# BENEFIT-COST ANALYSIS FOR RETROFITTING OF SELECTED RESIDENTIAL BUILDINGS IN ISTANBUL

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## ABSTRACT

### BENEFIT-COST ANALYSIS FOR RETROFITTING OF SELECTED RESIDENTIAL BUILDINGS IN ISTANBUL



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During the evaluation of the seismic retrofitting option for risk reduction/mitigation measures to be applied over buildings, Benefit Cost Analysis is an often-used method. During this study of Benefit Cost Analysis, the condition that the earthquake can happen just after or sometime after retrofitting will be taken into consideration rather than some approaches that focus on the benefits and costs regarding the annual probability of the occurrence for possible earthquakes. The analysis will use conditional probability such that the earthquake will be assumed to occur at different periods of time (5, 10, 20 years etc.) after the mitigation measures are taken so that benefit-cost ratios and net social benefits can be observed over time using the results at these periods. Also during this study the indirect effects of earthquake such as business disruption, social disturbance will also be taken into consideration. As a final step, it is aimed to conclude with convincing financial results regarding the direct and indirect effects of the earthquake in terms of benefits and costs to encourage people and the public officials to reduce the potential vulnerability of the housing units people live by taking the necessary precautions against the earthquake.



Keywords: benefit cost analysis, life cycle cost analysis, seismic retrofitting, residential buildings.

# ÖZ

## İSTANBUL'DA SEÇİLEN BİNALARIN GÜÇLENDİRİLMESİ AMACIYLA FAYDA-MALİYET ANALİZİ YAPILMASI

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Binalarda risk ve zarar azaltma yöntemi olarak uygulanan sismik güçlendirme seçeneğinin değerlendirilmesi amacıyla Fayda-Maliyet analizi sık kulllanılan bir metottur. Bu Fayda-Maliyet Analiz çalışmasında olası depremlerin yıllık gerçekleşme olasılığını dikkate alarak fayda ve maliyetlere odaklanan yaklaşımlardan öte güçlendirmeden hemen sonra veya bir süre sonra depremin olabileceğini varsayan durumlar dikkate alınmaktadır. Analizde koşullu ihtimaller göz önünde bulundurulacak ve depremin zarar azaltma önlemleri alındıktan sonra farklı zamanlarda gerçekleşeceği varsayılacaktır (5, 10, 20 yıl vb.). Bu periyotlar boyunca fayda ve maliyet oranları izlenecektir. Ayrıca bu analiz sırasında depremin iş kaybı, sosyal etkileri gibi dolaylı sonuçları da göz önünde bulundurulacaktır. Son aşama olarak ise, insanların ve kamu kuruluşlarının insanların yaşadığı binaların zarar görme ihtimallerini düşürmeleri için depreme karşı gerekli tedbirleri almalarını teşvik etmek amacıyla ikna edici mali sonuçların depremin direk ve dolaylı etkilerinin fayda ve maliyet açısından dikkate alınarak ortaya konulması amaçlanmaktadır.

Anahtar kelimeler: fayda maliyet analizi, yaşam döngüsü maliyet analizi, sismik güçlendirme, konutlar.

To My Parents, Sister,  Brother

and

To My Wife

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**TABLE OF CONTENTS**

# LIST OF TABLES

TABLES

## LIST OF FIGURES

FIGURES

## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| B | : Benefit |
| $B_t$ | : Benefit at time t |
| BC | : Benefit Cost |
| BCA | : Benefit Cost Analysis |
| BCR | : Benefit/Cost Ratio |
| BE | : Benefit of Earthquake |
| BPV | : Benefit of Property Value |
| BR | : Benefit of Rental |
| $c_{cl}$ | : Coefficient of Content Loss |
| $c_{vi}$ | : Coefficient of Value Increase |
| C | : Cost |
| $C_0$ | : Recurring cost |
| $C_t$ | : Cost at time t |
| CA | : Cost of Accommodation |
| CC | : Construction Cost |
| CD | : Cost of Demolition |
| CI | : Cost due to Injuries |
| CL | : Cost due to Loss of Lives |
| CM | : Cost of Maintenance |
| CR | : Cost of Retrofitting |
| CS | : Cost of Strengthening the Building |
| CBI | : Cost of Business Interruption |
| CDB | : Cost of Damage to Building |
| CDG | : Cost of Damage to Household Goods |
| CIT | : Cost of Injury Treatment |
| CSD | : Cost of Social Disruption |
| CTA | : Cost of Temporary Accommodation |
| CTM | : Cost of Temporary Moving |
| CTR | : Cost of Temporary Relocation |

| | |
|---|---|
| CTS | : Cost of Temporary Resettlement |
| d | : Real Discount Rate |
| DRM | : Disaster Risk Management |
| LCC | : Life Cycle Cost |
| LCCA | : Life Cycle Cost Analysis |
| $M_w$ | : Moment Magnitude |
| NDRM | : National Disaster Risk Management |
| NO | : Number of Occupants |
| NPV | : Net Present Value |
| NSB | : Net Social Benefit |
| PR | : Period of Retrofitting |
| PV | : Present Value |
| RC | : Casualty Rate |
| R/C | : Reinforced Concrete |
| RD | : Damage Ratio |
| RM | : Rate for Movement for Occupants |
| RR | : Rental Rate |
| SL | : Severity Level |
| T | : Time horizon |
| t | : Time (expressed as number of years) |
| WB | : The World Bank |

# CHAPTER 1

# INTRODUCTION

## 1.1 GENERAL

In general terms, disasters are discrete events (such as flood, hurricane or earthquake) occurring at a specific point of time and a particular geographical area, affecting large population and require external assistance to cope with consequences.

Disasters caused by natural hazards such as earthquakes, floods, landslides, drought, tropical cyclones have a heavy burden on human lives, economic and social infrastructure, and on ecosystem. Although natural hazards remain part of our existence, human actions can either increase or reduce the vulnerability of societies to hazards and disasters.

In order to manage the risk from natural disasters, it is necessary to understand the threat posed by hazard, the magnitude of values (human lives and assets) exposed to the threat, susceptibility towards hazards in form of vulnerabilities and actions, and measures to protect human values [Demeter 2005]. The specific terms that are used to describe disasters are natural hazards, vulnerability, risk and risk management related with these disasters.

Since little can be done to reduce the occurrence and intensity of most natural hazards, actions and activities should focus against reducing existing and future vulnerabilities to damage and loss.

Risk management conducted for this purpose involves four distinct but interrelated components such as the risk identification, risk reduction/mitigation, risk transfer and preparedness at its pre-disaster phase.

From these components of risk management, risk reduction/mitigation covers the measures taken to eliminate or reduce the intensity of hazardous event. They can address existing vulnerabilities through measures like retrofitting or strengthening. Physical measures of risk reduction/mitigation are divided into structural and non-structural measures. Structural risk reduction measures include any actions that require the construction to reduce the effects of a hazard event, such as flood and wind proofing, elevation, seismic retrofitting and burial of utilities.

In order to understand the importance of the above-mentioned structural risk mitigation measures such as retrofitting for our country, the earthquake disasters experienced in the past and also the ones possible in the future should be taken into consideration for Turkey.

Turkey has experienced 1999 Kocaeli and Düzce earthquakes that caused considerable damage to residential and commercial buildings, public facilities and infrastructure and significant casualties and injuries. Concern for earthquakes in Istanbul has drastically increased since the 1999 earthquakes that caused more than 18,000 deaths and produced severe damage to housing and reduced production capacity in northwest Turkey, including some recently developed parts of Istanbul [U.S. Geological Survey 2000]. Scientifically the greatest concern about earthquakes in the Istanbul area is increased probability that a serious event will occur in the near future [Atakan et al. 2002].

From this point of view, it is a fact that the Disaster Risk Management (DRM) with its all components will give a chance to reduce these effects in Turkey for future. Particularly for Istanbul, seismic retrofitting of the existing building stocks is a structural risk reduction/mitigation option to substantially reduce the earthquake vulnerability.

In order to decide whether to retrofit a building or not, options of retrofitting shall be evaluated within financial terms for a proper and effective decision-making.

Life Cycle Cost Analysis (LCCA) can be used to evaluate the cost of a full range of projects, from an entire site complex to a specific building system component such as retrofitting [State of Alaska 1999]. LCCA accounts for all costs that can occur during the life of a building. If different cost options are to be compared for a building or if two buildings are to be compared from the cost point of view, either present value costs or annual equivalent value costs are calculated using an appropriate discount rate for comparison [Fabrycky and Blanchard 1991].

On the other hand, Benefit Cost Analysis measures as far as possible, the costs and benefits of a policy or action. Since the resource cost of policies or actions are invariably in monetary terms, comparison in BCA is undertaken by measuring benefits in monetary units. There are two fundamental features in BCA. First it forces the analyst to list the advantages and disadvantages of any policy or action. Second, the listing must reflect some goal. It is common that the ultimate goal in BCA is that increasing the society's well being. This implies that anything contributing to gains in the society is benefit and detracting from it is a cost [World Road Association (PIARC), 1999].

By the assessment of cost and benefits from the point of view of BCA, it can be seen that retrofitting is an economically viable solution as a risk mitigation measure within the extent of this study and BCA helps us to choose from different alternatives for retrofitting, demolishing the building and reconstructing it or leaving the building as it is by also regarding the financial burden of these activities for the homeowners in Istanbul and public institutions.

## 1.2 OBJECTIVE

The objective of this thesis is to evaluate from an economical point of view the seismic retrofitting option of risk reduction/mitigation measures to be applied over selected residential buildings in Istanbul by using the Benefit Cost Analysis method. During this study of Benefit Cost Analysis, the types of questions like "What happens if the earthquake happens just after retrofitting?" will be taken into consideration rather than some approaches that focus on the benefits and costs regarding the annual probability that the possible earthquakes will occur. The analysis will use conditional probability such that the earthquake will be assumed to occur at different periods of time (5, 10, 20 years etc.) after the retrofitting is completed so that benefit-cost ratios can be observed over time using results at these periods. Also during this study the indirect effects of earthquake such as business disruption, social disturbance will also be taken into consideration. As a final step, it is aimed to conclude with convincing financial results to encourage people and the public officials to take the necessary precautions against the earthquake and to reduce the potential vulnerability of the housing units they live regarding the direct and indirect effects of the earthquake in terms of benefits and costs.

## 1.3 SCOPE

This thesis consists of four chapters.

Chapter 1 introduces the general concepts, objective and scope of the thesis.

Chapter 2 presents the literature review and gives a general background on National Disaster Risk Management and components, Life Cycle Cost Analysis (LCCA), Benefit-Cost Analysis (BCA), retrofitting and relevant details.

Chapter 3 presents the case study for the evaluation of seismic retrofitting of selected residential buildings in Istanbul in terms of BCA, Benefit Cost elements, assigning values for them and the assumptions made, used methodology, evaluation procedures, and summarizes the case study data. It also presents the results of the case study focusing on the comparison of different retrofitting options vs. demolish and rebuild option and status quo.

Chapter 4 gives a summary of thesis and lists the findings of this research. The effect and importance of taking necessary risk reduction/mitigation measures and precautions during the period prior to the expected earthquake in Istanbul are emphasized. Recommendations for the possible further researches to complement this thesis are also included in Chapter 4.

# CHAPTER 2

# LITERATURE REVIEW AND BACKGROUND

## 2.1 NATURAL DISASTER RISK MANAGEMENT

To understand the concept of risk mitigation/reduction measures and the economical analysis for these where seismic retrofitting is an example for one of these measures, the concept of natural disaster, related risk management and the several components of the related risk management activities should be explained.

### 2.1.1 Natural Disasters

In general terms, natural disasters are discrete events, such as floods, hurricanes or earthquakes, occurring at a specific point of time, at a particular geographical area, affect large population and require external assistance to cope with consequences. In order to manage the risk from natural disasters it is necessary to understand the threat posed by hazard, the magnitude of values (human lives and assets) exposed to the threat, susceptibility towards hazards in form of vulnerabilities and actions, and measures to protect human values. The specific terms that are used to describe disasters are: natural hazards, vulnerability and risk [Demeter 2005].

Natural hazards are natural phenomena potentially causing losses to human settlements, economic activities, social structures and etc. Natural hazards can be classified by their origins under three headings:

a. Geological Hazards such as earthquakes, tsunamis, volcanic eruptions, landslides,
b. Climatic Hazards such as tropical cyclones, floods, drought,
c. Environmental Hazards such as environmental pollution or deforestation.

After defining natural hazards and types at a certain extent, the term vulnerability shall also be defined. Vulnerability is a set of conditions that result from physical, social, economic and environmental factors increasing susceptibility to losses from the impact of natural hazards. It is important to remember that incidence of natural events that could cause disasters lies beyond human control, while vulnerability can be controlled. This difference is the main concern for the definition of risk and risk management.

Risk is the probability of harmful consequences or expected losses resulting from interactions between natural hazards and vulnerable conditions (See Fig. 2.1.).

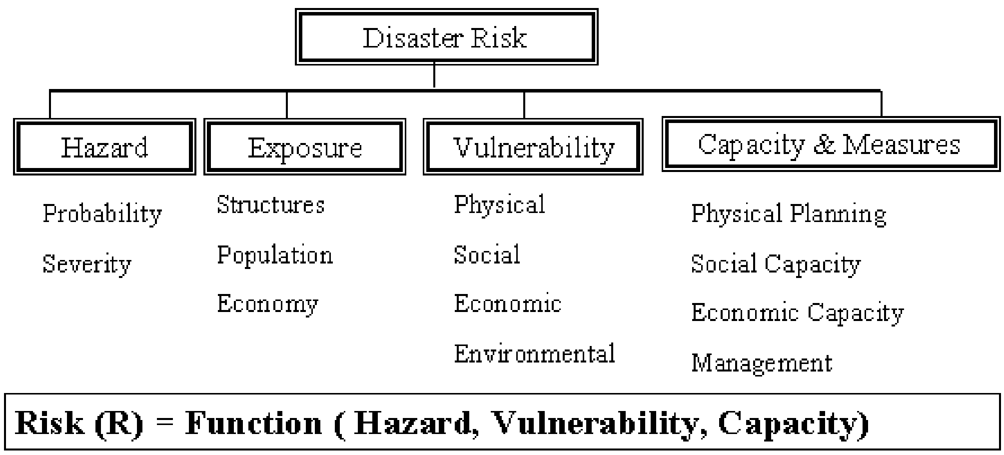



**Figure 2.1.** Factors Determining Risk

Disasters result from the combination of hazards, conditions of vulnerabilities that usually accumulate over time, and insufficient capacity or measures to reduce the potential damages. Since there is little to reduce the occurrence and intensity of most natural hazards, actions and activities should focus on reducing existing and future vulnerabilities to damage and loss [Demeter 2005].

### 2.1.2 Risk Management

Natural Disaster Risk Management (NDRM) is defined as the process of identifying, analyzing and quantifying the probability of losses in order to undertake preventive or corrective actions. This involves two types of activities:

a. Planning actions to reduce vulnerability in areas where risk can be controlled,
b. Establishing protective mechanisms against the potential economic losses from uncontrollable factors of natural hazards.

Natural hazard risk management significantly differs from traditional preparedness and response activities. It takes a pro-active and systemic approach by ensuring that growth and development policies incorporate vulnerability reduction measures and natural resource management considerations.

The pre-disaster phase of disaster risk management involves four distinct but interrelated components:
- Risk identification,
- Risk reduction/mitigation,
- Risk transfer,
- Preparedness.

These measures are mostly related to pre-disaster phases of disaster risk management and reflect the new approach that puts the emphasis on ex-ante (prior) actions instead of measures taken prior (e.g. preparedness), during and shortly after disaster event (e.g. disaster response, relief, recovery and rehabilitation).

Demeter (2005) defines these as below:

a. Risk identification and analysis is a thorough analysis of existing vulnerabilities, location, severity and intensity of threat. By determining the causes of existing vulnerabilities makes it possible to eliminate or reduce them. The following activities help to identify and understand natural hazard risk:

- Hazard data collection and mapping (frequency, magnitude and location),
- Vulnerability assessment (population and assets exposed),
- Risk assessment (probability of expected losses).

b. Risk reduction or prevention/mitigation are measures taken to eliminate or reduce the intensity of hazardous event. They can address existing vulnerabilities through measures like retrofit or strengthening. Actions can be taken to reduce future vulnerability, such as implementation and enforcement of building standards, environmental protection measures and resource management practices. Measures can be directed towards physical, social and environmental vulnerability. It is very important that post-disaster reconstruction and rehabilitation incorporates mitigation elements instead of rebuilding earlier vulnerability.

c. Risk transfer mechanisms do not reduce actual vulnerability, but reduce financial risk by transfer mechanisms in order to ensure that funds are available when loss occurs. Risk transfer mechanisms are often inefficient from cost perspective, so it is important to take all the necessary measures to reduce the vulnerability of assets to be covered before transferring the risk. Without getting into details the main risk transfer/ risk financing methods are (their application conditions in Turkey are not considered in this study):

    i. Budget self-insurance is an allocation of a small proportion of budget to be spent on improved maintenance. This allows to either forgo (give up) the purchase of regular insurance or to achieve a higher deductible, thus lowering the insurance cost.

ii. Market Insurance and Reinsurance. Insurance provides coverage for damage and expenses that are beyond the potential for budget self-insurance. Once the extent of coverage has been agreed and premiums are paid under an insurance contract, the insurer assumes the risk and makes available funds necessary to repair damage or rebuild shortly after a disaster event. Insurance costs for certain categories of buildings or uses, however, may be unaffordable, and coverage for some categories of natural hazards may be unavailable.

iii. Public asset coverage. Most public assets are not covered by insurance. Funds for rebuilding damaged assets, therefore, must come from annual budgets or external sources. This puts great pressure on public budgets in the post-disaster period when economies are often particularly weak, as typically little has been set aside for budget self-insurance purposes. Insurance coverage for critical public assets will ensure that key infrastructure can be rebuilt or rehabilitated quickly if damaged in a hazard event. Selection of assets that merit insurance coverage should be based on careful prioritization of public facilities and on comprehensive facility vulnerability assessments.

iv. Risk pooling and diversification. Insurance costs for geographically concentrated or relatively homogeneous groups or facilities are often high, due to the potential for simultaneous damage to all members of the group or category. Diversification of the risk pool, through banding with others from separate areas or industries can result in reduced insurance premiums for all participants.

v. Risk financing. Risk financing mechanisms allow losses to be paid off in the medium- to long-term via some form of a credit facility. Alternative risk financing mechanisms provide cost-effective, multi-year coverage that assists with the stabilization of premiums and increases the availability of funds for insurance purposes.

d. Preparedness. The fourth element of ex-ante phase is emergency preparedness. It aims at improving the capacity to respond rapidly and effectively to save lives, reduce suffering and enhance recovery of communities after a disaster strikes. It includes early warning systems, evacuation plans, and establishment of shelters. Improving understanding and communication among actors involved and mobilizing response is critical for reducing potential impact of disasters. Since preparedness is closely related to actions at the level of individuals and communities, coordination among them is critical.

Post disaster phases for natural hazard risk management include (i) emergency response, (ii) rehabilitation and recovery, and (iii) reconstruction [Demeter 2005].

### 2.1.3 Integration of NDRM to National System

Risk management is an ongoing process and aims at reducing vulnerability to natural hazards across all levels of society and all economic sectors. To be effective, disaster risk management needs to become an integral part of economic planning and policy making. The role of different stakeholders, public, private sector, government, communities and individuals should be clearly defined in the system. Comprehensive strategy, commitment from the government, and enabling environment for community initiatives are keys to success.

### 2.1.4 Seismic Safety Chain

In relation with disaster risk management activities and within an integrated risk reduction strategy, the following model of a linked chain of seismic safety elements was introduced in a Keynote Presentation in the 12th European Conference on Earthquake Engineering in London in 2002 [Davis 2002].

The imagery may be particularly appropriate for earthquake engineers with its similarity to a ring-beam. Each link in the chain can represent an element within an integrated risk reduction strategy.

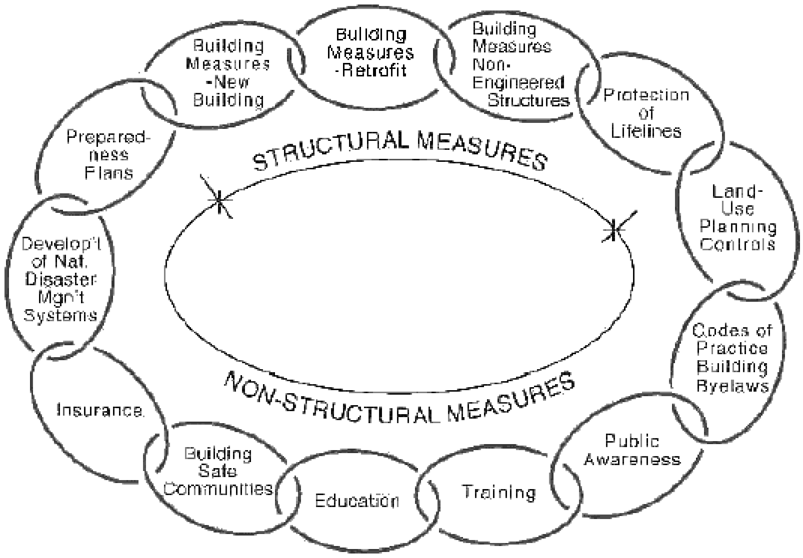



**Figure 2.2.** Seismic Safety Chain

Davis (2004) mentions about the components of this safety chain as below:

a. Structural Measures:
   i. Building measures: new buildings and infrastructure
   ii. Building measures: existing buildings and infrastructure (retrofit)
   iii. Protection of non-engineered structures
   iv. Protection of lifelines/critical facilities (including disaster plans for each facility)

b. Non-Structural Mitigation:
   i. Legislative framework:
      - Land use planning controls
      - Codes of practice/ building byelaws

ii. Human resource development (HRD):
   - Public awareness
   - Training
   - Education

iii. Public-private partnerships:
   - Building safe communities (this refers to the initiative within the USA developed by the Federal Emergency Management Agency (FEMA) now called ‘Project Impact’)
   - Insurance

iv. Risk reduction planning:
   - Development of national disaster management systems
   - Preparedness plans

Each element in the chain has to be strong, since much is demanded from it to contribute to the demanding function of protecting lives, livelihoods and property. A single weak element in a risk reduction strategy, such as a poorly devised and weakly enforced building code, can constitute a major source of failure. In the catch phrase of a popular TV quiz show a chain is ‘only as strong as its weakest link’.

### 2.1.5 Application of Pre-Disaster Phases of NDRM in Turkey

Related with term ‘Risk Identification and Analysis’, Directorate General of Disaster Affairs is updating the national seismic map of Turkey to help the shaping of the development plans and building code studies and other relevant regulations at the national and local level. Moreover regarding the hazards originating from different human (potential technological, industrial, population hazards etc.) and natural sources (floods, landslides etc.) in addition to earthquakes, the Metropolitan Municipality and some other municipalities in Istanbul initiated local micro-zonation studies to define the mentioned hazards on land basis.

Related with term ‘Risk Reduction or Prevention/Mitigation’, Turkey Directorate General of Emergency Management of the Prime Ministry has some assigned tasks that are to ensure the establishment of emergency management centers, to monitor and evaluate the taking of the necessary measures, the preparation of short and long term plans and the establishment of data banks. Also the Ministry of Industry and Commerce is involved with the determination of critical industrial plants in cooperation with the Ministry of Energy and Natural Resources. National Earthquake Council is involved with the determination of the priorities for risk mitigation studies related with earthquakes and generating strategies.

As retrofitting studies conducted in Istanbul are considered in this study as a component of mitigation phase DRM, risk transfer and risk preparedness mechanisms are not taken into consideration for the aim of this study.

### 2.1.6 Risk Mitigation Studies in Istanbul

Under the implementation of Prime Ministry Project Implementation Unit, ISMEP Project being a model to other countries also has just started and aims to cope with the effects of possible earthquake in Istanbul under different aspects and layers of DRM in the view of preparedness, mitigation and raising awareness. Under this project, Municipality of Bakırköy assessed the buildings within the boundaries of the municipality and found out that some of them are in need of retrofitting against a possible earthquake expected in Istanbul. Being a pre-disaster disaster risk management activity, a study is being held for these selected buildings to conclude with the economical feasibility of alternatives for retrofitting in different methods as a risk reduction/mitigation measure, demolishing and rebuilding and status quo options. These preliminary and ongoing studies are used during the preparation of this thesis.

## 2.2 LIFE CYCLE COST ANALYSIS

### 2.2.1 General

Life Cycle Cost Analysis Handbook (1999) states that the architecture and construction industries have focused on their primary concerns in the creation of buildings where the economics of facility management are not so widely considered and lists these concerns as:

a. The first, of utmost importance to architects, is the design of a building. The major concerns from the view of architecture were: Is the building enjoyable to view and occupy? Does the organization of spaces enhance the user's program? The client expects an architect to be able to design a building that satisfies their aesthetic and functional goals.

b. The second concern, the primary focus of contractors, is the construction of a building. How will the building be built? How much will it cost? The client expects a contractor to construct a sound building for the estimated cost.

These are typically the primary concerns of a client when the idea of constructing a building is addressed, so it is no surprise that architects and contractors focus their efforts to this end. Granted, these are significant concerns, however they are not the only concerns that should be addressed when planning for the future.

c. A third concern that is receiving more attention as building owners investigate the economics of facility management is the cost of building operations over the life of a building. Instead of merely looking at the facility in terms of cost to design and build, owners can broaden their perspective to include operations, maintenance, repair, replacement, and disposal costs. The sum of initial and future (time-dependent) costs associated with the construction and operation of a building over a period of time is called the Life Cycle Cost of a facility [Life Cycle Cost Analysis Handbook 1999].

Fuller et al. (1996) also defines Life Cycle Cost (LCC) as “the total discounted cost of owning, operating, maintaining, and disposing of a building or a building system” over a period of time. Life Cycle Cost Analysis (LCCA) is an economic evaluation technique that determines the total cost of owning and operating a facility over period of time. It should be noted that the concepts of LCCA are not new. The principles are based upon economic theories, which have been used in investment appraisal in many areas of industrial and commercial activities. It should also be remembered that the technique is an aid to the decision-making process [Ashworth A. 1992].

### 2.2.2 Terminology for LCCA

Life Cycle Cost Analysis is an essential design process for controlling the initial and the future cost of building ownership. LCCA can be implemented at any level of the design process and can also be an effective tool for evaluation of existing building systems or any possible structural or non-structural modifications on them such as retrofitting, renovation etc. LCCA can be used to evaluate the cost of a full range of projects, from an entire site complex to a specific building system component.

For this evaluation the basic steps to be followed are summarized by Fabrycky and Blanchard (1991):

a. Definition of problem
   For a sound analysis, clear definition of the problem is the beginning.

b. Identification of the feasible alternatives
   Identification of feasible alternatives and projection to each selected alternative are critical stages in the accomplishment of any life cycle cost.

c. Development of cost breakdown structure
   The cost breakdown structure to the depth required for the visibility of the activities must consider all costs and present them functionally.

d. Selection of a cost model for analysis

   A cost model sensitive to the problem being addressed can be selected from the many different models of cost for analysis (BCA, NPV, IRR etc.).

e. Development of cost estimates

   Cost estimates are developed using engineering projections, parametric methods or experiences specific to the area involved.

f. Development of cost profiles

   For the projection of costs into the future, cost profiles can be selected from the three mainly accepted concepts that are (i) discounted profile using the time value of money (ii) budgetary profile using constant dollars and (iii) budgetary profile using constant inflationary functions

g. Accomplishment of break-even analysis

   To reach a final analysis, cause-result relationships where time values of terms are kept in the analysis must be considered.

h. Identification of high-cost contributors

   After the review of the initial analysis results, high-cost areas, the possible causes for the high costs and relevant recommendations can be introduced.

i. Accomplishment of sensitivity analysis

   The data elements that can significantly affect the analysis results must be investigated in terms of source, validity and reliability etc.

j. Accomplishment of a risk analysis.

   In case the identification and elimination of potential risk areas are not possible, the outstanding risk (high-cost) areas can be noted in terms of probability for occurrence and adequately addressed through an appropriate risk management program.

To follow the steps of LCCA, also the major components need to be defined. Macit (2002) mentions the components of Life Cycle Costing in four items as it can simply be defined as the calculation of present value of costs and benefits of a project, system or product:

a. Costs
b. Benefits
c. Discount Rate (and inflation)
d. Life Expectancy (or study period)

#### 2.2.2.1 Costs

Life Cycle Cost Analysis Handbook (1999) categorizes cost 'the first component in a LCC equation' into two as initial and future expenses:

a. Initial expenses are all costs incurred prior to occupation of the facility.
b. Future expenses are all costs incurred after occupation of the facility.

Arditi and Messiha (1999) state that LCCA is a future-oriented methodology and there are many parameters used in the analysis such as future costs, future incomes, the analysis period, the useful life, the discount rate, the rate of inflation, agency cost (cost of construction, maintenance, rehabilitation, engineering and administration) and user cost (operation costs), hidden (cost due to detours, lost revenue to business and lost tax to government) and social cost (costs of controlling noise, vibration and air pollution) in municipal organizations.

Defining the exact costs of each expense category can be somewhat difficult since, at the time of the LCC study. However, through the use of reasonable, consistent, and well-documented assumptions, a credible LCCA can be prepared.

One should also note that not all of the cost categories are relevant to all alternatives to be compared. If costs in a particular cost category are equal in all project alternatives, they can be documented as such and removed from consideration in the LCC comparison.

#### 2.2.2.2 Benefits

Benefits are the most valued items of a project decision-making process since for the most of the investments making profit is the primary aim at the administrative level according to Macit (2002). But benefit can also considered as the difference of costs relevant to different alternatives.

#### 2.2.2.3 Discount Rate

Kirk and Dell'Isola (1995) define the discount rate as the "rate of interest reflecting the investor's time value of money". Basically, it is the interest rate that would make an investor indifferent as to whether he received a payment now or a greater payment at some time in the future.

Fuller et al. (1996) takes the definition of discount rates further and separates them into two types as real discount rates and nominal discount rates. Actually the rate of inflation is the difference between the nominal discount rate and real discount rate. Real discount rate excludes the rate of inflation and nominal discount rate includes the rate of inflation. But this does not mean that the real discount rate totally ignores inflation, their use simplifies the accounting for inflation within the PV equation.

For the case of this study in Turkey, it can be logical to ignore the rate of inflation, after the latest economical developments made in Turkey. So the discount rate can be used as the real discount rate rather than the nominal one.

Time value of money is found by the present value calculation where it is defined as "time-equivalent value of past, present and future cash flows as of the beginning of the base year".

The present value calculation uses the discount rate and the time a cost was or will be incurred to establish the present value of the cost in the base year of the study period. Since most initial expenses occur at about the same time, initial expenses are considered to occur during the base year of the study period. Thus, there is no need to calculate the present value of these initial expenses because their present value is equal to their actual cost.

The determination of the present value of future costs is time dependent. The time period is the difference between the time of initial costs and the time of future costs. Initial costs are incurred at the beginning of the study period at Year 0, the base year. Future costs can be incurred anytime between Year 1 and n. The present value calculation is the equalizer that allows the summation of initial and future costs.

Along with time, the discount rate also dictates the present value of future costs. Because the current discount rate is a positive value, future expenses will have a present value less than their cost at the time they are incurred.

Future costs can be broken down into two categories: one-time costs and recurring costs. Recurring costs are costs that occur ever year over the span of the study period. Most operating and maintenance costs are recurring costs. One-time costs are costs that do not occur ever year over the span of the study period. Most replacement costs are one-time costs. To determine the present value of future (one-time) costs the following formula is used [Life Cycle Cost Analysis Handbook 1999]:

$$PV = C_t \times \frac{1}{(1+d)^t}$$

Where:

$PV$ = Present Value,

$C_t$ = Cost at time t,

$d$ = Real Discount Rate,

$t$ = Time (expressed as number of years).

To determine the present value of future (recurring) costs the following formula is used [LCCA Handbook 1999]:

$$PV = C_0 \times \frac{(1+d)^t - 1}{d \times (1+d)^t}$$

Where:

PV = Present Value,

$C_0$ = Recurring cost,

d = Real Discount Rate,

t = Time (expressed as number of years).

#### 2.2.2.4 Life Expectancy (or Study Period)

Life expectancy can be defined as overall expected life of the subject element. However there are three different life definitions according to Kirk and Dell'Isola (1995):

a. Technological life.
   It's the estimated number of years until technology causes the item to be obsolete.

b. Useful life.
   It's the estimated number of years during which it will perform its functioning according to some established performance standard.

c. Economical life.
   It's the estimated number of years until that item no longer represents the least expensive method of performing its function.

On the other hand, study period is the period of time over which ownership and operation expenses are to be evaluated. Based on this, study period can vary from any years till the expected life of the facility. While the length of the study period is often a reflection of the intended life of the facility, the study period is usually shorter than the intended life of the facility [LCCA Handbook 1999].

### 2.2.3 Modes of Analysis for LCCA

Regarding and using these defined components of LCC, there are separate methods of LCCA for:

a. Projects which do not involve major capital investment and
b. Projects involving major capital investments

The methods using different ways to combine the data on cost and savings from the above-mentioned projects to evaluate their economic performances are referred in the Life Cycle Cost (LCC) rules as modes of analysis.

The first two of these methods are:

a. Payback period
b. Return on investment

These two modes of analysis frequently used by plants and are not fully consistent with LCC approach as they don’t take into account all relevant values over the entire life period and discount them to a common time basis. Despite the disadvantages, these two methods can provide a first level measure of profitability that is relatively quick, simple and inexpensive to calculate. Therefore they may be useful as initial screening devices for elimination of more obvious poor investments.

The additional three modes of analysis are fully consistent with the LCC approach:

c. Net present value (NPV)
d. Savings/investment ratio (benefit/cost ration method)
e. Internal rate of return (IRR)

The first two modes of analysis not fully consistent with LCC approach can be presented with advantages and disadvantages (See Table 2.1):

**Table 2.1.** Presentation of Modes of Analysis not consistent with LCCA

| Modes of Analysis | Advantages | Disadvantages |
|---|---|---|
| **a.** Payback Period | 1. A rapid payback may be a prime criterion for judging an investment when financial resources are available to the investor for only a short period of time.<br><br>2. The speculative investor who has a very limited time horizon will usually desire rapid recovery of the initial investment.<br><br>3. When the expected life of the assets is highly uncertain, determination of the break-even life i.e. payback period is helpful in assessing the likelihood of achieving a successful investment. | 1. The method does not give consideration to cash flows beyond the payback period, and thus does not measure the efficiency of an investment over its entire life.<br><br>2. The neglect of the opportunity cost of capital, that is failing to discount costs occurring at different times to a common base for comparison, results in the use of inaccurate measures of benefits and cost to calculate the payback period, and hence, determination of an incorrect payback period. |
| **b.** Return on investment | 1. It is simple to compute and is familiar concept in the business community. | 1. Like the payback method, this method does not take into consideration the timing of cash flows, and thereby may incorrectly state the economic efficiency of projects.<br><br>2. The calculation is based on an accounting concept, original book value, which is subject to the peculiarities of the firm's accounting practice, and which generally doesn't include all costs. The method therefore results in only a rough approximation of an investment's value. |

### 2.2.4 Drawbacks of LCCA

Although the LCCA has several advantages that give insight for the economical analysis and decision-making process, it also has some disadvantages originating from its components [Macit 2002]. Marshall and Picken (1987) mention some of these given as below under six headings:

a. Difficulties concerning data.
   For the new emerging sectors like the construction sector, it is difficult to make good estimations on the elements of LCC like costs, benefits, and economic life.

b. Difficulties concerning uncertainty and risk.
   The elements of LCC contain uncertainty and risk at a certain extent.

c. Changes in technology.
   New technology brings new indefiniteness to the future of analysis process.

d. Changes in fashion.
   The changing attitudes of people towards cheap costing, long lasting and other new marketing ideas may shape the LCC.

e. Changes in cost.
   Deviations in cost elements of LCC may completely change analysis.

f. Future predictions.
   Future developments should be taken into consideration comprehensively to make decisions.

g. Historical considerations.
   To make a future prediction, the experiences in the past should also be reviewed.

To sum up the above findings with the advantages and drawbacks, it can be said that the usefulness of a LCCA lies not in the determination of a total cost of a project alternative, but in the ability to compare the cost of project alternatives and to determine which alternative provides the best value spent.

## 2.3 BENEFIT COST ANALYSIS

### 2.3.1 General

Benefit Cost Analysis measures as far as possible, the costs and benefits of a policy or action. Since the resource cost of policies or actions are invariably in monetary terms, comparison in BCA is undertaken by measuring benefits in monetary units. There are two fundamental features in BCA. First it forces the analyst to list the advantages and disadvantages of any policy or action. Second, the listing must reflect some goal. It is common that the ultimate goal in BCA is that increasing the society's well being. This implies that anything contributing to gains in the society is benefit and detracting from it is a cost. In BCA, care has to be taken neither to double count nor to count as a benefit to society a simple transfer from one member of the community to another [World Road Association (PIARC), 1999].

### 2.3.2 Terminology for BCA

Benefit Cost Analysis (BCA) is a systematic procedure for evaluating decisions that have an impact on society [Altay et al. 2004]. There are different ways to conduct a valid BCA, depending on the information one has and the nature of the problem at hand.

To conduct a BCA for a project, it is important to complete the following steps as Özkan (2000) mentions:

a. Identify the problem easily,

b. Explicitly define the set of objectives to be accomplished,

c. Generate alternatives that satisfy the stated objectives,

d. Identify clearly the constraints that are technological, political, legal, social, financial that exist with the project environment. This step will help to narrow alternatives generated,

e. Determine and list the benefits and costs associated with each alternative. Specify each in monetary terms. If this cannot be done for all factors, this fact should be clearly stated in the final report,

f. Calculate the Benefit/Cost Ratios (BCR) and other indicators (e.g. Present value, rate of return, initial investment required, and payback period) for each alternative,

g. Prepare the final report, comparing the results of the evaluation of each alternative examined.

#### 2.3.2.1 Net Social Benefit

Net Social Benefit as the basic rule of BCA can be formulated as follows:

$$NSB = B - C$$

Where:

NSB = Net Social Benefit,
B = Benefit,
C = Cost.

At its most basic level, benefit-cost analysis determines whether the cost of investing in a mitigation project today (the "cost") will result in sufficiently reduced damages in the future (the "benefits") to justify spending money on the project. If the benefit (B) is greater than the cost (C) resulting a positive value for Net Social Benefit

(NSB), then the project is cost-effective; if the benefit is less than the cost, then the project is not cost-effective.

A key criterion for mitigation projects to be implemented is that they must be cost-effective. Benefit Cost Analysis, being a common measure for all hazard mitigation projects, considers a rehabilitation project as cost effective if project benefits after completion of the project are higher than the project.

Benefit-cost analysis is used for all cost-effectiveness determinations - for flood and earthquake mitigation projects alike. Although the following graph is an oversimplification, the concepts it illustrates are important. This graph provides an example of the kind of comparative benefit and cost data that can be seen after conducting a benefit-cost analysis (See Fig. 2.3.)

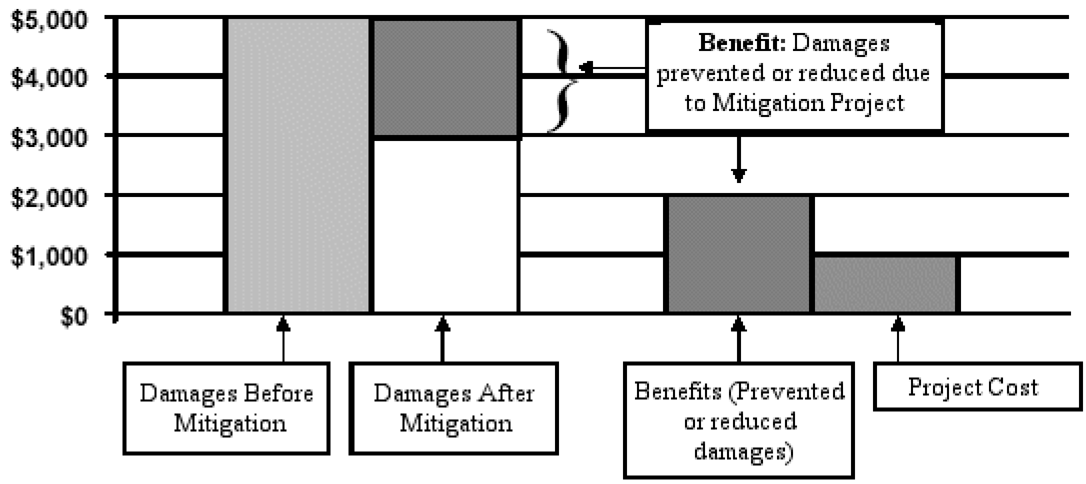



**Figure 2.3.** Basic Benefit-Cost Model (FEMA)

Regarding the cost-effectiveness and the comparability of benefits and costs, it should be kept in mind that the benefits and costs may occur at a later time after a project has been realized, so the time can be introduced into the formula as:

$$NPV = \sum_{t=0}^{T} (B_t - C_t)(1+d)^{-t}$$

Where:

NPV = Net Present Value of Net Social Benefits,

$B_t$ = Benefit at time t,

$C_t$ = Cost at time t,

T = Time horizon,

t = Time (expressed as number of years),

d = Real discount rate.

#### 2.3.2.2 Benefit Cost Ratio

Also a different decision rule used frequently is Benefit/Cost Ratio and it can be introduced as follows:

$$BCR = \frac{\sum_{t=0}^{T} B_t (1+d)^{-t}}{\sum_{t=0}^{T} C_t (1+d)^{-t}}$$

Where:

BCR = Benefit Cost Ratio,

$B_t$ = Benefit at time t,

$C_t$ = Cost at time t,

t = Time (expressed as number of years),

d = Real discount rate.

For the first one of the decision rules given above the case NPV > 0 is preferable and tried to be maximized, where the case BCR > 1 is preferable for the second of the decision rules.

#### 2.3.2.2 Kunreuther's Five Step Procedure

Kunreuther et al. (2001) suggests a simplified five-step procedure for estimating losses to structure and evaluating the benefits to the system. This procedure can be applied to lifeline systems and to residential buildings as well. A more comprehensive approach incorporating several additional steps is discussed in Boardman et al. (2001).

The Kunreuther's five-step procedure includes: defining the nature of the problem, including the alternative options and interested parties; determining the direct cost of the mitigation alternatives; determining the benefits of mitigation, via the difference between the loss to the system with and without mitigation; calculating the attractiveness of the mitigation alternatives; choosing the best alternative (Fig. 2.4.).

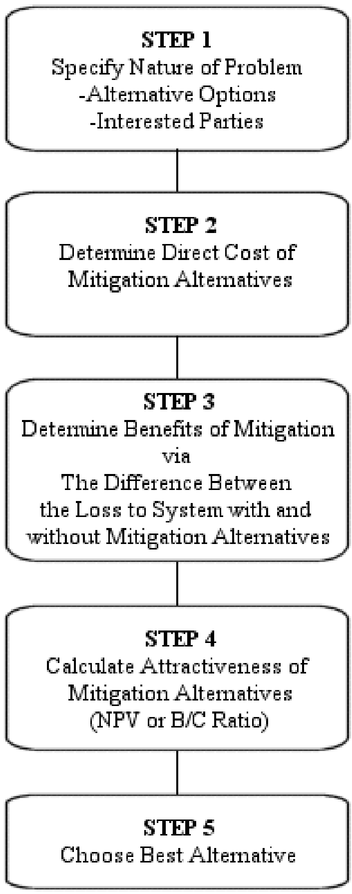



**Figure 2.4.** Kunreuther's Simplified Five Step Procedure for BCA

a. Step 1: Specify the Nature of the Problem

To initiate a BCA, one needs to specify the options that are being considered and the interested parties in the process. Normally, one alternative is the status quo. In the case of the current analyses, the status quo refers to the current vulnerability of the structures without a mitigation measure in place. The status quo is likely to be the reference point for evaluating how well other alternatives perform. In general, if there is sufficient political dissatisfaction with the proposed mitigation options and/or the perceived benefits (i.e., reduction in losses) are less than the expected costs to mitigate the risk to the structure, then the status quo will be maintained.

The status quo, no mitigation to the structure (Alternative 1), will be compared with other alternatives for retrofitting the property. Each of the alternative options will impact a number of individuals, groups and organizations [Kunreuther et al. 2001]. It is important to determine the people that will benefit and the ones that will pay the costs associated with different alternative options. In the case of the residential (apartment) buildings in Bakırköy-İstanbul, the interested parties cover the households in the buildings whether they are the owners or the tenants, private firms in the business of retrofitting, public sector agencies that fund the recovery process after a disaster, and also at a reduced extent the taxpayers as the ones which have to bear some of the repair costs of the damaged property in direct or indirect ways.

b. Step 2: Determine Direct Cost of Mitigation Alternatives

For each mitigation alternative one needs to specify the direct costs to implement the mitigation measure.

c. Step 3: Determine Direct Benefits of Mitigation Alternatives

Once the costs are estimated for each mitigation alternative, one needs to specify the potential benefits that impact each of the interested parties. In the case of seismic risk, one considers either a scenario earthquake event or a set of scenario earthquakes of different magnitudes, location, duration, and attenuation that can affect the system.

The status quo reflects the expected damage to the building without mitigation. With respect to each of the retrofitting alternatives, the expected benefits will be estimated as the reduction in damage to the building from earthquakes of different magnitudes relative to the status quo.

In addition to reducing the physical damage, there are additional benefits of mitigation in the form of fewer fatalities and injuries from an earthquake [Kunreuther et al. 2001]. Other benefits may include the reduction in business and social disruption costs that would have occurred if the mitigation measure had not been adopted and residents would have been forced to evacuate the building after an earthquake.

d. Step 4: Calculate the Attractiveness of Rehabilitation Alternatives

In order to calculate the attractiveness of mitigation, one compares the expected benefits to the residents in the apartment building and other interested parties to the expenditures associated with the proposed measure. These benefits are normally expressed in monetary terms but this poses a set of challenges. For example, in the case of a reduction in fatalities due to the adoption of a mitigation measure, the benefit is measured quantifying the value of a human life and multiplying this figure by the number of lives saved [Kunreuther et al. 2001].

As these benefits and costs are expected to accrue over the life of the building or the study period, a real discount rate (d) should be used to convert future returns and expenditures into a net present value (NPV).

If the difference between maximized net present value of (NPV) of benefits and minimized total costs >0, or B/C >1 then the alternative is considered attractive.

In the calculation of NPV, identifying discount rate (d) have a major importance and best effort should be given to assign a precise value for it.

e. Step 5: Choose the Best Alternative

Finally in the last step, Net Present Values have to be maximized. Alternative giving the highest NPV or benefit-cost ratio at the end of the BCA is the most attractive one around alternatives considered [Çetinceli 2005]. This criterion is based on the principle of allocating resources to its best possible use so that one behaves in an economically efficient manner.

There is normally uncertainty and disagreement among experts regarding the costs and benefits associated with different alternatives. In order to determine which of these estimates really matter, one should undertake sensitivity analyses by varying these values over a realistic range to see how it affects the choice between alternatives.

To the extent that one alternative dominates the picture over a wide range of values for a particular cost or benefit, one knows that there is little need to incur large expenditures for improving these estimates. On the other hand, if the choice between alternatives is highly dependent on a particular cost or benefit then one may want to incur some time and effort into refining this estimate [Kunreuther et al. 2001].

Benefit Cost Analysis is essential for determining the economic feasibility of the alternative rehabilitation strategies. Decision makers save time and resources by identifying unsuitable or unfeasible projects through evaluation of the consequences of BCA [Çetinceli 2005]. Benefit Cost Analysis can also assist interested participants in determining whether the considered project is worth undertaking.

### 2.3.3 Risk and Uncertainty

Risk and uncertainty have an important role for the arrangement of benefits and costs under Benefit Cost Analysis (BCA).

The benefits and costs of any project will not be known with certainty. At the very least, calculations of costs and benefits are based on estimates, and these estimates will have some degree of imprecision. The actual values for future parameters will always depend on future events. For example, the benefits of a new highway may depend on the rate of population growth in an area, and this rate of growth may turn out to be low, moderate or high. Uncertainty, even in the presence of exact cost and benefit calculations, may be unavoidable.

A well-expressed Benefit Cost study will incorporate consideration of the uncertainty and the associated risk into the analysis. Greater certainty has its own value and it may be worthwhile even if the expected values are reduced. This is similar to individuals' consideration of risk in personal decisions. The decision to fund a public disaster prevention project may be analogous to an individual's decision to purchase insurance for her house. While she can not expect to receive more in benefits than she pays in premiums to the insurance company (insurers could not stay in business if this were the case) the consequences of an uninsured house burning down are sufficiently severe that the homeowner is willing to pay more than the expected loss for financial protection.

Similarly, projects that reduce the risk to which a population is exposed may be desirable even if their benefits do not otherwise justify their costs. On the other hand, projects with positive net benefits that expose populations to increased risks may be undesirable even if they offer positive net benefits before accounting for risk.

All projects are conducted under some level of uncertainty. Any number of factors may be uncertain and may lead to a project being unexpected desirable or undesirable. Under some conditions, examining a project using expected value will yield a good decision about whether or not it should be undertaken. However, if there are relatively large potential losses for some members of the affected population, either as a result of doing or not doing a project, some consideration of risk may be appropriate.

### 2.3.4 Sensitivity Analysis

It's impossible to say for certain what the future holds. For many projects, some of the costs and benefits are subject to some degree of uncertainty. Sensitivity analysis is a technique for evaluating a project when there is considerable uncertainty about appropriate values to use in performing the evaluation. For example, uncertainty about the life of a project, the quantity of energy it will save, energy costs, and/or its future replacement costs may raise doubts about its cost effectiveness. In any case, an analysis of costs and benefits must include some provisions for uncertainty. Different "states of the world" may occur with different probabilities and the effects of these states on the project should be discussed in a cost benefit analysis.

Forgetting for a moment about floods, fires, earthquakes, hurricane, famine, ecological disaster and plague for just a moment, it can be seen that uncertainty regarding projects come in many other forms. Even fairly simple costs and benefits are difficult to estimate accurately. Even many people may disagree on appropriate values or figures. Even reputable contractors encounter unforeseen difficulties. In many ways, inaccuracies and disputable parameters find their way into benefit cost analyses. It can not be guaranteed that all numbers are iron clad and perfect before rendering judgment on a project, so a sensitivity analysis can be done to assess the impact of these factors by several evaluations of the project using a range of values for the parameters. By using upper and lower estimated values of each parameter, a clearer picture of a project’s potential cost effectiveness can be seen. Basically, a sensitivity analysis looks at a project a number of times, allowing different critical figures to vary in a wide variety of ways.

## 2.4 RETROFITTING

### 2.4.1 Terminology of Retrofitting

In order to define retrofitting concept, other terms that are synonymously used instead of retrofitting should be clarified. Strengthening is the process to create higher strength and/or ductility than the original building, repairing provide the same level of strength and/or ductility which the building had prior to the damage, remodeling is the reconstruction or renewal of any part of an existing building owing to change of usage or occupancy.

In the light of these, retrofitting is the general term used to define the processes done in strengthening, repairing and remodeling activities. In European countries, generally the terms structural intervention or building intervention are used instead of retrofitting. Rehabilitation is reconstruction or renewal of a damaged building to provide the same level of function, which the building had prior to the damage. Whereas restoring is the rehabilitation of building in a certain area and is a general term containing repairing, remodeling, strengthening and rehabilitation activities [Macit 2002].

The aim of retrofitting -being a risk mitigation measure and a pre-disaster disaster risk management activity- is to improve seismic performance of the buildings. For this reason, most suitable strategy must be chosen such that the desired performance objective is reached. For residential buildings, the scope of such projects is affected primarily by the people or establishments that pay the project costs [Çetinceli 2005].

### 2.4.2 Standardization

In 1997, the Federal Emergency Management Agency (FEMA) published resource documents FEMA 273 and FEMA 274, which were aimed to be guidelines and commentary for the seismic rehabilitation of buildings. These two documents were later combined into a new document, "Prestandard for Seismic Rehabilitation"

FEMA 356. This prestandard was intended as an applicable tool for design professionals, code officials and building owners undertaking the seismic rehabilitation of buildings. Provisions that include technical requirements for seismic rehabilitation were set up. Moreover the study includes foundations and geologic site hazards, design, rehabilitation requirements for steel, concrete, masonry, wood and light metal framing, seismic isolation and energy dissipation, simplified rehabilitation, architectural, mechanical, and electrical components. It provides a general point of view before initiating rehabilitation strategies for the cost concept [Çetinceli 2005].

### 2.4.3 Application Models

Available seismic rehabilitation procedures are summarized in the Seismic Evaluation and Retrofit of Concrete Buildings (ATC-40) prepared by Applied Technology Council (ATC). Alternative retrofitting strategies were classified into two groups, technical strategies and management strategies. The following sections explain briefly each of these strategies that have different considerations in reducing seismic risk [Çetinceli 2005]:

#### 2.4.3.1 Technical Strategies

Technical strategies provide reliable approaches for the seismic performance of the building by modifying demand and response elements of the building. Basic factors affecting the lateral force resisting system's behavior are:

a. Building mass
b. Stiffness
c. Damping
d. Configuration
e. Deformation capacity

There are four approaches used for technical strategies. They are system completion, system strengthening and stiffening, enhancing deformation capacity and reducing earthquake demands. Çetinceli (2005) explains these approaches and the relevant sub-components as below:

a. System completion

   Application of this approach can be made for the structures that reach an acceptable performance point with some local failures and for the structures that have walls, diaphragms and frames acting as a lateral force resisting system. Common causes for these local failures are as listed:

   i. Lack of inadequate chord and collector elements at diaphragms
   ii. Inadequate bearing length at precast element supports
   iii. Inadequate anchorage or bracing of structural or nonstructural components

   General methods for system completion are using diaphragm chords, collectors and drags that are commonly used for timber diaphragms, using steel element connectors for buildings that consist of precast elements and bracing and anchoring the building.

b. System strengthening and stiffening

   This approach is the most favorite and common seismic performance improvement. System stiffening and system strengthening are related to each other. They have to be introduced to the structure at the same time. Techniques used for stiffening strengthen the building and strengthening techniques stiffen the buildings. System strengthening increases total lateral force capacity of the building and system stiffening shifts performance point of the building to a better level.

   i. Shear walls:

      Introducing reinforced concrete shear walls into an existing building, one of the most favorable rehabilitation techniques, is very successful at increasing both building strength and stiffness.

Although this method is a traditional one, placement of shear walls often poses problems for the architectural design. The necessity of evacuation of the rehabilitated building and being a time consuming methodology are other adverse effects of this strengthening method.

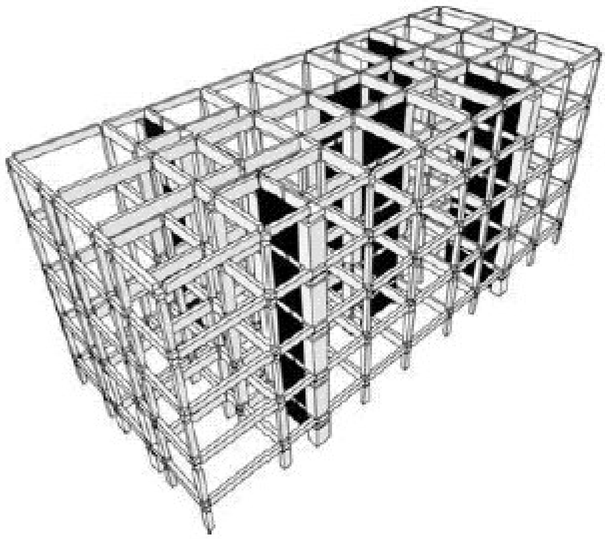


**Figure 2.5.** 3-D Model of A Building with Shear Walls

ii. Carbon Fiber Reinforced Polymer (CFRP) applied on the infill wall

Strengthening infill walls with carbon fiber reinforced polymer (CFRP) has become popular in the rehabilitation of reinforced concrete structures. However, limited number of studies exists for their use. These studies have revealed the significance of these techniques on the improvement of the seismic performance in terms of strength, stiffness and energy dissipation capacity. This technique is very simple and fast to apply in comparison with the other techniques. Furthermore it is a very efficient method because it does not require evacuation during rehabilitation.

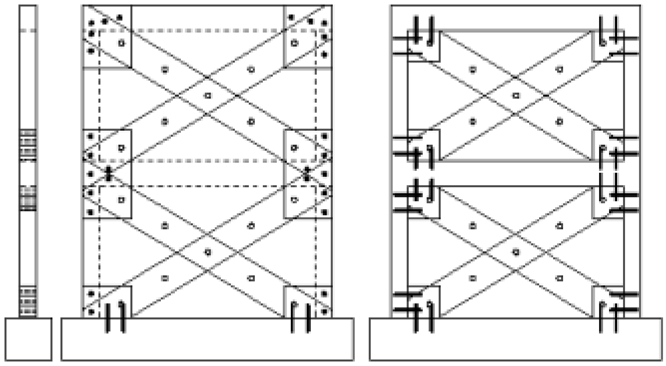


**Figure 2.6.** Diagonal Application of CFRP Over a Typical Infill Wall

iii. Braced frames

Although bracing frames with steel does not provide strength and stiffness as much as shear walls, it is another common method. As the masses of the bracing frames are less than the mass of shear walls, they do not result in a significant increase in building mass and therefore increase seismic forces induced by the lateral load. Besides its advantages, this technique has difficulties while attaching bracing steel members to the existing concrete structure.

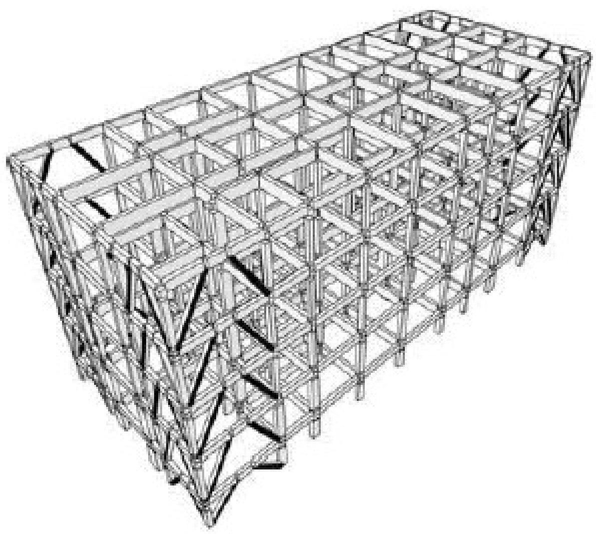


**Figure 2.7.** 3-D Model of A Building with Braced Frames

iv. Buttresses

This system is appropriate when occupancy is essential during rehabilitation. It can be applied outside the building by adding an additional construction.

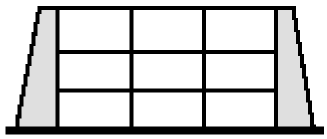


**Figure 2.8.** 2-D Simple Model of A Building with Buttresses

v. Moment resisting frames

Moment frames enhance improvement of strength of the building and have the advantage of occupying relatively a minimal floor space. However, their use is generally limited as they have relatively large lateral drift capacity than the building they are applied. This incompatibility is the main problem for the system.

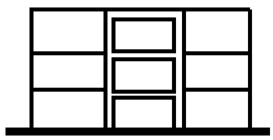


**Figure 2.9.** 2-D Simple Model of A Building with Moment-Frames

vi. Diaphragm strengthening

The most commonly used methods for diaphragm strengthening are:

- Topping slabs, metal plates laminated onto the top of the surface of the slab
- Bracing diaphragms below the concrete slabs

- Increasing existing nailing in the covering and replacing the covering with stronger material or overlaying the existing covering with plywood. (For buildings with timber diaphragms)

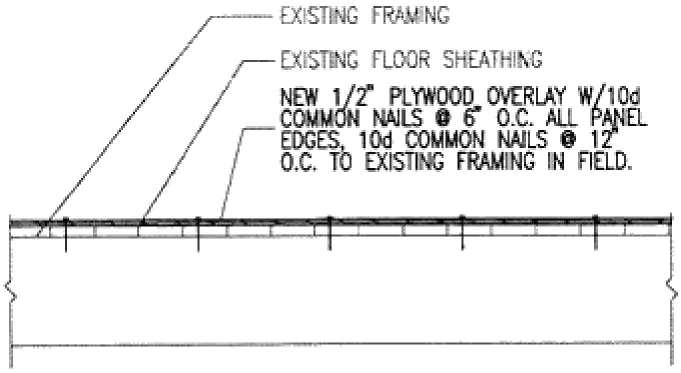



**Figure 2.10.** Diaphragm Strengthening for Buildings with Timber Diaphragms

c. Enhancing deformation capacity

Column jacketing, column strengthening and providing additional supports at places subjected to deformation are among the most typical applications of this technique.

i. Adding confinement

Another widespread method used in rehabilitation projects is confining the columns. Column jacketing improves deformation capacity of non-ductile columns. Jacketing can be made using three techniques, confining with continuous steel plates, concrete jacketing and with fiber-reinforced plastic fabrics. Effectiveness of the technique depends on attachment of confinement to resist pressure exerted on them.

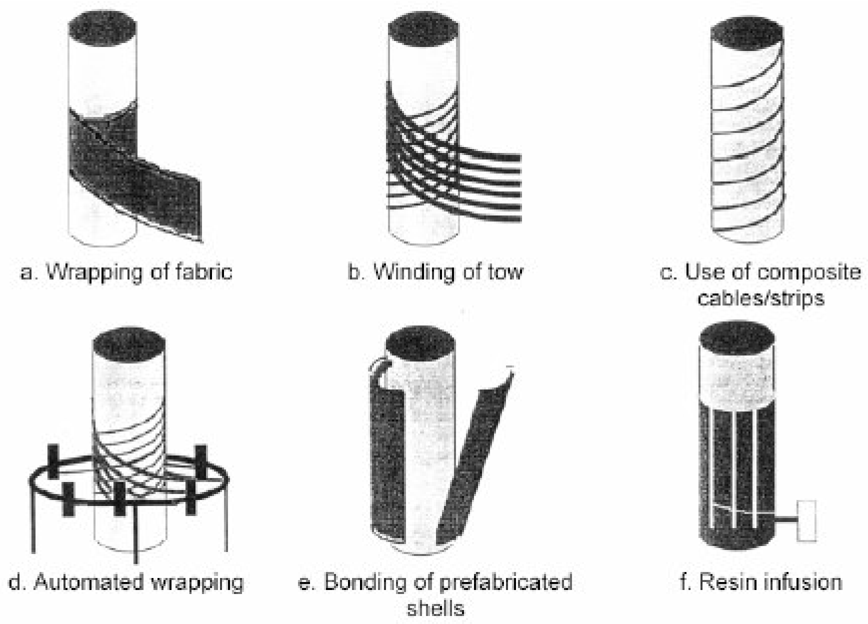



**Figure 2.11.** Column Jacketing Types with FRP

ii. Column strengthening

Column strengthening becomes necessary for buildings in which strong beam- weak column configurations appear. It will permit formation of story mechanisms and much larger drifts.

iii. Local stress reductions

This technique is implemented for the elements that are not primary for the building's performance. Procedures for local stress reductions are:

- Demolition of local members that are quite stiff and respond lateral forces that they cannot resist
- Introducing joints between face of the column and adjacent architectural elements.

iv. Supplemental support

Supplemental bearing supports should be effective for the gravity load bearing structure elements that are not effective in resisting lateral force induced by earthquake.

d. Reducing earthquake demands

Reducing earthquake demands includes new and very expensive special protective systems. Other techniques improve capacity of the building while these systems modify the demand spectrum rather than the capacity spectrum for the structure. Usage of these systems is appropriate for the important buildings like historical buildings or for the accommodation of critical occupancies with valuable equipments and machinery.

i. Base isolation

It is applied by inserting bearings that have relatively low stiffness, extensive lateral deformation capacity and advanced energy dissipation capacities. These characteristics counter lateral deformation demands induced on the building. Base isolation is applicable without performing significant modifications to the structure and suitable for important historic structures. This strategy may be cost effective when there are substantial performance objectives.

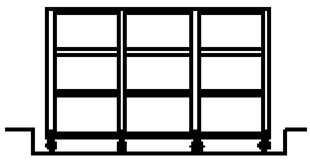


**Figure 2.12.** 2-D Simple Model of A Building with Base Isolation

ii. Energy dissipation systems

Using energy dissipation units (EDU's) is another successful technique to reduce the damping of building response. Primary characteristics and use of these systems are:

- EDU's directly reduce the displacement demands on the structure by dissipating energy.

- They are most effective when introduced in structures having greater lateral deformation capacity and they are also most appropriate for frame structures.
- They should be considered for protection of critical systems and contents in a building.

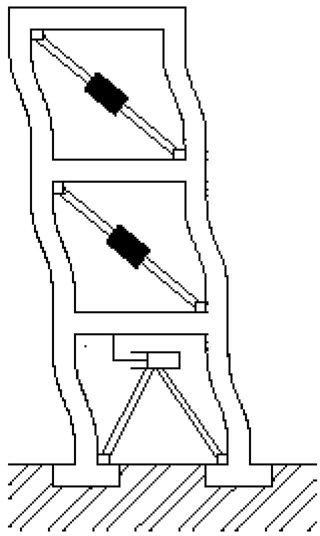


**Figure 2.13.** 2-D Simple Model of A Building with EDU's

iii. Mass reduction

Mass reduction is another method to reduce the demand imposed on the building. Mass reduction reduces natural period of the building. Some of the alternative ways of mass reduction are removing heavy nonstructural elements such as water tanks and storage, and removing one or more building stories.

#### 2.4.3.2 Management strategies

Complementary to the technical strategies of retrofitting, the management strategies have a great importance as well. It should be kept in mind that participants involved with the cost of rehabilitation projects generally control management strategies. Çetinceli (2005) defines the two primary types of management strategies as below:

a. Strategies directing building's performance after rehabilitation
b. Strategies controlling the way of employing technical strategy

Both of these strategies include such methods as:

- Occupancy change
- Demolition
- Temporary retrofit
- Phased retrofit
- Retrofit while occupying building
- Retrofit while vacant
- Exterior retrofit
- Interior retrofit

# CHAPTER 3

# CASE STUDY

## 3.1 GENERAL

In recent decades urban centers of Turkey became risky areas for earthquake disasters as these risks have increased mainly due to very high rate of urbanization, faulty land-use planning and construction, inadequate infrastructure and services, and environmental degradation. Also the unprecedented increase of the probability of occurrence of a large earthquake (magnitude seven or greater) in Istanbul as another important source increased the risk in Istanbul (which is predicted at a probability of about 65% during the following 30 years). The inevitability of the occurrence of such a large earthquake in Istanbul makes it compulsory that certain preparedness and emergency procedures should be realized during the event of and prior to an earthquake disaster, which in turn requires the quantification of effects of the earthquake physically and socially.

Through the development of this study, approach of five steps by Kunreuther to BCA will be used as a basis for the relevant steps of the analysis.

## 3.2 DEFINITION OF THE PROBLEM

Following the 1999 Marmara earthquakes, several damaged buildings had been repaired and strengthened by employing ordinary, local construction practices, without paying attention to the state of art methodologies in seismic rehabilitation. The outcome of such incompetent practices created a wide dissatisfaction and skepticism in the affected community regarding safety and economy, which eventually discouraged similar applications to vulnerable buildings in other seismic regions.

Regarding these unsatisfactory applications, Istanbul stays as the major candidate for wide scale retrofit applications, due to the heightened odds of a severe earthquake along the Marmara segment of the North Anatolian Fault. Also nearly the half of the huge building stock consisting of one million buildings in Istanbul is expected be effected significantly from the foreseen Marmara earthquake. However, retrofit activities to mitigate seismic risks have remained very sparse in Istanbul after 1999, especially in private residential buildings.

On the other hand, Municipality of Bakırköy has conducted a study for the evaluation of residential buildings that are potentially vulnerable against a possible earthquake at Bakırköy region recently and selected a representative group of residential building to be assessed in details. The Consultancy firm Beca-Prota is involved with the evaluation and assessment of these selected buildings against their vulnerabilities and possible retrofitting solutions for them.

To get the idea for the real earthquake, the probability of occurrence of a magnitude seven or greater earthquake in the Marmara Sea region targeting Istanbul is computed as 62±15 percent in the next 30 years by Parsons (2000).

JICA report (2002) identifies the scenario earthquake where North Anatolian Fault (NAF) is determined based on the study result conducted by CNRS-INSU, ITU and TUBİTAK. In this study moment magnitude $M_w$ is assumed to be 7.5. On the other hand Feigh et al. (2002) states that the GPS readings and on-site observations show that rupture length with respect to JICA study is shorter so the magnitude may be assumed to be diminished. So $M_w$ is taken as 7.2 for this study.

This study at this point aims to give ideas to help to convince and encourage the households living in residential buildings at this region to reduce their potential seismic vulnerabilities against a probable earthquake expected in Istanbul in someway parallel to the study of Beca-Prota. It also tries to provide an economical analysis for the evaluation of retrofitting works for a group of selected buildings, which can give a general idea about the subject and afterwards can be taken by households and the relevant institutions into consideration in a more general way.

### 3.3 DEFINITION OF THE ALTERNATIVES, INTERESTED PARTIES

Our objective in this study is the evaluation of the retrofitting risk reduction measures for residential buildings in Istanbul against earthquake in terms of Benefit Cost Analysis (BCA). Following an approach that is similar to Kunreuther's five-step approach, first of all it is a need to determine the alternative options at first and to compare them where they are considered during the evaluation of retrofitting:

a. Status quo

   Status quo simply means "no action or mitigation" taken for the structure where the buildings are left as they are in this study. This condition of no action will be used as a base level for the other alternatives and help to realize the possible effects of earthquake to the selected buildings.

b. Retrofitting options 1 and 2

   After the seismic assessment of the buildings by the consultancy firm Beca-Prota J.V, two different options are offered as the retrofitting scheme that may differ for different buildings. The important point here is to have sound and feasible valuation for these retrofitting options. Also these different retrofitting measures will be used to make a decision whether to retrofit or not the selected buildings.

   From these measures, Retrofitting Option 1 will be named as internal solution with retrofitting shear walls and beams inside the building and Option 2 will be named as external with retrofitting shear walls and beams outside the building and precast panel retrofitting inside the building.

   Retrofitting shear walls, beams and precast panels are R/C (reinforced concrete). Retrofitting shear walls and beams are traditional methods of retrofitting and they are widely used. On the other hand, the application of precast panels are made such that they are posted on one face of the masonry infill walls to form a strong layer. These panels are attached to each other by built-in keys and pasted onto wall with epoxy based resin. Anchor dowels are placed in built slots in the precast elements to provide integration.

c. Demolishing and rebuilding

   Reconstruction of a new building after the demolition of the existing one is also considered as an option in order to make a more sound decision as the last step of BCA. For this point the action takes the form of a replacement of the old building with a similar reconstructed one in area, type and function as well.

These alternatives will be evaluated on the base that the analysis will take account of time it takes for the scenario earthquake to occur (e.g. 1, 5, 10, 20 years). This is a conditional approach as noted by Hopkins et al. (2004) and differs from the approach of annual probability by asking the questions like "What happens if the earthquake happens just after retrofitting?" where the annual approach focus on the benefits and costs regarding the possible time earthquake will occur on an annual basis. So this study will not take the annual probabilities of existence for earthquake into consideration but will evaluate the effects for selection of alternatives at selected time intervals.

To conduct a BCA in Bakırköy-Istanbul, it is important to determine the people that will benefit and the ones that will pay the costs associated with different alternative options. In the case of the residential (apartment) buildings in Bakırköy-İstanbul, the interested parties cover the households in the buildings whether they are the owners or the tenants, private firms in the business of retrofitting, public sector agencies that fund the recovery process after a disaster, and also at a reduced extent the taxpayers as the ones which have to bear some of the repair costs of the damaged property in direct or indirect ways. At latest stage, it remains an important question whether the costs of potential retrofitting activities will be fully or partially met by the owners or the government will contribute to the costs for the applicability. But the conditions and alternatives of financing are not considered in this study.

The existing ages of the buildings are not considered in this study and the discount rate is taken as 4% regarding the recent developments in Turkish economy.

## 3.4 DEFINITION OF COSTS FOR MITIGATION ALTERNATIVES

### 3.4.1 List of BCA Cost Elements

After the definition of alternatives and the interested parties, the costs are to be defined related with the mitigation (risk reduction) alternatives for seismic improvement. Within the scope of this study, the costs will be considered and listed under the main headings as noted below due to their time dependencies:

a. Initial costs (Retrofitting or demolition & reconstruction alternative costs).
   Retrofitting alternative costs considered as initial costs, are the costs arising from retrofitting activities as its name implies. They can be listed under the following items (in case retrofitting alternative used):

   i. Cost of strengthening the building.
      The cost of strengthening the building covers the actions to strengthen the building to promote it to a structural condition if it were newly built in conformance with the earthquake codes. The cost of strengthening covers the structural costs and necessary architectural and services costs for reinstatement.

   ii. Cost of temporary relocation.
       Temporary relocation may be needed for the households of the residential buildings to implement the selected retrofitting alternatives properly. The action of temporary relocation covers:
       - Cost of temporary two-way moving (moving out and returning)
       - Cost of temporary accommodation

   Demolition and reconstruction alternative costs considered as initial costs, are the costs that result from the activities aiming to replace the demolished building with a similar one in area and functions at the same area by reconstruction (in case demolition and reconstruction alternative used):

i. Cost of demolition and reconstructing the building.

This cost covers the demolition and construction activities to rebuild the building with the functions and properties of the demolished one in terms of area and usage but in conformance with the existing earthquake codes in effect.

ii. Cost of temporary relocation.

Temporary relocation may be needed for the households of the residential buildings due to demolition and reconstruction activities. It covers:

- Cost of temporary two-way moving
- Cost of temporary accommodation

b. Earthquake-dependent disbenefits (costs).

Earthquake-dependent disbenefits (costs) include the direct and indirect disbenefits resulting from a probable earthquake after its occurrence. The term disbenefits is used as the costs resulting from an earthquake are not asked by people and they are unfavourable outcomes of a project. These may be summarized as below with the following main headings:

i. Cost of damage to building.

The cost of damage to building covers the actions to reinstate the building to its previous condition before the earthquake and due damages including the cost items of:

- Structural costs
- Architectural costs
- Services costs

ii. Cost due to injuries

iii. Cost due to loss of lives

iv. Cost of damage to household goods

v. Cost of temporary resettlement (moving cost and the relocation costs)

vi. Cost of business interruption and social disruption

c. Time-dependent costs (Maintenance costs).

   Time-dependent costs correspond to the costs of building maintenance needs at regular intervals although the type of time-dependent costs is not considered for this study.

### 3.4.2 Assignment of Values for BCA Cost Elements

For the cost items of the BCA to be conducted, the values are assigned with the considerations and assumptions as the followings. At this stage of valuation, several sources are searched; from these some values are directly used and for other values assumptions made and market researches conducted.

#### 3.4.2.1 Initial Costs

a. Retrofitting costs (CR)

   These costs will apply to the retrofitting cases. It will cover the cost of strengthening the building, and temporary relocation during the time retrofitting activities take place.

   i. Cost of strengthening the building (CS).

      Cost of strengthening the building will include all costs of structural work and of reinstating architectural and services elements disturbed by the retrofitting. No allowance for betterment will be made. The structural engineers of the consultancy firm Beca-Prota assessed the costs for these separate items for structural, architectural and services works individually for each building and these values of retrofitting costs found by them are used in this study. On the other hand Figure 3.1 can help to have a brief idea about this relation in a simple manner where the term structural capacity corresponds to the overall evaluated capacity of a building to meet the earthquake codes and regulations as a percentage.

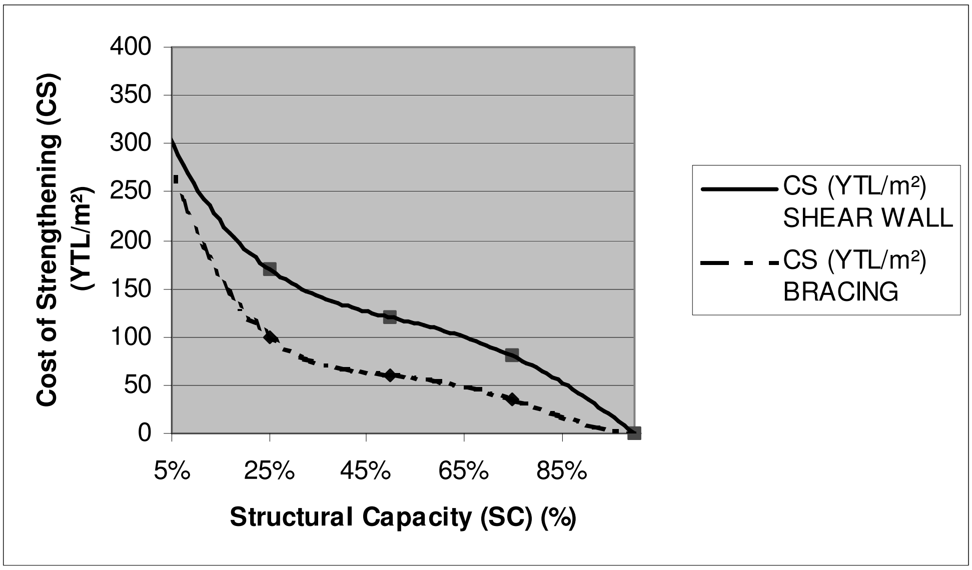



**Figure 3.1.** Cost of Strengthening vs. Structural Capacity

Also it does not seem logical to strengthen a building that has structural capacity of low values such as 5%, 50% etc., Figure 3.1 only aims to emphasize the fact that the cost for strengthening increases as the structural capacity decreases. On the other hand, it can be considered that a certain level of structural capacity can be chosen to start the strengthening activities from.

ii. Cost of temporary relocation (CTR).

Temporary relocation cost consists of two-way moving costs and cost of temporary accommodation during the time retrofitting process goes on.

$$CTR = CTM + CTA$$

Where:

CTR = Cost of Temporary Relocation,

CTM = Cost of Two-way Moving,

= (Area for flats) x (Hauling Rate) x (Rate of Movement)

CTA = Cost of Temporary Accommodation.

= (Time Moved Out) x (Rental Rate) x (Rate of Movement)

In this study Beca-Prota engineers' decision for the number of flats to be moved out (Rate of Movement) for each individual retrofitting option is taken as a basis. Also time moved out is given by the structural engineers for each option.

- Two-way moving costs (CTM) are costs of moving out before retrofitting and moving back in after retrofitting to the apartment. People have to be relocated and brought back during retrofitting. Using the percentage of occupants (RM=Rate of Movement) likely need relocation by using the number of flats to be moved out, the total cost of temporary moving can be found.

  Taking offers from hauling companies in Istanbul and making a search on Internet, an approximate rate of 600 YTL has been obtained to take goods from one building to another one within the boundaries of the city. With the assumption of an accommodation area of 110 m² for the region, an approximate hauling unit price of 5.5 YTL/m² is obtained for one way and 11 YTL/m² for two-way hauling.

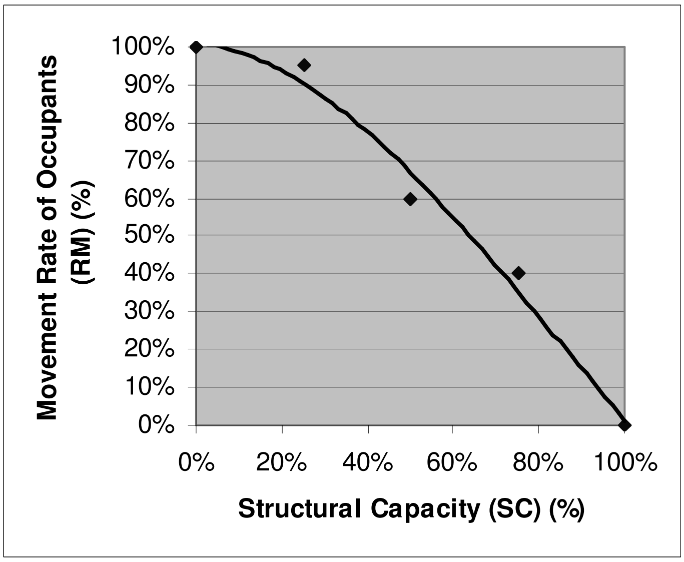



**Figure 3.2.** Movement Rate of Occupants vs. Structural Capacity

Although Figure 3.2 cannot give specific values for the movement rate of occupants, it can emphasize the idea that more people are moved out generally while making the building stronger due to increased disturbance of the households.

- Temporary accommodation costs (CTA) are costs of accommodation of people when they are moved out for retrofitting. The duration is determined according to the properties of retrofitting activities. Approximate rental rate (RR) from 7 YTL/m² to 14 YTL/m² per month is obtained from the web site of rental agency REMAX that ranges from location to location and from building to building in Bakırköy-İstanbul. So these values are considered as logical and realistic for Istanbul during relatively short period of accommodations. From these values, rental rate (RR) of 9 YTL/m² is chosen as an average value to simplify the condition and not to give separate rental values for different buildings, which is indeed the real case.

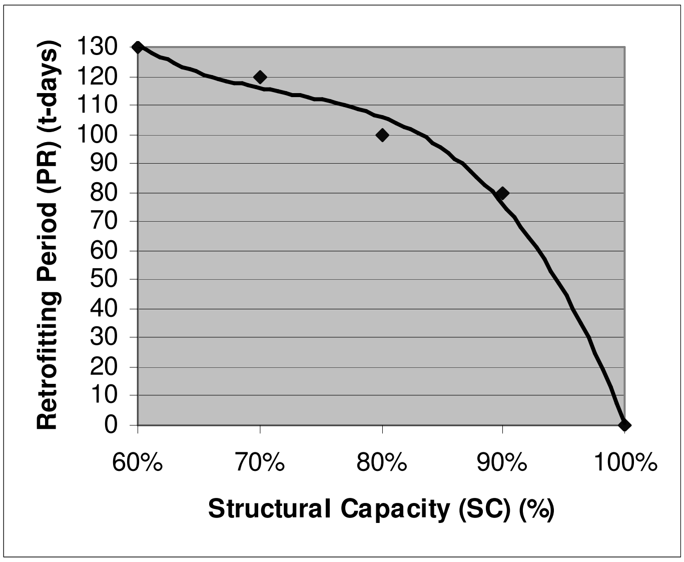



**Figure 3.3.** Relocation Period vs. Structural Capacity

Figure 3.3 can give a general idea that Relocation Period/Time Moved Out (PR) increases with the decreasing rate of structural capacity (SC) where retrofitting option is not considered for structural capacity lower than a certain level such as 50% or as 60% given in this graph.

b. Demolition (CD) and reconstruction cost (CC) consist of the cost of demolition and reconstruction of the building together with cost of temporary relocation:

   i. Cost of demolition (CD) and reconstructing the building (CC).
   The unit price for demolishing a Reinforced Concrete (R/C) building is taken about \$ 23/m² in Turkey (Arıkan et al., 2005). This price is comparable with the unit price set by Ministry of Public Works and Settlement in Turkey, so a value of 30 YTL/m² will be used in this study for the demolition of R/C buildings.

   For the calculation of reconstruction (CC), the value will be found by multiplying total area of the building by the unit price of constructing a similar building in that area. The unit prices announced by Ministry of Public Works and Settlement are taken for this purpose. The prices announced for 2005 are as below; idea for time of construction is given in Table 3.6:
   - 315 YTL/m² for Class 3-A (buildings with 4 or less storeys with no elevator)
   - 359 YTL/m² for Class 3-B (buildings with more than 4 storeys with an elevator)
   - 408 YTL/m² for Class 4-A (buildings over 21.5 m high with an elevator)

   ii. Cost of temporary relocation (CTR).
   Temporary relocation cost again consists of two-way moving costs and cost of temporary accommodation during the time of demolition and reconstruction process as similar for the case of retrofitting where the difference comes from the fact that all of the households of a buildings will

have to relocate and move as a result of the demolition and reconstruction activities where rate of movement (RM) was identified for the retrofitting case.

$$CTR = CTM + CTA$$

Where:

CTR = Cost of Temporary Relocation,

CTM = Cost of Two-way Moving,

= (Area for Flats) x (Hauling Rate)

CTA = Cost of Temporary Accommodation.

= (Time Moved Out) x (Rental Rate)

- Two-way moving costs (CTM) are costs of moving out before demolition and reconstruction and moving back in after demolition and reconstruction to the apartment. Using the full percentage of occupants likely need relocation, the total cost of temporary relocation can be found.

  The rate 11 YTL/m² suggested for two-way hauling during retrofitting activities will be used also for this calculation.

- Temporary accommodation costs (CTA) are costs of accommodation for people when they are moved out for demolition and reconstruction. The duration will be taken as constant value of 15 months for demolition and reconstruction case. For the determination of this value, the fact that reconstruction activities at a normal time can be conducted faster than an earthquake case and the facts of construction speed experiences in Turkey are considered. An average value of 9 YTL/m² as in retrofitting case will be selected from the values for the rental rate (RR) ranging from 7 YTL/m² to 14 YTL/m² in the area.

#### 3.4.2.2 Earthquake-dependent Disbenefits (costs)

Occurrence of an earthquake causes damages to both people and properties. Damage to buildings also result with the damage to the people as injuries or fatalities. In relation with these damages, owners and community will have to meet the hospital expenses, the expenses to reinstate the damages of buildings to their conditions prior to the earthquake, and also the other expenses due to the earthquake. These costs can be seen as unwanted costs to bear.

The intensity of the cost to the individuals and community will be measured by how buildings resisted to earthquake. Also it's a known fact that the stronger buildings in terms of seismic vulnerability are less susceptible to damages when compared with the less-strong near-by buildings around subject to the same earthquake effects. So this brings us to the fact that the cost of a weak building will be more than the cost of strong building that is similar in size and occupancy rate (function).

These kinds of costs due to earthquake are regarded as disbenefits meaning unfavorable outcomes of a project, as the people did not ask for them as also noted by Park (2001).

a. Cost of damage to building (CDB).

   Structural, architectural and service costs will be considered for the calculation of the cost of damage to buildings. The aim tried to be achieved under the heading for this cost item is the reinstatement of the building to its former condition prior to the earthquake in case of earthquake damage.

   In case of a total destruction (collapse) case, cost of moving debris and reconstruction will also be considered. For other cases, an assumption for the relation of Damage Ratio (RD) vs. Construction Cost (CC)/m² of a new building will be used such that Construction Cost will take the value of reconstruction at its maximum value for maximum damage ratio and the other values will be simply interpolated between '0%' and '100%' for Construction Cost Ratio and Damage Ratio. So the relevant values for structural costs, architectural costs, services costs for Cost of Damage to Building (CDB) will be assigned in a simple way. Figure 3.4 can also give an idea for this type of calculation.

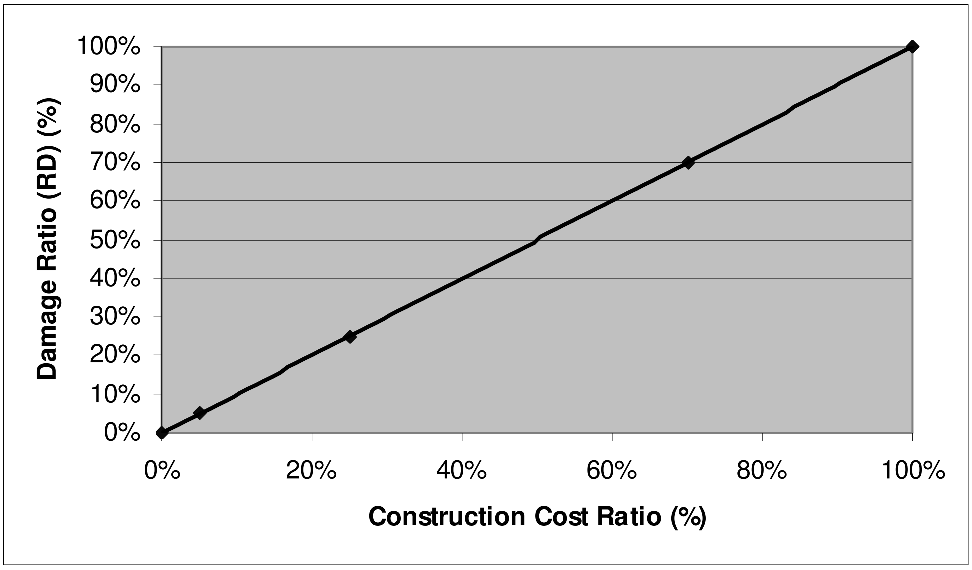



**Figure 3.4.** Damage Ratio vs. Construction Cost Ratio

$$CDB = RD \times CC$$

b. Cost due to injuries (CI).

The procedure in HAZUS will be followed with the numerical values modified for Turkey and using a graphical relationship between Damage Ratio (RD) and Casualty Rates (RC) for different injury levels in parallel with the approach of Beca Prota in their study for Bakırköy.

Four injury levels (4th is death or mortally injured case) given in HAZUS99 will be taken and costs for injury severity levels will be found by using Table 3.1 as referred by Erdik and Aydınoğlu (2002) where the cost per person column has the suggested values of Beca-Prota for severity levels. The value for the death case is calculated by assuming that the person who was killed would contribute to the society for 35 years with the minimum wage cost. The minimum wage per month in Turkey is 593 YTL, in July 2005 including all costs. This yields a value of nearly 250 YTL. General Directorate of State Highways in Turkey also calculates the value of a person killed in an accident using this criterion as referred by Özkan (2000).

**Table 3.1.** Injury Severity Levels modified from Erdik et al., 2002

| **Injury Severity Level** | **Cost/person (YTL)** | **Injury Description** |
|---|---|---|
| Severity 1 | 500 | Injuries requiring basic medical aid without requiring hospitalization |
| Severity 2 | 2,000 | Injuries requiring medical care and hospitalization, but not expected to progress into life threatening status |
| Severity 3 | 10,000 | Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries result because of structural collapse and subsequent collapse or impairment of occupants |
| Severity 4 | 250,000 | Instantaneously killed or mortally injured |

The damage state vs. injury level suggested for Turkey by Erdik and Aydınoğlu (2002) in Table 3.2 is used as a base to set up the graphical relationship, but the values used for casualty rates are not used in this table instead new values are assigned for the casualty rates. The idea to make this change is the total involvement rate of occupants as referred in Table 3.2 has low values for slight, medium and heavy damage states where at state of collapse stage, all occupants are disturbed. So the values of severity levels are re-arranged on the basis that the total number of disturbed people will be more at every state of damage when compared with Table 3.2. These new values are given Table 3.5.

In Table 3.2 Casualty Rate vs. damage states are considered, but for his study structural capacity of the building is considered rather than the damage state of the building when subjected to an earthquake. Therefore, casualty rates of Table 3.2 are transformed into graphics of Casualty Rate (RC) vs. Damage Ratio (RD) for each severity level with the suggested values (Fig. 3.5).

**Table 3.2.** Casualty Rates for R/C Structures (Erdik and Aydınoğlu, 2002)

| Injury Severity Level | Low Damage (Slight) | Medium Damage (Moderate) | Heavy Damage (Extensive) | | Very Heavy Damage (Collapse) | |
|---|---|---|---|---|---|---|
| Severity 1 | 0.05 | 0.2 | 1 | (1) | 10-50 | (5-50) |
| Severity 2 | 0.005 | 0.02 | 0.5 | (0.1) | 8-15 | (1-10) |
| Severity 3 | 0 | 0 | 0.01 | (0.001) | 4-10 | (0.01-2) |
| Severity 4 | 0 | 0 | 0.01 | (0.001) | 4-10 | (0.01-2) |

For this transformation, a damage ratio is to be assigned for each damage state. Table 3.3 lists the damage factors corresponding to damage states used by Applied Technology Council (ATC) in the study of Çetineli (2005). ATC considers six damage states in this table. On the other hand, HAZUS table (Table 3.2) considers only four damage states. Combining the information in these two tables, Damage Ratios are suggested in Table 3.4. Graphs of Damage Ratio vs. Casualty Rates using the above information are drawn in Figure 3.5. To calculate the cost due to injuries, Severity Levels (SL-1, 2 and 3) will be used.

**Table 3.3.** Damage Factors Corresponding to Damage States (ATC-13)

| Damage State | Damage Factor (%) | Average Damage Factor (%) |
|---|---|---|
| None | 0 | 0 |
| Slight | 0-1 | 0,5 |
| Light | 1-10 | 5 |
| Moderate | 10-30 | 20 |
| Heavy | 30-60 | 45 |
| Major | 60-100 | 80 |
| Destroyed | 100 | 100 |

**Table 3.4.** Damage Ratios Corresponding to Damage States (suggested)

| Damage State | Damage Ratio (%) |
|---|---|
| Slight | 12,5 |
| Moderate | 25 |
| Extensive | 50 |
| Collapse | 100 |

The overall table to be used for calculation cost of lives and losses to respond to the conditions in this study is arranged by using Table 3.1, Table 3.2, Table 3.3 and Table 3.4 and given as Table 3.5 below:

**Table 3.5.** Casualty Rates vs. Damage Ratios

| **Damage Ratio (%)** | **Severity Level 1 RC (%)** | **Severity Level 2 RC (%)** | **Severity Level 3 RC (%)** | **Severity Level 4 RC (%)** |
|---|---|---|---|---|
| 12,5 | 8 | 4 | 1,5 | 0,5 |
| 25 | 12 | 8 | 6 | 2 |
| 50 | 20 | 15 | 12 | 10 |
| 100 | 10 | 15 | 30 | 40 |

By using the assigned values for Casualty Rate is found from the relevant Damage Ratio and Cost of Injury Treatment, also with the provided data for Number of Occupants (NO) of the buildings at the time earthquake. Here NO is found by multiplication of number flats by an assumed factor of 1 people per flat as the day and night time intensity and number of people in housing units vary, where cost for an injury severity level can be calculated as follows:

$$CI_i = NO \times RC_i \times CIT_i$$

Where:

CI = Cost of Injury,

NO = Number of Occupants,

RC = Rate of Casualty,

CIT = Cost of Injury Treatment,

i = Injury Severity Level.

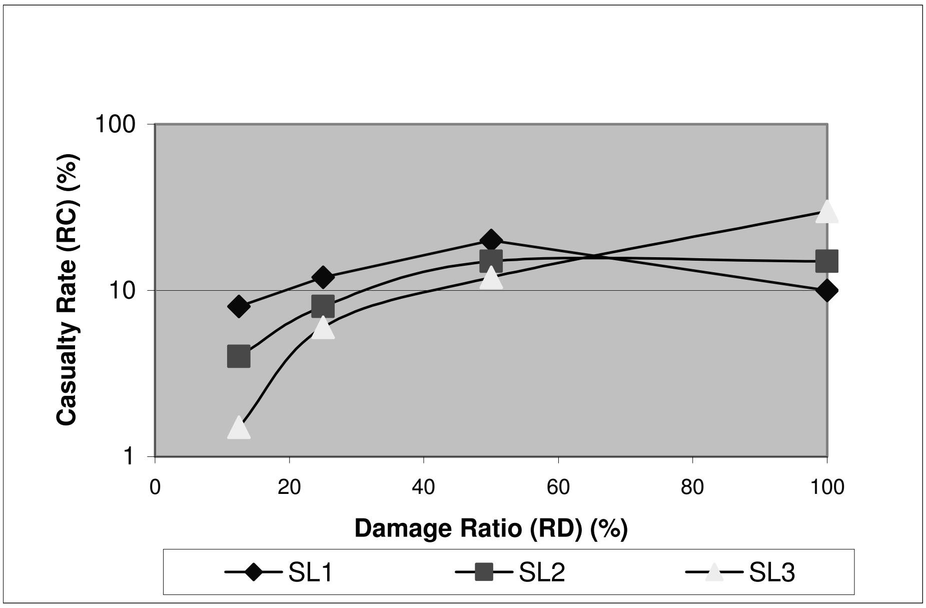



**Figure 3.5.** Casualty Rate vs. Damage Ratio (SL-1, 2, 3)

c. Cost due to loss of lives (CLL).

Cost due to loss of lives will be calculated using the same procedure as given for cost of injuries. In this case Severity Level 4 (SL-4) will be used (Figure 3.6). The Cost for Loss of a person will be taken as 250 YTL as given in Table 3.1.

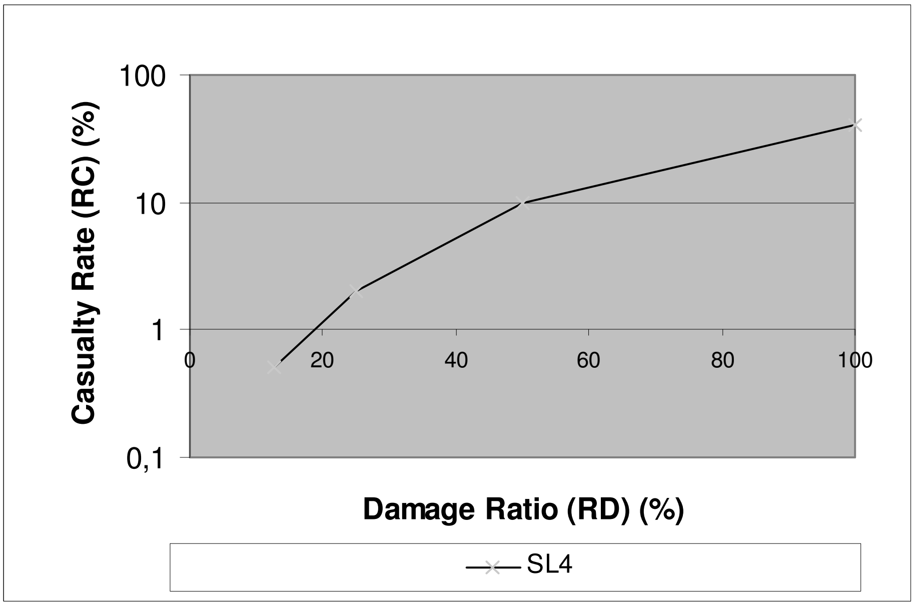



**Figure 3.6.** Casualty Rate vs. Damage Ratio (SL-4)

d. Cost of damage to household goods (CDG).

Cost will also cover damages to content in buildings. The value of the damaged goods inside a building will be calculated by multiplying Cost of Damage to Building (CDB) by a coefficient of content loss ($c_{cl}$). Coefficients of content loss for various types of buildings have been suggested and used by Ho (2001). Coefficient content loss ($c_{cl}$) suggested by Ho (2001) is 0.5. This value is suggested for USA. A coefficient of 0.25 is suggested in this study for residential buildings in Istanbul. So Cost of Damage to Household Goods (CDG) can be calculated as follows:

$$\mathrm{CDG} = \mathrm{CDB} \text{ x } c_{cl}$$

Where:

CDG = Cost of Damage to Household Goods,

CDB = Cost of Damage to Building,

$c_{cl}$ = Coefficient of Content Loss (0.25).

e. Cost of temporary resettlement (moving cost and the accommodation costs) (CTS).

$$\mathrm{CTS} = \mathrm{CTM} + \mathrm{CTA}$$

Where:

CTS = Cost of Temporary Settlement,

CTM = Cost of Two-way Moving,

= (Area for Flats) x (Hauling Rate) x (Rate of Movement)

CTA = Cost of Temporary Accommodation.

= (Time Moved Out) x (Rental Rate) x (Rate of Movement)

Movement Rate of Occupants (RM) after an earthquake will take value of 60 %, as the Rate of Casualties (RC) for 4 levels of Injury Severity Levels have an average value of nearly 50 % meaning that half of occupants in buildings are injured at low or high levels at time of earthquake so they have to be evacuated from the buildings prior to the movement of remaining occupants. Taking into consideration that some of these injured people may return home after first aid, Movement Rate of Occupants (RM) is arranged as 60 %.

i. Cost of Temporary Moving (CTM) will be found by the same method used for cost of moving during initial actions of retrofitting or demolition and reconstruction.

ii. Cost of Temporary Accommodation (CTA) can be less when compared to cost of accommodation during initial actions of retrofitting or demolition and reconstruction, as people will have to live in the available environment after the earthquake. To calculate this, time of repair and rental rate are needed. HAZUS99 values given in Table 3.6 have been used in a study in Turkey conducted by Yanmaz and Luş (2005) to estimate the time of repair. In the same study a rental rate of \$ 0.06/day/m² has been used. This is about 0.08 YTL per day per square meter that makes 192 YTL/month for an area of 80 m² of accommodation area. This value is assumed as reasonable as people may have to live in tents or barracks without much comfort after an earthquake.

**Table 3.6.** Time to Repair after the Earthquake (Yanmaz and Luş, 2002)

| **Type of Building** | **Low Damage (Slight)** | **Medium Damage (Moderate)** | **Heavy Damage (Extensive)** | **Very Heavy Damage (Collapse)** |
|---|---|---|---|---|
| Residential | 5 | 120 | 480 | 960 |
| Hospital | 20 | 135 | 540 | 720 |
| School | 10 | 90 | 360 | 480 |

On the other hand, time values offereb by Yanmaz and Luş (2002) are not used, instead a direct relation between Time of Relocation after earthquake and Damage Ratio after earthquake is established assuming that the construction period will be doubled differing from the case before earthquake due to the general damage possible at the area affecting this period. Time of Relocation that is also the reinstatement time for building to its former condition will take its maximum value and remain constant after the Damage Ratio (RD) value of '50 %' taking into consideration that the reinstatement activities beyond this limit will take long time as if the building was reconstructed.

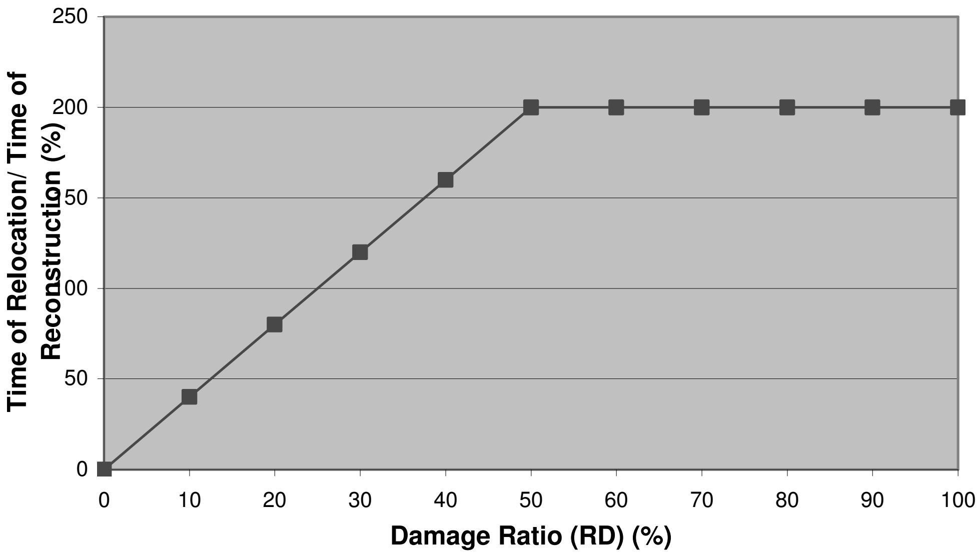



**Figure 3.7.** Time of Relocation/Time of Reconstruction vs. Damage Ratio

f. Cost of business interruption and social disruption (CBI, CSD).

Business interruption and social disruption cost is hard to assess. It may, due to material damages, include cost of not being able to produce or serve so many different products or services to not being able to consume as much as before even if products or services are available. It may even include cases where people cannot perform their regular activities because of psychological effects.

In this study, Cost of Business Interruption (CBI) and Social Disruption (CSD) will be estimated by multiplying the sum of damage to building, injury and fatality costs by a coefficient. This coefficient will be assumed as 0.50. Although the data given in The World Bank (WB) Marmara Earthquake Assessment

Report (1999) can be used to conclude with an approximate value of 1.0 for this coefficient, this value is not used as its certainty and applicability is not clear. So the factor to be used for CBI and CSD may need to be further assessed in future studies.

#### 3.4.2.3 Time-dependent Costs

Time-dependent costs will not be taken into consideration for this study as initial and earthquake-dependent disbenefits (costs) and benefits are regarded as the major elements of costs and benefit items. Also another reason to discard the time dependent costs is that the effects of time-dependent costs are assumed to be lower when compared with the effects of major initial and earthquake costs. On the other hand, maintenance costs can be considered as time-dependent costs. It’s normal that as the building gets older money spent on maintenance gets more. A study taking maintenance items, cost and frequencies proposed by Arıkan et al. (2005) has shown that NPV, total net present value of maintenance cost is about 70 % of reconstruction cost for 50 years of life period at 4% discount rate. Taking this study into consideration, a graphical data Maintenance Cost (CM) vs. Time (t) has been obtained as follows also it is not used in this study (Figure 3.8):

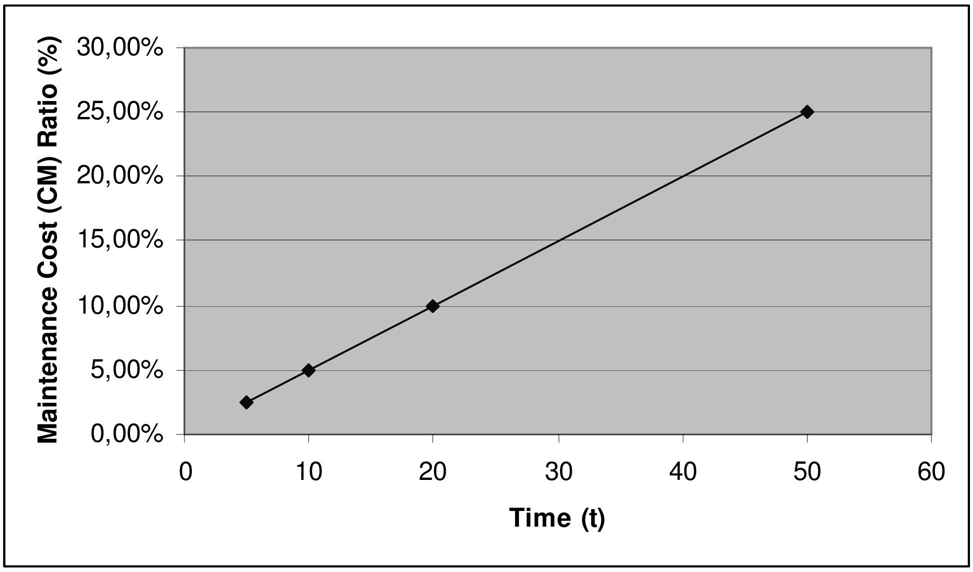



**Figure 3.8.** Maintenance Cost vs. Time

## 3.5 DEFINITION OF BENEFITS FOR MITIGATION ALTERNATIVES

### 3.5.1 List of BCA Benefit Elements

After the definition of alternatives and the interested parties, the benefits are to be defined related with the mitigation (risk reduction) alternatives for seismic improvement. As Kunreuther (2001) mentions benefits of mitigation are determined via the difference between the loss to the system with and without mitigation. Within the scope of this study, the benefits will be considered and listed under the main headings as noted below due to their time dependencies:

a. Initial benefits.

   Initial benefits correspond to the benefits in terms of property value of the buildings.

b. Earthquake-dependent benefits.

   Earthquake-dependent benefits will be the expected benefits related with the reduction in damage to the building from earthquakes of different magnitudes relative to the status quo condition for different mitigation alternatives.

   In addition to reducing the physical damage, there are relevant additional benefits of mitigation in the form of fewer fatalities, injuries and also reduction in business and social disruption costs that would have occurred if the mitigation measure had not been adopted and residents would have been forced to evacuate the building after an earthquake. So in general terms, difference between the earthquake-dependent disbenefits (costs) of mitigation alternatives and the earthquake-dependent disbenefits (costs) of status quo condition form the earthquake-dependent benefits of the related alternatives.

c. Time-dependent benefits.

   Time-dependent benefits correspond to the benefits of building rental rates through the alternatives although these are not used for this study.

### 3.5.2 Assignment of Values for BCA Benefit Elements

For the benefit items of the BCA to be conducted, the values are assigned with the considerations and assumptions as the followings:

#### 3.5.2.1 Initial Benefits

Property value (PV) is the sale/market value of the property at the relevant time. It will take the values for the different mitigation alternatives and the base case of status quo as below:

a. For do nothing (status quo), it will be the assessed current market value of the property including the value of land.

b. For retrofitting solutions, it will be the assessed market value of the property after all retrofit costs are spent. It is assumed that the attitudes of the potential buyers for retrofitted buildings will be higher after the retrofitting actions therefore increasing the market value of the building. Coefficient for value increase ($c_{vi}$) of the market value is taken as 1.1 for this case.

c. For demolition and reconstruction, it will be the assessed market value of the property after completion of construction. Coefficient for value increase ($c_{vi}$) of the market value is taken as 1.2 for this case.

d. For post earthquake repair or reconstruction, it will be the market value after repair or reconstruction work is completed. It is the condition after the repair of damage and reinstatement of the building or after reconstruction to the same total area and to the same overall quality as the building was before the building was damaged or collapsed. ($c_{vi}$) is 1.0 for this case.

The current property value will be the base valuation and the values for other alternatives will be based on this value with a coefficient of value increase ($c_{vi}$) that reflects the state of the property and the market. The benefit will be found by the difference between the alternatives and status quo. Present market values within the vicinities of Bakırköy are searched from the web site of REMAX agency and an approximate rate of 1,350 YTL/m² ($ 1,000/m²) is obtained.

#### 3.5.2.2 Earthquake-dependent Benefits

Earthquake-dependent benefits (BE) are expected as the reductions in the following earthquake-dependent disbenefit (cost) items for mitigation alternatives when compared with the condition of status quo where no mitigation alternative is used.

a. Benefit due to differences of Cost of damage to building.
b. Benefit due to differences of Cost due to injuries
c. Benefit due to differences of Cost due to loss of lives
d. Benefit due to differences of Cost of damage to household goods
e. Benefit due to differences of Cost of temporary resettlement (moving cost and the accommodation costs)
f. Benefit due to differences of Cost of business interruption and social disruption

#### 3.5.2.3 Time-dependent Benefits

Rental (BR) as the time-dependent benefit is the revenue an owner will collect either by renting or inhabiting the building until the assumed time that earthquake will happen. (0 years time right after retrofit, 5, 10, 20, 50 years from retrofit are being considered for the study).

Naturally a building with high structural capacity will bring more than the ones with less structural capacities. A market search for the actual rental rates in Bakırköy has been done over web site of REMAX and an approximate rental rate of 7-14 YTL/m² per month is obtained. The same coefficients used for the market values for different mitigation alternatives can also be applied for determination of the rental rates for the different mitigation alternatives.

On the other hand, for similar reasons that the time-dependent items for costs are not used, time-dependent items for benefits will not be used also for this study.

An illustrative figure is given as Figure 3.9 to visualize the components and relations of the benefit and cost items on a timetable.

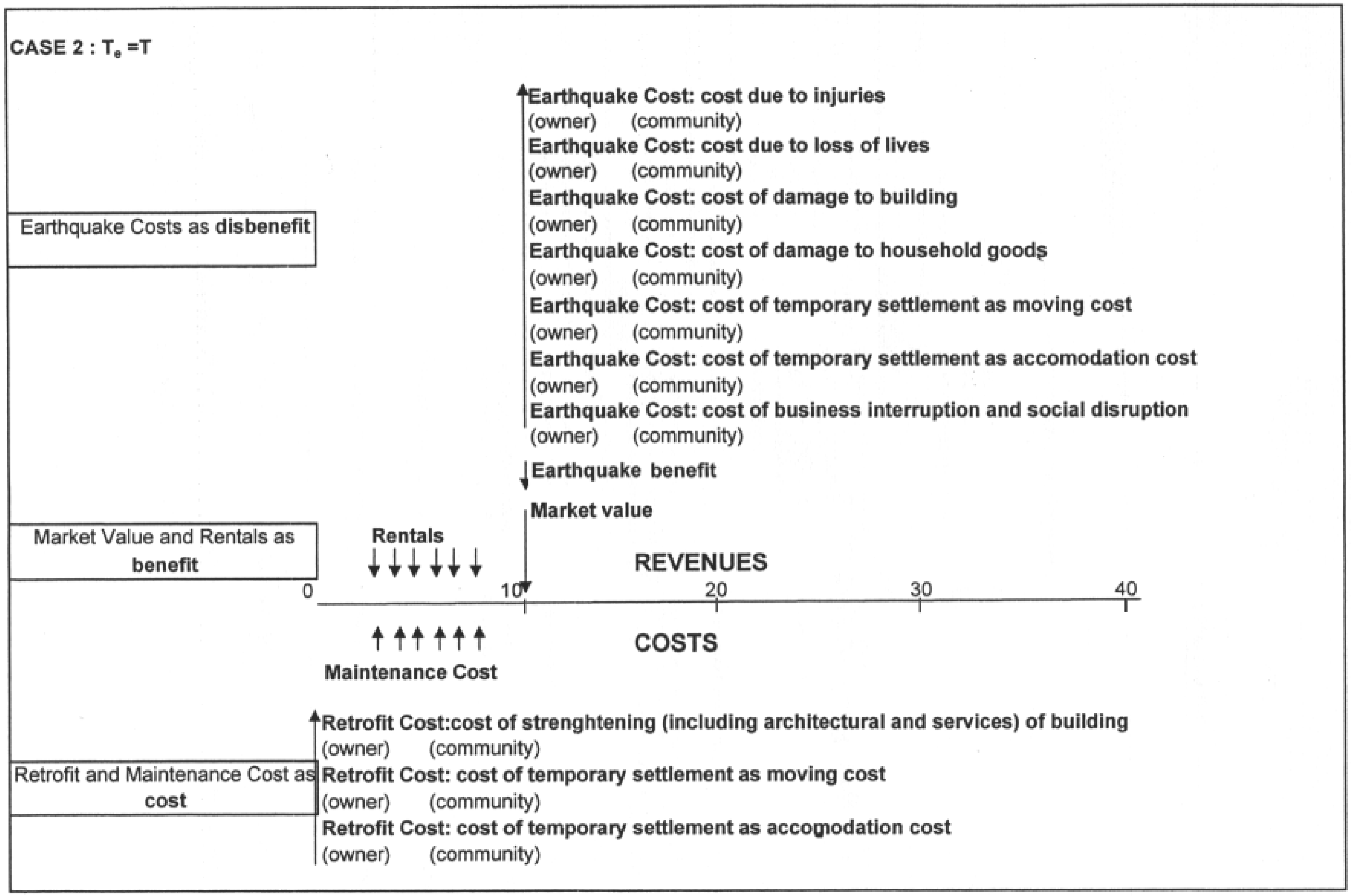



**Figure 3.9.** Benefit and Cost Items

## 3.6 ATTRACTIVENESS OF MITIGATION ALTERNATIVES

### 3.6.1 Calculation of Attractiveness of First Sample Building

After the definition and determination of the values for the benefit and cost items of the BCA, the attractiveness of the mitigation alternatives for one of the residential buildings in Kartaltepe, Bakırköy-İstanbul will be calculated as follows:


**Figure 3.10.** Building 1 in Kartaltepe

a. First the basic information for benefit-cost analysis of buildings will be listed:

**Table 3.7.** Summary of Information for Building 1

| Summary of Benefit Cost Information for Building-1 in Kartaltepe | | | DISCOUNT RATE : | 4% |
|---|---|---|---|---|
| | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| **Time to Earthquake (years)** | 0 | 0 | 0 | 0 |
| | | | | |
| **Building Information** | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Age of building | 21 | 21 | 21 | 21 |
| Building area (m²) | 1.970 | 1.970 | 1.970 | 1.970 |
| Number of Flats | 12 | 12 | 12 | 12 |
| Flats to Move Out (retroftting/reconstruction) | 0 | 12 | 12 | 0 |
| Time Moved Out (month) (Pre-EQ) | 0 | 15 | 3 | 0 |
| Number of occupants people/building (at time of EQ) | 12 | 12 | 12 | 12 |
| Retrofitting/Reconstruction cost (YTL/m2) | 359 | 359 | 57 | 77 |
| Demolition cost YTL/m2 | - | 30 | _ | _ |
| Type of building | 3-B | 3-B | 3-B | 3-B |
| Damage Ratio after EQ | 100% | 19,1% | 19,1% | 19,1% |
| Reinstatement time (months) (Post-EQ) | 30 | 11,46 | 11,46 | 11,46 |

This table covers real information such as the age of the building, type of building, building area available for the occupants, number of flats. Also the calculated or assumed values for flats to move out during retrofitting or reconstruction, time period for this action, number of occupants at the time of earthquake, reconstruction and retrofitting costs for the building, demolition cost, damage ratio and time of reinstatement period after the possible earthquake for the building, expected time to earthquake after the completion of mitigation actions are also covered. The data entered in this list are all site specific. The other data for injury and loss of life rates could also be located at this part, but it's preferred to get them directly from the graphs during the running stage of the analysis. Also the discount rate is used as a constant value of 4 %.

For Retrofitting Option 1 (internal retrofitting), two reinforced R/C shear walls in X direction and two concrete walls in Y direction are used. The layout does not interfere with the existing functions.

For Retrofitting Option 2 (external retrofitting), three coupled shear walls are attached to the free sides of the building. Two of these are located immediately adjacent to the exterior frames. Three existing masonry walls are strenghtened by placing a layer of precast panels from the inside face.

The layout of these retrofitting types are given in the following figure.

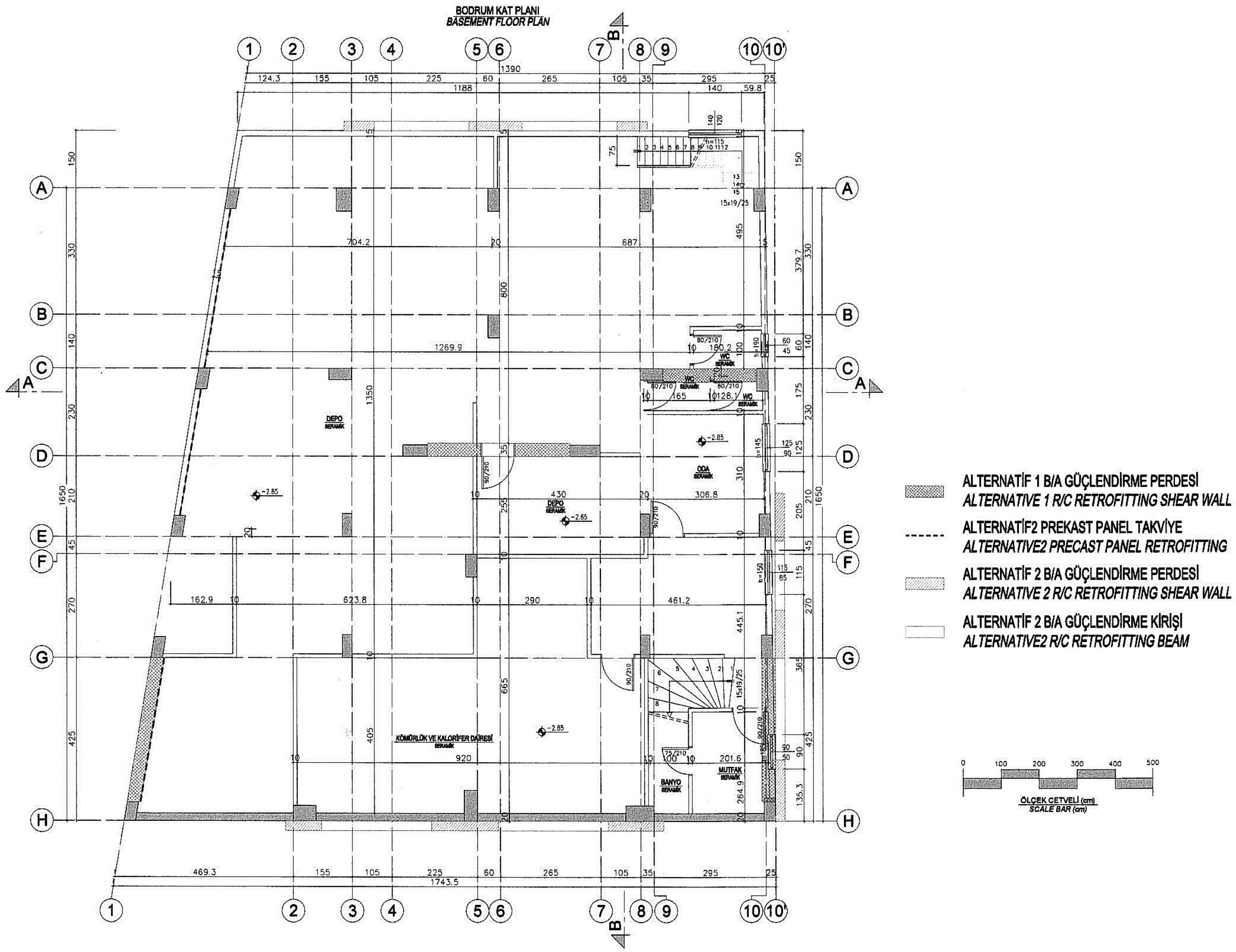



**Figure 3.11.** Retrofitting Floor Plan for  Building 1 in Kartaltepe

b. Using the data from Table 3.7, the analysis components of benefits and costs and relevant values are determined as below:

**Table 3.8.** Valuation for BCA Components for Building 1

| Benefit/Cost Elements | | | | |
|---|---|---|---|---|
| Initial Benefits and Costs | | | | |
| BENEFITS | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Property value (PV) | 2.659.500 | 3.191.400 | 2.925.450 | 2.925.450 |
| Difference between the condition and status quo (BPV) | 0 | 531.900 | 265.950 | 265.950 |
| Total Initial Benefits | **0** | **531.900** | **265.950** | **265.950** |
| COSTS | | | | |
| Retrofit/ Reconstruct Cost: cost of strenghtening of building (CS) | 0 | 766.330 | 113.000 | 152.000 |
| Total Ret/Reb. Cost | 0 | 766.330 | 113.000 | 152.000 |
| Cost of temporary relocation (CTR) | | | | |
| Two-way moving costs (CTM) | 0 | 21.670 | 21.670 | 0 |
| Temporary accommodation cost (CTA) | 0 | 265.950 | 53.190 | 0 |
| Total Rel. Cost | 0 | 287.620 | 74.860 | 0 |
| Total Initial Costs | **0** | **1.053.950** | **187.860** | **152.000** |
| Earthquake-dependent Benefits and Costs | | | | |
| DISBENEFITS | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Earthquake Cost: cost of damage to building (CDB) | 707.230 | 135.081 | 135.081 | 135.081 |
| Earthquake Cost: cost of damage to goods (CDG) | 176.808 | 33.770 | 33.770 | 33.770 |
| Earthquake Cost: cost due to injuries (CI) | | | | |
| Injury cost (SL-1, SL-2, SL-3) | 40.200 | 9.840 | 9.840 | 9.840 |
| Earthquake Cost: cost due to loss of lives (CLL) | | | | |
| Fatality cost (SL-4) | 1.200.000 | 60.000 | 60.000 | 60.000 |
| Cost of temporary resettlement (CTS) | | | | |
| Two-way moving costs (CTM) | 8.668 | 8.668 | 8.668 | 8.668 |
| Temporary accommodation cost (CTA) | 56.736 | 21.673 | 21.673 | 21.673 |
| Total Resettlement Cost | 65.404 | 30.341 | 30.341 | 30.341 |
| Total Earthquake Disbenefits without Business Interruption and Social Distruption | 2.189.642 | 269.032 | 269.032 | 269.032 |
| Cost of business interruption and social disruption (CBI, CSD) | 1.094.821 | 134.516 | 134.516 | 134.516 |
| Total Earthquake Costs | **3.284.462** | **403.548** | **403.548** | **403.548** |
| Total Earthquake Costs at time t (NPV) | **3.284.462** | **403.548** | **403.548** | **403.548** |
| BENEFITS | | | | |
| Dıfference of earthquake-dependent cost between the condition and the status quo (BE) | **0** | **2.880.914** | **2.880.914** | **2.880.914** |

All benefit and cost elements are expressed in New Turkish Liras (YTL).

c. After the evaluation of benefits and costs, the values are summed up and the necessary calculation made and the relevant NPV's and BCR's are found for alternative options of status quo, demolishing and rebuilding, internal retrofitting, and external retrofitting:

**Table 3.9.** NPV and BCR Values After Analysis for Building 1

| Summary of Benefit Cost Information for Building-1 in Kartaltepe | | | DISCOUNT RATE : | 4% |
|---|---|---|---|---|
| | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| **Time to Earthquake (years)** | **0** | **0** | **0** | **0** |
| | | | | |
| Benefit to Cost Ratio | 0,00 | 3,24 | 16,75 | 20,70 |
| | | | | |
| Net Benefit=Total Benefits less Total Costs (NPV) | 0 | 2.358.864 | 2.959.004 | 2.994.864 |
| | | | | |
| Total Benefits (NPV) | 0 | 3.412.814 | 3.146.864 | 3.146.864 |
| Total Costs (NPV) | 0 | 1.053.950 | 187.860 | 152.000 |
| | | | | |
| Net Earthquake-dependent Benefits | 0 | 2.880.914 | 2.880.914 | 2.880.914 |
| | | | | |
| Time-dependent Benefits | 0 | 0 | 0 | 0 |
| Time-dependent Costs | 0 | 0 | 0 | 0 |
| | | | | |
| Initial Benefits | 0 | 531.900 | 265.950 | 265.950 |
| Initial Costs | 0 | 1.053.950 | 187.860 | 152.000 |

c. As it's seen from the final results for NPV of net benefits (total benefits less total costs) and BCR (total benefits/total costs), the values are as below for the alternatives at time (t) =0:

i. Status quo
- NPV=0
- BCR=0

The reason to get value of '0' for status quo is that all the calculations of the other alternatives use the difference between the values of status quo and the relevant values of alternatives. So status quo is used as basis value and taken as '0' to enable to use the difference of values for other alternatives in accordance with Kunreuther's approach as defined in the previous chapter.

ii. Demolition and Reconstruction
NPV=2,358,864 YTL>0 and BCR=3.24>1

iii. Retrofitting Option 1 (Internal application)
NPV=2,959,004 YTL>0 and BCR=16.75>1

iv. Retrofitting Option 2 (External application)

NPV=2,994,864 YTL>0 and BCR=20.70>1

### 3.6.2 Choosing the Best Alternative for First Sample Building

Using the NPV and BCR calculations, the best alternative can be found by the maximization of net present value and/or the benefit cost ratio. For the evaluated example above maximized values for both NPV and BCR show the same alternative of Retrofitting Option 2 (External application). So for this particular evaluation of Building 1 in Kartaltepe, it can be said that the Retrofitting Option 2 is the most feasible solution if the time to earthquake after the mitigation activity is 0 years. This evaluation can be broadened for different periods of 1, 5, 10, 20 or 50 years.

The overall results for the benefit cost analysis calculations for Building 1 for the above mentioned time intervals is given below:

**Table 3.10.** Overall Results After Analysis for Building 1

| Retrofit Option | Item | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | 50 |
| Demolish and Reconstruct | B/C Ratio Demolish and Reconstruct | 3,13 | 2,75 | 2,35 | 1,75 | 0,89 |
| | NPV Benefits (M YTL) | 3,30 | 2,90 | 2,48 | 1,85 | 0,94 |
| | NPV Costs (M YTL) | 1,05 | 1,05 | 1,05 | 1,05 | 1,05 |
| | **NPV (B-C)** | **2,25** | **1,85** | **1,42** | **0,79** | **-0,12** |
| Retrofitting Option-1 (Internal) | B/C Ratio Retrofitting Option-1 | 16,16 | 14,02 | 11,78 | 8,41 | 3,57 |
| | NPV Benefits (M YTL) | 3,04 | 2,63 | 2,21 | 1,58 | 0,67 |
| | NPV Costs (M YTL) | 0,19 | 0,19 | 0,19 | 0,19 | 0,19 |
| | **NPV (B-C)** | **2,85** | **2,45** | **2,02** | **1,39** | **0,48** |
| Retrofitting Option-2 (External) | B/C Ratio Retrofitting Option-2 | 19,97 | 17,33 | 14,55 | 10,40 | 4,42 |
| | NPV Benefits (M YTL) | 3,04 | 2,63 | 2,21 | 1,58 | 0,67 |
| | NPV Costs (M YTL) | 0,15 | 0,15 | 0,15 | 0,15 | 0,15 |
| | **NPV (B-C)** | **2,88** | **2,48** | **2,06** | **1,43** | **0,52** |
| Status Quo | B/C Ratio Status Quo | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Benefits (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Costs (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | **NPV (B-C)** | **0,00** | **0,00** | **0,00** | **0,00** | **0,00** |

As it can be seen from Table 3.10, the cost items remain the same over time as NPV is applied over initial benefits and earthquake benefits, the costs at the time of earthquake are evaluated and used to find the earthquake benefits so they are not used as cost items directly. On the other hand time-dependent cost and benefits like maintenance and rentals are not considered in this study, so change in time only affects the earthquake benefits as an overall result.

After the expression of all relevant results a graphical presentation for BCR values and NPV values of net benefit is necessary to make a selection from these alternatives with the existing information (Fig. 3.12 and Fig. 3.13):

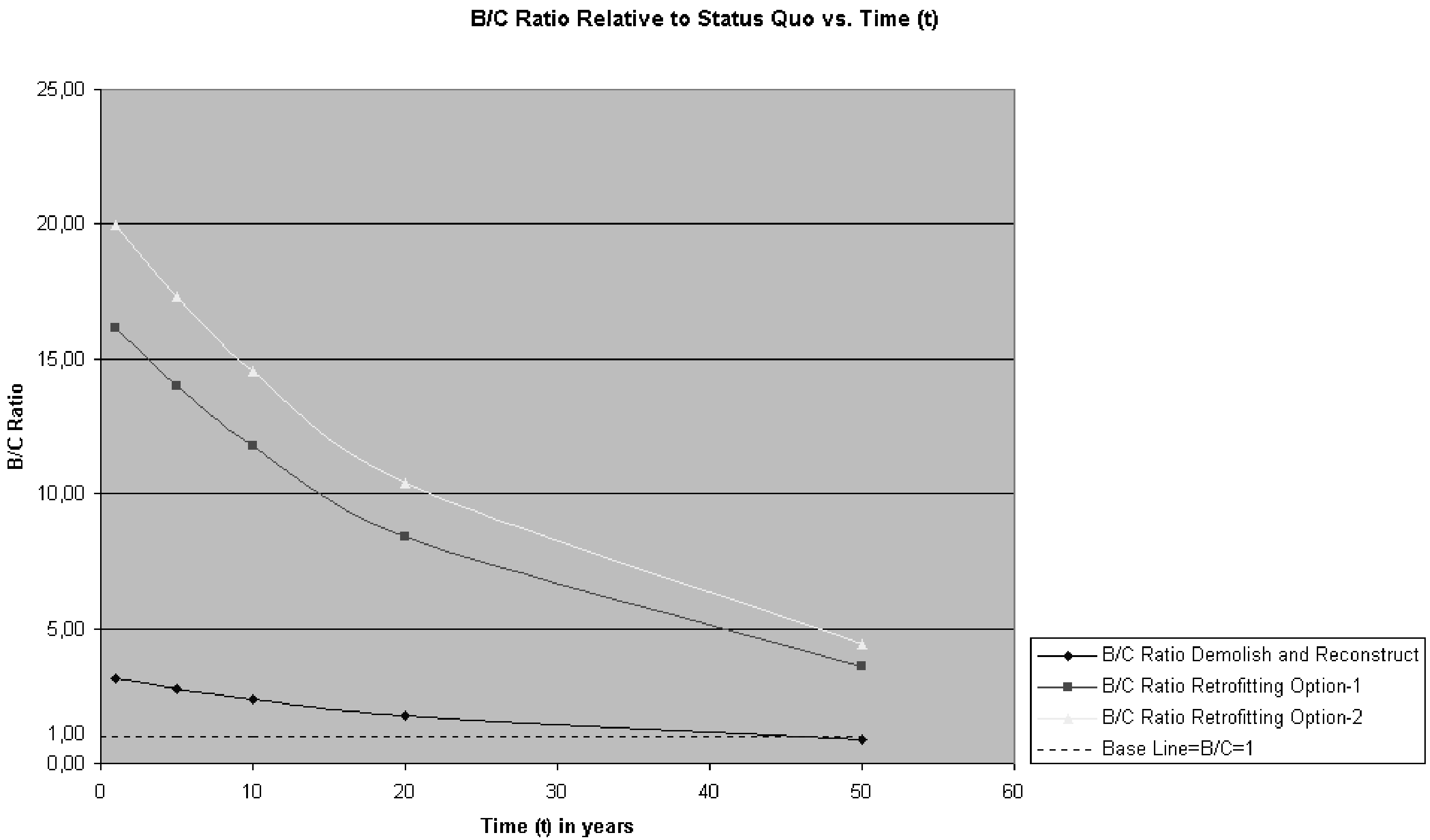
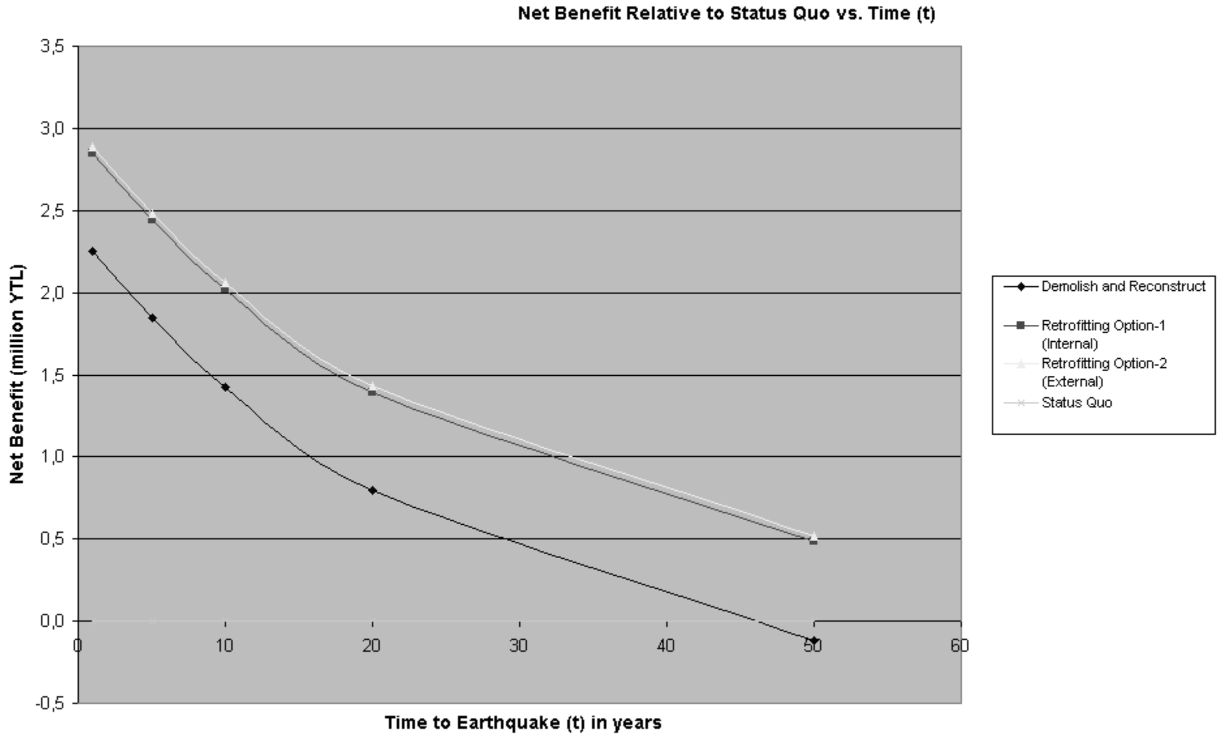



**Figure 3.12.** BCR Graph for Building 1 in Kartaltepe




| Option | Initial cost (M YTL) |
|---|---|
| Demolish and Reconstruct | 1,05 |
| Retrofitting Option-1 (Internal) | 0,19 |
| Retrofitting Option-2 (External) | 0,15 |

**Figure 3.13.** NPV Graph for Building 1 in Kartaltepe

The graphical data of Benefit Cost Ratios (BCR) (Fig. 3.12) representing the values of Retrofitting Option 2 (external retrofitting) has greater values in Figure 3.12 when compared with the other alternatives and the difference of these values can be seen as considerable and differentiating. On the other hand Retrofitting Option 1 (internal retrofitting) is still a viable solution but has lower values than Option 2. Demolish and Reconstruct Option is quite far from the values of the other two retrofitting options although the difference gets smaller as time increases, but at time (t) that is approximately 46 years the option of Demolish and Reconstruct decreases to the limit and base value of '1.0' (BCR=1) and is not evaluated as a viable solution anymore after this time point.

Also in graphical data of Net Present Value of Net Benefits (NPV) (Fig. 3.13), it is seen that Retrofitting Option 2 is ahead of Retrofitting Option 1 with a very slight difference. Alternative of Demolish and Reconstruct is again far from the other two alternatives. Again at time (t) that is approximately 46 years, the option of Demolish and Reconstruct decreases to the limit and base value of '0.0' (NPV=0) and is not evaluated as a viable solution anymore after this time point.

In Figure 3.13 the initial cost values for each alternative are given separately. By this, it is aimed to give a reference point during the review of the graph and to see at what stage the proposed alternative is still viable and has a greater value of NPV when compared with the initial costs.

The evaluation of graphical data for Building 1 in Kartaltepe, we may conclude that Retrofitting Option 2 can be selected as the preferred solution as it has greater values of BCR and NPV and also has the option that occupants do not have to leave their houses during retrofitting studies, as Retrofitting Option 2 is an external solution with the combination of retrofitting beams, retrofitting shear walls and precast panels. Regulations relevant with the possibility and applicability of external retrofitting at the selected building are major points of concern, but not the subject of this study. In any case, the selection can be turned to Retrofitting Option 1 as it also gives satisfactory results of analysis.

### 3.6.3 Application on Other Sample Buildings

#### 3.6.3.1 Application of BCA on Building 2

**Figure 3.14.** Building 2 in Kartaltepe

The building specific data can be presented as below:

**Table 3.11.** Summary of Information for Building 2

| Summary of Benefit Cost Information for Building-2 in Kartaltepe | | | DISCOUNT RATE : | 4% |
|---|---|---|---|---|
| | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| **Time to Earthquake (years)** | 0 | 0 | 0 | 0 |
| **Building Information** | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Age of building | 23 | 23 | 23 | 23 |
| Building area (m²) | 1.189 | 1.189 | 1.189 | 1.189 |
| Number of Flats | 18 | 18 | 18 | 18 |
| Flats to Move Out (retroftting/reconstruction) | 0 | 18 | 18 | 0 |
| Time Moved Out (month) (Pre-EQ) | 0 | 15 | 3 | 0 |
| Number of occupants people/building (at time of EQ) | 18 | 18 | 18 | 18 |
| Retrofitting/Reconstruction cost (YTL/m2) | 359 | 359 | 95 | 128 |
| Demolition cost YTL/m2 | - | 30 | _ | _ |
| Type of building | 3-B | 3-B | 3-B | 3-B |
| Damage Ratio after EQ | 97% | 19,1% | 19,1% | 19,1% |
| Reinstatement time (months) (Post-EQ) | 30 | 11,46 | 11,46 | 11,46 |

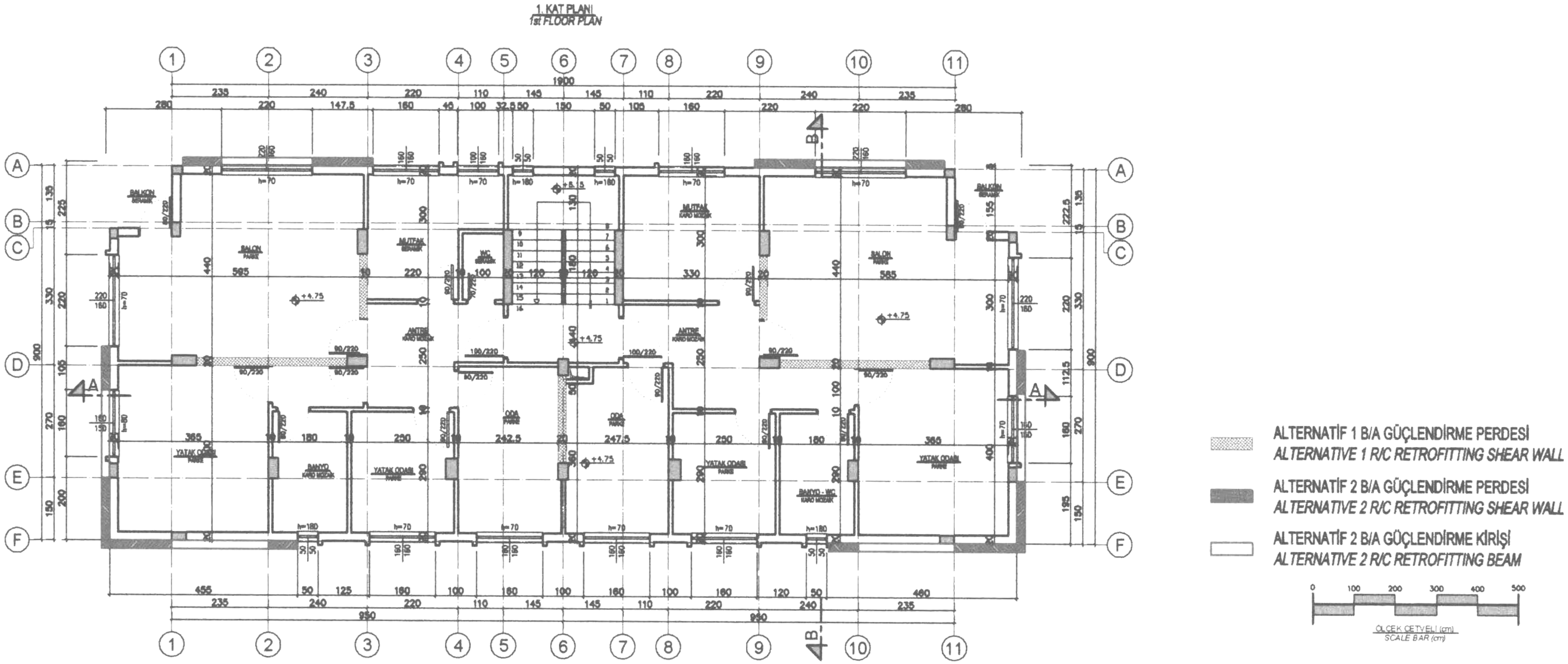



**Figure 3.15.** Retrofitting Floor Plan for  Building 2 in Kartaltepe

After presentation of the building data and retrofitting layout as made for Building 1, the procedure for the valuation and calculation of BCR's and NPV's for the alternative options of mitigation is applied and the results are given for Building 2:

**Table 3.12.** Overall Results After Analysis for Building 2

| Retrofit Option | Item | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 5 | 10 | 20 | 50 |
| Demolish and Reconstruct | B/C Ratio Demolish and Reconstruct | 5,50 | 4,78 | 4,02 | 2,88 | 1,24 |
| | NPV Benefits (M YTL) | 3,50 | 3,04 | 2,56 | 1,83 | 0,79 |
| | NPV Costs (M YTL) | 0,64 | 0,64 | 0,64 | 0,64 | 0,64 |
| | **NPV (B-C)** | **2,87** | **2,40** | **1,92** | **1,19** | **0,15** |
| Retrofitting Option-1 (Internal) | B/C Ratio Retrofitting Option-1 | 22,25 | 19,17 | 15,95 | 11,12 | 4,17 |
| | NPV Benefits (M YTL) | 3,34 | 2,88 | 2,40 | 1,67 | 0,63 |
| | NPV Costs (M YTL) | 0,15 | 0,15 | 0,15 | 0,15 | 0,15 |
| | **NPV (B-C)** | **3,19** | **2,73** | **2,24** | **1,52** | **0,48** |
| Retrofitting Option-2 (External) | B/C Ratio Retrofitting Option-2 | 24,93 | 21,49 | 17,87 | 12,46 | 4,67 |
| | NPV Benefits (M YTL) | 3,34 | 2,88 | 2,40 | 1,67 | 0,63 |
| | NPV Costs (M YTL) | 0,13 | 0,13 | 0,13 | 0,13 | 0,13 |
| | **NPV (B-C)** | **3,21** | **2,75** | **2,26** | **1,54** | **0,49** |
| Status Quo | B/C Ratio Status Quo | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Benefits (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Costs (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | **NPV (B-C)** | **0,00** | **0,00** | **0,00** | **0,00** | **0,00** |

Benefit Cost Ratios (BCR) in Fig. 3.16 and Net Present Value of Net Benefits (NPV) in Fig. 3.17, show that Retrofitting Option 2 (external retrofitting with beams and shear walls) seems to be the preferable and viable option in both terms of BCR and NPV when compared with the others and the difference of these values can be seen as differentiating. Also occupants do not have to move out during the implementation of Option 2. On the other hand Retrofitting Option 1 (internal retrofitting with shear walls) is still a viable solution but has lower BCR and NPV values than Option 2. Demolish and Reconstruct Option has lowest values when compared with other retrofitting options with a considerable difference although the difference gets smaller as time increases, but at time (t) that is approximately 50 years the option of Demolish and Reconstruct has BCR value of 1.24 very near to the base value of '1.0' (BCR>1) that is the limit for an option to be evaluated.

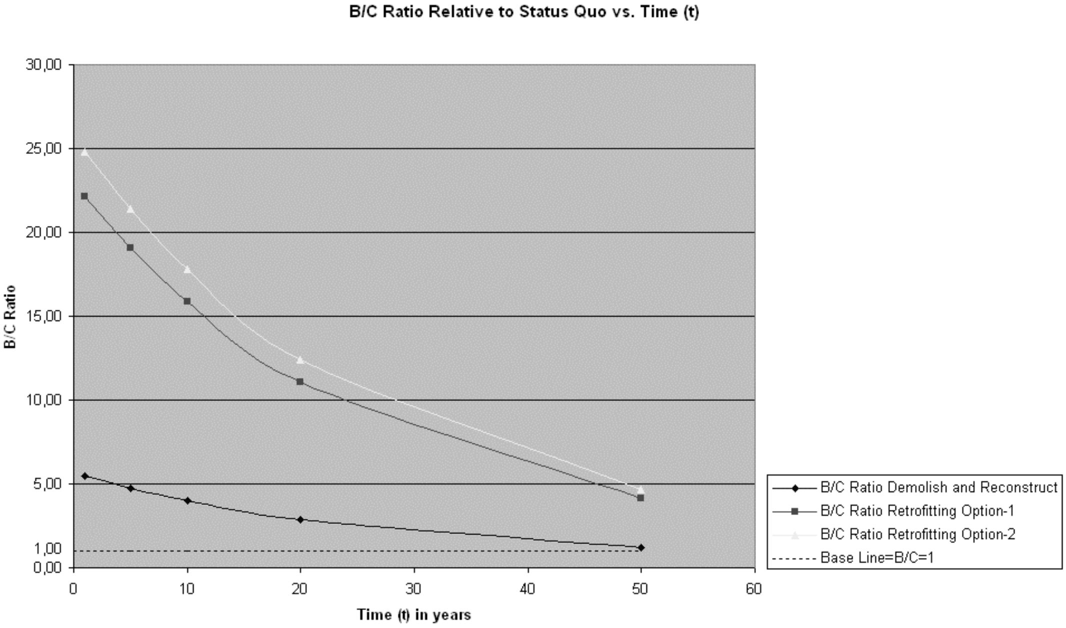
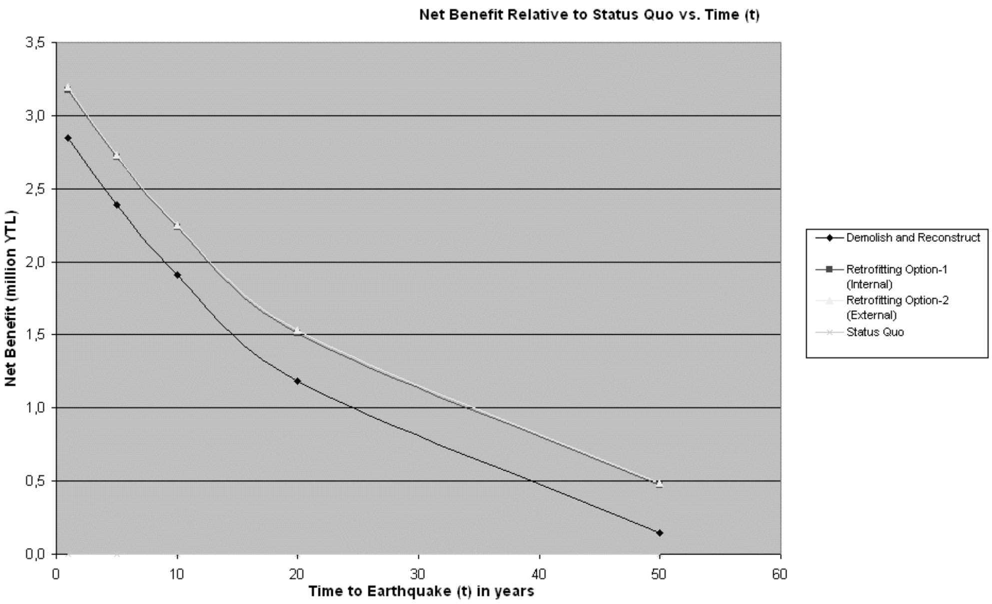



**Figure 3.16.** BCR Graph for Building 2 in Kartaltepe




| Option | Initial cost (M YTL) |
|---|---|
| Demolish and Reconstruct | 0,64 |
| Retrofitting Option-1 (Internal) | 0,15 |
| Retrofitting Option-2 (External) | 0,13 |

**Figure 3.17.** NPV Graph for Building 2 in Kartaltepe

#### 3.6.3.2 Application of BCA on Building 3

**Figure 3.18.** Building 3 in Osmaniye

The building specific data for Building 3 can be presented as below:

**Table 3.13.** Summary of Information for Building 3

| Summary of Benefit Cost Information for Building-3 in Osmaniye | | | DISCOUNT RATE : | 4% |
|---|---|---|---|---|
| | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| **Time to Earthquake (years)** | 0 | 0 | 0 | 0 |
| | | | | |
| **Building Information** | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Age of building | 23 | 23 | 23 | 23 |
| Building area (m$^2$) | 807 | 807 | 807 | 807 |
| Number of Flats | 8 | 8 | 8 | 8 |
| Flats to Move Out (retroftting/reconstruction) | 0 | 8 | 8 | 0 |
| Time Moved Out (month) (Pre-EQ) | 0 | 15 | 2 | 0 |
| Number of occupants people/building (at time of EQ) | 8 | 8 | 8 | 8 |
| Retrofitting/Reconstruction cost (YTL/m2) | 359 | 359 | 126 | 94 |
| Demolition cost YTL/m2 | - | 30 | _ | _ |
| Type of building | 3-B | 3-B | 3-B | 3-B |
| Damage Ratio after EQ | 72% | 19,1% | 19,1% | 19,1% |
| Reinstatement time (months) (Post-EQ) | 30 | 11,46 | 11,46 | 11,46 |

After the presentation of the building specific data, the retrofitting application layout is given in Figure 3.19 below and the results are given in the Table 3.14 for Building 3 after procedure for the valuation and calculation of BCR's and NPV's for the alternative options of mitigation is applied:

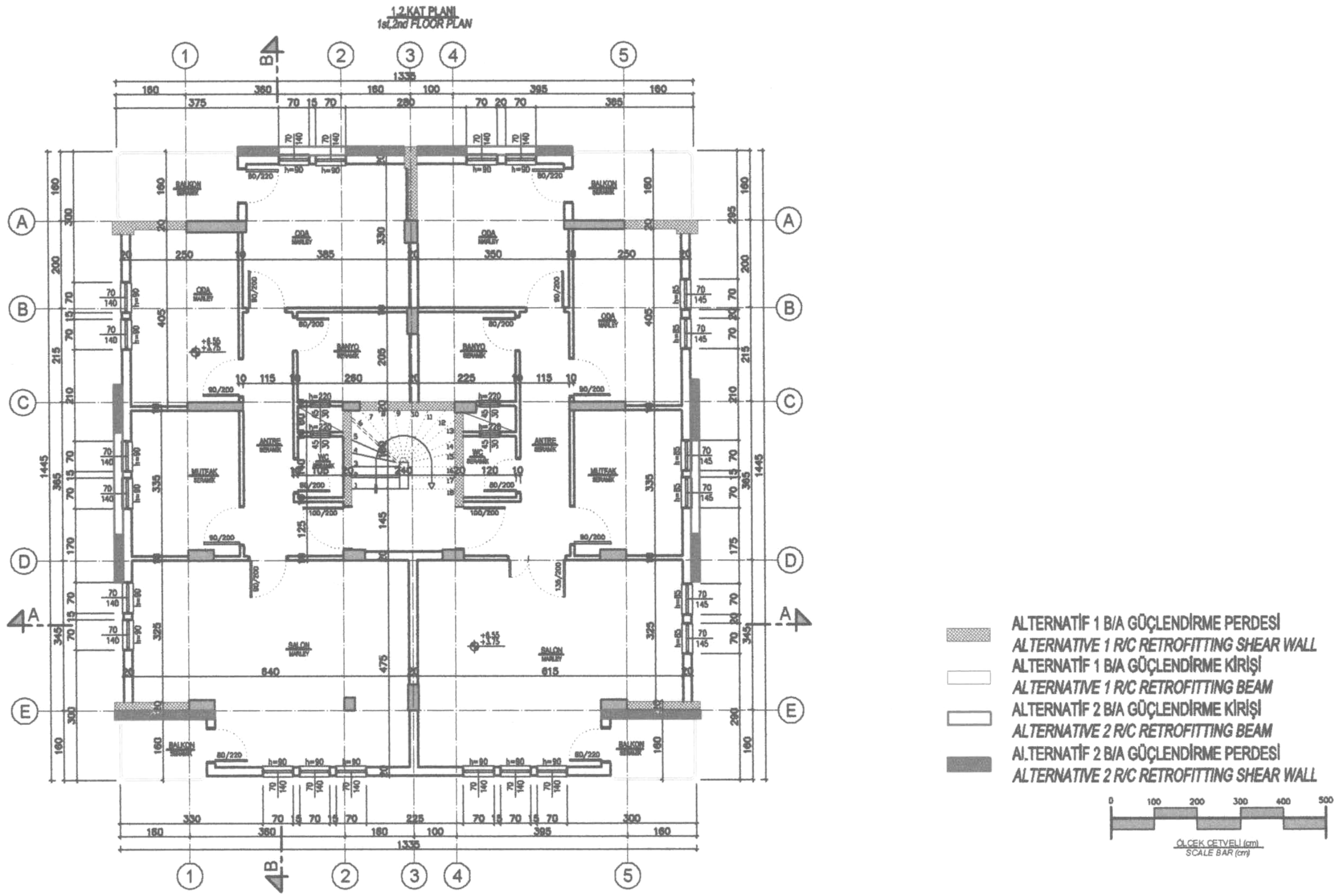



**Figure 3.19.** Retrofitting Floor Plan for Building 3 in Osmaniye

**Table 3.14.** Overall Results After Analysis for Building 3

| Retrofit Option | Item | Time to Earthquake (Years) 1 | 5 | 10 | 20 | 50 |
|---|---|---|---|---|---|---|
| Demolish and Reconstruct | B/C Ratio Demolish and Reconstruct | 3,82 | 3,34 | 2,84 | 2,08 | 0,99 |
| | NPV Benefits (M YTL) | 1,65 | 1,44 | 1,22 | 0,90 | 0,43 |
| | NPV Costs (M YTL) | 0,43 | 0,43 | 0,43 | 0,43 | 0,43 |
| | **NPV (B-C)** | **1,22** | **1,01** | **0,79** | **0,47** | **0,00** |
| Retrofitting Option-1 (Internal) | B/C Ratio Retrofitting Option-1 | 12,29 | 10,63 | 8,90 | 6,29 | 2,54 |
| | NPV Benefits (M YTL) | 1,54 | 1,33 | 1,12 | 0,79 | 0,32 |
| | NPV Costs (M YTL) | 0,13 | 0,13 | 0,13 | 0,13 | 0,13 |
| | **NPV (B-C)** | **1,42** | **1,21** | **0,99** | **0,66** | **0,19** |
| Retrofitting Option-2 (External) | B/C Ratio Retrofitting Option-2 | 20,29 | 17,55 | 14,68 | 10,38 | 4,19 |
| | NPV Benefits (M YTL) | 1,54 | 1,33 | 1,12 | 0,79 | 0,32 |
| | NPV Costs (M YTL) | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 |
| | **NPV (B-C)** | **1,47** | **1,26** | **1,04** | **0,71** | **0,24** |
| Status Quo | B/C Ratio Status Quo | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Benefits (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Costs (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | **NPV (B-C)** | **0,00** | **0,00** | **0,00** | **0,00** | **0,00** |

The graphical data of Benefit Cost Ratios (BCR) in Fig. 3.20 and Net Present Value of Net Benefits (NPV) in Fig. 3.21 given below in small scale, give the information that Retrofitting Option 2 (external retrofitting with shear walls and beams) is the viable option when compared with the other two alternatives and the difference of these values can be seen as considerably high and increasing the possibility for choice on selection. The difference between Option 2 and 1 is high on BCR values. On the other hand Retrofitting Option 1 (internal retrofitting with shear walls and beams) is still a viable solution but has lower values than Option 2. Demolish and Reconstruct Option has values lower than the other two retrofitting options with a considerable difference. But at time (t) that is approximately 50 years, the option of Demolish and Reconstruct has BCR value of 0.99 slightly lower than the base value of ‘1.0’ (BCR<1) that is the limit for an option to be evaluated and has a NPV value equal to the base value of ‘0.0’ (NPV=0). On both cases, these limit conditions do not have effect on selection of alternatives as time limit is arranged as 50 years.

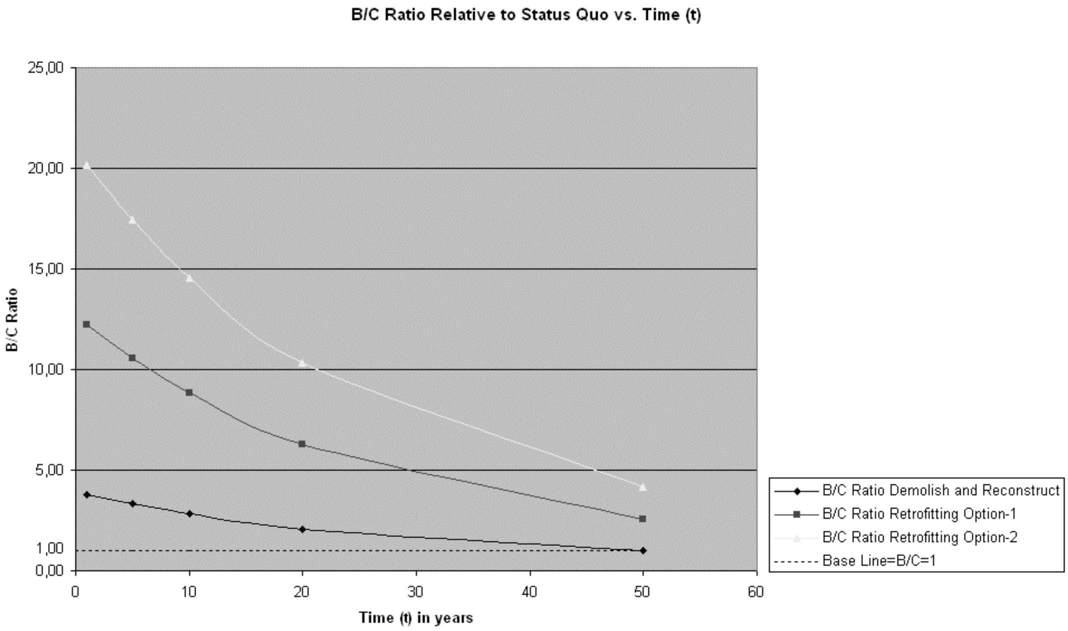
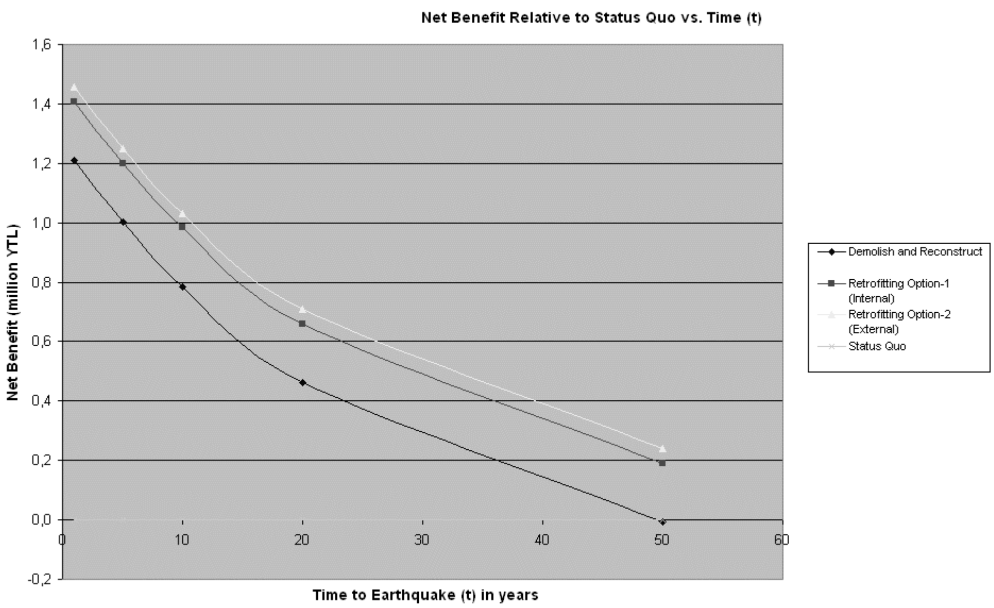



**Figure 3.20.** BCR Graph for Building 3 in Osmaniye




| Option | Initial cost (M YTL) |
|---|---|
| Demolish and Reconstruct | 0,43 |
| Retrofitting Option-1 (Internal) | 0,13 |
| Retrofitting Option-2 (External) | 0,08 |

**Figure 3.21.** NPV Graph for Building 3 in Osmaniye

### 3.6.3.3 Application of BCA on Building 4

**Figure 3.22.** Building 4 in Osmaniye

Using the same procedure for the previous buildings, the building specific data for Building 4 can be presented as below:

**Table 3.15.** Summary of Information for Building 4

| Summary of Benefit Cost Information for Building-4 in Osmaniye | | | DISCOUNT RATE : | 4% |
|---|---|---|---|---|
| | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Time to Earthquake (years) | 0 | 0 | 0 | 0 |
| | | | | |
| Building Information | Status quo | Demolish and Rebuild | Retrofit 1 | Retrofit 2 |
| Age of building | 13 | 13 | 13 | 13 |
| Building area (m²) | 898 | 898 | 898 | 898 |
| Number of Flats | 10 | 10 | 10 | 10 |
| Flats to Move Out (retroftting/reconstruction) | 0 | 10 | 10 | 2 |
| Time Moved Out (month) (Pre-EQ) | 0 | 15 | 2 | 2 |
| Number of occupants people/building (at time of EQ) | 10 | 10 | 10 | 10 |
| Retrofitting/Reconstruction cost (YTL/m2) | 359 | 359 | 164 | 133 |
| Demolition cost YTL/m2 | - | 30 | _ | _ |
| Type of building | 3-B | 3-B | 3-B | 3-B |
| Damage Ratio after EQ | 100% | 19,1% | 19,1% | 19,1% |
| Reinstatement time (months) (Post-EQ) | 30 | 11,46 | 11,46 | 11,46 |

After the presentation of the building specific data, the retrofitting application layout is given in Figure 3.23 below and the results are given in the Table 3.16 for Building 4 after procedure for the valuation and calculation of BCR's and NPV's for the alternative options of mitigation is applied:

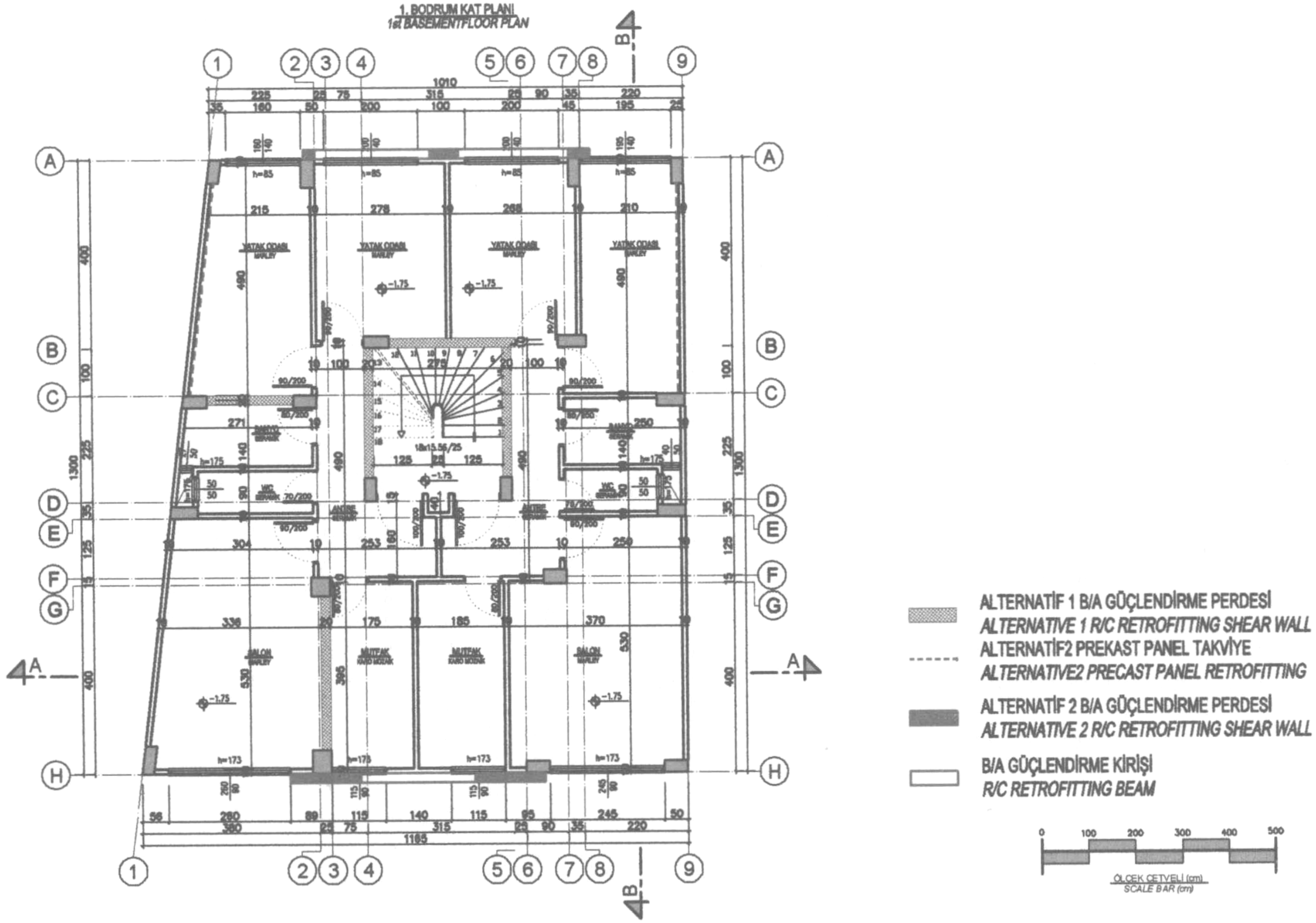



**Figure 3.23.** Retrofitting Floor Plan for Building 4 in Osmaniye

**Table 3.16.** Overall Results After Analysis for Building 4

| Retrofit Option | Item | Time to Earthquake (Years) 1 | 5 | 10 | 20 | 50 |
|---|---|---|---|---|---|---|
| Demolish and Reconstruct | B/C Ratio Demolish and Reconstruct | 4,48 | 3,91 | 3,30 | 2,39 | 1,09 |
| | NPV Benefits (M YTL) | 2,15 | 1,88 | 1,59 | 1,15 | 0,52 |
| | NPV Costs (M YTL) | 0,48 | 0,48 | 0,48 | 0,48 | 0,48 |
| | **NPV (B-C)** | **1,67** | **1,40** | **1,11** | **0,67** | **0,04** |
| Retrofitting Option-1 (Internal) | B/C Ratio Retrofitting Option-1 | 11,75 | 10,14 | 8,46 | 5,94 | 2,32 |
| | NPV Benefits (M YTL) | 2,03 | 1,76 | 1,46 | 1,03 | 0,40 |
| | NPV Costs (M YTL) | 0,17 | 0,17 | 0,17 | 0,17 | 0,17 |
| | **NPV (B-C)** | **1,86** | **1,58** | **1,29** | **0,86** | **0,23** |
| Retrofitting Option-2 (External) | B/C Ratio Retrofitting Option-2 | 16,37 | 14,13 | 11,79 | 8,28 | 3,23 |
| | NPV Benefits (M YTL) | 2,03 | 1,76 | 1,46 | 1,03 | 0,40 |
| | NPV Costs (M YTL) | 0,12 | 0,12 | 0,12 | 0,12 | 0,12 |
| | **NPV (B-C)** | **1,91** | **1,63** | **1,34** | **0,90** | **0,28** |
| Status Quo | B/C Ratio Status Quo | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Benefits (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | NPV Costs (M YTL) | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 |
| | **NPV (B-C)** | **0,00** | **0,00** | **0,00** | **0,00** | **0,00** |

The graphical data of Benefit Cost Ratios (BCR) in Fig. 3.24 and Net Present Value of Net Benefits (NPV) in Fig. 3.25 given below, give the information that Retrofitting Option 2 (external retrofitting with shear walls, beams, and precast panels) again seems to be preferable solution both in terms of BCR and NPV when compared with the other alternatives. On the other hand Retrofitting Option 1 (internal retrofitting with shear walls) is still a viable solution but has lower values than Option 2, especially the difference between two options is large at BCR values. Demolish and Reconstruct Option has values lower than the other two retrofitting options with a considerable difference although the difference gets smaller as time increases. But at time (t) that is approximately 50 years, the option of Demolish and Reconstruct has BCR value of 1.09 slightly higher than the base value of ‘1.0’ (BCR>1) that is the limit for an option to be evaluated. Again at time (t) that is approximately 50 years, the option of Demolish and Reconstruct has a NPV value ‘0.04’ very near to the base value of ‘0.’ (NPV>0). On both cases, these limit conditions do not have effect on selection of alternatives.

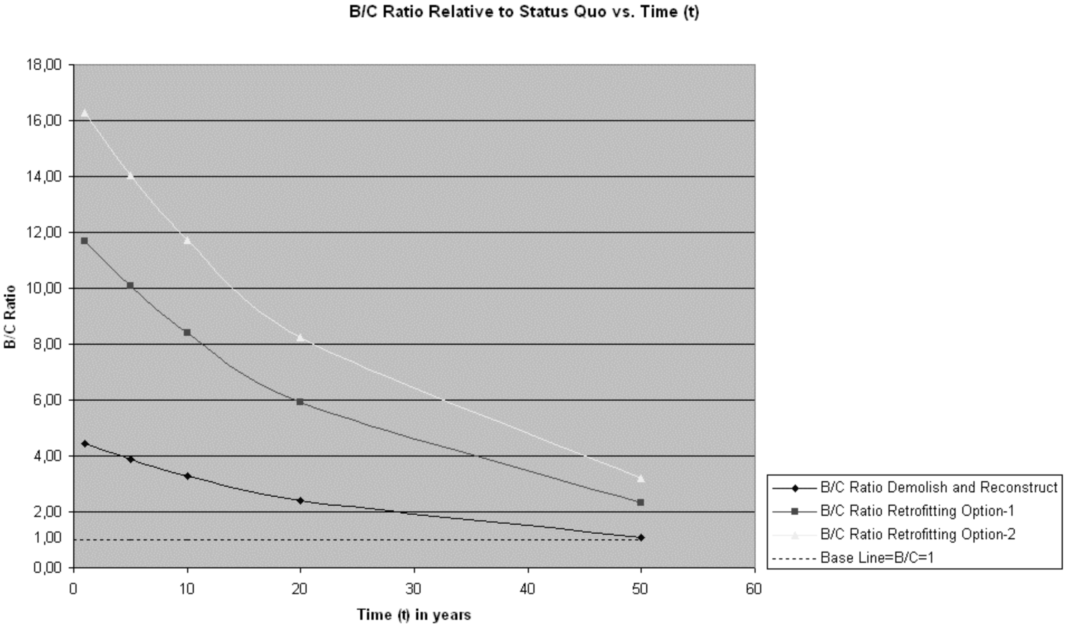
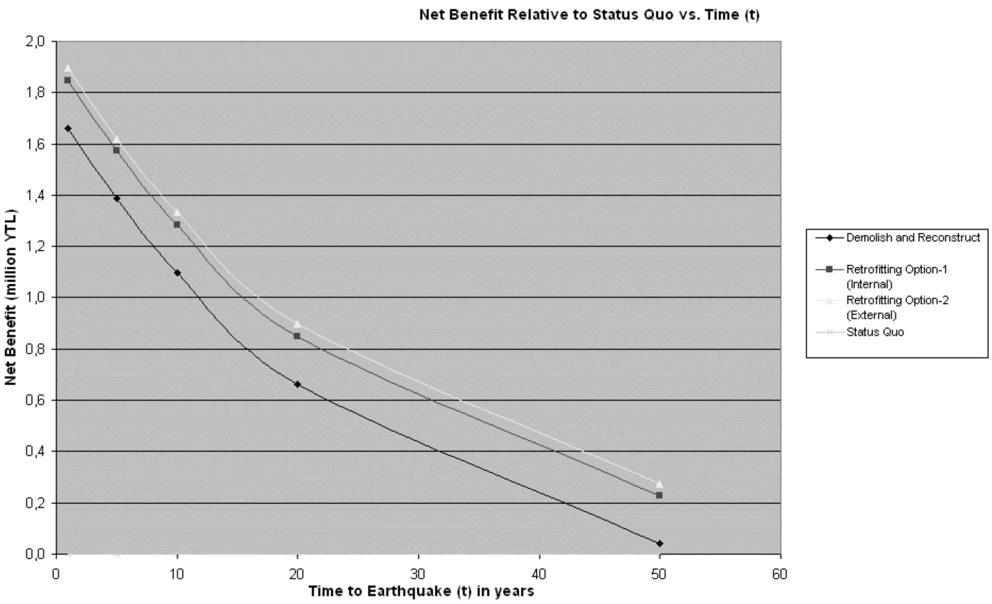



**Figure 3.24.** BCR Graph for Building 4 in Osmaniye




| Option | Initial cost (M YTL) |
|---|---|
| Demolish and Reconstruct | 0,48 |
| Retrofitting Option-1 (Internal) | 0,17 |
| Retrofitting Option-2 (External) | 0,12 |

**Figure 3.25.** NPV Graph for Building 4 in Osmaniye

### 3.6.4 Evaluation of Results

#### 3.6.4.1 Evaluation of Results for Sample Buildings

For all of four of the buildings we have derived results concluding Retrofitting Option-2 (external retrofitting) is the preferable solution. On the other hand, values for Retrofitting Option-1 (internal retrofitting) have given an idea that this option can still be chosen as it has NPV values near to Retrofitting Option-2, although it has largely varying BCR values for two buildings in Osmaniye. Demolishing and Reconstruction Option has values that can make it an economically viable solution in terms of NPV and BCR values, but it's hard to recommend it in case of existence of the other two retrofitting options that are economically more preferable. It should be stated at this point that factors that can be effective on variation of the results and the mentioned values for alternative options are expected as given below where the third item for retrofitting costs is not evaluated in terms of sensitivity:

a. Existence of the social disturbances in the analysis
b. Discount rate applied for all of the alternatives
c. Retrofitting costs

#### 3.6.4.2 Sensitivity Analysis

To see the effects of variations in the items as noted above, a sensitivity analysis will be applied over the values by shifting the relevant values of items by +50% and -50% for Building 4 in Osmaniye where the other remaining key elements remain the same to see the changes in BCR and NPV values for Retrofitting Option 2.

a. After application of variations on business interruption and social disruption (CBI, CSD), the graphs for BCR and NPV are found as below:

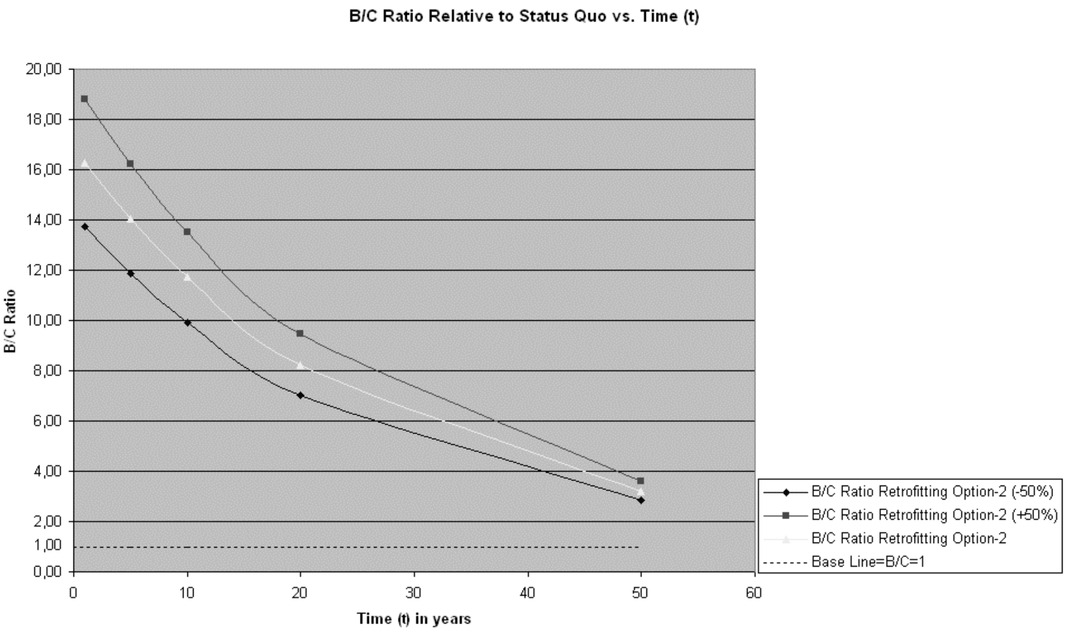



**Figure 3.26.** BCR Values after Sensitivity under Social Disturbance

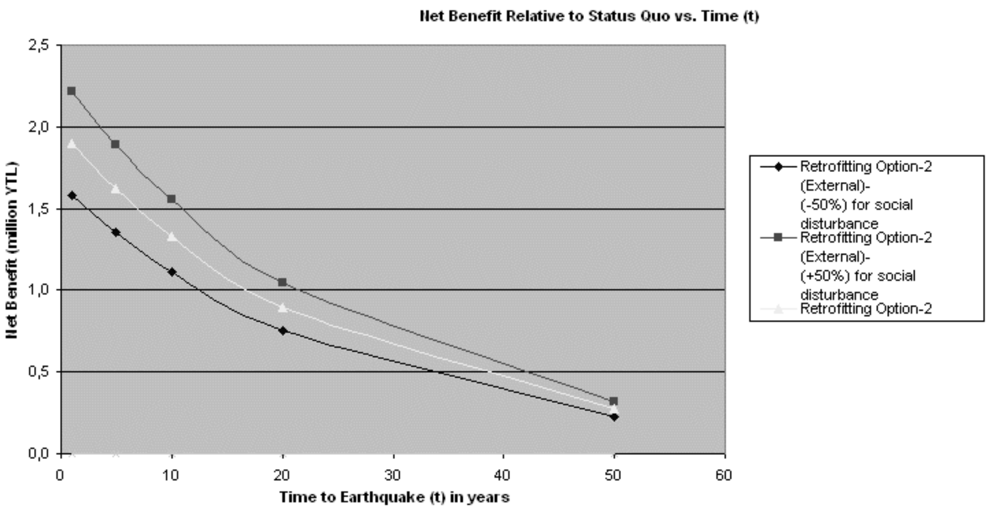



**Figure 3.27.** NPV Values after Sensitivity under Social Disturbance

**Table 3.17.** Variations in BCR after Change in Social Disturbance

| Change in Social Disturbance factor | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|
| | 1 | 5 | 10 | 20 | 50 |
| | Percentage changes in BCR values (%) | | | | |
| 50% (-) | -15,7 | -15,5 | -15,3 | -14,7 | -11,6 |
| 50% (+) | 15,7 | 15,5 | 15,3 | 14,7 | 11,6 |

**Table 3.18.** Variations in NPV after Change in Social Disturbance

| Change in Social Disturbance factor | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|
| | 1 | 5 | 10 | 20 | 50 |
| | Percentage changes in NPV values (%) | | | | |
| 50% (-) | -16,7 | -16,7 | -16,7 | -16,7 | -16,8 |
| 50% (+) | 16,7 | 16,7 | 16,7 | 16,7 | 16,8 |

The data provided in Table 3.17 and Table 3.18 give an idea that lift factor of 50% or –50% has a considerable effect on BCR and NPV values at a rate that 10 units of social disturbance brings us approximately 3 units of change on NPV and BCR with the same sign of shift direction. This change shows that social disturbance values and the assumptions made to assign these values together with its effect for the earthquake dependent costs are major and effective points of concern. So the valuation of the multiplication factor to assign the value for social disturbance and business interruption should be selected carefully.

b. Variations on item discount rate (d) are applied, the graphs for BCR and NPV are found as below:

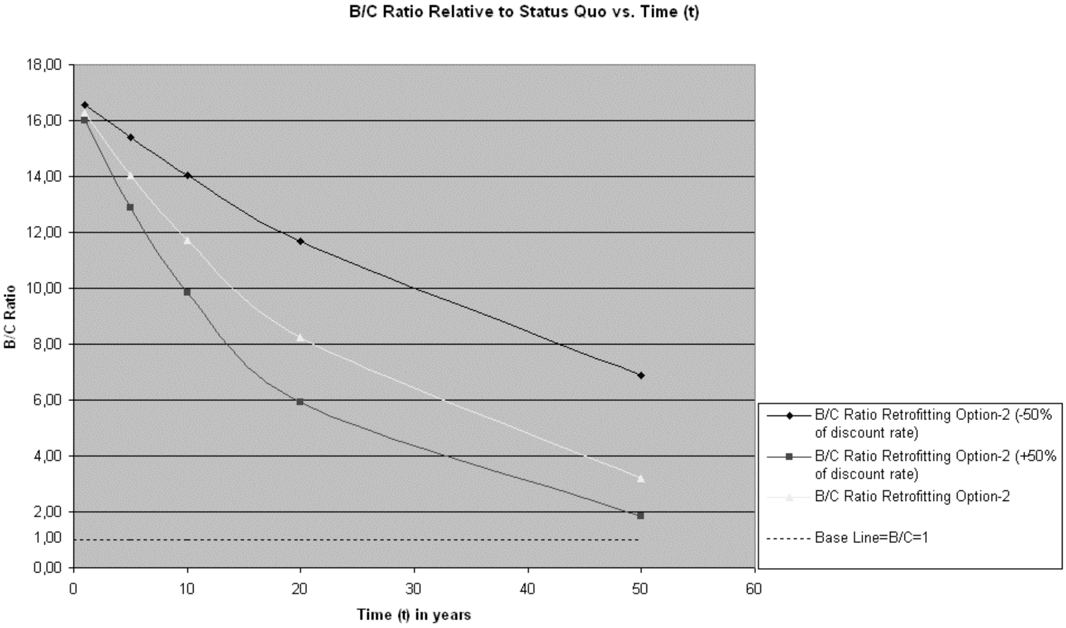



**Figure 3.28.** BCR Values after Sensitivity under Discount Rate

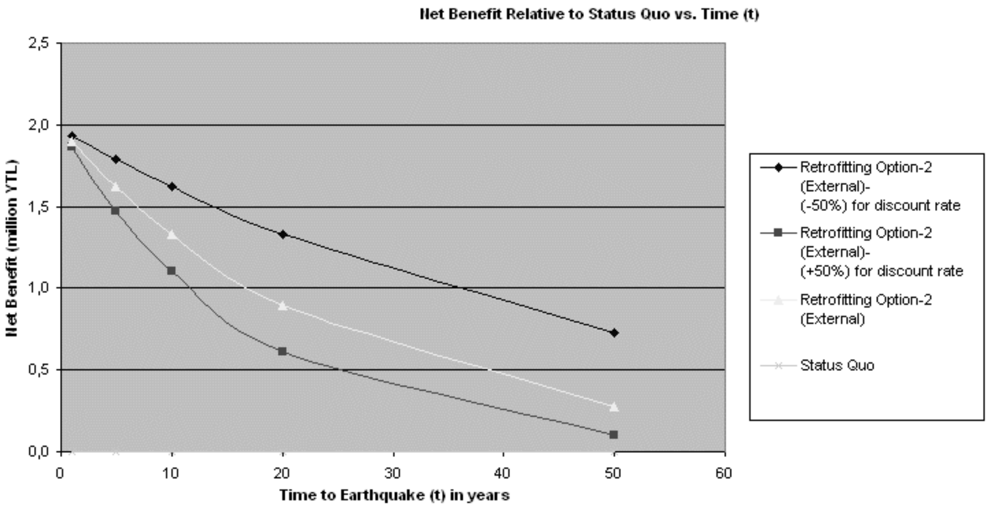



**Figure 3.29.** NPV Values after Sensitivity under Discount Rate

**Table 3.19.** Variations in BCR after Change in Discount Rate

| Change in Discount Rate | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|
| | 1 | 5 | 10 | 20 | 50 |
| | Percentage changes in BCR values (%) | | | | |
| 50% (-) | 1,8 | 9,5 | 19,6 | 41,8 | 114,2 |
| 50% (+) | -1,8 | -8,5 | -15,9 | -27,9 | -42,8 |

**Table 3.20.** Variations in NPV after Change in Discount Rate

| Change in Discount Rate | Time to Earthquake (Years) | | | | |
|---|---|---|---|---|---|
| | 1 | 5 | 10 | 20 | 50 |
| | Percentage changes in NPV values (%) | | | | |
| 50% (-) | 2,0 | 10,2 | 21,5 | 47,6 | 165,8 |
| 50% (+) | -1,9 | -9,1 | -17,4 | -31,8 | -62,1 |

The data provided in Table 3.19 and Table 3.20 give an idea that lift factor of 50% or –50% has a considerable effect on BCR and NPV values at a rate that 10 units of discount rate change brings us approximately 7 units of positive change for factor of –50%, 4 units of negative change for lift factor of +50% on BCR, 10 units of positive change for factor of – 50%, 5 units of negative change for lift factor of +50% on NPV by taking the average changing values at years 1,5,10, 20 and 50. The lift factor for discount rate also has a high variation effect on BCR and NPV values at assigned years. This high variation is expected due to the fact that discount rate directly affects the earthquake-dependent net benefits as NPV is only applied for earthquake-dependent items that constitute the majority of the total costs. So discount rate is a governing factor over the implementation of analysis. Discount rate factor also shows that a higher value than 4 %, which is assigned for this study, may lead to a condition that the retrofitting or demolition and reconstruction solutions may not be economically feasible anymore before reaching to the time limit of 50 years. Figure 3.28 and 3.29 give hints that values of BCR and NPV are very near to the limit values for +50% alternative for the most feasible solution of the study that is Retrofitting Option 2.

# CHAPTER 4

# CONCLUSION AND RECOMMENDATIONS

## 4.1 CONCLUSION

In this study, the results of the Benefit Cost Analysis (BCA) give the idea that net benefits of retrofitting and demolishing and reconstructing activities for risky buildings are significant and these benefits due to mitigation activities maintain feasible positive net present values and benefit cost ratios even the time to earthquake increases. This can give the conclusion that investment on mitigation actions for sample buildings in this study is worthwhile. Also the effect of social disturbances after earthquakes is tried to be integrated into the analysis in an economical point of view, where it is arguable that if cost of life is quantifiable or not.

As stated in Chapter 3, Retrofitting Option 1 is the internal retrofitting solution that gives disturbance to the occupants and force them to move out during retrofitting and Retrofitting Option 2 is the external type of solution that does not give disturbance to the house owners or tenants. These options together with the alternative of demolition and reconstruction have all economically feasible solutions for the selected buildings in Kartaltepe and Osmaniye.

The differences of BCR and NPV values between Retrofitting Option 1 and Option 2 for the buildings in Kartaltepe, are not so significant so this condition gives an opportunity either to choose from Option 1 or Option 2 taking the applicability of external types of solutions into consideration for apartment type of buildings in Kartaltepe.  On the other hand, variation between the values of Retrofitting Option 1 and Option 2 for buildings in Osmaniye gets higher values when compared with Kartaltepe. Although this recommends Retrofitting Option 2 as the solution, again the condition of external applicability of retrofitting studies needs to be carefully considered in terms of legal and practical views.

The variations in discount rate and factor of the social disturbances are highly effective on the results of Benefit Cost Analysis although they do not change overall results, but rather have effects on the applicable periods of alternatives.

The factor of social disturbance and business interruption reminds us the fact that an earthquake does not mean only the damage to the building but also means the damage to the occupants and household goods in these damaged buildings as well. So this factor of integration to the analysis strengthens the decision makers' hands in case of a decision for mitigation activities either by retrofitting, reconstruction or etc. The discount rate either increasing or decreasing has an effect on the time period or point, when the mitigation activities are intended to be performed at. A very high rate of discount due to inflation may lead to a condition that taking mitigation actions can only be economically feasible for short periods of time where the house owners may prefer to wait as the possibility of occurrence of a high magnitude earthquake (magnitude seven or greater) has approximately a possibility of 65 % in the next 30 years in Istanbul.

## 4.2 RECOMMENDATIONS

In this study, the effects of time-dependent costs (maintenance or others) and benefits (rentals or others) are not taken into consideration, so these can be evaluated in further studies on the subject to see if these costs and benefits can make a change on the possible preferred solution under time effect. When time-dependent benefits and costs are considered, an option may be better than the other after a period of time although it is the preferable one until that mentioned time. This type of evaluation can increase the alternatives to make choices by the occupants or the other decision makers.

Also the number of people at the buildings at time of earthquake and other assumptions such as the property value increase due to mitigation activities, movement rates, movement periods, rental rates after earthquake, coefficient for cost of damage to goods can be developed further to get more sound results.

The retrofitting activities or the demolition and reconstruction activities have an effect on the economical lives of the buildings. Although the rate of this effect due to retrofitting may be arguable, reconstruction will result a definitely longer period of life. During this study, the effects of these activities on the life cycles of buildings are not considered as the time-dependent benefits and costs are not evaluated. But in real life, the differences of BCR and NPV values between the alternatives of retrofitting and demolition and reconstruction may decrease due to the fact that a newer building may get more benefits and have fewer costs for a longer time. This condition can be developed to reach a more realistic approach.

In any case, the procedures to complete and assess the results of similar Benefit and Cost Analyses should be simple and understandable if it is aimed to convince the occupants of housing units of similar type subject to the analysis in this study.

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