Preliminary Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings in Turkey

Part II: Inclusion of Site Characteristics

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Abstract: The vulnerability assessment method, described in the companion paper [1], relies on a damage score, which is compared with an appropriate cutoff value to identify the buildings as “safe”, “unsafe” or “intermediate”. The cutoff values are considered to be valid for damaging earthquakes and regions similar to Düzce, where the data were gathered. To generalize the procedure, the variability of ground motion with respect to soil properties and the distance to source needs to be incorporated. This was done by modifying the cutoff values based on the above factors. Sites are classified according to the Turkish Seismic Code’s [2] definitions based on the shear wave velocity. Various attenuation relations are used to account for the variation of the ground motion with distance and the soil type.

Key words: Attenuation Model, Building Damage, Site Effect, Vulnerability Assessment

1. INTRODUCTION

This study focuses on modifying the vulnerability assessment procedure developed based on the structural characteristics of buildings located in the city of Düzce. The procedure, which is described in detail in the companion paper [1], relies on the damage cutoff values developed using a statistical analysis approach based on the damage data compiled from Düzce in the wake of 1999 earthquakes. Some selected building attributes are entered into a relation obtained from discriminant analysis to compute a damage score. This damage score is then compared with a cutoff value, which identifies the buildings as “safe”, “unsafe” or “intermediate”.

The cutoff values recommended are considered to be valid for damaging earthquakes and the regions that have similar distance to source and site conditions to that of Düzce. To apply this procedure to the sites, which have different distance to source and soil properties than Düzce, further modifications must be made to improve the procedure that is presented in the companion paper [1].

2. PROCEDURE

The central point of the study is to capture the relative variation of the ground motion intensity with the distance to source and the soil type. The spectral displacement value was selected as the damage inducing ground motion parameter, as it is a widely used parameter for expressing the vulnerability of buildings. A typical damage curve expressed in terms of the spectral displacement is shown in Figure 1 [3]. It is important to observe that the variation of damage with S_d follows the form of an exponential function. This inference is used to link the change in S_d to the change to be imposed on the cutoff values obtained in [1]. The spectral displacement can be obtained from elastic site spectra computed using available attenuation relations. A number of relations, available in the literature, can be employed to relate inelastic spectral displacement to the elastic one. Although the expressions seem quite different, their influence on the cutoff modifications is shown to be insignificant, especially in the range considered in this study as illustrated in Figure 2 [4,5]. For this reason, equal displacement rule is considered to be adequate.

The proposed procedure is developed on the basis of several assumptions, which are listed below:

- The earthquake magnitude in the region to which the method is applied is similar to the one that affected the reference site, i.e. Düzce.

- Attenuation relations are believed to represent the variation of the ground motion adequately.
- Construction practice does not show regional variations.
- Damage pattern observed in the reference site would be the same for other sites that have same distance to source and soil type.

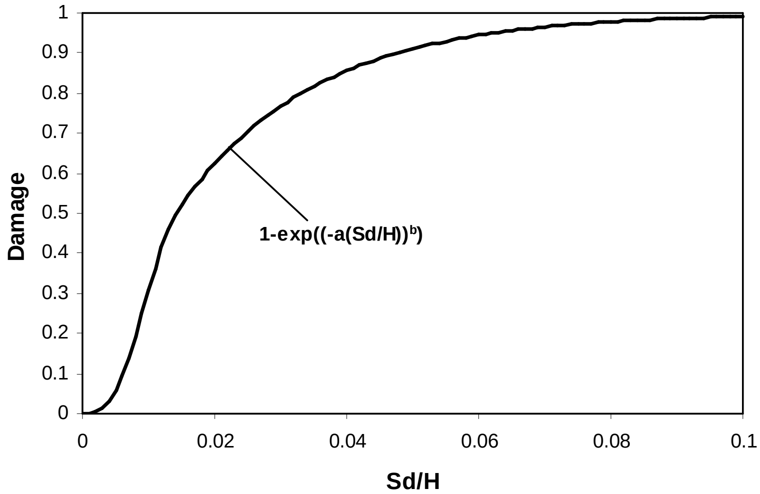


Figure 1. A typical damage curve

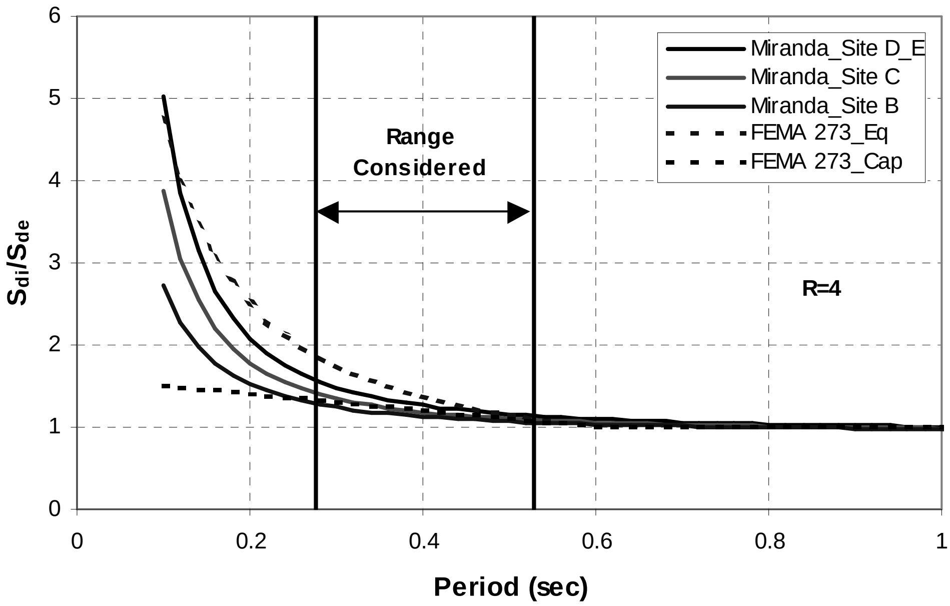


Figure 2. Comparison of S_{di}/S_{de} relations

The steps involved in this procedure can be outlined as follows;

Step 1: Obtain site-specific response spectra using an appropriate attenuation model.
Step 2: Calculate spectral displacement at the fundamental periods of interest.
Step 3: Plot spectral displacement/n as a function of the fundamental period (or n), n representing number of stories considered in the Düzce study.
Step 4: Convert spectral displacement to a damage index (cutoff value) by assuming an exponential relation.
Step 5: Normalize all damage indexes at different sites and distances with the damage index obtained for the reference site, i.e. Düzce.
Step 6: Modify Düzce cutoff values by multiplying them with the cutoff modification coefficients, i.e. normalized values calculated in Step 4.

2.1 Site Classification

Two major parameters used for site classification are the "distance to source (d_s)" and the "soil type (ST)". The sites were characterized by a pair of d_s and ST bins. Five d_s bins were selected in view of the variation in the response spectra with the distance. ST bins were determined based on the shear wave velocity (Vs) of the soil types employed by the Turkish Seismic Code. Twenty different site classes were obtained from the combination of d_s and ST bins, which are illustrated in Table 1. Note that type C2 represents the reference site (Düzce). This way, any region with a certain d_s and ST is assigned a site class according to Table 1, excluding the sites located farther than 50 km from the source. The number of sites can easily be increased by incorporating other distance ranges and soil types (Vs>1000 m/s).

Table 1. Site classification

Soil Type	Shear Wave Velocity (m/s)	Distance to Source (km)				
		0-4	**5-8**	**9-15**	**16-25**	**26-50**
A	701-1000	A1	A2	A3	A4	A5
B	401-700	B1	B2	B3	B4	B5
C	201-400	C1	C2	C3	C4	C5
D	<200	D1	D2	D3	D4	D5

2.2 Attenuation Models

Three attenuation relationships that are suitable for the source mechanism of the North Anatolian Fault were considered. The models developed by Boore et al. [6], Gulkan and Kalkan [7], and Abrahamson and Silva [8] were used to generate site-specific response spectra for all twenty sites included in Table 1. Boore et al., and Gulkan and Kalkan are the most convenient ones because they use the shear wave velocity directly to account for the soil type. For Abrahamson and Silva, however, NEHRP amplification functions were applied on the rock motion to obtain site response spectra. Since the uncertainty in attenuation models can be substantial, using different attenuation models is believed to give a better representation of the actual condition. Among the ones selected, Gulkan and Kalkan's model has been developed based on the local data recorded in Turkey. These models are compared at different distances as shown in Figure 3. Although at short distances Gulkan and Kalkan's model suggest lower estimates as compared to others, at far distances the situation is the other way around.

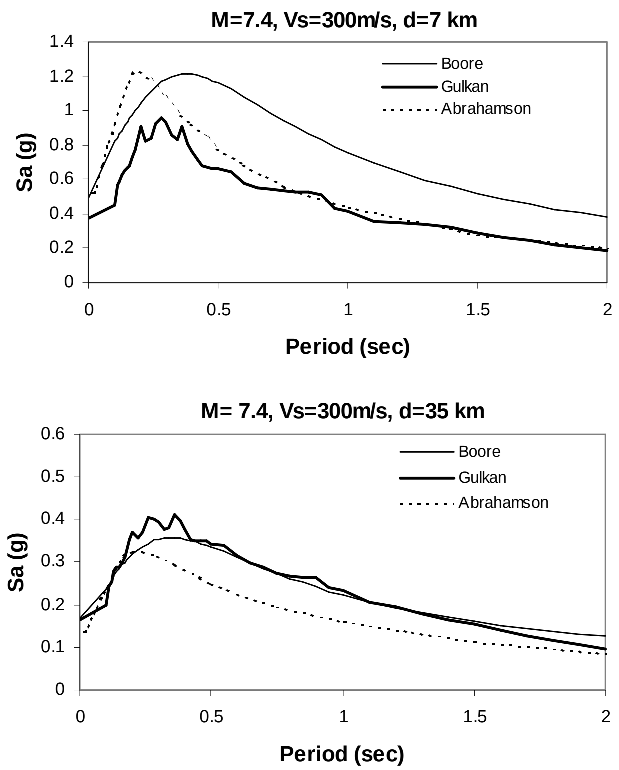


Figure 3. Comparison of the attenuation models

2.3 Number of Story and Period Relationship

Since the reference cutoff values were obtained as a function of the building height (number of stories), modification factors were also intended for the discrete height levels included in the database. Hence, a relationship between number of stories and the fundamental period was established based on the Turkish Seismic Code formulae. The mean values of the period and the number of stories obtained for the buildings contained in the Düzce seismic damage database are given in Table 2. Although the variation and dispersion of the period with number of stories is large for the buildings in the database, this would not significantly affect the modification factors as will be shown later.

Table 2. Period vs. number of stories for Düzce seismic damage database

Number of stories	Period (sec)
2	0.275
3	0.355
4	0.433
5	0.504
6	0.529

2.4 Calculation of Spectral Displacement

A series of site-specific response spectra computed for a magnitude 7.4 earthquake and a shear wave velocity of 350 m/s is shown in Figure 4. The variations in the spectral ordinates were considered insignificant within the distance bins that were selected. Spectral displacement values were obtained from the calculated spectral accelerations at all periods given in Table 2 for each of the twenty site classes. The spectral displacement normalized with number of stories (corresponding to the building period) is plotted against the number of stories as shown in Figure 5.

This normalization was done to obtain a similar term that would mimic the average drift. The change of S_d with the site class is also evident from these plots. When a linear regression is used to represent data a constant line develops, this is the simplest and the most convenient choice because it leaves out the number of stories. The trend of data implies a nonlinear behavior, so power function was used as an alternative to represent the data as displayed in Figure 6. The modification coefficients were developed for both cases. The influence of the attenuation functions on the calculated response for site C3 is shown in Figure 7. Abrahamson and Silva yields similar results to that of Boore et al., Gulkan and Kalkan, however, provides lower estimates of S_d at all periods.

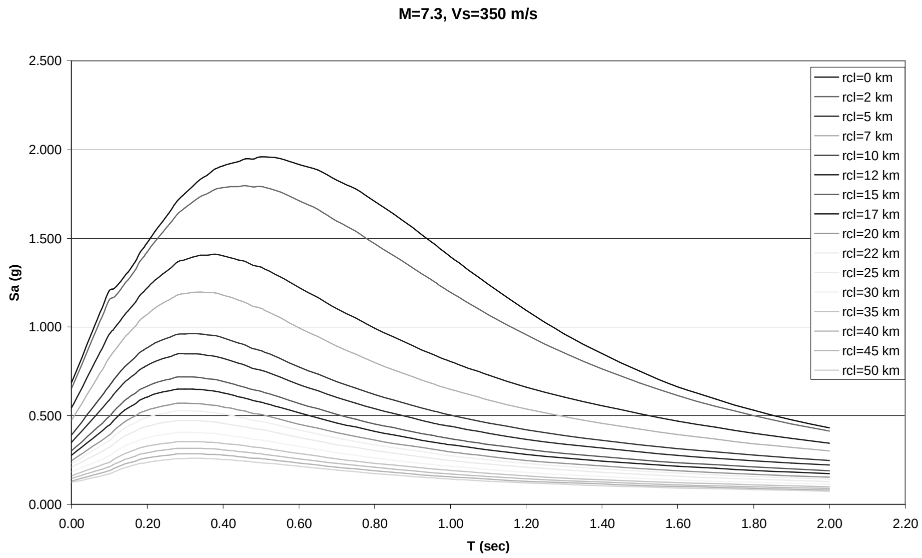


Figure 4. Acceleration response spectra

2.5 Calculation of Modification Factors

Once S_d values for all sites are computed, they are translated into damage terms. In the vulnerability assessment procedure developed for Düzce, there is a reverse relationship between the cutoff value and the damage score of the evaluated building. In other words, as the cutoff value is raised the number of "unsafe" buildings decreases. In view of this relation, the change of the cutoff value (CV) with the normalized spectral displacement was assumed to follow a similar trend observed between damage and S_d/H (Figure 1). Thus, the following function is assumed to reflect the relation between the CV and the normalized spectral displacement (S_d/n);

$$CV = f\left[\frac{1}{1-e^{-S_d/n}}\right] \tag{1}$$

Since the objective is to obtain cutoff modification coefficients (CMC) to be applied on the reference cutoff values (CV_r), the variable of the function in Equation 1 can be used to get CMC values. The CMC values are presented in Tables 3-6 for the three attenuation models employed.

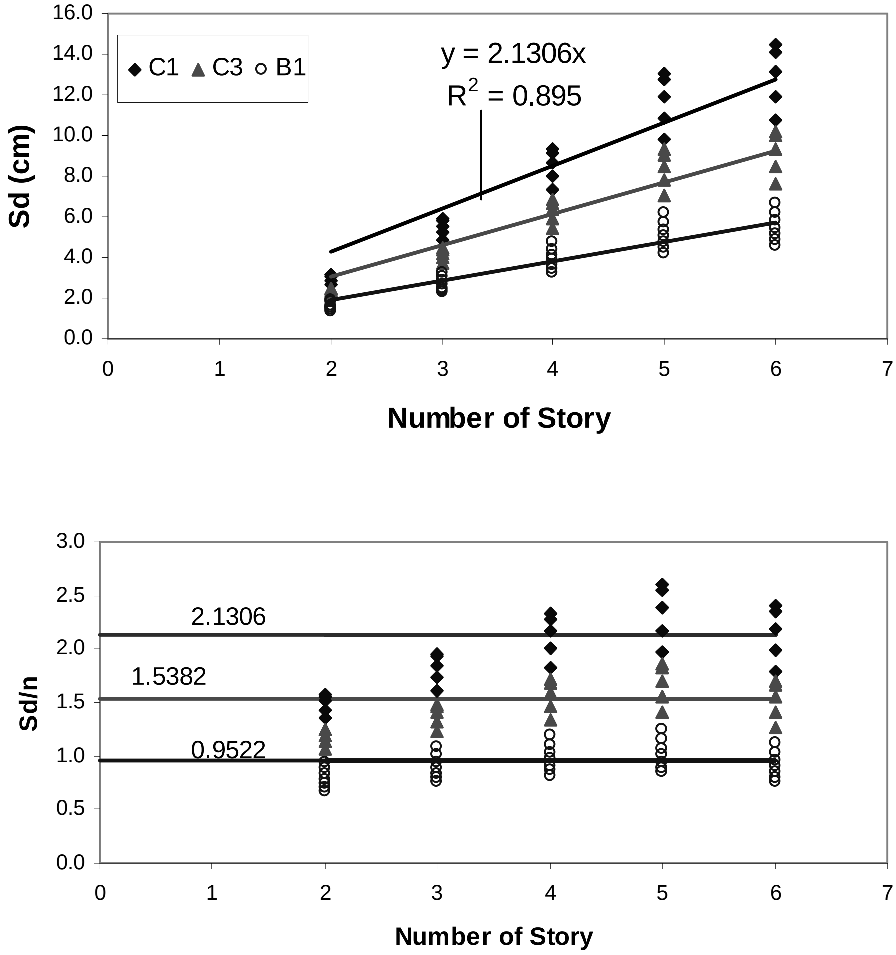


Figure 5. Normalized S_d versus Number of Story (Linear Representation)

Close inspections of these tables reveal that non-linear and linear formulations of the spectral displacement versus number of story relation provide similar values. The CMC can take values between 0.78-3.90, 0.80-2.14, 0.83-3.03 for Boore et al., Gulkan and Kalkan, and Abrahamson and Silva, respectively. Moreover, among all attenuation models, the one by Gulkan and Kalkan led to narrower range of modification values, meaning that performance differences of the buildings between the sites would be less. The CMC value for reference site class C2 is 1.0 because of the normalization with respect to this site. Obviously, at better site conditions and farther distances cutoff values should be larger. These CMC values were multiplied with the respective reference cutoff values to obtain the cutoff values for other site classes. Modified cutoff values are computed merely from Equation 2, which can handle negative as well as positive values of reference cutoff values.

$$CV = CVR + ABS(CVR)*(CM-1) \quad (2)$$

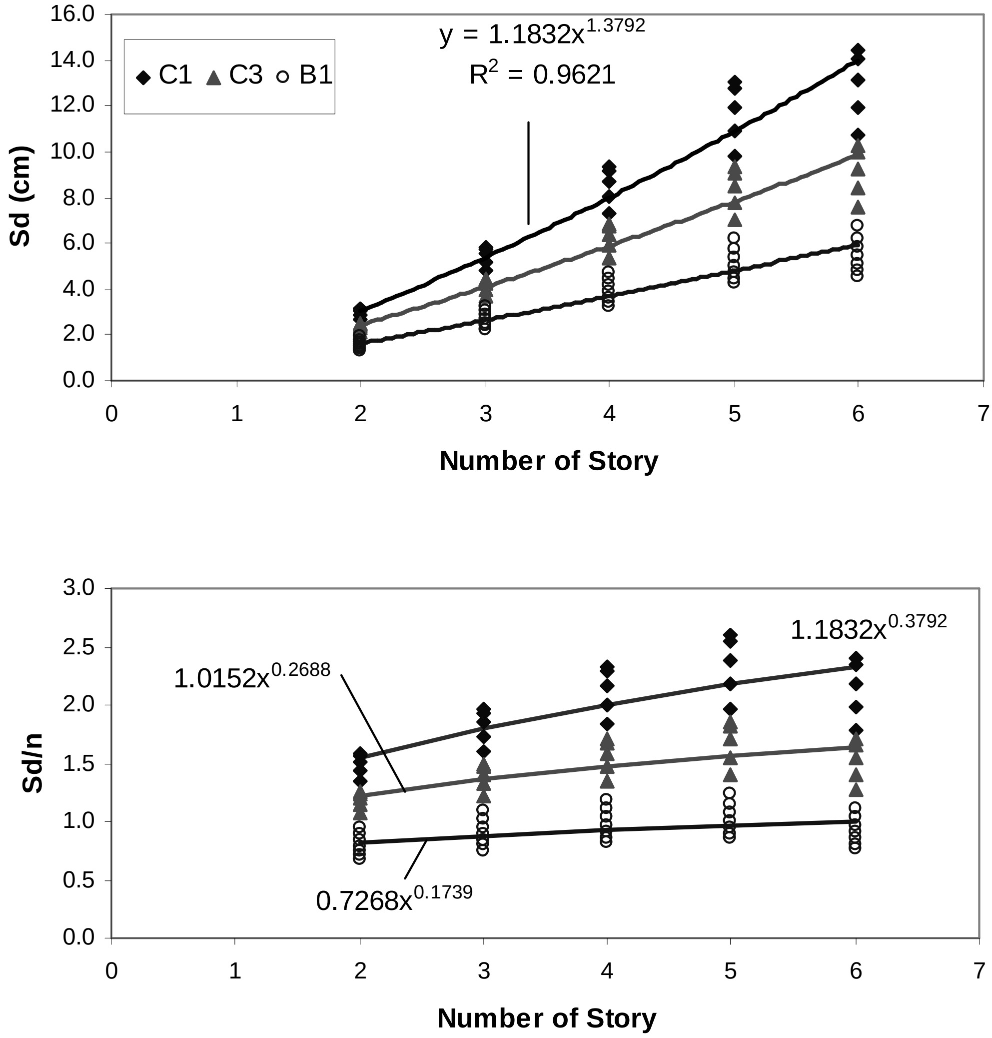
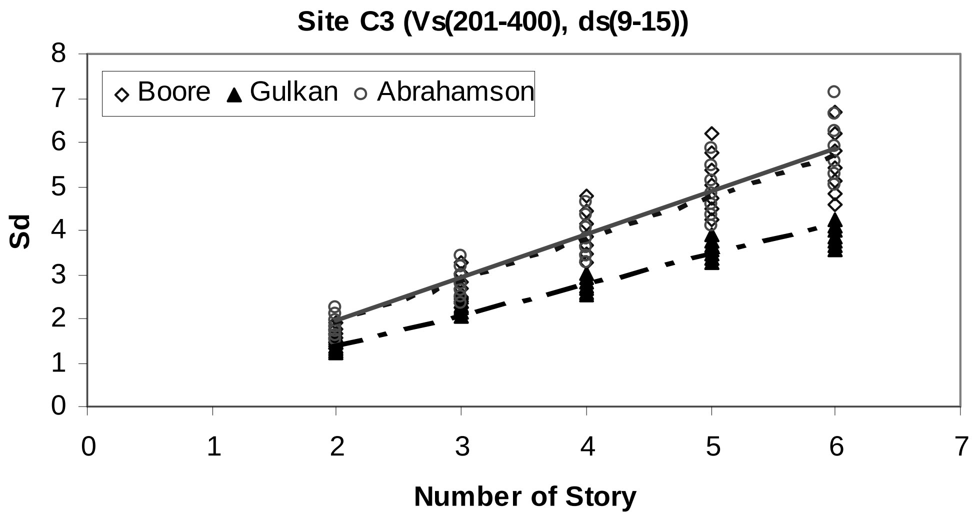


Figure 6. Normalized S_d vs. number of story (non-linear representation)

3. AN APPLICATION OF THE PROPOSED PROCEDURE

As alluded to before, Istanbul is on the verge of being struck by a devastating earthquake, similar to the one that hit Düzce. Assuming that the construction practices in Düzce and in Istanbul are similar, the procedure would provide reasonable results when applied to Istanbul. To see the extent and relativity of the expected damage or the layout of the risk within Istanbul an exercise was undertaken, in which, all buildings in Düzce database were assumed to portray buildings all over Istanbul. In other words, a uniform exposure that is identical to the compiled database for Düzce, is assigned to all districts of Istanbul. The earthquake scenario "Model A" and shear wave velocity estimates of JICA study [9] were employed to model the fault and to classify the sites. The modified cutoff values were applied and all buildings were identified as "safe", "unsafe" or "intermediate" in all districts of Istanbul. It should be pointed out that "safe" buildings represent the structures that would experience none or light damage states, "unsafe" buildings include those that are expected to suffer severe damage or would collapse, and "intermediate" buildings might encompass buildings with all degrees of damage, which can not be clearly identified.



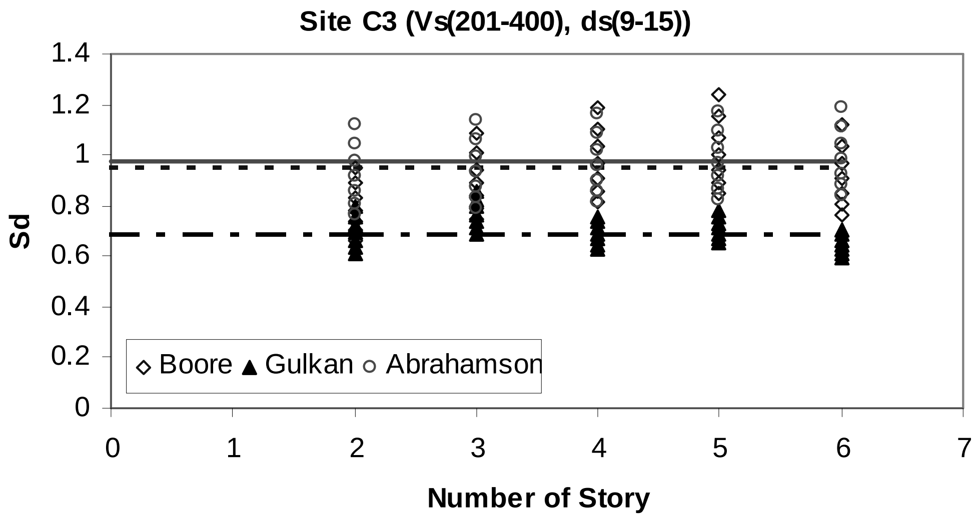


Figure 7. Influence of attenuation relation

Table 3. Cutoff modification coefficients (CMC) for Boore et. al. [6]

		LINEAR					NON-LINEAR				
		Distance (km)									
N	**Vs (m/s)**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**
2-3	**0-200**	0.778	0.824	0.928	1.128	1.538	0.764	0.826	0.959	1.207	1.72
	201-400	0.864	1.000	1.240	1.642	2.414	0.875	1.000	1.239	1.654	2.49
	401-700	0.970	1.180	1.530	2.099	3.177	0.978	1.150	1.468	2.010	3.10
	701+	1.082	1.360	1.810	2.534	3.900	1.075	1.288	1.675	2.329	3.64
4-6	**0-200**	0.778	0.824	0.928	1.128	1.538	0.781	0.825	0.928	1.125	1.53
	201-400	0.864	1.000	1.240	1.642	2.414	0.865	1.000	1.242	1.642	2.42
	401-700	0.970	1.180	1.530	2.099	3.177	0.970	1.182	1.537	2.106	3.20
	701+	1.082	1.360	1.810	2.534	3.900	1.082	1.364	1.824	2.552	3.94

Table 4. Cutoff modification coefficients (CMC) for Gulkan and Kalkan [7]

		LINEAR					NON-LINEAR				
		Distance (km)									
n	**Vs (m/s)**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**
2-3	**0-200**	0.791	0.840	0.931	1.083	1.359	0.748	0.815	0.926	1.099	1.413
	201-400	0.932	1.000	1.126	1.334	1.706	0.892	1.000	1.171	1.431	1.896
	401-700	1.032	1.113	1.263	1.508	1.946	1.006	1.142	1.355	1.678	2.252
	701+	1.115	1.207	1.376	1.652	2.144	1.106	1.265	1.514	1.891	2.558
4-6	**0-200**	0.791	0.840	0.931	1.083	1.359	0.799	0.843	0.932	1.081	1.357
	201-400	0.932	1.000	1.126	1.334	1.706	0.939	1.000	1.121	1.324	1.695
	401-700	1.032	1.113	1.263	1.508	1.946	1.037	1.110	1.253	1.492	1.927
	701+	1.115	1.207	1.376	1.652	2.144	1.120	1.201	1.363	1.630	2.118

Table 5. . Cutoff modification coefficients (CMC) for Abrahamson and Silva [8]

		LINEAR					NON-LINEAR				
		Distance (km)									
n	**Vs (m/s)**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**	**0-4**	**5-8**	**9-15**	**16-25**	**26+**
2-3	**0-200**	0.826	0.917	1.084	1.362	1.887	0.850	0.967	1.185	1.554	2.288
	201-400	0.873	1.000	1.219	1.575	2.236	0.870	1.000	1.240	1.642	2.438
	401-700	0.919	1.077	1.341	1.765	2.542	0.903	1.055	1.329	1.783	2.676
	701+	0.999	1.205	1.539	2.065	3.032	0.947	1.125	1.439	1.957	2.970
4-6	**0-200**	0.826	0.917	1.084	1.362	1.887	0.825	0.917	1.085	1.362	1.894
	201-400	0.873	1.000	1.219	1.575	2.236	0.872	1.000	1.221	1.574	2.241
	401-700	0.919	1.077	1.341	1.765	2.542	0.919	1.078	1.344	1.763	2.550
	701+	0.999	1.205	1.539	2.065	3.032	1.001	1.208	1.545	2.069	3.046

Figures 8-10 display results obtained using Boore et al. [6]. In these figures, results are presented in the form of the ratio of the classified buildings to the total number of buildings. The visual plots indicate some spotty areas, which reflect the local soil profile. The effect of distance to source is clearly observed. The range of safe buildings varies from 38% to 60% depending on the site class. Unsafe buildings constitute 1-40 % and buildings identified as intermediate, which represent buildings that could not be clearly classified as safe or unsafe, have a share of 21-39%. Of the indeterminate buildings, around 50% were moderately damaged, 38% had light or no damage and 10% were severely damaged in Düzce.

The JICA estimates of the heavily damaged building percentages are shown in Figure 11. These results were obtained based on the actual exposures extracted from the data released by the State Statistics Institute of Turkey; the apparent discrepancy is due to this fact.

4. CONCLUSIONS

It has been shown that vulnerability assessment procedures based on observed damage from a particular region can be extrapolated to other sites having similar construction practices and building stock. The variation of ground motion parameters that have known relationship to the damage of buildings are captured using attenuation models that reflect the properties of the sites, i.e. the distance to source and soil type. When the assumptions made are considered to be convincing, which is the case for Istanbul, high-risk areas and vulnerable regions can be identified in a reliable way. This would help determine the rank of regional vulnerability and the mitigation priorities, especially for the mega city of Istanbul for which a large earthquake is due.

This technique is a reasonable theoretical approach that uses available tools to predict the spatial variation of ground motion. Further improvements to the procedure can be made, especially in the intermediate steps, but the end results, which are the modification coefficients, would not be influenced considerably. Besides, the assumptions and approximations already introduced are far beyond the accuracy that would be gained this way.

ACKNOWLEDGEMENTS

The research work presented in this study is supported in part by the Scientific and Research Council of Turkey (TUBITAK) under grant: YMAU-ICTAG-1574 and by NATO Scientific Affairs Division under grant: NATO SfP977231.

REFERENCES

1. Ozcebe, G., M. S. Yucemen, V. Aydogan and A. Yakut, Preliminary Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings in Turkey -Part I: Statistical Model Based on Structural Characteristics, NATO Workshop, Izmir May 2003.
2. Turkish Ministry of Public Works and Settlement, Turkish Seismic Code, Ankara., 1997.
3. E. Erduran and A. Yakut, Drift Based Damage Functions for Reinforced Concrete Columns, Submitted to Computers & Structures for possible publication, in Review, 2003
4. Craig D. Comartin, A Progress Report on ATC-55: Evaluation and Improvement of Inelastic Seismic Analysis Procedures, Fall, 2002.
5. FEMA 273, NEHRP Guidelines for the Seismic Rehabilitation of Buildings, Federal Emergency Management Agency, October 1997.
6. D. M. Boore, W. B. Joyner and T. E. Fumal, Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes: A Summary of Recent Work, Seismological Research Letters, Volume 68, Number 1, January/February, pp.128-153, 1997.
7. P. Gulkan and E. Kalkan, Attenuation Modeling of Recent Earthquakes in Turkey, Journal of Seismology, 6:397-409. Kluwer Academic Publishers, 2002.
8. N. A. Abrahamson and W. J. Silva, Empirical Response Spectral Attenuation Relations for Shallow Crustal Earthquakes, Seismological Research Letters, Volume 68, Number 1, January/February, pp.94-127, 1997.
9. Japan International Cooperation Agency (JICA) and Istanbul Metropolitan Municipality (IBB), The Study on A Disaster Prevention / Mitigation Basic Plan in Istanbul including Seismic Microzonation in the Republic of Turkey, Final Report, December, 2002.

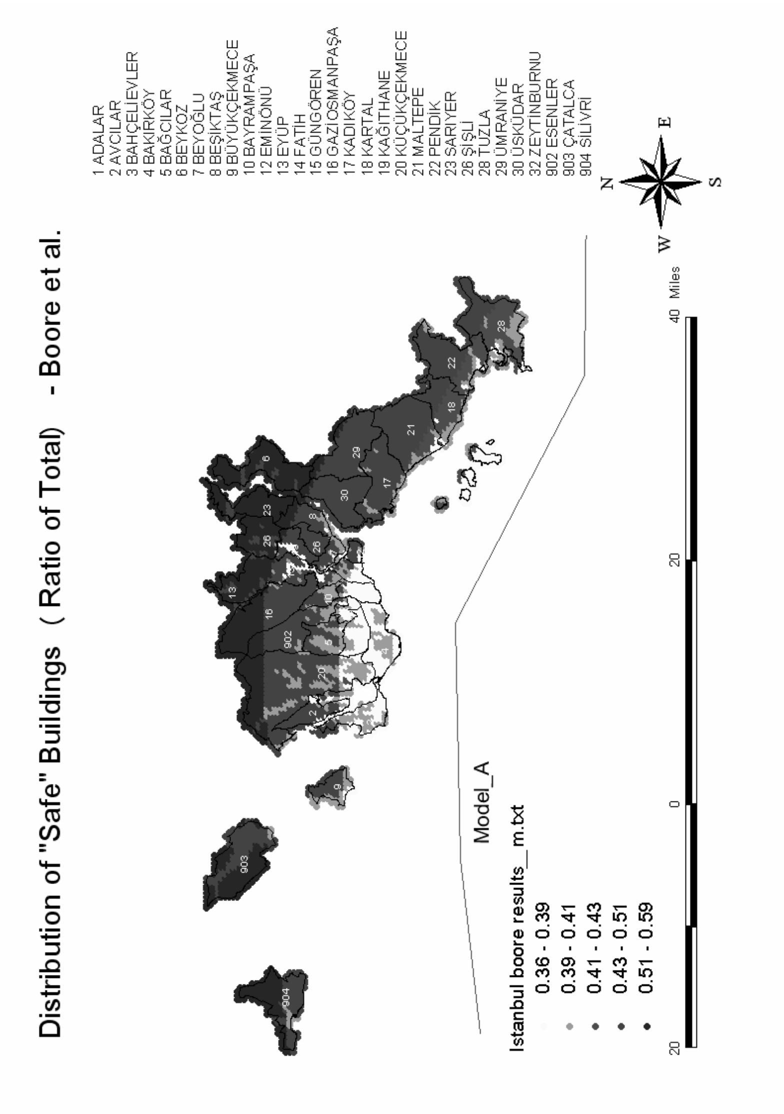


Figure 8. Results using Boore et al. attenuation relationship safe buildings

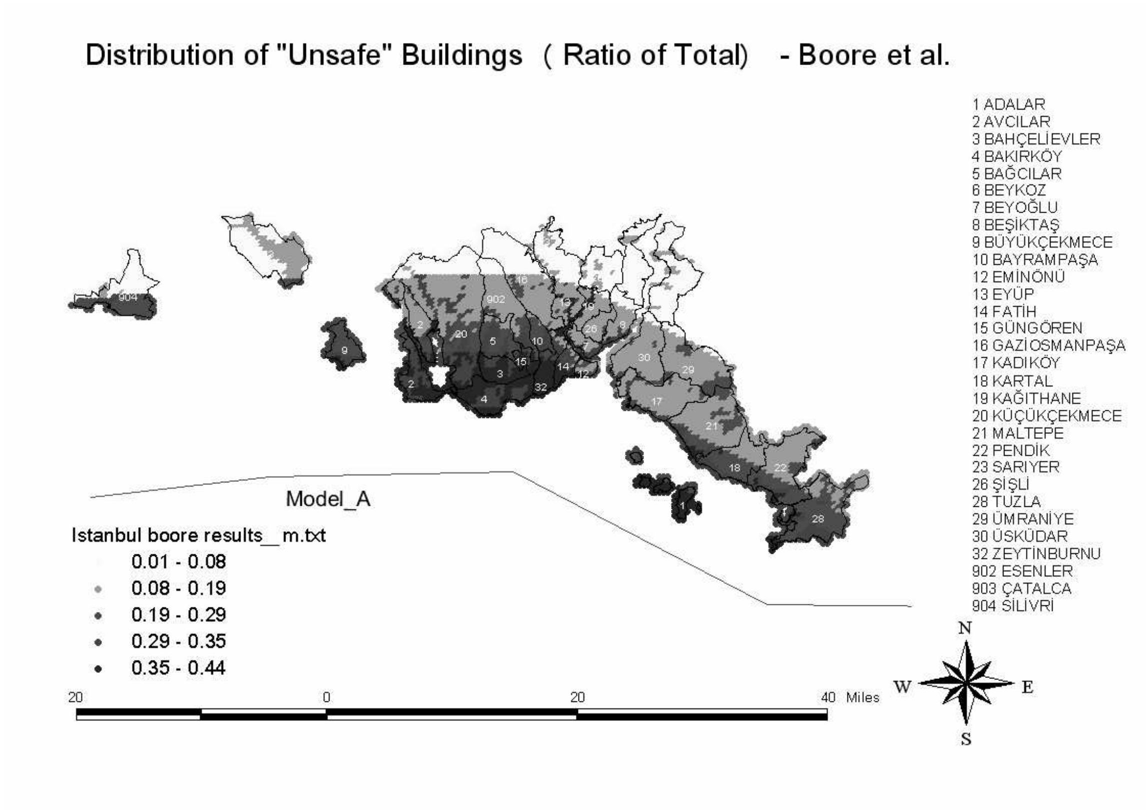


Figure 9. Results using Boore et al. attenuation relationship unsafe buildings

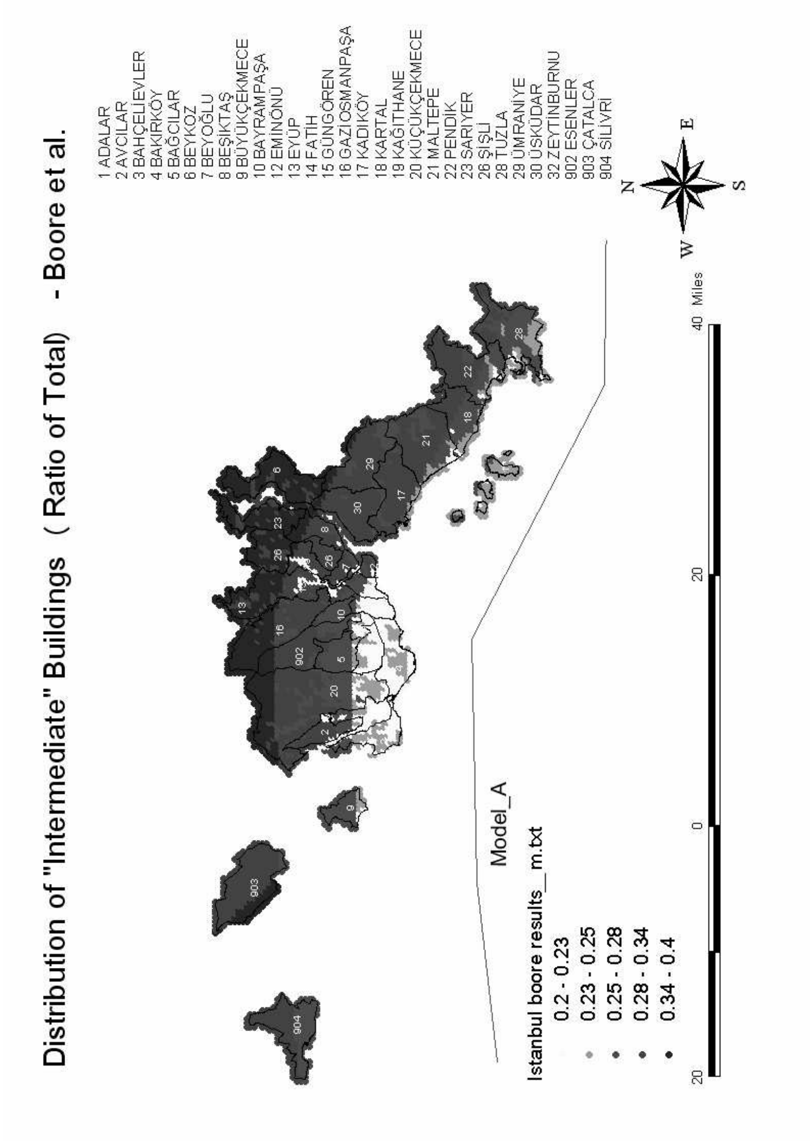


Figure 10. Results using Boore et al. attenuation relationship intermediate buildings

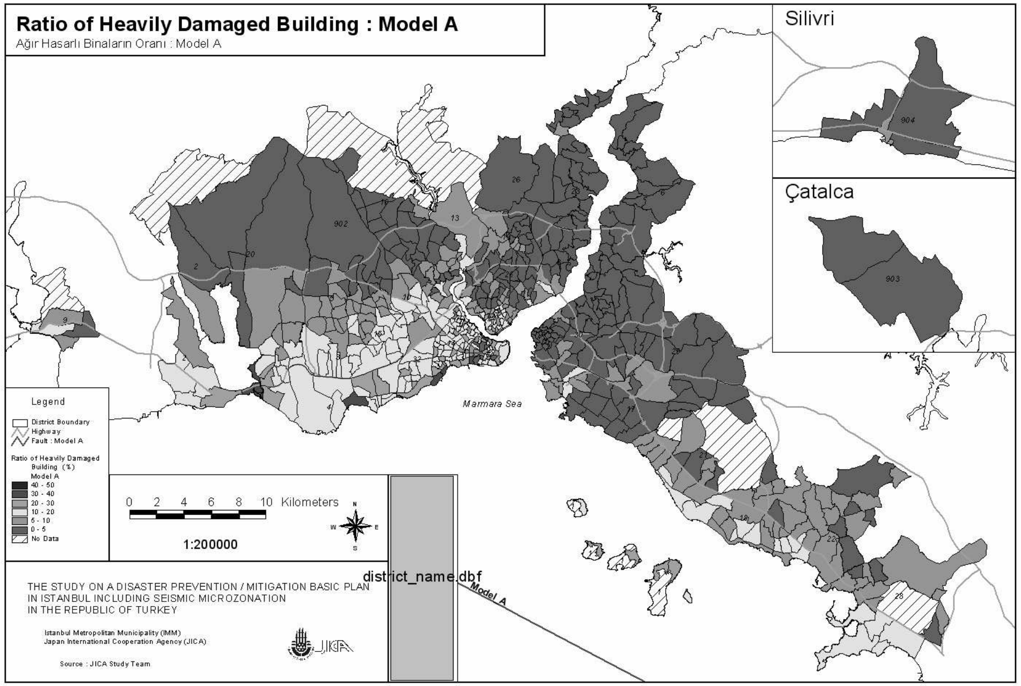


Figure 11. JICA estimates of heavily damaged buildings (from JICA, 2002)