SEISMIC ENERGY DEMAND MAPPING OF REGIONS USING ENERGY-BASED METHODOLOGY

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ABSTRACT :

Different seismic hazard maps, showing probable peak ground accelerations and velocities or intensities in terms of magnitudes and damage indices, which were developed for specific regions in the world, are based on past earthquake records. They are useful source of information in predicting the affects of future earthquakes. With these maps, seismic spectra or artificial earthquakes could be produced to estimate the seismic forces acting on the structures. The earthquakes produce energy and depending on the level of intensity of the earthquake and the natural period of the structure including the effect of soil-structure interaction, the produced energy (named as input energy) is imparted into to the structure. If the total input energy is known, the structure could be designed in such as way that its members dissipate enough energy and sudden collapse could be prevented. This paper introduces a concept and a procedure to determine the input energy through constructing regional seismic energy demand contours. The analysis is based on obtaining an attenuated earthquake record, using a bi-linear hysteresis SDOF system and the equation of motion integrated in the displacement domain, and producing charts showing the relationship between input energy, mass, period and scaled ground motion intensity. These charts are then incorporated into seismic energy demand contours or mapping of a selected region.

KEYWORDS: Input Energy, Elastic SDOF, Hazard Mapping

1. INTRODUCTION

The current design codes and engineering practice are based on either strength or displacement capacity of the structures. Besides these methods, energy-based approach has gained increasing recognition over the years. It couples both the strength and deformation provisions. Therefore, energy-based methodology is another alternative tool for the analysis and understanding the overall performance of structures.

The aim of this study is to determine the input energy seismic hazard mapping of a specific region. The hazard maps that were studied in the literature were based on peak ground acceleration and velocity values of the soil and also spectral response of SDOF systems (i.e. S_a, S_v). Based on soil and seismicity characteristics of any region involved, it is possible to create a hazard map that shows the ground motion-induced energy that is imparted into the structure. This paper discusses a step-by-step procedure for the development of such energy-based hazard maps.

The proposed methodology is limited with certain seismic and soil properties of the region and the characteristics of the structure. As an example, the input energy hazard maps were determined for the northern of the Marmara region in Turkey using only elastic SDOF system.

2. SITE SPECIFIC INFORMATION

The study area is within the boundaries of the city Istanbul, which is in Marmara region where two destructive earthquakes were experienced a decade ago.

Figure 2.1 Zone map

The classification of the soils in the study zone was taken from Turkish National Earthquake Code (TNEC 2007). Accordingly, the classification and description of the soil characteristics are described as shown in Table 2.1.

Table 2.1 Soil classification in TNEC 2007

Soil Group	Seismic Classification	Description	Standard Penetration (N/30)		Shear Wave Velocity (m/s)
A	Z1	1. Massive igneous rocks	-	>1000	400-700
		2. Very dense sands	>50	-	200-400
		3. Hard Clays	<32	>400	200-300
B	Z2	1. Tuff, agglomerate	-	500-1000	700-1000
		2. Dense sands	30-50	-	400-700
		3. Very stiff clays	16-32	200-400	300-700
C	Z3	1.Highly weathered rocks	-	<500	400-700
		2. Mid-dense sands	10-30	-	200-400
		3. Stiff clays	8-16	100-200	200-300
D	Z4	1. Alluvium deposits	-	-	< 200
		2. Loose sands	<10	-	< 200
		3. Soft clays	<8	<400	< 200

The soil classification of the region of interest was determined by a project called “HAZTURK” where its results are shown in Figure 2.2.

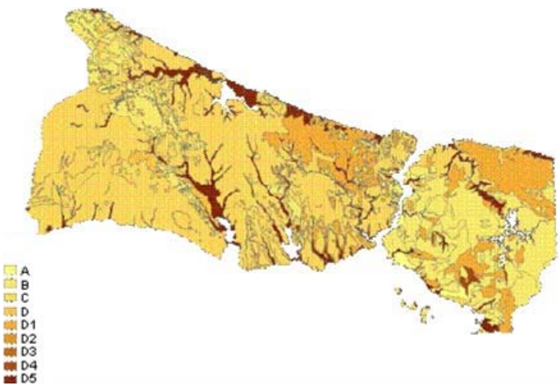

Figure 2.2 Seismic soil classification map (HAZTURK)

The seismicity of the region is demonstrated in Figure 2.3 where it shows seismic zones from 1 (high seismicity) to 4 (low seismicity).

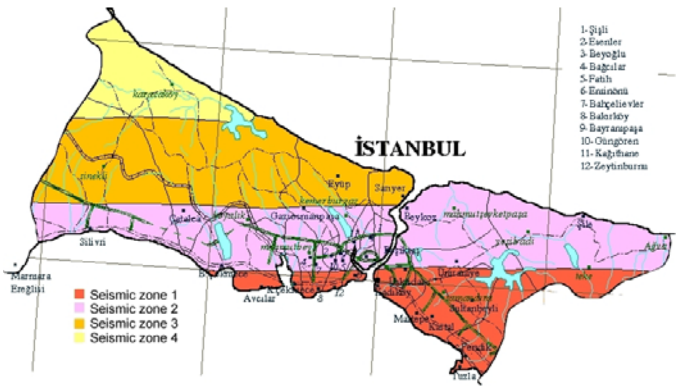

Figure 2.3 Seismic intensity map of Marmara region

The soil classification and the seismic zone information are the main tools for the determination of response spectra which is given in TNEC 2007 for elastic, %5 damped SDOF systems. In this study, various response spectra representing different soil and earthquake intensity conditions are the basis for the synthetic ground motion records that were produced for time-history analyses to determine the input energy values.

3. ANALYSIS BACKGROUND

The region was divided into 2.5 km x 2.5 km grids in order to define the station points at which the input energy values could be estimated. The grid layout of the region is given in Figure 3.1.

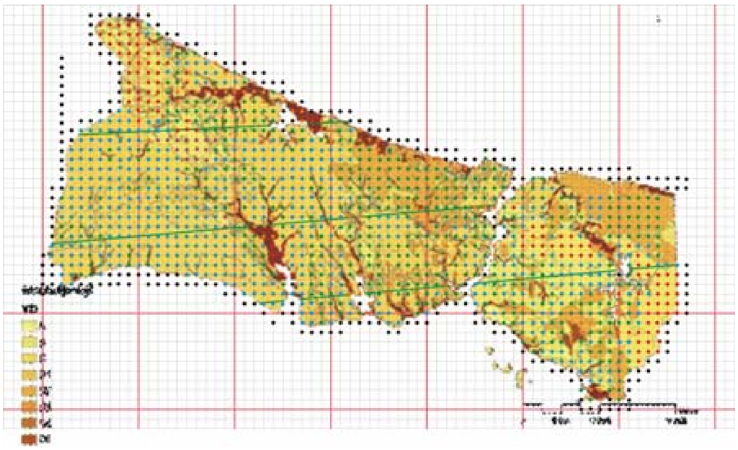

Figure 3.1 Grid layout of the study area

The spectral acceleration coefficient is related to the peak ground acceleration and the importance factor. Since this study is limited to 1 to 10-story residential buildings, the building importance factor was taken as 1.0. The spectral acceleration coefficient is estimated by using response spectrum relationship which is given in Figure 3.2.

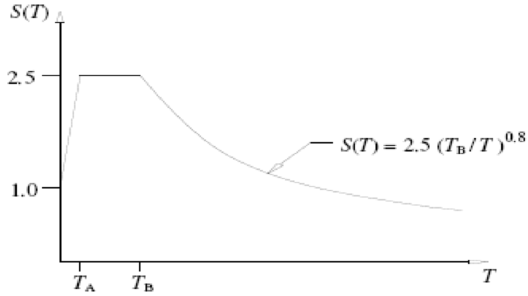

Figure 3.2 Turkish response spectrum for %5 damping

The T_A and the T_B values, in seconds, could be determined with respect to different soil conditions, as given in Table 3.1.

Table 3.1 Spectrum Characteristic Periods (T_A and T_B)

Soil Classification	T_A (s)	T_B (s)
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

The effective ground acceleration as per TNEC 2007 is given in Table 3.3.

Table 3.3 Effective ground acceleration (A_o)

Earthquake zone	A_o
1	0.40
2	0.30
3	0.20
4	0.10

If the elastic spectrum was derived from the time-history analysis of several earthquake records, it is possible to produce the synthetic time-history ground motions that closely result the given spectra. The authors of this paper have used an algorithm that was developed in Bogazici University (Sagiroglu, 2004).

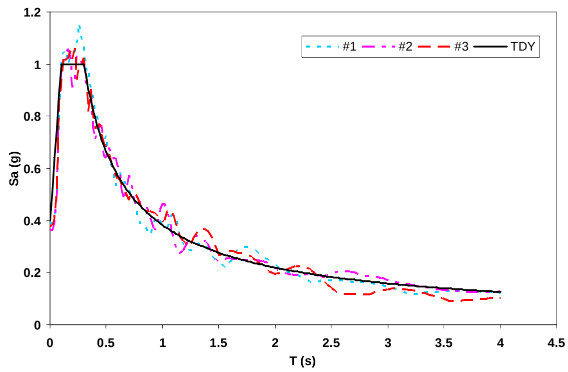

Figure 3.3 The elastic response spectra of the produced ground motions

For each soil type and for every earthquake region, 3 synthetic ground motions were produced. 4 different soil classes and 4 earthquake regions and 3 different earthquake motions resulted in 48 ground motions. Each set was highly consistent with the reference spectra. Thus, the next step was to choose the most appropriate ground motion time-history that fits 16 possible spectra describing 4 different soil conditions and 4 different earthquake zones. As an example, Figure 3.3 shows a synthetic ground motion record for Z1 and A==0.4g.

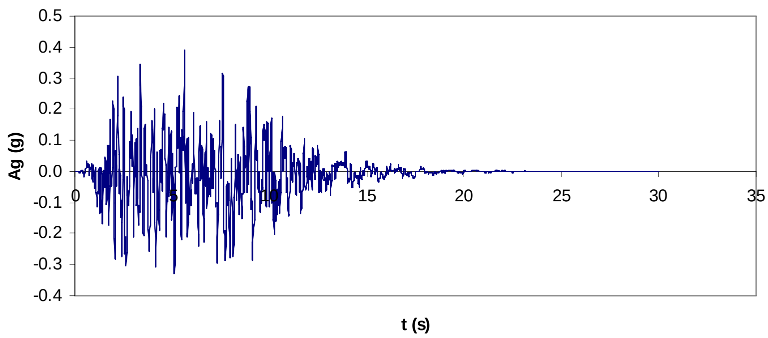

Figure 3.3. Synthetic ground motion (Z_1, A_0=0.4)

The properties of the SDOF system used in the analysis were taken as shown in Figure 3.4.

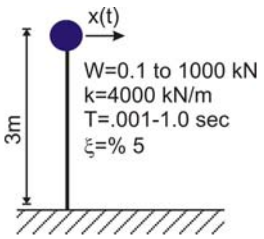

Figure 3.4 SDOF system properties

4. INPUT ENERGY ANALYSIS

In the analysis, the equation of motion of a SDOF system is integrated with respect to the relative displacements that resulted in equation where its terms involve energy components.

$$\text{Kinetic Energy} + \text{Damping Energy} + \text{Strain Energy} = \text{Input Energy} \tag{4.1}$$

the energy components are formulated as the following:

$$\int (m \times \ddot{u}(t))du + \int (c \times u(t))du + \int (f_S(u,\dot{u}))du = \int (m \times \ddot{u}_g(t))du \tag{4.2}$$

The time-history analyses and all the numerical calculations were performed as described in the flowchart provided in Figure 4.1. A computer program was developed in MATLAB that uses IDARC2D as the main solver for the time-history analysis.

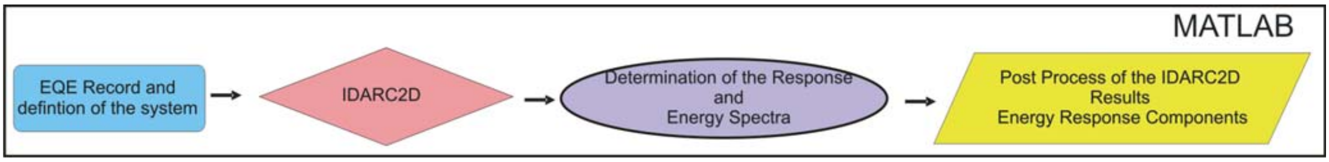

Figure 4.1 The analysis steps of the study

Resulting energy time-history components for a SDOF system having properties as illustrated in Figure 3.4 with a period of 1.0 second is shown, as an example, in Figure 4.2. Similar analyses were conducted for other parameters.

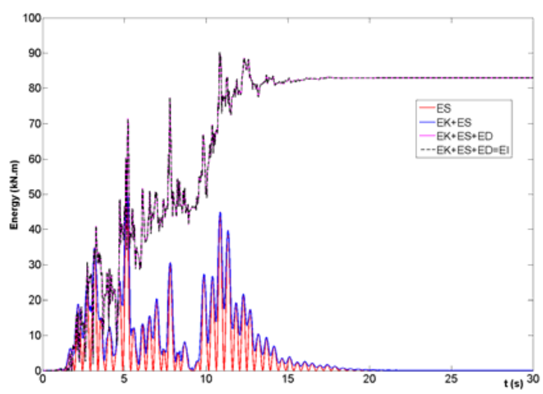

Figure 4.2 Energy time-history of the energy componets

If the differentiation of the stiffness is evaluated in the input energy values, it was found that for the elastic SDOF system, stiffness does not have a significant effect on mass normalized input energy values as seen Figure 4.3.

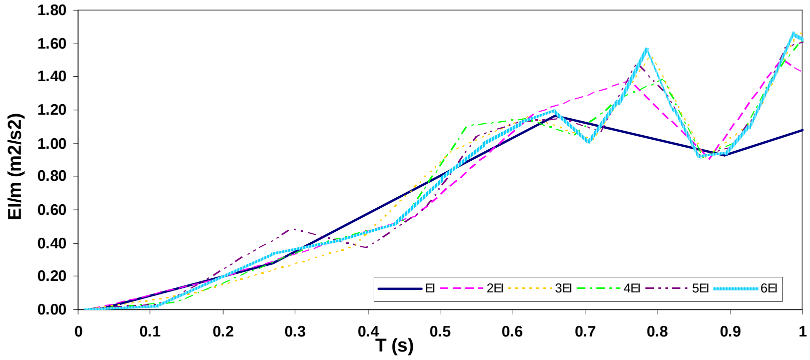

Figure 4.3 Elastic input energy spectra. for %5 damped SDOF having different stiffness

5. ENERGY-BASED HAZARD MAPS

The following Figure 5.1 was produced as a result of the analysis procedure described in Section 4. It shows the mass-normalized input energy counters of the Marmara region for period of T=0.2 second. Figure 5.2 is the known PGA hazard map of the same region where its color codes are very similar to the input energy contours.

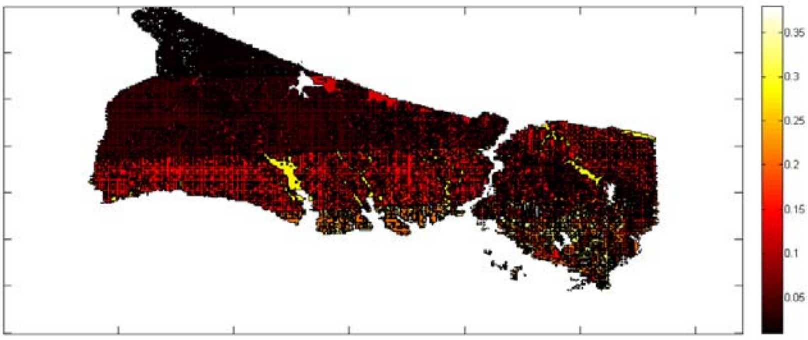

Figure 5.1 The mass normalized input energy hazard map (T=0.2 s)

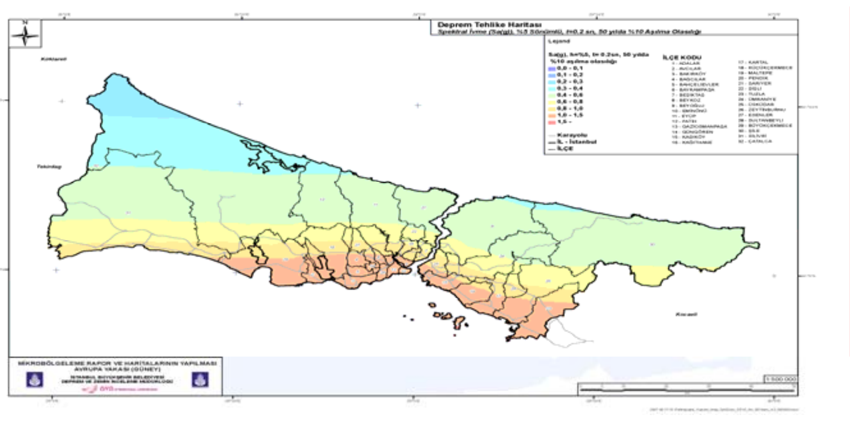

Figure 5.2 Spectral acceleration hazard map of interested zone (HAZTURK)

6. CONCLUSIONS

Mass-normalized (Input Energy/mass) values for all possible soil and earthquake intensity zones were determined.

The input energy imparted into the structure could be determined by multiplying the values given in the input energy hazard map by the structure's own weight. This energy value could then be used in the structural analysis as a demand parameter which would ultimately lead to the design of a particular structure with specified period, mass, soil characteristic and intensity zone.

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