CE 505
APPLIED STOCHASTIC ANALYSIS AND MODELLING

TERM PROJECT

CALCULATION OF THE PROBABILISTIC SEISMIC HAZARD OF KADIKOY BY USING BOORE ATTENUATION RELATIONSHIP

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1. INTRODUCTION

If we design a facility or a building, we have to incorporate some load level we provide, there is a chance that such level will be exceeded in the future. The longer the facility is to be functional, the greater is the chance that the design level will be exceeded. This chance or probability that the design capacity will be exceeded is the seismic risk we are taking. In this case, the economic factor is the so-called economic lifespan of the facility to be functional.

EARTHQUAKE INTENSITY	FREQUENCY OF OCCURRENCE	DESIRED PERFORMANCE
1. Minor	Several times during service life	No damage to structure or nonstructural components
2. Moderate	One or more times during service life	Limited damage to non-structural components and no significant damage to Structure
3. Major (Catastrophic) (10% exceedance in 50 years)	Rare and unusual event as large as any experienced in vicinity of site	No collapse of structure or other damage that would create a life safety hazard

Table: The performance goals according to The Uniform Building Code (UBC).

According to The Uniform Building Code (UBC), three levels of performance under different earthquakes are desired, but only one design earthquake is given - the major event. In order to calculate the probability of exceedance, i.e. probabilistic seismic hazard, a stochastic model called 'attenuation relationship' is utilized. Attenuation relationship is a relationship between the magnitude of an earthquake and the distance away from the fault rupture for a particular ground motion parameter. Attenuation relationships are developed by statistical analyses performed on a large number of records, which were obtained in compatible geomorphic regions.

The limited strong motion data in Turkey and also in the Eastern Mediterranean region and ambiguities on the station site descriptions does not allow for the development of reliable region and site specific development of ground motion attenuation relationships.

Although the relationships are only as good as the data they were generated from, the geological and geo-tectonic similarity of Anatolia to the California (Strike slip faults similar to North and East Anatolian Faults) Boore attenuation relationship for peak ground acceleration can be used for Turkey.

2. METHODOLOGY

The Boore et al. (1997) Peak Ground Acceleration Attenuation Relationship is based on the selected strong motion data from Western North America. This relationship is used to calculate horizontal peak ground acceleration and is valid for moment magnitudes 5.5 to 7.5 and distances 0 to 80 km.

The ground motion estimation equation is:

$$\ln(Y) = b_1 + b_2\,(M\text{-}6) + b_3\,(M\text{-}6)^2 + b_5 \ln r + b_V \ln\,(V_S / V_A)$$

where:

$$r = (r_{jb}^{\,2} + h^2)^{1/2}$$

In this equation;

Y = peak horizontal accelerations in g

M= moment magnitude M ≥5.00

r = closest distance from rupture to the station in km r ≥ 20km.

r_{jb} = closest horizontal distance from the station to a point in km.

V_S = average shear-wave velocity to a depth of 30 m (m/s)

b_1 = b_{1SS} for strike-slip earthquakes

= b_{1RS} for reverse-slip earthquakes

= b_{1ALL} if mechanism is not specified

b_{1SS}, b_{1RS}, b_{1ALL}, b_2, b_3, b_5, b_V, V_A and h = Coefficients presented in the related table.

Period	b_{1SS}	b_{1RS}	b_{1ALL}	b_2	b_3	b_5	b_V	V_A	h	$\sigma_{\ln Y}$
PGA	-0.313	-0.117	-0.242	0.527	0.000	-0.778	-0.371	1396	5.57	0.520

Table. Smoothed coefficients for Boore Peak Ground Acceleration attenuation relationship.

The aim of this study is to calculate the probabilistic seismic hazard by using Boore Attenuation Relationship, at a specific point in Istanbul, namely "Kadıköy". The location of Kadıköy is exactly N40.97905 – E29.08346.

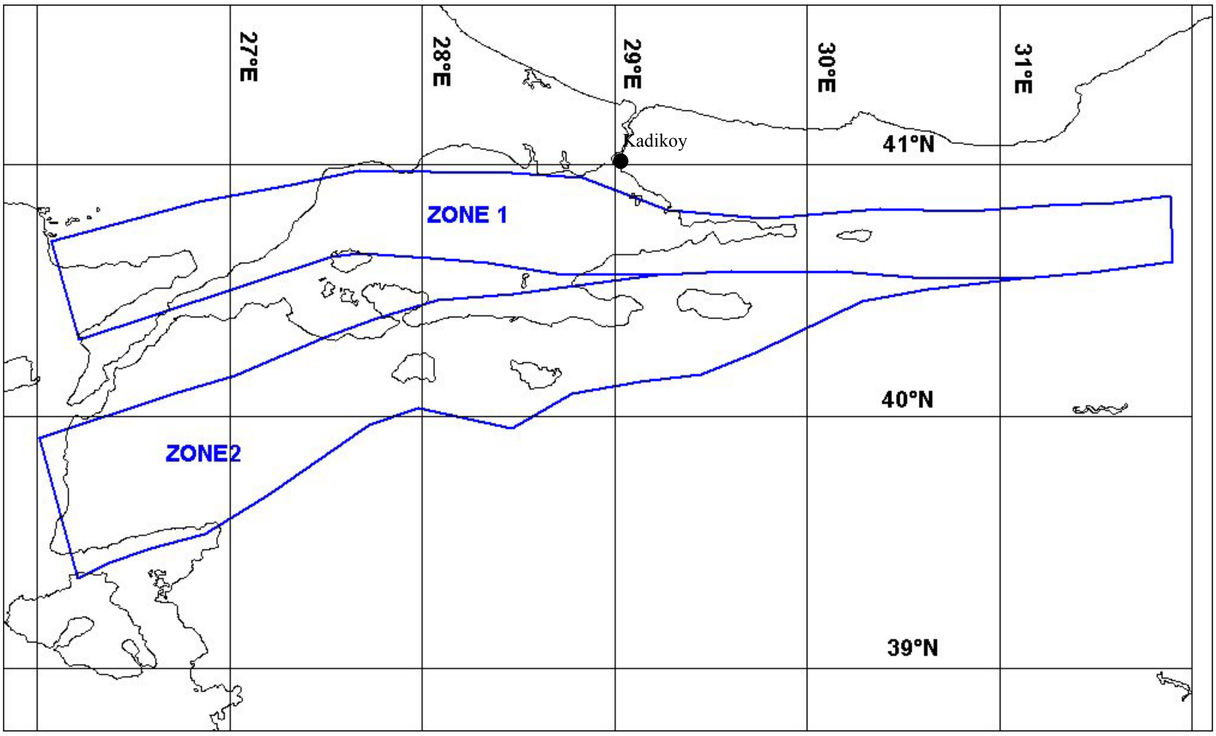


Figure. Two earthquake source zones which can affect Istanbul.

3. CALCULATIONS

The following steps were applied in order to calculate the probabilistic seismic hazard of Kadıköy:

3.1. Calculation of Recurrence Relations:

There are two earthquake sources, which can affect Istanbul. The number of earthquakes with magnitude equal or greater than 4.0 in a 50-year period was taken from the historical data collected for the sources. The number of earthquakes with magnitude equal or greater than 4.0 in the last 50-year period was taken from the historical data collected for the sources. Thereby, recurrence relations were obtained to calculate the occurrence of earthquakes for one year. In Appendix 1 and 2, 50-year data of these sources are listed.

For Zone1

M	4	4.5	5	5.5	6	6.5	7	7.5
N	169	72	19	7	5	4	4	1

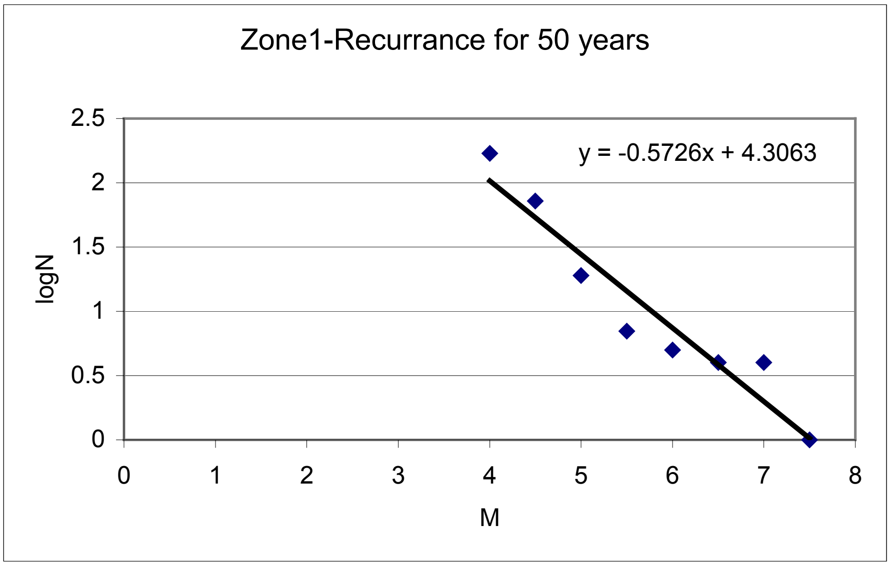


Figure. 50-year recurrance relationship of Zone 1

For Zone2

M	4	4.5	5	5.5	6	6.5	7	7.5
N	52	19	8	6	4	2	1	0

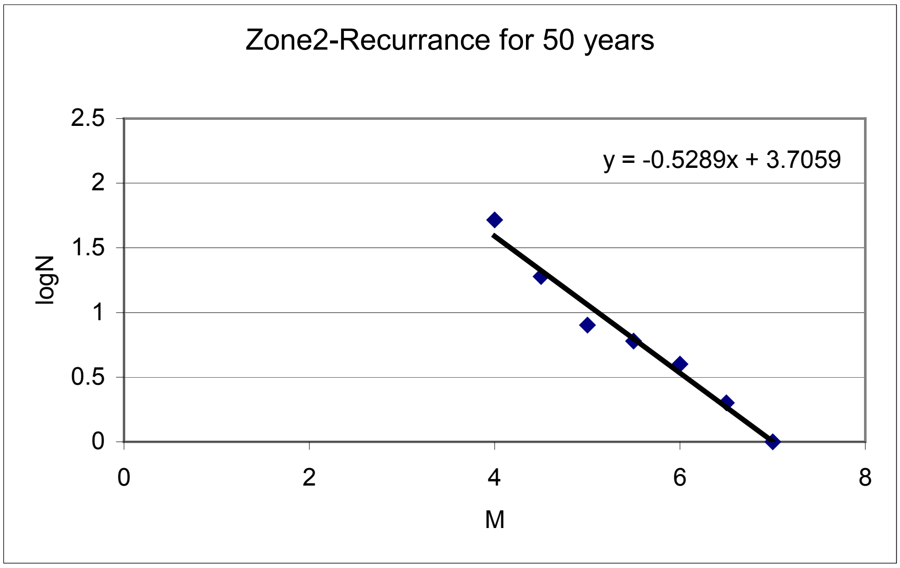


Figure. 50-year recurrance relationship of Zone 2

Recurrence for 50 years and 1 year

Recurrence relationships for 50 years and 1 year are calculated by using the trendline formulas of the graphs.

RECURRENCE FOR 50 YEARS

SOURCE	Mo	M1	M2	M3	M4	M5	Mu
	3.75-4.25	4.25-4.75	4.75-5.25	5.25-5.75	5.75-6.25	6.25-6.75	6.75-7.25
S1	70	36	19	10	5	3	1
S2	24	13	7	4	2	1	1

RECURRENCE FOR 1 YEARS

SOURCE	Mo	M1	M2	M3	M4	M5	Mu
	3.75-4.25	4.25-4.75	4.75-5.25	5.25-5.75	5.75-6.25	6.25-6.75	6.75-7.25
S1	1.40	0.72	0.38	0.20	0.10	0.06	0.02
S2	0.48	0.26	0.14	0.08	0.04	0.02	0.02

3.2. Composing of RM Matrix:

A number in RM matrix represents the annual number of earthquake occurrences corresponding to the magnitude interval $M_j \pm \Delta M$ and $R_i \pm \Delta R/2$. Radiuses of corresponding circles were from 20 km to 80 km with 10 km intervals. Magnitudes were from 5.5 to 7.0 with 0.5 intervals. The ratios of shaded area for corresponding radius to total area of zones were calculated to construct RM matrix. Afterwards, total number of earthquakes for $M_j \pm \Delta M$ and $R_i \pm \Delta R/2$ per year was computed by considering the effect of each earthquake sources.

$$M_j R_i = \sum_{k=1}^{n_{source}} \frac{shaded \quad area \quad for \quad each \quad source}{total \quad area \quad of \quad that \quad source} * annual \quad number \quad of \quad earthquakes \quad within \quad that \quad source$$

Total Areas of the earthquake source zones are 25,140.05 km^2 and 26,822.45 km^2 respectively. For example to calculate the R = 20 km and M = 5.5 we first draw to circles which have the radiuses 15 km. And 25 km. The intersection zone (shaded area) between the circles and source zone is measured. Since R = 15 km. and R = 25 km. circles not intersecting the Zone 2, R = 20 / M = 5.5 is calculated;

617.608 / 25,140.05 * 0.20 = 0.004913

Then all circles are drawn in the map like in the figure and all the shaded areas are calculated to construct RM matrix.

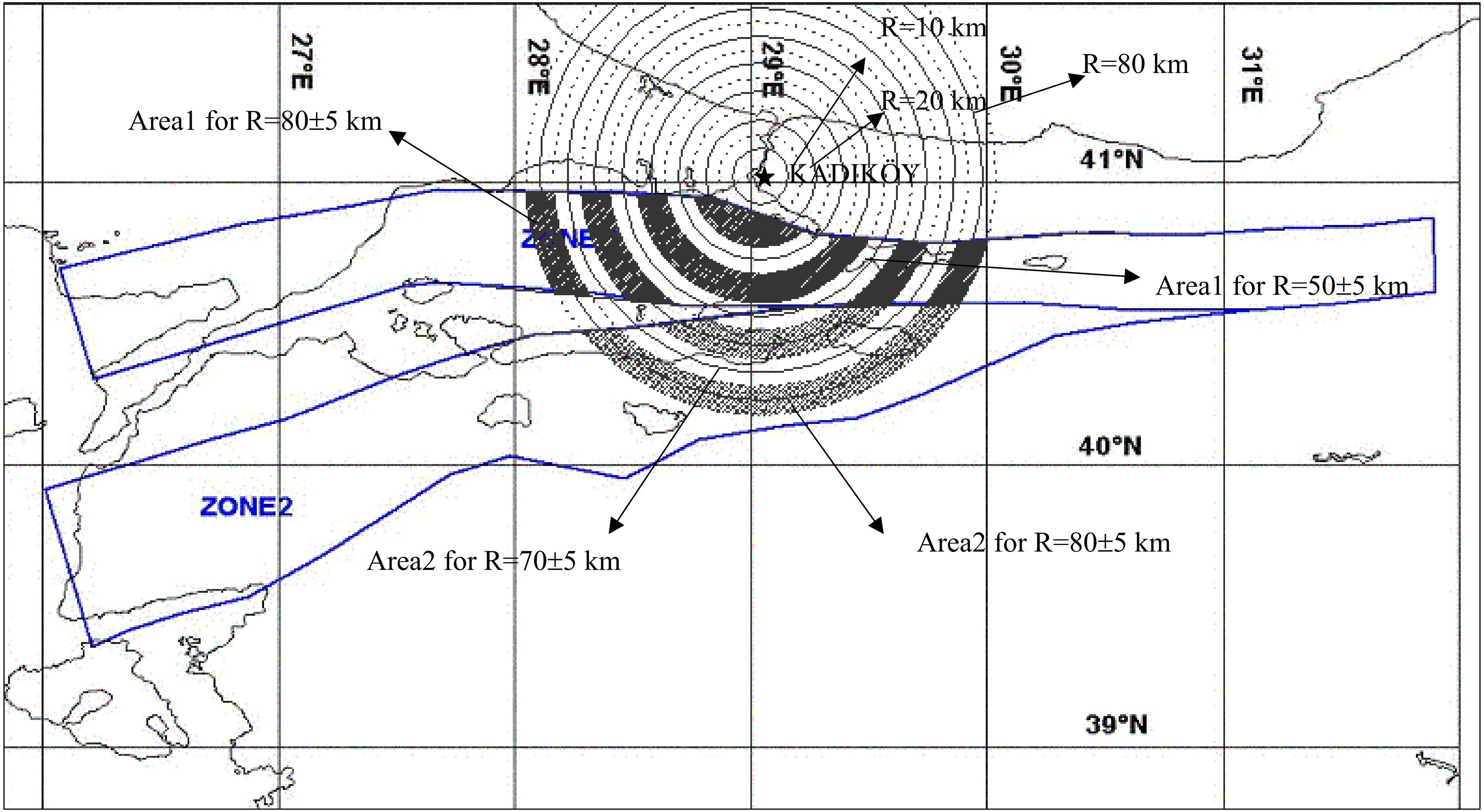


Figure. Shaded areas for both earthquake source zones

	ZONE 1		ZONE 2	
	Total area: 25,140.05 km²		Total area: 26,822.45 km²	
RADIUS	AREA	RATIO	AREA	RATIO
R=20	617.608	0.024567	0.000	0.000000
R=30	1085.134	0.043164	0.000	0.000000
R=40	1553.407	0.061790	0.000	0.000000
R=50	1434.901	0.057076	397.681	0.014826
R=60	1175.781	0.046769	1126.858	0.042012
R=70	1079.463	0.042938	1665.070	0.062077
R=80	1035.936	0.041207	2160.996	0.080567

Table. Shaded areas and ratios to the total area of the zones respectively.

[RM]=

M: 5.5	6.0	6.5	7	R
0.004913	0.002457	0.001474	0.000491	20
0.008633	0.004316	0.002590	0.000863	30
0.012358	0.006179	0.003707	0.001236	40
0.012601	0.006301	0.003721	0.001438	50
0.012715	0.006357	0.003646	0.001776	60
0.013554	0.006777	0.003818	0.002100	70
0.014687	0.007343	0.004084	0.002435	80

Table. RM Matrix of the point ‘Kadıköy’

3.3. Calculation of Attenuation Relationship:

In Boore’s attenuation formula for Kadıköy, average shear wave velocity V_s was taken as 700 m/sec and fault type is strike-slip. Then Peak Ground Acceleration matrix is constructed using formula. For example to calculate the cell R = 20 km and M = 5.5 the formula is;

$$\ln(Y) = b_1 + b_2 (M\text{-}6) + b_3 (M\text{-}6)^2 + b_5 \ln r + b_V \ln (V_S / V_A)$$

$$\ln (PGA) = (-0.313) + (0.527)(5.5-6) + (0)(5.5-6)^2 + (-0.778) \ln (r) + (-0.371) \ln (700/1396)$$

where:

$r = (r_{jb}^2 + h^2)^{1/2}$

$r = (20^2 + 5.57^2)^{1/2}$

$r = 20.761$

then;

$\ln (PGA) = -2.69862$

$PGA = 0.067298$

[PGA]=	5.5	6.0	6.5	7		
	M					
	0.067298	0.087587	0.113993	0.148359	20	
	0.049935	0.064989	0.084581	0.110081	30	
	0.040183	0.052298	0.068064	0.088584	40	
	0.033892	0.04411	0.057408	0.074715	50	R
	0.029469	0.038353	0.049916	0.064964	60	
	0.026173	0.034064	0.044334	0.057699	70	
	0.023614	0.030733	0.039998	0.052057	80	

Table. Peak Ground Acceleration Matrix of the point 'Kadıköy'

3.4. Finding the Probability of Exceedence for 50 Years:

The annual number of occurrence, γ_l, where the site PGA exceeds the specified PGA_l level is computed by constructing the relation between PGA matrix provided by an attenuation relationship and RM matrix.

$PGA_{ij}=f(R_i,M_i) > PGA_l$

$PGA_o=f(R_o,M_o)$

$PGA_m=f(R_m,M_m)$

$\gamma_l = \sum \lambda_{iji}$ all i and j satisfying $PGA_{ij}>PGA_l$

$PGA_{ij}=f(R_i,M_i) > PGA_l$

For example for Peak Ground Acceleration equal or greater than 0.03, γ is equal to the sum of the corresponding values in the RM matrix;

[PGA]=	5.5	6.0	6.5	7		
	M					
	0.067298	0.087587	0.113993	0.148359	20	
	0.049935	0.064989	0.084581	0.110081	30	
	0.040183	0.052298	0.068064	0.088584	40	
	0.033892	0.04411	0.057408	0.074715	50	R
	0.029469	0.038353	0.049916	0.064964	60	
	0.026173	0.034064	0.044334	0.057699	70	
	0.023614	0.030733	0.039998	0.052057	80	

Shading the same cells in the RM matrix;

M

[RM]=	5.5	6.0	6.5	7	R
	0.004913	0.002457	0.001474	0.000491	20
	0.008633	0.004316	0.002590	0.000863	30
	0.012358	0.006179	0.003707	0.001236	40
	0.012601	0.006301	0.003721	0.001438	50
	0.012715	0.006357	0.003646	0.001776	60
	0.013554	0.006777	0.003818	0.002100	70
	0.014687	0.007343	0.004084	0.002435	80

Summing up the shaded values in the RM matrix we found γ = 0.111616 for PGA ≥ 0.03.

In the same way for PGA ≥ 0.05;

M

[PGA]=	5.5	6.0	6.5	7	R
	0.067298	0.087587	0.113993	0.148359	20
	0.049935	0.064989	0.084581	0.110081	30
	0.040183	0.052298	0.068064	0.088584	40
	0.033892	0.04411	0.057408	0.074715	50
	0.029469	0.038353	0.049916	0.064964	60
	0.026173	0.034064	0.044334	0.057699	70
	0.023614	0.030733	0.039998	0.052057	80

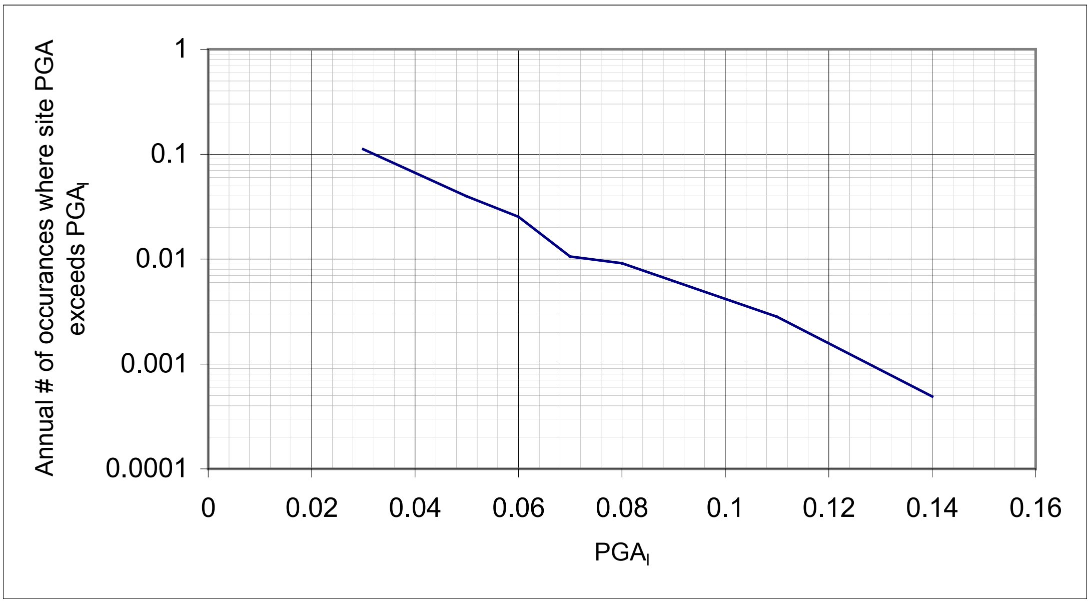
Shading the same cells in the RM matrix;

M

[RM]=	5.5	6.0	6.5	7	R
	0.004913	0.002457	0.001474	0.000491	20
	0.008633	0.004316	0.002590	0.000863	30
	0.012358	0.006179	0.003707	0.001236	40
	0.012601	0.006301	0.003721	0.001438	50
	0.012715	0.006357	0.003646	0.001776	60
	0.013554	0.006777	0.003818	0.002100	70
	0.014687	0.007343	0.004084	0.002435	80

Summing up the shaded values in the RM matrix we found γ = 0.03698 for PGA ≥ 0.05. To draw the γ vs. PGA graph few more values are taken for PGA and corresponding γ's are found;

$$\text{For } PGA = \begin{Bmatrix} 0.03 \\ 0.05 \\ 0.06 \\ 0.07 \\ 0.08 \\ 0.11 \\ 0.14 \end{Bmatrix},\ \gamma = \begin{Bmatrix} 0.111616 \\ 0.039698 \\ 0.025262 \\ 0.010549 \\ 0.009111 \\ 0.002829 \\ 0.000491 \end{Bmatrix}$$

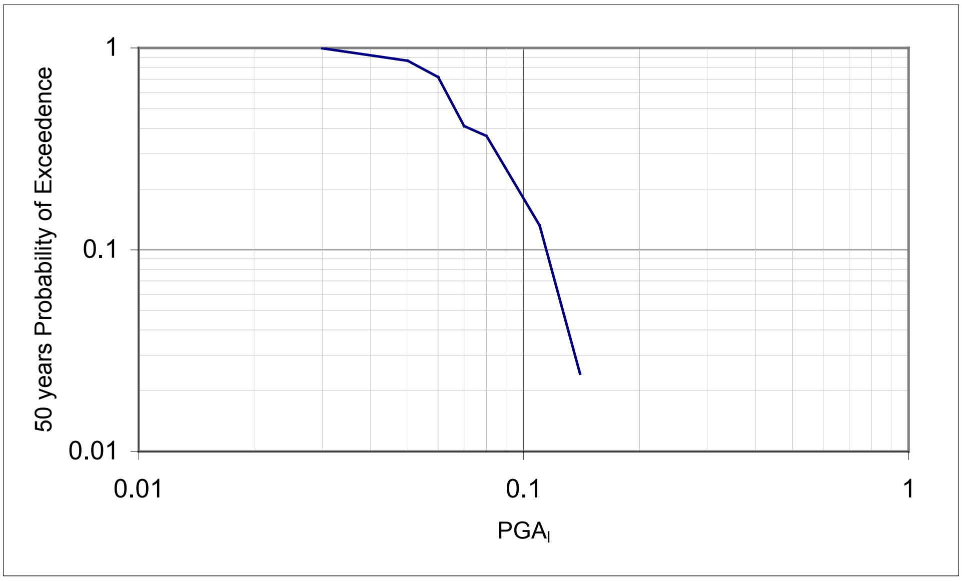


3.5. Finding the Probability of Exceedenceof 10% for 50 years:

Using the Poisson model, the probability of n occurrence of the site PGA equal to or greater than PGA_l in a time span T_l can be found by the following expression:

$$\Pr(n > 0 | PGA_l, T) = 1 - \exp(-\gamma_l * T)$$

For T=50 years



According to Boore Attenuation Relationship Probability of exeedance of 10% for 50 years for Kadıköy is 0.12 g.

4. CONCLUSION

If the site that we want to construct a building or a facility on it, is in the vicinity of an earthquake zone or zones, the seismic risk we are taking is greater than the sites farther from the earthquake zone(s). And it is obvious that the risk is getting greater when the site is closer to the earthquake source zone(s). The problem is then how much load level we should incorporate in the economic lifespan of our building. According to the Uniform Building Code; we should design a facility that can resist major (catastrophic) earthquakes that means the seismic load of 10% exceedance of 50 years.

For a case study Boore's attenuation relationship model is utilized for Kadıköy and probabilistic seismic hazard of Kadıköy is found 0.12 g of peak ground acceleration for 10% exceedance for 50 years.

A1. APPENDIX 1: 50-YEAR EARTHQUAKE DATA OF ZONE 1.

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
1	1956	1	6	12	15	44	40,390	26,290	10	5,70
2	1957	5	26	6	33	0	40,700	30,900		7,20
3	1963	9	18	16	58	8	40,670	29,000		6,30
4	1965	8	23	14	8	59	40,500	26,200	33	5,60
5	1967	7	22	17	48	6	40,600	30,700	26	5,00
6	1967	7	22	18	9	56	40,800	30,400	33	5,00
7	1967	7	22	19	47	26	40,800	30,900	33	4,60
8	1967	7	22	20	35	41	40,600	30,400	16	4,50
9	1967	7	22	22	8	30	40,700	30,700	13	4,50
10	1967	7	22	23	41	60	40,600	30,700	33	4,70
11	1967	7	23	2	25	37	40,800	30,600	27	4,00
12	1967	7	23	4	3	39	40,600	30,600	21	4,50
13	1967	7	23	4	48	53	40,600	30,700	33	4,50
14	1967	7	23	7	42	22	40,800	30,800	19	4,10
15	1967	7	23	15	57	9	40,700	30,600	33	4,40
16	1967	7	23	23	19	14	40,600	30,700	15	4,30
17	1967	7	24	3	40	20	40,800	30,800	4	4,20
18	1967	7	30	1	19	32	40,600	30,500	33	4,60
19	1967	7	30	18	58	45	40,700	30,700	33	4,50
20	1967	8	1	0	13	35	40,800	30,400	33	4,50
21	1967	8	1	1	5	11	40,800	30,300	33	4,30
22	1967	8	2	15	33	23	40,700	30,600	33	4,50
23	1967	8	14	20	9	26	40,700	30,500	33	4,70
24	1967	7	22	16	56	58	40,670	30,690	33	7,00
25	1968	9	28	0	53	26	40,457	26,398	28	4,40
26	1971	5	1	13	45	26	40,877	27,845	13	4,90
27	1978	6	15	0	26	43	40,846	27,695	16	4,40
28	1979	6	28	21	22	11	40,782	31,834	10	4,60
29	1981	3	12	4	5	59	40,801	28,109	10	5,00
30	1981	5	3	20	41	10	40,799	28,142	24	4,30
31	1984	5	26	8	39	36	40,656	30,324	7	4,10
32	1984	8	27	6	32	12	40,720	30,062	12	4,00
33	1985	4	11	13	11	46	40,688	28,874	10	4,30
34	1985	4	27	12	33	7	40,770	27,344	7	4,30
35	1985	9	14	15	23	10	40,752	29,163	11	4,70
36	1986	5	15	18	13	56	40,718	27,572	10	4,60
37	1986	6	27	18	33	37	40,889	28,285	10	4,70
38	1986	10	26	4	49	32	40,751	28,994	32	4,10
39	1988	4	24	20	49	34	40,857	28,227	16	5,00
40	1991	1	7	5	15	15	40,687	28,556	19	4,00
41	1991	2	12	9	54	58	40,816	28,878	10	4,80
42	1991	3	3	8	39	26	40,623	29,017	21	4,50
43	1991	3	8	9	23	13	40,828	27,892	11	4,50
44	1991	5	28	18	26	51	40,507	26,411	27	4,40
45	1992	4	5	0	48	2	40,854	27,903	26	4,00
46	1994	1	22	7	48	45	40,773	27,493	10	4,00
47	1994	1	26	3	21	39	40,723	27,335	10	4,00
48	1994	5	28	18	1	19	40,675	29,878	13	4,00
49	1994	6	20	1	36	16	40,591	27,330	8	4,00

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
50	1994	7	22	22	22	57	40,458	26,225	25	4,00
51	1995	2	8	21	24	54	40,822	27,774	23	4,50
52	1995	3	28	8	0	52	40,777	27,789	10	4,00
53	1995	4	13	4	8	2	40,856	27,672	24	4,70
54	1995	4	18	5	36	2	40,856	27,707	10	4,50
55	1995	10	28	10	44	59	40,831	27,959	10	4,00
56	1996	4	14	8	31	4	40,706	27,614	10	4,00
57	1997	10	21	10	49	33	40,676	30,559	10	4,10
58	1997	10	25	0	38	45	40,487	26,332	30	4,20
59	1999	8	17	22	12	48	40,759	30,588	6	4,20
60	1999	8	17	0	1	39	40,748	29,864	17	7,60
61	1999	8	17	0	15	18	40,648	30,751	10	4,90
62	1999	8	17	0	16	26	40,741	29,970	10	5,00
63	1999	8	17	0	21	5	40,653	30,435	10	4,60
64	1999	8	17	0	34	48	40,722	29,947	10	4,10
65	1999	8	17	0	44	21	40,654	30,646	10	4,40
66	1999	8	17	0	47	0	40,696	30,547	10	4,00
67	1999	8	17	0	57	42	40,711	29,801	10	4,10
68	1999	8	17	1	7	52	40,700	30,018	10	4,60
69	1999	8	17	1	31	57	40,700	29,061	10	4,20
70	1999	8	17	1	33	7	40,648	29,117	10	4,60
71	1999	8	17	1	36	35	40,594	30,717	10	4,00
72	1999	8	17	2	23	14	40,709	29,110	10	4,20
73	1999	8	17	2	26	15	40,752	30,979	10	4,10
74	1999	8	17	2	34	53	40,643	30,708	10	4,50
75	1999	8	17	2	42	55	40,561	30,648	10	4,80
76	1999	8	17	2	50	45	40,715	30,113	10	4,90
77	1999	8	17	3	8	14	40,693	30,960	10	4,00
78	1999	8	17	3	14	0	40,616	30,688	10	5,10
79	1999	8	17	3	23	15	40,755	30,300	10	4,20
80	1999	8	17	3	43	6	40,727	30,389	10	4,10
81	1999	8	17	4	14	23	40,694	29,194	10	4,20
82	1999	8	17	4	20	17	40,585	30,466	10	4,50
83	1999	8	17	4	39	58	40,739	30,408	10	4,10
84	1999	8	17	5	45	22	40,739	30,203	10	4,10
85	1999	8	17	6	1	33	40,736	29,964	10	4,00
86	1999	8	17	6	35	1	40,644	30,617	10	4,00
87	1999	8	17	6	35	19	40,674	30,651	10	4,60
88	1999	8	17	7	21	2	40,741	30,753	10	4,20
89	1999	8	17	8	9	19	40,676	30,840	10	4,30
90	1999	8	17	8	11	20	40,655	30,741	10	4,10
91	1999	8	17	9	2	10	40,741	31,230	10	4,60
92	1999	8	17	10	46	41	40,711	29,942	10	4,50
93	1999	8	17	11	58	9	40,631	30,668	10	4,40
94	1999	8	17	18	35	24	40,597	29,086	10	4,00
95	1999	8	17	21	47	39	40,763	30,079	10	4,10
96	1999	8	18	1	4	24	40,649	30,915	10	4,10
97	1999	8	18	21	15	52	40,644	31,037	10	4,10
98	1999	8	19	13	4	13	40,619	30,769	10	4,70
99	1999	8	19	14	15	59	40,608	29,200	10	4,50
100	1999	8	19	15	17	45	40,618	29,138	10	5,20

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
101	1999	8	20	0	3	2	40,720	29,994	10	4,10
102	1999	8	20	9	28	55	40,580	29,274	10	4,50
103	1999	8	20	9	48	37	40,694	29,708	10	4,00
104	1999	8	20	10	0	17	40,573	30,677	10	4,30
105	1999	8	20	15	59	2	40,753	30,819	10	4,20
106	1999	8	22	14	30	59	40,638	30,773	10	4,50
107	1999	8	23	21	54	52	40,615	29,162	10	4,10
108	1999	8	24	18	58	57	40,659	30,160	10	4,20
109	1999	8	26	17	49	38	40,744	30,016	10	4,80
110	1999	8	29	10	15	2	40,725	31,173	10	4,20
111	1999	8	31	8	10	50	40,711	29,949	10	5,20
112	1999	8	31	8	33	24	40,708	29,954	10	4,50
113	1999	9	2	14	25	20	40,563	30,532	10	4,00
114	1999	9	4	10	30	46	40,741	30,032	17	4,00
115	1999	9	9	1	32	8	40,718	29,144	13	5,00
116	1999	9	17	19	50	5	40,711	30,154	10	4,30
117	1999	9	18	0	48	25	40,607	29,297	10	4,50
118	1999	9	19	20	26	36	40,636	30,527	10	4,30
119	1999	9	20	21	27	59	40,644	27,589	10	4,80
120	1999	9	29	0	13	6	40,739	29,346	10	5,20
121	1999	10	20	23	8	20	40,770	29,087	10	4,60
122	1999	11	7	16	54	42	40,693	30,725	10	4,90
123	1999	11	7	17	6	6	40,738	30,751	10	4,20
124	1999	11	11	14	55	24	40,784	30,448	10	4,10
125	1999	11	12	16	57	20	40,730	31,122	10	7,10
126	1999	11	12	17	16	50	40,755	31,022	10	4,80
127	1999	11	12	17	22	54	40,793	31,116	10	4,60
128	1999	11	12	17	26	15	40,697	31,515	10	4,50
129	1999	11	12	17	29	32	40,742	31,471	10	5,20
130	1999	11	12	17	46	57	40,732	30,953	10	4,50
131	1999	11	12	18	7	52	40,762	31,302	10	4,00
132	1999	11	12	18	14	31	40,738	31,339	10	4,80
133	1999	11	12	18	23	52	40,770	31,037	10	4,20
134	1999	11	12	19	6	30	40,781	31,179	10	4,10
135	1999	11	12	19	15	34	40,770	31,442	10	4,40
136	1999	11	12	20	4	45	40,758	31,219	10	4,50
137	1999	11	12	20	44	36	40,803	31,270	10	4,00
138	1999	11	12	20	53	53	40,724	31,596	10	4,10
139	1999	11	12	21	38	33	40,809	31,105	10	4,40
140	1999	11	12	21	42	26	40,831	31,279	10	4,20
141	1999	11	12	22	1	12	40,794	31,394	10	4,00
142	1999	11	12	22	20	54	40,757	31,339	10	4,40
143	1999	11	12	22	49	30	40,684	30,871	10	4,10
144	1999	11	13	0	14	48	40,820	31,496	10	4,40
145	1999	11	13	0	54	55	40,768	31,050	10	4,80
146	1999	11	13	3	57	33	40,733	31,505	10	4,30
147	1999	11	13	4	10	21	40,627	31,508	10	4,00
148	1999	11	13	8	14	37	40,776	31,047	10	4,00
149	1999	11	13	8	33	43	40,781	31,374	10	4,20
150	1999	11	13	9	59	23	40,784	30,962	10	4,10
151	1999	11	13	10	10	34	40,762	31,530	10	4,00

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
152	1999	11	14	22	55	16	40,736	31,559	10	4,10
153	1999	11	15	16	26	59	40,771	30,851	10	4,00
154	1999	11	16	17	51	18	40,717	31,608	10	5,10
155	1999	11	17	8	15	26	40,807	31,467	9	4,80
156	1999	11	17	3	36	0	40,717	31,420	10	4,20
157	1999	11	19	19	59	8	40,809	30,967	7	4,80
158	1999	11	19	10	27	59	40,785	31,071	10	4,10
159	1999	11	19	14	1	15	40,797	30,734	10	4,10
160	1999	11	21	4	31	43	40,783	30,804	10	4,20
161	1999	11	21	7	53	41	40,676	31,208	10	4,00
162	1999	11	21	22	27	33	40,720	31,557	10	4,40
163	1999	12	13	19	13	38	40,734	30,756	10	4,30
164	1999	12	20	3	27	20	40,785	30,873	10	4,30
165	2000	1	5	14	10	5	40,792	31,237	10	4,00
166	2000	1	20	10	35	58	40,760	31,369	10	4,30
167	2000	1	31	14	38	51	40,713	29,345	10	4,10
168	2000	4	2	18	57	38	40,803	30,244	7	4,60
169	2000	7	7	0	15	31	40,837	29,218	9	4,20

A2. APPENDIX 2: 50-YEAR EARTHQUAKE DATA OF ZONE 2.

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
1	1951	9	15	22	52	12	40,150	28,020	40	5,60
2	1953	3	18	19	6	13	40,100	27,300	10	7,50
3	1953	6	3	16	5	24	40,100	28,800		6,00
4	1961	11	28	8	58		40,000	26,300	120	6,00
5	1964	10	6	14	31	23	40,100	27,930		6,90
6	1967	5	9	4	5	10	39,590	26,962	16	4,30
7	1967	7	22	21	21	34	40,500	30,500	16	4,40
8	1968	5	6	9	38	47	40,348	28,607	21	4,30
9	1968	11	9	12	38	58	40,091	28,661	41	4,20
10	1969	3	3	0	59	10	40,100	27,500	6	5,90
11	1969	3	5	14	41	16	40,043	27,460	33	4,70
12	1971	12	2	9	40	59	39,605	26,259	36	4,50
13	1972	2	28	2	4	35	40,394	29,053	6	4,10
14	1972	4	26	6	30	24	39,500	26,346	26	5,00
15	1972	4	26	15	59	45	39,506	26,343	28	4,80
16	1972	5	9	17	40	25	39,581	26,294	37	4,70
17	1972	6	4	16	29	34	39,403	26,215	17	4,10
18	1973	11	22	14	54	56	40,307	29,807	33	4,20
19	1974	1	3	7	39	47	39,803	26,883	33	4,30
20	1974	1	18	10	57	14	40,429	28,904	23	4,20
21	1974	2	7	8	46	55	40,081	26,860	37	4,40
22	1974	12	1	12	9	29	39,520	26,198	36	4,50
23	1976	5	29	22	42	10	40,413	28,845	14	4,40
24	1981	7	23	16	35	29	40,211	28,928	15	4,50
25	1981	8	28	7	17	10	40,408	29,225	28	4,10
26	1981	12	26	17	53	36	40,124	28,716	10	5,10
27	1982	5	20	2	42	49	40,407	29,057	10	4,00
28	1982	5	23	16	23	7	40,368	28,964	10	4,50
29	1982	6	9	4	13	39	40,435	28,852	10	4,70
30	1982	7	27	10	23	14	40,395	28,977	11	4,20
31	1983	2	1	13	54	11	40,179	28,958	10	4,80
32	1984	1	21	10	4	5	39,448	26,354	10	4,00
33	1984	8	8	16	47	46	39,465	26,351	10	4,10
34	1985	12	19	14	34	57	40,184	27,264	12	4,10
35	1986	9	12	10	34	51	40,251	27,330	10	4,10
36	1987	9	3	16	24	54	40,489	29,263	11	4,10
37	1987	10	27	3	15	30	40,425	28,436	17	4,30
38	1989	1	27	9	48	36	40,420	29,251	22	4,10
39	1990	5	24	5	49	5	39,995	27,500	15	4,10
40	1992	3	22	16	52	24	40,186	28,340	19	4,80
41	1993	3	18	7	19	40	40,388	27,980	14	4,20
42	1993	3	18	7	22	45	40,405	27,952	12	4,00
43	1993	3	18	7	51	38	40,429	27,986	10	4,50
44	1993	9	2	21	3	42	40,190	27,263	14	4,40
45	1993	9	25	9	39	11	40,067	27,185	10	4,10
46	1994	2	21	4	36	21	40,203	29,319	5	4,00
47	1994	3	28	16	59	1	40,395	29,975	20	4,10
48	1994	4	6	15	33	8	40,064	28,091	10	4,00
49	1995	8	19	19	57	15	40,343	29,644	33	4,10

NO	YEAR	MONTH	DAY	HR	MIN	SEC	LATTITUDE	LONGITUDE	DEPTH	Mw
50	1997	12	28	20	46	38	39,795	26,911	10	4,00
51	1999	8	17	11	36	43	40,568	30,197	10	4,00
52	1999	9	6	6	33	23	40,542	29,985	10	4,00