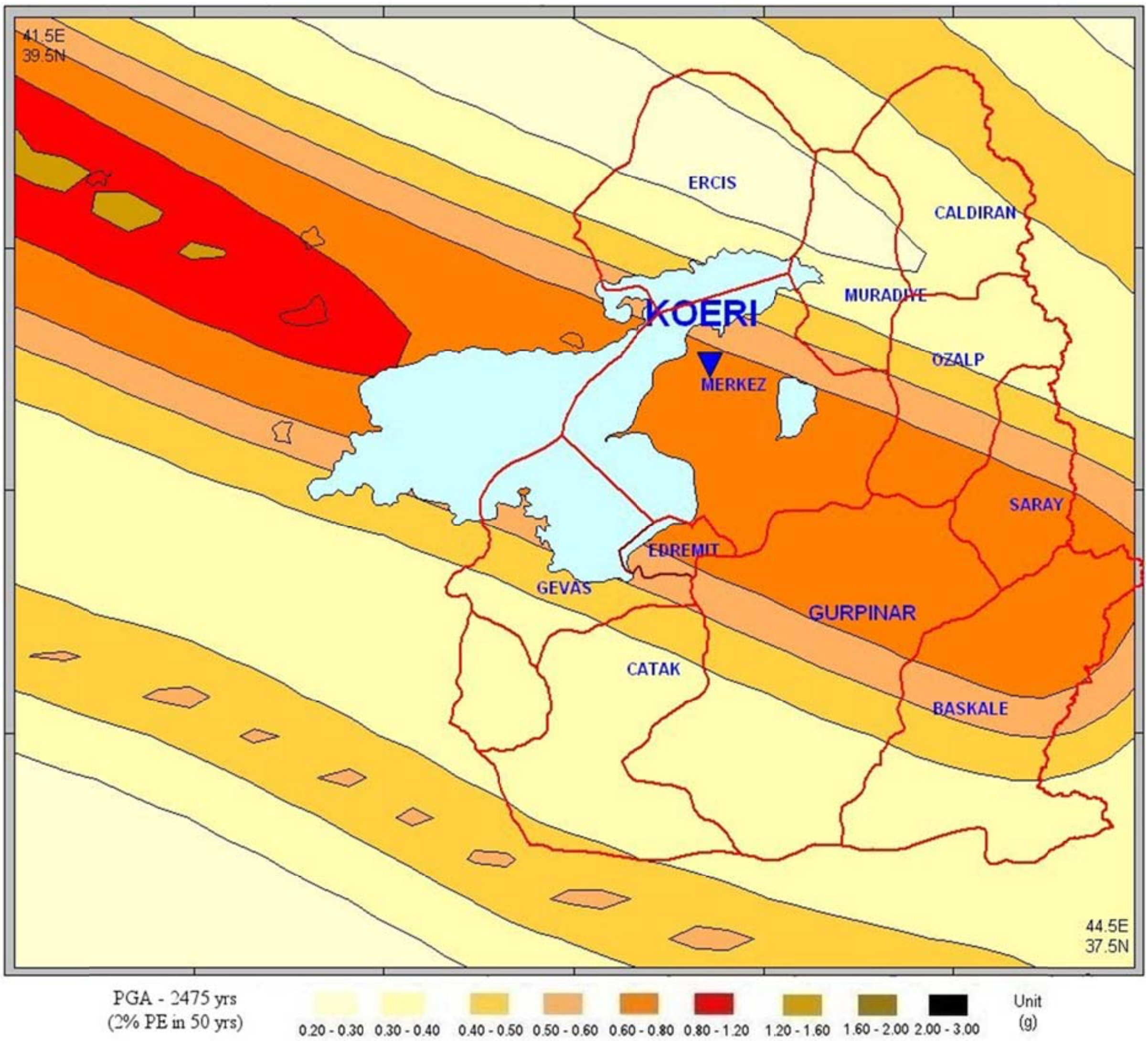


Figure 5. PGA for 2% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

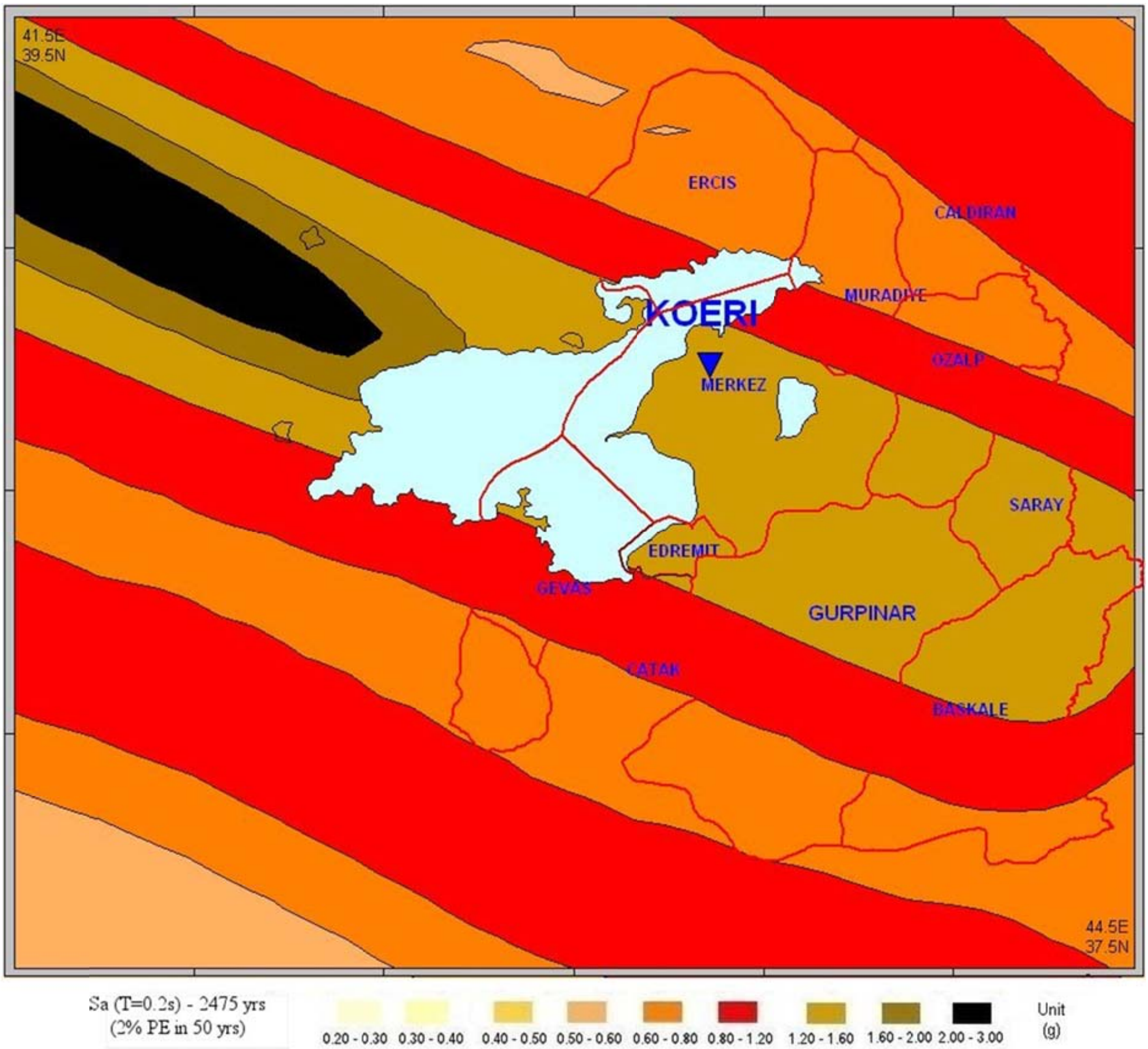


Figure 6. SA (T=0.2s) for 2% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

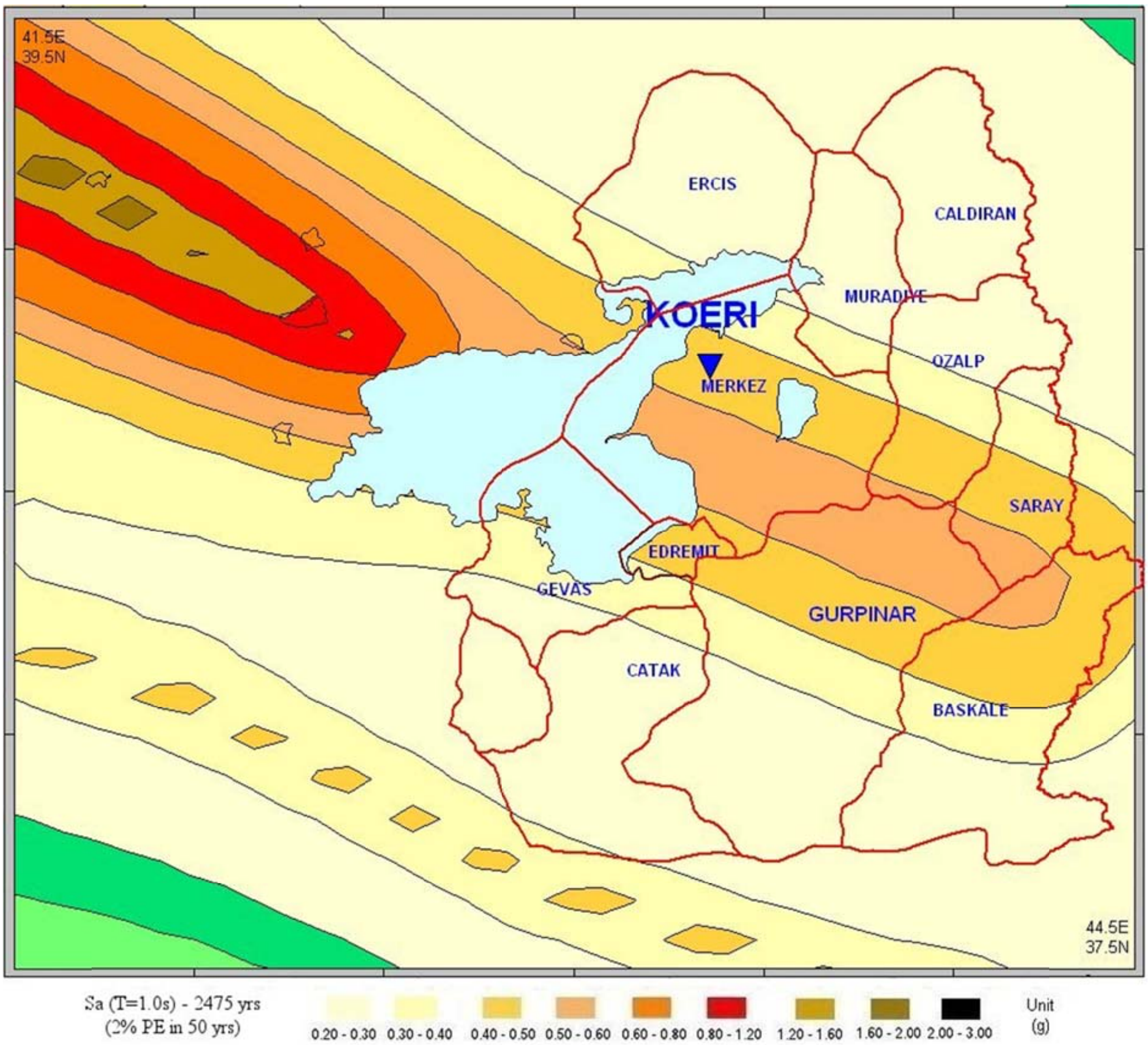


Figure 7. SA (T=1.0s) for 2% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

Site Specific Modification of Design Basis Ground Motion

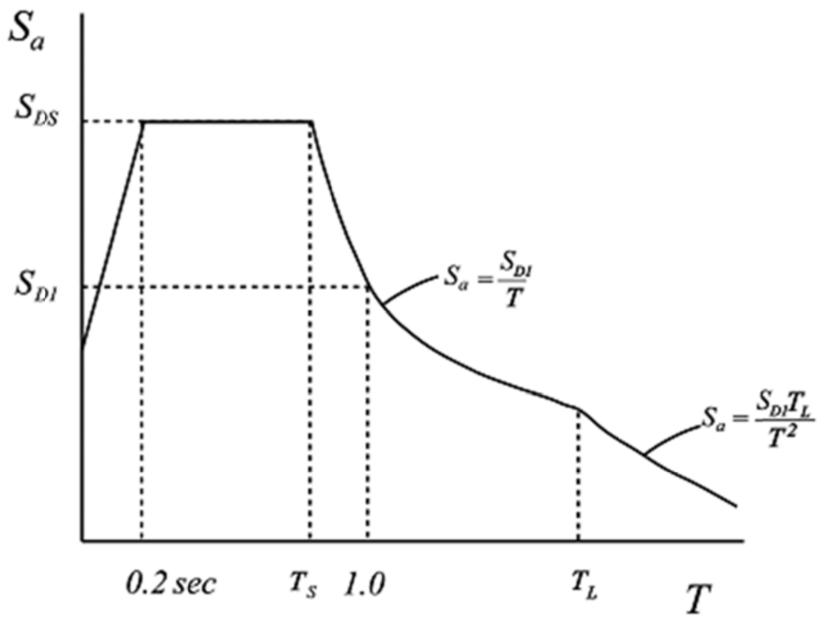
The construction of the design basis response spectrum for different Site Classes can be achieved through the modification of the spectral acceleration (SA(0.2s) and SA(1s)) given by the hazard maps in Chapter 6 or SEE and FEE level earthquakes. The Uniform Hazard Response Spectrum presented in NEHRP (2003, 2009) that will be employed as the appropriate spectral shape is constructed with two parameters: the site-specific short period (S_{MS}); and medium-period (S_{M1}). The shape of the spectrum for 5% damping is illustrated in Figure 8.

The site-specific short-period spectral response acceleration parameter, S_{MS} and medium-period parameter S_{M1} can be obtained as follows:

S_{MS} = Fa * Ss where Ss = SA(0.2s)

S_{M1} = Fv * S1 where S1= SA(1s)

Where Ss and S1 are represented by the spectral accelerations at T=0.2 sec and T=1.0 sec at reference soil site ($V_{s,30}$ ≥760m/s.) obtained from the hazard analysis. Fa and Fv are respectively the applicable Short and Medium Period Amplification Factors, defined in NEHRP (2003 and 2009) (Table 3 and Table 4). The site classes indicated on these tables are to be obtained from the geo-technical investigations to be carried along the pipeline route.



*T_S: transition period from constant response acceleration to constant response velocity, in units of seconds, and T_L: transition period from constant response velocity to constant response displacement, in units of seconds

Figure 8. Standard Shape of the Response Spectrum (NEHRP, 2009)

Table 3. Values of Fa as a function of Site Class and 0.2s Spectral Acceleration (at B/C boundary with Vs = 760 m/s)

Site Class	Ss≤0.25	Ss=0.50	Ss=0.75	Ss=1.0	Ss≥1.25
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.2	1.2	1.1	1	1
D	1.6	1.4	1.2	1.1	1
E	2.5	1.7	1.2	0.9	0.9
F	*	*	*	*	*

** Site-specific geotechnical investigation and dynamic site response analyses shall be performed.*

Table 4. Values of Fv as a function of Site Class and 1.0s Spectral Acceleration (at B/C boundary with Vs = 760 m/s)

Site Class	Ss≤0.1	Ss=0.20	Ss=0.3	Ss=0.4	Ss≥0.5
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	*	*	*	*	*

** Site-specific geo-technical investigation and dynamic site response analyses shall be performed.*

QTM based Site Dependent Hazard Results

The QTM map based site dependent analysis has been conducted for return periods of 72, 475 and 2,475 years corresponding to 50%, 10% and 2 % probabilities of exceedence in 50 years respectively. The selected ground motion parameters of analysis were the Peak Ground

Acceleration (PGA), and the Spectral Accelerations (SA) at periods of 0.2 sec and 1 sec. The results are presented in Figure 9 through Figure 12 in form of the mean of the log normally distributed results obtained from computations with the above GMPEs in site conditions.

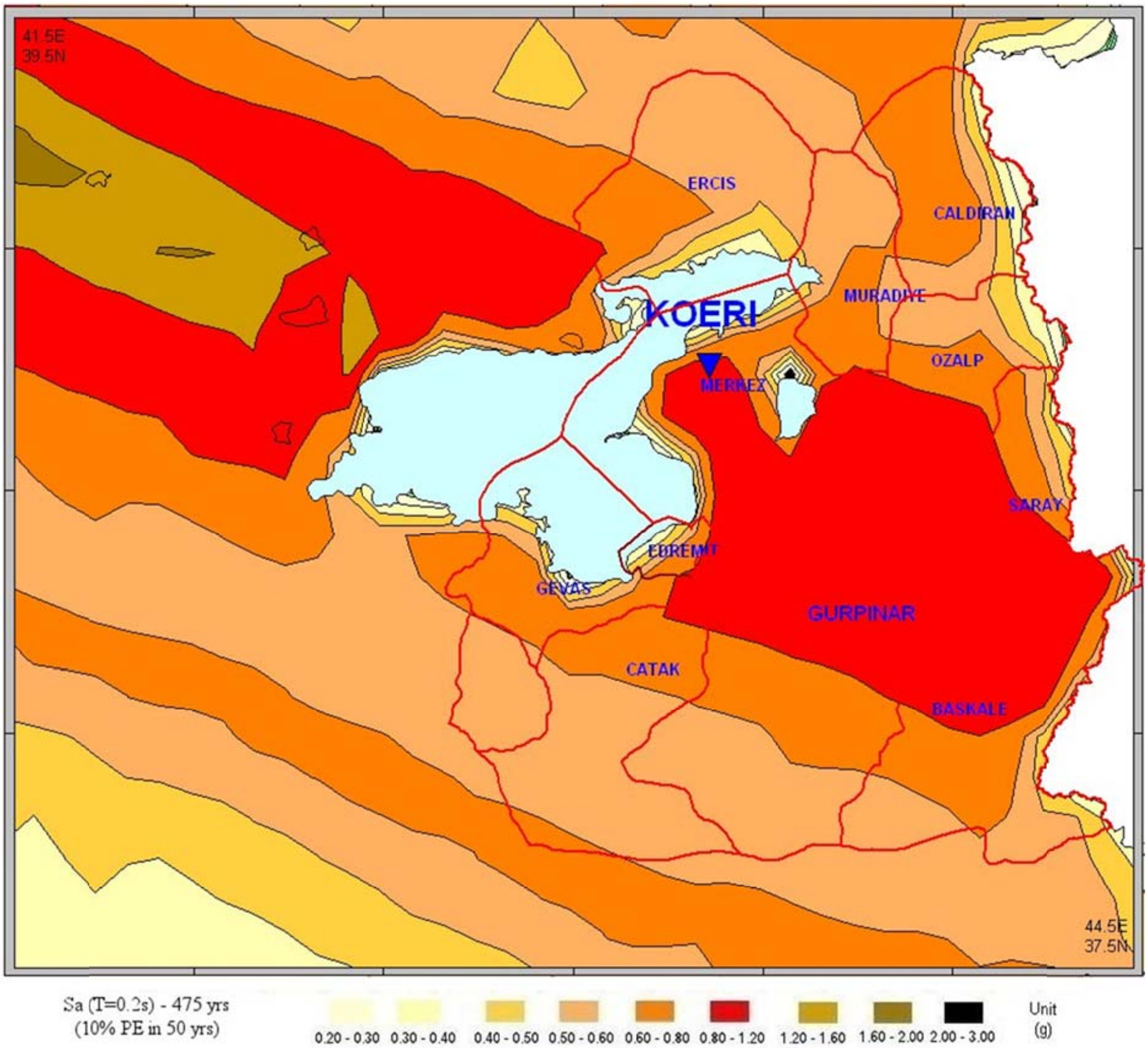


Figure 9. QTM based SA (T=0.2s) for 10% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

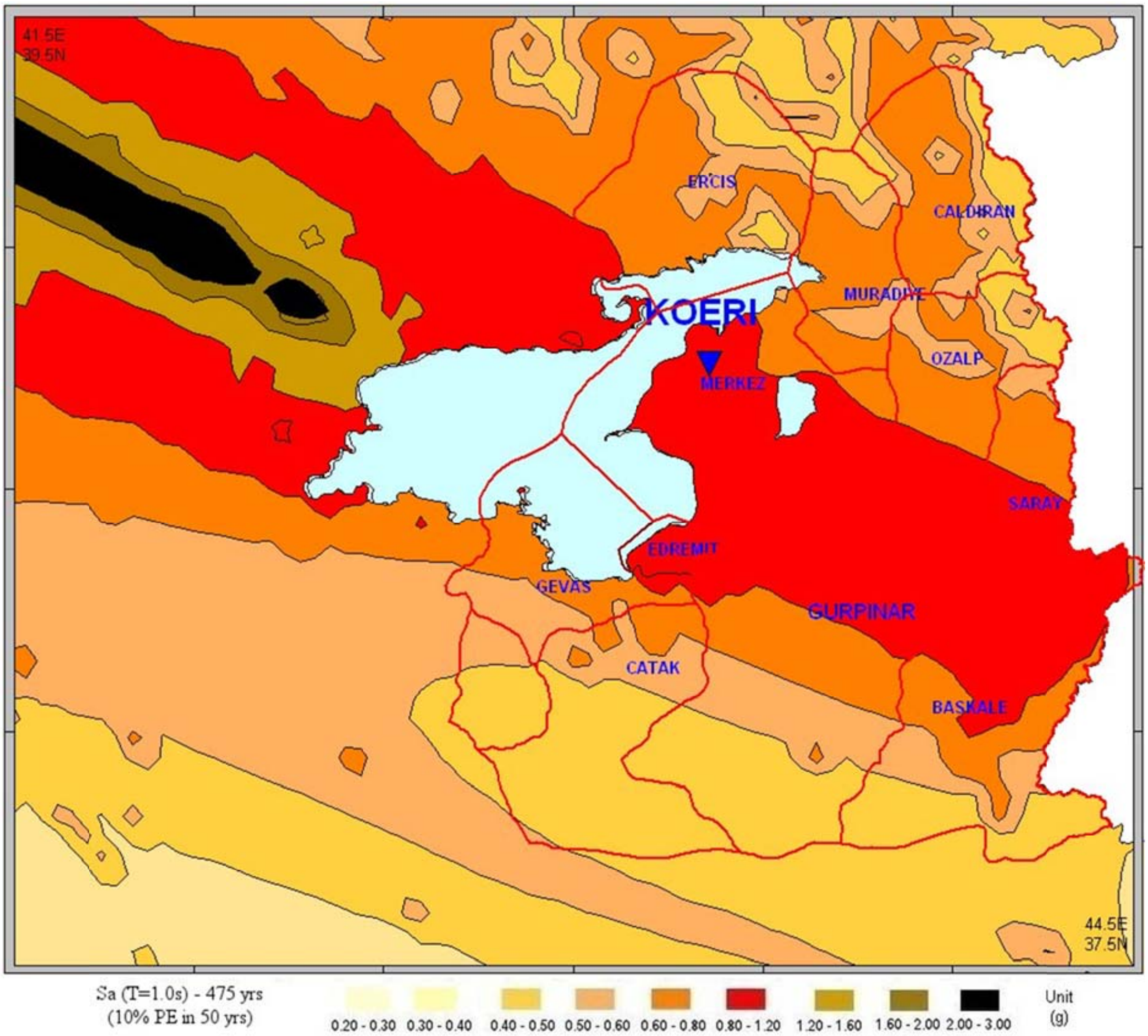


Figure 10. QTM based SA (T=1.0s) for 10% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

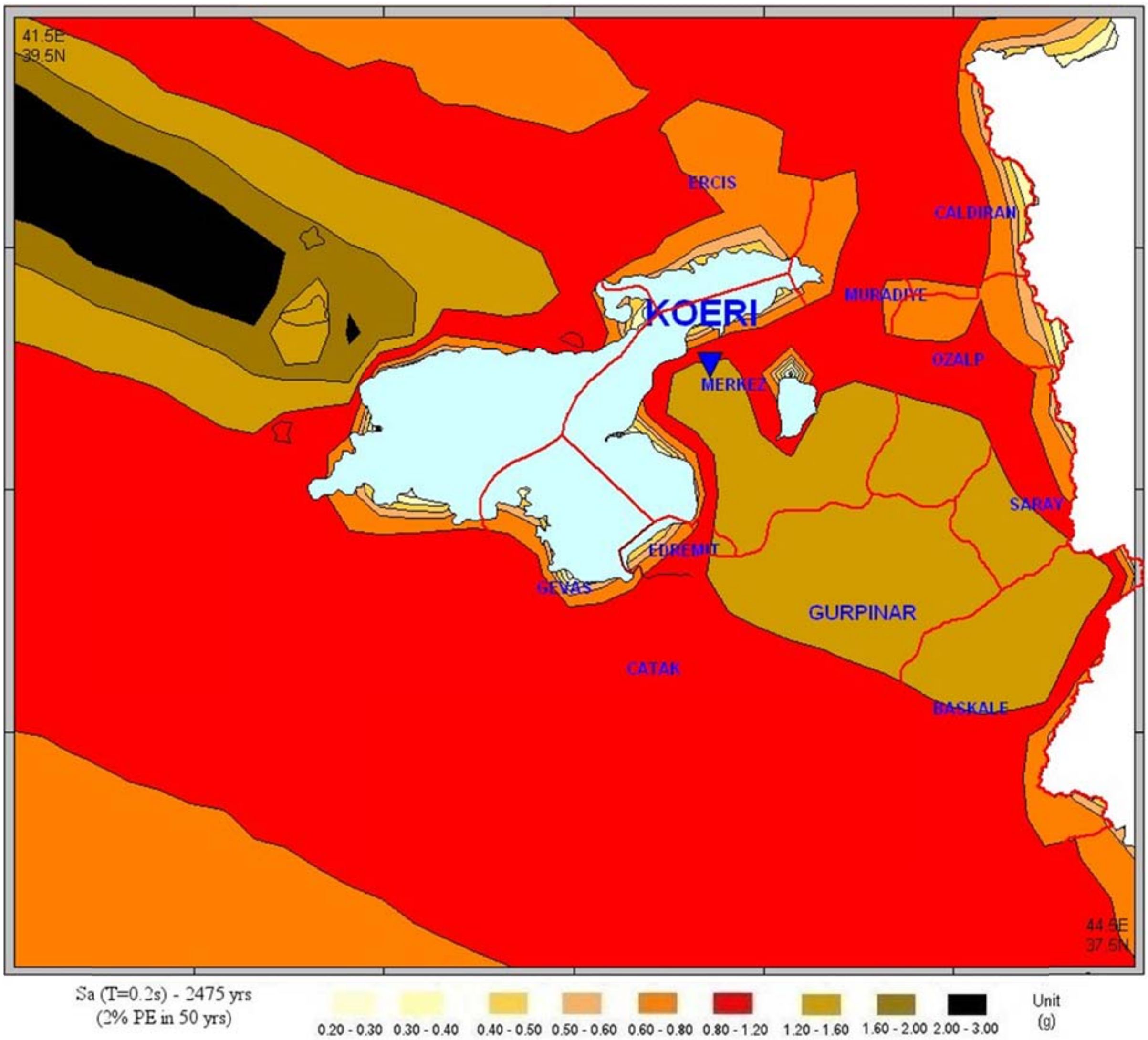


Figure 11. QTM based SA (T=0.2s) for 2% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

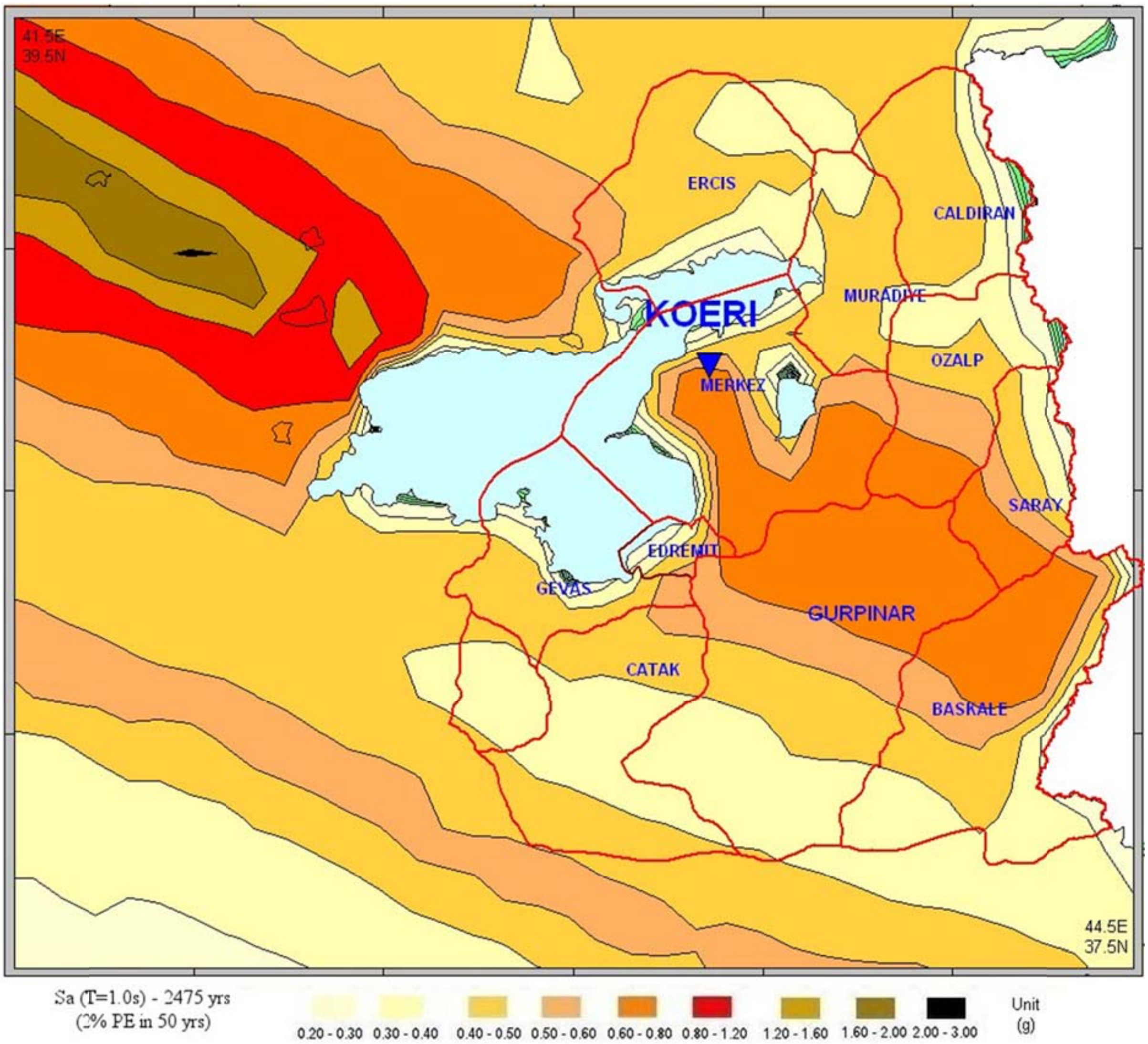


Figure 12. QTM based SA (T=1.0s) for 2% probability of exceedence in 50 years (blue triangle shows the epicenter of the Van earthquake given by KOERI).

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