A BENEFIT/COST ANALYSIS FOR THE SEISMIC REHABILITATION OF EXISTING REINFORCED CONCRETE BUILDINGS IN IZMIR

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ABSTRACT

The Aegean is one of the most seismically active regions of Turkey. The Earthquake disasters which occurred in Turkey recently, obligate the seismic rehabilitation of existing buildings and the new construction projects produced to require well-detailed seismic strengthening.

On the other hand, before starting an expensive project such as seismic rehabilitation, a benefit/cost analysis is needed to determine whether the proposed project is economically feasible.

In this study, a benefit/cost analysis model for the seismic rehabilitation of existing reinforced concrete buildings in Izmir is presented. To express the seismicity of Izmir City, between 1900-2003, the magnitude of Ms≥4.9 earthquakes which occurred in Izmir and its vicinity are used as data. The Poisson Model is used to calculate the probability of occurrence. For the seismic risk of Izmir which includes damage to buildings and loss, various damage estimation methods are described.

As a generalization of all of the existing reinforced concrete buildings in Izmir Region, two existing reinforced concrete buildings with total building area of 735 square meters and 716 square meters, respectively, which have different social functions, are chosen to estimate whether the seismic rehabilitations of the investigated buildings are economically justified.

As a result of the analysis, benefit/cost ratios of both structures are found greater than one which means both rehabilitation projects are economically feasible.

ÖZET

Türkiye deprem bölgeleri haritasında, Ege Bölgesinin nerede ise tamamının I. Derecede deprem bölgesi olduğu görülmektedir. Geçmişte yaşanılan ve her geçen gün bir yenisi eklenen deprem felaketleri, yeni inşaat projelerinin depreme dayanıklı olarak üretilmesinin yanısıra mevcut betonarme binaların da depreme dayanıklı olarak güçlendirilmesini ya da yıkılıp yeniden projelendirilmesini şart koşmuştur.

Diğer bir yandan, mühendisliğin aynı zamanda bir ekonomi işi olduğunu hesaba katarak sismik güçlendirme gibi maliyeti yüksek bir işe başlanmadan önce incelenen yapının güçlendirilmesinin ekonomik açıdan uygun olup olmadığının tespit edilmesi için bir fayda/maliyet analizinin yapılması bir gereksinim halini almıştır.

Bu çalışmada, İzmir ve çevresindeki mevcut binaların depreme dayanıklı olarak güçlendirilmesinin ekonomik açıdan uygun olup olmadığının tespit edilmesi amacıyla, 1900-2003 yılları arasında İzmir ve çevresinde meydana gelmiş; magnitüdleri Ms≥4.9 olan depremler incelenmiş ve Poisson Modeli kullanılarak bölgenin sismik risk değerleri hesaplanmıştır. İncelenen bölgedeki depremlerin gelecekte olma olasılıkları ve dönüş periyodları tespit edilmiştir. Ayrıca gerekli varsayımlar yapılarak bölgedeki hasar olasılıkları ve kayıp değerleri ortaya konmuştur. Bu değerler doğrultusunda, Federal Emergency Management Agency (FEMA) tarafından 1991 yılında Amerika'nın çeşitli eyaletlerinde uygulanan Fayda/Maliyet Analizi Modeli, İzmir bölgesindeki mevcut binalara uygulanabilecek şekilde uyarlanmış ve toplam inşaat alanları 735 m^2 ve 716 m^2 olan iki farklı betonarme binanın güçlendirme projeleri üzerinde tatbik edilmiştir.

Yapılan analizler sonucunda bu iki betorname binanın Fayda/Maliyet oranlarının 1'den büyük olduğu ve dolayısıyla uygulanacak güçlendirme projelerinin ekonomik açıdan uygun olduğu tespit edilmiştir.

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CHAPTER 1

INTRODUCTION

Disasters such as earthquakes have always been a source of pain and of great losses throughout history. Although much improvement in earthquake resistant design has been achieved, people still suffer from the consequences of such a disaster even in the developed countries. The 1994 Northridge and 1995 Kobe earthquakes clearly proved that mother nature is still superior to mankind. Turkey is located in an earthquake prone region and the people of Turkey live with the fact that at any time occurrence of a serious earthquake is highly probable. Although it has been known that the buildings in Turkey are vulnerable by earthquakes due to many reasons, and not much has been done to the buildings to assure a better performance during an earthquake. The tremors which hit in 1999 in Izmit and Düzce, did not forgive accumulated mistakes and malpractice; the official death toll was about 30,000 and 120,000 houses were totally collapsed or badly damaged and a $20 billion estimated loss due to physical damage, social and economic disruptions. Since the epicenters of these two major earthquakes were located in industrialized regions, collateral effects were much more than expected. It is a fact that the building stock in Turkey, especially located in seismically active regions is substandard. These buildings should be assessed rapidly and either rehabilitated/strengthened or demolished and rebuilt. Since 1999, unfortunately not much has been achieved.

Seismic rehabilitation is the way to improve the existing buildings' performance under the seismic forces. Poor workmanship, substandard materials, poor design details, lack of proper lateral load resisting systems and improper soil conditions are among the common problems observed in Turkey. Assessing the current condition and diagnosing the problems and producing proper rehabilitation details are important and very hard tasks.

Rehabilitation of a building is not the only alternative to assure safety during an earthquake; replacement, demolishing the building and constructing it again is another alternative.

It is obvious that the current condition of some buildings makes it extremely difficult to rehabilitate because of the cost issues. A decision tool has to be present to reach a reasonable solution. It is the most common approach in Turkey, to use a simple calculation to determine whether the proposed seismic rehabilitation project is economically justified. According to this approach, the rehabilitation and the replacement costs are computed respectively and rehabilitation cost is divided by replacement cost. If the ratio is greater than 40%, the proposed rehabilitation project is rejected, where this decision is based on initial costs. It is the modern way to use a system approach and it is more appropriate to reach a risk based decision.

The benefit/cost analysis is a powerful method used to determine the best choice among different alternatives over the long-term. Whenever decision makers determine whether the advantages of a particular project are probable to outweigh its disbenefits or not, they use a form of benefit/cost analysis (BCA). In the public arena, formal BCA is a relative technique for thoroughly and compatibly evaluating the benefits and disbenefits combined with prospective policy changes. Although it is an attempt to identify and express in monetary terms all of the effects of proposed projects, BCA can be a valuable tool for decision makers (Portney 1994).

BCA was first proposed by a French engineer, Jules Dupuit (1804–1866). He used the method to measure the utility of public works. Subsequently, BCA has become synonymous with public works projects in the United States. Since then, it has also been applied to analyze projects affecting transportation, public health, criminal justice, defense, education, and the environment etc.

In Chapter 2 of this thesis, the benefit/cost analysis is described in detail. The goal of this study is to justify the economic sufficiency of a seismic rehabilitation project by using a benefit/cost model. For this, the sample existing reinforced concrete buildings in Izmir is investigated. The benefit/cost model that was applied by Federal Emergency Management Agency (FEMA) in the U.S. is used to analyze the benefit/cost ratios of the sample existing reinforced concrete buildings in Izmir.

The benefit/cost analysis for the seismic rehabilitation has four main steps which are estimating seismic risk of investigated region, damage estimation, loss estimation and benefit/cost analysis.

In Chapter 3, the seismology of Izmir is investigated and the observed seismic activity of Izmir region is described. The active faults encompassing Izmir are presented.

Seismic hazard is defined as a determination of the consequences of ground shaking arising from an earthquake which causes serious damages and loss of life in a determined place and time period. Due to the indefinitiness of the location, time and magnitude of an earthquake, probabilistic approaches are important decision tools for assignment of seismic risk (RADIUS 1997).

Probabilistic methods are used to determine seismic hazard. Traditionally, seismic hazard is measured as seismic intensity. Seismic intensity is a subjective appraisement which defines the effect of the earthquake that forms physical damages observed.

In this study, between 1900-2003, the magnitude of $Ms \geq 4.9$ earthquakes are investigated for the probabilistic seismic hazard of Izmir and its surrounding region with the 37° – 40.45° N latitude and 25.5° – 29° E longitude. Earthquake data is modelled using the Poisson Model and seismic risk values are estimated. In the studied area, return periods and probability of earthquake occurrences are determined and presented in tables.

In Chapter 4, different damage estimation methodologies are presented. Seismic risk values including expected mean damage ratios and average range of percent losses of building contents are classified by Applied Technology Council (ATC) and Federal Emergency Management Agency (FEMA) for various social function classes and building types. The values for the reinforced concrete buildings in Izmir have been adapted from these data and shown in the tables in Appendix C.

Seismic risk definition requires a set of earthquakes, the associated consequences, and probabilities of occurrence over a defined time period. This concept is consistent with definition of risk in the general risk analysis literature. Damage can be measured in monetary terms, casualties, or loss of function. In this chapter, different damage estimation methods such as Emprical Methods, Analytical Method, Capacity Spectrum Method, and Displacement Coefficient Method are also described.

It is known that structures in seismic regions are under risk and seismically vulnerable. Thus building owners and decision makers must determine whether they will rehabilitate their structures. This may seem to be a simple decision, but in business it could possibly not be justified to retrofit, especially if the retrofitting costs are very large or the probability of a damaging earthquake is considerably low (Foltz 2004). At this point, a benefit-cost analysis is required to determine whether to rehabilitate a structure is economically justified. Smyth et al. (2002) defines that BCA is a systematic procedure for appraising decisions that have an impact on society.

In Chapter 5, a benefit-cost model for the seismic rehabilitation of buildings presented by Federal Emergency Management Agency (FEMA) in 1991 is described. The expected result in benefit/cost analysis is that benefit/cost ratio is greater than one which means the prospective rehabilitation project of the building is economically justified. Benefit/cost ratio is calculated plainly by dividing the expected present value of future benefits by the rehabilitation costs.

The loss of life and injuries due to an earthquake is the most important issue, however, since there is no consensus among researchers, while estimating the expected net present value, the value of life is neglected in this study. The monetary value of human life is very difficult to estimate and it can affect the result of benefit-cost analysis on a large scale.

In Chapter 6, the benefit/cost analysis described in Chapter 5 is applied to two different reinforced concrete buildings in Izmir. One of them is a retail store in Konak, the other is a bank in Tire. All examples use a 4% discount rate and 50 years time period. Discount rate is an important paramater that affects the result of benefit/cost analysis. It is not possible to determine a fixed discount ratio for Turkey during a long-term period such as 50 years.

As the last step of the analysis, the benefit/cost ratios are calculated and it is established whether the results are greater than unity. If the result of the benefit/cost ratio is greater than unity, this proves that the investigated seismic rehabilitation project is economically justified. The ratios are calculated with 4% discount rate and a time period of 50 years. However, in order to obtain a sensitive conclusion, the benefit/cost ratios are recalculated using different discount rates and time periods, and the results are given in Table 6.3 and Table 6.6.

CHAPTER 2

BENEFIT/COST ANALYSIS

Benefit/Cost Analysis (BCA) is a method used deciding the economic appropriateness of an investigated project. BCA is simply estimated by subtracting the initial cost of the investment from the discounted present value of the investigated project. If the result is positive, the investment project is economically feasible.

In this chapter, BCA is described with an example of reservoir construction and the steps of its methodology are stated.

2.1. Definition of Benefit/Cost Analysis

BCA is an arithmetic way used for deciding whether an action is financially feasible or not. The benefit of an investment project is the discounted present value of its net cash flows in the future (Peterson 1975). BCA is calculated by dividing the benefit of the system by the initial cost of the investment project which yields to B/C ratio (Douglas 1987). Symbolically, it may be shown as:

$$B/C = \frac{\sum_{t=1}^{n} \frac{R_t}{(1+i)^t}}{C_0} \tag{2.1}$$

where R_t is the contribution to overheads and profits in each future period; C_0 represents the initial cost of the project; i is the discount rate; and t=1,2,3,…,n is the number of period in years which the revenue stream is expected.

The art of BCA is constantly evolving and there is no single methodology for benefit-cost analysis, although there are some characteristics that most studies share. These include a common unit of measurement and the calculation of net present value of the future cost which is defined above. Net present value (NPV) is basically the discounted present value of a future benefit. BCA seeks to identify both tangible and intangible benefits, and compare these to the costs.

Bruce P. Schauer states that benefit-cost analysis is distinguished from other forms of cost analyses because it attempts to “estimate the cost and benefits which accrue to the society, as well as these that accrue to the individual” (Schauer 1986).

The most complicated phase of BCA is the determination of benefits and costs which are expressed in monetary terms. Benefits and costs are certainly flip sides of the same coin. The benefits represent the positive side, contrarily, costs represent the negative side. This pair, which is the foundation stone of BCA, is measured differently; benefits are measured by the willingness of individuals to pay for outputs of the investment project, and the peculiar calculation of costs is the amount of compensation required to exactly offset negative consequences.

For example, on the positive side of the evaluation of the benefits and costs of a proposal to control air pollution emissions from a large factory; the benefits are pollution abatement will mean reduced damage to exposed materials, decreased health risk to people living nearby, improved visibility, and even new jobs for these who manufacture pollution control equipment. On the negative side as the costs, the required investments in pollution control may cause the firm to raise the price of its products, close down several marginal operations at its plant and lay off workers, and put off other planned investments designed to modernize its production facilities.

There are three additional issues in BCA; first, projects typically produce streams of benefits and costs overtime rather than in one-shot increments. Commonly, a substantial portion of the costs are incurred early in the life of a project, while benefits may extend for many years. BCA typically discounts future benefits and costs back to present values. At a discount rate of 10%, for instance, $1 million in benefits to people for 50 years from now has a present value of only $8,500. This powerful effect of discounting is of concern when BCA is applied to the evaluation of projects with significant generational effects.

A second point in BCA is the fact that the willingness to pay for the favorable effects of a project depends on the distribution of income. BCA analysts use money to estimate benefits, because there is no another direct way to measure the intensity that people desire. As a result of this approach, some critics dislike BCA.

Third, suppose that benefits and costs could be easily expressed in monetary terms and converted to present values. According to BCA, a project would be attractive if the benefits would exceed the costs.

In spite of these sticky points, BCA seems to be playing a more important role in decision making.

People have been using BCA in their daily lives throughout the written history. They clearly think of the profits and nonprofits, for instance, while they are planning to buy a property or open a new shop. In business, of course, decision making must be done by systematic and rational techniques and an investment project must posses a realistic result. At this point, BCA provides that result and helps to be aware of the risk undertaken before deciding.

2.2. The Steps of Benefit/Cost Analysis

There is no stationary handbook for benefit-cost analysis. A project might have different procedure and innovative requests than another, thus each project might be analyzed by using different benefit/cost method. It is useful, however, to have fixed sequence consistency from one analysis to another. The Treasury Board of Canada Secretariat formed a guide about BCA which includes a set of standard steps for BCA WEB_1 (1994). These steps are listed below:

- "Examine needs, consider constraints, and formulate objectives and targets. State the point of view from which costs and benefits will be assessed.
- Define options in a way that enables the analyst to compare them fairly. If one option is being assessed against a base case, ensure that the base case is optimized.
- Analyze incremental effects and gather data about costs and benefits. Set out the costs and benefits over time in a spreadsheet.
- Express the cost of measurement (for example, convert nominal dollars to constant dollars, and use accurate, undistorted prices).
- Run the deterministic model (using single-value costs and benefits as though the values were certain). See what the deterministic estimate of net present value (NPV) is.
- Conduct a sensitivity analysis to determine which variables appear to have the most influence on the NPV. Consider whether better information about the values of these variables could be obtained to limit the uncertainty, or whether action can limit the uncertainty (negotiating a labor rate, for example). Would the cost of this improvement be low enough to make its acquisition worthwhile? If so, act.
- Analyze risk by using what is known about the ranges and probabilities of the costs and benefits values and by simulating expected outcomes of the investment. What is the expected net present value (ENPV). Apply the standard decision rules.
- Identify the option, which gives the desirable distribution of income (by income class, gender or region whatever categorization is appropriate).
- Considering all of the quantitative analysis, as well as the qualitative analysis of factors that cannot be expressed in dollars, make a reasoned recommendation."

2.3. An Example of Benefit/Cost Analysis

One of the most popular applications of cost-benefit models is water control, involving the construction of a reservoir and the machinery for flood control, irrigation or electricity generation. The methods of estimating costs and benefits for such projects have some specialized literature, because the range of practical outlines for multiple-purpose project is much larger than it is for other common applications of benefit-cost analyses, such as tunnels, bridges and airports (Mishan 1988).

In Mishan (1988), an application of a possible cost-benefit approach to reservoir construction is described. A reservoir is defined as "to be built on each, or on either, of two tributaries to a river in order to reduce flood damage beyond the point of confluence" (Mishan 1988). It is assumed that flood damage valued at $75,000 occurred in four out of fifty years, it is possible to be judged whether climatic and other conditions are likely to change little enough to warrant the using a frequency of 4/50 or 8 percent for that amount of damage over the future. If it is decided that the events over the past fifty years can be accepted as a fair sample, then the expected benefit of any construction designed to prevent damage above a certain figure is the value of the damage it can prevent times the probability of its occurrence.

The distribution shown in Figure 2.1 interprets the minimum damage of $10,000 which can certainly be prevented by the construction of either a single reservoir or two reservoirs, has an 8 percent probability of occurring in any year. "An estimate of the benefit B_1 of such a construction can therefore be reckoned as equal to the minimum saving times the probability of its occurrence", thus B_1 is equal to $800 as $10,000 times 8%.

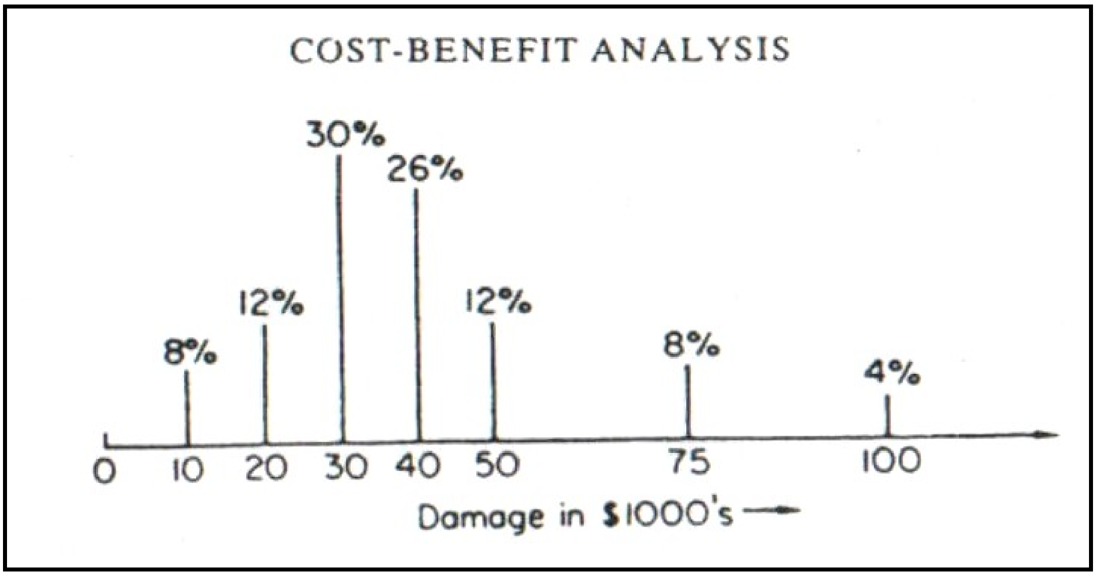


Figure 2.1. Probability distribution of reservoir construction example
(Source: Mishan 1988)

As it is seen in Figure 2.1 as well, there will be a larger construction which will prevent the occurrence of a larger damage, for instance, $20,000 with a frequency of 12 percent; this larger construction offers a benefit B_2 equals to $20,000 times 12 percent plus the B_1 benefit of $800. It means this larger construction will also prevent the smaller damage of $10,000 from ever happening.

It is continued until the seventh alternative construction, which is most costly and which will prevent all damage up to $100,000 from occurring.

After the present discounted value for each of the expected streams of benefits B_1, B_2 ... B_7 the cost of these reservoirs has to be estimated as C_1, C_2 ... C_7.

The last step is to find the distances between the benefits B_1, B_2 ... B_7 and the costs C_1, C_2 ... C_7.

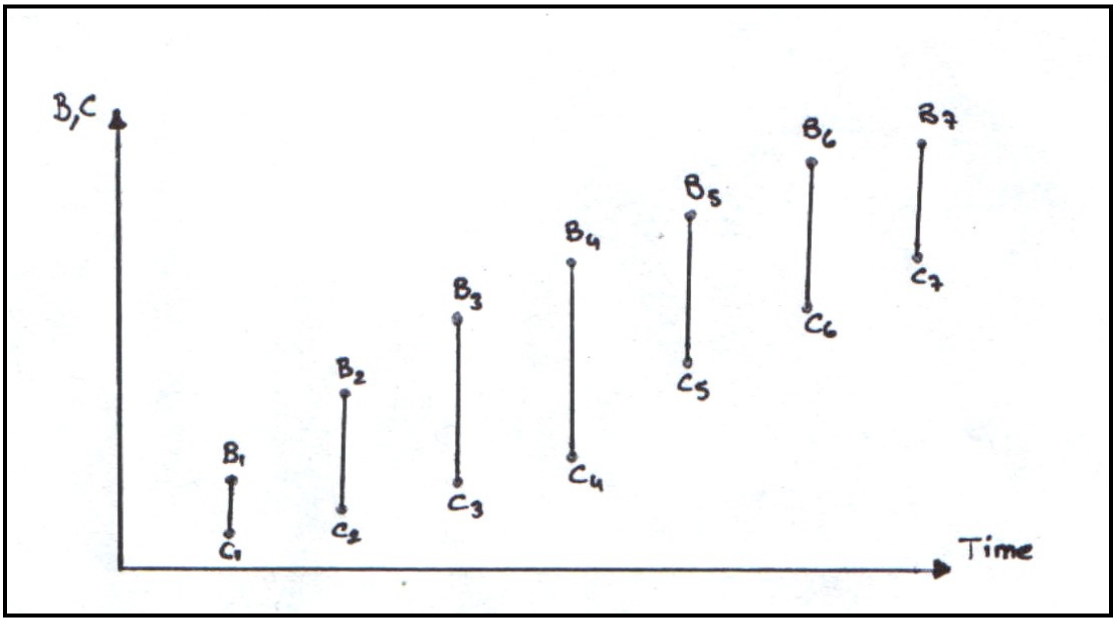


Figure 2.2. Alternative projects in increasing order of expected benefit
(Source: Mishan 1988)

The largest distance or excess benefit over cost gives the best alternative of the reservoir construction.

As it is seen in the example described above, BCA is a powerful way to estimate the alternatives and to find out the best one which is economically feasible.

In this thesis, the benefit/cost analysis is used for the purpose of proving that the seismic rehabilitation project of a construction is economically feasible. By the method, the cost and the benefits of the project can be determined. A benefit/cost method presented by Federal Emergency Management Agency is used to state the future benefits at the seismic rehabilitation work of a reinforced concrete building. The method is applied to existing reinforced concrete buildings in Izmir. In future, a benefit/cost method similar to the one presented in this study can be applied to other existing reinforced concrete buildings in Izmir which need seismic rehabilitation and it can be determined which seismic rehabilitation project is economically feasible. In conclusion, the building owners/decision makers will have a tool to measure the economic viability of alternative seismic rehabilitation approaches. They may consider to use another seismic rehabilitation project or to replace the building unless the benefit/cost ratio of the proposed seismic rehabilitation project is equal or greater than one.

CHAPTER 3

SEISMICITY AND EARTHQUAKE SOURCES OF IZMIR

3.1. Active Faults of Izmir Region

3.1.1. Introduction

City of Izmir, the pearl of Aegean is located in a seismically very active region (Figure 3.1). The Aegean Graben System and the Aegean Trench are two of the main geographic factors which control Neogene Deformation and the tectonic evolution of Turkey. The Aegean Region shows a complex and rapidly changing tectonic pattern due to surrounding tectonic plates (Akıncı et al. 2000).

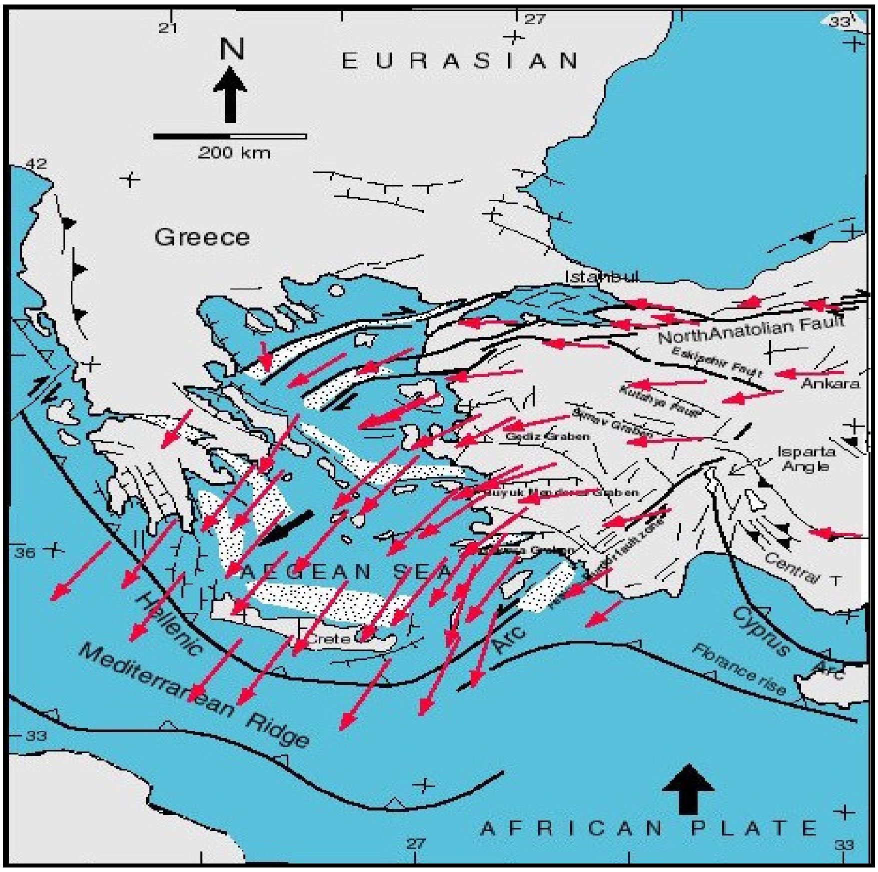


Figure 3.1. Main tectonic properties of the Aegean Sea and its vicinity
(Source: Barka et al. 1997)

The vicinity of Izmir is one of the most seismically active parts of Turkey (Figure 3.2). Most of the earthquake epicenters in this region are located between Karaburun-Sakız Island, Izmir Gulf-Midilli Island and Doğanbey Cape-Sisam Island. Other earthquakes occur in the vicinities of Akhisar-Soma-Manisa which are located between Gediz Graben and Aegean Sea.

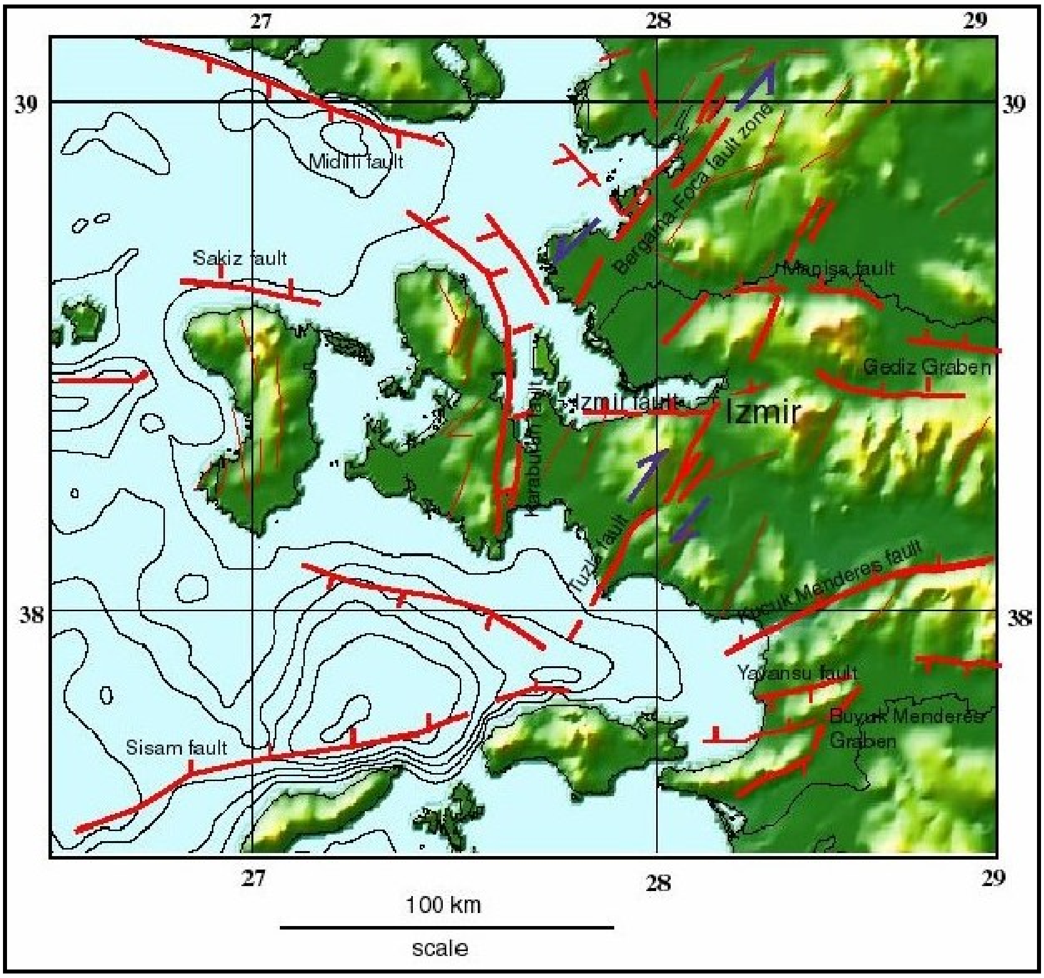


Figure 3.2. The Active Fault Map of Izmir and its vicinity
(Source: RADIUS 1997)

The faults of neotectonic period in Izmir area are classified as active and possibly active faults (Emre and Barka 2000). Izmir is the third largest city of Turkey which is surrounded with the active Karaburun Fault, Tuzla Fault and Gediz Graben (Akıncı et al. 2000). The other active faults in this region are Manisa and Kemalpaşa faults located in the west of Gediz Graben, and Izmir Fault on the southern side of the gulf.

If the historical and recent earthquakes and their distribution on these faults were investigated, it is seen that most of the hazardous earthquakes occurred along the active faults mentioned above.

3.1.2. The Faults on the Western Side of Gediz Graben

The faults on the western side of Gediz Graben are defined as normal active faults. NW – SE trending Gediz Graben between Turgutlu-Sarıgöl splits into two subgraben (Uluç 1999). The northen subgraben which is called Manisa Fault extends towards Manisa in the NW – SE direction (Figure 3.3). The southern subgraben which is called Kemalpaşa Fault turns to the west from Turgutlu and ends in Kemalpaşa region (Figure 3.3).

The Active Manisa Fault dipping 50-60° is about 25 km long. The fault scarps exposed along the zone show that severe earthquakes with surface ruptures occurred during the last few thousand years (Uluç 1999).

The Kemalpaşa Fault, which is about 20 km long, runs along E–W direction. Morphotectonic evidences indicate that this fault is also active fault (Emre and Barka 2000).

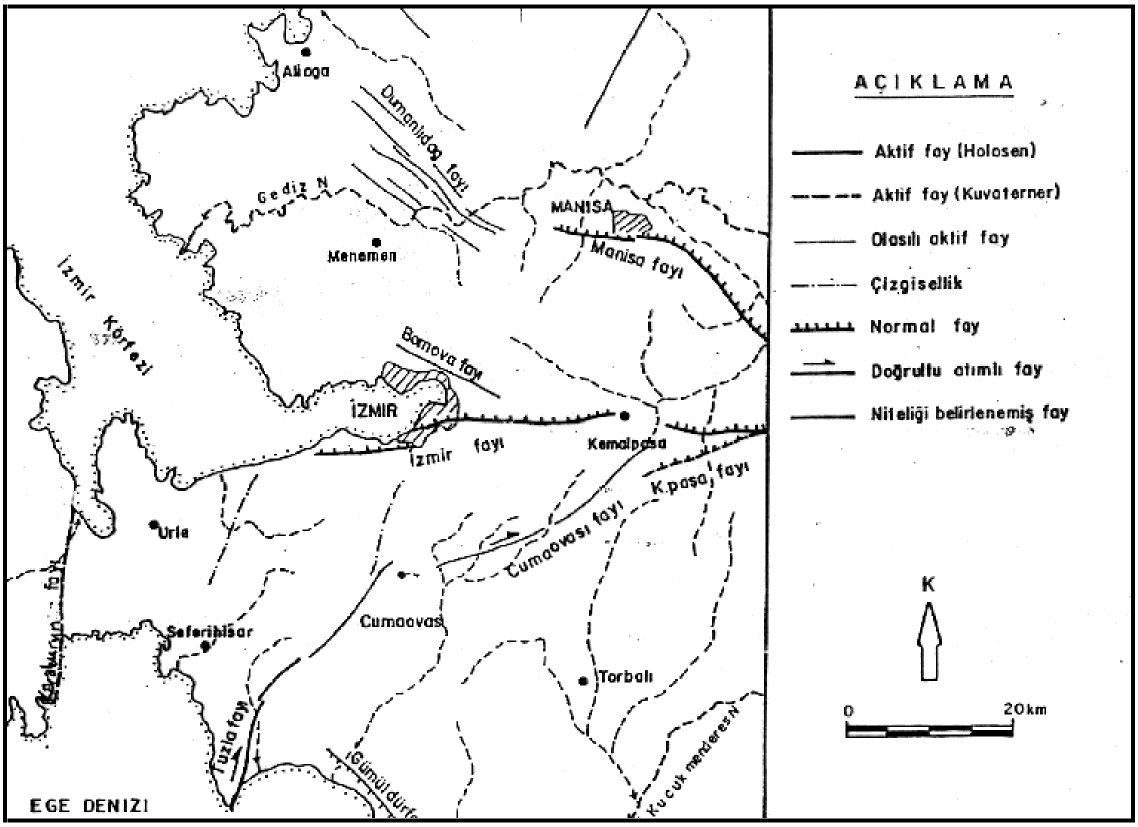


Figure 3.3. The Active Faults in Izmir Region
(Source: Emre 1997)

3.1.3. Dumanlıdağ Fault

The NW – SE tending faults on Dumanlıdağ volcanic complex in the north of Menemen are defined as Dumanlıdağ Fault Zone. There are no detailed data gathered for Quaternary activity of the faults although they are clearly viewed on the aerial photographs. However, the faults in this zone can be defined as possibly active owing to their Neogene morphology.

3.1.4. Bornova Fault

E – W and NW – SE tending Bornova fault is located in the northeast of Izmir Gulf. It cuts Miocene old volcanoes of the Yamanlar Mountain. It is a normal fault but there are not enough data about its activity. Nevertheless, Bornova Fault is an important fault in the Neotectonic period (Uluç 1999).

3.1.5. Izmir Fault

The E – W tending fault which morphologically forms the southern boundary of Izmir Gulf is defined as Izmir Fault (Figure 3.3). The fault consists of two segments and its length is about 35 km (RADIUS 1997). The segment tending between Izmir Gulf and Kemalpaşa in the western boundary of Gediz Graben is the continuation of the Kemalpaşa Fault (Emre and Barka 2000). The data about the characteristic activity of the fault are inadequate due to the dense urbanization. Nevertheless, Izmir Fault shows normal fault features as its general geo-morphological character.

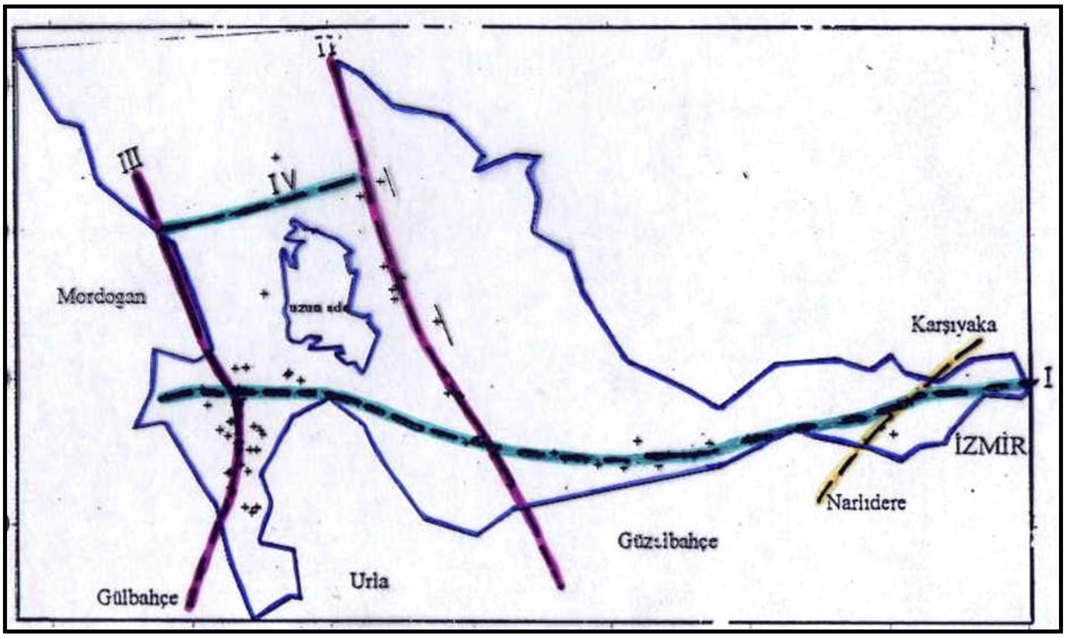


Figure 3.4. Neotectonic Fault Systems Map of Izmir Gulf
(Source: İlhan et al. 2004)

Izmir Fault makes a spring of 5 km from the west to the south in Kadıfekale and it intersects with the Tuzla Fault lying from the South. The western segment is located between Üçkuyular and Narlıdere-Güzelbahçe (Figure 3.4). The base block of the fault formed a small mound of 1,000 m. Due to the increase of dense urbanization in this area, the data about the fault is not known well.

It is presumed that the earthquake which caused a casualty of 19,000 on 10 July 1668 occurred on the Izmir Fault, and it is assumed as a sign that the fault is an active fault (Uluç 1999).

3.1.6. Cumaovası Fault

The Cumaovası Fault is located in the southeast of Izmir and it tends to run approximately NE between Gediz Graben and Tuzla Fault. On the eastern boundary, it unites with the southern subgraben of Gediz Graben. No relation has been found between Tuzla Fault and Cumaovası Fault in the Cumaovası alluvial sediment.

Although there is not data about the activity of the fault, it is observed that the macroseismic epicenter of the earthquake occurred in 31 March 1928 in Torbalı is located on this fault.

3.1.7. Karaburun Fault

It is an important structural zone which severs Izmir Gulf and Karaburun Peninsula (Figure 3.2). It morphologically borders Seferihisar Cape in the south. “Limited morphological evidences indicate that this fault might be a strike-slip fault” (Emre and Barka 2000). Dense earthquake activity is seen along the zone especially on the southern side. Thus it is classified as an active fault (Emre and Barka 2000).

3.1.8. Gümüldür Fault

The NW – SE tending fault is located in the northeast of Kuşadası Gulf. The fault cuts the rock blocks forming the Menderes massif in the south and Miocene sediments in Gümüldür region in the north (Uluç 1999). This fault does not show an active feature although it belongs to Neotectonic period (RADIUS 1997).

3.1.9. Tuzla Fault

Tuzla Fault between the Cumaovası and Doğanbey Cape in the southwest of Izmir tends NE – SW direction and it forms the southwestern boundaries end of lineament which is formed by three fault segments (Emre and Barka 2000). Tuzla Fault reaches Aegean Sea in the Doğanbey Cape. Morphologic data of the sea indicates that the fault continues under the sea (Uluç 1999).

Tuzla Fault has an important position for the active tectonic structure of West Anatolia. Furthermore, it is also important for the seismic risk of Izmir. As it is indicated in RADIUS (1997) that lots of earthquakes occurred on this fault, for instance, the last one occurred in 1992 with a magnitude of Ms=6.0 (Uluç 1999). This earthquake caused serious damage to 60 buildings in Doğanbey region. Therefore, it might be stated that the Tuzla Fault is one of the most important active structures of the region that has a high seismic potential.

3.2. Historical and Recent Earthquakes Occurred in Izmir and its Vicinity

This part briefs historical earthquakes (pre-1900) and recent earthquakes (1900-2003) with magnitude of 4.9 and greater. Epicentral distribution of historical earthquakes is shown in Figure 3.5. The gathered data about these earthquakes is presented in Appendix A.

Most of the data have been obtained from Izmir RADIUS Program (1997) which has been presented by Boğaziçi University Kandilli Observatory and Earthquake Research Institute.

When the data of historical earthquakes is investigated, it is seen that the hazardous earthquakes occurred mostly around Izmir Gulf, Ephesus and Manisa (Figure 3.5). The most destructive registered earthquake which had magnitude of Ms=7 occurred in the year 17 A.D. It was felt in Izmir, Ephesus, Aydın, Manisa and Alaşehir. According to the registries, twelve Ionia cities were destroyed by the earthquake. This severe earthquake which is assumed as one of the biggest disasters of the Aegean Region caused heavy damage in the valleys of Gediz and Büyük Menderes Rivers (Ergin et al. 1967). Other important historical earthquakes are gathered in Appendix A.

The most severe recent earthquake determined which had magnitude of Ms=7.2 occurred in 1953. But there is not any data except its magnitude, location and date. Another destructive earthquake was in epicenter of Edremit Gulf on October 6, 1944. Its magnitude reported as 6.8 and it affected all Edremit, Ayvalık and Havran with casualties of 30 and damage to 5,500 houses. The recent (1900-2003) earthquakes in Izmir region are also gathered in detail in Appendix A. In Figure 3.6 adapted from İlhan et al. (2004), epicentral distribution of recent (1900-2003) earthquakes is given.

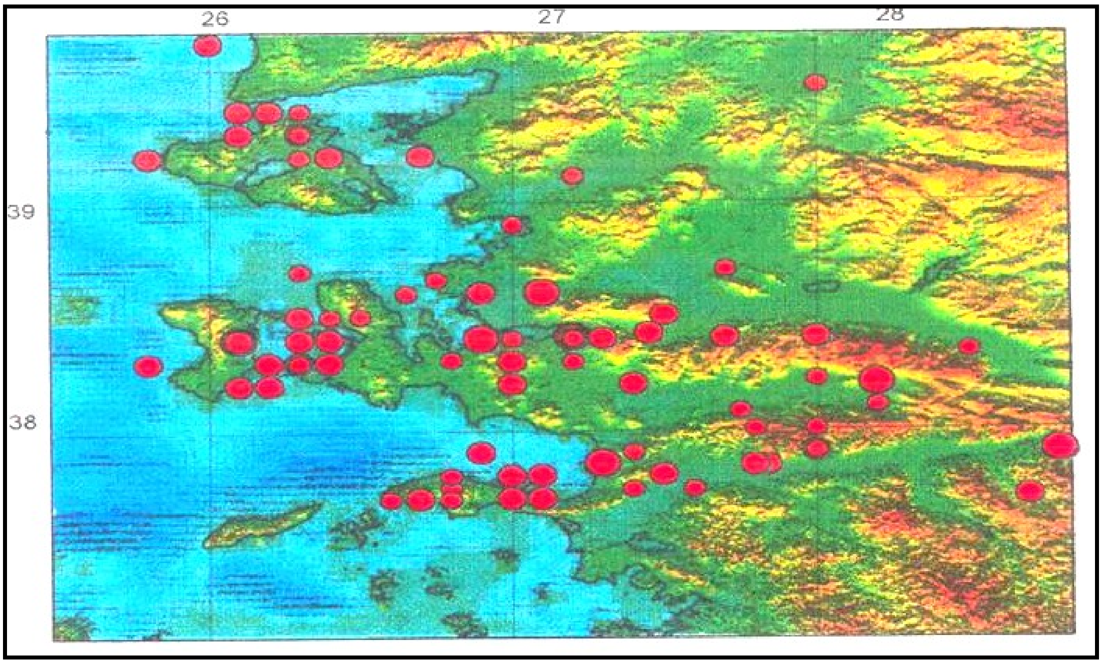
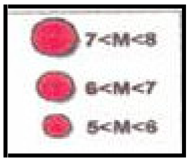


Figure 3.5. Epicentral Distribution of Historical (pre-1900) Earthquakes
(Source: RADIUS 1997)



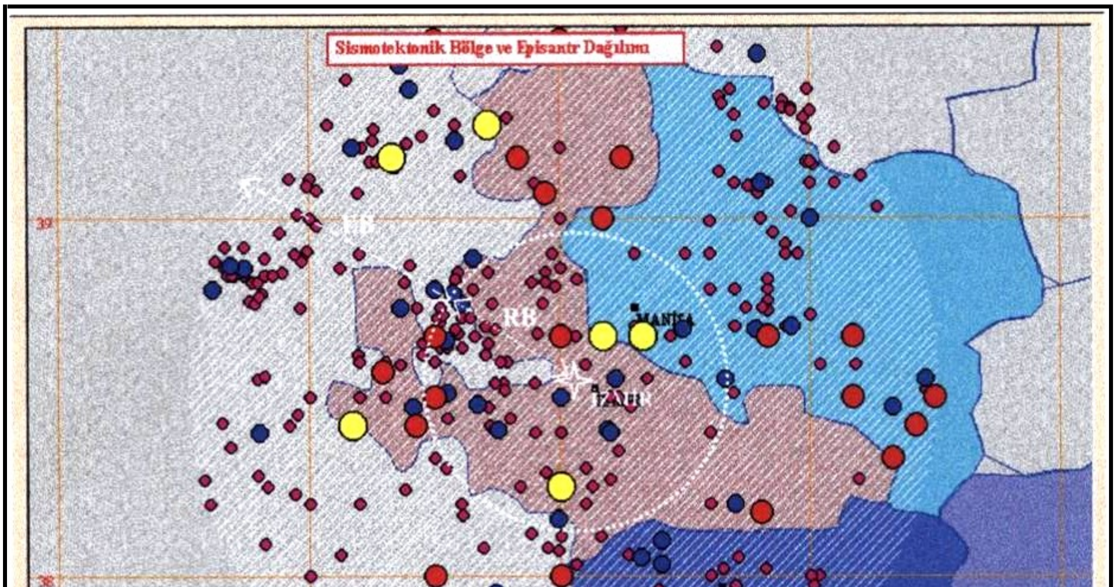


Figure 3.6. Epicentral Distribution of Recent (1900-2003) Earthquakes
(Source: İlhan et al. 2004)

3.3. Earthquake Probabilities in time and Seismic Hazard in Izmir

Seismic hazard can be defined as the seismic risk of an earthquake which can cause damage and loss. It is possible to describe the seismic hazard by the relationship between frequency and magnitude. Probabilistic methods are used to determine seismic hazard. Traditionally, seismic hazard is measured as seismic intensity, which is a subjective appraisement defining the effect of the earthquake that forms physical damages observed. There are various scales used in seismology such as Richter Maginitude Scale and Modified Mercalli Intensity Scale (MMI) which are also used in this study.

The Richter Magnitude Scale is the most common intensity to represent an earthquake's impact, but MMI is commonly used by seismologists in the United States seeking information on the severity of earthquake effects. The earthquake severity of the Richter Scale is shown in Table 3.1.

Intensity ratings of the Modified Mercalli Intensity Scale are expressed as Roman numerals between "I" at the low end and "XII" at the high end. The definitions of MMI are given in Table 3.2, adapted from the Federal Emergency Management Agency (FEMA).

The Modified Mercalli Intensity Scale differs from the Richter Magnitude Scale in that the effects of any one earthquake vary greatly from place to place, thus there may be many intensity values (e.g. IV, VII) measured for an earthquake depending on the observation location. As it also is seen on the isoseismal map of October 17, 1989 Loma Prieta earthquake (Figure 3.7), intensities typically increase close to an earthquake's epicenter and with ten miles of intervals locations have higher intensities.

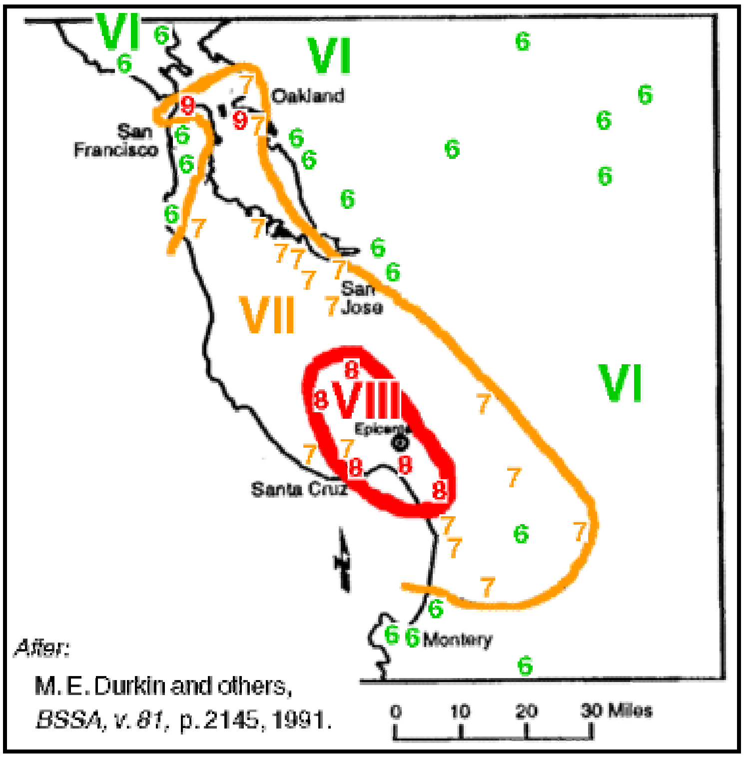


Figure 3.7. Isoseismal Map of October 17, 1989 Loma Prieta Earthquake
(Source: WEB_2 (1996))

On the other hand, each earthquake should have only one magnitude although it is felt in different severity. Surely, an earthquake occurs with an epicenter within Izmir central area will be felt in less severity in the locations far from the epicenter such as Çeşme or Tire and have less MMI. FEMA classifies the loss of functions and damage probabilities using Modified Mercalli Intensity Scale and the analysis is modelled by MMI. Therefore, in this thesis, it is needed to be dependent on MMI as finding the annual earthquake probabilities for Izmir Region in Modified Mercalli Intensity by using the data of Richter Magnitude Scale. Due to this obligation, it is assumed that the effect of any earthquake is felt with the same severity in the all locations of Izmir Region and has same intensity value of MMI.

The assumed correlation between MMI and Richter Magnitude Scale is given in Table 3.3 below.

Table 3.1. Earthquake Severity of Richter Magnitude Scale
(Source: WEB_2 (1996))

Richter magnitude	**Earthquake Effects**
<3.5	Generally not felt, but recorded.
3.5~5.4	Often felt, but rarely causes damage.
5.5~6.0	At most slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions.
6.1~6.9	Can be destructive in areas up to about 100 kilometers across where people live.
7.0~7.9	Major earthquake. Can cause serious damage over larger areas.
>8	Great earthquake. Can cause serious damage in areas several hundred kilometers across.

Table 3.2. Modified Mercalli Intensity Scale
(Source: FEMA 156 1994)

Intensity	**Observed Effects**
I	Not felt at all
II	Felt only by a few individuals, indoors and at rest, usually on upper floors of tall buildings.
III	Felt indoors by many persons, but not necessarily recognized as an earthquake. Chandeliers and hanging plants swing.
IV	Felt both indoors and out. Feels like the vibration caused by a heavy truck or train passing. Windows rattle.
V	Strong enough to awaken sleeping persons. Small objects knocked off shelves. Beverages may splash out of cups or glasses on tables.
VI	Perceptible to everyone. May cause public fright. Pictures fall off walls. Weak masonry cracks. Some plaster may fall from ceilings.
VII	Difficult to stand upright. Ornamental masonry falls from buildings. Waves may be seen in ponds and swimming pools.
VIII	Mass panic may occur. Chimneys, smoke stacks and water towers may lean and fall. Unsecured frame houses slide off foundations.
IX	Panic is general. Heavy damage to masonry structures and to underground pipes. Large cracks open in ground.
X	Many buildings collapse. Water splashes over riverbanks.
XI-XII	Virtually total destruction.

Table 3.3. The Relationship between MMI and Richter Scale
(Source: WEB_2 (1996))

Magnitude Richter	Degree Mercalli
<3.5	I
3.5~4.1	II
4.2~4.4	III
4.5~4.7	IV
4.8~5.3	V
5.4~6.0	VI
6.1~6.4	VII
6.5~6.8	VIII
6.9~7.2	IX
7.3~8.0	X
8.1~	XI - XII

3.3.1. Probabilistic Seismic Hazard for Izmir

Probabilistic seismic hazard is defined as the probability of occurrence of a destructive ground shaking in a determined place and time period. In another expression, probabilistic seismic hazard can be expressed as annual probabilities of earthquake occurrences and their return periods (Erdik et al. 1985).

If the numbers of earthquake occurrences are investigated, it can be assumed that a linear relationship between magnitude and frequency might be obtained as a function of magnitude. The Magnitude-Frequency relationship is defined by Gutenberg-Richter (1954) as below:

$$LogN = a - bM \tag{3.1}$$

where;

N: cumulative number of magnitude of *M* and greater earthquakes

M: studied magnitude

a: a parameter representing the seismic activity of the investigated region

b: a parameter which characterizes the earthquake’s intensity in the region

In this study, between 1900-2003, the magnitude of Ms≥4.9 earthquakes, as given in Appendix B, are investigated for the probabilistic seismic hazard of Izmir and its surrounding region with the 37° – 40.45° N latitude and 25.5° – 29° E longitude. It is another assumption that any earthquake in the boundaries of these coordinations is also hazardous for Izmir City.

Figure 3.8 shows the numbers of earthquakes occurred in Izmir Region for the years between 1999 and 2003 in a graph.

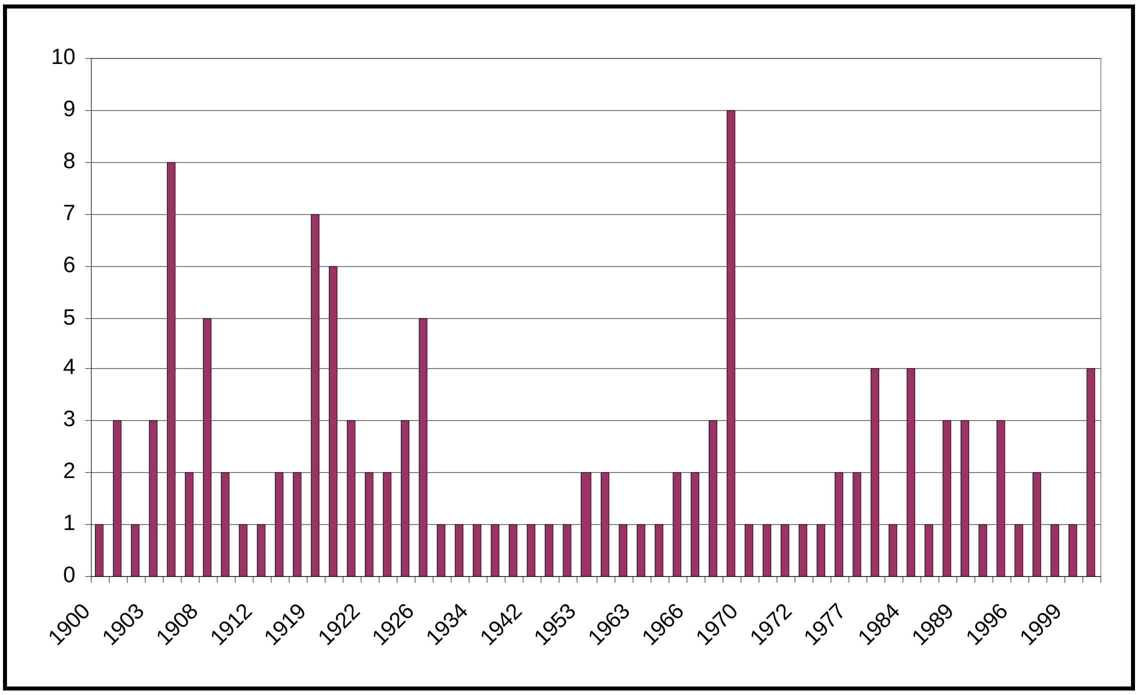


Figure 3.8. Annual Earthquakes Occurred in Izmir Region between 1900-2003

The magnitude-frequency relationship for Izmir and its surrounding region is calculated with ΔM=0.1 magnitude interval. For the investigated region, the magnitude-frequency relationship is;

$$LogN = 4.71 - 0.92M \quad (3.2)$$

For the determination of frequency-magnitude relationship which is a measure of seismic activity, "*a*" and "*b*" values are found as 4.71 and 0.92, respectively.

The magnitude-frequency relationship of recent (1900-2003) earthquakes occurred in Izmir is also given graphically in Figure 3.9.

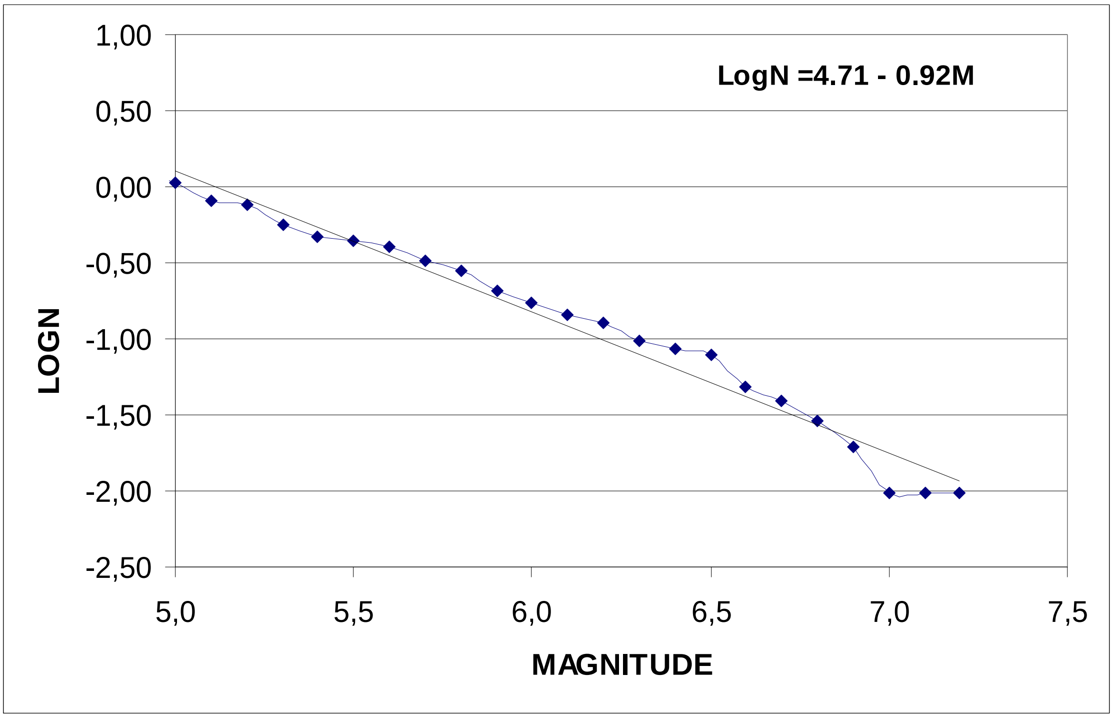


Figure 3.9. Magnitude-Frequency Relationship

3.3.1.1. Poisson Model

It is important to determine return periods and probabilities of earthquake occurrences in the regions that have high seismic activity. Statistical methods are used to determine return periods and probabilities of earthquake occurrences. Poisson Model is one of them that mostly used to expose the seismic risks. Bağcı (2000) also expressed that the earthquakes occurred in Izmir and its surrounding region show a better consistency with Poisson Model.

If it is assumed that earthquake occurrences have a Poisson distribution, the cumulative frequency distribution, which is the probability of occurrence of *N* or less earthquakes in "*t*" time period, is given as (Feller 1968):

$$F(N,t) = p(k;\lambda t) = \sum_{\lambda=0}^{N} \frac{(\lambda t)^k}{k!} e^{-\lambda t} \qquad (3.3)$$

where, λ is the frequency.

In particular, the probability of no earthquake in an interval of length *t* is;

$$p(0;\lambda t) = e^{-\lambda t} \tag{3.4}$$

Times between earthquake occurrences show a negative distribution. Thus the probability of a time period given between two earthquakes in (*t*,*t*+*dt*) is;

$$P(t) = -\lambda . e^{-\lambda t} . dt \tag{3.5}$$

The probability of one or more earthquake occurrences F(*t*) can be expressed as 1-p(0;λt). Therefore;

$$F(t) = 1 - e^{-\lambda t} \tag{3.6}$$

The probabilities of magnitude of M_1 and greater earthquakes in *t* years can be calculated by equation (3.7) (Gençoğlu 1972, Tuksal 1976, Tabban and Gençoğlu 1975).

$$P(M \geq M_1) = 1 - e^{-n(M \geq M_1)t} \tag{3.7}$$

where $n(M \geq M_1)$ is annual numbers of magnitude of M_1 and greater earthquakes. And the return periods can be obtained with;

$$Q = \frac{1}{n(M \geq M_1)} \tag{3.8}$$

Calculated seismic risk values and return periods for Izmir region in 50 years are shown in Table 3.4 in Richter Magnitude Scale and Table 3.5 in MMI, respectively. Figure 3.10 represents the histogram and Figure 3.11 represents the earthquake occurrence probabilities in different time periods.

Table 3.4. Calculated Seismic Risk Values and Return Periods in Richter Scale

M_1	$n(M \geq M_1)$	$\lambda = n(M \geq M1)/103$	$P(M \geq M1)$	$Q = 1/\lambda$
4.9	127	1.233	1	0.8
5.0	111	1.077	1	0.9
5.1	84	0.816	1	1.2
5.2	79	0.767	1	1.3
5.3	58	0.563	1	1.8
5.4	48	0.466	0.9999	2.1
5.5	45	0.437	0.9999	2.3
5.6	41	0.398	0.9999	2.5
5.7	34	0.330	0.9999	3.0
5.8	29	0.281	0.9999	3.6
5.9	21	0.203	0.9999	4.9
6.0	18	0.174	0.9998	5.7
6.1	15	0.146	0.9993	6.8
6.2	13	0.126	0.9980	7.9
6.3	10	0.097	0.9920	10.3
6.4	9	0.087	0.9870	11.5
6.5	8	0.077	0.97	13.0
6.6	5	0.048	0.91	20.8
6.7	4	0.038	0.85	26.3
6.8	3	0.029	0.77	34.5
6.9	2	0.019	0.62	52.6
7.0	1	0.009	0.38	111.1
7.1	1	0.009	0.38	111.1
7.2	1	0.009	0.38	111.1
>7.2	0	0.000	0.00	

Table 3.5. Calculated Probability Values for Different Time Periods in MMI

MMI	20 yrs	30 yrs	50 yrs	60 yrs	80 yrs	100 yrs
VI	1	1	1	1	1	1
VII	0.997998	0.99991	1	1	1	1
VIII	0.788472	0.902714	0.979421	0.990535	0.997998	0.999577
IX	0.540078	0.688092	0.856547	0.902714	0.955256	0.979421
X	0.176486	0.25268	0.384572	0.441513	0.540078	0.621248
XI	0	0	0	0	0	0
XII	0	0	0	0	0	0

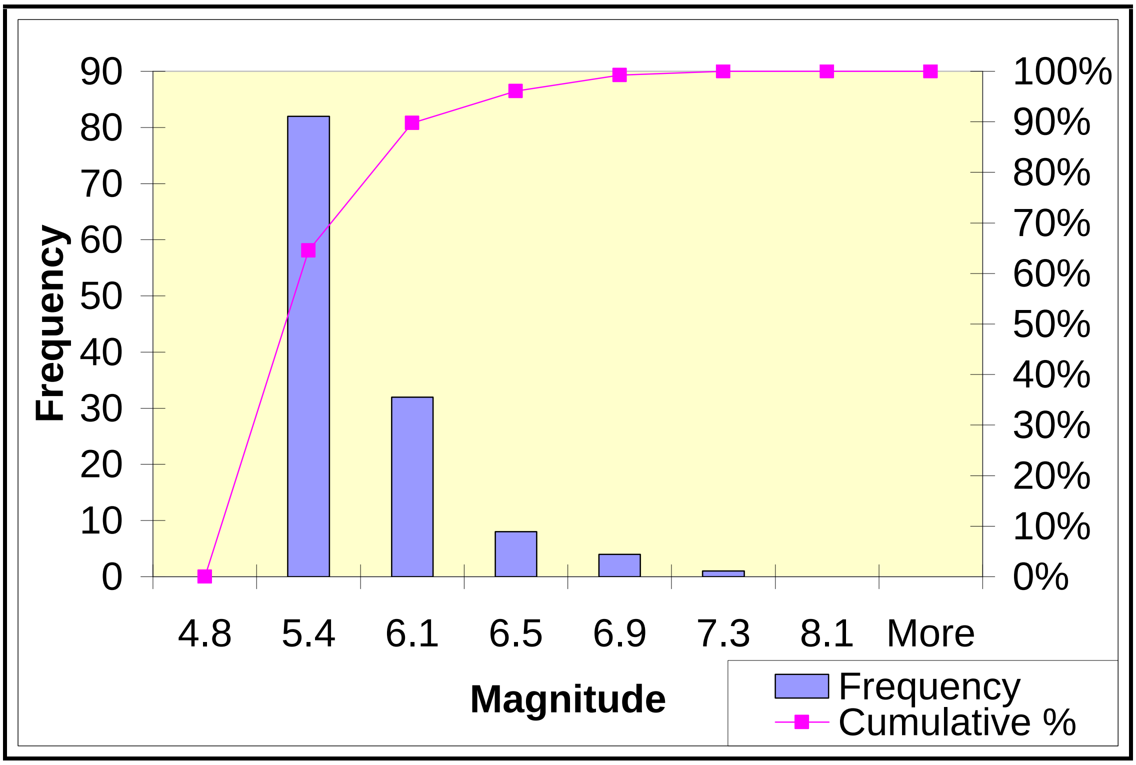


Figure 3.10. Histogram

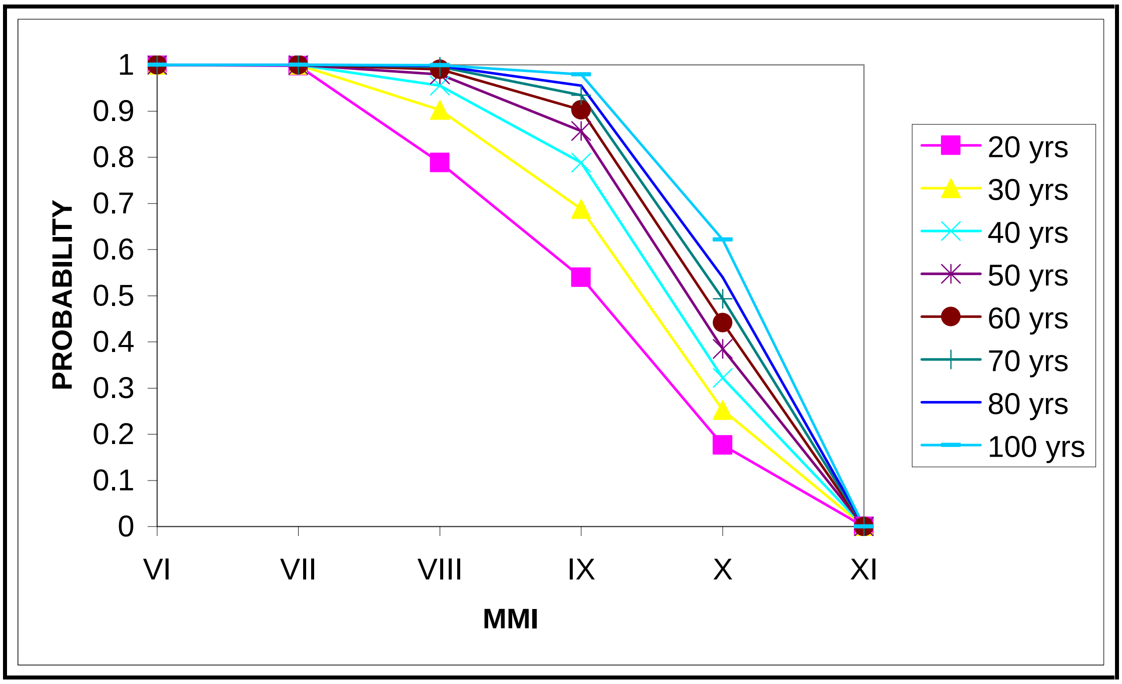


Figure 3.11. Earthquake Occurrence Probabilities in Different Time Periods

CHAPTER 4

DAMAGE ESTIMATION AND SEISMIC RISK OF IZMIR

4.1. Introduction

According to the general risk analysis literature, possible disasters, the damage caused by the disaster and the probability of occurrence are the basic components of the nature of risk. Similarly, seismic risk necessitates a set of earthquakes, the associated damages and losses, and the associated probabilities of earthquake occurrence over a defined time period.

In this chapter, different damage estimation methodologies are presented. Researchers and institutes such as Applied Technology Council (ATC) and Federal Emergency Management Agency (FEMA) categorize seismic risk values for different building types and social functions. Expected mean damage ratios and average range of loss functions adapted from these data are presented for Izmir.

Evaluating seismic risk is a guidance to establish seismic safety and a logical way for making decisions about possible earthquakes. Direct earthquake damage to structures is only one part of the total economic loss from an earthquake. The number of human casualties caused by an earthquake could be one of the most important bases of economic losses in seismic risk. It is possible to estimate seismic risk by estimating damage to structures and loss as a function of ground motion (McGuire 2004).

Damage can be measured in monetary terms, casualties, or loss of function and earthquake damage can be defined as a destructive physical effect on a natural or artificial structure. Broken windows, cracked columns and beams, broken equipment and installation, or total collapse are some of the effects of seismic shaking on a building. Özcebe et al. (2003) classified reasons of damage in reinforced concrete structures into three groups:

- Incorrect configuration of architectural and structural systems
- Inadequacy in detailing and proportioning
- Poor construction quality due to inadequate supervision

Almost 90 percent of the observed damage in reinforced concrete buildings in Turkey during the past 30 years is due to one of the listed mistakes or combination of them (Ersoy 1988). Damage function can be defined as a relationship between levels of ground shaking and levels of damage. For example, with this function, the damage to a structure for a given ground motion input can be estimated. Damage functions can be derived either empirically or analytically.

Definition of loss of function is “a relationship between monetary or human loss and earthquake damage or levels of ground shaking” (McGuire 2004). From ground motion amplitudes, the loss can be estimated as a fraction of building value or in monetary values. Another way to determine loss is also possible after the damage levels are estimated and comparing then to this data.

Damage to structures can be expressed in categories as below:

- No damage
- Slight (damage to architectural features)
- Minor (repairable damage to structural features)
- Major (damage that is not worth repairing)
- Total (collapse)

The point of estimating seismic risk is to estimate damage to structures and to lifelines as a function of ground motion. The methods which are used for estimating damage probabilities have been defined in the following sections.

4.2. Empirical Method of Damage Estimation

The relationship between damage and ground motion is the start point of seismic risk which has traditionally relied on an intensity scale such as MMI to represent the ground motion.

“The damage to a structure is usually normalized by the total replacement cost, leading to a damage ratio (the cost of repairing the structure divided by replacement cost)” (McGuire 2004).

There are two widely used MMI-based methods that were developed by ATC (1985) and by Steinbrugge (1982).

The ATC (1985) study was accepted as an attempt to derive unanimity by a group of engineers whose level of experience studying earthquake damage was varied. The Steinbrugge method was based on a lifetime of experience (McGuire 2004).

Figure 4.1 represents the comparison of damage ratios for single-family, wood-frame residences predicted by the ATC (1985) and Steinbrugge (1982) studies with data from the 1994 Northridge earthquake (Toro 1997). The damage estimates are different from the data due to several factors:

- The Steinbrugge (1982) curve is for a probable maximum loss (PML) estimated to be the 90% confidence level of damage, not the mean or median.
- The ATC (1985) curve is an estimate of the mean damage function, derived from subjective opinion.
- The Northridge data are summaries of losses paid by insurance companies after deductibles (which averaged 8%) were applied.

In any case, translating seismic hazard into seismic risk is straightforward as a concept. Once the damage function (damage ratio versus intensity) has been chosen, the annual probability of damage P [damage>d] is calculated as;

$$P[damage > d] \cong \sum_{MMI} P[damage > d \mid MMI]\gamma'[MMI] \qquad (4.1)$$

where γ'[MMI], the frequency of occurrence of MMI, is obtained from the seismic hazard analysis. P[*damage*>*d* | MMI] requires a distribution of damage ratio given MMI as illustrated in Figure 4.1.

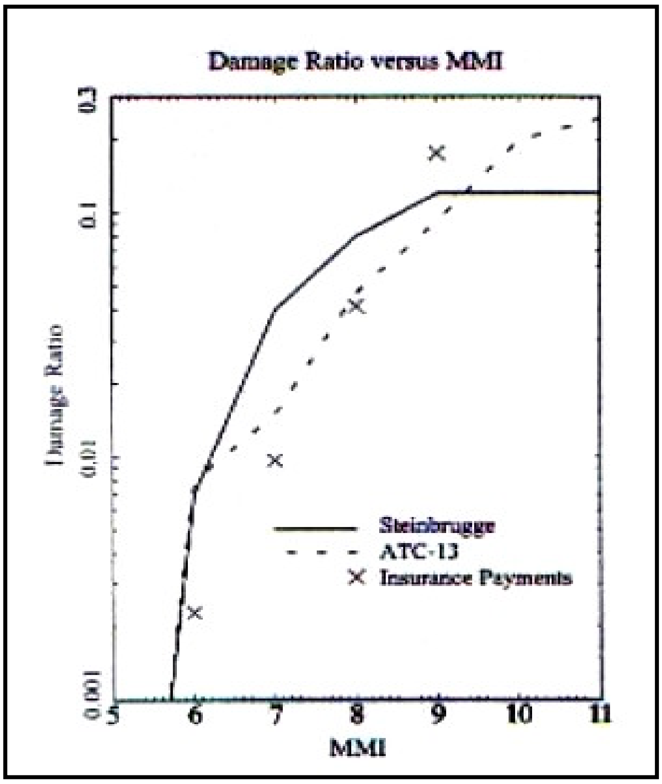


Figure 4.1. Residential damage ratio from the Northridge earthquake
(Source: McGuire 2004)

A probability distribution on damage when MMI values are given is required by Equation 4.1 that means a distribution shape and measure of dispersion are required, in addition to a mean or median damage. The density function is defined by standard beta distribution as (Devore 1991);

$$f_x(x) = \frac{1}{\beta} x^{r-1} (1 - x)^{t-r-1} \tag{4.2}$$

where *r* and *t* are parameters.

$$\beta = \frac{\Gamma(r)\Gamma(t-r)}{\Gamma(t)} \tag{4.3}$$

where Γ is the gamma function. The relationships of the mean and variance with parameters *t* and *r* are;

$$m_x = \frac{r}{t} \tag{4.4}$$

$$\sigma^2{}_x = \frac{r(t-r)}{t^2(t-1)} \tag{4.5}$$

Damage ratio and loss are dependent on each other (e.g. the structure will have a total loss when the damage ratio exceeds a certain amount, often estimated at 0.5. Therefore, the structure will be reconstructed) (McGuire 2004).

4.3. Analytical Methods of Damage Estimation

Structures such as bridges, dams, towers etc. can be represented with Single Degrees of Freedom (SDOF) models. One of the most straightforward methodologies of seismic risk determination can be described as to run the nonlinear model by using a set of recorded strong motions, calculate some measure of structural response, and then perform a direct seismic risk analysis with regressing the structural response on earthquake magnitude and distance.

The start point in analytical methods of damage estimation is recognizing that a structure behaves in a nonlinear manner during strong ground motion. This nonlinearity can be qualified with a force-deformation curve. Figure 4.2 represents the spectral accelerations associated with a range of spectral displacements for the structural model, and it makes clear that, beyond the yield acceleration SA_y and yield displacement SD_y, small increases in acceleration can engender large increases in displacement on the structure (McGuire 2004).

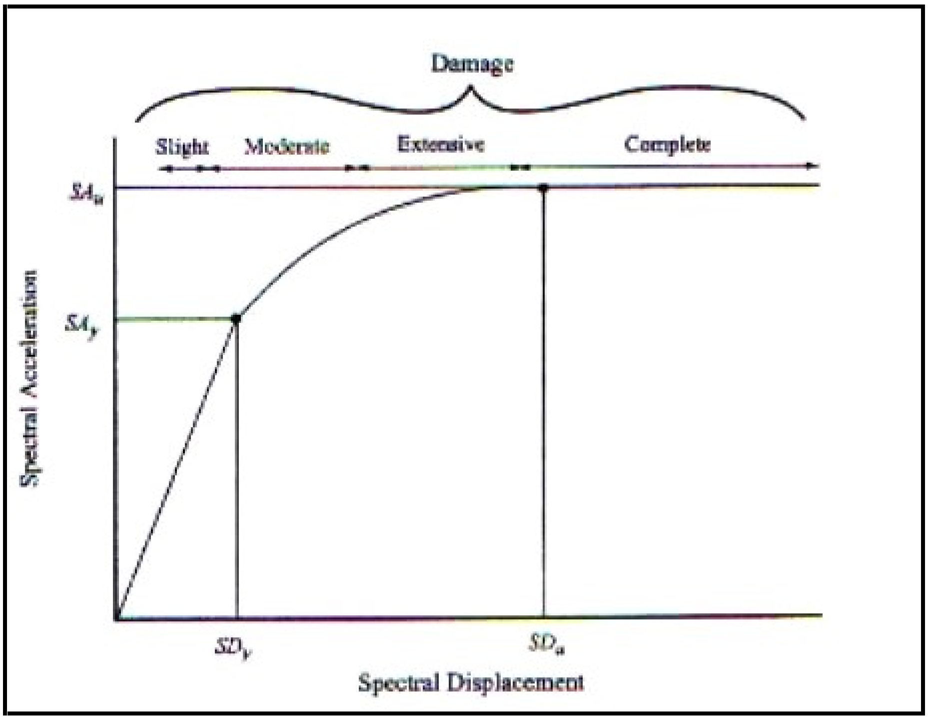


Figure 4.2. Acceleration versus displacement, showing various levels of damage (Source: McGuire 2004).

As it is indicated in Figure 4.2, there is a correlation between the maximum displacement during the earthquake shaking and damage. Thus, it is important to estimate the maximum displacement of the nonlinear model of the structure for estimating damage.

There are two analytical methods for estimating nonlinear displacement such as Capacity Spectrum Method and Displacement Coefficient Method.

4.3.1. Capacity Spectrum Method

Capacity spectrum method is one of the nonlinear statical analysis methods which have been developed for estimating displacements and comparing the capacity of a structure with the demands of earthquake ground motion on it. The inelastic strength and displacement spectra used for the determination of an earthquake demand can be obtained by time-history analysis of inelastic SDOF systems (Ye 1999).

This method recognizes that when the structure is shaken on the further side of its yield point, as shown in Figure 4.2, its effective damping and its effective period will increase.

This method aims to reduce the 5% damped elastic spectrum of the ground motion to a lower spectrum that is in agreement with the structure's response (McGuire 2004).

By determining a maximum displacement and acceleration on the capacity curve, as given in Figure 4.2, that is in agreement with the ground motion "demand" at the higher damping and longer period that the structure experiences, the structural response to a given ground motion can be estimated. Figure 4.3 represents the ground motion demand diagram which quantifies the spectral displacements and accelerations of higher damping levels for given ground motion.

The point where the capacity curve crosses the demand diagram, for a consistent damping and period, represents the estimated maximum response of the structure.

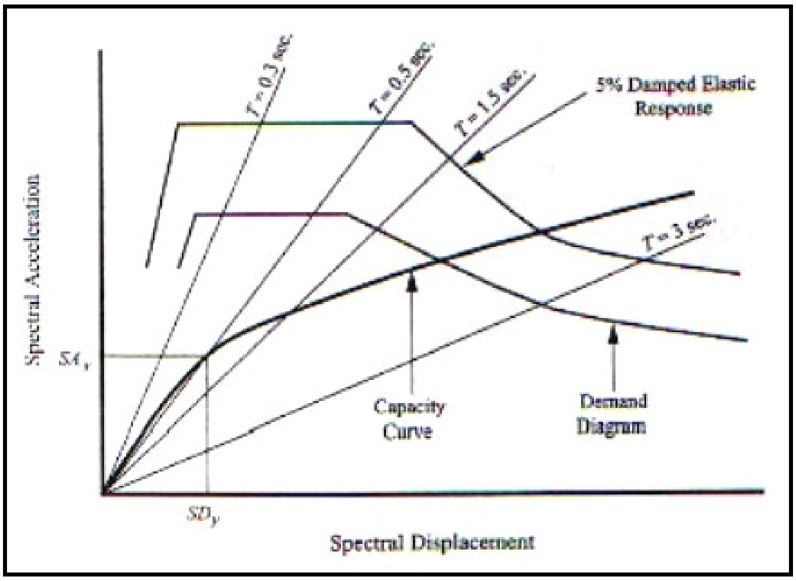


Figure 4.3. Capacity curve, elastic response curve, and demand diagram. The maximum structural response is estimated to be the point where the capacity curve crosses the demand spectrum
(Source: McGuire 2004)

4.3.2. Displacement Coefficient Method

Another method of estimating nonlinear structural response that estimates the maximum displacement by using ductility μ is displacement coefficient method. Figure 4.4 represents the relationship among μ, structural period T, and R_y, which is the ratio of elastic acceleration SA to yield acceleration SA_y. This diagram shows a relationship for a bilinear system with stiffness after yield as 2% of the elastic stiffness. As illustrated in Figure 4.5, this relationship presents the development of inelastic demand diagrams from elastic A-D diagrams for a broad-banded motion anchored to 0.5 g.

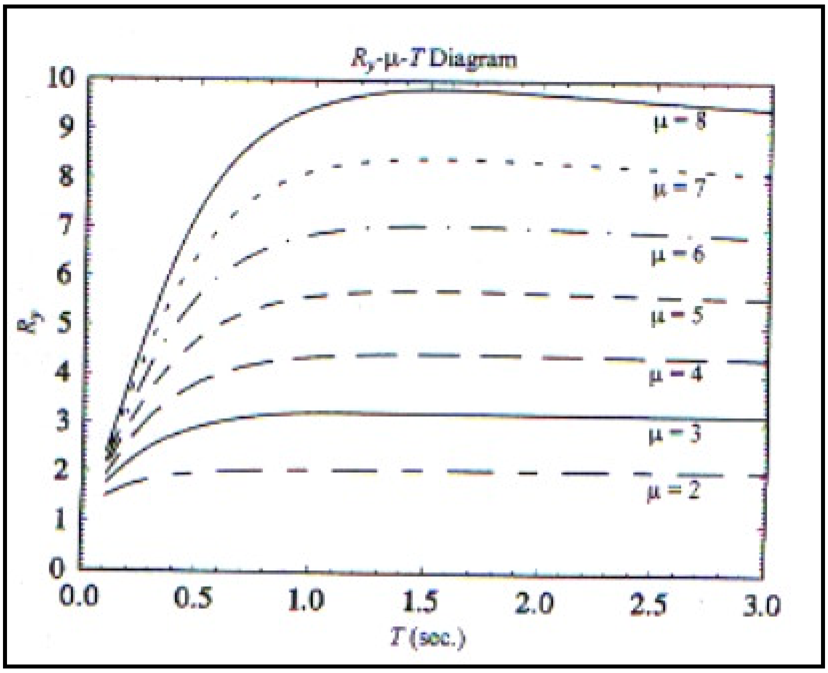


Figure 4.4. R_y-μ-T relationship for 2% of elastic stiffness after yield
(Source: McGuire 2004)

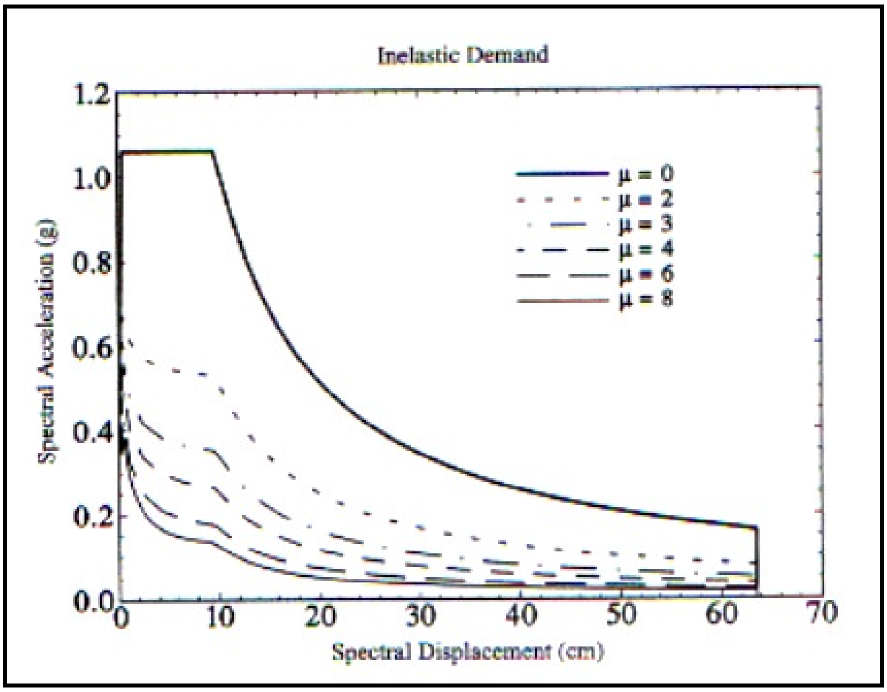


Figure 4.5. Inelastic demand A-D diagram for broad-banded ground motion
(Source: McGuire 2004)

The procedure for estimating nonlinear response for a given input motion starts by the calculation of *Ry* which is the ratio of the elastic *SA* of the input motion to the yield *SA* of the structure, then μ is determined from Figure 4.4, and lastly, the maximum inelastic displacement is calculated as μ times SD_y (McGuire 2004).

4.4. Calculation of Damage

Damage can be estimated after the response spectrum has been estimated for a given structural capacity and inelastic demand. It is assumed that, for each damage state *ds* and for a given spectral displacement *sd*, the probability of equalling or exceeding *ds* is calculated from the lognormal distribution as follow;

$$P\left[ds / sd\right] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{sd}{\hat{s}d_{ds}}\right)\right] \qquad (4.6)$$

where Φ is the Gaussian complementary cumulative function, β_{ds} is the standard deviation of the natural log of *sd* for damage state *ds*, and $\hat{s}d_{ds}$ is the median spectral displacement at which the structure reaches the threshold of damage state *ds*.

Of course, for a quantitative analysis of damage, it is possible to translate damage descriptions into a percentage of the structure's value (McGuire 2004).

4.5. Seismic Risk Classifications

This section comprises the tables which show the seismic risk of Izmir Region. First, the earthquake engineering facility classifications prepared by ATC-13 (1985) are given in Table 4.1. For each facility class under consideration, it is necessary to estimate the building performance in earthquakes of MMI ranging from VI (below which damage is minimal) to the maximum MMI earthquake expected in Izmir. Damage probability matrices give consensus values of the expected amounts of damage as a function of MMI. The general form of damage probability matrices is shown in Table 4.2. Seven building damage states are defined, ranging from no damage to total destruction. For each damage state, a range of damage factors is given in percentages of building replacement value and a central damage factor (CDF) is defined as the midpoint of the range. Expected mean damage factors for MMI levels (from VI to XI) of reinforced concrete buildings in Izmir are given in Table 4.3. Z1, Z2, Z3 and Z4 represent local site classes as illustrated in Table 4.7 prepared by Ministry of Public Works and Settlement Government of Republic of Turkey.

Earthquake damage may render buildings unfit for their normal functions until repairs are made (FEMA 227 1992). Different approaches about expected loss of function and restoration times were developed in ATC-13 (1985). Loss of function depends on damage state and social function classification. Estimated loss of functions for each social function class given in Table 4.4, from ATC-13 (1985), are compiled in Table 4.5. It is assumed that these values adapted from FEMA 227 (1992) are valid for the reinforced concrete buildings in Izmir Region as well.

Table 4.1. Earthquake Engineering Facility Classifications
(Source: FEMA 227 1992)

BUILDING TYPE	FACILITY CLASSIFICATION NUMBER
Wood Frame (Low Rise)	1
Unreinforced Masonry (Bearing Wall) a. Low Rise (1-3 Stories)	75*
b. Medium Rise (4-7 Stories)	76*
Unreinforced Masonry (with Load Bearing Wall) a. Low Rise	78*
b. Medium Rise	79*
c. High Rise (8+ Stories)	80*
RC Shear Wall (with Moment-Resisting Frame) a. Low Rise	3
b. Medium Rise	4
c. High Rise	5
RC Shear Wall (without Moment-Resisting Frame) a. Low Rise	6
b. Medium Rise	7
c. High Rise	8
Reinforced Masonry Shear Wall (without Moment-Resisting Frame) a. Low Rise	9
b. Medium Rise	10
c. High Rise	11
Reinforced Masonry Shear Wall (with Moment-Resisting Frame) a. Low Rise	84
b. Medium Rise	85

c. High Rise	86
Braced Steel Frame a. Low Rise	12
b. Medium Rise	13
c. High Rise	14
Moment-Resisting Steel Frame (Perimeter Frame) a. Low Rise	15
b. Medium Rise	16
c. High Rise	17
Moment-Resisting Steel Frame (Distributed Frame) a. Low Rise	72
b. Medium Rise	73
c. High Rise	74
Moment-Resisting Ductile Concrete Frame (Distributed Frame) a. Low Rise	18
b. Medium Rise	19
c. High Rise	20
Moment-Resisting Non-Ductile Concrete Frame a. Low Rise	87*
b. Medium Rise	88*
c. High Rise	89*
Precast Concrete (other than Tilt-up) a. Low Rise	81*
b. Medium Rise	82*
c. High Rise	83*
Tilt-up (Low Rise)	71*

Table 4.2. General Form of Damage Probability Matrices
(Source: FEMA 227 1992)

Damage State	Damage Factor Range (%)	Central Damage Factor (%)	Probability of Damage in Percent By MMI and Damage State					
			VI	VII	VIII	IX	X	XI
1-None	0	0	95	49	30	14	3	1
2-Slight	0-1	0.5	3	38	40	30	10	3
3-Light	1-10	5	1.5	8	16	24	30	10
4-Moderate	10-30	20	0.4	2	8	16	26	30
5-Heavy	30-60	45	0.1	1.5	3	10	18	30
6-Major	60-100	80	...	1	2	4	10	18
7-Destroyed	100	100	...	0.5	1	2	3	8

Definitions of damage states from FEMA 227 (1992):

1-None: No damage.

2-Slight: Limited localized minor damage not requiring repair.

3-Light: Significant localized damage of some components generally not requiring repair.

4-Moderate: Significant localized damage of many components warranting repair.

5-Heavy: Extensive damage requiring major repairs.

6-Major: Major widespread damage that may result in the facility being razed, demolished, or repaired.

7-Destroyed: Total destruction of the majority of the facility.

Table 4.3. Expected Mean Damage Factors (%) for Reinforced Concrete Buildings in Izmir
(Source: Erdik and Aydınoğlu 2000)

SITE CLASS	MODIFIED MERCALLI INTENSITY					
	VI	VII	VIII	IX	X	XI
Low-rise (Z1)	1.0	4.5	13.0	27.0	43.0	59.0
Low-rise (Z2)	1.8	6.5	17.5	31.0	52.5	74.0
Low-rise (Z3)	3.3	8.7	19.3	35.9	57.0	78.1
Low-rise (Z4)	4.3	13.0	27.0	43.8	67.6	86.0
Mid-rise (Z1)	4.5	13.0	27.0	43.0	59.0	74.0
Mid-rise (Z2)	6.5	17.5	31.0	52.5	74.0	86.0
Mid-rise (Z3)	8.7	19.3	35.9	57.0	78.1	92.0
Mid-rise (Z4)	13.0	27.0	43.8	67.6	86.0	97.0

Table 4.4. Social Function Classifications
(Source: ATC-13, 1985)

SOCIAL FUNCTION CLASSIFICATION	SOCIAL FUNCTION CLASS
RESIDENTAL	
*Permanent Dwelling	1
*Temporary Lodging	2
*Group Institutional Housing	3
COMMERCIAL	
*Retail Trade	4
*Wholesale Trade	5
*Personal and Repair Services	6
*Professional, Technical and Business Services	7
*Health Care Services	8
*Entertainment and Recreation	9
*Parking	10
INDUSTRIAL	
*Heavy Fabrication and Assembly	11
*Light Fabrication and Assembly	12
*Food and Drugs Processing	13
*Chemicals Processing	14
*Metal and Minerals Processing	15
*High Technology	16
*Construction	17
*Petroleum	18
RELIGION AND NON-PROFIT	21
GOVERNMENT	
*General Services	22
*Emergency Response Services	23
EDUCATION	24
COMMUNICATION	34

Table 4.5. Loss of Function
(Source: FEMA 227 1992)

SOCIAL FUNCTION CLASSES 4,5,6,7,9 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.2	2.4	5.8
5	3.4	10.2	20.0
20	9.8	44.6	71.0
45	37.0	111.6	202.7
80	114.7	213.7	343.1
100	214.8	355.9	439.3

Table 4.6. Soil Groups
(Source: Ministry of Public Works and Settlement Government of Republic of Turkey)

SOIL GROUP	DESCRIPTION OF SOIL GROUP
A	1. Massive volcanic rocks, metamorphic rocks, stiff cemented sedimentary rocks 2. Very dense sand 3. Hard clay
B	1. Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity 2.Dense sand 3. Very stiff clay
C	1. Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity 2. Medium dense sand 3. Silty clay
D	1. Soft, deep alluvial layers with high water table 2. Loose sand 3. Silty clay

Table 4.7. Local Site Classes
(Source: Ministry of Public Works and Settlement Government of Republic of Turkey)

LOCAL SITE CLASS	Soil Group According to Table 4.6 and Topmost Layer Thickness (h_1)
Z1	Group A soils and Group B soils with h_1<15m
Z2	Group B soils with h_1>15m and Group C soils with h_1<15m
Z3	Group C soils with 15m<h_1<50m and Group D soils with h_1<10m
Z4	Group C soils with h_1>50m and Group D soils with h_1>10m

CHAPTER 5

A BENEFIT/COST MODEL PRESENTED BY FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA)

5.1. Introduction

It is evident that structures in seismically active regions are under high risk and should be assessed. Considering the assessment, building owners and decision makers must decide whether they will rehabilitate their structures or not. This may seem to be a simple decision, but for business purposes it could possibly not be justified to retrofit, especially if the retrofitting costs are very large or the probability of a damaging earthquake is considerably low (Foltz 2004). One has to bear in mind; there is a trade-off between safety and cost and to observe that, a long term economic analysis should be performed. It is important to review alternatives of a decision in rational way. At this point, a benefit-cost analysis is a useful tool to determine whether to rehabilitate a structure is economically feasible or not.

Smyth et al. (2002) defines that, benefit-cost analysis (BCA) is a systematic procedure for appraising decisions that have an impact on society. In this chapter, a benefit-cost model for the seismic rehabilitation of reinforced concrete buildings, which is applied by Federal Emergency Management Agency (FEMA) in the United States in 1991, is presented.

As a benefit/cost analysis can be used for determining the best alternative among different rehabilitation models, it can be used to decide which alternative between rehabilitation and replacement is more sensible as well.

In the model of the benefit/cost analysis presented by FEMA, the expected present value model of a seismic rehabilitation investment is used. “The term “expected” indicates that future benefits are not known with certainty, but rather are estimated based on mean or average values of currently available information” (FEMA 227 1992). For the expected net present value of a seismic rehabilitation investment, first, the total present value of expected future benefits and the present value of the salvage value of the rehabilitation investment at the end of the planning period are summed, and then the initial cost of the rehabilitation project is subtracted.

The expected result in benefit/cost analysis is that benefit/cost ratio is greater than one which means the prospective rehabilitation project of the building is economically justified. Division of the expected present value of future benefits to the rehabilitation costs gives the Benefit/Cost ratio.

The loss of life and injuries due to an earthquake is the most important issue, however, while estimating the expected net present value, the value of life will be neglected in this analysis. The monetary value of human life is very disputable subject, on which no consensus is reached yet and it can affect the result of benefit/cost analysis on a large scale.

The Federal agency studies suggest that the value of human life ranges from $1 to $8 million per life (FEMA 228 1992). Although to prevent the injuries and loss of life is the primary goal of the structural rehabilitation, the benefit/cost model for the seismic rehabilitation presented by FEMA allows running the analysis including or excluding the value of human life.

The value of future losses avoided which could result from expected earthquake damages to unrehabilitated buildings constitutes all benefits arising from a seismic rehabilitation project. Costs involve the engineering, construction, and other costs required for the rehabilitation of a building (FEMA 227 1992).

In this chapter, the equations of expected net present value model are given and the definitions which form the benefit-cost analysis for the seismic rehabilitation are described.

It should always be known that this analysis is made for the owners of the buildings or occupants and the decision makers who consider building rehabilitation programs that seek to decrease expected casualties and property damage from future earthquakes. Decision makers want to see that the invested rehabilitation project is economically worthwhile or not, before they start to apply it. At this point, the benefit-cost analysis is a useful tool to answer their question.

5.2. Expected Net Present Value Model without the Value of Life

The expected net present value of a seismic rehabilitation investment is calculated by the sum of the present value of benefits expected to accrue each year over the planning period, plus the present value of the salvage value of the rehabilitation investment at the end of the planning period, minus the initial cost of the rehabilitation. The expected net present value model is defined by FEMA as:

$$NPV = -INV + \frac{B_1}{1+i} + \frac{B_2}{(1+i)^2} + \ldots + \frac{B_T}{(1+i)^T} + \frac{V_T}{(1+i)^T} \tag{5.1}$$

where:

INV is the cost of the rehabilitation;

B_T is the expected annual benefit attributed to the rehabilitation in year *T*;

V_T is any change that the rehabilitation will have on the salvage value of the buildings in the terminal year *T*;

T is the length of the planning horizon which should reflect the effective life of the rehabilitation of the buildings; and

i is the discount rate.

In this model, it is assumed that each year's expected benefit which is discounted to its present value and then added together to yield the total expected net present value is constant. As it is mentioned above, the cost of the rehabilitation (INV) includes direct engineering, construction costs and, desirably, other indirect costs. FEMA indicates that the salvage value of the rehabilitation project is the change that the retrofit will have on the value of the buildings at the end of the planning horizon. The planning horizon *T* is the time period which is generally taken as 50 years in Turkey. The discount rate *i* is the annual percentage rate. The discount rate is an important factor used to calculate the present value of benefits which occur in the future. The choice of an appropriate discount rate is one of the most difficult aspects of benefit/cost analysis. The discount rate ranges from 3% to 6% in the US. FEMA suggests that for private sector considerations, a discount rate of 4 to 6% is reasonable and for public sector considerations, 3 or 4% is reasonable. In Turkey, it is not possible to determine a fixed discount rate, in particular, for a project over long-term such as seismic rehabilitation. Therefore, various discount rates are used for the samples described in Chapter 6.

When expected benefits are constant each year during the time period, the expected net present value can be written as:

$$NPV = -INV + B_T \left[\frac{1-(1+i)^{-T}}{i} \right] + \frac{V_T}{(1+i)^T} \tag{5.2}$$

If expected benefits are constant each year, equivalently, the annual probabilities of future earthquakes in different intensities are also constant, and this means the effectiveness of the rehabilitation in reducing damages, casualties and losses is constant (FEMA 227 1992).

The expected annual benefit that accrues from the rehabilitation is estimated by the sum of expected avoided losses accounting for the expected annual probability of hazardous earthquakes. Avoided building damages, rental income losses, relocation expenses, personal and proprietor's income losses, business inventory losses, and personal property losses are the expected future losses that produce the expected annual benefit(FEMA 228 1992). The expected annual benefit is thus calculated by:

$$B_T = \sum_{m=VI}^{XI} EAE^m \left[\sum_{s=1}^{S} \sum_{f=1}^{F} BD_{sf}^m + RT_{sf}^m + REL_{sf}^m + Y_{sf}^m + INV_{sf}^m + PP_{sf}^m \right] \tag{5.3}$$

where:

EAE^m is expected number of earthquakes annually by MMI ranging from VI-XI;

BD_{sf}^m is building damages avoided by social function and facility classes, and MMI;

RT_{sf}^m is rental losses avoided by social function and facility classes, and MMI;

REL_{sf}^m is relocation expenses avoided by social function and facility classes, and MMI;

Y_{sf}^m is personal and proprietor's income losses avoided by social function and facility classes, and MMI;

INV_{sf}^m is business inventory losses avoided by social function and facility classes, and MMI; and

PP_{sf}^m is personal property losses avoided by social function and facility classes, and MMI.

Since the model is adapted for the buildings in Izmir and the probability of MMI=XII earthquake is zero for this region, the hazardous earthquakes range from VI to XI in the equation. FEMA indicates that, expected damages and losses avoided must be calculated separately for each combination of social function classification *S* and facility classification *F* and then added each other. Avoided damages and losses represent the reduction in expected damages and losses in unrehabilitated buildings of the same facility and social function classification (FEMA 227 1992).

Building damages avoided are calculated by the floor area of the buildings times the building replacement value per square meter times the expected mean damage function for building damages as a function of MMI of earthquakes times the expected rehabilitation effectiveness in reducing building damage. Meanwhile, the product of the floor area of the buildings and the building replacement value per square meter gives the total replacement value of the building. Building damages avoided are defined by FEMA as:

$$BD_{sf}^{m} = FA_{sf} RV_{sf} MDF_{f}^{m} ERE_{f}^{m} \quad (5.4)$$

where:

FA_{sf} is the floor area by social function and facility classes;

RV_{sf} is building replacement value per square meter;

MDF_f^m is mean damage function by facility classification and MMI; and

ERE_f^m is expected rehabilitation effectiveness by facility class and MMI.

"Replacement" is described by FEMA as the term used for replacing the function that a demolished building served. The mean damage function (MDF) has been described in previous chapter and the expected mean damage factors in percentage for reinforced concrete buildings in Izmir (Turkey) has been given in Table 4.3.

Rental losses avoided are calculated by the floor area of the buildings times the rental rate per square meter per day times expected loss of function in days times the expected effectiveness of the rehabilitation in reducing loss of function. Rental losses avoided can be estimated by:

$$RT_{sf}^{m} = FA_{sf}\, RR_{sf}\, LOF_{s}^{m}\, ERE_{f}^{m} \tag{5.5}$$

where:

RR_{sf} is rental rate per square meter per day by social function and facility classes; and

LOF_s^m is loss of function in days by social function class and MMI.

FEMA 227 (1992) indicates that "the expected loss of function in damaged facilities is the total number of days of function expected to be lost". Earthquake damage may render buildings unfit for their normal functions until repairs are made or until destroyed buildings are replaced. Rents and other incomes maybe lost during this loss of function interval and relocation costs may also be incurred. In the model, values of loss of function presented by ATC-13 and shown in Appendix C are used. It is considered that these values are also valid for Turkey.

Relocation expenses avoided are calculated by the floor area in square meter times the relocation costs per square meter per day times the expected loss of function in days due to earthquake damage times the expected loss of function due to earthquake damage times the expected effectiveness of the rehabilitation in reducing loss of function. According to FEMA, relocation expenses are:

$$REL_{sf}^{m} = FA_{sf}\, RC_{s}\, LOF_{s}^{m}\, ERE_{f}^{m} \tag{5.6}$$

where:

RC_s is relocation costs per square meter per day by social function class.

Relocation costs occur when damage of the building requires repairs and the pre-earthquake function of the facility is partially or fully lost.

Income losses avoided are calculated by the floor area of the buildings times the income generated per square meter per day times the expected loss of function in days due to earthquake damage times the expected effectiveness of the rehabilitation in reducing loss of function. Income losses avoided are expressed as:

$$Y_{sf}^{m} = FA_{sf}\, INC_{s}\, LOF_{s}^{m}\, ERE_{f}^{m} \tag{5.7}$$

where:

INC_s is personal and proprietors' income generated per square meter per day.

Disruption of income which is defined as personal and proprietor's income in the model depends on occupancy and social function of the building. For income loss to occur, damage of the building has to disrupt commercial activity.

Business inventory losses are calculated by the floor area of the buildings in square meter times the annual gross sales or production times the percent of gross sales or production which constitutes inventory times mean damage function times the effectiveness of the rehabilitation in reducing building damage. Business inventory losses are defined as:

$$INV_{sf}^{m} = FA_{sf} SALES_{s} BI_{s} MDF_{f}^{m} ERE_{f}^{m} \qquad (5.8)$$

where:

$SALES_s$ is annual gross sales or production; and

BI_s is inventory as a percent of gross sales or production.

Business inventory varies drastically depending on the specific businesses and social function. Furthermore, business inventory losses must be estimated in accordance with the types of business concerned (FEMA 227 1992).

Personal property losses are calculated by the floor area of the buildings in square meter times the replacement value of the buildings per square meter times the value of personal property (building contents) as a percentage of building value times the mean damage function times the effectiveness of the rehabilitation in reducing building damages. Personal property losses are:

$$PP_{sf}^{m} = FA_{sf} RV_{sf} PPROP_{s} MDF_{f}^{m} ERE_{f}^{m} \qquad (5.9)$$

where:

$PPROP_s$ is personal property (building contents) as a percentage of building replacement value.

All building contents except business inventory and non-structural building elements produce personal losses. The estimated compositions and contents of various facilities are determined by Applied Technology Council (ATC) and it summarizes typical values of building contents for various social function classifications.

The classifications and values described above are shown in Appendix C for various social functions.

5.3. Seismic Rehabilitation Cost

Estimating the cost of seismic rehabilitation for existing buildings is a difficult and important issue, because assessment of existing buildings is a complex process. According to FEMA 228 (1992), seismic rehabilitation costs vary by:

- Building type (masonry, concrete frame, steel frame, etc.)
- Building characteristics (height, configuration, footprint size) and
- Building conditions (original construction quality and maintenance).

“Typical cost” is the mean structural cost of seismic rehabilitation of a building. Turkish Standardizations Institute (TSE) expressed the structural costs for various building types in Turkish Liras per square meter.

FEMA classifies the structural costs into two categories such as direct costs and indirect costs. “The direct costs represent the bill received by the owner from the contractor” (FEMA 156 1994). Indirect costs, on the other hand, are costs that come about as a result of the rehabilitation work and affect the owner.

Direct costs are also divided into two sub-categories: construction costs and non-construction costs. Construction costs are described as the amount paid to the contractor and non-construction costs are described as the amount paid to anyone other than the contractor in order to complete the project.

Indirect costs are also subdivided into two parts as seismic and non-seismic. Seismic indirect costs are those associated with costs directly incurred in actually making the building better able to withstand seismic forces. Non-seismic indirect costs are those that are often incurred by the seismic construction work (FEMA 156 1994).

In following section, the direct rehabilitation costs are clarified.

5.3.1. Direct Rehabilitation Costs

Direct rehabilitation costs can be ranged as below:

Construction Costs

Seismic

- Structural rehabilitation work
- Non-structural rehabilitation work
- Demolition and restoration
- Damage repair

Non-seismic

- System improvements
- Disabled access improvements
- Hazardous material removal

Non-construction Costs

- Project management
- Architectural and engineering design fees
- Relocation
- Testing and permits

5.3.1.1. Seismic Construction Costs

Seismic construction costs are the costs dictated directly by the decision to fulfil seismic rehabilitation work. The other expenditures made to the architectural, electrical, mechanical, plumbing, or other systems of the building are exterior while estimating the direct seismic construction costs. The cost components adapted from FEMA 156 (1994) are defined below:

- **Structural Rehabilitation Cost:** This is the cost for structural work fulfilled by the contractor and the sub-contractor.
- **Non-Structural Rehabilitation Costs:** This is the cost to reduce the risk of failure of certain non-structural elements of the building. Non-structural rehabilitation costs include consideration of cladding, hazards relating to the failure of exterior walls, and other elements that may interact with structural systems.
- **Demolition and Restoration Costs:** The structural rehabilitation also necessitates the architectural work. The cost for architectural work included items such as demolition and replacement cost for wall and ceiling finishes, removal and

reinstallation of electrical and mechanical equipment, and roofing are called as demolition and restoration costs.

- **Damage Repair:** This is the cost to repair any of the existing lateral force resisting elements that have been damaged due to previous earthquakes, ground settlement and deterioration.

5.3.1.2. Non-Seismic Construction Costs

These costs represent the items that do not directly improve the seismic performance of the building but may be triggered by the seismic rehabilitation. These costs can vary greatly depending upon the individual building characteristics and the applicable regulations. These costs can be classified as system improvement costs such as fire and life safety, mechanical, plumbing and electrical renovation, architectural renovation, hazardous material removal costs and disabled access improvement costs.

5.3.1.3. Non-Construction Costs

Non-construction costs are the costs paid by the owner of the building to other persons than the contractor.

- **Management Costs:** This is the cost necessary to manage the project. As indicated in FEMA 156 (1994), “these costs may include performing analyses to determine the impact of various levels of rehabilitation; determining the scope and organization of the project; obtaining financing; hiring, answering questions, paying and negotiating with design consultants, testing laboratories, and contractors; addressing city requirements and the concerns of affected tenants and clients; and handling the many other tasks needed to successfully complete a rehabilitation project.”
- **Design Fees, Testing and Permitting Costs:** Design fees cover the costs of design professionals such as structural and civil engineers, architects, geology engineers, surveyors, and cost estimators required to perform the structural work. Obtaining a building permit requires paying a fee to the building department to cover their plan checking, field inspection and recording costs.

- **Relocation Costs:** These are the costs to relocate occupants and equipment due to the disruption expected by the construction.

In addition, any extra costs paid by the owner of the building during the construction can be added to the seismic rehabilitation costs. In the calculations of the applications of benefit/cost analysis upon the existing reinforced concrete buildings in Izmir, the seismic rehabilitation cost has been taken as expected total amount which will be paid by the owners of the buildings to any persons till the buildings are ready to use.

5.4. Benefit/Cost Ratio

The last step of the befit/cost analysis is to determine the benefit/cost ratio which will give the result of whether the seismic rehabilitation investment is economically justified.

When the obtained present value of future benefits including the salvage value is less than costs, then the expected net present value is also negative. When the present value of future benefits exceeds the initial cost, then the expected net present value is also positive.

Benefit/cost ratio is calculated by dividing the expected present value of future benefits by the rehabilitation cost. If the benefit/cost ratio is greater than one, the proposed rehabilitation project is economically justified; unless benefit/cost ratio is greater than one, the project is not justified on the basis of the economic assumptions made in the model.

In both cases, the results of the analysis must be interpreted carefully and the choice should be left to the owners or decision makers.

CHAPTER 6

EXAMPLE APPLICATIONS OF THE BENEFIT/COST MODEL

6.1. Introduction

Two examples illustrating the implication of benefit/cost model described in the previous chapter are included in this chapter. These examples are chosen to represent a broad range of geographic locations in Izmir, soil types and building uses. Both examples use a 4% discount rate and 50-year planning horizon. However, to be more representative, the results are recalculated by using different discount rates.

The examples include:

- Konak, Izmir – Tontoş Bebe retail store as retail trade in reinforced concrete building,
- Tire, Izmir – a bank as professional, technical and business services in reinforced concrete building.

6.2. Konak, Izmir–Tontoş Bebe Retail Store

The Konak example considers a retail store called Tontoş Bebe, a reinforced concrete building which has a structure area of 735 square meters. Daily occupancy in this store is about 45 people in business hours, at night the store is closed. The soil type in the region of the building is Z4.

The 5-storey building was constructed in 1965 as a reinforced concrete building. This building has already been decided by the owner for seismic rehabilitation and the rehabilitation construction was almost completed when its benefit/cost analysis started.

In order to estimate the concrete quality used in the main construction, cylindrical specimens of Ø100 mm in diameter taken from eight columns in each storey have been tested in compression by a private structure laboratory. According to the results, the concrete quality was concluded as inadequate. The building has also been investigated for the rebar adequacy, and the quantity of steel used in some columns was observed below the level required.

Therefore, a rehabilitation project was prepared based on the current Turkish code for a seismic design published in 1997. Since upgrading lots of columns and beams is not practical and economic, new shear walls have been used to resist the seismic forces (Figure 6.2). The columns, which were inadequate for gravitational loads according to the rehabilitation project of the building, have been rehabilitated by using the jacketing method.

The owner of the building paid 247.450 YTL. For the rehabilitation of the building which included direct rehabilitation costs (172.850 YTL.), indirect rehabilitation costs (17.100 YTL.) and extra costs (57.500 YTL.).

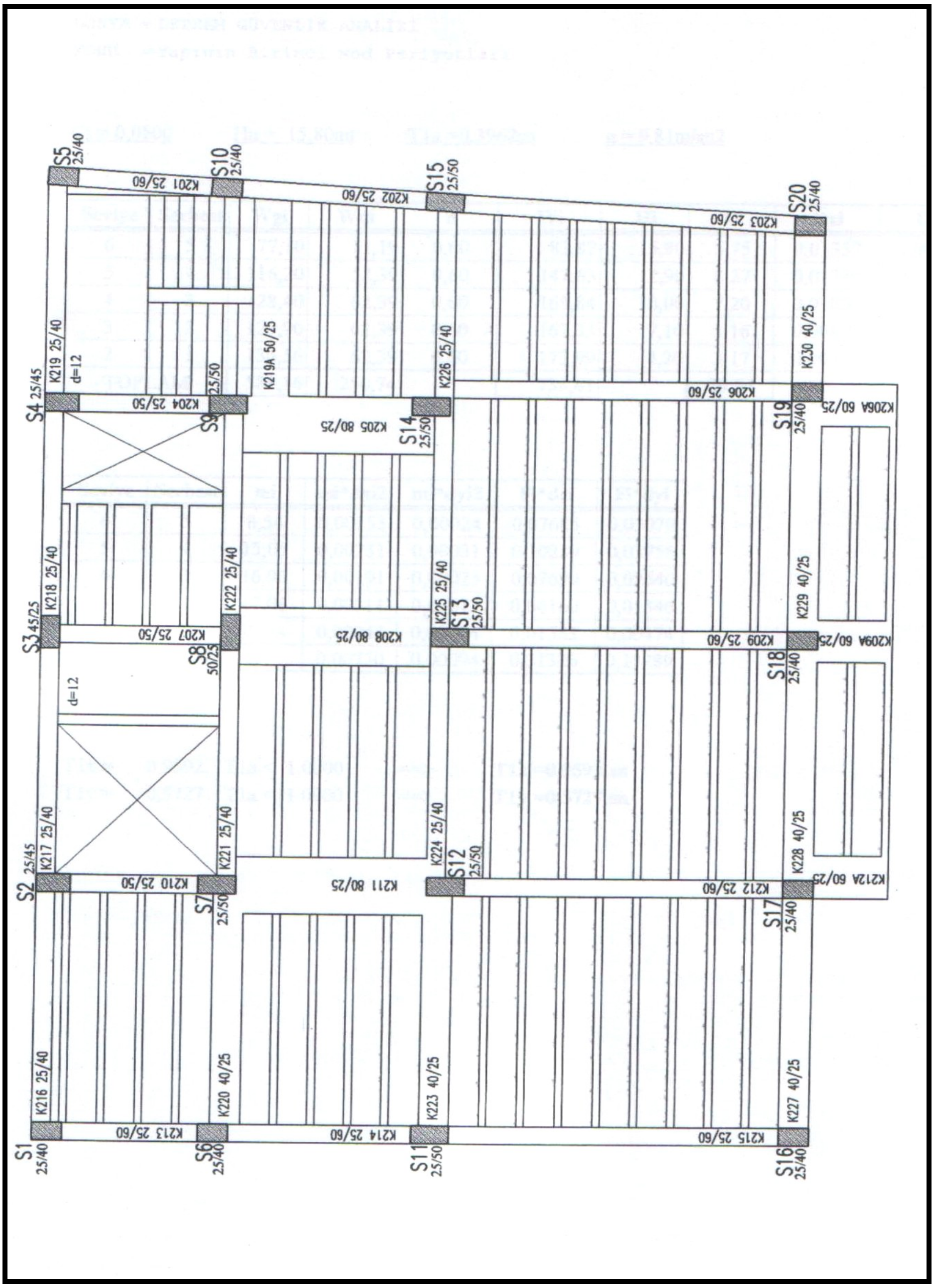


Figure 6.2. Floor Plan of the Main Project

(Source: Uzakgören, 2004)

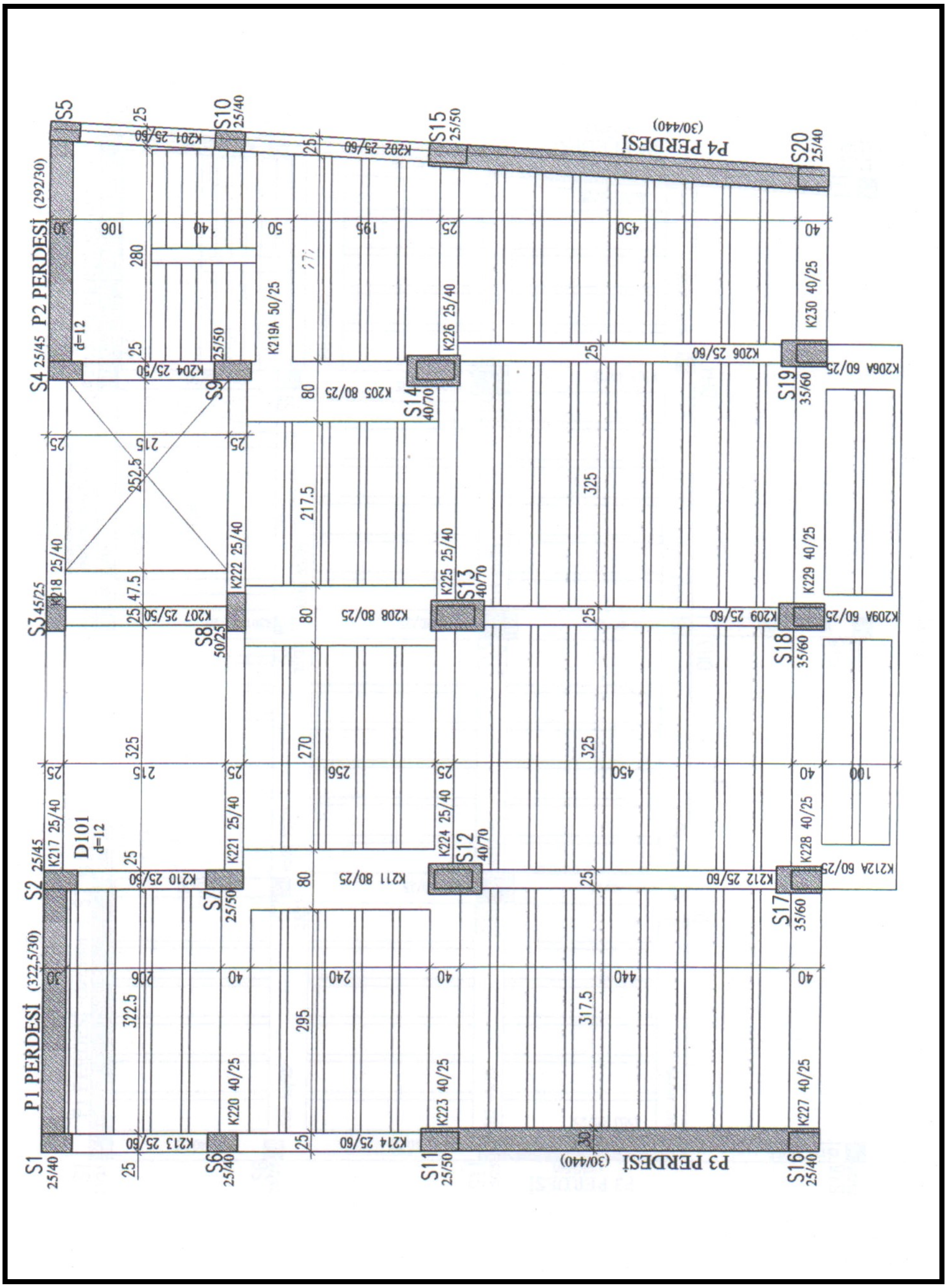


Figure 6.2. Floor Plan of the Rehabilitation Project

(Source: Uzakgören 2004)

Figure 6.3. A Rehabilitated Column by using Jacketing Method
(Courtesy of Rehber Yapı Denetim San. Ve Tic. A.Ş.)

Figure 6.4. A Rehabilitated Column by using Jacketing Method
(Courtesy of Rehber Yapı Denetim San. ve Tic. A.Ş.)

Figure 6.5. A New Shear Wall
(Courtesy of Rehber Yapı Denetim San. ve Tic. A.Ş.)

Figure 6.6. A New Shear Wall

(Courtesy of Rehber Yapı Denetim San. ve Tic. A.Ş.)

Table 6.1. Main Data of Tontoş Bebe Retail Store

DATA ENTRY			
Geographic&Geologic Information			
1. Facility ID:	Tontoş BEBE Five Storey Reinforced Concrete Retail Store		
2. City:	Izmir		
3. Annual Earthquake Probabilities:		MMI	Probability
		VI	1
		VII	1
		VIII	0.07473
		IX	0.03809
		X	0.00966
		XI	0
4. Soil Type:	Z4		
Structural&Engineering Information			
5. Facility Class:	Reinforced Concrete Medium Rise, # 4 (Table 4.1)		
6. Size of Building (sq. m.):	735.00		
7. Damage Probability Matrix:		MMI	Probability (%)
		VI	13.0
		VII	27.0
		VIII	43.8
		IX	67.6
		X	86.0
		XI	97.0
8. Average Retrofit Effectiveness(Table C5):		MMI	Damages (%)
		VI	35
		VII	35
		VIII	31
		IX	28
		X	24
		XI	20
9. Direct Retrofit Costs:			172.850 YTL.
10. Indirect Retrofit Costs:			17.100 YTL.
11. Additional Indirect Cost:			57.500 YTL.
12. Total Rehabilitation Cost:			247.450 YTL.
13. Retrofit Salvage Value as a % of Retrofit Cost:			10%

Table 6.1. Continued Main Data of Tontoş Bebe Retail Store

Building Use		
14. Social Function Classification:	Retail #4	
Building Economic Information		
15. Replacement Building Value/sq.m.:		283 YTL.
16. Total Building Replacement Value:		208.005 YTL.
17. Rental Rates per sq.m. of building size per month:		0 YTL.
18. Relocation Expenses per sq.m. per month:		22,92 YTL.
19. Income per sq.m. of building size per month:		90 YTL.
20. Loss of function see Appendix C (Table C.1):		
21. Business Inventory per sq.m.		476 YTL.
22. Personal Property Value (% of Replacement Value) (Table C.2):		9%
General Economic Information		
23. The Discount Rate:		4%
24. The Planning Horizon in years:		50
25. The Net Present Value Coefficient to be used for this analysis see Appendix C (Table C.3):		21.482
26. The Coefficient to determine the present value of initial rehabilitation investment see Appendix C (Table C.4)		0.141

Table 6.1 represents the main data of the building. First part identifies the building in geographic and geologic details. The soil type of the area that the building located in is silty clay with medium dense sand which is classified as Z4. The annual probabilities have been calculated in Chapter 3. The following section describes the structural and engineering information about Tontoş Bebe Retail Store. Damage probabilities for Izmir have been described in Chapter 4 and the average effectiveness matrix has been adapted from FEMA. Total rehabilitation cost has been obtained with the sum of the costs that the owner has paid directly and indirectly. The replacement value per square meter is 283,00 YTL for the social function of retail stores in unit prices list of Turkey. Total replacement value has been calculated by the product of replacement value and total building area in square meters. Other unit prices of future benefits are given in the section of building economic information in the table. In general economic information, the discount rate and planning horizon are optional, as 4% discount rate and 50 years of planning horizon chosen for the sample. The coefficients used in the analysis are shown in the tables in Appendix C.

In the Benefit/Cost analysis of FEMA, after the description of the building properties, scenario damages and economic losses are computed with the formulation of possible damages, times mean damage function, plus possible economic losses, times loss of function. The scenario damages and economic losses are calculated for each expected benefits in each MMI. The calculations of the row in MMI=VI are shown below as an instance.

<u>Building Damages</u>= Replacement Value*MDF= 208005*0,13=27040,65

<u>Rental Income</u>= Rental Rate*Time not Rented (LOF)= 0*3,4=0

<u>Relocation Expenses</u>= Relocation Expenses*Time of Relocation (LOF)=

2,92*735*3,4/30=1909,2 (LOF in days, thus it is divided by 30)

<u>Income Losses</u>= Income Rates*Time Out of Business=90*735*3.4/30=7497

<u>Business Inventory</u>= Inventory Value*MDF= 476*735*0,13=45481,80

<u>Personal Property</u>= Property Value*MDF= 208005*0,09*0,13=2433,70

Other rows are calculated similarly.

Table 6.2.a. Model Results

Scenario Damages and Economic Losses=(Possible Damages*Mean Damage Function)+(Possible Economic Losses*Loss of Function)				
Facility ID:	Tontoş BEBE (Five Storey Reinforced Concrete Retail Store)			
MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
	(Replacement Value*MDF)	(Rental Rate*Time Not Rented)	(Relocation Expenses*Time of Relocation)	(Income Rates*Time Out of Business)
VI	27040,65	0,00	1909,24	7497,00
VII	56161,35	0,00	6783,40	26636,40
VIII	91106,19	0,00	25112,07	98607,60
IX	140611,40	0,00	70563,12	277080,30
X	178884,30	0,00	132388,67	519850,80
XI	201764,90	0,00	194815,07	764980,65

MMI	Business Inventory	Personal Property	Total Scenario Losses
	(Inventory Value*MDF)	(Property Value*MDF)	
VI	45481,80	2433,70	84362,39
VII	94462,20	5054,50	189097,85
VIII	153238,70	8199,60	376264,16
IX	236505,40	12655,00	737415,22
X	300879,60	16099,60	1148102,97
XI	339364,20	18158,80	1519083,62

The second rank at the analysis is calculation of the expected damages and economic losses. Hence, the scenario damages and economic losses are multiplied by expected earthquake probabilities. For the same row of MMI=VI, the annual probability of earthquake occurrence is 1, thus the values on the row have not changed.

Table 6.2.b. Model Results

Expected Damages and Economic Losses=Scenario Damages & Economic Losses*Expected Number of Earthquakes				
Facility ID:	Tontoş BEBE (Five Storey Reinforced Concrete Retail Store)			
MMI	Building Damages (Replacement Value*MDF)	Rental Income (Rental Rate*Time Not Rented)	Relocation Expenses (Relocation Expenses*Time of Relocation)	Income Losses (Income Rates*Time Out of Business)
VI	27040,65	0,00	1909,24	7497,00
VII	56161,35	0,00	6783,4	26636,40
VIII	6808,37	0,00	1876,62	7368,95
IX	5355,88	0,00	2687,75	10553,99
X	1728,02	0,00	1278,87	5021,76
XI	0,00	0,00	0,00	0,00
Total	97094,27	0,00	14535,88	57078,10
MMI	Business Inventory (Inventory Value*MDF)	Personal Property (Property Value*MDF)	Total Scenario Losses	
VI	45481,8	2433,7	84362,39	
VII	94462,2	5054,5	189097,85	
VIII	11451,5	612,75	28118,19	
IX	9008,5	482	28088,12	
X	2906,5	155,5	11090,65	
XI	0,00	0,00	0,00	
Total	163310,50	8738,45	340757,20	

In the last result table, the total expected benefit is obtained. Expected damages and economic losses avoided are calculated as expected damages and economic losses times Therefore, the values in previous table are multiplied by the average effectiveness values. For example;

Building Damages= 27040,65*35/100=9464,23

Rental Income= 0

Relocation Expenses= 1909,2*35/100= 668,23

Income Losses= 7497*35/100=2623,95

Business Inventory= 45481,80*35/100=15918,60

Personal Property= 2433,70*35/100=851,80

Table 6.2.c. Model Results

Expected Damages and Economic Losses Avoided=Expected Damages & Economic Losses*Effectiveness of the Rehabilitation				
Facility ID:	Tontoş BEBE (Five Storey Reinforced Concrete Retail Store)			
MMI	Building Damages	Rental Income	Relocation Expenses	Income Losses
	(Replacement Value*MDF)	(Rental Rate*Time Not Rented)	(Relocation Expenses*Time of Relocation)	(Income Rates*Time Out of Business)
VI	9464,23	0,00	668,23	2623,95
VII	19656,50	0,00	2374,19	9322,74
VIII	2110,60	0,00	581,75	2284,37
IX	1499,60	0,00	752,57	2955,12
X	414,70	0,00	306,93	1205,22
XI	0,00	0,00	0	0
Total	33145,63	0,00	4683,67	18391,40
MMI	Business Inventory	Personal Property	Total Scenario Losses	
	(Inventory Value*MDF)	(Property Value*MDF)		
VI	15918,60	851,80	29526,81	
VII	33061,80	1769,00	66184,23	
VIII	3549,97	189,95	8716,64	
IX	2522,40	134,96	7864,65	
X	697,56	37,32	2661,73	
XI	0,00	0,00	0,00	
Total	55750,33	2983,03	114954,06	

At the end of the calculations, the total benefit value of Tontoş Bebe Retail Store has been obtained as 114.954,06 YTL. Next step of the analysis which is the last one is to compute the Benefit/Cost ratio.To determine the present value of benefits, the annual benefits during 50 years are discounted. For that reason, total benefit value is multiplied by the the net present value coefficient to be used for the analysis, which is

21.482 for 50 years horizon and 4% discount rate. Likely, present value of investment cost is calculated with the product of rehabilitation cost and the coefficient which is 0.141. As it defined in Chapter 5, the expected net present value of a seismic rehabilitation investment is calculated by the sum of the present value of benefits expected to accrue each year over the planning period, plus the present value of the salvage value of the rehabilitation investment at the end of the planning period, minus the initial cost of the rehabilitation. Thus, the B/C for Tontoş Bebe Retail Store is obtained as 10,12.

Table 6.2.d. Model Results

TOTAL BENEFITS	114.954,06 YTL.
PRESENT VALUE of BENEFITS	2.469.443,12 YTL.
REHABILITATION COST	247.450 YTL.
PV of INVESTMENT in TERMINAL YEAR	3.489,05 YTL.
TOTAL COST	243.961 YTL.
B-C (without value of life)	2.225.482,12 YTL.
B/C (without value of life)	10.12

Table 6.3. B/C Ratios Calculated by using Different Discount Rates (1)

DISCOUNT RATE	TOTAL BENEFITS (YTL)	TOTAL COST (YTL)	B-C (YTL)	B/C
3	2.957.768,00	241.808,14	2.715.959,86	12.23
4	2.469.443,12	243.961,00	2.225.482,12	10.12
5	2.098.601,32	245.297,20	1.853.304,12	8.55
6	1.811.905,90.	246.113,77	1.565.792,13	7.36
8	1.405.888,15	246.922,93	1.158.965,22	5.69
10	1.139.769,51.	247.239,67	892.529,84	4.61
15	765.594,04	247.427,16	518.166,88	3.09
20	574.655,35	247.447,28	327.208,07	2.32
25	459.701,28	247.449,65	212.251,63	1.85

As it is seen in Table 6.3, the Benefit/Cost ratios decrease by the increased discount rates. Due to the benefit/cost ratio is greater than one, the investigated rehabilitation project of the Tontoş Bebe Retail Store is economically justified.

6.3. A Bank in Tire

Three storey reinforced concrete building is used as a bank in Tire region. Daily occupancy is average 80 people in business hours and at night the bank is closed. The bank classified the soil type as Z2 in the area. Total building area is 716,00 square meters.

The bank has been decided first to rehabilitate seismically but then decision has been changed into replacement. Due to it is a public bank, it has been thought that daily income and relocation expenses of the bank are private. Thus these values have not been gathered.

In order to not effect the benefit/cost ratio of the building, a conjectural value for the income of the bank has been used as 68,16 YTL. per meter per month and the relocation expenses are same with the previous example, as 22,92 YTL. per month. The total net revenue of this bank is 204.000.000 YTL during 2005 and it has 836 branch offices in Turkey. It is assumed that each branch office has the same revenue. Thus the income of the bank in Tire has been established as 68,16 YTL. per square meter per month.

The building is planned to rehabilitate by the shear walls shown in Figure 6.3, Figure 6.4 and Figure 6.5. Particularly, Figure 6.3 represents only the axes C-E and 7-9.

The expected rehabilitation cost of the building is 29.417,11 YTL. and the total replacement value is 287.832 YTL.

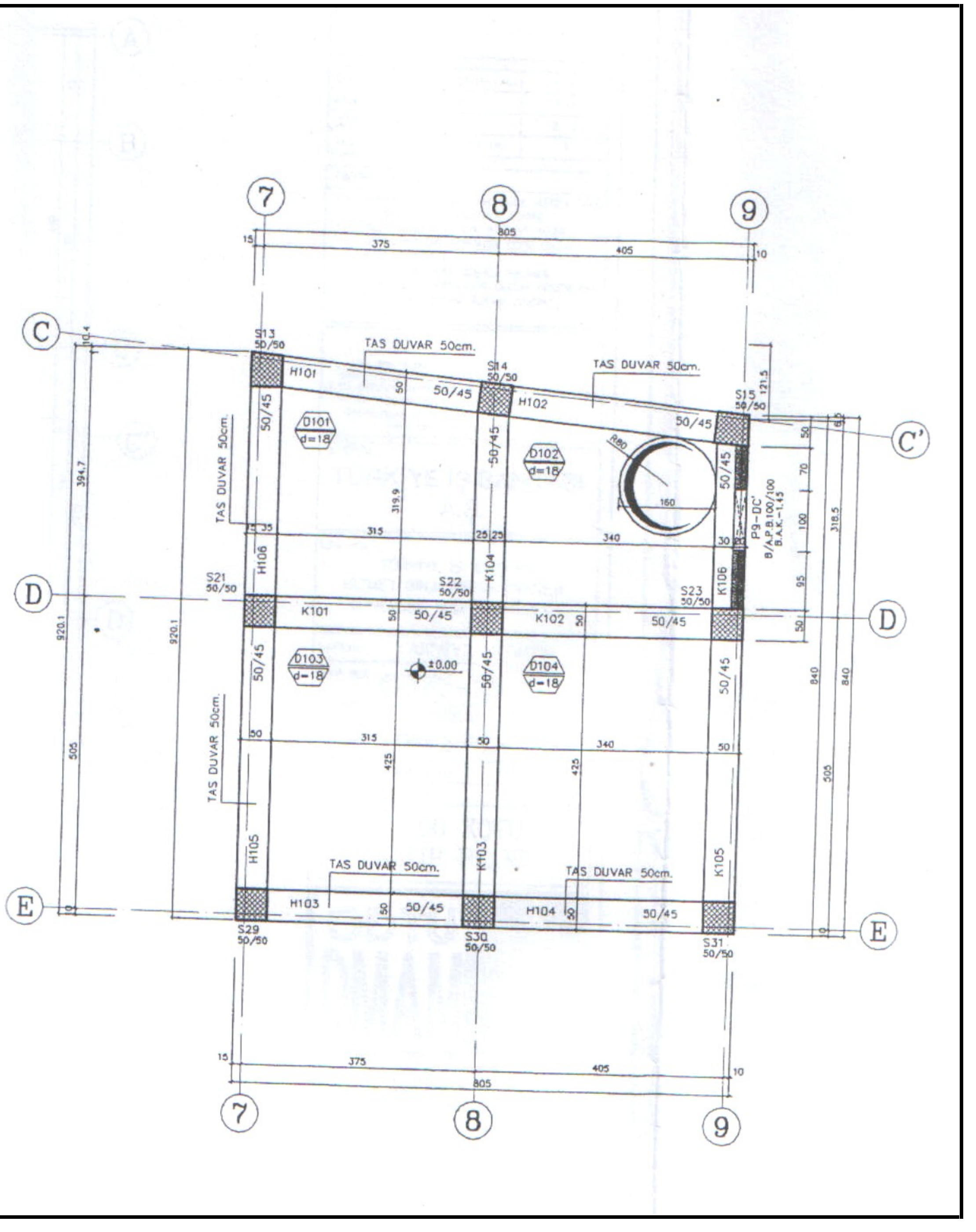


Figure 6.7. Basement Floor Plan of the Expected Rehabilitation Project
(Courtesy of Prota Mühendislik Proje ve Danışmanlık Hizmetleri Ltd. Şti.)

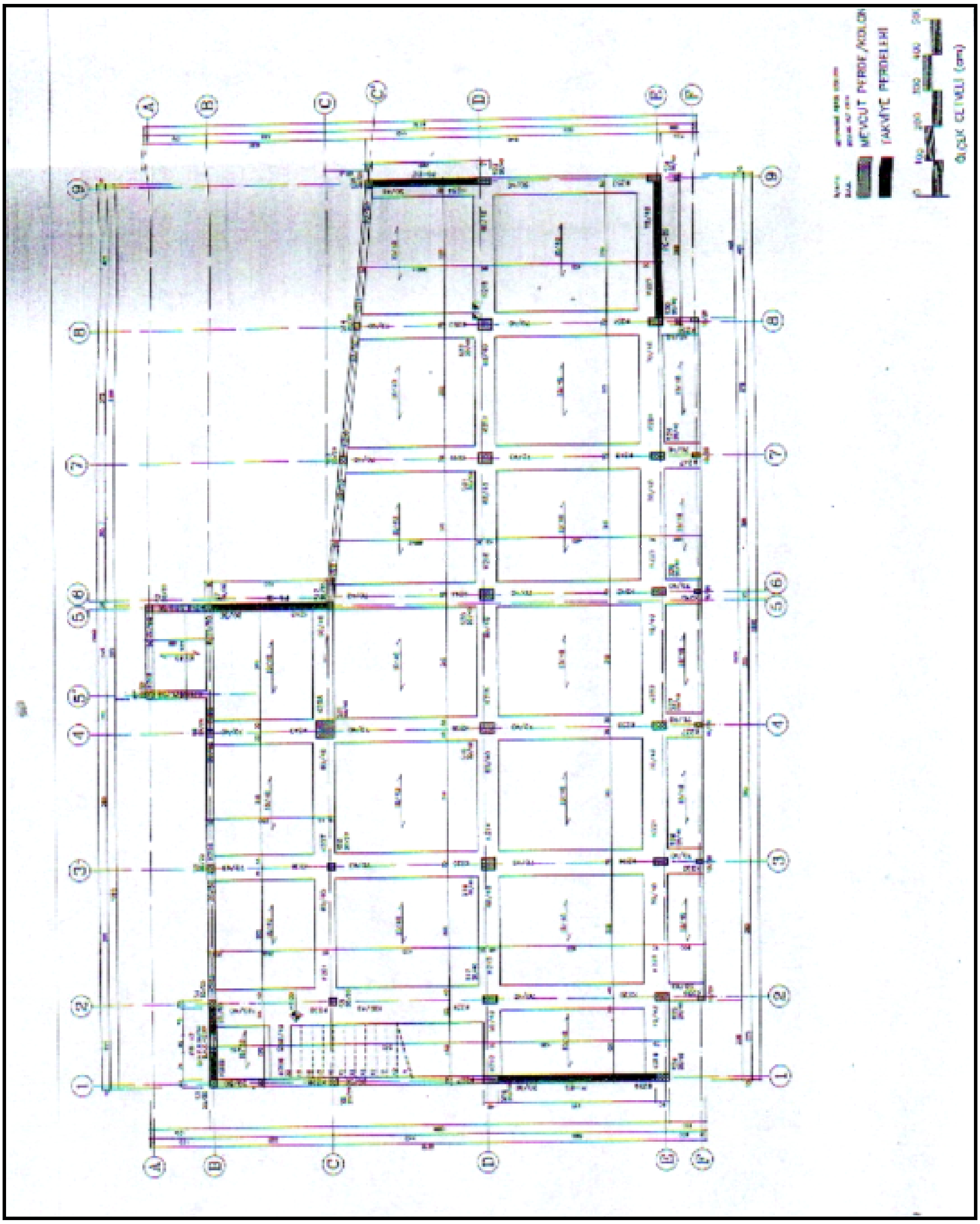


Figure 6.8. Ground Floor Plan of the Expected Rehabilitation Project
(Courtesy of Prota Mühendislik Proje ve Danışmanlık Hizmetleri Ltd. Şti.)

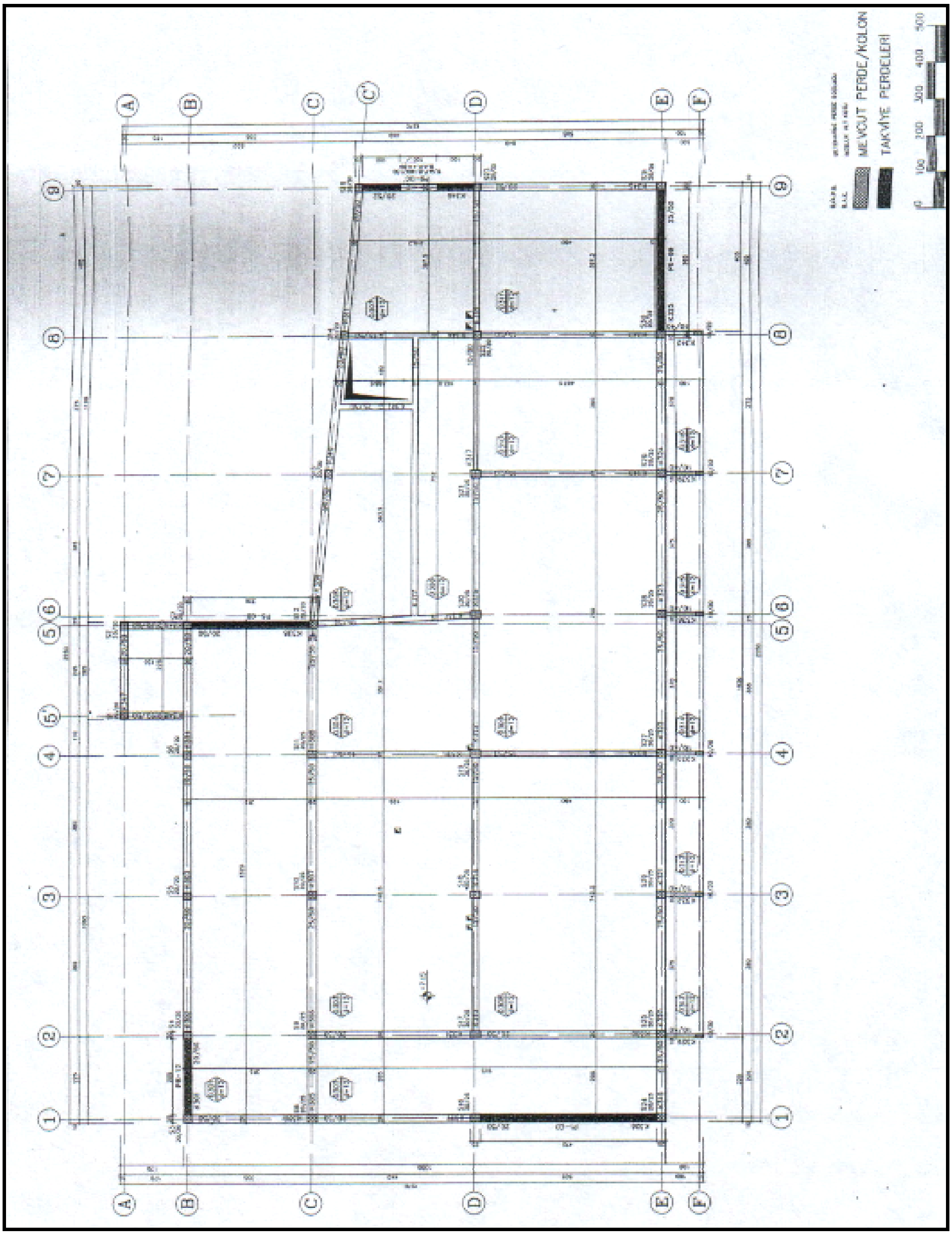


Figure 6.9. First Floor Plan of the Expected Rehabilitation Project

(Courtesy of Prota Mühendislik Proje ve Danışmanlık Hizmetleri Ltd. Şti.)

Table 6.4. Main Data of the Bank in Tire

DATA ENTRY			
Geographic & Geologic Information			
1. Facility ID:	A Bank in Tire Three Storey Reinforced Concrete Building		
2. City:	Izmir		
3. Annual Earthquake Probabilities:		MMI	Probability
		VI	1
		VII	1
		VIII	0.07473
		IX	0.03809
		X	0.00966
		XI	0
4. Soil Type:	Z2		
Structural & Engineering Information			
5. Facility Class:	Reinforced Concrete Low Rise, # 3 (Table 4.1)		
6. Size of Building (sq. m.):	716.00		
7. Damage Probability Matrix:		MMI	Probability (%)
		VI	1.8
		VII	6.5
		VIII	17.5
		IX	31.0
		X	52.5
		XI	74.0
8. Average Retrofit Effectiveness (Table C5):		MMI	Damages (%)
		VI	35
		VII	35
		VIII	31
		IX	28
		X	24
		XI	20
9. Direct Retrofit Costs:			22.019,83 YTL.
10. Indirect Retrofit Costs:			7.397,28 YTL.
11. Additional Indirect Cost:			0,00 YTL.
12. Total Rehabilitation Cost:			29.417,11YTL.
13. Retrofit Salvage Value as a % of Retrofit Cost:			10%

Table 6.4. Continued Main Data of the Bank in Tire

Building Use		
14. Social Function Classification:	Business Services #7	
Building Economic Information		
15. Replacement Building Value/sq.m.:		402 YTL.
16. Total Building Replacement Value:		287.832 YTL.
17. Rental Rates per sq.m. of building size per month:		0 YTL.
18. Relocation Expenses per sq.m. per month:		22,92 YTL.
19. Income per sq.m. of building size per month:		68,16 YTL.
20. Loss of function see Appendix C (Table C1):		
21. Business Inventory per sq.m.		0 YTL.
22. Personal Property Value (% of Replacement Value) (Table C.2):		34%
General Economic Information		
23. The Discount Rate:		4%
24. The Planning Horizon in years:		50
25. The Net Present Value Coefficient to be used for this analysis (Table C.3):		21.482
26. The Coefficient to determine the present value of initial rehabilitation investment see Appendix C (Table C.4):		0.141

As in the previous sample, all procedures are valid for this bank. Due to its social function as number 3, some values are different from Tontoş Bebe Retail Store. The soil class is Z2 in this sample and total rehabilitation cost of the project is 29.417,11 YTL. Total replacement value is 287.832 YTL. Personal property value for a bank is 34% of replacement value. There is no production in a bank, for this reason, business inventory is zero.

The results of the bank are given in Table 6.5.a, Table 6.5.b, and Table 6.5.c below.

Table 6.5.a. Model Results

Scenario Damages and Economic Losses= (Possible Damages*Mean Damage Function) + (Possible Economic Losses*Loss of Function)				
Facility ID:	A Bank in Tire (Three Storey Reinforced Concrete Building)			
MMI	Building Damages (Replacement Value*MDF)	Rental Income (Rental Rate*Time Not Rented)	Relocation Expenses (Relocation Expenses*Time of Relocation)	Income Losses (Income Rates*Time Out of Business)
VI	5180,98	0,00	1859,88	5530,96
VII	18709,08	0,00	6608,05	19651,16
VIII	50370,60	0,00	24462,92	72748,35
IX	89227,92	0,00	68739,04	204417,66
X	151111,80	0,00	128966,38	383523,05
XI	212995,68	0,00	189779,04	564369,07
MMI	Business Inventory (Inventory Value*MDF)	Personal Property (Property Value*MDF)	Total Scenario Losses	
VI	0,00	1761,53	14333,35	
VII	0,00	6361,09	51329,38	
VIII	0,00	17126,00	164707,87	
IX	0,00	30337,49	392722,11	
X	0,00	51378,01	714979,24	
XI	0,00	72418,53	1039562,32	

Table 6.5.b. Model Results

Expected Damages and Economic Losses=Scenario Damages & Economic Losses*Expected Number of Earthquakes				
Facility ID:	A Bank in Tire (Three Storey Reinforced Concrete Building)			
MMI	Building Damages (Replacement Value*MDF)	Rental Income (Rental Rate*Time Not Rented)	Relocation Expenses (Relocation Expenses*Time of Relocation)	Income Losses (Income Rates*Time Out of Business)
VI	5180,98	0,00	1859,88	5530,96
VII	18709,08	0,00	6608,05	19651,16
VIII	3764,2	0,00	1828,11	5436,48
IX	3398,69	0,00	2618,27	7786,27
X	1459,74	0,00	1245,81	3704,83
XI	0,00	0,00	0,00	0,00
Total	32512,69	0,00	14160,12	42109,70
MMI	Business Inventory (Inventory Value*MDF)	Personal Property (Property Value*MDF)	Total Scenario Losses	
VI	0,00	1761,53	14333,35	
VII	0,00	6361,09	51329,38	
VIII	0,00	1279,83	12308,62	
IX	0,00	1155,55	14958,78	
X	0,00	496,31	6906,69	
XI	0,00	0,00	0,00	
Total	0,00	11054,31	99836,82	

Table 6.5.c. Model Results

Expected Damages and Economic Losses Avoided=Expected Damages & Economic Losses*Effectiveness of the Rehabilitation				
Facility ID:	A Bank in Tire (Three Storey Reinforced Concrete Building)			
MMI	Building Damages (Replacement Value*MDF)	Rental Income (Rental Rate*Time Not Rented)	Relocation Expenses (Relocation Expenses*Time of Relocation)	Income Losses (Income Rates*Time Out of Business)
VI	1813,34	0,00	650,96	1935,84
VII	6548,17	0,00	2312,82	6877,91
VIII	1166,90	0,00	566,71	1685,31
IX	951,63	0,00	733,12	2180,16
X	350,34	0,00	298,99	889,16
XI	0,00	0,00	0,00	0,00
Total	10830,38	0,00	4562,6	13568,38

MMI	Business Inventory (Inventory Value*MDF)	Personal Property (Property Value*MDF)	Total Scenario Losses
VI	0,00	616,54	5016,68
VII	0,00	2226,38	17965,28
VIII	0,00	396,75	3815,67
IX	0,00	323,55	4188,46
X	0,00	119,12	1657,61
XI	0,00	0,00	0,00
Total	0,00	3682,34	32643,70

Following the same steps explained in previous sample, the scenario damages and economic losses for each possible damage and loss have been calculated. The expected damages and economic losses have been estimated multiplying the scenario damages by expected number of earthquakes. Then the estimation of benefits has been completed with the expected damages and economic losses avoided multiplied by the effectiveness of the rehabilitation. At the end of the analysis of the bank in Tire, the total benefits have been obtained as 32.643,70 YTL. The present value of benefits is calculated as 701.251,96 from 32.643,70*21,482. Present value of investment in terminal year is 414,78 YTL. Therefore, the Benefit/Cost ratio is determined as 24,18 for the bank in Tire.

Table 6.5.d. Model Results

TOTAL BENEFITS	32.643,70 YTL.
PRESENT VALUE of BENEFITS	701.251,96 YTL.
REHABILITATION COST	29.417,11 YTL
PV of INVESTMENT in TERMINAL YEAR	414,78 YTL.
TOTAL COST	29.002,33 YTL.
B-C (without value of life)	672.249,63 YTL.
B/C (without value of life)	24.18

Table 6.6. B/C Ratios Calculated by using Different Discount Rates (2)

DISCOUNT RATE	TOTAL BENEFITS (YTL)	TOTAL COST (YTL)	B-C (YTL)	B/C
3	839.922,40	28.746,40	811.176,00	29.21
4	701.251,96	29.002,33	672.249,63	24.18
5	595.943,39	29.161,18	566.782,21	20.44
6	514.530,00	29.258,26	485.271,74	17.59
8	399.232,45	29.354,45	369.878,00	13.60
10	323.662,30	29.392,11	294.270,19	11.01
15	217.407,04	29.414,39	187.992,65	7.39
20	163.185,86	29.416,79	133.769,07	5.55
25	130.542,16	29.417,07	101.125,09	4.44

The B/C ratio is also greater than one for this sample which means the investigated seismic rehabilitation project of the bank in Tire is economically justified. Although the B/C ratio estimated with the model presented by FEMA is greater than one, the owners of the bank have decided to replace the structure to resist the seismic forces in the reason of changing its architecture.

It obviously is seen that, the rehabilitation costs are quite lower than the benefits to each year accrue over the planning horizon of the proposed rehabilitation projects in Turkey.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

In this thesis, a benefit/cost model for seismic rehabilitation of the existing reinforced concrete buildings in Izmir has been studied. The model constituted by Federal Emergency Management Agency has been applied to two different reinforced concrete buildings which have different social function and soil type. Both examples use a 4% discount rate and 50-year planning horizon. In order to gather the data of the benefit/cost analysis for the seismic rehabilitation of existing reinforced concrete buildings in Izmir, the seismology of Izmir has been investigated and the earthquake probabilities of Izmir Region for 50 years of return period have been calculated with Poisson Model by using the magnitude of 4.9 and greater earthquakes which occurred between 1900-2003. For the determination of frequency-magnitude relationship which is a measure of seismic activity, "*a*" and "*b*" values have been calculated with 0.1 magnitude interval. Different damage estimation methods have been described in this study and damage probabilities for reinforced concrete buildings in Turkey have been shown. Seismic rehabilitation costs have been explained. The results of this study are given below.

1. According to the literature review, it is obvious that the region where Izmir is located in is one of the most seismically active regions of Turkey. There are many active faults in the region and the hazardous earthquakes occur in Izmir and its surrounding region owing to the fractures of these active faults.
2. For the investigated region with 37° – 40.45° N latitude and 25.5° – 29° E longitude, the magnitude – frequency relationship has been obtained as LogN=4.71-0.92M.
3. The calculated earthquake probabilities for 50 years of return period show that Izmir Region is under seismic risk. The occurrence probabilities in the region are "1" for MMI=VI and VII, "0.979" for MMI=VIII, "0.857" for MMI=IX, "0.385" for MMI=X and "0" for MMI=XI.
4. According to the benefit/cost analysis of Tontoş Bebe Retail Store, total expected net present value of benefits is 2.469.443,12 YTL, and total rehabilitation cost is 243.961 YTL. Benefit/Cost Ratio with 4% discount rate

and 50 years time period has been obtained as 10.12. Therefore, the seismic rehabilitation project of Tontoş Bebe is economically justified.

5. In the analysis of the private bank in Tire, the expected net present value of benefits for 4% discount rate and 50 years time period, and total rehabilitation cost have been found as 701.251,96 YTL and 29.002,33 YTL, respectively. The Benefit/Cost Ratio for this project is 24.18 without the value of life. The high ratio arises in part because of the low project cost (only 10% of the building replacement value).
6. The Benefit/Cost Ratio decreases, when the discount rate increased or the planning horizon increased. If it is generalized, the seismic rehabilitation costs of the buildings in Izmir, which affect the benefit/cost ratios in negative proportion, are not expensive. Therefore, the benefit/cost ratios get high values.

In view of the conclusions of this study stated above, the following points should be considered in future studies.

1. The researchers should use the benefit/cost analysis for the seismic rehabilitations of all of the reinforced concrete buildings in Izmir and get an inventory about their economic effectiveness.
2. The results should be improved by acquiring better data on retrofitting techniques and costs, on the seismic performance of rehabilitated structures, and on damages and other expected losses in existing buildings.
3. The earthquake data should be updated in order to estimate the probability of occurrences and the model should be improved by using the new values.
4. There are various statistical methods to determine the seismic risk. The researchers should estimate the probabilities of earthquake occurrences using these methods and compare them.
5. Modified Mercalli Intensity Scale should be investigated widely and clarify the effects of an earthquake in the locations far from the epicenter and their intensities.
6. Expected effectiveness of retrofit should be estimated for the buildings in Izmir and the results of the benefit/cost analyses should be recalculated.
7. Fragility Curves of the reinforced concrete buildings in Izmir should be plotted and the expected damage functions of the buildings should be estimated for Izmir Region.

8. The user of the benefit/cost analysis should consider if there is any change of the expected benefits during the planning horizon of the project. If so, all of the future benefits should be discounted to their net present values, and summed.
9. It should be clarified whether a real discount rate can be determined or not for the benefit/cost analyses of the seismic rehabilitation projects in Turkey.

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APPENDIX A

DETAILS OF HISTORICAL AND RECENT EARTHQUAKES

Earthquakes of Historical (Pre-1900) Period in Izmir Region

Date: 17 A.D.
Epicenter: Asia Minor-Sardeis (Izmir, Ephesus, Aydın, Manisa and Alaşehir)
Coordinates: 38.63 N; 27.59 E
Magnitude: Ms=7.0; MMI=X
Details: According to Tacitus, the earthquake happened at night. 12 of the important Ionia cities were destroyed by this earthquake. This severe earthquake which is assumed as one of the biggest disasters of the Aegean Region also caused heavy damage in the valleys of Gediz and Büyük Menderes River (Ergin et al. 1967).

Date:105 A.D.
Epicenter: Asia Minor-Aliağa
Coordinates: 38.90 N; 27.00 E
Magnitude: Ms=6.4; MMI=VII
Details: According to Eusebios; Aliağa, Myrina (Limni Island), Çandarlı, and Nemrut Harbour were completely collapsed by this ruinous earthquake (RADIUS 1997).

Date: 178 A.D.
Epicenter: Izmir
Coordinates: 38.30 N; 27.10 E
Magnitudes: Ms=6.5; MMI=VIII
Details: The City of Izmir was devastated by this earthquake. It took 10 years to rebuild the city again (Uluç 1999). It is stated in RADIUS (1997) that the earthquake caused very serious damage in Izmir, Ephesus, Aydın, Manisa and Serdeis and big splits in the ground.

Date: 688 A.D.

Epicenter: Izmir

Coordinates: 38.41 N; 27.20 E

Magnitudes: Ms=6.5; MMI=VIII

Details: One of the severe earthquakes that killed 20,000 people (Ergin et al. 1967).

Date: 1039 A.D.

Epicenter: Izmir

Coordinates: 38.40 N; 27.30 E

Magnitudes: Ms=6.8; MMI=VIII

Details: It is known that it was a catastrophic earthquake. Lots of areas and cities were damaged as a result of this earthquake. Izmir City was filled with a terrible view, because the most beautiful buildings were collapsed and lots of people died (RADIUS 1997).

Date: 1389, March 20th

Epicenter: Sakız Island

Coordinates: 38.40 N; 26.30 E

Magnitudes: Ms=6.7; MMI=VIII

Details: According to the books in the libraries in Palermo and Vatican, the earthquake of 20 March 1389 caused houses to collapse, two women died and lots of churches were seriously damaged. As a result of a huge wave, tsunami was formed by this earthquake, many people in the middle of the commerce center were wounded and Izmir, the Foça Tower and Sisam Island were devastated (Ergin et al. 1967).

Date: 1546

Epicenter: Sakız Island

Coordinates: 38.20 N; 25.90 E

Magnitudes: Ms=6.3; MMI=VII

Details: According to Torelli, this was an earthquake which was strongly felt especially in Katomeria and caused heavy destruction in numerous places on Sakız Island (Ergin et al. 1967).

Date: 1653, February 23th
Epicenter: Aydın and its vicinity
Coordinates: 37.90 N; 28.30 E
Magnitudes: Ms=7.0; MMI=X
Details: It affected all western Anatolia. According to Calvi, half of Aydın collapsed with this earthquake. 3,000 people died, and heavy damage occurred in Nazilli, Denizli, Tire (RADIUS 1997).

Date: 1654, March 20th
Epicenter: Izmir
Coordinates: 38.50 N; 27.10 E
Magnitudes: Ms=6.4; MMI=VII
Details: The earthquake caused to towers, mosques and houses to collapse and a large number of people died. Many people left their houses and moved to tents. Aftershocks were felt till June 25th (Ambraseys and Finkel 1995).

Date: 1664, June 2nd
Epicenter: Izmir
Coordinates: 38.41 N; 27.20 E
Magnitudes: Ms=5.8; MMI=VI
Details: This was an earthquake which caused general panic and a few houses collapsed (Ambraseys and Finkel 1995).

Date: 1668
Epicenter: Izmir
Coordinates: 38.41 N; 27.20 E
Magnitudes: Ms=7.0; MMI=IX
Details: It caused destruction in Izmir and 2,000 people died (Ergin et al. 1967)

Date: 1674, January 23th
Epicenter: Sakız Island
Coordinates: 38.40 N; 26.30 E
Magnitudes: Ms=6.2; MMI=VII

Details: According to Johan Michael Wansleben, this earthquake happened at 3:00 A.M. in Sakız Island. It was felt in all Aegean Region (RADIUS 1997).

Date: 1680, February 14th
Epicenter: Izmir
Coordinates: 38.40 N; 27.20 E
Magnitudes: Ms=6.2; MMI=VII
Details: Three towns 10 miles from Izmir were completely destroyed by this earthquake (Ambraseys and Finkel 1995).

Date: 1684
Epicenter: Sakız Island
Coordinates: 38.30 N; 26.20 E
Magnitudes: Ms=6.0; MMI=VI
Details: There is no data about the earthquake.

Date: 1688, July 10th
Epicenter: Izmir
Coordiantes: 38.30 N; 26.20 E
Details: This earthquake occurred at 11:45 A.M. and continued during 20-30 seconds. Most damage to the city happened at the sea side and lots of building collapsed. The earthquake caused a huge fire in the European quarter of the city and over 5,000 people lost their lives by the fire. Patriarch of Alexandria also was among the dead people (Ambraseys and Finkel 1995). According to a report presented by a French researcher, 15,000-16,000 people died at this earthquake (RADIUS 1967)

Date: 1690, January 13th
Epicenter: Izmir
Coordinates: 38.60 N; 27.40 E
Magnitudes: Ms=6.4; MMI=VII
Details: This earthquake caused damage in Izmir and its vicinity. The damage was dense along the sea side (Ambraseys and Finkel, 1995).

Date: 1709, July 3rd

Epicenter: Foça

Details: There is no exact data about the coordinates and magnitude of this earthquake. But it is known that the earthquake devastated old Foça Castle in the northwest of Izmir. According to documents, six towers in the castle and the western wall were collapsed. Additionally, 30-40 houses in the castle were heavy damaged (Ambraseys and Finkel 1995).

Date: 1723, September

Epicenter: Izmir

Coordinates: 38.40 N; 27.00 E

Magnitudes: Ms=6.4; MMI=VII

Details: Baykara (1974) indicates that around 60 houses collapsed and 500 people died by this earthquake.

Date: 1738, December 23th

Epicenter: Sakız Island

Coordinates: 38.50 N; 26.90 E

Details: There is not data about the earthquake.

Date: 1739, April 4th

Epicenter: Izmir Gulf

Coordinates: 38.50 N; 26.90 E

Magnitudes: Ms=6.9; MMI=IX

Details: According to historical documents, this earthquake continued for 10 minutes, and all of the houses in Izmir were damaged. The damage in old and new Foça was serious. According to another report, the damage in Izmir was mostly at sea side in the European quarter. Quantity of dead people was about 80. The French Consulate was also damaged by this earthquake (Ambraseys and Finkel 1995).

Date: 1772, November 24th

Epicenter: Foça

Coordiantes: 38.80 N; 26.70 E

Magnitudes: Ms=6.4; MMI=VII

Details: The earthquake and the waves at the sea formed by the earthquake collapsed five gates of the Foça Castle and its mosque. A few houses were also collapsed in Midilli Island. It was felt in Sakız Island but there was no damage (Ambraseys and Finkel 1987).

Date: 1778, June 16th, 18th, 19th

Epicenter: Izmir

Magnitudes: Ms=6.5; MMI=VIII

Details: Heavy damage occurred to the houses in Izmir due to this earthquake (Ambraseys and Finkel 1987).

Date: 1778, July 3rd, 5th

Epicenter: Izmir

Coordinates: 38.40 N; 26:80 E

Magnitudes: Ms=6.4; MMI=VII

Details: It occurred at 02:30 A.M. and continued during 15 seconds and destroyed almost all of Izmir. Over 200 people lost their lives. This was the main shock of the seismic chain that had been lasting since 16 June 1778. Three hammams, three minarets and a big mosque were among the damaged structures reported (Ergin et al. 1967).

Date: 1778, October 1st

Epicenter: Izmir

Details: It is known that some buildings which were damaged by 3-5 July earthquakes were collapsed after this one (Ambraseys and Finkel 1995).

Date: 1801

Epicenter: Izmir

Details: There is no data about the earthquake.

Date: 1820, March

Epicenter: Sakız Island

Coordinates: 38.40 N; 26.20 E

Magnitudes: Ms=6.0; MMI=VI

Details: There is no data about the earthquake.

Date: 1850, October 13th
Epicenter: West Anataolia
Coordinates: 38.40; 27.20 E
Magnitudes: Ms=6.4; MMI=VII
Details: It was severely felt in Izmir, Manisa, Turgutlu, Bayındır, Ödemiş, Tire and caused to various damage (Uluç 1999).

Date: 1862, November 3rd
Epicenter: Turgutlu
Coordinates: 38.50 N; 27.90 E
Magnitudes: Ms=6.9; MMI=IX
Details: The earthquake destroyed all of the houses in Turgutlu town and caused the death of 280 people. It was felt even in Afyon and Isparta (Uluç 1999).

Date: 1863, August 16th
Epicenter: Sakız Island
Coordinates: 38.30 N; 26.10 E
Magnitudes: Ms=6.2; MMI=VII
Details: It was a destructive earthquake. 30,000 people became homeless due to this earthquake (Uluç 1999).

Date: 1865, November 11th
Epicenter: Sakız Island
Coordinates: 38.30 N; 26.20 E
Magnitudes: Ms=6.1; MMI=VII
Details: There is no data about the earthquake.

Date: 1862, February 2nd
Epicenter: Sakız Island
Coordinates: 38.40 N; 26.00 E
Magnitudes: Ms=6.4; MMI=VII
Details: There is no data about the earthquake.

Date: 1890, December 14th
Epicenter: Ephesus
Coordinates: 37.90 N; 27.10 E
Magnitudes: Ms=6.2; MMI=VII
Details: 35 houses were collapsed and 150-200 houses were damaged in Ephesus (Ergin et al. 1967).

Date: 1893, June
Epicenter: Çeşme
Coordinates: 38.30 N; 26.30 E
Magnitudes: Ms=5.8; MMI=VI
Details: There is no data about the earthquake.

Date: 1899
Epicenter: Izmir
Coordinates: 38.5 N; 27.30 E
Magnitudes: Ms=5.7; MMI=VI
Details: There is no data about the earthquake.

Recent (1900-2003) Earthquakes in Izmir Region

Date: 1904, August 11th
Epicenter: Sisam Island
Coordinates: 37.66 N; 26.93 E
Magnitudes: Ms=6.8; MMI=VIII
Details: The damage was mostly in the towns which were built on the alluvion such as Ano Vaathy, Chora, Pyrgos, Koumaeika, Skouraeika and Aghia Triada. Hundreds of houses in Chora and the Monastery of Aghia Triada were damaged, 4 people died and 7 were seriously wounded in the island. The earthquake was felt in Athens too (Ergin et al. 1967).

Date: 1909, January 19th
Epicenter: Foça

Coordinates: 38.00 N; 26.50 E

Magnitudes: Ms=6.0; MMI=VI

Details: According to Ambraseys and Finkel (1987), the epicenter of this earthquake was in the middle of Güzelhisar, Menemen and Foça. Hundreds of houses were damaged. 700 houses collapsed and 8 people died.

Date: 1928, March 31th

Epicenter: Tepeköy-Torbalı

Coordinates: 38.2 N; 27.5 E

Magnitudes: Ms=6.5; MMI=VIII

Details: A lot of houses in Izmir were devastated. Manisa, Alaşehir and Uşak were seriously damaged. 30 people lost their lives (Ambraseys and Finkel 1995).

Date: 1939, September 22th

Epicenter: Dikili

Coordinates: 39.07 N; 26.64 E

Magnitudes: Ms=6.6; MMI= IX

Details: The epicenter was close to Dikili in between Dikili and Midilli Island, 215 of 4,565 houses in Bergama were damaged and 30 houses were completely devastated. In Dikili, 627 houses were collapsed, 50 houses were seriously damaged, 41 people died. Aftershocks continued for months (Uluç 1999).

Date: 1941, January 9th

Epicenter: Selçuk

Coordinates: 38.00 N; 27.30 E

Magnitudes: Ms=6.0; MMI=VI

Details: It caused damage in Değirmendere and Selçuk (Uluç 1999).

Date: 1944, October 6th

Epicenter: Edremit Gulf

Coordinates: 39.37 N; 26.06 E

Magnitudes: Ms=6.8; MMI=IX

Details: It affected all Edremit, Ayvalık, and Havran. 30 people died and 5,500 houses were damaged (Uluç 1999).

Date: 1949, July 23th

Epicenter: Karaburun, Çeşme

Coordinates: 28.55 N; 26.35 E

Magnitudes: Ms=6.6; MMI=IX

Details: It caused heavy damage in the eastern part of Karaburun Peninsula, in the villages of Mordoğan and Çeşme. It was also felt in Foça and Menemen. In total 7 people died and 2,200 houses were damaged (Ergin et al. 1967).

Date: 1953, May 2nd

Epicenter: Karaburun

Coordinates: 38.60 N; 26.6 E

Magnitudes: Ms=5.6; MMI=VII

Details: The earthquake which caused heavy damage in Karaburun and was felt in Bergama and Foça (Ambraseys and Finkel, 1995).

Date: 1955, July 16th

Epicenter: Izmir, Söke

Coordinates: 37.50 N; 27.00 E

Magnitudes: Ms=6.7; MMI=IX

Details: It caused very serious damage in Söke. It was felt even in Muğla (Ergin et al. 1967). Eyidoğan et al. (1991) indicates that the earthquake was felt in Izmir and a few minarets were damaged.

Date: 1966, June 19th

Epicenter: Menemen

Coordinates: 38.60 N; 27.40 E

Magnitudes: Ms=4.9; MMI=VI

Details: Menemen Earthquake was felt in Izmir and it caused damage to 100 houses in Menemen (Eyidoğan et al., 1991).

Date: 1974, February 1st

Epicenter: Izmir

Coordinates: 38.5 N; 27.20 E

Magnitudes: Ms=5.6; MMI= VII

Details: The epicenter was 15 km away to Izmir City Center and caused a lot of damage to both old and modern structures (Eyidoğan et al. 1941). Ergünay et al. (1974) indicates that 2 people died and 7 were wounded due to this earthquake. The earthquake damaged 47 buildings in the boundaries of the Municipality of Izmir. The most serious damage was in Alsancak area. An old abandoned structure collapsed next to a building and killed 2 people. Some parts of the Clock Tower in the Konak Square collapsed and the clock stopped working (Uluç 1999).

Date: 1977, December 16th
Epicenter: Izmir
Coordinates: 38.41 N; 27.19 E
Magnitudes: Ms=5.3, MMI= VI
Details: According to the Hürriyet Newspaper, two ground shakings happened that morning and some houses collapsed and 20 people were wounded. SSK hospital in Buca was seriously damaged and emptied. Lots of walls of the houses in Alsancak, Hatay, İkiçeşmelik, Karşıyaka, Bornova, Gültepe, Gürçeşme and Tepecik areas collapsed (Uluç 1999).

Date: 1992, November 6th
Epicenter: Izmir, Doğanbey
Coordinates: 38.19 N; 27.05 E
Magnitudes: Ms=6.2; MMI= VII
Details: It was felt in all Izmir and caused serious damage to Doğanbey area. It was felt in Girit Island too (Uluç 1999).

Date: 2003, April 10th
Epicenter: Urla, Izmir
Coordinates: 38.25 N; 26.83 E
Magnitudes: Ms=5.6; MMI= VII
Details: According to the Hürriyet Newspaper, the earthquake occurred at 03:40 A.M. and was felt in all Izmir and its villages. The epicenter was in Urla. There was no serious damage but it caused panic. Some people jumped from the balconies and were wounded. The walls in 2 houses in Seferihisar were damaged due to this earthquake.

APPENDIX B

GATHERED DATA OF RECENT EARTHQUAKES IN IZMIR

Table B.1. Recent Earthquakes with Magnitude of Ms≥4.9 (MMI=VI~XII)

DATE					SPACE		MAGNITUDE	
YEAR	MONTH	DAY	HOUR	MINUTE	LATITUDE	LONGITUDE	Ms	MMI
1900	10				39,64	27,90	5,20	VI
1901	4				37,80	29,00	5,20	VI
1901	5				37,80	27,80	5,00	VI
1901	12	18	3	51	39,40	26,70	5,90	VI
1902	6	21			37,75	28,10	5,20	VI
1903					38,00	28,50	5,20	VI
1903	4				38,60	27,40	5,20	VI
1903	6				38,60	27,40	5,20	VI
1904	5	19	10	2	38,40	27,20	5,00	VI
1904	8	11	5	56	37,65	26,70	6,20	VII
1904	8	11	7		38,00	27,00	5,00	VI
1904	8	18	20	7	38,00	27,00	6,00	VI
1904	8	18	20	50	38,00	27,00	5,00	VI
1904	10	10	17	7	38,40	27,20	5,80	VI
1904	10	18			38,10	27,00	5,80	VI
1904	12				38,70	27,70	5,20	VI
1905	1	11	17	32	39,60	27,90	5,00	VI
1905	4	30	16	1	38,81	28,52	6,10	VII
1908	3	8			37,80	27,80	5,00	VI
1908	4	12			38,20	27,70	5,30	VI

1908	6	23	14	20	38,40	27,20	5,20	VI
1908	6	23	14	45	38,40	27,20	5,10	VI
1908	6	23	16	7	38,40	27,20	5,00	VI
1909	1	19	4	56	38,66	26,94	5,80	VII
1909	10	29	16	8	38,00	27,00	5,30	VI
1910	8	7	21	45	37,80	28,70	5,30	VI
1912	7	13			38,00	26,25	5,30	VI
1917	8	20	23	2	39,75	26,00	5,70	VII
1917	12	24	9	13	39,40	25,45	5,80	VII
1918	6	13	18	13	39,00	27,00	4,90	VI
1918	11	13	10	13	37,50	27,50	5,20	VI
1919	4	5	4	17	37,00	26,00	5,20	VI
1919	10	25	17	10	37,00	26,00	6,00	VI
1919	10	25	17	20	37,00	26,00	4,90	VI
1919	10	25	17	53	37,00	26,00	5,50	VI
1919	10	26	6	2	37,00	26,00	5,00	VI
1919	11	18	21	44	39,35	27,44	6,90	IX
1919	11	27			39,20	27,20	6,00	VI
1920	4	2	15	34	37,50	27,50	5,30	VI
1920	5	1	6	34	37,00	28,70	5,00	VI
1920	7	4	12	17	37,50	29,00	5,00	VI
1920	7	4	20	45	37,50	29,00	5,20	VI
1920	9	28	15	17	37,89	28,35	5,70	VII
1920	11	27	16	26	39,50	26,50	4,90	V
1921	5	22	21	23	37,00	28,70	5,20	VI
1921	6	14	1	42	38,80	25,50	5,00	VI
1921	7	24	19	20	38,80	26,50	5,20	VI
1922	11	20	4	24	37,50	29,00	4,90	VI
1922	12	6	14	1	37,50	29,00	5,20	VI
1924	1	22	11	5	39,51	28,40	5,30	VI
1924	12	22	17	49	39,60	27,70	5,40	VI

1925	3	17	15	32	37,20	26,20	5,00	VI
1925	8	16	20	59	37,44	28,77	5,00	VI
1925	9	1	8	16	38,00	29,00	5,60	VII
1926	1	13	1	47	38,64	28,11	5,80	VII
1926	1	13	8	8	38,53	28,19	5,70	VII
1926	2	8	19	48	37,10	27,90	5,20	VI
1926	3	16	17	53	37,50	29,00	6,30	VIII
1926	3	24	7	5	38,24	27,07	5,40	VI
1927	2	19	23	35	37,00	28,70	4,90	VI
1928	3	31		30	38,09	27,35	6,50	VIII
1934	11	9	13	40	37,00	26,00	5,80	VII
1939	9	22		37	39,05	26,93	6,50	VIII
1941	5	23	19	52	37,16	28,17	5,90	VII
1942	11	15	17	1	39,38	28,08	6,20	VIII
1944	10	6	2	34	39,64	26,52	6,80	IX
1949	7	23	15	3	38,50	26,27	6,60	IX
1953	3	18	19	6	40,00	27,50	7,20	IX
1953	5	2	18	38	38,60	26,60	5,60	VII
1955	7	16	7	7	37,50	27,00	6,70	IX
1955	8	28	13	39	38,00	27,50	5,00	VI
1961	6	21	16	4	37,90	28,70	5,10	VI
1963	3	11	7	27	37,90	29,00	5,60	VII
1964	12	15	21	3	40,00	28,90	4,90	VI
1965	3	2	22		38,60	28,30	5,20	VI
1965	4	29	9	46	37,00	26,90	4,90	VI
1966	5	7	13	8	37,80	27,65	5,50	VII
1966	6	19	17	55	38,51	27,21	4,90	VI
1968	2	20		39	39,70	25,20	4,90	VI
1968	2	20	2	21	39,60	25,40	5,00	VI
1968	2	20	21	5	39,00	25,10	4,90	VI
1969	3	3		59	40,00	27,50	5,90	VII

1969	3	23	21	8	39,16	28,48	5,70	VII
1969	3	24	1	59	39,13	28,48	4,90	VI
1969	3	25	13	22	39,10	28,45	6,50	VIII
1969	3	28	1	48	38,45	28,50	6,50	VIII
1969	3	28	10	2	39,11	28,44	4,90	VI
1969	4	6	3	50	38,35	26,00	5,80	VII
1969	4	30	20	20	39,16	28,59	5,50	VII
1969	10	7	5	9	39,19	28,37	4,90	VI
1970	4	23	9	1	39,13	28,70	5,30	VI
1971	2	23	19	41	39,50	27,35	5,60	VII
1972	4	26	6	30	39,30	26,30	4,90	VI
1974	2	1		1	38,50	27,20	5,60	VII
1976	8	19	1	12	37,70	29,00	5,00	VI
1976	11	12	9	55	38,57	26,71	5,20	VI
1977	2	24	20	47	38,74	27,72	5,00	VI
1977	12	16	7	37	38,44	27,22	5,30	VI
1979	6	14	11	44	38,81	26,53	5,80	VII
1979	6	16	18	42	38,75	26,63	5,10	VI
1979	7	18	13	12	39,67	28,66	5,20	VI
1979	8	23	16	47	39,69	28,57	5,00	VI
1981	12	19	14	10	39,24	25,23	6,20	VIII
1984	2	5		20	37,21	28,65	5,10	VI
1984	5	6	9	12	38,84	25,63	5,00	VI
1984	6	17	7	48	38,86	25,72	5,00	VI
1984	10	5	20	58	39,16	25,32	4,90	VI
1985	12	18	5	46	39,20	26,18	5,00	VI
1986	3	25	1	41	38,35	25,15	5,20	VI
1986	3	29	18	36	38,38	25,17	5,00	VI
1986	10	11	9		37,93	28,57	5,50	VII
1989	2	19	14	28	37,01	28,23	4,90	VI
1989	4	27	23	6	37,03	28,18	5,30	VI

1989	4	28	13	30	37,00	28,14	5,10	VI
1992	11	6	19	8	38,16	27,00	5,70	VII
1994	1	28	15	45	38,69	27,49	5,20	VI
1994	5	24	2	5	38,66	26,54	5,00	VI
1994	5	24	2	18	38,77	26,60	5,00	VI
1996	4	2	7	59	37,83	27,00	5,40	VI
1997	2	15	9	26	39,14	27,56	5,00	VI
1997	11	14	21	38	38,86	25,80	6,10	VII
1998	7	9	17	36	37,57	26,44	5,30	VI
1999	9	20	21	28	40,41	27,34	5,00	VI
2003	7	26	4	0	38,11	28,87	5,00	VI
2003	7	23	7	56	38,17	28,85	5,20	VI
2003	7	26	11	36	38,11	28,89	5,60	VII
2003	4	10	3	40	38,25	26,83	5,60	VII

APPENDIX C

TABLES OF THE VALUES USED IN BCA

Table C.1. Weighted Statistics for Loss of Function and Restoration Time of Social Function Classification (in days)
(Source: FEMA 227 1992)

Social Function Classes 1, 2, 3 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	0.2	0.2	0.8
5	0.3	1.5	3.3
20	1.9	5.4	10.5
45	15.2	30.5	71.9
80	57.2	93.8	146.6
100	105.5	152.1	211.9

Social Function Classes 4, 5, 6, 7, 9 Mean Time in Days to Restore to Given Percent of Function			
Central Damage Factor	30%	60%	100%
0.5	1.2	2.4	5.8
5	3.4	10.2	20.0
20	9.8	44.6	71.0
45	37.0	111.6	202.7
80	114.7	213.7	343.1
100	214.8	355.9	439.3

Table C.2. Estimated Composition and Contents of Various Facilities in Terms of Earthquake Engineering Facility Classifications (Source: FEMA 227 1992)

SOCIAL FUNCTION CLASSIFICATION (SFC)	SFC NO.	FACILITY INCLUDED IN BASE VALUE	CATEGORY 2 EQUIPMENT/CONTENTS					
			RESIDENTIAL	OFFICE	ELECTRICAL	MECHANICAL	HIGHTECH	VEHICLES
RESIDENTIAL								
• PERMANENT DWELLING	1	HOUSES AND CONDOMINIUMS	30	-	2	2	-	15
		APARTMENTS	25	-	2	2	-	10
		MOBILE HOMES	25	-	2	2	-	-
• TEMPORARY LODGING	2	HOTELS AND MOTELS	15	2	2	2	-	-
• GROUP INSTITUTIONAL LODGING	3	DORMITORIES, ETC.	15	2	2	2	-	-
COMMERCIAL								
• RETAIL TRADE[1]	4	STORES	-	5	2	2	-	-
• WHOLESALE TRADE[1]	5	WAREHOUSES & SALES OFFICES	-	10	1	1	-	-
• PERSONAL AND REPAIR SERVICES	6	REPAIR SHOPS, SERVICE STATIONS, ETC.	-	5	5	5	-	10
• PROFESSIONAL, TECHNICAL AND BUSINESS SERVICES	7	OFFICES, BANKS, ETC.	-	25	2	2	5	-
• HEALTH CARE SERVICES	8	HOSPITALS	-	15	15	70	80	5
		MEDICAL OFFICES & CLINICS	-	15	10	10	10	-
• ENTERTAINMENT & RECREATION	9	RESTAURANTS, BARS, THEATERS, ETC.	-	5	5	5	5	-
• PARKING	10	GARAGES	-	-	-	-	-	40
RELIGION AND NONPROFIT	21	CHURCHES	-	15	2	2	-	-
		OTHER OFFICES	-	25	2	2	5	-
GOVERNMENT								
• GENERAL SERVICES	22	OFFICES	-	25	2	2	5	-
• EMERGENCY RESPONSE SERVICES	23	POLICE AND FIRE STATIONS	5	20	5	5	20	25
EDUCATION	24	SCHOOLS, COLLEGES & UNIVERSITIES	-	20	5	5	5	10
COMMUNICATION	34	BROADCAST STUDIOS	-	20	50	10	15	-

Table C.3. The Net Present Value Criterion
(Source: FEMA 227 1992)

Discount Rate	Planning Horizon (Years)			
	10	20	30	50
3%	8.530	14.877	19.600	25.730
4%	8.111	13.590	17.292	21.482
5%	7.722	12.462	15.372	18.256
6%	7.360	11.470	13.765	15.762

Table C.4. The Salvage Value of the Rehabilitation Investment
(Source: FEMA 227 1992)

Discount Rate	Planning Horizon (Years)			
	10	20	30	50
3%	0.744	0.554	0.412	0.228
4%	0.676	0.456	0.308	0.141
5%	0.614	0.377	0.231	0.087
6%	0.558	0.312	0.174	0.054

Table C.5. Expected Effectiveness of Retrofit Most Vulnerable Facility Classifications (Source: FEMA 227 1992)

FACILITY CLASSIFICATION NUMBER (EXPECTED PERCENTAGES OF REDUCTION IN DAMAGES)												
MMI	1	3	4	75	76	78	79	80	81	82	83	21
VI	50	35	35	50	50	40	40	40	40	40	40	50
VII	50	35	35	50	50	40	40	40	40	40	40	50
VIII	43	31	31	45	45	36	36	36	36	36	36	45
IX	35	28	28	40	40	33	33	33	33	33	33	40
X	28	24	24	35	35	29	29	29	29	29	29	35
XI	20	20	20	30	30	25	25	25	25	25	25	30
XII	20	20	20	30	30	25	25	25	25	25	25	30