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EARTHQUAKE LOSS ESTIMATION FOR A TOWN IN SEISMIC ZONE USING LIFE CYCLE COST MODEL

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CONTENTS

SUMMARY

Earthquakes result in damage to housing, social and technical facilities and severe casualties. Emergency responses following an earthquake and recovery of damaged structures have major impact on the government budget. Scarce resources assigned for development projects have to be diverted to the recovery of earthquake damages. This research work aims the estimation of earthquake loss for a town in seismic zone using life cycle cost model that can be of assistance in decision making process before and after an earthquake that strikes the town. Earthquake loss in this study is defined as the difference between the future worth of a town, at any year of the analysis period, in the case of having no earthquake and in the case of having earthquakes.

Life cycle cost model developed in this study considers that a town is an entity with its expenditures and revenues but not worth for investment. The model consists of planned and unplanned costs of a town. Planned costs are initial cost, annual expenditures and economic value, which are expected regardless of the occurrence of an earthquake. If an earthquake occurs disaster and recovery costs are to be anticipated.

Initial cost in the model refers to the land and construction costs of housing, social and technical facilities to accommodate a certain population. Maintenance cost, public and private investments are considered as annual expenditures, which are necessary for the growth of a town. Revenues from different resources are also necessary for the survival of a town and expressed as economic value in the model. Disaster cost includes supply cost (temporary accommodation, temporary hospitals, emergency aids), physical damage cost and economic loss. Structures damaged after an earthquake are classified as lightly, moderately and heavily damaged and the costs of damages are reflected in the physical damage cost. Damaged structures are recovered either by repairing or retrofitting or reconstruction or soil improvement. Recovery cost refers to the cost of the recovery of the damaged structures.

An analysis period of 50 years is adopted to observe the effects of earthquakes on the cost of a town under earthquake risk. This period is also considered to be long enough to cover two earthquakes. The sensitivity of cost effective parameters such as recovery period, initial cost, interest rate and earthquake pattern (occurrence time of earthquakes) is evaluated for earthquake losses of four different cases. A case study is also carried out to apply the model to an actual case, Adapazarı, which is damaged heavily during the earthquake in 1999. In order to analyze the earthquake losses of different situations for Adapazarı, six scenarios are created. In the sensitivity measurement of cost-effective parameters and case study, the earthquake loss at the end of the analysis period is adopted to allow the meaningful comparison of different situations. However, the model enables the computation of the earthquake losses at any year of the analysis period.

ÖZET

Depremler bir kentin ekonomisini büyük ölçüde etkilerler. O kentin gelişmesi için ayrılmış olan sınırlı kaynaklar depremin yaralarını sarmak için kullanılmakta ve kentin ekonomik büyümesi gecikmektedir. Bu çalışmada, deprem riski altında bulunan bir kentin deprem kaybının yaşam boyu maliyet modeli geliştirilerek hesaplanması amaçlanmıştır. Kent, harcamaları ve gelirleri olan bir ekonomik varlık olarak kabul edilmiştir. Ancak, bu kabul ile geliştirilen model kentin yatırımcı açısından önemli olan getirisini değil, depremin ekonomik açıdan orada oluşturduğu parasal kaybı göstermektedir. Burada deprem kaybı, analiz süresi içindeki herhangi bir yıl için kentin hesaplanan ekonomik değerleri arasındaki fark olarak tanımlanmıştır. Bu fark deprem olmadığı durumdaki ekonomik değerden deprem olduğundaki ekonomik değer çıkarılarak bulunur.

Geliştirilen yaşam boyu maliyet modelinde deprem riski altında olan bir kentin harcamaları ilk yatırım maliyeti, yıllık harcamalar, deprem maliyeti ve iyileştirme maliyeti; geliri de ekonomik getirileri olarak ele alınmıştır. Belirli bir nüfusu barındırabilmek için bir kentin konutlara, sosyal ve teknik servislere ihtiyacı vardır. Bu konut ve servislerin arsa ve yapım maliyetleri o kentin ilk yatırım maliyetini oluşturmaktadır. O kentin büyüme ve gelişmesi için gerekli bakım maliyeti, kamu ve özel teşebbüs yatırımları yıllık harcamalar olarak değerlendirilmiştir. Yine söz konusu kentin yaşayabilmesi için çeşitli kaynaklardan (tarım, endüstri, ticaret ve turizm) elde ettiği gelirleri mevcuttur. Bütün bu harcamalar ve gelirler deprem olsun veya olmasın bir kent için söz konusudur. Ancak, deprem olduğu takdirde deprem maliyeti ve iyileştirme maliyeti gündeme gelecektir.

Deprem maliyeti; acil yardım maliyeti, fiziksel hasar maliyeti ve ekonomik kayıp olarak üç grupta irdelenmiştir. Depremden hemen sonra ihtiyaç duyulan harcamalar, geçici hastane kurulması, yiyecek ve giyecek yardımı ve geçici konut ihtiyacı acil yardım maliyetini oluşturmaktadır. Depremde hasar gören yapılar az, orta ve ağır hasarlı olarak incelenmiş ve bu yapılarda oluşan hasarın maliyeti fiziksel hasar maliyeti olarak modele yansıtılmıştır. Deprem sonrasında işçi kaybı,

motivasyon eksikliği, iş yerindeki ve/veya alt yapıdaki hasardan dolayı üretim yapılamaması kentin gelirinde bir azalmaya yol açacaktır. Bu azalma ekonomik kayıp olarak modelde ele alınmıştır.

Depremde hasar gören yapıların iyileştirilmesi hasarın miktarına göre, onarım (yapının deprem öncesi durumuna getirilmesi), sağlamlaştırılma (yapının deprem öncesi durumundan daha dayanıklı hale getirilmesi), yeniden yapım olarak düşünülmüştür. Ayrıca, yapı sağlam olmayan zeminden dolayı hasar görmüş ise zemin ıslahı da modelde yer almaktadır. Eğer hasarlı yapı yalnızca onarılacaksa fiziksel hasar maliyeti o yapının iyileştirme maliyetine eşit kabul edilmiştir. Diğer seçeneklerde iyileştirme maliyeti fiziksel hasar maliyetinden fazla olacaktır.

Deprem kaybını etkileyen parametreler iyileştirme süresi, ilk yatırım maliyeti, faiz oranı ve depremin oluş yılı olarak belirlenmiş ve geliştirilen model kullanılarak bunların deprem kaybına olan etkileri (duyarlılık) değerlendirilmiştir. Modelde bir kent için analiz süresi iki depremi kapsamak için 50 yıl olarak alınmakla birlikte bu süreyi değiştirmek mümkündür. Duyarlılık analizinde incelenen dört durum için ilk depremin analiz süresinin onuncu yılında olacağı varsayılmıştır. Birinci durum, yalnızca bir deprem içerirken ikinci durumda iki deprem düşünülmüştür. Her iki durumda da depremlerden sonra hasarlı yapıların sadece onarımı söz konusudur. Üçüncü ve dördüncü durumlar yine iki deprem içermektedir. Ancak, üçüncü durumda birinci depremden sonra hasarlı yapılar sağlamlaştırılırken dördüncü durumda hem sağlamlaştırma hem de zemin ıslahı yapılmaktadır. Her iki durumda da ikinci depremden sonra yalnızca onarım yapılacağı varsayılmıştır.

Modelin gerçek bir duruma uygulanması için vaka analizi gerçekleştirilmiş ve 1999 yılındaki depremde büyük hasar gören Adapazarı'na ilişkin veriler toplanmış ve modelde bunlar kullanılarak deprem kayıpları hesaplanmıştır. Kent için 6 senaryo üretilmiş ve her bir senaryoda deprem kaybının ne olacağı maliyeti etkileyen parametreler doğrultusunda gözlenmiştir. Bu senaryolarda aşağıdaki kabuller yapılmıştır.

Senaryo 1 – Bir deprem içerir ve deprem sonrası hasarlı yapılar sadece onarılır.

Senaryo 2 – İki deprem içerir. Birinci depremden ve ikinci depremden sonra hasarlı yapılar sadece onarılır.

Senaryo 3 – İki deprem içerir. Birinci depremden sonra hasarlı yapılar sağlamlaştırılır ve.ikinci depremden sonra sadece onarılır.

Senaryo 4 – İki deprem içerir. Birinci depremden sonra hasarlı yapılar sağlamlaştırılır ve ikinci depremden sonra sadece onarılır. İkinci depremin büyüklüğünün Senaryo 3'dekinden daha küçük olduğu kabul edilir.

Senaryo 5 - İki deprem içerir. Birinci depremden sonra hasarlı yapılar sağlamlaştırılır ve zemin ıslahı yapılır. İkinci depremden sonra ise sadece onarılır.

Senaryo 6 – İki deprem içerir. Birinci depremden sonra hasarlı yapılar sağlamlaştırılır ve zemin ıslahı yapılır. İkinci depremden sonra ise sadece onarılır. İkinci depremin büyüklüğünün Senaryo 5'dekinden daha küçük olduğu kabul edilir.

Sayısal incelemelerde deprem kayıpları, anlamlı bir karşılaştırma yapabilmek açısından elli yıllık analiz süresinin sonundaki değerleri dikkate alınarak değerlendirilmiştir. Gerek deprem kaybını etkileyen parametrelerin irdelenmesi ve gerekse de vaka analizi sonuçları göstermiştir ki; iyileştirme süresi arttıkça deprem kaybı da artmaktadır. İlk yatırım maliyeti arttıkça yani depreme daha dayanıklı yapılar yapılması ve yapılar arasında daha geniş mekanlara yer verilmesi deprem kaybını azaltmaktadır. Yüksek faiz oranları deprem kaybını artırırken, ikinci depremin analiz süresinin son yıllarında olması deprem kaybını azaltmaktadır. Bu çalışmada elde edilen sonuçlar nitelik açısından genel bulgular olarak alınabilirse de sayısal açıdan burada kullanılan giriş verileri ile bağımlı sonuçlardır. Farklı veri grupları kullanarak sayısal açıdan daha geniş sonuçları verecek parametrik bir çalışmanın ilerdeki bir aşama olacağı düşünülmektedir.

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Sema Ergönül, Architect

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LIST OF ABBREVIATIONS

AE = Annual Expenditures
EL = Economic Loss
EQ = Earthquake
EQL = Earthquake Loss
EQP = Earthquake Pattern
EV = Economic Value
FW = Future Worth
IC = Initial Cost
IR = Interest Rate
LB = Lower Bound
LCC = Life Cycle Cost
PB = Planned Benefits
PC = Planned Costs
RC = Recovery Cost
RP = Recovery Period
SC = Supply Cost
TLCC = Total Life Cycle Cost
UB = Upper Bound
UC = Unplanned Costs

CHAPTER 1

RESEARCH METHODOLOGY

1.1. Introduction

A large portion of the wealth of any nation is invested in its built environment: housing, infrastructure, industrial and commercial facilities. The quality of this built environment, expressed in terms of durability, safety, and functionality, is a determining factor in the quality of life and economic development of the society and the competitiveness of its industry and services (“Hazard-Resistant”, 2000). Size of the social and technical facilities of the built environment in an urban area depends on the population to be accommodated and their needs.

The costs of land, construction, operation and maintenance of the facilities of the built environment affect the cost of any town development. Each town development has its own income resources, depending on its location, for the survival and the development of that town. Towns can also be subjected to natural disasters. The value of a town, therefore, based on where it is located, how it is planned and how it is constructed. In planning the budget of municipalities, investments for the development of that town has to be considered to rectify the budget. It is most likely that unexpected natural disasters like earthquakes generate a variety of economic impacts and will result in a budget deficit.

Klaus Jacob, an earthquake expert at Lamont-Doherty, the Earth Sciences Research Center at Columbia University, says: "More and more people and more and more buildings are at stake. As the world gets more populous and richer, allowing a built-up environment, higher buildings and all the infrastructure that supports our civilization, communication and the like, the risk goes up." (William, 1999). The risk is also related to poverty in countries where informal buildings are not built according to rules, regulations and building codes - where mismanagement and non-compliance with building codes, rules and regulations are not an exception, but the general rule. Especially for the countries like Turkey, where 92 per cent of the total surface area and 95 per cent of the total population are situated in seismic zones, the occurrence of earthquake risk, with varying degrees is very high. In addition, 75 per cent of the industrial centers in Turkey are located in these earthquake prone areas. Moreover, 53 per cent of the land, 50 per cent of the population and 15 per cent of industry are situated in areas of first and second-degree risk, liable to a violent earthquake any time. The earthquake implies major impacts on the government budget. According to statistical studies carried out in the last 70 years, natural disasters in Turkey cause a direct economic loss of 1 per cent of the Gross National Product. When the indirect losses, such as market loss, production loss, unemployment and price increases are taken into account, this loss can go up to 3-4 per cent. ("Eastern, 2000").

All very highly populated, industrial urban areas are killing and injuring thousands of people and rendering tens of thousands of people homeless. Even though rate of earthquakes over time is not changing, due to the population explosion and rapid organization, more and more people are now occupying fault lines, earthquake zones and vulnerable coastal areas.

The cost of damage caused by earthquakes to governments, businesses, and families is very high. The money spent for the recovery from earthquakes is the money lost to economic development. Planning, design, and construction techniques can greatly reduce costs due to earthquakes. Siting of a structure is also important to minimize the effects of earthquakes. Unfortunately, governments resist making the small investments that would make buildings and infrastructure safer. Individuals are unwilling to insist on construction that makes their homes and businesses more seismic-resistant. Therefore, governments, investors, and individuals in seismic regions should be persuaded to deal more wisely with earthquakes than they have to date (CDMP, 1999a).

1.2. Approach to the Research

This research work is a basic attempt which is undertaken to understand more about the problem under investigation and how to solve it. Its objective is exploratory rather than descriptive or hypothesis testing as described by Sekaran (1992). Figure 1.1 summarizes the overall approach to the research. A literature review was necessary for the following reasons;

- To provide greater precision and clarity of the area studied,
- To be useful in theoretical development,
- To be usable in practical applications,
- To enable replication,
- To prevent duplication.

The literature review facilitated clear formulation of the problem.

1.3. Problem Statement

On 17 August and 12 November 1999, earthquakes struck the Marmara and Bolu areas of Turkey, causing significant material damage and severe casualties. These two earthquakes are the largest events which ruined modern and industrialized urban area since the 1906 San Francisco and the 1923 Tokyo earthquakes (EQE, 1999). The effects of these earthquakes on the built environment become important to be aware of the seismic risk in regions having high population densities, modern infrastructure, industry and buildings. Several thousands of buildings collapsed in the earthquakes because they did not meet the design requirements of the code. In the construction of many of the buildings, construction materials used were not good quality. Many of the buildings were constructed on active faults and in areas with poor soil and this fact leads the government to attach importance to the relocation of the affected areas to geologically secure sites.

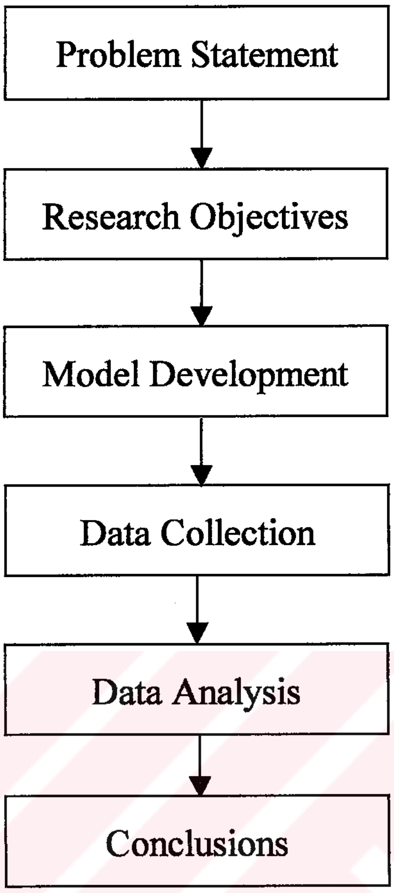


Figure 1.1 Approach to the Research

As a result of the damages of the Marmara and Bolu earthquakes, industry also suffered heavy losses of business interruption. Only small number of facilities recovered within a short time while large facilities had to stop working because of the damages of failed craines, equipment and building collapses, etc.. There was also extensive damage to infrastructure (electric power, water supply) and roads in the epicentral locations. All these losses due to damages caused by earthquakes have a strong negative impact in the economy of the towns. The effects of these earthquakes, including severity of damage, business interruption losses, and environmental impact at petrochemical facilities, were much more severe than previously experienced in strong motion earthquakes. The preliminary Marmara earthquake assessment report by World Bank (1999) outlines that the likely impact of the earthquake is on the economy and the cost of reconstruction and recovery.

Earthquakes create a growing threat to the development strategies of countries by destroying infrastructure and production capacity, interrupting economic activity, and creating irreversible changes in the natural resource base. With increasing frequency, earthquake countries are facing situations in which scarce resources that were earmarked for development projects have to be diverted to relief and reconstruction following disasters, thus setting back economic growth. Disasters also directly impact on the foreign exchange earnings capacity of a country, at a time when extra resources are needed to finance imports of food, energy, and inputs for the agricultural and manufacturing sectors. If sustainable development is to be achieved, countries will have to take effective measures to reduce their vulnerability to natural disasters.

The effects of earthquakes can be avoided or mitigated by the rehabilitation of existing buildings, better design of new construction, proper use of land and increased preparedness in all areas. Performance of the built environment can determine both the magnitude of the losses and the speed of recovery from earthquakes. In the public and private sectors, long term earthquake mitigation have to compete for scarce investment resources with other development initiatives such as basic infrastructure, production and employment needs. The benefits of long-term earthquake mitigation go beyond economics. Nevertheless, economic arguments built on a sound benefit-cost analysis are essential when one has to defend the use of scarce resources for investment in mitigation. Therefore, there is a need to develop models for better articulation of the benefits of investing in mitigation, and for more accurate estimates of the costs of alternative mitigation options.

Each disaster leaves in its wake an overwhelming volume of evidence of human ignorance or neglect that directly contributed to the magnitude of the damages. It is therefore not surprising that a systematic analysis of how decisions made by planners and developers may contribute to vulnerability and the consequent risk of earthquakes will effectively identify where earthquake mitigation and risk reduction may be best applied.

The decision to invest in measures that can protect property against possible damages from earthquakes is primarily an economic decision. It should therefore be taken in the framework of an economic analysis, evaluating the costs of investing in mitigation or prevention against the expected benefits, in terms of risk reduction, that will be derived from the investment. In selecting opportunities for earthquake mitigation it is essential to remember that the most effective approach to reducing the long-term impact of earthquakes is to incorporate earthquake assessment and mitigation activities into the process of integrated development planning and investment project formulation and implementation.

For new development projects, the economic analysis of mitigation should be implemented as part of the project appraisal phase. For retrofitting of existing development, the analysis must be carried out on a stand-alone basis.

A life cycle cost model, which is a system that aims to identify the probable results of various design changes to improve the cost/benefit ratio of the design, can be of assistance in decision making process. However, a town development is a very complex system and it is difficult to simplify the relationships between the components of that system.

In this study, earthquake loss for a town in seismic zone is estimated by using life cycle cost model, which combines all the costs and benefits of a town over its life span. Town is considered as an asset in national economics' point of view, with its costs (expenditures) and benefits (revenues). However, town is not accepted as an asset, which is worth to invest. The occurrence of an earthquake causes direct and indirect losses in economy and these losses can be minimized by the use of planning techniques. Life cycle cost model enables the computation of earthquake loss at any year within analysis period. In order to compute earthquake loss of a town at a specified year within analysis period, first future worth in case of having no earthquakes and then future worth in case of having earthquakes at that specified year is determined. Earthquake loss at a certain year of analysis period is the difference between the future worth without earthquakes and the future worth with earthquakes of that year. Knowing that life cycle cost model includes all the expenditures and revenues of a town during its life span, earthquake loss at any year of the analysis period reflects not only the effects of the costs of a town in seismic zone but also the effects of the benefits of that town. Therefore, components of town planning and earthquake effective parameters are discussed to be able to estimate earthquake loss by using life cycle cost model reflecting the real situation. Although this study is concern about the economic aspects of earthquakes, the social aspects of should not be ignored when making a decision.

1.4. Aims and Research Objectives

Earthquakes can damage buildings and infrastructure and cause direct and indirect losses. There is increased understanding of the potential problems that must be considered and resolved before the earthquake strikes a town or region. Only using a proper recovery planning it will be possible to act effectively not only to reduce human suffering but also to minimize economic loss and correspondingly earthquake loss. The aim of this research work is the estimation of earthquake loss for a town in seismic zone using a life cycle cost model that can be of assistance in decision making process before and after an earthquake that strikes a town.

The objectives of this research are as follows;

1. to review the costs (expenditures) and benefits (revenues) of a town during its life cycle.
2. to review the direct and indirect losses that occur after an earthquake.
3. to review the cost-effective parameters throughout the life cycle of a town.
4. to develop a model to analyze the life cycle cost of a town under earthquake risk.
5. to determine earthquake loss at any year of the analysis period for a certain interest rate.
6. to evaluate the sensitivity of cost-effective parameters for earthquake loss using the model developed.
7. to apply the model to an actual case.

1.5. Data Collection and Data Analysis

Qualitative and quantitative data are needed for the development and application of the model to analyze earthquake losses as described in the research objectives. Survey design and case study approach will form the method of data collection.

Published documents about the physical, social and economical effects of earthquakes provided data for the model development. Interviews were also held with Professors of Civil Engineering Department of Sakarya University in Adapazarı.

The case study approach had been chosen in order to evaluate the actual situation using the model. Adapazarı would be a good choice because it was the most damaged town during the earthquakes in 1999. An interview was held with the staff of Municipality, Professors of Civil Engineering Department of Sakarya University and a consultant engineer in Adapazarı to collect data required by the model. Published documents about the earthquakes in Turkey are also of great help in carrying out the case study. However, it is not possible to provide data as required. Therefore, some revisions are required in order to make the data useable.

The fieldwork and data analysis are appropriate to the data collected. The earthquake losses for different scenarios will reflect the economic impact of earthquakes on Adapazarı according to actual situation obtained from relevant agencies. Analyzing existing situation will fulfill a case study.

1.6. Literature Review

No matter where an earthquake occurs, in the city or the countryside, it does damage in varying degrees to the area, and causes injury and death as well as economic losses. Recent studies on physical, economical and social impacts of earthquakes and a variety of approaches to mitigate the effects of these impacts are discussed in this section.

Many researchers have investigated the economic impacts of earthquakes and developed models to assess the economic consequences of earthquakes. Jones and

Chang (1994) have introduced direct and indirect methods of estimating the elements of the built physical environment at risk from earthquakes. For indirect estimates, parameters have been developed to reflect the relationship between population and the elements of built physical environment which are assumed as residential, non-residential (commercial & industrial and agriculture), infrastructure and on-site improvements. For direct estimates, information about the elements of built physical environment is collected from a number of different sources. Information about existing elements of the built environment in a region is necessary for risk assessment, determining damage rates, and planning for recovery and reconstruction but they are rarely available. Three attributes of the built environment, number, quantity and replacement cost are used for the comparison of indirect and direct estimates. It is found that the indirect estimates proved to be valuable guides in the case of the lack of direct data.

Jones and Chang (1995) approach to the economic aspects of earthquakes, at the urban and regional level, considering two aspects for research; Economic impact on the investment in the built physical environment and impact on production and income resulting from destruction of the physical elements. First aspect is important for calculating damage rates and establishing the severity of the disaster. Second aspect is important to assess the magnitude of an event, to plan assistance and to assign priorities to mitigation measures and to recovery processes. They further investigate the usefulness and applicability of methods of urban and regional economic analysis. Input-Output models, econometric models, mathematical programming and also Benefit/Cost analysis are some of the methods that can be used for the analysis of economic impacts caused by earthquakes.

Even though losses caused by the damages of earthquakes are attributable to the property damages, there are some other losses such as loss of business caused by directly the failure of infrastructure (electricity, water, gas etc.). Rose et al (1997) has developed a methodology to estimate the direct impacts of electricity lifeline disruption caused by an earthquake. The methodology which is based on input-output and linear programming models, considers basic usage of electricity, the resiliency of productive activities to loss of electricity, and the restoration time of service after disaster in addition to the physical damage affecting electric service.

The planners to make decisions on mitigation measure and implementing recovery policies can use the methodology.

A set of loss estimations is facilitated by the Earthquake Loss Estimation Methodology (HAZUS) developed by Brookshire et al (1997). The methodology includes two types of modules: direct loss module which determines loss estimates for repair and replacement of structural and nonstructural buildings, building contents and inventory, and business interruption losses. Indirect damage refers to any damage apart from that directly produced by a disaster and HAZUS estimates the impacts by economic sector. The direct loss information provides the inputs to the indirect loss module. External reconstruction funding and speed of reconstruction that may depend on economic and mitigation policy variables affect indirect impacts of an earthquake.

Cochrane (1996) discusses the design and application of a new regional economic model for rapidly assessing the indirect economic consequences of damage to residential structures, manufacturing facilities, and lifelines (particularly power generation and distribution, water supply, telecommunications, and transportation). He demonstrated that indirect loss can be an important and significant element of regional earthquake damages. It has also demonstrated that indirect loss is elusive; it can be quite large or diminish to zero, regardless of the severity of the event.

A great attention has been given by researchers to the direct and indirect losses caused by earthquake damage. As stated by Chang et al (1999) economic disruption is dependent on not only the loss of structural and infrastructural functionality but also recovery duration. They have developed a loss estimation model, which is based on post-disaster repair and system restoration, for urban water delivery systems. The model simulates economic impacts within Monte Carlo framework, develops economic fragility reflecting economic loss and hazard curves and then produces expected annual loss. The model can be used to explore earthquake loss reduction in following ways;

1. Expected annual loss results can be used to assess the benefit/cost analysis of pre-event mitigation measures such as upgrading vulnerable pipes. As

far as post-event measures are concerned, prioritization of restoration can be explored.

2. The simulation approach enables the identification of the areas at greatest risk loss.
3. The magnitudes of economic loss and repair costs can also be evaluated in the framework of the model.

National Center for Earthquake Engineering Research (NCEER) (Shinozuka et al, 1997) has developed loss estimation methodologies related to building and lifeline systems damage for Memphis, Tennessee in a magnitude of 7.5. The Loss Assessment of Memphis Buildings (LAMB) project focused on the expected seismic performance and losses associated with gravity-load designed reinforced concrete and masonry buildings. The model is implemented in a Geographic Information System (GIS) software and direct losses are evaluated in terms of repair costs. The lifeline project focused on three utility systems managed by the Memphis Light, Gas and Water Division (MLGW). The model estimates the direct loss; repair costs, revenue losses and direct business interruption losses, and indirect loss which is evaluated for electric power disruption only. The results obtained from the model show that economic losses of lifeline damage in an earthquake could be substantial. Repair costs, revenue losses and economic impacts differ between lifelines. Restoration policy is a major factor influencing economic loss.

Nigg (1996) investigates the importance of lifelines for business continuity in the immediate post-earthquake impact period. In a survey carried out in Shelby County, businesses are stratified on two criteria. First, because it is hypothesized that different types of businesses might have different needs for lifeline services, businesses are classified into five sectors: Wholesale and retail trade; manufacturing and construction; business and professional services; financial, real estate and insurance; and a residual category of other businesses (including agriculture, fishing, mining, foresty and transportation). Second, it is hypothesized that large businesses, if they could not function, could have a potentially larger impact on the economics of the region. The results of the survey show that even businesses that could function because their facilities and buildings sustained no structural damage would be disrupted if lifeline systems fail.

Each year earthquakes exert a heavy toll on human life and property. The United Nations estimates that, in the past 20 years, nearly three million lives have been lost to earthquakes and some 800 million people have been affected (Katayama 1994). Despite technological advances in forecasting, early warning, housing and disaster management services, earthquakes continue to claim lives and cause severe losses of property. Earthquake mitigation is essential for sustainable development, because the effects of disasters pose heavy strains on development efforts and divert funds from other needed purposes.

In many developing countries, natural disasters, such as cyclones, floods, landslides, drought, volcanic eruptions and earthquakes, are recurrent events. Yet, often little is or can be done to enhance the preparedness and to minimize the risk. Although earthquakes may equally hit industrialized countries, the generally good quality of structures, and preparedness and response strategies tend to moderate the losses. Losses due to earthquakes cannot be nullified, but they may be mitigated by integrating new and existing knowledge, and by managing risk through various structural and non-structural strategies. International cooperation is needed to meet the challenge of this ever present and complex problem (Uitto, 2000).

The impacts of earthquakes can be mitigated or in some instances, prevented entirely. Hazard mitigation is defined, by FEMA (1998), as sustained action taken to reduce or eliminate the long-term risk to people and property from hazards and their effects. This distinguishes mitigation from other major emergency management functions such as preparedness and training, response, and short-term recovery. The strategy has two goals:

- to substantially increase the public awareness of earthquake risk so that the public demands safer communities in which to live and work; and

- to significantly reduce the risk of loss of life, injury, economic costs, and destruction of natural and cultural resources that result from earthquakes.

Communities and development organizations can reduce earthquake losses through a continuous prevention and mitigation program that is integrated into a comprehensive disaster prevention program. Land-use planning and building standards are two of the major strategies for reducing vulnerability. Preparedness plans and warning systems are also essential elements. Mitigation can only be effective if it is a top priority. It must be integrated into an overall planning and development process involving all relevant organizations and government agencies (Hamilton, 2000).

Mitigation measures may be structural or non-structural. Structural mitigation includes physical measures or standards such as building codes, materials specifications, and performance standards for new buildings; the retrofitting of existing structures to make them more hazard-resistant; and protective devices such as dikes. Non-structural measures typically concentrate on identifying seismic-prone areas and limiting their use. Examples include land-use zoning, the selection of building sites, tax incentives, insurance programs, relocation of residents to remove them from the path of an earthquake, and the establishment of forecasting and warning systems ("Primer on Natural", 2000).

Mader (1997) defines primary planning instruments used in controlling land use as the general plan, zoning regulations, subdivision regulations and redevelopment. Recognition of seismic hazards in the planning process includes at least;

1. the availability of good geologic information,
2. the utilization of such information,
3. the imposition of reasonable seismic safety standards.

As stated by Bahrainy (1998) urban planning and design can play an effective role in mitigating seismic risk in the urban areas of the seismic-prone regions. Planning and design are considered at regional, metropolitan, city, sector and project level so that seismic risks in urban areas may be reduced. Location, size, density, height, type, accessibility are determinant factors of land use vulnerability to seismic risk. He further recommends that for land use planning in a seismic-prone area, ample open space should be provided throughout building areas. Areas with higher densities need more space than those with lower densities. The most sensitive and vulnerable activities should be located in areas with least potential seismicity. Development in areas with liquefaction, landslide and rockfall potentials should be avoided. Lower density is generally recommended for areas with medium to high seismic risks.

Wang (1996) presents a state-of-art application of a logical combination of geographic information system (GIS) and artificial intelligence (AI) to urban planning for earthquake disaster mitigation. That system provides vast amount of referenced data for use in earthquake hazard analyses for microzonation. Satisfactory results can be obtained by using the AI+GIS technology for such factors as the estimation of damage distribution and infrastructures, the attenuation of strong ground motion, the economic impact and losses, and the evaluation of earthquake disaster mitigation strategies.

The actual cost of a facility comprises not only its initial cost but also costs for operation, maintenance, repair and rehabilitation incurred over the life span of the facility. The research carried out by Arditi and Messiha (1996) investigates the use of Life Cycle Cost (LCC) analysis in Municipalities in U.S. LCC analysis can be used during the design and construction process including maintenance. However, it provides greatest savings in the early stage of a project. The survey has shown that 60 per cent of the municipalities did not use LCC analysis because there was no standard guidelines for the analysis and no reliable historical data. 40 per cent of the municipalities used LCC in municipal facilities, transportation projects and sewer systems. They conclude that LCC is commonly used in new projects, rehabilitation works and reconstruction works, and during the design stage only.

Arditi and Messiha (1999) state that LCC analysis 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 and user costs, and hidden and social costs in municipal organizations. The choice of the discount rate and the inflation rate have a major impact on the results of LCC analysis since a low rate favors long term improvements with a large initial cost while a high rate favors short term improvements. Agency cost refers to the cost of construction, maintenance, rehabilitation, engineering and administration while user cost refers to operation costs. Social costs include the costs of controlling noise, vibration, and air pollution while hidden costs include the cost due to detours, lost revenue to business, and the lost tax dollars to government. Knowing that the LCC analysis is not a deterministic method, the uncertainties involved in these parameters can be eliminated by a sensitivity analysis, which helps decision-makers to assess the effects of these parameters on the result.

In recent years, life cycle cost concept has been an important factor in estimating the earthquake cost. A life cycle cost framework developed by Chang and Shinozuka (1996) includes initial cost, discounted maintenance cost and also discounted cost for seismic retrofit and damage/repair cost from seismic events for bridges located in earthquake-prone areas. The life cycle cost is considered at four categories; planned owner cost, planned user cost, unplanned owner cost and unplanned user cost. Planned costs consist of expenditures and user costs related to construction, maintenance, and seismic retrofit. Unplanned costs relate to damage inflicted by earthquakes. Sensitivity of total life cycle cost to variations in discount rate, time frame and retrofit costs have also been tested to assist decision-makers. The results show that total life cycle cost increases when interest rate decreases and when time frame increases. Sensitivity of total cost to retrofit parameters are tested for moderate and high seismicity regions. It is seen that the cost change is more sensitive to retrofit effectiveness in the high seismicity regions.

Novick (1990) considers life cycle cost to make a decision on whether to repair, rehabilitate, reconstruct or replace an urban infrastructure system. According to Novick, a rational method for estimating life-cycle costs of engineered structures needs to be developed, one that includes consideration of realistic estimates of structure life for various type of structures, recognizing the constraints on replacement at a new location. The total cost includes initial cost and future expenditures for inspection, maintenance, repair and rehabilitation over the anticipated life of the structure including inflation factors. He supports the use of guidelines for preparing and maintaining a lifetime file and operating manual for all important structures that include basic design assumptions and contract documents for the original construction, to be updated for the various reconstructions so that the structure's construction history is current and available over its entire functional life.

Warszawski et al (1996) propose a methodology for economic evaluation of design codes. The life cycle cost approach is used in the methodology and is composed of the initial cost of a building designed for a selected level of peak ground acceleration and the expected cost of failure because of an excessive earthquake. The total cost of damage caused by an earthquake is consisted of the physical damage to the buildings, injuries and death of the occupants, and the cost of inactivity due to damage. The optimum level of design acceleration result in a minimum total life cycle cost assuming an economic life of 50 years and an interest rate of 2 per cent.

After an earthquake reconstruction (recovery) becomes an important matter and researchers have carried out models to analyze the reconstruction process. Yaoxian (1996) states that rational decision making is the key to accelerate the reconstruction process and to improve the pattern of human settlement. He proposes a post-earthquake activity model for reconstruction including land-use planning, emergency shelter construction, priority of recovery of economic sectors and financial resources for reconstruction. The model consists of four phases:

1. Emergency Phase: Emergency measures are usually those which are taken immediately following disaster impact and are mainly directed towards saving lives and protecting property, and dealing with the immediate disruption, damage and other effects caused by the disaster. This phase applies to a fairly short period ranging from several days to 2-3 weeks after impact. The end of this phase is characterized by completion of the following activities: search and rescue; provision of emergency food, shelter and medical assistance; clearance of ruins on the main roads.

2. Recovery Phase: is the process by which impacted areas are assisted in returning to their normal level of functioning following a disaster. The recovery process can be protracted, taking several months, or even more than one year. The following three categories of activity are usually regarded as coming within this phase: Restoration of essential services,

such as main urban services, public utilities, traffic and transportation, and of repairable buildings and structures; Provision of temporary housing and adoption of measures to assist the physical and psychological rehabilitation of disaster victims; Basic clearance of ruins caused by the disaster.

3. Reconstruction Phase I: During this phase, the affected areas are assisted in returning to their level of functioning prior to disaster impact. Long-term measures of reconstruction, including the replacement of buildings and infrastructure, which has been destroyed by the disaster, are also taken in this segment.

4. Reconstruction Phase II: Since the results of disaster are effectively reflected in future policies and the interest of regional or national progress, the following activities should be undertaken in this segment; Introducing improved and advanced building systems and programs; Applying experiences learned from the disaster to future research and development programs; Utilizing international assistance to optimum effect. A typical post-earthquake reconstruction model is of the first three phases, the duration of the latter phase is ten times more than the former.

Ang and Leon (1996) state that the economics of upgrading of existing structures, for earthquake protection is of fundamental concern and importance in engineering. A key decision in upgrading of existing structures, or rehabilitating damaged structures, through strengthening or retrofitting, for protection against future earthquakes is the specification of appropriate level of upgrading. As in the design of new structures, the level of upgrading may require a trade-off between the cost of upgrading and the desired level of protection against potential future losses caused by earthquakes. This involves the consideration of the expected damage costs from future earthquakes, besides the cost of upgrading. The decision problem, therefore, may be formulated on the basis of minimizing the expected life-cycle cost as a function of the underlying risk (probability of damage or collapse) or reliability. The essence of the approach, therefore, is based on the minimization of the life-cycle cost as a function of structural reliability against earthquake damage. For completeness, the life-cycle cost must include the potential damage cost from all possible earthquakes that may occur in the future. As the cost of upgrading, as well as the potential damage cost, will depend on the intensity of the earthquake ground motion and the times of occurrence of future earthquakes which are unpredictable, the expected life-cycle cost function may be formulated for specific future earthquakes intensities. In the formulation of the cost functions, the different cost items may be classified into three categories as follows: the cost of upgrading; repair cost and other damage losses; cost of finishing. Cost items of the first category are directly functions of the underlying risk or reliability, whereas those of the second category depend on the level of damage and, therefore, are indirectly functions of risk. Cost items of the third category are constants and therefore will not influence the determination of the optimal risk. The cost of upgrading will naturally increase with the level of upgrading and, therefore, with the reliability of the upgraded structure relative to that of the original (unstrengthened) structure. Damage cost function: the cost associated with a structural damage or collapse must include the cost of repair as well as all the consequent losses caused by the damage; the latter would include the loss of contents, subsequent economic loss, and in the case of severe damage and collapse the cost of injury and life loss.

After a strong earthquake, how to restore normal life and work is an important problem. Thus, rapid repair of damaged structures is valuable. Bolong and Zhoudao (1996) state that during a strong earthquake, in general about 15 per cent of buildings may collapse and the other 85 per cent have damage that can be repaired. If people can repair all the damaged buildings within 1 or 2 days, it is a significant contribution to the mitigation of disaster.

Bolton (1996) indicates that large earthquakes in urban areas can bring about considerable disruption to the built environment (buildings and lifelines), to the economy of the area, and to the physical and psychological well being of the population. The extent of the damage is related to many seismic, geophysical, engineering and social elements. Social factors play an important role since human decisions about where to build, what to build and how to build set the stage for disasters. He proposes four important goals for reconstruction planning as given below;

- to achieve rapid recovery of homes, businesses and urban lifelines;
- to retain the familiar character of the city;
- to provide enhanced livability and urban amenity;
- to have a city with reduced vulnerability to future earthquake.

In a major disaster, all aspects of recovery often need to be addressed, including business and industry recovery, lifeline recovery and housing recovery. Whatever the extent of losses in commerce and lifelines, when the residential building stock sustains considerable damage and destruction, attention to housing recovery is likely to become a central concern. The goals for good housing recovery are fairly parallel to those for city reconstruction in general. The damaged city's residents will want their newly repaired or replaced housing to meet the following criteria:

- be quickly available to them;
- be socially habitable, that is, be consistent in type and location with their social and cultural identity, and permit them to maintain prior social interaction patterns;
- be sustainable to them, in terms of costs to live in it and maintain in a habitable condition;
- be safer in future earthquakes.

Business preparedness, mitigation, and recovery programs must start at the grass roots level and are needed in every community. Responsible public and private leaders understand that, if businesses do not survive a disaster, the community will not survive. Furthermore, disasters not only affect one community, but can also have far-reaching economic effects. In fact, large-scale disasters can result in economic disruptions on a global scale. If businesses do not survive a disaster, people are out of work, a community's revenue stream is severely disrupted, and the impact prolongs the recovery process. Businesses are the lifeblood of the community. When businesses fail, a community loses both its people and the tax base that a community needs to provide lifeline services. Loss of small businesses as well as major employers can have an effect on the economy of the community. It is essential that every business protect its survivability with Internal Contingency Planning (Carrido, 2000).

Evaluating earthquake mitigation is a complex and difficult undertaking which is influenced by several variables (FEMA, 1998). First, earthquakes affect all segments of the communities they strike, including individuals, businesses, and public services such as fire, police, utilities and schools. Second, while some of the direct and indirect costs of disaster damages are measurable, some of the costs are non-financial and difficult to quantify in dollars. Third, many of the impacts of such events produce "ripple-effects" throughout the community, thus increasing the variables to be considered. Mitigation is typically less expensive to implement when included in the planning and construction stage rather than after a building has been constructed. Mitigating the potential for earthquake damages in existing structures is generally more costly, but when carried out effectively before a disaster, prevents loss of life or reduces damages, and also avoids the outlay of associated costs for response and recovery operations. The design and construction of seismic-resistant structures are perhaps the most cost-effective mitigation measure. The adoption and enforcement of earthquakes building codes, for example, will ensure that structures are resistant to the effects of earthquakes. However, it is important to note that such codes generally apply only to new or substantially improved structures, and this does not guarantee the rehabilitation of most existing hazardous structures.

Literature review has shown that researchers have developed models for the purpose of measuring direct and indirect economic losses because of earthquakes. Life Cycle Cost models have been developed for the economic evaluation of infrastructure, bridges and buildings which are damaged due to earthquakes. As far as current literature is concerned, there is no model developed to evaluate the economic aspects of a town, which experiences earthquake. This has led this study to estimate earthquake loss for a town in seismic zone using life cycle cost model.

CHAPTER 2

PLANNING AND ECONOMIC ASPECTS OF A TOWN

2.1. Introduction

A Town plan is a statement of the objectives, policies and programs that a community has chosen to guide its future growth and land use. The core of a town plan is land use. Towns may adopt four planning regulations by-laws; a zoning ordinance, subdivision regulations, an official map and a capital budget and program. A map and inventory define current and prospective land uses. Zoning involves the organization of the community into districts of specific permitted uses, such as agricultural, residential, industrial, commercial, education etc. Along with land use, zoning regulations establish guidelines for lot size, density (people per hectare), signs, parking and landscaping. Zoning began as an urban regulatory tool to manage growth and provide healthy living conditions, including light and air. Today, zoning is one of the more effective methods available to a municipality for the control of land use. Effective zoning regulations can identify areas of future growth while providing protection of existing rural areas ("Rural", 2000).

FEMA (1998) indicates that the process of establishing and implementing state and community comprehensive development and land use plans provides significant opportunities to mitigate damages caused by earthquakes. Land use planning is generally most effective in areas that have not been developed, or where there has been minimal investment in capital improvements. Since location is a key factor in determining the risks associated with earthquakes, land use plans are a valuable tool. They can designate low-risk uses for areas and/or most vulnerable regions to earthquake impacts. A community also can influence the location and density of development through its capital improvement plans, which determine where the community places critical infrastructure needed for development, such as roads, water supply, and wastewater treatment. Low-density development will sustain far less monetary damages than a densely developed area, which would likely occur if full infrastructure had been provided. Planning for low-density development therefore reduces the opportunity for sustained damages.

2.2. Principals of Town Planning

Local governments routinely use zoning, subdivision and building codes to regulate the type and density of development, including standards for building design, streets, parking, and landscaping. These regulations are supported by policies in comprehensive plans. However, land development is occurring in ways that do not achieve growth-management objectives (TGM, 2001):

- Low-density and dispersed development that discourages future infill development is occurring in urbanizable areas without adequate urban services.
- Fringe area residential development is occurring at densities below those planned.
- Infill and redevelopment is not occurring in most urban areas.
- Mixed-use, higher-density development that encourages travel by non-auto modes is not being built.

TGM (2001) also questions the priority of infrastructure or development. On one hand, land that is well served by transportation, public utilities, schools, police, fire and parks attracts development. On the other hand, a lot of development occurs on land with low levels of urban services. Public facility planning is not new to local governments. Statewide planning requires local jurisdictions to plan and develop public facilities and urban services to support planned growth. Local governments also consider urban service issues in planning for economic development, urban growth, transportation and recreation.

Town planning targets the development, improvement and management of the town environment. However, it depends on;

- Physical, economic, social and political forces which shape cities and regions,
- Financial, environmental, legal, cultural and historical aspects of urban development processes,
- Design and conservation of the built environment,
- Quality of the natural environment.

Governments and municipalities regulate town planning. There are several factors, which affect the establishment of a town. Density is one of the factors in the formation of a town and directly related with the wealth of that town. Therefore, important point is to determine the most fitting density, which provides the best living conditions. In the area with high density the buildings will be high. However, this does not mean that we can construct buildings at any height we require. Physical environment (topography, direction of wind, rain), socio-economic structure, historical and religious environment, aesthetical factors will affect the height of buildings. Usually density is low on the area of high wealth and high on the area of low wealth. Another factor to form a town is population that will be accommodated in that town. It defines the type, capacity and quality of facilities to serve economic, administrative, cultural, technical needs of that town (Göçer, 1990).

In Turkey, land requirements of facilities for a town development respecting to population to be accommodated, are stated in the Municipal and Regional Act of 3194. Table 2.1 gives the land requirements of social and technical facilities as square meter per person in relation with the population considered in planning.

Although an emphasis on vulnerable buildings is important, it is also important for local government officials and related professionals to look beyond individual buildings to consider the entire built environment - the block, the neighborhood, and the community as a whole; the streets, parks, and other infrastructure that connect them; and other elements that unify and define this complex system. All the physical components and systems of a community are impacted to some degree by the forces of extreme natural events and therefore have an important role to play individually and as a part of the larger whole. How these components and systems are planned and developed can make a significant difference in a community's overall capacity to resist these forces (Geis, 1996).

Table 2.1 Land Requirements of Social and Technical Facilities, m^2/person

Facilities	Population			
	0-15.000	15.000-45.000	45.000-100.000	100.000-+
Nursery	1	1	1	1
Primary School	4	4	4,5	4,5
Secondary School	3	3	3	3
Recreation Area	10	10	10	10
Health Services	2	2	3	4
Cultural Services	0,5	1	2	2,5
Social Services	0,5	0,5	1	1,5
Public Education Center	0,4	0,4	0,4	0,4
Religious Services	0,5	0,5	0,5	0,5
Administrative Services	3	3,5	4	5
Infrastructure (Roads&carpark not included)	1	2	3	4

Part of the long-term solution is for localities to implement disaster-resistant community design. Disaster-resistant community design includes code solutions but moves well beyond them to encompass site and neighborhood design approaches that take into account the more complex interaction of earthquakes with the built environment. Common examples of design practices fostering effective mitigation in earthquake-prone areas include (Petterson, 1999):

- Limiting development densities and/or requiring large lot sizes;
- Transferring allowable densities to safer areas on- or off-site;
- Setting buildings back from flood, landslide, and fault seismic zones;
- Requiring adequate minimum paved street widths;
- Limiting street grades to assure fire truck access;
- Requiring second access points into each development in case primary access is blocked during an emergency;
- Restricting the lengths of cul-de-sacs as well as the number of dwelling units on them;
- Developing adequate water supply, maintaining adequate flow to fight fires, and providing redundant storage; and
- Using open space easements for firebreaks, equipment staging, and evacuation areas.

Unfortunately, until now there has been no separate regulations for town development on seismic-prone regions. The experience of Kobe should encourage the creation of more areas of open spaces within the city, where people can assemble, as well as redundant networks and pathways for public services, infrastructure, and massive campaigns of public information and training (Bibbee et al, 2000).

The high density of population and expensive infrastructure of cities makes them more susceptible to the impacts of natural events. Mitigation measures are both more critically needed and more amenable to economic justification than in less-developed areas. For small towns and villages non-structural mitigation measures may be only affordable alternative. The physical characteristics of the land, land-use patterns, susceptibility to earthquakes, income level and cultural characteristics similarly condition the options of an area in dealing with earthquakes ("Primer on Natural", 2000).

As stated by Baocai (1996) the layout of a city may be improved after a strong earthquake. Enterprises, which cause pollution, use a large amount of water and energy or need major transportation should be outside the urban area and separated from residential or commercial zones. Industry may be relocated on the basis of advantageous resources, and a better development plan formulated.

Land use planning for sustainability requires consideration of a wide spectrum of factors including transportation, development density, energy efficiency, natural corridors and open space, and growth management (EREN, 2000). Land-use planning is the means for gathering and analyzing information about the suitability for development of land exposed to earthquakes, so that the limitations of seismic-prone areas are understood by citizens, potential investors, and government officials. Burby (2000) states that local governments are slowly coming to realize that land-use planning is an important tool for reducing losses in earthquakes.

Yaoxian (1996) considers three possible choices for land-use planning in post-earthquake reconstruction. Rebuilding at the original place which should be given the first priority; partially rebuilding at the original place , partially moving to a close neighboring place; renouncing the original place and moving to a new place which is more expensive and difficult solution. It can be adopted under the following conditions: damage to buildings and structures from ground motion, willingness of inhabitants to relocate, difficulty of measures to mitigate future distress and finally, economic feasibility.

As far as zoning is concerned, in the 1995 report, California Seismic Safety Commission, after experiencing several earthquakes recommends that: zoning regulations can require special review procedures or development standards to reflect the seismic hazards in specific areas of a community; zoning can be used to provide incentives such as development bonuses to encourage risk mitigation in buildings vulnerable to earthquakes; areas with seismic or geological hazards, such as unstable slopes or liquefaction potential, can be zoned to allow only low-density uses, such as agriculture, open space, or very-low density residential development (Mader, 1997).

In areas where earthquakes are likely, knowing where to build and how to build can help reduce injury, loss of life and property damage during an earthquake.

Knowing what to do when an earthquake strikes can also help prevent injuries and deaths.

2.3. Economic Value of a Town

One of the enduring questions of economics is "Where do profits come from?". The philosophers and others now known as the classical political economists started by investigating two central economic questions: what causes an economy to grow; and what determines the distribution of income into its three forms of wages, rent and profit. Profit is certainly a factor in economic growth. Economic growth requires investment. Profit is both the goal of most investment activity and a major source of investment funds. And, since profit is itself one of the three forms of income, we cannot go very far in an investigation of either the distribution of income or economic growth without a grasp of the sources of profit (Taylor, 1996).

Depending on where it is located, a town may have a variety of sources for living. Agriculture, mining, manufacturing, trade, construction and tourism are some of the sources that provide revenue for that town.

Tourism makes a major contribution to the national economy of towns. As stated by Romaya and Alden (1994) in many countries tourism is one of the main growth industries, reflecting increasing personnel incomes, leisure time and mobility. Tourism growth has also been seen as the panacea to solving urban and rural planning problems, especially in terms of economic activity and new job formation. Damage to roads, utilities, airports, harbors, and shopping centers affect the industry.

Formulating strategies to enhance cities' prospects for economic growth in the global market place is a relatively new challenge, but one increasingly imposed on urban government. Yet, despite the significant economic roles played by cities, they often receive less than they might warrant for their contribution to the national economy, negatively influencing their productive potential. Key constraints on urban productivity include infrastructure deficiencies, inappropriate regulatory frameworks for urban land and housing markets, weak municipal institutions, and inadequate financial services for urban development. The cumulative effects of such constraints reduce the productivity of the urban economy, and, therefore, its contribution to macroeconomic performance.

Infrastructure deficiencies can seriously constrain the productivity of private investment. In many cities of the developing world, inadequate energy and water supply, traffic congestion, and problems in telecommunications negatively affect the growth of production activities. Inadequate collection and disposal of vast quantities of solid waste and the deterioration of air, water, and land have further negative consequences on the quality of life and the efficiency of the economy. Nearly all public infrastructure services constitute indispensable intermediate inputs to economic activity. If such services are unavailable or substandard, private enterprise is forced to provide these itself, increasing total investment requirements, while constraining productivity, profits, incomes, employment, at the same time as raising prices. The failure to maintain infrastructure has reached crisis proportions in many cities, especially in developing countries, and maintenance has become a priority for development.

Improving the productivity of the urban economy - and its contribution to macroeconomic performance - will require action at national and city levels to reduce the constraints, as well as sustained policy reform and increased efforts to strengthen urban institutions. It involves a shift in the role of central governments from direct providers of urban services and infrastructure to becoming ‘enablers’: helping create a regulatory and financial environment in which private enterprise, households, and community groups can play an increasing role in meeting their own needs. It will also require decentralization of responsibility and authority for urban finance and management of infrastructure to local levels, while providing adequate safeguards to ensure accountability. This is often a complex and politically difficult process, requiring the establishment of a productive and sustainable balance between local and central levels of government.

Building liveable cities requires broad-based growth of employment, incomes, and investment. Promoting urban equity and social safety nets needs to be consistent with incentive systems those foster productive and competitive firms of all sizes. Local economic development strategies that promote diverse rather than dualistic growth, and which serve domestic as well as international markets, should be further explored in many countries. The city product per capita is generally higher than the national product. The city product is the 'gross national product' of the city, an estimate of city-level economic output. It is an important indicator of urban productivity providing a strong measure of the level of economic development of the city with regard to the national level, and informing about the level of investment, the efficiency of public and private enterprises and the generation of productive employment (UNCHS, 2001).

As stated by Vermeiren et al (2000) insufficient attention is paid to the manner in which governments, private sector investors and communities handle the threat of earthquakes to their development. Failure of infrastructure and other public and private facilities can disrupt economic development and divert resources for new development to the repair or rehabilitation of what was damaged.

Beside the indirect social and economic impacts on a given region or sector, disasters can affect employment, the balance of trade, foreign indebtedness, and competition for scarce development investment funds. It has even been said that the effect of earthquakes in seismic-prone developing countries tends to cancel out real growth in the countries" ("Primer on Natural", 2000).

2.4. Actual Situation in Turkey and Adapazarı Regarding Town Planning Criteria

Urban residential land development is an important planning matter. In developing countries, it becomes more important owing to rapid urbanization. Turkey is one of the countries with the most rapid process of urbanization in the world. There is a great migration into the cities from rural areas and the urban population is increasing rapidly. As a result, these metropolitan cities encounter serious problems such as the need for shelter and hence urban residential land. Unbalanced and unplanned urban growth is probably the greatest obstacle to sustainable development in Turkey and increases the rate of unemployment and underemployment in major cities.

Organization for Economic Co-operation and Development, OECD, (Bibbee et al, 2000) reports that Turkey has actually coped with urban growth through migration by tolerating the illegal construction of housing, often on publicly-owned land, thereby encouraging the large construction sector to supply housing at lower cost by eliminating the need to purchase and improve land. The illegal settlements were not exclusively for the poor, as is often the case in some developing countries; even middle class people have had to compromise on the quality of construction, infrastructure and public services.

National economy could not manage to provide employment, technical and social facilities such as housing, transportation, communications, sewerage, public health, educational and cultural services needed. Unfortunately, policies of urbanization, migration, housing, urban land as squatter settlements have failed in meeting the requirements of sustainable urban development.

The recent earthquakes in Turkey struck the country's industrial heartland with high per capita incomes and where population growth had been managed through the construction of multi-storey housing, which had replaced with traditional buildings. Adapazarı was one of the hardest hit areas in the earthquake of 17 August 1999. The earthquake indicated poor land use planning due to the ignorance of geological and geotechnical properties of the region. Large-scale urbanization has been permitted on loose and soft soils, which may have amplified human toll of the disaster.

CHAPTER 3

EARTHQUAKE EFFECTS

3.1. Introduction

An earthquake is a shaking of the ground caused by the sudden breaking and shifting of large sections of the earth's rocky outer shell. Earthquakes are among the most powerful events on earth, and their results can be terrifying. Earthquakes may produce ground shaking, surface faulting and vertical movements that cause direct damage to buildings and other structures and also may trigger ground failures such as landslides, differential compaction of soil and liquefaction of water-saturated deposits like landfills, sandy soils and river deposits. Such ground failures may cause more damage to structures than the shaking itself.

The main concern in this study is neither to discuss how and why earthquakes occur nor to discuss the measurement of earthquakes. However, as far as the cost of damages caused by an earthquake is concerned, the size of that earthquake becomes important to assess the rate of damage. Therefore, this chapter briefly describes the earthquake parameters, which cause damages and also earthquake losses

3.2. Earthquake-Effective Parameters

Magnitude

Magnitude is the amount of energy released from the earthquake. It is not possible to measure the energy release directly, so it must be computed from measurements of the amplitude of the ground vibrations. The most common method of describing the size of an earthquake is the Richter magnitude scale, which can only be used when seismographs are within 600 km of the earthquake. ("Seismology",2000).

Intensity

Intensity is the amount of shaking and type of damage at a particular location. Intensity can be greater or weaker depending on the distance from the epicenter. The effects of earthquake waves at the surface can be measured using an intensity scale. The most common intensity scale used is the 12-point Modified Mercalli Scale. On this scale, intensities up to 5 are felt but cause no damage, while intensities from 6 to 12 cause, increasing amounts of damage. Maximum intensity normally occurs near the earthquake epicenter, with intensity values then decreasing with distance. An earthquake has a single magnitude, but its intensity varies with distance. On the Modified Mercalli intensity scale, values range from I to XII. The most commonly used adaptation covers the range of intensities from the conditions of "I - not felt except by very few, favorably situated," to "XII - damage total, lines of sight disturbed, objects thrown into the air" (see Table 3.1). As it is mentioned above while an earthquake has only one magnitude, it can have many intensities, which decrease with distance from the epicenter ("Seismology", 2000).

Table 3.1 Modified Mercalli Intensity Scale

Magnitude	Intensity	Damage
2	I	Not felt. Recorded by seismographs.
2	II	Rarely felt, usually only on top floors of high buildings.
2	III	Felt indoors, like a passing light truck.
4	IV	Windows, dishes, doors rattle. Like passing train.
4,5	V	Felt by all. Small objects upset.
5,1	VI	Books off shelves. Trees shake. Isolated damage.
5,6	VII	Difficult to stand. Many poor buildings damaged.
6,2	VIII	Significant damage. Branches broken from trees.
6,6	IX	General panic. Serious damage. Ground cracking.
7,3	X	Most buildings destroyed. Rails bent slightly.
7,8	XI	Rails bent greatly. Pipelines destroyed.
8,4	XII	Near total damage. Objects thrown into the air.

Ground Shaking

The magnitude of an earthquake, distance to the earthquake focus, type of faulting, depth, and type of material are important factors in determining the amount of ground shaking that might be produced at a particular site. The magnitude of an earthquake influences ground shaking in several ways. Large earthquakes usually produce ground motions with large amplitudes and long durations. In addition, large earthquakes produce strong shaking over much larger areas than do smaller earthquakes. The distance of a site from an earthquake affects the amplitude of ground shaking. In general, the amplitude of ground motion decreases with increasing distance from the focus of an earthquake. The frequency content of the shaking also changes with distance. Close to the epicenter, both high (rapid) and low (slow)-frequency motions are present. Farther away, low-frequency motions are dominant, a natural consequence of wave attenuation in rock. The frequency of ground motion is an important factor in determining the severity of damage to structures and which structures are affected (Noson et al, 1988). Ground shaking is a direct hazard to any structure located near the earthquake's center.

Ground Failures

Major property damage, death and injury have resulted from ground failures triggered by earthquakes. There are three other features of earthquakes that can cause permanent ground displacements and have adverse effect upon structures, roadways, pipelines etc. (Noson et al, 1988).

Fault Rupture: It can reach the surface of the earth as a narrow zone of ground offsets. The area of a fault that ruptures in a particular earthquake correlates with the magnitude of the earthquake. Typical fault rupture dimensions are as follows. The consequences of major fault rupture at the surface can be extreme. Buildings may be torn apart, gas lines severed, and roads made impassable. Damage by faults is more localized than the widespread damage caused by ground shaking. Nevertheless, the identification of active surface faults is an important part of estimating future earthquake losses.

Liquefaction: This sudden loss of strength and stiffness in soils can occur when loose, water-saturated soils are shaken strongly and can cause settlement and horizontal movement of the ground. In areas with soft, wet soils, a process called liquefaction may intensify earthquake damage. Liquefaction occurs when strong ground shaking causes wet soils to behave temporarily like liquids rather than solids.

Land Sliding: This refers to large downhill movements of soil or rock that are shaken free from hillsides or mountainsides and that can destroy anything in their path. Earthquake shaking of saturated soil creates particularly dangerous conditions. Although landslides are highly localized, they can be particularly hazardous due to their frequency of occurrence.

Structural Failure of Buildings

A building's structure may be damaged if its vibratory response to ground motion exceeds design limits. The response depends on the interaction between structural elements of the building and the direction, frequency, and duration of ground motion. These factors must be considered to produce a building design that prevents structural failure during earthquakes. In the absence of proper design, a building is exposed to greater risk of earthquake damage, particularly if the building has been subjected to prior strong earthquakes (Noson et al, 1988).

Importance of type of construction to building damage: Usually, buildings can better withstand the vertical component of the earthquake-induced ground motion because they are designed to resist the large loads generated by their own weight. Many are, however, vulnerable to large horizontal motions. Resistance to horizontal motion accomplished by using lateral bracing and strong connections to hold structural elements together. Horizontal elements like floors and beams can then distribute the building's weight to the building's strong vertical elements. Construction that provides a continuous path to transfer the lateral load from roof to foundation is more resistant to ground shaking than construction in which that path can be easily broken. For example, a well-nailed wooden frame house resists ground shaking better than an un-reinforced brick house because, once the brick cracks, the path along which the lateral load is transferred is broken. Proper ties between the foundation and the structure and between the various elements of the structure are essential for good earthquake resistance. Buildings or other structures that are poorly attached or unattached to their foundations may shift off the foundation during an earthquake (Noson et al, 1988).

Importance of frequency of ground shaking to building damage: Building damage commonly depends on the frequency of ground motion. Damage can be particularly severe if the frequency of ground motion matches the natural vibration frequencies of the structure. In this case, the shaking response of the structure is enhanced, and the phenomenon is called resonance. Tall buildings, bridges and other large structures respond most to low-frequency ground shaking and small structures respond most to high frequency shaking (Noson et al, 1988).

Importance of building shape to damage: The shape of a building can influence the severity of damage during earthquakes. Buildings that are L or U shaped in plan view may sustain more damage than a symmetrical building. This damage occurs because large stresses develop at the intersection between the building's segments, which respond differently to ground vibrations of different frequencies and different directions of motion. A building with sections that differ in height or width may develop large stresses at certain points because each section will be in tendency to vibrate at its own natural frequency in response to ground shaking. Separate buildings that vibrate at different frequencies can damage each other if they are built close together (Noson et al, 1988).

Importance of past earthquakes to building damage: The history of a building and its exposure to prior earthquakes are also important in estimating the amount of damage it may sustain in future earthquakes. People often assume that a building that has survived an earthquake with no visible damage will likely not be damaged in subsequent earthquakes. However, ground shaking can weaken a building by damaging load-carrying elements internally. Failure to detect and strengthen concealed damage can lead to complete destruction in a subsequent earthquake (Noson et al, 1988).

Importance of building remodeling to damage: A building also may be weakened by structural alterations since its initial construction. For example, doors or other openings may have been cut through bearing walls, thereby increasing the risk of damage in future earthquakes (Noson et al, 1988).

Non-structural damages

The non-structural elements of a building include parapets, architectural decorations, chimneys, partition walls, ceiling panels, windows, light fixtures, and building contents. Displacement or distortion of these elements during ground shaking can be a major hazard to building occupants and result in extensive building damage. Damage to the non-structural elements of a building can include the destruction of costly equipment, such as computer systems, and the loss or extensive disorganization of important company records. Displacement of non-structural elements occurs when they are unattached or poorly attached to the surrounding structure. Distortion of the non-structural elements occurs when the building flexes, putting extreme stress on rigid items like windows, panels, and built-in furniture. Economic loss during an earthquake is not confined to damaged building elements, equipment, and products. Loss of important company records, including inventory and customer lists, sales records, information about suppliers, and accounting, can contribute to disastrous interruption costs (Noson et al, 1988). Earthquakes cause damages to contents in buildings. The buildings like hospitals and communication buildings are strongly needed after an earthquake and special care should be given to the equipment in these buildings. Therefore, in these buildings not only the damage of the equipment but also the movement of the equipment should be avoided.

Damaged Lifelines

Lifelines include the utilities (power, water, gas), communication networks, and transportation systems that crisscross and link our communities. Damage to these lifelines by earthquakes can create dangerous situations. Broken gas and power lines are serious threats to safety, largely because of risk of fire. Cracked water mains reduce the amount of water available for fire suppression. Lack of communication isolates people from help and needed information. Blocked or damaged transportation routes interfere with the ability of emergency personnel to respond promptly to request for assistance (Noson et al, 1988).

3.3. Earthquake Damages

Earthquakes can damage buildings and infrastructure causing direct and indirect losses. It, depending on its severity, can have a negative effect on all aspects of society. Federal Emergency Management Agency (FEMA, 1985) classifies losses due to earthquake damage, as direct physical damage, economic loss and social loss.

Nanning and Xiaoyun (1996) make a distinction between damage and loss. Damage is defined as the physical impact of an earthquake on a facility, while loss is a measure of the amount of money necessary to repair the damage to a facility. Therefore, direct physical damage is a monetary value loss, which occurs as a result of damage to a given building or structure and includes damage to structural and non-structural components and damage to contents. Economic loss includes the monetary value of the direct physical damage loss and also the industrial production and commercial loss in the effected region. Social losses involve physical-health, political, societal and psychological implications. Deaths and injuries are regarded as the most important social impact of earthquakes (FEMA, 1985).

The direct losses, borne by the property owner and partially offset by insurance payments, can be approximated by the cost of repair and reconstruction. The indirect losses arise as a consequence of disruption of production and services and spread through the entire economy. Indirect losses are difficult to estimate and can easily exceed direct losses (CDMP, 1999a). A study of infrastructure that failed due to earthquakes finds that 1) better design and construction could have largely eliminated damage, 2) these changes would have added 5 to 10 percent to the original project cost, 3) this added up first cost would have been a small fraction of the cost of reconstruction (CDMP, 1999b).

The three primary determinants of earthquake damage are the level of ground shaking, local soil quality, and the ability of the individual building to withstand damage, as described in the previous section. In Kobe earthquake of 1995, most of the serious damage to larger commercial and industrial buildings and infrastructure occurred in areas of soft soil and reclaimed land. The worst industrial damage occurred at or near the waterfront because of severe ground failures liquefaction, lateral spreading and settlement (EQE, 1995). Turkey is accustomed to earthquakes and the facilities were damaged, in recent earthquakes, by fault rupture and strong ground shaking. With respect to buildings it become clear that residential and commercial buildings constructed of un-reinforced masonry or inadequately reinforced concrete were unable to resist lateral forces of ground shaking without collapsing. In addition buildings and structures sited, designed and constructed without adequate consideration of the proximity to the fault were vulnerable to the intense near-field ground shaking or to surface fault rupture, and buildings sited on poor soil were susceptible to enhanced ground shaking from soil amplification. Old and new parts of the infrastructure that had not been constructed in accordance with lifeline standard were highly susceptible to ground shaking and the permanent ground failure caused by surface faulting and liquefaction (Hays et al, 1999).

The degree of damage at a given facility and the degree of damage to lifelines are defined by Rojahn and Sharpe (1985) as primary factors that affect loss of function and restoration time. Special factors affecting the loss of function or usability of a facility are;

1. Direct damage to the facility (structural/non-structural),
2. Equipment damage at the facility (contents),
3. Damage to service lifelines at the facility,
4. Personnel loss,
5. Damage to remote lifelines serving the facility,
6. Interruption of raw material supplies, replacement parts and services to the facility.

Subsequent restoration of function for a facility is dependent on;

1. Degree of damage,
2. Importance of the facility in post-earthquake recovery,
3. The availability of manpower and resources (construction material and equipment) for restoration or reconstruction.
4. The availability of supplies, replacement parts and services.

3.4. Earthquake Loss in Urban Texture

Earthquakes cause damages to housing, public facilities and infrastructures because of siting a town on weak soils or close or on the fault line, inadequate structural system and also poor construction materials. The level of damage that results from a major earthquake depends on how well a building has been designed and constructed. Earthquake damage of buildings can be classified as collapsed, destroyed, seriously damaged, moderately damaged, slightly damaged or no damage.

Many factors determine the ability of a facility to withstand the effects of earthquakes. Decisions made throughout the life span of an infrastructure project or a building from design and construction through ongoing maintenance affect the resilience and, consequently, the life span of these investments. Therefore, it is clear that incorporation of earthquake and vulnerability information into the earliest stages of project design or reconstruction is essential to ensure both earthquake resilience and the lowest costs over the life of the project. The best protection against earthquakes is to select project locations that are not earthquake prone. It is not always possible, however, to avoid siting facilities in vulnerable areas. The effects of most earthquakes can be avoided or mitigated by applying design principles appropriate to the prevailing earthquakes. It is essential that the existence and magnitude of any earthquake that may affect the project must be established during the preliminary design phase. The factors to be taken into account include: siting of the facility to avoid earthquakes, design and shape of the buildings and structural system to minimize effects of high winds and earthquake forces and also construction materials that are corrosion resistant and of appropriate durability and strength (Vermeiren et al, 2000).

A strong earthquake causes loss and destruction to a larger extent. Baocai (1996) indicates that earthquake relief is the basis for minimizing loss, restoring production and normal life and for reconstruction. Restoration and reconstruction are the culmination of disaster relief. Restoration and reconstruction work are linked to earthquake magnitude and the damage conditions.

Comerio et al (1996) state that the post-disaster period should be seen as consisting of two distinct phases: response and relief, and recovery and rebuilding.

The response and relief phase includes the activities of providing immediate shelter, food and medical care to victims. The recovery and rebuilding phase includes the activities of funneling appropriate funds and financing to those whose property has been destroyed or damaged, including local infrastructure. They further state that the best way to reduce the cost of post-disaster rebuilding, particularly post-earthquake re-building, is through mitigation. The ultimate benefit of a proper mitigation programme will be improved life-safety and significantly reduced rebuilding costs.

Retrofitting and reconstruction are the choices to be made upgrading a damaged facility. The magnitude of the earthquake and the resistance of the facility against the earthquake determine the rate of the damage which guides the decision makers either retrofitting or reconstructing the damaged facility.

3.4.1. Retrofitting

There are many terms, which are used for post-disaster upgrading of damaged structures. In this study, the term, Retrofitting is preferred and defined as improving the structural qualities to move a better grade.

Denning (1993) points out that a growing trend in seismic retrofitting is a special design to ensure the survival not only of people but of the structure as well. Two types of structures; infrastructure and structures challenge to retrofit to ensure the survival of both people and structure. He further states that the size and complexity of the infrastructure make its retrofitting more difficult than those of structures. Celik (1998) states that retrofitting an existing building to desirable earthquake resistance standards is very costly and technically difficult. In new construction, the earthquake resistant precautions cost no more than 10 to 20 per cent of the total cost of construction.

The improvement of structures to resist earthquake damages and thereby avoid most of the deaths and financial losses must have the prime importance. It is demonstrated in EQE summary report of Kobe earthquake (EQE, 1995) that it usually costs less to prepare for earthquakes in advance than to repair the damage afterwards. In the event of a severe earthquake the focus of the first one-two days is exclusively on emergency response and relief such as controlling fires, rescuing victims, providing medical assistance, food and shelter for displaced victims. These activities are largely in the domain of the local government and civil organizations.

Recent earthquakes have demonstrated that the failure of transportation systems can have a significant economic impact. Their functionality is critical in the emergency response period immediately after an earthquake and during the recovery period following the event. Thus, insuring the proper operation and functionality of transportation systems when subjected to large earthquakes has become of great importance (Audigier and Kiremidjian, 2000).

The California Earthquake Loss Plan which incorporates lessons learned from the Loma Prieta, CA (1989), Northridge, CA (1994) and Kobe, Japan (1995) earthquakes, emphasizes the importance of upgrading existing vulnerable structures, better design of new construction, and increased preparedness in all areas as the most cost-effective methods of reducing loss and improving recovery from earthquakes (“California”, 1998).

When planning for disaster recovery there are two fundamental hurdle to overcome (“Getting”, 2001). First is to realize that large variety of possible disasters can actually be reduced to a manageable number. Second is in accepting the fact that “business-as-usual" will be suspended at the time of the disaster. There will be two time periods, which must be planned for following a disaster. First will be the immediate, disorganized, “limited-operation” time span, which will then be followed by a period of “makeshift-operations”, which can be quite lengthy until normal operations can be resumed. The limited-operations time span can extend for up to a week or more, while the makeshift operations time span can last for several months until normal operations are restored. The objective of the planning of recovery process is to systematically sort out the various issues and priorities so that a cost-effective plan can be developed which is in perspective to the level of loss exposure which the organization is risking.

3.4.2. Reconstruction

Reconstruction following an earthquake is a complicated problem with social, economical and technological aspects. Those that use reconstruction seem to stress almost exclusively the post impact rebuilding of the physical structures destroyed or damaged in a disaster (Quarantelli, 1999).

Earthquake-resistant constructions are examples of measures that can increase the capacity of facilities to withstand the impact of an earthquake. Measures such as zoning ordinances, insurance, and tax incentives lead to impact avoidance.

While the recovery will take some time, as reconstruction gets underway, the rebuilding efforts give people many different hopes for the future. Residential and other facilities and infrastructure are expected to be safer and improved during the reconstruction process. New measures of code enforcement and insurance are also expected to be introduced for rebuilt properties. Private investment is needed to encourage economic activity so that employment and incomes can recover.

The World Bank project appraisal points out that reconstruction “in situ”, replacing a damaged or destroyed building by a new one, would be more costly than construction of an equivalent number of houses on a green –field site (Bibbee et al, 2000). However, earthquake damaged cities almost always rebuild themselves on the same sites rather than relocate safer territory (Mileti and Passerini, 1996). Although relocation of whole cities is unusual, decisions are made to relocate damaged buildings and infrastructure in less earthquake-prone areas of the city

With regard to new construction (Novick, 1990) in heavily urbanized area, studies are carried out likely to show that the cost of new facilities will be very high compared with benefits, and that funds are not available. With regard to reconstruction, studies may also show that reconstruction in place, although disruptive to rail or highway operations, can be a successful solution when very carefully planned by engineers who are knowledgeable in rail/highway operations as well as design and construction.

Reconstruction can take months, if not years. It also requires that individuals receive the means to begin recovering, in the form of financial assistance and/or payouts from insurance. Costs of earthquakes may be borne by individuals, insurance companies, re-insurers, private businesses, and government (“Primer on Natural”, 2000).

3.5. Earthquake Loss in Economy

Earthquakes cause economic losses due to business interruption of industrial and commercial enterprises by earthquake damage.

Nigg (1996) states that one of the major problems in anticipating the magnitude of economic losses that can be caused by a destructive earthquake is understanding the various complex ways in which the economic sector-including both large and small businesses- can be effected. If businesses must close due to structural damage, inventory losses, losses of employees, or losses of markets, the economic strain on families whose members were employed by those enterprises will be high. Also, when businesses that provide basic goods and services to community residents are not operational, the greater the temporal constraint—the length of time it takes household members to complete routine daily tasks—on family recovery. Beyond these obvious implications for household recovery, community recovery can be effected by business disruption in two important ways. First, the longer commercial enterprises are non-operational, the greater the impact on revenues for the local government. Local governments receive a great deal of their operational income by collecting fees and taxes on commercial transactions or from property taxes. Following a disaster, a community's revenues from these sources may drop dramatically, until property owners can repair commercial buildings and businesses can recover sufficiently to put employees back to work, providing goods and services. If the business sector does not sufficiently recover, community-based services (public works maintenance, social and health services, schools, cultural and recreational programs, and planned economic development initiatives) will be cut back, delayed or eliminated. Second, some businesses serve the needs of particular neighborhoods and rely on local residents to use their establishments. When such businesses can not recover from a disaster, what consequences does this have for the neighborhood or the community that business serves? Some research has suggested that the character of the community may actually be changed if people have to leave their neighborhoods to market, shop, bank and use recreational facilities, or if their children have to go to schools at a greater distance from their homes.

As stated by Yaoxian (1996), it is necessary to idendify priorities for recovery of economic sectors because financial resources are limited. After a damaging earthquake, rehabilitation and reconstruction of the infrastructure, such as water supply, power supply and communication should have top priority. Secondly, more attention should be paid to job generation and housing construction. At the same time, attention should be paid to recovery of the most effective industrial sectors.

According to Kircher et al (1997) economic and social losses are primarily a function of damage to buildings because of two reasons; Buildings are the predominant kind of facility in the Built Environment and they are vulnerable to earthquake damage. Buildings meet a variety of needs of society; providing shelter for people, whether at home or at work, housing commercial and industrial operations and serving as essential facilites such as schools and hospitals. They describe building loss functions as a part of earthquake loss estimation methodology (FEMA/NIBS). Ground shaking and ground failure are required to estimate the building damage by the methodology. Estimate of building damage is used as an input of other damage modules such as lifelines. Most importantly, estimate of building damage is used to as an input to a number of loss modules; casualties, economic losses, shelter needs emergency facilities as the time required to restore functionality. In the methodology direct dollar loss is defined as either capital-related or income-related. Capital-related losses for buildings include costs for repair and replacement of damage to the structural system, nonstructural components and building contents (including business inventory for commercial facilities). Income-related losses for a building include rental income loss, relocation expenses, and other losses directly caused by damage to the building. Direct economic losses depend on building occupancy class such as single- family residences, and also depend on building type such as light-frame wood. Damage state is classified as slight, moderate, extensive and complete.

King et al (1997) developed a methodology to evaluate the socio-economic impacts of large earthquakes. The methodology depends on GIS (Geographic Information System) and Benefit-Cost Analysis. Seismic Hazard characteristics (ground motion, liquefaction, landslides), and Building and Lifeline inventory are integrated in GIS to evaluate regional damage as direct loss, indirect loss and casualties. Evaluation of critical facilities and regional damage results in the estimation of direct economic loss, casualties and loss of function. Benefit-Cost analysis in the socio-economic consequence modeling is used for seismic rehabilitation of structures.

The direct and indirect business interruption losses will most likely outweigh repair costs, particularly with respect to the consequences of the transportation and other lifeline failures. The overall economic impact and long-term effects of a disaster will be influenced to a large extent by the speed with which physical infrastructure can be repaired and business activity resumed (EQE, 1995). Economic loss during an earthquake is not confined to damaged building elements, equipment, and products. Loss of important company records, including inventory and customer lists, sales records, information about suppliers, and accounting, can contribute to disastrous business interruption costs.

3.6. Earthquake Loss in Social Environment

Earthquake damages affect the enterprise sector by disrupting the labour supply due to deaths, injuries and also de-motivation. A rapid response to earthquake damages will reduce loss of life, complications from injuries and secondary damage and loss, and will expedite relief to victims.

Social loss is a function of damage to structures. Community recovery following a disaster consists of three interdependent components - social, economic and physical. A major impact on any one component in the system will have dramatic effects on the other two. For community recovery to be effective, plans must include contingencies for all three elements. From the standpoint of the people suffering from earthquake, the period of reconstruction and general community recovery can never be considered satisfactorily short enough. People want to return to normal conditions as quick as possible. They seldom want to relocate, even after experiencing the worst impacts of disaster. The social relationships and conditions that exist before any disaster will be carried forward into the relief and recovery periods. Those individuals without financial resources will find it even more difficult to meet daily needs. Those with compound problems – the poor elderly, poor singleparent families, poor families with disabled members – will not only find it difficult to find temporary assistance, but the organizational and social relationships that made it possible to function in normal times may be absent for an extended period after the earthquake (McLean, 1995).

On the macro level, there is a great deal of evidence showing that communities are not changed, in the long run, by disasters. Social stratification, economic viability, political motivation and structural features, all tend to return to pre-disaster conditions. Change sometimes occurs in the short term – but it is rarely lasting. Many people, after a disaster, hope the disaster can help accelerate hopes and plans for change. There is an assumption that a "window of opportunity" exists in the aftermath of a disaster in which change may be easier to effect than in ordinary times. The idea of a window of opportunity is an assumption that there is greater potential for solving social problems after a disaster than there was before the disaster (Passerini, 2000).

In general, most studies do not show any evidence of long-term psychological effects (Drabek, 1986), and physical infrastructure is usually rebuilt without much change from the original. Disaster communities rarely relocate. Earthquake-damaged cities almost always rebuild themselves on the same sites rather than relocate to safer territory (Mileti and Passerini, 1996). Decisions are sometimes made to relocate damaged buildings and infrastructure in less disaster-prone areas of the city.

3.7. Earthquakes in Turkey

Turkey is located on a highly active Eurasian Geological Plate, which has caused numerous big scale earthquakes throughout the history. The earliest earthquake records date back to 411 B.C. Turkey ranks high among the countries, which have suffered significant losses of life and property due to earthquakes. Majority of these earthquakes has happened due to relative movements of Eurasian Plate, African Plate and Arabian Plate, which is still in progress. The Arabian/African and Eurasian plates move north and south towards each other. As a result, Turkey is being squeezed out westwards ("Seismicity ", 2001). Figure 3.1 shows active faults and seismic zones in Turkey.

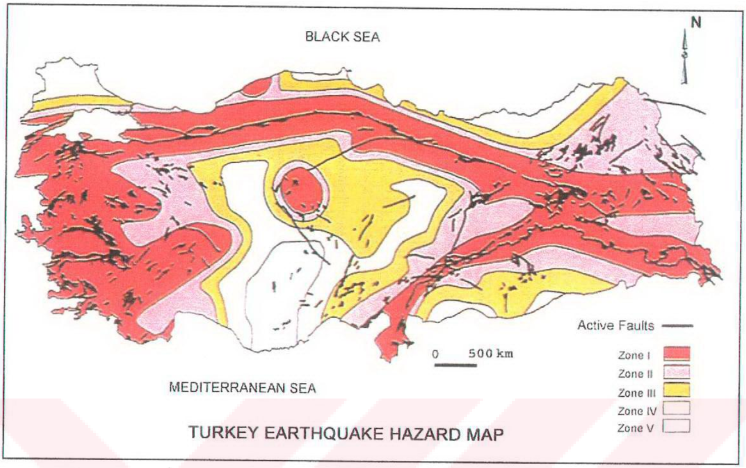


Figure 3.1 Active Faults and Seismic Zones in Turkey

Turkey has a surface area of 780.360 square kilometer and is essentially a country of mountains and high plateaus, having a population of approximately 65 million. As a result of orogenic system, geology, topography and climate, Turkey is exposed to various natural disasters causing substantial losses of life and property. There have been 129 earthquakes during the period of 1900 and 1999, including the two newest earthquakes in western Turkey (Celep and Kumbasar, 2000). As presented in Figure 3.2 the highest number of earthquakes occurred in the Eastern Anatolia Region. There have been about 20 major destructive earthquakes during this period with magnitudes 7.0 or greater in Turkey (Figure 3.3). Most destructive earthquakes occurred in the Aegean Region. Collectively, they have killed more than 80,000 people, injured and impaired another 150,000 and destroyed about 420,000 homes and buildings (Figure 3.4). Most of the damages and deaths because of earthquakes also occurred in the Eastern Anatolia Region.

A magnitude of 7,4 earthquake of 1999 is the largest to occur in Turkey since the magnitude 7,9 earthquake that struck near Erzincan in 1939. The earthquake struck the most populous and one of the most rapidly growing industrialized regions in the country. The result of the earthquake revealed several defects in urban planning and construction techniques, which amplified the material and human toll of the disaster. Surface fault opening, ground shaking and soil-liquefaction caused structural damage that was dramatically exacerbated by poor construction quality. A primary cause of the destruction in Adapazarı results from shallow foundations built over liquefiable soil.

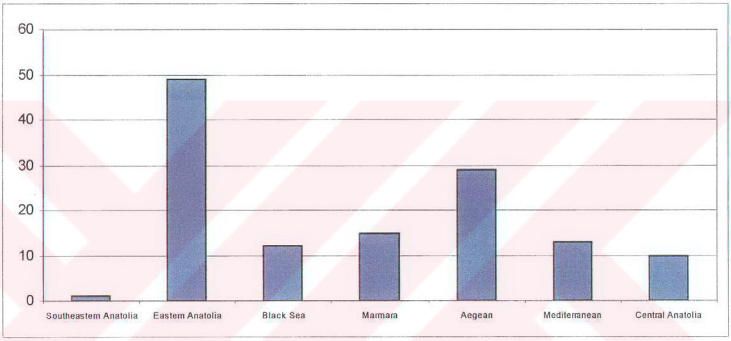


Figure 3.2 Number of Earthquakes According to Regions in Turkey

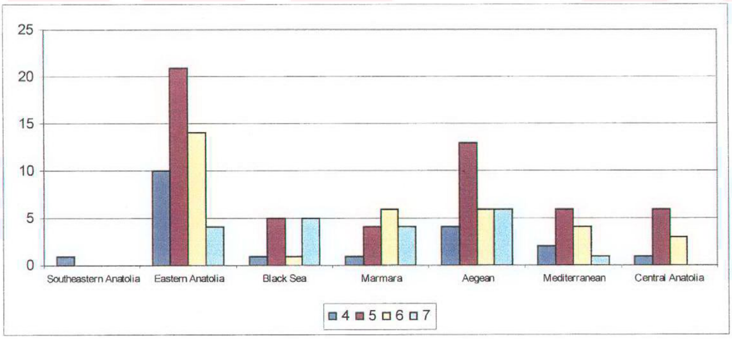


Figure 3.3 Number of Earthquakes According to Magnitudes

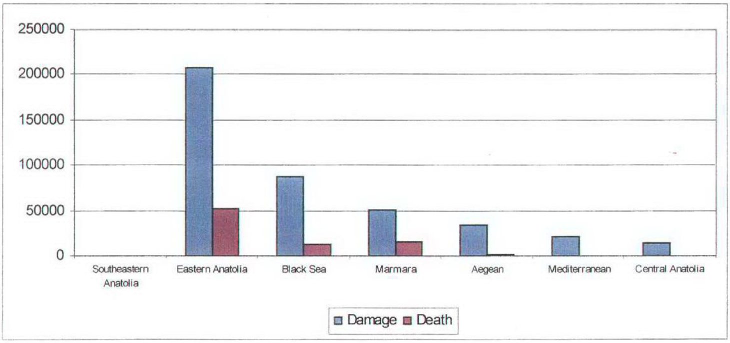


Figure 3.4 Number of Damages and Deaths in Earthquakes

The aim of this study is to estimate earthquake loss for a town in seismic zone using life cycle cost model. Earthquake-effective parameters and hence damages of earthquakes are discussed in this chapter to be able to develop a model which reflects the probable earthquake damages and their corresponding costs. The magnitude of the earthquake, soil conditions, resistance of the structures against earthquakes and land use planning are important parameters to determine the magnitude of the damages.

Earthquakes result in direct and indirect losses, which affect the economy of a town. Damages to structures are considered as direct losses and their cost to the town is included in the model as physical damage cost. The model also covers the recovery of the damaged structures and the recovery cost. Moreover, economic loss caused by business interruption as a result of physical damage, loss of labour and de-motivation is included in the model.

CHAPTER 4

LIFE CYCLE COST MODEL

4.1. Introduction

It has long been recognized that to evaluate the costs of assets (buildings, machinery, equipment etc.) on the basis of their initial costs alone is unsatisfactory. Some consideration must also be given to the cost-in-use that will be necessary during the lifetime of the building. Life Cycle Costing is a technique that has a potential for the economic evaluation of construction works. It should be noted that the concept of life cycle costing is not new. The technique used is based upon sound economic principles which have been used in investment appraisal in many areas of industrial and commercial activity (Ashworth, 1992). Further, the life cycle concept recognizes that the life cycle of a facility have environmental and economical impacts. Government, business and non-governmental organizations during the decision-making processes concerning environment, product policy, design and improvement can apply the concept.

This research work is carried out to estimate earthquake loss for a town in seismic zone by using life cycle cost model. Therefore, this chapter introduces a LCC model, which is developed in this study to estimate earthquake loss. As presented in Figure 4.1 earthquake loss is expressed as the difference between the future worth of a town in case of having no earthquake and its future worth in case of having earthquakes. The evaluation of the sensitivity of cost-effective parameters for earthquake loss using the LCC model is also discussed in this chapter.

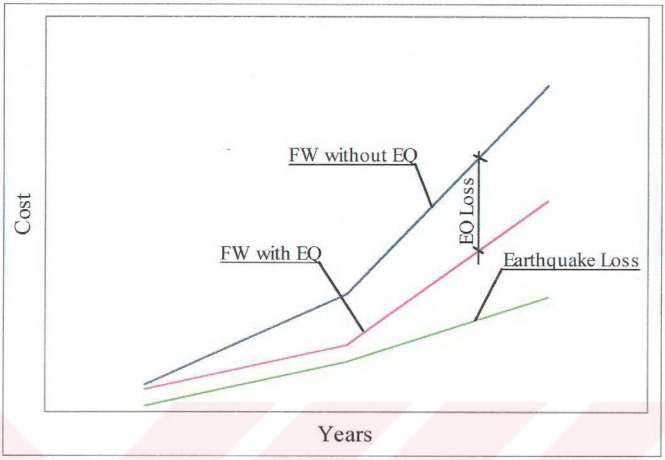


Figure 4.1 Earthquake Loss

4.2. General Structure of the Model

A Life Cycle Cost (LCC) model has been developed in this study to analyze the earthquake effects on the cost of a town under earthquake risk assuming that it is an asset in national economics' point of view with its revenues and expenditures. The model includes all the costs and benefits which are probable to occur during the life span of the town. The costs can be considered as planned and unplanned as described by Chang and Shinozuka (1996). Planned costs include expenditures related to construction and maintenance and unplanned costs are related to damage inflicted by earthquakes. Traditional life cycle cost is limited to planned cost. The benefits are also considered as planned economic value of a town and necessity for the survival of the town. Life cycle cost model includes planned costs and benefits without concerning an earthquake occurrence. Unplanned costs are introduced to model as disaster and recovery costs in the case of an earthquake occurrence. Figure 4.2 shows the main components of life cycle cost model. Total life cycle cost combines all the planned and unplanned costs as explained below.

$$TLCC = PB - (PC + UC)$$

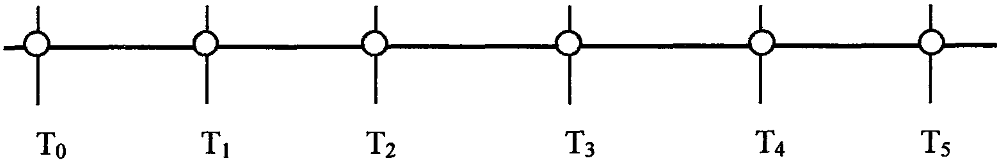
where; TLCC = Total Life Cycle Cost

PB = Planned Benefits (Economic Value)

PC = Planned Costs (Initial Construction and Annual Expenditures)

UC = Unplanned Costs (Earthquake Damage Cost including Disaster and Recovery Costs)

In an economic analysis, the selection of appropriate analysis period and an interest rate is important. In this model, analysis period for a town is assumed to be 50 years. However, the model enables the use of an analysis period, which is less than 50 years. But, the model can be used for an analysis period of more than 50 years, with a small modification. This period is divided into five stages and it is possible to use different interest rates at each stage. Ang and Leon (1996) state that the life cycle cost must include the possible damage cost from all possible earthquakes that may occur in the future. Therefore, the model in this study is constructed to cover the damages of two possible earthquakes during the analysis period. In Turkey, it is observed that there is approximately 30 years period of time between two major earthquakes. A time of 50 years satisfactorily covers this period with sufficient beginning and final time lengths. To analyze the effects of these potential earthquakes on the total cost, the model enables the user to change T_1, T_2, T_3 and T_4 values as shown below.



T_0 = Present time

T_1 = First earthquake point

T_2 = End of first recovery period.

T_3 = Second earthquake point.

T_4 = End of the second recovery period.

T_5 = End of analysis period (50 years in this study).

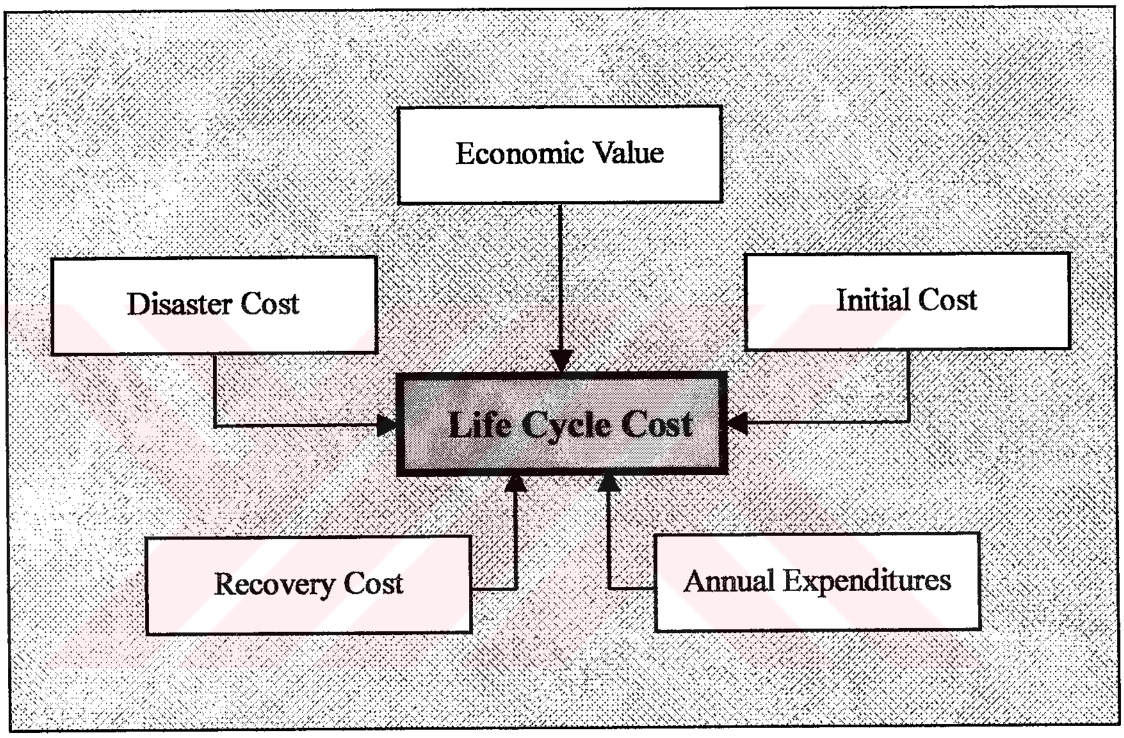


Figure 4.2 Elements of Life Cycle Cost Model

4.3. Assessment of the Model

In the previous section the elements of the life cycle cost model were introduced. Details of each element are explained in the following sections. An example of cost and benefit computations of a town is presented in Appendix A and numeric values required by the model are input arbitrarily just to show how the model works.

4.3.1. Initial Cost

A town is planned in order to accommodate certain population and to serve its growth and needs. A town is consisted of some technical and social facilities, which vary depending on the population accommodated. A master plan of the town is prepared by the town planning commission to specify the land uses of the facilities that are described in the Municipal and Regional Act of 3194. The facilities and their land requirements have already been explained in Chapter 2.

Warszawski et al (1996) describes the initial cost as the initial production or construction cost of a facility. However, in the initial cost of a town not only construction cost of the facilities but also costs of land on which the facilities are to be constructed have to be taken into account. In this study, the initial cost refers to both the land cost and construction cost of the facilities, which provide the needs of the inhabitants of a town. There are many parameters, which affect the initial cost of a facility, such as quality, size, resistance against earthquakes, soil conditions, and location. Leaving more open spaces (green area and roads) and more resistant structures increase the initial cost of a town. Warszawski et al (1996) states that "For economic reasons, a building is seldom designed to withstand 'any earthquake', rather to withstand one of the magnitude with a low probability to be exceeded".

Building importance factor is one of the important parameters in the structural design of buildings to be constructed in an earthquake-zone. This factor has a highest value for the buildings that must be used soon after the earthquake occurrence and also for the buildings those shelter a large number of people. High building importance factor means the construction of more earthquake-resistant buildings and affects the construction cost. Therefore, the unit construction costs of the buildings cover the effects of building importance factor.

In relation with the land uses of facilities described in Act of 3194, the model developed in this study investigates the initial cost of a town under 10 major facilities. As shown in Figure 4.3, these major facilities are classified as Residential, Infrastructure, Roads and Squares, Recreation, Education, Health Services, Commerce, Social Services, Industrial and Administrative. Each major facility is composed of sub-facilities which, are sorted concerning their unit construction cost.

In order to estimate the total initial cost of a town under investigation, the model requires, firstly, the population of that town. Then, the land area of each major facility is computed according to the land requirement per square meter per capita, given by the Act of 3194. The unit land cost is input the model and multiplied by the land area to determine the total land cost for the facility. After determining the total land cost the model calculates the construction area for the buildings which will be constructed. The construction area is determined by inputting the coefficient of ground floor area (TAKS) and the coefficient of gross floor area (KAKS) stated by the law of municipalities. The total land cost plus the total construction cost of sub-facilities provides the initial cost of that major facility. Finally, the model produces a total initial cost for the town by summing all the initial costs of the major facilities.

The land requirement for the facility of Residential is not specified in the ACT of 3194. According to Gocer (1990) land requirement for Residential ranges between 15-30 square meter per capita. The model accepts a land requirement of 30 square meter per capita as a default value. However, the model enables the alteration of this value. The residential area is divided into three density groups; low, medium and high as a reverse of income, i.e. high income people live in low density area (see Figure A.1 of Appendix A). Low density is usually settled on the outskirts of a town while high density is in town center. The buildings to be constructed in low density area are assumed to be single or double storeys. Those in medium density area are to be 3 to 5 storeys and over 5 storeys in high density area. The cost of land in high density area is supposed to be higher than that in low density. However, the cost of construction in high density area is usually less than that in low density. The model requires either total residential land area knowing the share of each density group within the total area or the land area of each density group, so that, total land cost can be computed as shown in Table A.1 of Appendix A. The construction area and the construction cost are computed in accordance with the KAKS and TAKS as explained above and then the initial cost for the facilities of residential is obtained.

Infrastructure consists the facilities of gas, water, communication, electricity, waste water, rain water and underground as presented in Figure A.2 of Appendix A. For these facilities there is no need for separate land area and corresponding land cost. Therefore, infrastructure is assessed only for construction cost, which is determined separately for each sub-facility and then summed to have the total construction cost. Table A.2 in Appendix A shows the construction costs which are added together to have an initial cost for Infrastructure.

In some researches Roads and Squares are accepted as a part of infrastructure. But, in the ACT of 3194, these facilities are considered separately. Therefore, in the model they are taken into account separately as well. As shown in Figure A.3 of Appendix A, Roads and Squares include sub-facilities of Open and Multi-storey Car Parks, Bridges & Overpasses, Avenues and Streets of Roads & Pavements, and Squares. The total land area requirement for Roads and Squares is computed for the major facility and then multiplied by the unit land cost to provide the total land cost. However, land area of each sub-facility is also needed to compute their construction area and corresponding construction cost. The initial cost of Roads and Squares is also obtained by summing the total land cost and construction cost (see Table A.3 in Appendix A).

Recreation comprises of Botanic Garden, Picnic Area and Parks & Gardens. As presented in Figure A.4 of Appendix A, a total land cost is determined for the major facility. The construction cost covers all the costs including construction cost of the buildings (if there is any), making green area, planting flowers etc. The initial cost of Recreation combines the total land and construction costs as given in Table A.4 of Appendix A.

Education includes the sub-facilities of nursery, elementary, high school and university as given in Figure A.5 of Appendix A. However, it is not necessary that each town is going to have all of these facilities. The user of the model has a chance of selecting any of them. Accepting that unit land costs of sub-facilities are equal to each other, the total land cost is determined for the major facility. Land area of each facility has to be known in order to determine construction area by using KAKS and TAKS methods. Each facility has a different unit construction cost, which is multiplied by the construction area to obtain total construction cost. Summation of total land and construction costs provides the initial cost for education services (see Table A.5 in Appendix A).

Health Services consists of hospitals and other health structures such as maternity hospitals, health houses and dispensaries (see Figure A.6 in Appendix A). The total land cost and the total construction cost are computed to provide an initial cost for Health Services as given in Table A.6 of Appendix A.

Commerce includes office, shopping district and malls as presented in Figure A.7 of Appendix A. The initial cost of Commerce is computed as the initial costs of previous facilities and shown in Table A.7 of Appendix A.

Social Services are mainly divided into three groups; cultural, sports and historical buildings as given in Figure A.8 of Appendix A. Cultural structures are considered as four groups according to their construction cost and each group provides the services below;

1. group- Fairs, District Libraries, Cultural Establishments,
2. group- City Libraries, Cultural Structures, Cinema,
3. group- Convention Centers, Museums, Exhibition Halls, Library Complexes,
4. group- Opera, Theatre, Concert Halls, Religious Buildings.

Structural buildings of sport facilities are consisted of simple sport establishments, stadium and sport centers and swimming pools. The calculation of the initial cost of Social Services is presented in Table A.8 of Appendix A.

Industrial includes the sub-facilities of small industrial establishments and industrial region structures as shown in Figure A.9 of Appendix A. Table A.9 in Appendix A shows the cost calculations for Industrial.

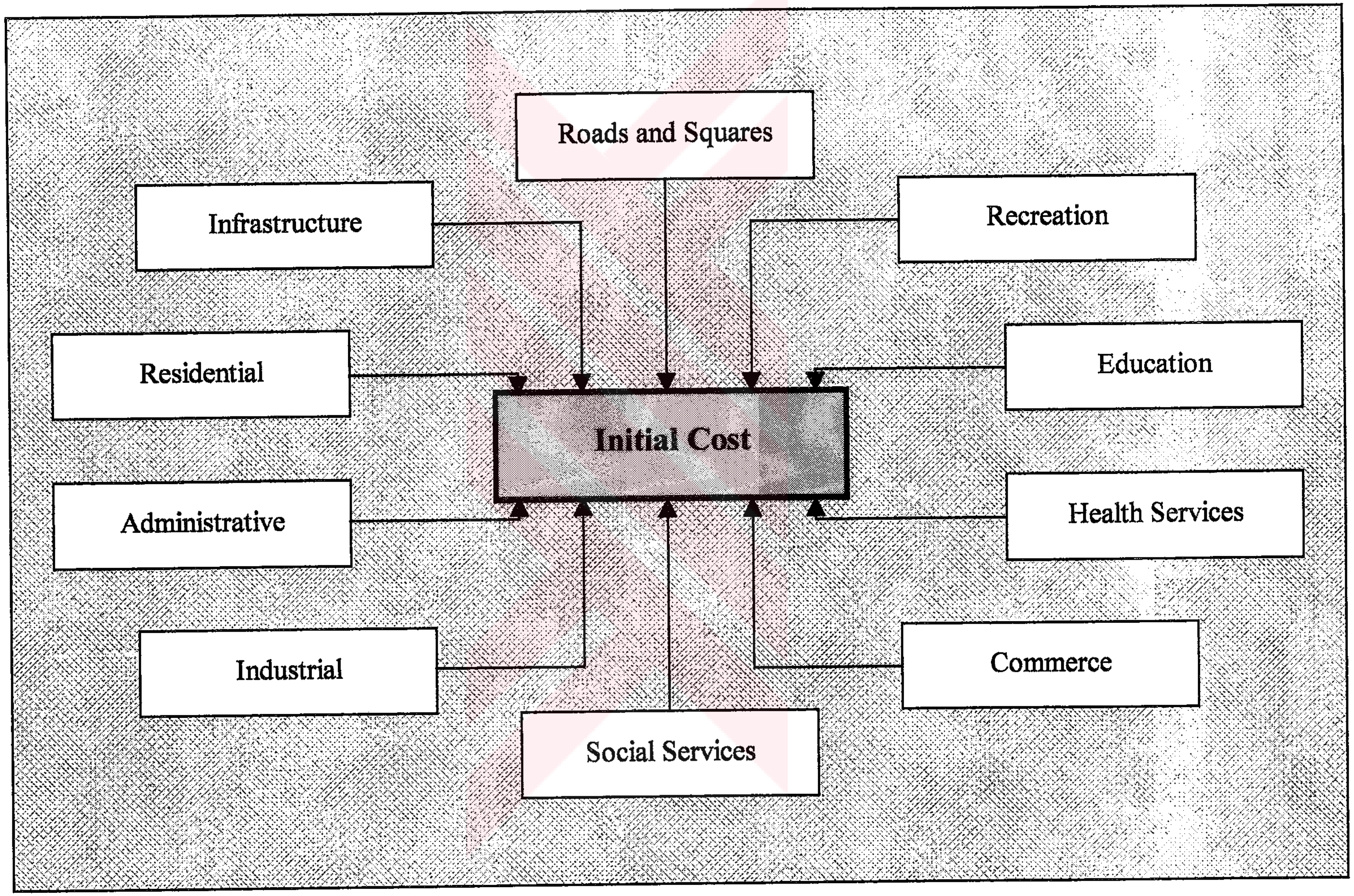


Figure 4.3 Total Initial Cost of a Town

Finally, Administrative Buildings are investigated at four groups as given in Figure A.10 of Appendix A. Table A.10 in Appendix A shows the initial cost calculation for Administrative.

1. group- Security Buildings, Normal Administrative Buildings,
2. group- Government Offices, Big Administrative Buildings,
3. group- Bank and Stock-Exchange Buildings, Central Post offices, Bus Terminals, Railway Station Buildings,
4. group- Buildings for Courts of Justice.

The summation of the initial costs of the major facilities provides an initial cost for the town under investigation.

4.3.2. Economic Value

Economic Value in the model refers to the revenues from different sources and enables the town to survive and grow throughout its economic life. Production, Commerce, Services and Tourism are considered as main sources to assess the economic value as shown in Figure 4.4. Each source is also evaluated in terms of revenue per person. However, the occurrence of an earthquake, depending on its magnitude and the resistance of the buildings, will cause an economic loss and this will directly affect the total economic value.

Production is consisted of Agriculture and Industry as shown in Figure A.11 of Appendix A. The number of persons working in each group and revenue per person are required to determine the total revenue of Production per year (see Table A.11 in Appendix A). Commerce comprises domestic trade and international trade as import and export as shown in Figure A.12 of Appendix A. The number of person in each trade and the revenue per person are required to find the total revenue of Commerce per year (see Table A.12 in Appendix A). Services include private and public services. Private services are grouped as education, health, hand-craft and technical services while public services are grouped as administrative, education and health as presented in Figure A.13 of Appendix A. The number of persons working in each group and their revenue will provide the total revenue of Services per year as shown in Table A.13 in Appendix A.

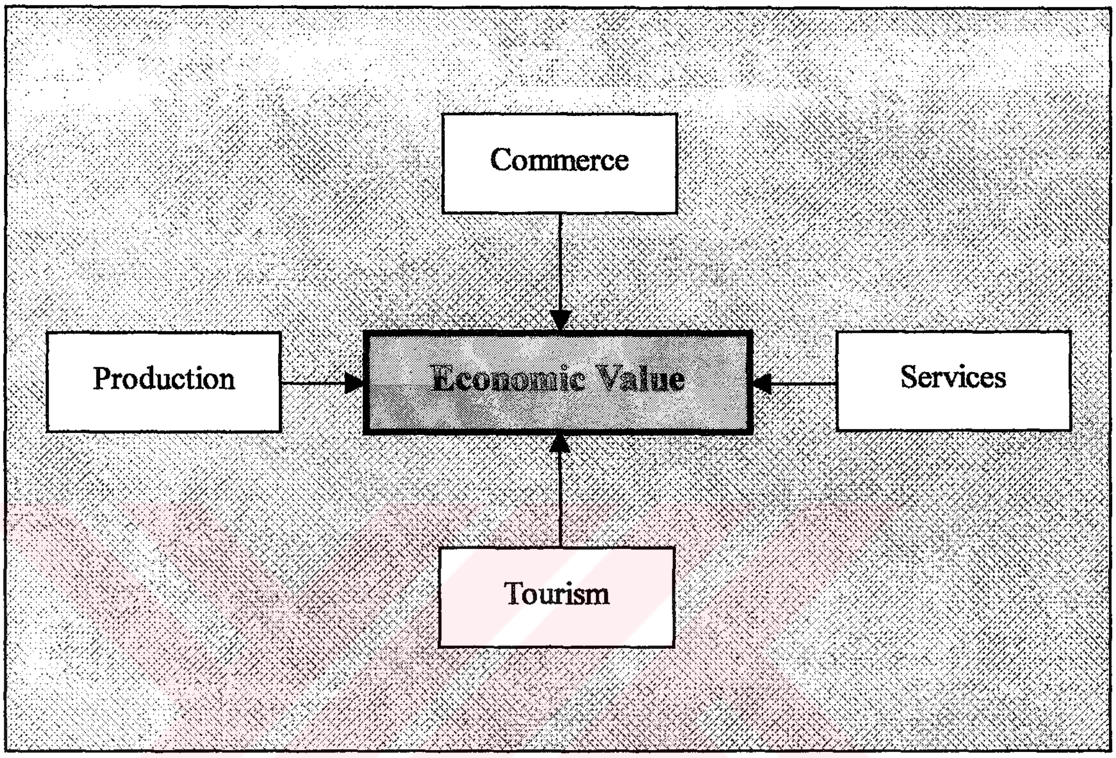


Figure 4.4 Total Economic Value of a Town

Tourism is one of the major sources to the national economy of towns as stated by Romaya and Alden (1994). In the model Tourism is consisted of native and foreign tourists as shown in Figure A.14 of Appendix A. The number of tourists visiting that town and revenue per tourist determine the total revenue from tourism sector per year (see Table A.14 in Appendix A).

4.3.3. Disaster Cost

Earthquakes produce direct and indirect losses in a society. Besides the physical damage loss, the regional economy is also affected by temporary business interruption and the loss of import/export capabilities. Depending on the size of the earthquake this cost can be heavy for a town and may exceed the budget. In the event of a major earthquake, the focus of the first 24-48 hours is exclusively on emergency response and relief: controlling fires, rescuing victims, providing medical assistance, and securing food and shelter for displaced victims. These activities are largely in the domain of the local government and civil organizations. Depending on what is damaged and what services are required, dozens of other federal agencies (departments of agriculture, education, health and human services, transportation) may also step in to provide funding and assistance. Disaster cost in the model refers to the costs caused by an earthquake such as emergency relief expenses, structural damage cost and business interruption cost. Therefore, Disaster cost is composed of supply, physical damage cost and economic loss as presented in Figure 4.5.

Supply includes Health &Temporary Hospitals, Emergency Aids (foods etc.) and Temporary Accommodation as shown in Figure A.15 of Appendix A and their cost consequences on the government's budget may be substantially high. The number of injured person and the cost, which is going to be spent per person in each group, are required to determine the total cost of supply (see Table A.15 in Appendix A).

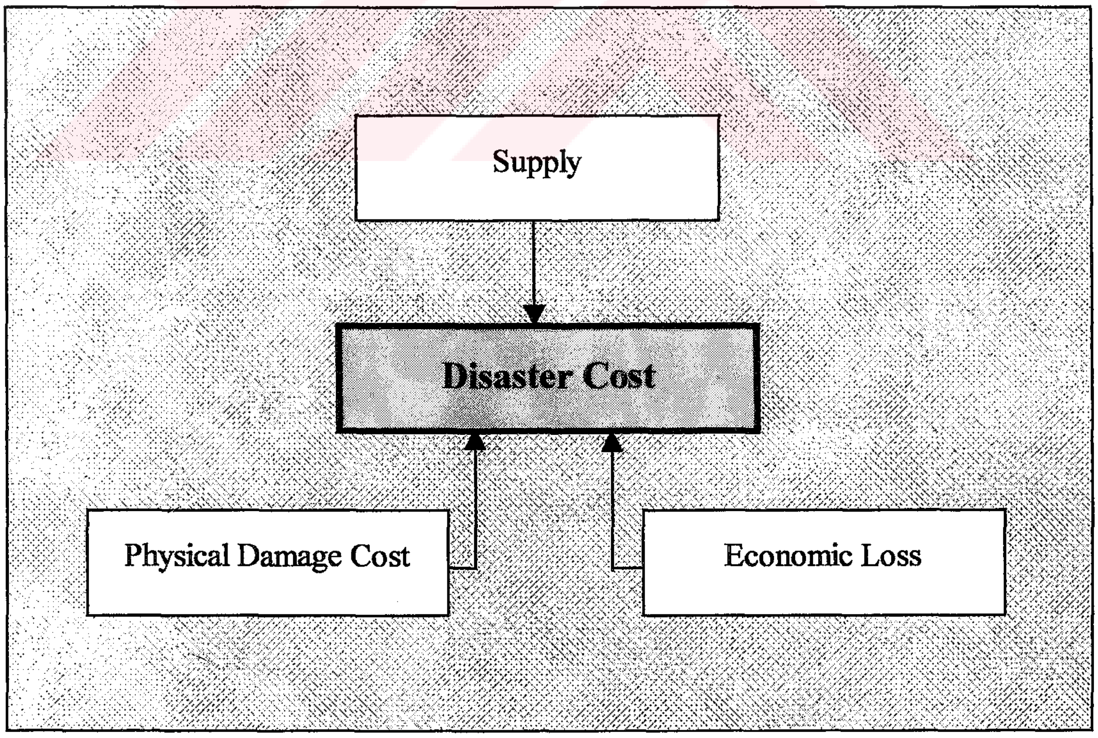


Figure 4.5 Total Disaster Cost of a Town

Since most of the serious damage to buildings and infrastructure occurs in areas of soft soils and reclaimed land, the magnitude and soil conditions will actually determine the physical damage cost. However, the resistance of the buildings against the severity of an earthquake is another consideration to measure the damage of the earthquake.

According to the Specification for Structures to be Built in Disaster Areas (1998) the general principle of earthquake resistant design in Turkey is;

- to prevent structural and non-structural elements of buildings from any damage in low-intensity earthquakes;
- to limit the damage in structural and non-structural elements to repairable levels in medium-intensity earthquakes,
- to prevent the overall or partial collapse of buildings in high-intensity earthquakes in order to avoid the loss of life.

The same Specification also emphasizes that no structure shall be erected on the land, which is un-permitted for structure by reason of earthquake and existing structures on that land shall not be repaired. Also, no structure shall be erected on a filled land if a period of 30 years is not over since it has been filled unless special ground improvement is fulfilled or a required foundation type is used. However, in many countries there is possibility of not complying with the building codes and regulations. The regulations may be strictly applied to new constructions but for existing structures there may be a need for strengthening against possible earthquakes.

Physical damage cost in the model is composed of ordinary, special and industrial structures, infrastructure and Roads and Squares as presented in Figure A.16 of Appendix A. Buildings are classified as lightly damaged, moderately damaged and heavily damaged. Depending on the rate of the damage, structures are either repaired, or retrofitted, or reconstructed. In this study, repairing means to bring the performance of the structures back to pre-damage level, while retrofitting refers to the improvement of the structural qualities to a better grade. In some cases the structures are damaged because of ground failures. In this case soil improvement is required before any other action is taken. The cost required for the recovery of the damaged structures can be determined using the physical damage cost as a guide. Table A.16 in Appendix A shows the determination of this cost. Physical damage cost gives us an idea about the recovery cost of the damaged facilities. The recovery cost can be more or less than the physical damage cost, depending on the method and/or level of recovery. Therefore, physical damage cost is presented in the model as a basis for the cost of the recovery.

The cost of economic loss is indirect cost of earthquake and caused by the disruption of business. A business is disrupted by the loss of labour force, destruction in enterprises, de-motivation of workers and destruction of infrastructure and roads and squares.

Tourism is an important source for national economy. A severe earthquake will actually affect the number of tourists. Since the reduction in the number of tourists affects the revenue of that town, lessening number of tourists is also involved in the economic loss as shown in Figure A.17 of Appendix A. The total cost of economic loss is determined by inputting the required parameters as shown in Table A.17 of Appendix A. The cost of economic loss is reflected in the model as a reduction from the economic value of the town. Carrido (2000) states if businesses do not survive a disaster, people are out of work, a community's revenue stream is severely disrupted and the impact prolongs the recovery process.

4.3.4. Recovery Cost

Structural and ground failures cause significant damage to structures. If a building is damaged by structural failure, that building is either reconstructed or repaired or retrofitted depending on the rate of the damage. Ground failures commonly appear to be associated with areas of filled land and occasional liquefaction in underlying alluvial deposits. If a structure is damaged by ground failure, liquefaction, it is likely to have more extensive damage. Repair of liquefaction-related damage is likely to require extensive foundation work that can be extremely expensive and may require demolition of the structure. Increasing the strength of soil through ground improvement can reduce the losses.

Considering all above, Recovery Cost in the model refers to the cost of reconstruction, repair and retrofitting of structures damaged by earthquakes and also ground improvement in the case of liquefaction-related damage. Recovery period is very important factor in order to resume the normal life. The severity of earthquakes, the resistance of buildings and soil conditions determine the amount of the recovery cost. As mentioned in the previous section the cost of physical damage gives an idea about the recovery cost but the actual cost will be known at the end of recovery period. As stated by Shinozuka et al (1997) recovery time and policy represent a major factor influencing economic loss. Denning (1993) states that retrofitting of infrastructure is more difficult than those of structures. Recovery of structures are investigated under five categories considering that each will have a different construction method and cost; Ordinary, Special and Industrial Structures, Infrastructure and Roads and Squares as presented in Figure 4.6. After the occurrence of a major earthquake, the recovery of damaged structures within reasonable time period (considering government's budget) is quite important to make the town live again. Ordinary, Special and Industrial structures are evaluated for retrofitting, repair, reconstruction and ground improvement as shown in Figures A.18, A.19 and A.20 of Appendix A. The model requires the number of damaged structures and their total area, the unit cost of retrofitting, repair, reconstruction and ground improvement to determine the recovery cost (see Tables A.18, A.19 and A.20 in appendix A). It is assumed in the model that infrastructure and Roads and Squares can only be reconstructed in the case of any damage and ground failure. The cost of soil improvement for Roads and Squares can be included in the reconstruction cost. Therefore, the damaged length of infrastructure and roads, the damaged areas of squares and unit construction cost for each are input the model to compute the recovery cost of infrastructure and Roads and Squares as presented in Figures A.21 and A.22 of Appendix A. Tables A.21 and A.22 show the calculation of the recovery costs for infrastructure and Roads and Squares.

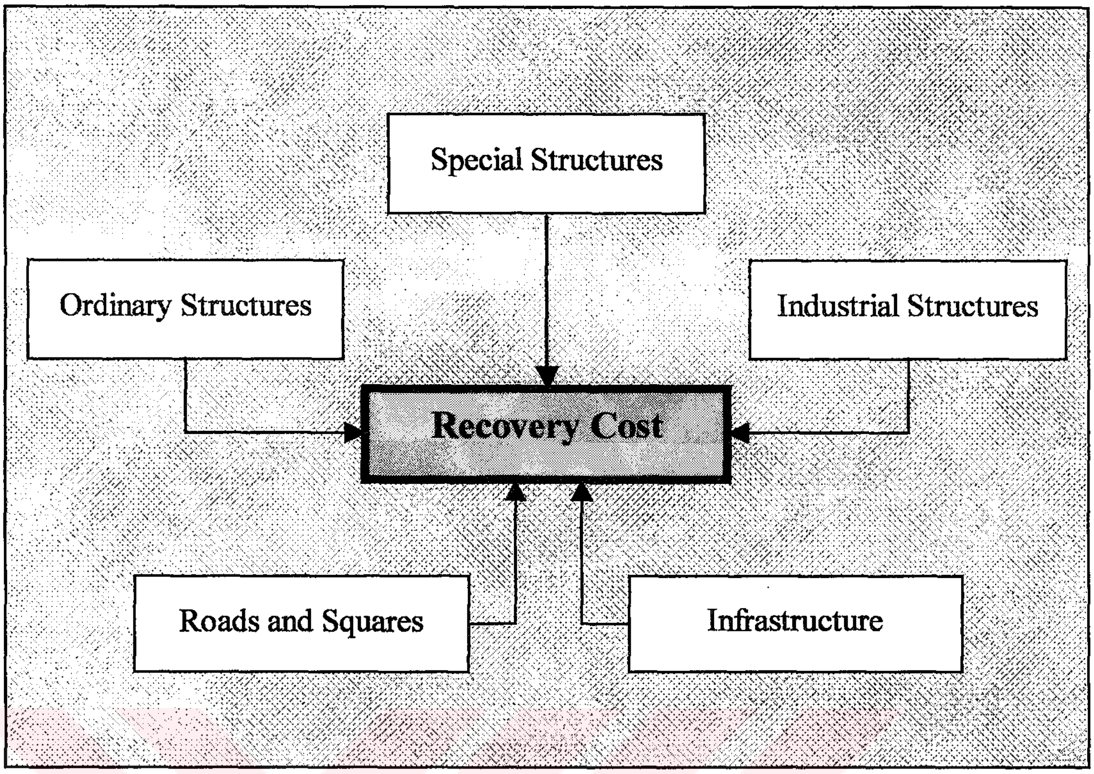


Figure 4.6 Total Recovery Cost of a Town

Yaoxian (1996) states two pressures faced immediately after a damaging earthquake. First, economic, social, psychological and political pressures foster rehabilitation and reconstruction as rapidly as possible. Second, recent bitter experience and the concern for significant reduction of future risk foster improving safety in post-earthquake reconstruction. Survivors hope to build and to repair buildings and structures to much better withstand future earthquakes.

The study carried out by Nigg (1996) indicates how vulnerable businesses are to economic disruption because of lifeline system failures. The tourism industry can be virtually destroyed and tourists may not return for many years.

4.3.5. Annual Expenditures

Annual expenditures in this model refer to the expenditures for the improvement and growth of a town. It consists of public and private investments and maintenance cost per year as presented in Figure 4.7. Public and private investments are essential for the growth of a town.

Maintenance costs are ordinary costs for upkeep of property and the restoration required when assets are damaged but not replaced. Items under maintenance include the costs of inspecting and locating trouble areas, replacement of minor parts, power, labor, materials and minor changes in or rearrangements of existing facilities for more efficient use. The maintenance cost in the model refers to all expenses of Municipality to maintain the town to upkeep its facilities. Maintenance cost consists of the facilities of Roads and Squares, Parks and Gardens, Garbage Disposal, Lighting, State Buildings and Infrastructure. Annual maintenance cost of each facility is input the model and sum together in order to determine the total maintenance cost. The total annual expenditures are the summation of the total maintenance cost and total amount spent for public and private investments as shown in Figure A.23 and Table A.23 in Appendix A.

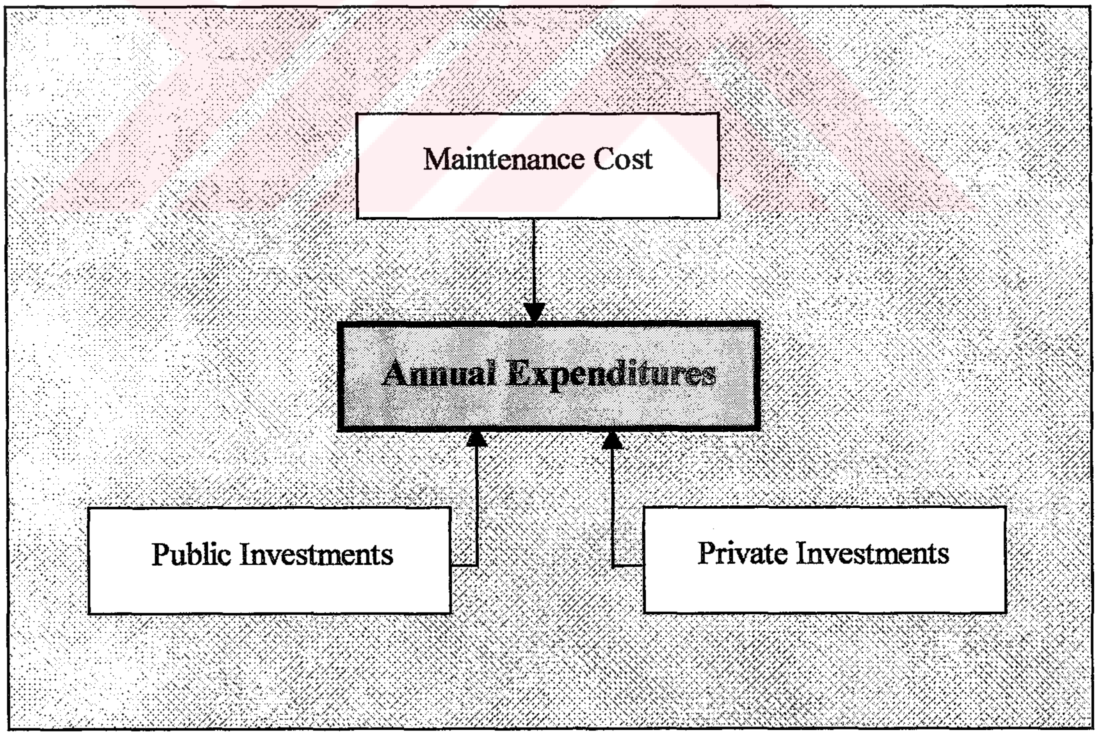


Figure 4.7 Annual Expenditures of a Town

As Arditi and Messiha (1996) state it is likely in a constructed facility that the cost of maintenance will not be uniform during the life of the facility, but will increase with age or show a variation consistent with the utilization of the facility. Therefore, the maintenance cost can be altered at any stage of the analysis period in the model developed in this study. Maintenance of important facilities, including institutional buildings, roads, waterways and bridge structures, is a critical component of a long-term hazard mitigation strategy (Vermeiren and Stichter, 2000).

4.3.6. Cash Flow Diagram

A cash flow diagram is a graphical representation of cash inflow (benefit or revenue) and cash outflow (cost or expenditure). The construction of a cash flow diagram makes the structure of a problem more clear. In LCC analysis, a cash flow diagram allow us to view all the costs and benefits of an asset over a specified analysis period. It is usually advantageous to first define the time frame over which cash flows occur. Therefore, the horizontal scale is divided into time periods mostly years. Then, costs and benefits are located by vertical lines on the time scale. Depending on whose viewpoint is portrayed a cash flow is positive or negative (positive above the axis, negative below). In this study as it is mentioned at the beginning of this Chapter a town has been considered an asset for national economy. Therefore, while the investments and its expenditures are plotted in negative signs its production and income in positive.

Figure 4.8 shows an example of cash flow diagram, which illustrates the cash flows structured in the life cycle cost model developed. In the diagram, an analysis period of 50 years is taken and is consisted of 5 stages as described before. In the example of the cash flow diagram the first earthquake point is accepted to be at year 10. Since the model covers two earthquakes within the analysis period, the occurrence of the second earthquake is presented at year 25 in the cash flow diagram. However, it is possible to alter the occurrence time of both earthquakes.

Initial cost as a negative cash flow (disbursement) is presented at zero time. Dashed lines before time zero in the cash flow diagram means that the construction of new developments in a town takes more than one year and their annual costs are

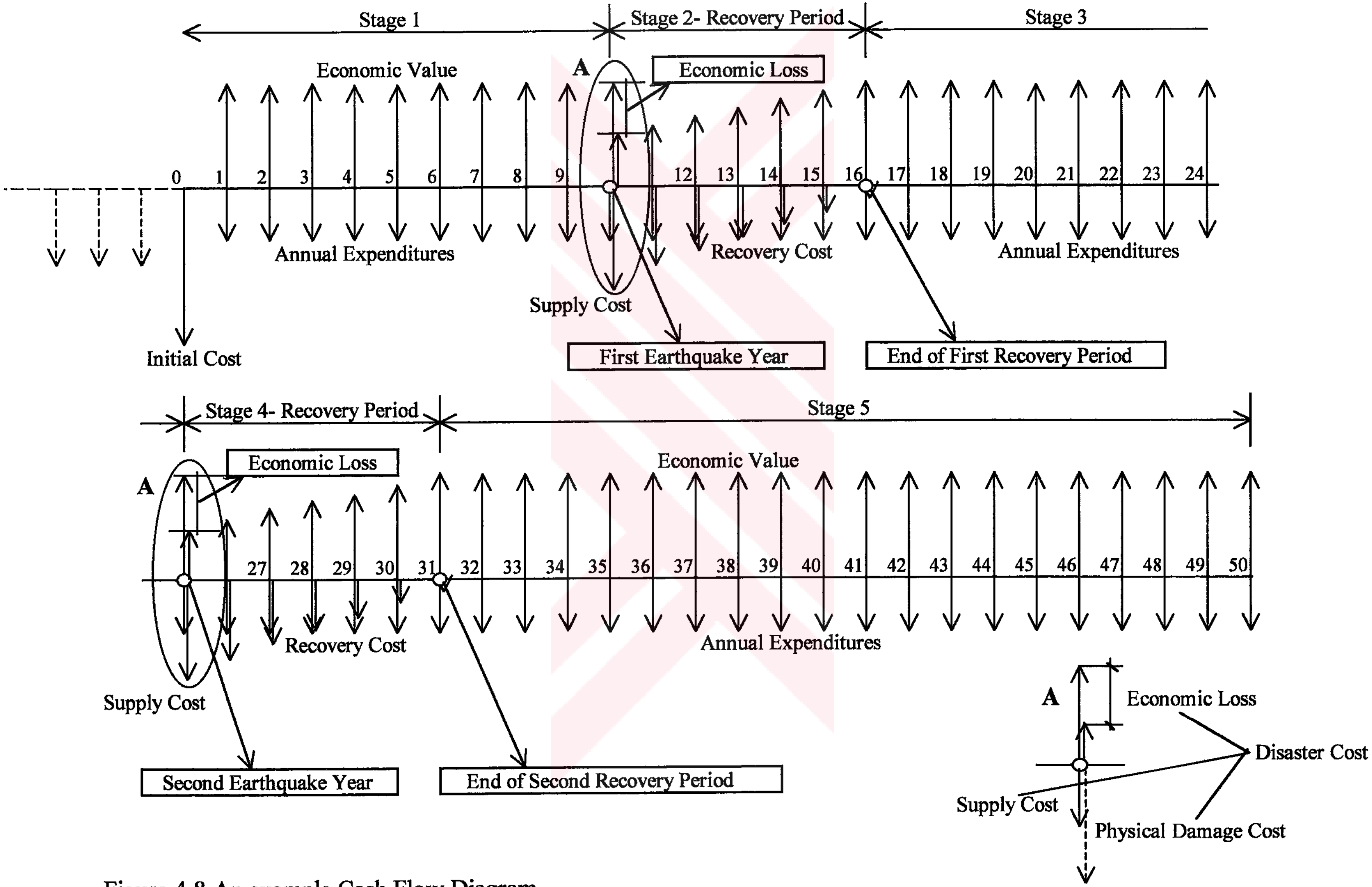


Figure 4.8 An example Cash Flow Diagram

compounded to zero time as initial cost. Annual Expenditures are also a negative cash flow and may change at any stage of the time period. Disaster cost caused by earthquakes is presented as a negative cash flow at the year of the occurrence of earthquakes. As mentioned before disaster cost includes supply cost, physical damage cost and economic loss. The cost for supply has to be spent within a short time (at least little than a year) therefore, it is directly presented in the diagram.

Economic value is a positive cash flow above the axis. Since the economic loss affects the economic value, this effect is reflected as a decrease in economic value during the recovery period. The model assumes that the economic value increases at a constant amount as the recovery of the damaged structures proceeds. At the end of the recovery period the economic value reaches the pre-earthquake level. The constant amount of increase at the end of each year throughout the recovery period is determined as

$$I = \frac{EL}{RP}$$

where; I = Amount of increase in the economic value at each year of the recovery period (see Figure 4.9).

EL = Economic Loss

RP = Recovery Period

The physical damage cost actually is a base to define the cost of recovery of the damaged structures. Recovery cost determined may be equal or greater or less than this value. So the physical damage cost is not directly entered the model but its cost effects are reflected in the recovery cost. It is assumed that once recovery period is completed, the town will resume its economy. In the diagram recovery period is assumed to be six years for both of the earthquakes. But this period is also alterable to see the cost effects of the recovery period. It is assumed in the model that the amount of money required for the recovery of damaged structures is reduced at a constant rate as the recovery process continuous. The recovery cost required at each year of the recovery period is computed from;

$$RC(y) = \frac{RC}{\sum_{y=1}^{RP} y} \times (RP + 1 - y)$$

where; RC(y) = Recovery Cost at any year in Recovery Period

RP = Recovery Period in years

RC = Recovery cost

y = years after earthquake (1, 2, 3……RP)

Recovery cost is equal to the summation of the recovery costs at each year of the recovery period (see Figure 4.9).

Considering all the cash flows throughout the analysis period the total life cycle cost of a town is calculated from

$$TLCC = -IC(F/P,i,n) - AE(F/A,i,n) + EV(F/A,i,n) - SC(F/P,i,n) - RC(y)(F/A,i,n)$$

where; TLCC. = Total Life Cycle Cost,

IC = Initial cost of the facilities in town development,

AE = Annual Expenditures,

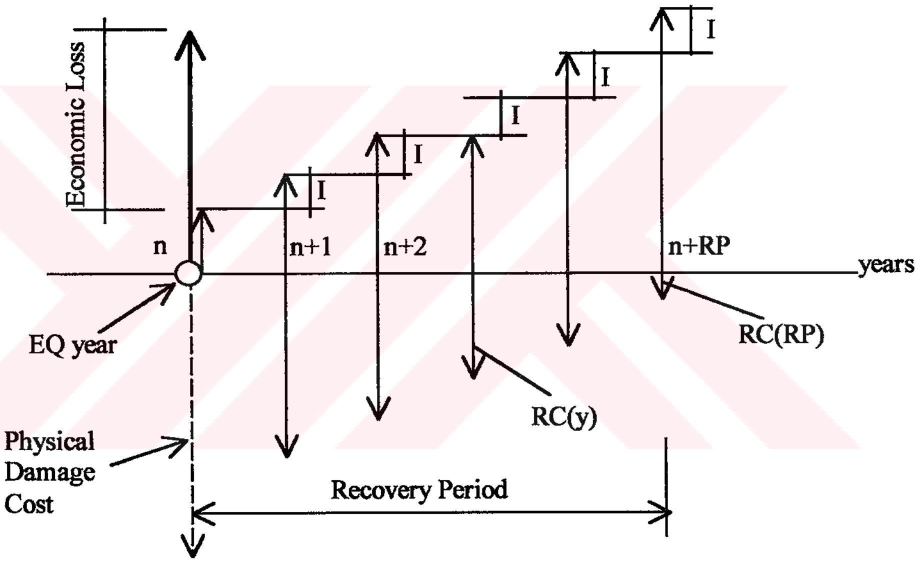
EV = Economic value,

SC = Supply cost,

RC (y) = Recovery cost at any year in Recovery Period,

(F/P, i, n) = Future worth factor of the present cost over a period of year n with interest rate, i,

(F/A, i, n) = Future worth factor of a series of annual costs over a period of year n with interest rate, i.



$$RC = RC(1)+RC(2)+\ldots+RC(y)+\ldots+RC(RP)$$

Figure 4.9 Recovery Cost and Economic Value in the Model

4.4. Evaluation of Cost-Effective Parameters for Earthquake Loss

In this study, recovery period, initial cost, interest rate and earthquake pattern (the occurrence year of earthquakes) are accepted as parameters which affect the earthquake loss. The sensitivity of these parameters is evaluated by using a life cycle cost model, for a specified analysis period and input data. The aim of the evaluation is not to conclude a general statement of the results obtained from the model but provide a guide for planners to be used in their decision making process. Any change in numeric values of input data causes a change in output. Therefore, in the evaluation of the parameters, the results of the model are valid only for the values input into the model. Analysis period is defined as the length of the time in which costs will be computed for alternatives. A survey conducted by Arditi and Messiha (1999) involving a group of cities in the United States shows that municipalities use the analysis period of 5, 6, 20 and 50 years in their life cycle cost analysis. In this study the analysis period is assumed to be 50 years which cover two earthquakes. Results calculated from the model illustrate analytical capabilities of the model. In the evaluation of the parameters the following assumptions are made;

- Four cases are considered to measure the sensitivity of the cost-effective parameters.
  - Case 1 indicates the occurrence of only one earthquake, at year 10 of the analysis period. Structures damaged after the earthquake are only repaired.
  - Case 2 comprehends two earthquakes and it is assumed that the structures damaged after the first earthquake would only be brought to their previous conditions, namely only repairing has been carried out. After the second earthquake the damage and its corresponding cost is the same as the previous one. In this case the recovery cost is equal to the repairing cost.
  - Case 3 indicates the occurrence of two earthquakes. However, in this case, the structures damaged after the first earthquake will be retrofitted against a possible future earthquake. Therefore, the recovery cost of Case 1 is increased by 20 percent to comprise the retrofitting cost. This led the disaster cost after the second earthquake to be less than those of the second case. Therefore, the disaster cost after the second earthquake is assumed to be 40 per cent of those after the first earthquake, assuming that structures damaged after the second earthquake are only repaired.

  - Case 4 assumes the occurrence of two earthquakes as in the second and third cases. In addition to the assumptions in the third case, the fourth case includes the soil improvement considering that structures, after the first earthquake, is damaged because of ground failure as liquefaction. The recovery cost is increased by 35 per cent (20 per cent for retrofitting plus 15 per cent for soil improvement). Hence, disaster cost after the second earthquake is assumed to be 20 per cent of those after the first earthquake. The recovery cost after the second earthquake considers the repairing cost of damaged structures

- The first earthquake, in all cases, occurs at year 10.

- Interest rate throughout the analysis period is taken as 8 per cent, which is the mean value of last ten years in Turkey (T.C. Merkez Bankası, 2001), for the evaluation of the parameters of initial cost, recovery period and earthquake pattern.

- The second earthquake occurs at year 30 for the evaluation of the parameters of initial cost, recovery period and interest rate.

- Recovery period is assumed to be 3 years for the evaluation of the parameters of initial cost, interest rate and earthquake pattern.

- While changing one of the parameters, the others kept constant.

- The sensitivity of the parameters mentioned above is evaluated in terms of earthquake loss at the end of analysis period which is 50 years. The earthquake loss is the difference between the future worth (FW) at any year of the analysis period, in the case of having earthquakes and in the case of having no earthquakes as shown below.

$$EQLoss = FWwithoutEQ - FWwithEQ$$

- The numerical values to input the model are fictitious values. However, the balance between the input values is adjusted in accordance with the values provided for Adapazarı in the case study. For example, the ratio between initial cost and economic value in the case study is kept same in the evaluation of the parameters.

4.4.1. Recovery Period

The overall economic impact and long-term effects of the disaster will be influenced to a large extent by the speed with which infrastructure and housing units can be repaired or retrofitted and business and industry activities resumed. The rate of the damages caused by earthquakes, external financial aids and government's financial situation affect the recovery period. To see how the recovery period affects the earthquake loss of a town during its life cycle, a range of recovery periods, from 1 to 6, is input the model and their effects are assessed as shown in Figures 4.10, 4.11, 4.12 and 4.13. Table B.1 of Appendix B shows the data required by the model and the earthquake loss computed at year 10, 16, 30, 36 and 50 of each case. Assuming that the first earthquake occur at year 10 and the second one at year 30, the recovery process is completed before the year of 16 and 36 for the recovery periods of less than 6 years. However, the earthquake losses for all the recovery periods are computed for the years of 16 and 36 to allow the comparison of earthquake losses at the same year.

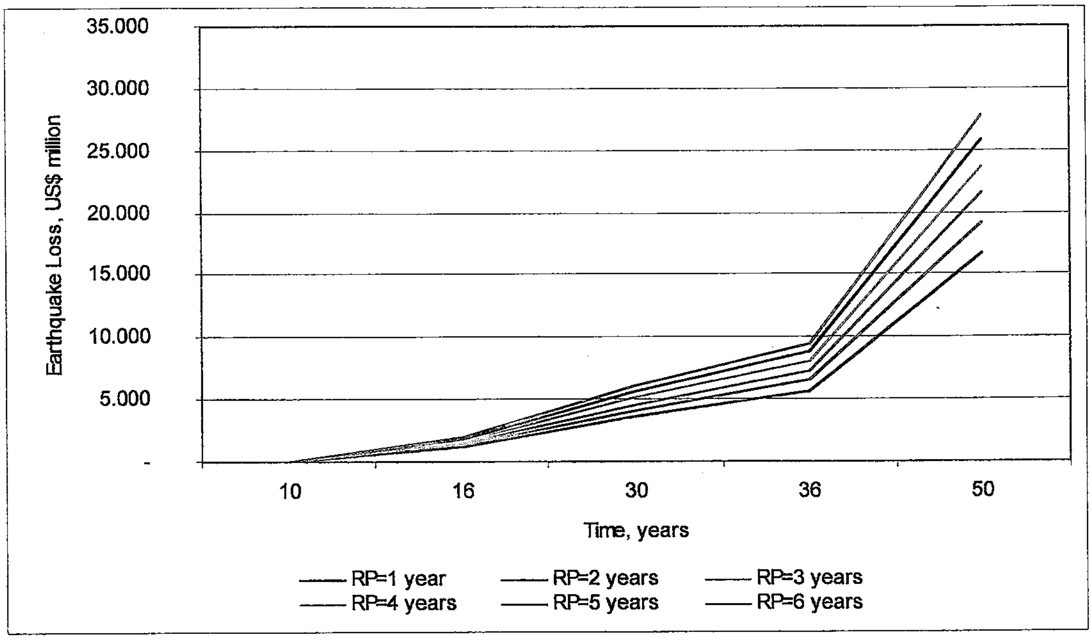


Figure 4.10 EQL against RP, Case 1 (1 EQ, Repairing)

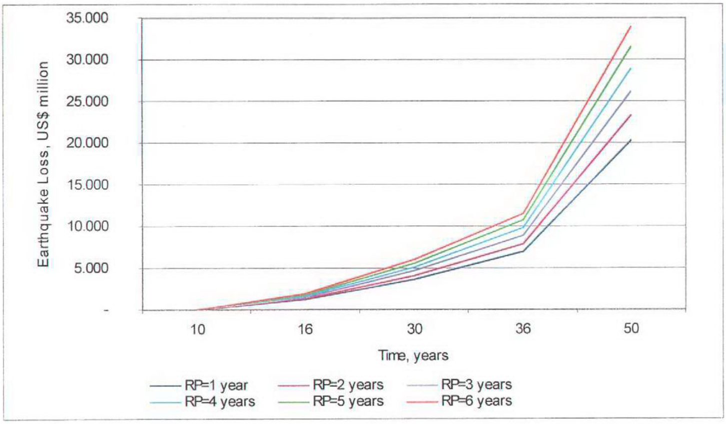


Figure 4.11 EQL against RP, Case 2 (2 EQs, Repairing)

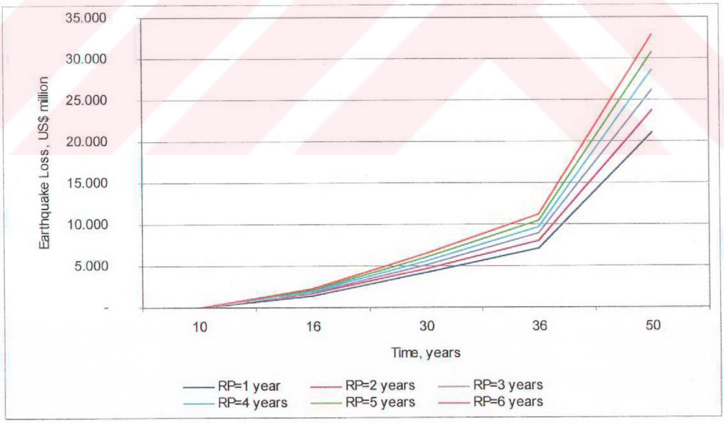


Figure 4.12 EQL against RP, Case 3 (2 EQs, Retrofitting)

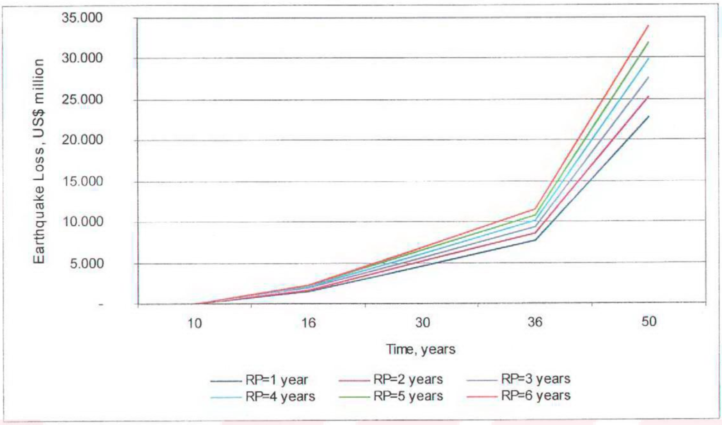


Figure 4.13 EQL against RP, Case 4 (2 EQs, Retrofitting +Soil Improvement)

4.4.2. Initial Cost

Initial cost is consisted of land and construction cost of the facilities in a town. An increase in initial cost is attributed to an increase in the resistance of buildings against earthquakes. More resistant structures and accommodating same population on a larger area with more open spaces increase the initial cost. Therefore, constructing earthquake resistant buildings increase the initial cost but decrease the economic and social impacts of earthquakes. In another way, the cost of supply and recovery is anticipated to be less. In addition, since there is fewer casualties, economic loss because of de-motivation, destruction in enterprises, physical damage etc. are reduced as well. Celik, (1998) says that "earthquakes in urban areas have shown that in order to prevent deaths, the best solution is to build higher-cost structures that are more durable".

In the evaluation of the initial cost of a town, firstly, buildings are accepted to be in their normal condition with less initial cost, which is assumed to be 2.000.000.000 US$ and more recovery cost after earthquakes. The initial cost is increased firstly by 25 per cent (2.500.000.000 US$) and then 50 percent

(3.000.000.000 US$) to have more resistant structures. Therefore, the cost of disaster is assumed to be reduced to 50 percent and 25 percent respectively. The effects of initial cost on the life cycle cost of a town are illustrated in Figures 4.14, 4.15, 4.16 and 4.17. The data required by the model and cost results are given in Table B.2 of Appendix B.

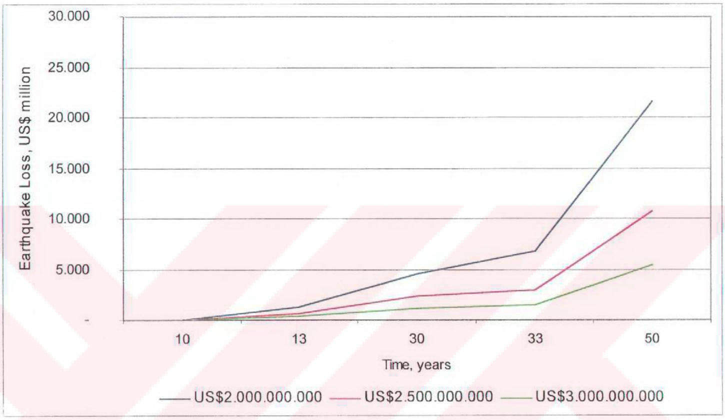


Figure 4.14 EQL against IC, Case 1 (1 EQ, Repairing)

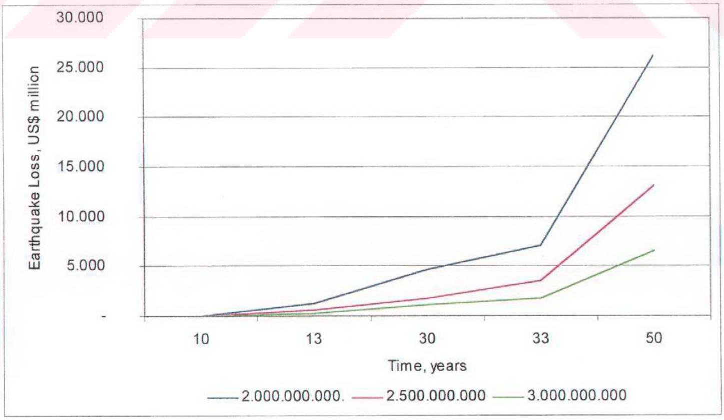


Figure 4.15 EQL against IC, Case 2 (2 EQs, Repairing)

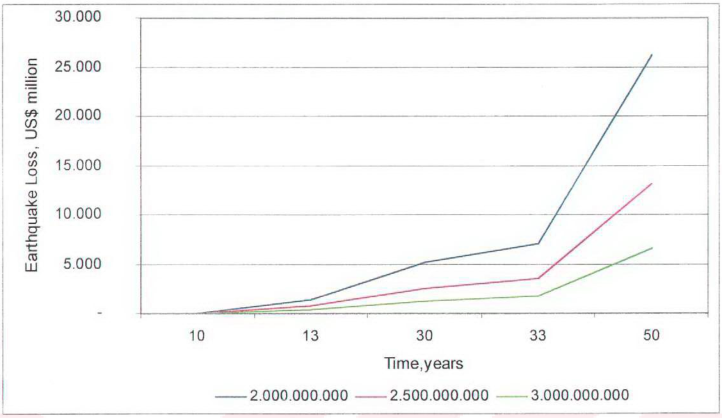


Figure 4.16 EQL against IC, Case 3 (2 EQs, Retrofitting)

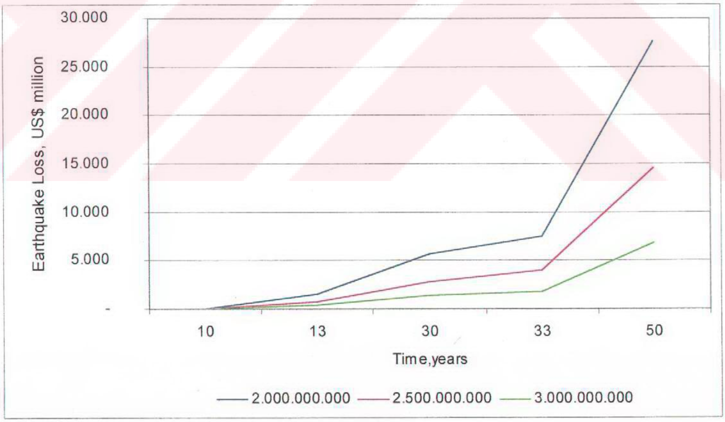


Figure 4.17 EQL against IC, Case 4 (2 EQs, Retrofitting + Soil Improvement)

4.4.3. Interest Rate

An interest rate is one of the important parameters of life cycle cost analysis to compare alternatives. The interest rate chosen should reflect the investor's time value of money. The model enables the alteration of the interest rate value at any one of the five stages as explained before. Therefore, its effect on total life cycle cost can be easily observed. A specific inflation rate is not included in the model. However, it is assumed that the interest rate chosen also reflects the inflation rate. A sensitivity analysis clearly shows the effects of interest rate on life cycle cost as presented in Figures 4.18, 4.19, 4.20 and 4.21. In the evaluation, 4, 8 and 12 per cent of interest rates are considered to see their effects on the earthquake loss. The data required by the model and cost results are given in Table B.3 of Appendix B.

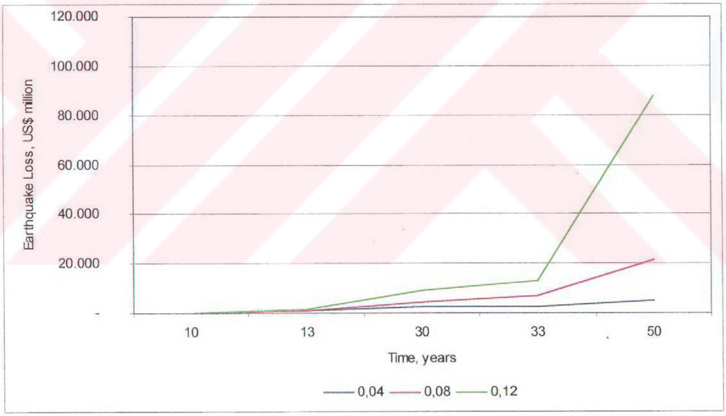


Figure 4.18 EQL against IR, Case 1 (1 EQ, Repairing)

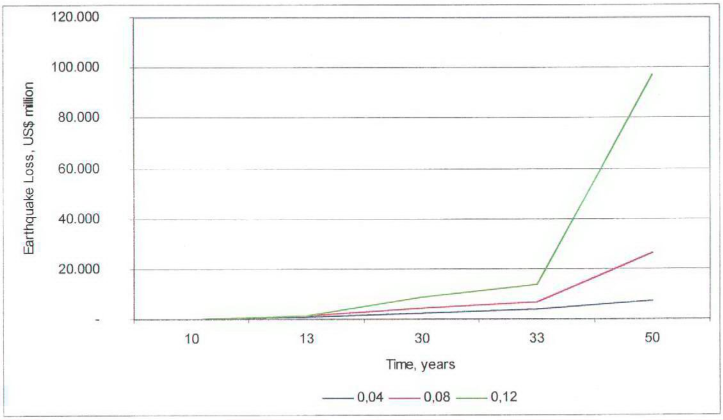


Figure 4.19 EQL against IR, Case 2 (2 EQs, Repairing)

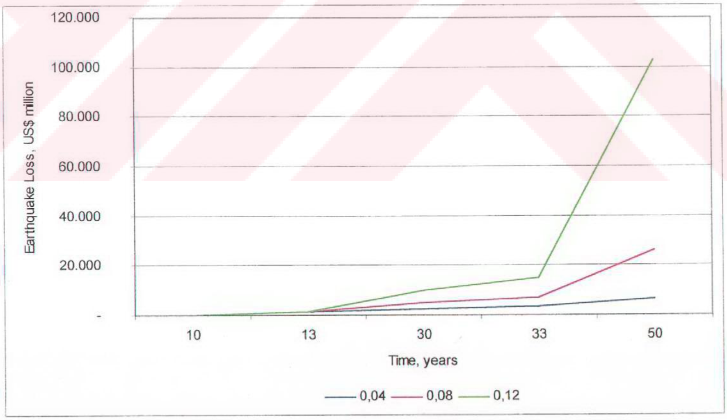


Figure 4.20 EQL against IR, Case 3 (2 EQs, Retrofitting)

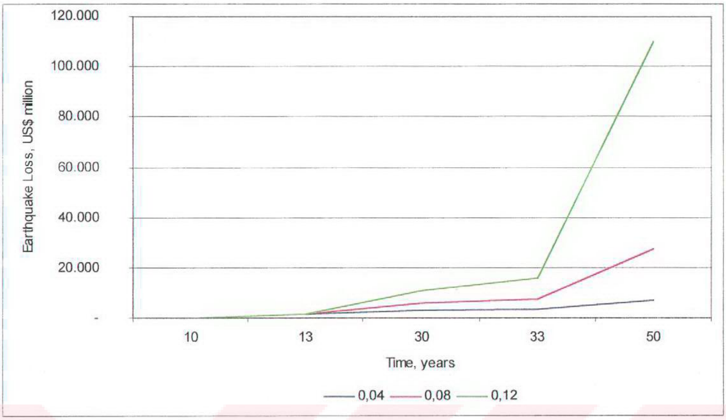


Figure 4.21 EQL against IR, Case 4 (2 EQs, Retrofitting + Soil Improvement)

4.4.4. Earthquake Pattern

The occurrence time of an earthquake affects the growth of a town, especially of a new development. Number of earthquakes in a certain period also affects the economy of that town. To evaluate the sensitivity of the earthquake pattern, it is assumed that earthquake loss is determined considering that the second earthquake occurs at year 25, 30, 35 and 40. Figures 4.22, 4.23, 4.24 and 4.25 show the earthquake losses for the cases explained above. It is seen that two earthquakes within the analysis period increase the economic loss. The data required by the model and cost results are given in Table B.4 of Appendix B.

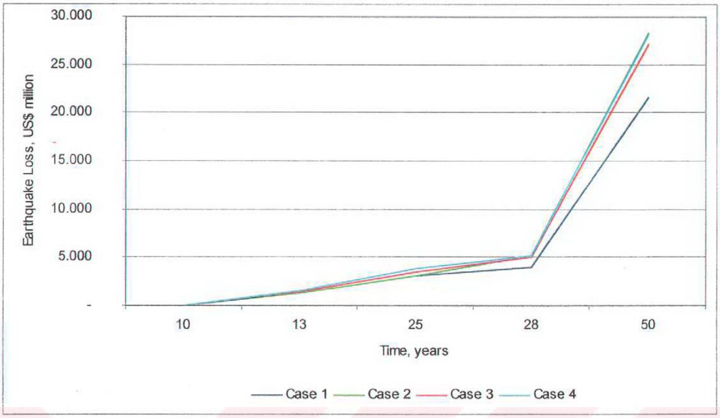


Figure 4.22 EQL against EQP (2nd EQ at 25th year)

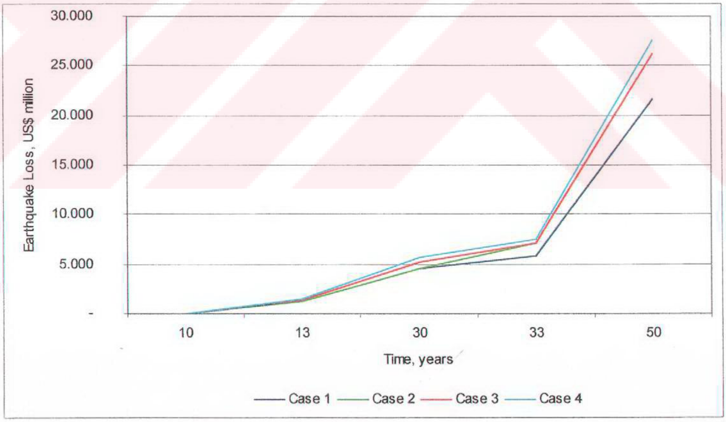


Figure 4.23 EQL against EQP (2nd EQ at 30th year)

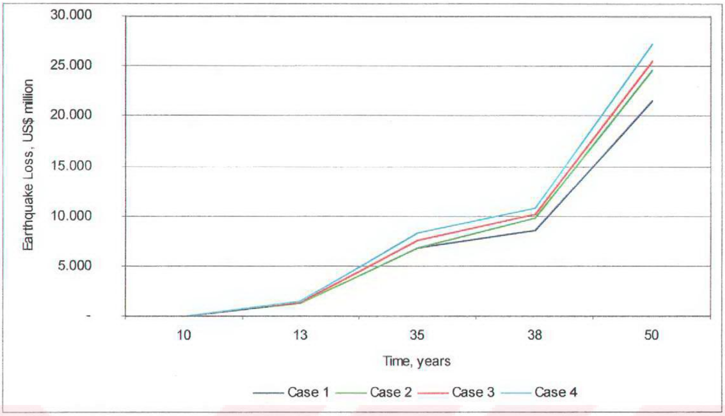


Figure 4.24 EQL against EQP (2nd EQ at 35th year)

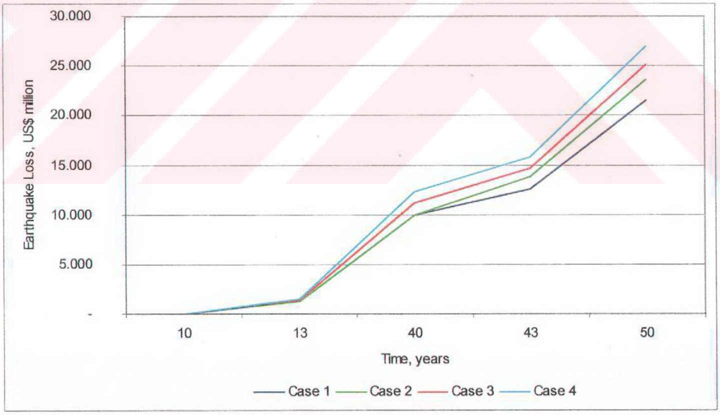


Figure 4.25 EQL against EQP (2nd EQ at 40th year)

4.5. Results

In this chapter the elements of the life cycle cost model developed in this study are discussed and the evaluation of the sensitivity of the cost-effective parameters recovery period, initial cost, interest rate, and earthquake pattern is presented. In the evaluation earthquake losses are determined at year 50 which is the end of the analysis period. As far as the assumptions made in the evaluation is concerned the results are as follows:

- In all cases the length of the recovery period is very effective on the earthquake loss and longer periods increase the earthquake loss. In order to compare the earthquake losses for each recovery period, the ratios to show increases are computed assuming that a recovery period of 1 year is a base and the ratios are defined as follows; [(EQ Loss; RP=2,3,4,5 and 6 years)/(EQ Loss; RP=1 year)]. Table 4.1 presents the ratios of increases in earthquake losses.

Table 4.1 Ratios of Increases in EQL for RP

Cases	Recovery Periods, years					
	1	2	3	4	5	6
Case 1	1	1,15	1,29	1,42	1,55	1,67
Case 2	1	1,15	1,29	1,42	1,55	1,67
Case 3	1	1,12	1,24	1,35	1,46	1,56
Case 4	1	1,11	1,21	1,31	1,40	1,48

- As far as initial cost is concerned, in all cases, constructing more resistant buildings and leaving more open spaces decreases the earthquake loss. While 25 per cent increase in the initial cost cause about 50 per cent decrease in the earthquake loss, 50 per cent increase causes about 75 per cent decrease in the earthquake loss. Assuming an initial cost of US$2.000 million as a base [(EQ Loss; US$2.500 and 3.000 million)/(EQ Loss;

US$2.000 million)], the ratios of increases in earthquake losses are shown in Table 4.2.

Table 4.2 Ratios of Increases in EQL for IC

Cases	Initial Costs, US$ million		
	2.000	2.500	3.000
Case 1	1	0,499	0,250
Case 2	1	0,500	0,249
Case 3	1	0,500	0,250
Case 4	1	0,530	0,246

- An Interest rate of 4 per cent produces less earthquake loss than the interest rates of 8 and 12 per cent, while 12 per cent produces more earthquake loss than others. The ratios of increases in earthquake losses are given in Table 4.3, assuming that the interest rate of 4 per cent is a base [EQ Loss; i=8% and 12%)/(EQ Loss; i=4%)].

Table 4.3 Ratios of Increases in EQL for IR

Cases	Interest Rates, %		
	4	8	12
Case 1	1	4,30	17,58
Case 2	1	3,59	13,32
Case 3	1	3,95	15,44
Case 4	1	4,10	16,37

- The occurrence time of the second earthquake also effects the earthquake loss. It is seen that at the end of the analysis period, which is 50 years the earthquake loss decreases at late occurrence of the second earthquake. The occurrence of the second earthquake at year 25 is accepted as a base and the ratios of increases in earthquake losses are computed [(EQ Loss; 2nd EQ in 30, 35 and 40 years)/(EQ Loss; 2nd EQ in 25 years)], as shown in Table 4.4.

Table 4.4 Ratios of Increases in EQL for EQP

Cases	Second Earthquake Time, years			
	25	30	35	40
Case 1	1	1	1	1
Case 2	1	0,92	0,87	0,84
Case 3	1	0,96	0,94	0,92
Case 4	1	0,98	0,97	0,96

CHAPTER 5

CASE STUDY

5.1. Introduction

Turkey is a prominent earthquake country in the world. On August 17 and November 12, 1999 two earthquakes with magnitude 7,4 and 7,2 respectively, hit the Marmara and Bolu areas of Turkey. The area affected was the country's industrial heartland, the immediate and adjacent provinces (including Istanbul) accounting for around one-third of Turkey's overall output. The two earthquakes caused considerable damage to housing, public facilities and infrastructures. Over 16.000 people are estimated to have died and around 50.000 were injured. Large portions of the area were devastated, with around 109.000 housing units and business premises completely destroyed, and another 249.000 damaged to varying degrees. Numerous schools, health facilities, roads, bridges, water pipes, power lines, phone lines and gas pipelines were severely damaged. The earthquake caused widespread liquefaction in extensive area covering from Adapazarı to Gölkaya. Damaged and collapsed buildings were attributable to liquefaction and low bearing capacity of the underlying soil thickness and water-saturated delta deposits filled by man-made materials caused structural damage in and around the İzmit Bay. On the other hand, the earthquake triggered some rock falls and landslides in Gebze and Düzce (Bibbee et al, 2000).

Since the earthquake affected a large and densely populated area, the extent and the dimensions of the damage were increased. The reality is the fact that the buildings were not designed and constructed according to the earthquake resistant design codes. In addition, many buildings were allowed to be built on active faults and in areas of high liquefaction potential.

One of the most spectacular aspects of the earthquake is the damage to buildings inflicted directly by the faulting. This was the first earthquake with major faulting to strike through heavily populated areas. The effects of the earthquake on the built environment are important in understanding the seismic risk to regions of the world that have high population densities, modern infrastructure, industry and buildings, and are in the immediate vicinity of major fault systems. Most of the buildings are typically multi-storey commercial/residential structures built of reinforced concrete. A large percentage of the severely damaged and collapsed buildings were typically in the 6 to 8 storey range, either under construction or built within the last few years. One of the surprising aspects of this earthquake was the amount and severity of damage to modern engineered structures and equipment in industrial facilities, especially in light of the relatively low ground motion readings. The major damage at these facilities could have been avoided with better earthquake resistant structural design, systems design, and planning (EQE, 1999).

5.2. Application of LCC Model to Adapazarı

The earthquakes in 1999 affected the cities of Kocaeli (İzmit), Sakarya (Adapazarı), Bolu, Yalova, İstanbul, Bursa and Eskişehir as shown in Figure 5.1. Adapazarı is one of the intensely and extensively damaged cities. A magnitude of 7,2 had also struck Adapazarı in 1967 and caused about 90 dead and damaged 5569 structures. In 1999 earthquake, Adapazarı is mainly damaged by extensive liquefaction. Therefore, Adapazarı is chosen as a pilot area for the application of the life cycle cost model developed in this study to an actual case. The case study is focused on the center of Adapazarı that is located on an area of about 1.920.000 square meter and has a population of 183.265.

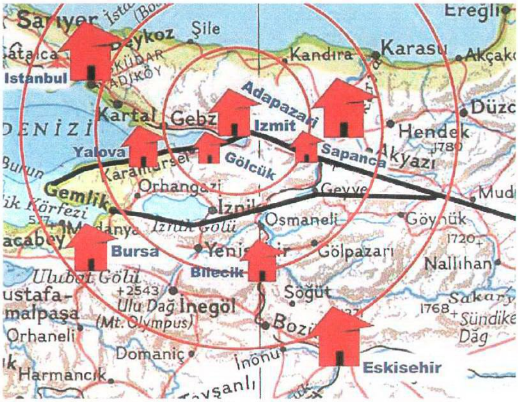


Figure 5.1 Epicentral Area, Showing Areas of Extensive Damage (EQE, 1999)

5.2.1. Provision of Cost Data for the Parameters in the Model

The LCC model requires the input parameters of initial cost, annual expenditures, recovery cost, supply cost and economic value. Therefore, the values of these parameters are collected for Adapazarı in order to analyze the earthquake effects on the town cost throughout the analysis period. As explained in Chapter 4, each input parameter is divided into sub-parameters so that the user can be able to know what sort of cost information is required to determine the cost of the main parameter. However, during the data collection process it is realized that the collection of data as required by the model is difficult because there is no proper data recording system in the agencies. Hence, published data are used in order to provide the values for input parameters, and assumptions have to be made in some cases to be able to run the model. This section explains the provision of the cost data for all parameters.

Initial cost, comprises of the land cost and the construction cost of technical and social facilities, which serve the needs of population accommodated in an area. To determine the initial cost for Adapazarı firstly the area of land and construction for each facility are determined from the master plan of Adapazarı. Then, the unit cost of land is accepted to be about $120 per square meter as provided from a property agency in Adapazarı. The unit construction costs for the facilities of Residential, Education, Health Services, Commerce, Social Services, Industrial and Administrative are taken from the Chamber of Architects. The unit construction cost of Roads and Squares are obtained from General Directorate of Highways. Unfortunately, there is no available cost data for Infrastructure as required by the model. Therefore, infrastructure cost is derived from the damage and reconstruction costs of infrastructure since they are only data available. According to the information obtained from a local authority in Adapazarı, the reconstruction of waste and fresh water systems cost about US$ 93 million. MAE Center (1999) states that about 70 per cent of the structures in Adapazarı were damaged. Hence, total construction cost of waste and fresh water is accepted to be about US$ 133 million. State Planning Organization (2000) estimates the finance need for the repair of electricity system and telecom as US$ 73 and 75 million, respectively, for the cities damaged after the earthquake. Its share value for Adapazarı is about US$ 16 million. Considering that 70 per cent of the structures damaged, the construction cost for electricity and telecom is about US$ 23 million. Hence, the total construction cost of infrastructure is accepted to be US$ 156 million for Adapazarı. The land and construction costs for each facility are determined by multiplying the land area with the unit cost of land and also the construction area with the unit cost of construction. Finally, summation of the costs (land plus construction) of each facility provides the total initial cost of about US$ 812 million for Adapazarı. Table C1 of Appendix C presents the calculation of the initial cost.

Economic value is defined as the revenues from different sectors as production, commerce, tourism and services. However, because of the difficulties in the collection of data for the model, economic value is assumed to be the Gross National Product (GNP) per person in Adapazarı. Organization for Economic Co-operation and Development (Bibbee et al, 2000) reports that the earthquake region accounts for 35 per cent of national GNP and almost half of the nation's industrial output. According to the report of OECD (Bibbee et al, 2000) and Economic Report of Sakarya (1997) average income in Sakarya is indicated as about US$2730 per capita per year. Therefore, the economic value per year for Adapazarı is determined by multiplying income per capita with population and found as about US$500.000.000.

Annual expenditures include public investment expenditures, private sector investment incentives and maintenance cost such as painting, lighting and repairing works. State Planning Organization (SPO) reveals that public investment expenditures in Marmara region is US$80 per capita for a period of 1983-1997 ("Bölgesel Gelişmeler", 1999). This value is about US$15.000.000 for Adapazarı. Undersecretariat of Treasury states the private sector investment incentives as about US$72.000.000 for Sakarya and about US$36.000.000 for Adapazarı during a period of 1991-1997 ("Private Sector", 1997). Unfortunately, there was no available data about the maintenance cost of Adapazarı. The projects carried out in Unites States show that about 0,7 per cent of the initial cost is spent for operation and maintenance of transportation systems (WSDOT, 2000), about 1,30 per cent for water supply ("Economics", 1999) and about 2 per cent for power supply ("Electricity", 1993). Taking into account the conditions in Turkey it is assumed that 0,5 per cent of the initial cost for transportation, 1 per cent of the initial cost for water supply and 1,0 per cent of the initial cost for electricity supply are sufficient to cover maintenance cost of Adapazarı. Therefore the maintenance cost is accepted to be US$20.000.000. Then, the total annual expenditures are US$71.000.000.

A variety of resources provides different cost data for recovery, supply and economic loss caused by two earthquakes. Unfortunately, available resources do not provide cost data for Adapazarı itself. Instead they cover all the cities in the region. Therefore, the required cost data for Adapazarı is derived from the total cost given by the sources. In the provision of the cost data, the share value of Adapazarı within the total cost would be determined first. The available information about Adapazarı is its population, the number of deaths and injuries and the number of the buildings damaged by the earthquake. The population would not give reliable results because having the highest population would not mean to have the highest damage. So, the number of deaths and injuries and also the number of damages are considered in the determination of the share value of Adapazarı in the total cost in order to have a range for cost information. Table 5.1 shows the number of deaths and injuries for the cities in earthquake region. Since the cost effects of dead is higher than those of injuries, a coefficient of 1,0 was assigned to the number of dead and 0,50 to the number of injuries and a weighted total number of deaths and injuries for each city was found. Then, the weighted number for Adapazarı is divided into the total weighted number and the share value of 5.989/38.584=0,155 is found for Adapazarı in accordance with the number of deaths & injuries.

As shown in Table 5.2 damages are classified as heavy, moderate and light. A coefficient of 1,0 was assigned to the number of heavily damaged buildings, 0,75 to moderately damaged buildings and 0,50 to lightly damaged buildings. In the same way the share value of Adapazarı is found for the number of deaths and injuries, a share value of 19.116/180.155=0,106 was found in accordance with the number of damaged buildings.

Recovery Cost refers to the cost of the recovery of structures damaged by the earthquake and rent aids for housing. The investigation of Turkish Industrialization and Businessmen's Association (TUSIAD), State Planning Organization (SPO) and World Bank reveal roughly the recovery cost of two earthquakes as given in Table 5.3 (Bibbee et al, 2000; World Bank, 1999).

Table 5.1 Number of Deaths and Injuries in the Earthquake Region

Cities	No. of Deaths (1)	No. of Injuries (2)	Weighted Total (1)x1,0 + (2)x0,50
Kocaeli	9.476	19.447	19.200
Sakarya * **Adapazarı**	3.890 **3.694**	7.284 **4.589**	7.532 **5.989**
Yalova	2.504	6.042	5.525
İstanbul	454	7.204	4.056
Bolu	271	1.165	853
Bursa	10	2.375	1.198
Eskişehir	33	375	220
TOTAL	16.638	43.892	38.584

*Since the number of deaths and injuries in Sakarya covers the number of deaths and injuries in Adapazarı the TOTAL does not include the numbers for Adapazarı.

Table 5.2 Number of Damaged Buildings in the Earthquake Region

Cities	Heavy (1)	Moderate (2)	Light (3)	Weighted Total (1)x1,0+(2)x0,75+(3)x0,50
Kocaeli	22.346	24.288	25.679	53.402
Sakarya *	23.111	14.163	20.387	43.927
Adapazarı	**11.472**	**4.951**	**7.861**	**19.116**
Yalova	10.189	8.953	14.566	24.187
İstanbul	3.605	15.338	13.694	21.955
Bolu	3.744	5.195	3.785	9.532
Bursa	68	453	1008	912
Eskişehir	99	104	336	345
Gölcük	14.180	8.675	10.417	25.895
TOTAL	77.342	77.169	8.872	180.155

*Since the number of damaged buildings in Sakarya covers the number of damaged buildings in Adapazarı the TOTAL does not include the numbers for Adapazarı.

Table 5.3 Cost for the Recovery of Damaged Structures (US$ billion)

Structures	TUSIAD	SPO	World Bank
Housing	4,0	3,5-5,0	1,1-3,0
Enterprise	4,5	2,5-4,5	1,1-2,6
Infrastructure	1,5	0,5-1,0	0,9
Education	---	---	0,1
Health	---	---	0,037

Supply Cost includes emergency relief expenses such as cure aids, medicine aids, tent aids, various aids in cash. According to TUSIAD and World Bank emergency relief expenses range from US$0,6 to 0,8 billion (Bibbee et al, 2000). World Bank (1999) also estimates a range for the economic loss of US$1,2-2 billion, equivalent to 0,6 per cent-1,0 per cent of GNP in 1999.

Based on the available data it is possible to estimate lower bounds (LB) and upper bounds (UB) for the costs of recovery, supply and economic loss. These estimates are summarized in Table 5.4. Lower and upper bounds are determined in accordance with the number of dead and injuries and the number of damaged buildings. The lower and upper bounds are computed by multiplying the share value of Adapazarı (0,155 for dead and injuries; 0,106 for damages) with the available lowest and highest cost data. Finally, the lowest and the highest value among the lower and upper bounds of dead and injuries and also damages are input the model.

Table 5.4 Input Data for the Model (US$ million)

Input Parameters	Deaths and Injuries		Damages	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Physical Damage Loss	440	**1.726**	**301**	1.181
Supply	93	**124**	**64**	85
Economic Loss	186	**310**	**127**	212
Economic Value	500	500	500	500
Initial Cost	812	812	812	812
Annual Expenditures	71	71	71	71

5.2.2. Earthquake Loss Evaluation

Earthquake Loss, as described in Section 4.3 of Chapter 4, is the difference between the future worth at any year of the analysis period, in the case of having earthquakes and having no earthquakes. In the case study for Adapazarı, six scenarios are designed to evaluate the earthquake effect on the earthquake loss. Although each scenario evaluates the earthquake loss for different approach, principals are the same as explained below;

- The first earthquake in each scenario occurs at year 10 in the analysis period of 50 years.

- Recovery periods of 1 and 6 years are considered in order to examine the effect of the recovery period on the earthquake loss.

- Each recovery period is analyzed against lower and upper cost bounds explained in the previous section.
- The probable second earthquake occurrence is evaluated for the years of 25, 30, 35 and 40. However, the earthquake loss is determined at year 50 which, is the end of the analysis period.
- Interest rate is accepted to be 8 per cent throughout the analysis period. According to the electronic data delivery system of the Central Bank of the Republic of Turkey, the accepted interest rate is the mean of the interest rates for the years between 1990-2001 (Central Bank of the Republic of Turkey, 2001).
- In all scenarios the initial cost of Adapazarı is taken as US$ 812 million and economic value throughout the analysis period is US$ 500 million.
- The structures damaged after the second earthquake are only repaired.
- The computation of the recovery cost for each scenario is summarized in Table 5.5.

Table 5.5 Recovery Cost for Each Scenario (US$ million)

Scenarios	Bounds	After 1st EQ	After 2nd EQ
Scenario 1	Lower	Repair=301	no EQ
	Upper	Repair=1.726	no EQ
Scenario 2	Lower	Repair=301	Repair=301
	Upper	Repair=1.726	Repair=1.726
Scenario 3	Lower	Retrofit=301x1,2=361 * New development=902 ** Summation=1.263	Repair=361x0,4=144 No damage in new development
	Upper	Retrofit=1.726x1,2=2.071 * New development=902 ** Summation=2.973	Repair=2.071x0,4=828 No damage in new development
Scenario 4	Lower	Retrofit=301x1,2=361 * New development=902 ** Summation=1.263	Repair=361x0,2=72 *** no damage in new development
	Upper	Retrofit=1.726x1,2=2.071 * New development=902 ** Summation=2.973	Repair=2.071x0,2=414 *** No damage in new development
Scenario 5	Lower	Retrofit+Soil Impr. =301x1,6=482 **** New development=902 ** Summation=1.384	Repair=482x0,2=96 ***** No damage in new development
	Upper	Retrofit+Soil Impr. =1.726x1,6=2.762 New development=902 ** Summation=3.664	Repair=2.762x0,2=552 ***** No damage in new development
Scenario 6	Lower	Retrofit+Soil Impr. =301x1,6=482 New development=902 ** Summation=1.384	Repair=482x0,1=48 *** No damage in new development
	Upper	Retrofit+Soil Impr. =1.726x1,6=2.762 New development=902 ** Summation=3.664	Repair=2.762x0,1=276 *** No damage in new development

* Retrofitting cost is assumed as 1,2 x Repairing Cost

** New development is included in Recovery Cost

*** The second EQ has a smaller magnitude than that in Scenario 3.

**** Retrofitting and soil improvement cost is assumed as 1,6 x Repairing Cost.

***** It has a less damage than Scenario 3 in the same magnitude of EQ because of soil improvement.

Scenario 1

The first scenario assumes the occurrence of one earthquake at year 10 and structures damaged after the earthquake are only repaired. The input values are given in Table 5.6. The lower and upper bounds of future worth and earthquake losses corresponding to the years of the earthquake occurrences and the end of the recovery periods are presented in Tables 5.12-5.27. Figures 5.2-5.17 show the earthquake losses graphically for the scenarios assuming the recovery periods as 1 year and 6 years.

Table 5. 6 Values of Input Parameters (US$ million), Scenario 1

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	-	-
Economic Value	500	500	-	-
Annual Expenditures	71	71	-	-
Economic Loss	127	310	-	-
Supply Cost	64	124	-	-
Recovery Cost	301	1.726	-	-

Scenario 2

If a second earthquake occurs at any time after the first earthquake how it will affect the economy of Adapazarı. The second scenario is created to evaluate the effect of the second earthquake on the earthquake loss. As explained previously, the second earthquake may occur at year 25, 30, 35, or 40. It is assumed that the structures damaged by the first earthquake are only repaired but not retrofitted against a probable future earthquake. It is also assumed that the second earthquake results in the same damage as the first one. Therefore, the cost data of economic loss, supply and recovery for the first earthquake is accepted to be same for the second earthquake. Table 5.7 shows the values of input parameters. Future worth and earthquake losses are presented in Tables 5.12-5.27. Figures 5.2-5.17 show the earthquake loss against the occurrence time of the second earthquake.

Table 5.7 Values of Input Parameters (US$ million), Scenario 2

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	812	812
Economic Value	500	500	500	500
Annual Expenditures	71	71	7	71
Economic Loss	127	310	127	310
Supply Cost	64	124	64	124
Recovery Cost	301	1.726	301	1.726

Scenario 3

The third scenario considers the effect of retrofitting on the earthquake loss. It is assumed that the buildings damaged after the first earthquake are retrofitted against a probable earthquake in the future. The cost of constructing an earthquake resistant building is almost 8 percent more than that is not resistant (Celep and Kumbasar, 2000). However, the strengthening of existing and damaged buildings is more costly than constructing an earthquake resistant building. Considering all these, in this scenario the recovery cost of the damaged buildings is increased as the 20 per cent of the recovery cost in the previous scenario.

Adapazarı is located on a weak soil and most of the damages after the earthquake in 1999 are because of ground failure, liquefaction. Some parts of the town have been located on strong soil outside Adapazarı. Therefore, the cost effects of new developments, namely, Karaman and Camili are also analyzed in this scenario. The initial cost calculations of these new developments are presented in Tables C2 and C3 of Appendix C. Total initial cost of US$ 902 million is reflected in the recovery cost because the construction of new developments is assumed to be a part of the recovery process.

The structures retrofitted after the first earthquake become more resistant against a probable future earthquake and result in less disaster cost. Therefore, the recovery cost, supply cost and economic loss after the second earthquake are accepted as the 40 per cent of the corresponding values for the first earthquake. However, maintenance cost is increased twice as much as the previous one (i.e. US$40.000.000) because of the maintenance and operation of the new developments, Karaman and Camili. Hence, the total annual expenditures are increased to US$ 91 million after the first earthquake. Table 5.8 gives the values of input parameters. The lower and upper bounds of future worth and earthquake losses are shown in Tables 5.12-5.27. Figures 5.2-5.17 present the earthquake losses.

Table 5.8 Values of Input Parameters (US$ million), Scenario 3

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	812	812
Economic Value	500	500	500	500
Annual Expenditures	91	91	91	91
Economic Loss	127	310	50.8	124
Supply Cost	64	124	25.6	49.6
Recovery Cost	1.263	2.973	144.4	828.4

Scenario 4

Fourth scenario is also designed to show the effect of retrofitting on the earthquake loss. As a difference from the third scenario this one assumes that the damage of the second earthquake is not as much as the previous one, depending on the magnitude of the earthquake. The recovery cost after the second earthquake is assumed to be 20 per cent of the first recovery cost. The amount of the annual expenditures is US$ 91 million after the first earthquake year. Table 5.9 shows the values of input parameters. Tables 5.12-5.27 give the future worth and earthquake losses. Figures 5.2-5.17 present the earthquake losses graphically.

Table 5.9 Values of Input Parameters (US$ million), Scenario 4

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	812	812
Economic Value	500	500	500	500
Annual Expenditures	91	91	91	91
Economic Loss	127	310	25.4	62
Supply Cost	64	124	12.8	24.8
Recovery Cost	1.263	2.973	72.2	414.2

Scenario 5

Adapazarı is located on weak soil and some structures are damaged because of liquefaction. The soil has to be improved before reconstructing a structure. This scenario covers the effects of soil improvement in addition to the retrofitting of the structures damaged after the earthquake. As explained in Scenario 3, the recovery cost is increased by 20 per cent to cover the retrofitting cost. The cost of soil improvement depends what type of method is used. According to the information obtained from a practicing engineer, who is experienced with soil improvement in Adapazarı, the soil improvement increases the construction cost by 40 per cent. Therefore, the recovery cost after the first earthquake is accepted to be 60 per cent more than the recovery cost in Scenario 1. Improved soil and retrofitted structures result in less damage during a probable second earthquake. Hence, the disaster cost after the second earthquake is taken as the 20 per cent of the first recovery cost. The amount of the annual expenditures is US$ 91 million, including the maintenance cost of new developments. Table 5.10 shows the values of input parameters. Future worth and earthquake losses are given in Tables 5.12-5.27. Figures 5.2-5.17 present the earthquake losses graphically.

Table 5.10 Values of Input Parameters (US$ million), Scenario 5

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	812	812
Economic Value	500	500	500	500
Annual Expenditures	91	91	91	91
Economic Loss	127	310	25.4	62
Supply Cost	64	124	12.8	24.8
Recovery Cost	1.384	3.664	96.4	552.4

Scenario 6

Scenario 6 also indicates the effect of soil improvement and retrofitting. The recovery cost after the first earthquake is increased by 60 per cent as explained in Scenario 5. In this scenario it is assumed that the magnitude of the second earthquake is not as high as the magnitude considered in Scenario 5. Therefore, less damage is expected after the second earthquake and the recovery cost is accepted to be 10 per cent of the first recovery cost. The annual expenditures are US$ 91 million during the analysis period. Table 5.11 presents the other input values. Tables 5.12-5.27 and Figures 5.2-5.17 show the future worth and earthquake losses for all scenarios.

Table 5.11 Values of Input Parameters (US$ million), Scenario 6

Parameters	First Earthquake		Second Earthquake	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Initial Cost	812	812	812	812
Economic Value	500	500	500	500
Annual Expenditures	91	91	91	91
Economic Loss	127	310	12.7	31
Supply Cost	64	124	6.4	12.4
Recovery Cost	1.384	3.664	48.2	276.2

Table 5.12 FW and EQL (2^{nd} EQ year= 25, RP=1 year, LB), US$ million

Scenarios	Years				
	10	11	25	26	50
Non-EQ	4.462	5.248	25.801	28.295	208.063
Scenario 1	4.462	4.878	24.714	27.121	200.618
EQ Loss	-	**370**	**1.087**	**1.174**	**7.445**
Scenario 2	4.462	4.878	24.714	26.750	198.271
EQ Loss	-	**370**	**1.087**	**1.545**	**9.792**
Scenario 3	4.462	3.896	21.346	23.290	174.995
EQ Loss	-	**1.352**	**4.455**	**5.005**	**33.068**
Scenario 4	4.462	3.896	21.346	23.376	175.541
EQ Loss	-	**1.352**	**4.455**	**4.919**	**32.522**
Scenario 5	4.462	3.775	20.990	22.968	172.953
EQ Loss	-	**1.473**	**4.811**	**5.327**	**35.110**
Scenario 6	4.462	3.775	20.990	23.023	173.303
EQ Loss	-	**1.473**	**4.811**	**5.272**	**34.760**

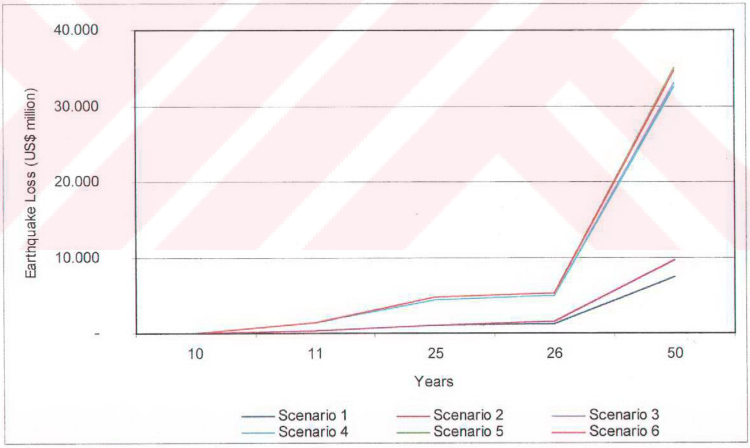


Figure 5.2 EQL (2^{nd} EQ year= 25, RP=1 year, LB)

Table 5.13 FW and EQL (2^{nd} EQ year= 25, RP=6 years, LB), US$ million

Scenarios	Years				
	10	16	25	31	50
Non-EQ	4.462	10.227	25.801	44.091	208.063
Scenario 1	4.462	9.311	23.970	41.185	195.523
EQ Loss	-	**916**	**1.831**	**2.906**	**12.540**
Scenario 2	4.462	9.311	23.970	40.269	191.570
EQ Loss	-	**916**	**1.831**	**3.822**	**16.493**
Scenario 3	4.462	7.913	20.926	35.809	171.495
EQ Loss	-	**2.314**	**4.875**	**8.282**	**36.568**
Scenario 4	4.462	7.913	20.926	36.008	172.353
EQ Loss	-	**2.314**	**4.875**	**8.083**	**35.710**
Scenario 5	4.462	7.756	20.611	35.478	170.062
EQ Loss	-	**2.471**	**5.190**	**8.613**	**38.001**
Scenario 6	4.462	7.756	20.611	35.593	170.559
EQ Loss	-	**2.471**	**5.190**	**8.498**	**37.504**

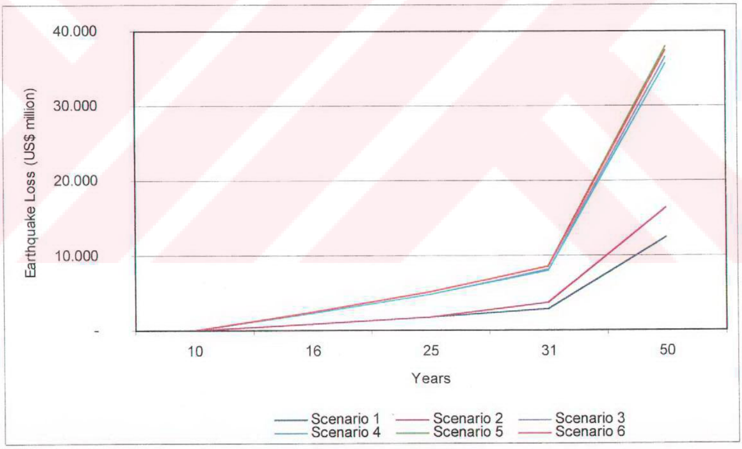


Figure 5.3 EQL (2^{nd} EQ year= 25, RP=6 years, LB)

Table 5.14 FW and EQL (2^{nd} EQ year= 25, RP=1 year, UB), US$ million

Scenarios	Years				
	10	11	25	26	50
Non-EQ	4.462	5.248	25.801	28.295	208.063
Scenario 1	4.462	3.388	20.339	22.395	170.650
EQ Loss	-	**1.860**	**5.462**	**5.900**	**37.413**
Scenario 2	4.462	3.388	20.339	20.535	158.856
EQ Loss	-	**1.860**	**5.462**	**7.760**	**49.207**
Scenario 3	4.462	2.121	16.133	16.950	134.793
EQ Loss	-	**3.127**	**9.668**	**11.345**	**73.270**
Scenario 4	4.462	2.121	16.133	17.391	137.589
EQ Loss	-	**3.127**	**9.668**	**10.904**	**70.474**
Scenario 5	4.462	1.430	14.103	15.061	122.813
EQ Loss	-	**3.818**	**11.698**	**13.234**	**85.250**
Scenario 6	4.462	1.430	14.103	15.351	124.650
EQ Loss	-	**3.818**	**11.698**	**12.944**	**83.413**

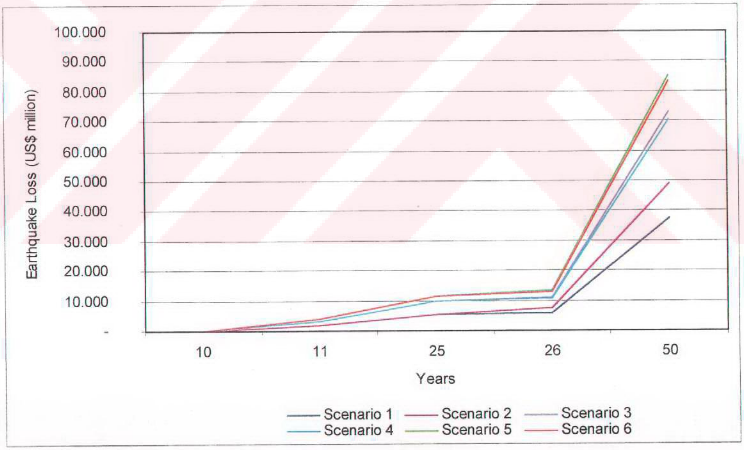


Figure 5.4 EQL (2^{nd} EQ year= 25, RP=1 year, UB)

Table 5.15 FW and EQL (2nd EQ year= 25, RP=6 years, UB), US$ million

Scenarios	Years				
	10	16	25	31	50
Non-EQ	4.462	10.227	25.801	44.091	208.063
Scenario 1	4.462	6.753	18.856	33.070	160.500
EQ Loss	-	**3.474**	**6.945**	**11.021**	**47.563**
Scenario 2	4.462	6.753	18.856	29.596	145.506
EQ Loss	-	**3.474**	**6.945**	**14.495**	**62.557**
Scenario 3	4.462	4.984	15.070	25.347	126.340
EQ Loss	-	**5.243**	**10.731**	**18.744**	**81.723**
Scenario 4	4.462	4.984	15.071	26.131	129.727
EQ Loss	-	**5.243**	**10.730**	**17.960**	**78.336**
Scenario 5	4.462	4.085	13.274	23.100	116.646
EQ Loss	-	**6.142**	**12.527**	**20.991**	**91.417**
Scenario 6	4.462	4.085	13.274	23.582	118.726
EQ Loss	-	**6.142**	**12.527**	**20.509**	**89.337**

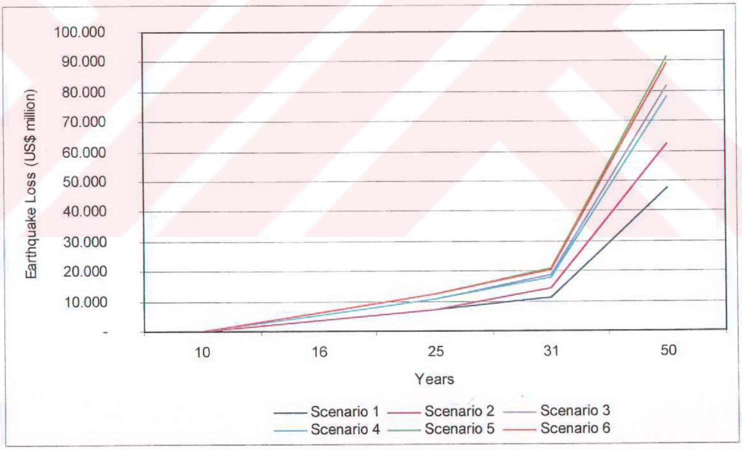


Figure 5.5 EQL (2nd EQ year= 25, RP=6 years, UB)

Table 5.16 FW and EQL (2^{nd} EQ year= 30, RP=1 year, LB), US$ million

Scenarios	Years				
	10	11	30	31	50
Non-EQ	4.462	5.248	40.428	44.091	208.063
Scenario 1	4.462	4.878	38.830	42.366	200.618
EQ Loss	**-**	**370**	**1.598**	**1.725**	**7.445**
Scenario 2	4.462	4.878	38.830	41.996	199.020
EQ Loss	**-**	**370**	**1.598**	**2.095**	**9.043**
Scenario 3	4.462	3.896	33.763	36.701	175.346
EQ Loss	**-**	**1.352**	**6.665**	**7.390**	**32.717**
Scenario 4	4.462	3.896	33.763	36.787	175.715
EQ Loss	**-**	**1.352**	**6.665**	**7.304**	**32.348**
Scenario 5	4.462	3.775	33.241	36.199	173.177
EQ Loss	**-**	**1.473**	**7.187**	**7.892**	**34.886**
Scenario 6	4.462	3.775	33.241	36.254	173.414
EQ Loss	**-**	**1.473**	**7.187**	**7.837**	**34.649**

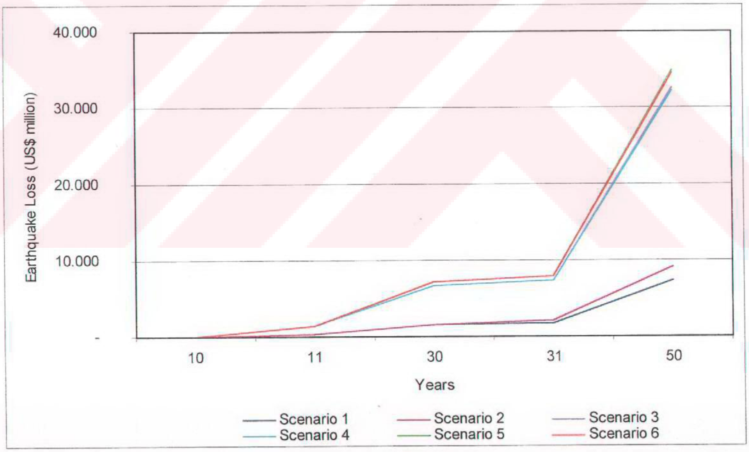


Figure 5.6 EQL (2^{nd} EQ year= 30, RP=1 year, LB)

Table 5.17 FW and EQL (2^{nd} EQ year= 30, RP=6 years, LB), US$ million

Scenarios	Years				
	10	16	30	36	50
Non-EQ	4.462	10.227	40.428	67.301	208.063
Scenario 1	4.462	9.311	37.737	63.031	195.523
EQ Loss	-	**916**	**2.691**	**4.270**	**12.540**
Scenario 2	4.462	9.311	37.737	62.115	192.832
EQ Loss	-	**916**	**2.691**	**5.186**	**15.231**
Scenario 3	4.462	7.913	33.146	55.202	172.043
EQ Loss	-	**2.314**	**7.282**	**12.099**	**36.020**
Scenario 4	4.462	7.913	33.146	55.401	172.627
EQ Loss	-	**2.314**	**7.282**	**11.900**	**35.436**
Scenario 5	4.462	7.756	32.684	54.636	170.379
EQ Loss	-	**2.471**	**7.744**	**12.665**	**37.684**
Scenario 6	4.462	7.756	32.684	54.751	170.718
EQ Loss	-	**2.471**	**7.744**	**12.550**	**37.345**

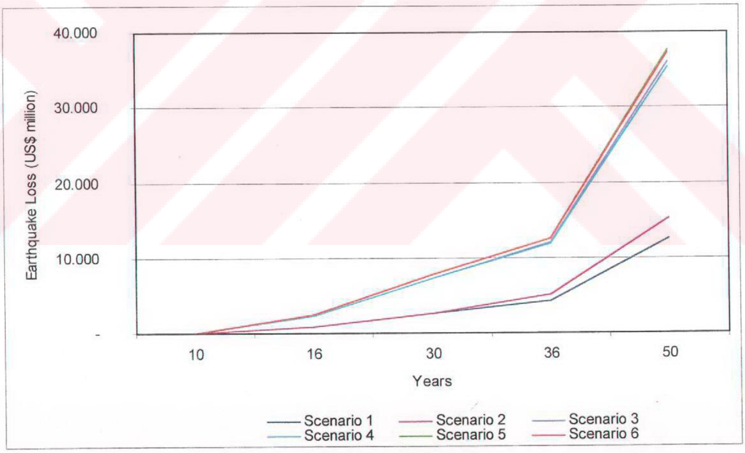


Figure 5.7 EQL (2^{nd} EQ year= 30, RP=6 years, LB)

Table 5.18 FW and EQL (2nd EQ year= 30, RP=1 year, UB), US$ million

Scenarios	Years				
	10	11	30	31	50
Non-EQ	4.462	5.248	40.428	44.091	208.063
Scenario 1	4.462	3.388	32.400	35.422	170.650
EQ Loss	**-**	**1.860**	**8.028**	**8.669**	**37.413**
Scenario 2	4.462	3.388	32.401	33.562	162.624
EQ Loss	-	**1.860**	**8.027**	**10.529**	**45.439**
Scenario 3	4.462	2.121	26.104	27.719	136.579
EQ Loss	-	**3.127**	**14.324**	**16.372**	**71.484**
Scenario 4	4.462	2.121	26.104	28.160	138.482
EQ Loss	**-**	**3.127**	**14.324**	**15.931**	**69.581**
Scenario 5	4.462	1.430	23.122	24.801	123.986
EQ Loss	-	**3.818**	**17.306**	**19.290**	**84.077**
Scenario 6	4.462	1.430	23.122	25.091	125.236
EQ Loss	-	**3.818**	**17.306**	**19.000**	**82.827**

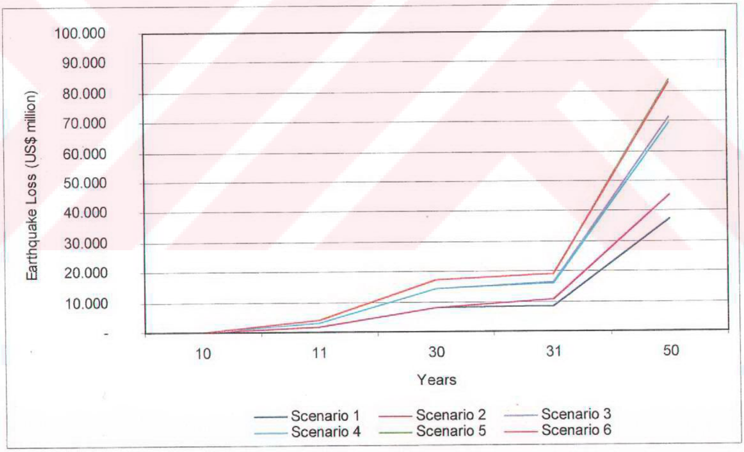


Figure 5.8 EQL (2nd EQ year= 30, RP=1 year, UB)

Table 5.19 FW and EQL (2nd EQ year= 30, RP=6 years, UB), US$ million

Scenarios	Years				
	10	16	30	36	50
Non-EQ	4.462	10.227	40.428	67.301	208.063
Scenario 1	4.462	6.753	30.223	51.107	160.500
EQ Loss	-	**3.474**	**10.205**	**16.194**	**47.563**
Scenario 2	4.462	6.753	30.223	47.633	150.296
EQ Loss	-	**3.474**	**10.205**	**19.668**	**57.767**
Scenario 3	4.462	4.984	24.543	40.379	128.504
EQ Loss	-	**5.243**	**15.885**	**26.922**	**79.559**
Scenario 4	4.462	4.984	24.543	41.163	130.808
EQ Loss	-	**5.243**	**15.885**	**26.138**	**77.255**
Scenario 5	4.462	4.085	21.903	36.794	117.975
EQ Loss	-	**6.142**	**18.525**	**30.507**	**90.088**
Scenario 6	4.462	4.085	21.903	37.276	119.391
EQ Loss	-	**6.142**	**18.525**	**30.025**	**88.672**

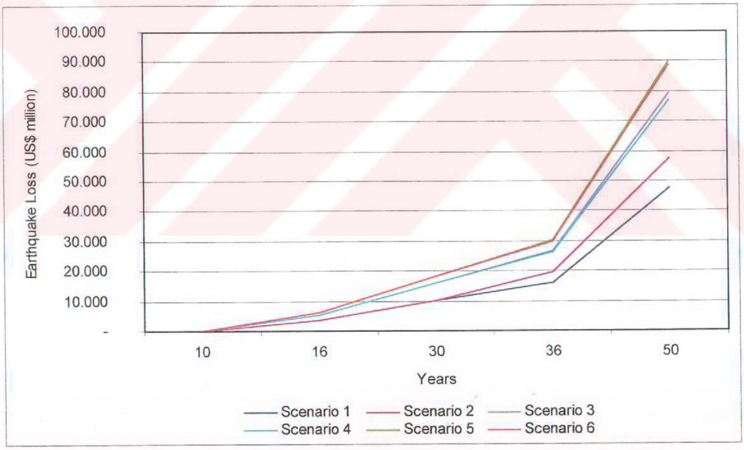


Figure 5.9 EQL (2nd EQ year= 30, RP=6 years, UB)

Table 5.20 FW and EQL (2nd EQ year= 35, RP=1 year, LB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	4.462	5.248	61.918	67.301	208.063
Scenario 1	4.462	4.878	59.571	64.766	200.618
EQ Loss	-	**370**	**2.347**	**2.535**	**7.445**
Scenario 2	4.462	4.878	59.571	64.396	199.531
EQ Loss	-	**370**	**2.347**	**2.905**	**8.532**
Scenario 3	4.462	3.896	52.009	56.407	175.581
EQ Loss	-	**1.352**	**9.909**	**10.894**	**32.482**
Scenario 4	4.462	3.896	52.009	56.493	175.833
EQ Loss	-	**1.352**	**9.909**	**10.808**	**32.230**
Scenario 5	4.462	3.775	51.242	55.640	173.328
EQ Loss	-	**1.473**	**10.676**	**11.661**	**34.735**
Scenario 6	4.462	3.775	51.242	55.695	173.490
EQ Loss	-	**1.473**	**10.676**	**11.606**	**34.573**

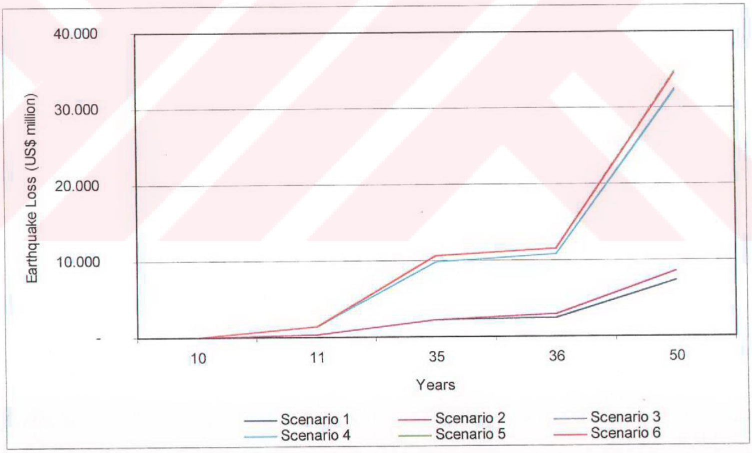


Figure 5.10 EQL (2nd EQ year= 35, RP=1 year, LB)

Table 5.21 FW and EQL (2nd EQ year= 35, RP=6 years, LB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	4.462	10.227	61.918	101.404	208.063
Scenario 1	4.462	9.311	57.965	95.130	195.523
EQ Loss	-	**916**	**3.953**	**6.274**	**12.540**
Scenario 2	4.462	9.311	57.965	94.214	193.692
EQ Loss	-	**916**	**3.953**	**7.190**	**14.371**
Scenario 3	4.462	7.913	51.102	83.696	172.416
EQ Loss	-	**2.314**	**10.816**	**17.708**	**35.647**
Scenario 4	4.462	7.913	51.102	83.895	172.813
EQ Loss	-	**2.314**	**10.816**	**17.509**	**35.250**
Scenario 5	4.462	7.756	50.423	82.785	170.595
EQ Loss	-	**2.471**	**11.495**	**18.619**	**37.468**
Scenario 6	4.462	7.756	50.423	82.900	170.826
EQ Loss	-	**2.471**	**11.495**	**18.504**	**37.237**

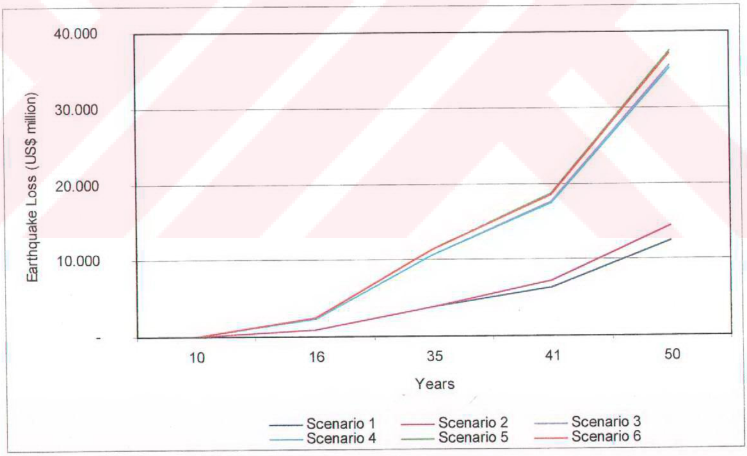


Figure 5.11 EQL (2nd EQ year= 35, RP=6 years, LB)

Table 5.22 FW and EQL (2nd EQ year= 35, RP=1 year, UB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	4.462	5.248	61.918	67.301	208.063
Scenario 1	4.462	3.388	50.124	54.563	170.650
EQ Loss	-	**1.860**	**11.794**	**12.738**	**37.413**
Scenario 2	4.462	3.388	50.124	52.703	165.187
EQ Loss	-	**1.860**	**11.794**	**14.598**	**42.876**
Scenario 3	4.462	2.121	40.755	43.542	137.795
EQ Loss	-	**3.127**	**21.163**	**23.759**	**70.268**
Scenario 4	4.462	2.121	40.755	43.983	139.090
EQ Loss	-	**3.127**	**21.163**	**23.318**	**68.973**
Scenario 5	4.462	1.430	36.373	39.112	124.785
EQ Loss	-	**3.818**	**25.545**	**28.189**	**83.278**
Scenario 6	4.462	1.430	36.373	39.402	125.635
EQ Loss	-	**3.818**	**25.545**	**27.899**	**82.428**

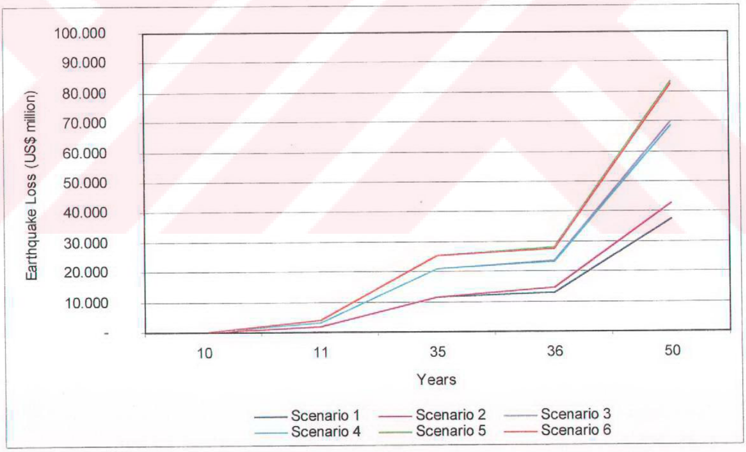


Figure 5.12 EQL (2nd EQ year= 35, RP=1 year, UB)

Table 5.23 FW and EQL (2nd EQ year= 35, RP=6 years, UB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	4.462	10.227	61.918	101.404	208.063
Scenario 1	4.462	6.753	46.924	77.610	160.500
EQ Loss	-	**3.474**	**14.994**	**23.794**	**47.563**
Scenario 2	4.462	6.753	46.924	74.136	153.555
EQ Loss	-	**3.474**	**14.994**	**27.268**	**54.508**
Scenario 3	4.462	4.984	38.462	62.465	129.976
EQ Loss	-	**5.243**	**23.456**	**38.939**	**78.087**
Scenario 4	4.462	4.984	38.462	63.250	131.544
EQ Loss	-	**5.243**	**23.456**	**38.154**	**76.519**
Scenario 5	4.462	4.085	34.583	56.914	118.880
EQ Loss	-	**6.142**	**27.335**	**44.490**	**89.183**
Scenario 6	4.462	4.085	34.583	57.397	119.844
EQ Loss	-	**6.142**	**27.335**	**44.007**	**88.219**

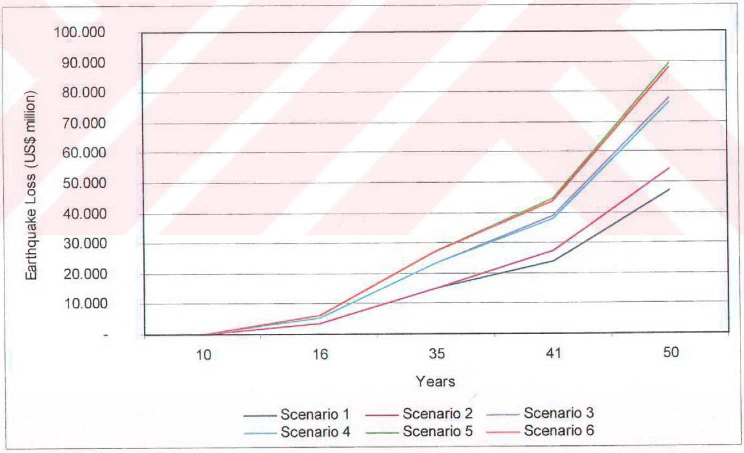


Figure 5.13 EQL (2nd EQ year= 35, RP=6 years, UB)

Table 5.24 FW and EQL (2^{nd} EQ year= 40, RP=1 year, LB), US$ million

Scenarios	Years				
	10	11	40	41	50
Non-EQ	4.462	5.248	93.495	101.404	208.063
Scenario 1	4.462	4.878	90.046	97.679	200.618
EQ Loss	-	**370**	**3.449**	**3.725**	**7.445**
Scenario 2	4.462	4.878	90.046	97.309	199.878
EQ Loss	-	**370**	**3.449**	**4.095**	**8.185**
Scenario 3	4.462	3.896	78.818	85.360	175.742
EQ Loss	-	**1.352**	**14.677**	**16.044**	**32.321**
Scenario 4	4.462	3.896	78.818	85.446	175.914
EQ Loss	-	**1.352**	**14.677**	**15.958**	**32.149**
Scenario 5	4.462	3.775	77.690	84.204	173.432
EQ Loss	-	**1.473**	**15.805**	**17.200**	**34.631**
Scenario 6	4.462	3.775	77.690	84.259	173.542
EQ Loss	-	**1.473**	**15.805**	**17.145**	**34.521**

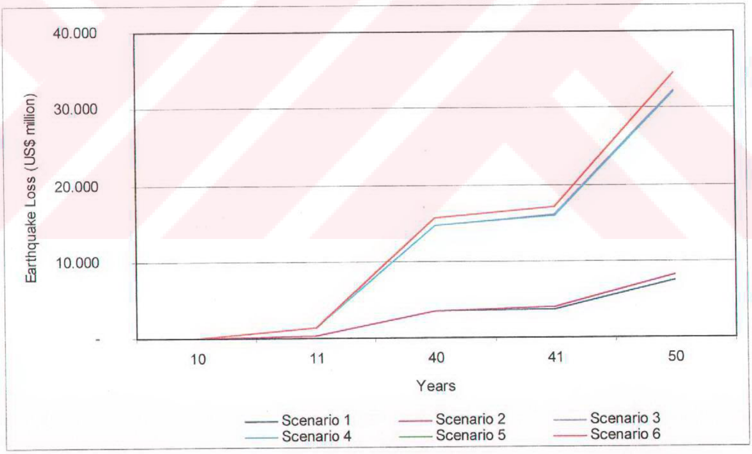


Figure 5.14 EQL (2^{nd} EQ year= 40, RP=1 year, LB)

Table 5.25 FW and EQL (2^{nd} EQ year= 40, RP=6 years, LB), US$ million

Scenarios	Years				
	10	16	40	46	50
Non-EQ	4.462	10.227	93.495	151.512	208.063
Scenario 1	4.462	9.311	87.686	142.294	195.523
EQ Loss	-	**916**	**5.809**	**9.218**	**12.540**
Scenario 2	4.462	9.311	87.686	141.378	194.277
EQ Loss	-	**916**	**5.809**	**10.134**	**13.786**
Scenario 3	4.462	7.913	77.486	125.563	172.670
EQ Loss	-	**2.314**	**16.009**	**25.949**	**35.393**
Scenario 4	4.462	7.913	77.486	125.761	172.940
EQ Loss	-	**2.314**	**16.009**	**25.751**	**35.123**
Scenario 5	4.462	7.756	76.488	124.146	170.742
EQ Loss	-	**2.471**	**17.007**	**27.366**	**37.321**
Scenario 6	4.462	7.756	76.488	124.261	170.899
EQ Loss	-	**2.471**	**17.007**	**27.251**	**37.164**

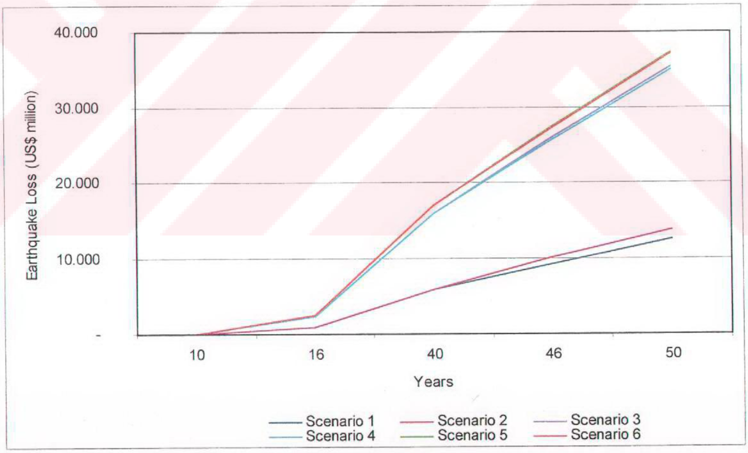


Figure 5.15 EQL (2^{nd} EQ year= 40, RP=6 years, LB)

Table 5.26 FW and EQL (2nd EQ year= 40, RP=1 year, UB), US$ million

Scenarios	Years				
	10	11	40	41	50
Non-EQ	4.462	5.248	93.495	101.404	208.063
Scenario 1	4.462	3.388	76.166	82.688	170.650
EQ Loss	-	**1.860**	**17.329**	**18.716**	**37.413**
Scenario 2	4.462	3.388	76.166	80.828	166.932
EQ Loss	-	**1.860**	**17.329**	**20.576**	**41.131**
Scenario 3	4.462	2.121	62.281	66.791	138.622
EQ Loss	-	**3.127**	**31.214**	**34.613**	**69.441**
Scenario 4	4.462	2.121	62.281	67.232	139.504
EQ Loss	-	**3.127**	**31.214**	**34.172**	**68.559**
Scenario 5	4.462	1.430	55.843	60.140	125.328
EQ Loss	-	**3.818**	**37.652**	**41.264**	**82.735**
Scenario 6	4.462	1.430	55.843	60.430	125.907
EQ Loss	-	**3.818**	**37.652**	**40.974**	**82.156**

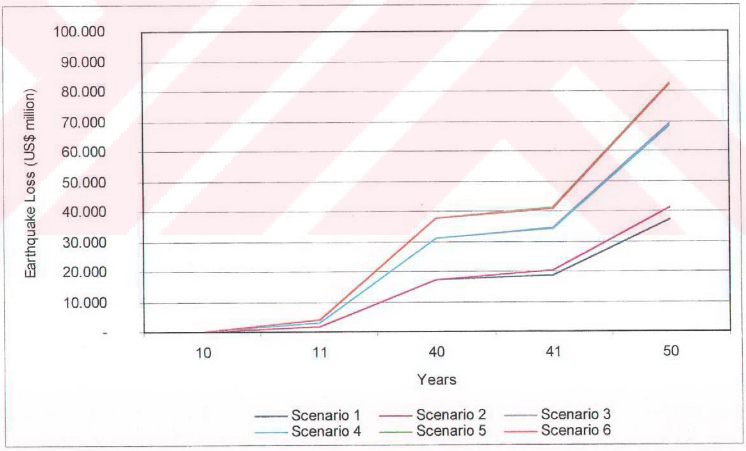


Figure 5.16 EQL (2nd EQ year= 40, RP=1 year, UB)

Table 5.27 FW and EQL (2nd EQ year= 40, RP=6 years, UB), US$ million

Scenarios	Years				
	10	16	40	46	50
Non-EQ	4.462	10.227	93.495	151.512	208.063
Scenario 1	4.462	6.753	71.464	116.552	160.500
EQ Loss	-	**3.474**	**22.031**	**34.960**	**47.563**
Scenario 2	4.462	6.753	71.464	113.077	155.774
EQ Loss	-	**3.474**	**22.031**	**38.435**	**52.289**
Scenario 3	4.462	4.984	58.913	94.918	130.978
EQ Loss	-	**5.243**	**34.582**	**56.594**	**77.085**
Scenario 4	4.462	4.984	58.913	95.703	132.045
EQ Loss	-	**5.243**	**34.582**	**55.809**	**76.018**
Scenario 5	4.462	4.085	53.213	86.478	119.495
EQ Loss	-	**6.142**	**40.282**	**65.034**	**88.568**
Scenario 6	4.462	4.085	53.213	86.960	120.151
EQ Loss	-	**6.142**	**40.282**	**64.552**	**87.912**

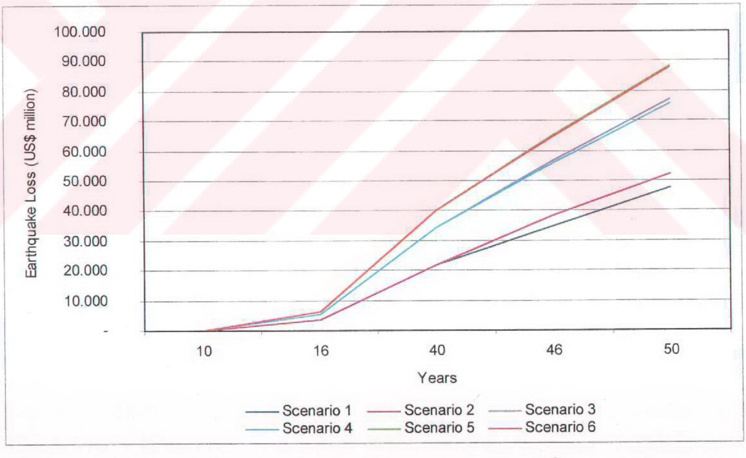


Figure 5.17 EQL (2nd EQ year= 40, RP=6 years, UB)

5.2.3. Effect of Interest Rate

In the previous scenarios, the interest rate is kept constant throughout the analysis period. However, the interest rate is one of the important parameters in a decision making process. Therefore, it would be valuable to evaluate the effect of interest rate on the earthquake loss. The Central Bank of the Republic of Turkey (2001) provided a range of interest rates for a period of 1990-2001 as shown in Table 5.28. By taking the information provided by the Central Bank, it is decided that earthquake loss is evaluated against the interest rates of 4 and 12 per cent in order to show the effect of low and high interest rates. Therefore, each scenario is also evaluated for the interest rates of 4 and 12 per cent assuming that the second earthquake occurs at year 35 of the analysis period. Results are shown in Tables 5.29-5.36 and Figures 5.18-5.25.

Table 5.28 Interest Rates by Central Bank of the Republic of Turkey

Year	Interest Rate, %	Year	Interest Rate, %
1990	8.1303	1996	7.3179
1991	8.9307	1997	8.0755
1992	4.9324	1998	10.0816
1993	4.2333	1999	12.4923
1994	4.9865	2000	10.7658
1995	6.1038	2001	13.0505

Table 5.29 FW and EQL (2nd EQ year=35, RP=1 year, i=4%, LB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	3.949	4.536	28.393	29.957	59.724
Scenario 1	3.949	4.168	27.450	28.977	58.027
EQ Loss	-	**368**	**943**	**980**	**1.697**
Scenario 2	3.949	4.168	27.450	28.610	57.390
EQ Loss	-	**368**	**943**	**1.347**	**2.334**
Scenario 3	3.949	3.186	24.152	25.356	51.389
EQ Loss	-	**1.350**	**4.241**	**4.601**	**8.335**
Scenario 4	3.949	3.186	24.152	25.441	51.537
EQ Loss	-	**1.350**	**4.241**	**4.516**	**8.187**
Scenario 5	3.949	3.065	23.841	25.094	50.937
EQ Loss	-	**1.471**	**4.552**	**4.863**	**8.787**
Scenario 6	3.949	3.065	23.841	25.149	51.032
EQ Loss	-	**1.471**	**4.552**	**4.808**	**8.692**

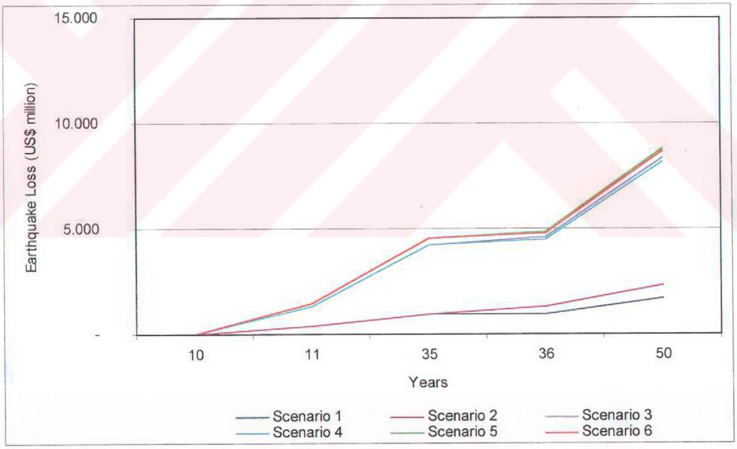


Figure 5.18 EQL (2nd EQ year=35, RP=1 year, i=4%, LB)

Table 5.30 FW and EQL (2^{nd} EQ year=35, RP=6 years, i=4%, LB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	3.949	7.842	28.393	38.771	59.724
Scenario 1	3.949	7.050	26.725	36.661	56.720
EQ Loss	-	**792**	**1.668**	**2.110**	**3.004**
Scenario 2	3.949	7.050	26.725	35.869	55.593
EQ Loss	-	**792**	**1.668**	**2.902**	**4.131**
Scenario 3	3.949	5.819	23.578	32.203	50.163
EQ Loss	-	**2.023**	**4.815**	**6.568**	**9.561**
Scenario 4	3.949	5.819	23.578	32.375	50.407
EQ Loss	-	**2.023**	**4.815**	**6.396**	**9.317**
Scenario 5	3.949	5.681	23.287	31.979	49.844
EQ Loss	-	**2.161**	**5.106**	**6.792**	**9.880**
Scenario 6	3.949	5.681	23.287	32.079	49.986
EQ Loss	-	**2.161**	**5.106**	**6.692**	**9.738**

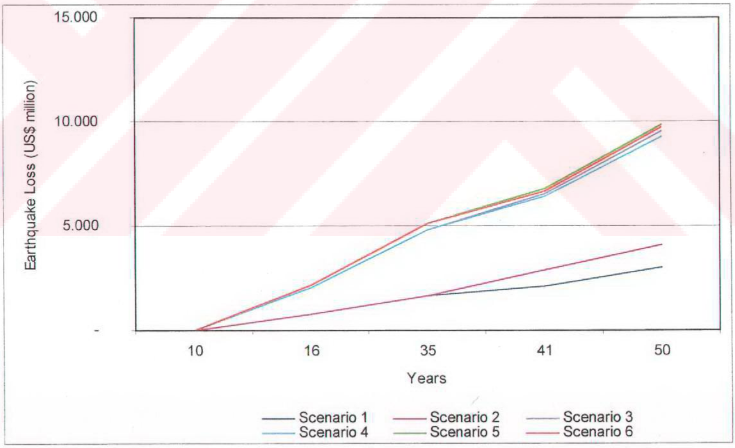


Figure 5.19 EQL (2^{nd} EQ year=35, RP=6 years, i=4%, LB)

Table 5.31 FW and EQL (2^{nd} EQ year=35, RP=1 year, i=4%, UB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	3.949	4.536	28.393	29.957	59.724
Scenario 1	3.949	2.681	23.638	25.012	51.160
EQ Loss	-	**1.855**	**4.755**	**4.945**	**8.564**
Scenario 2	3.949	2.681	23.638	23.157	47.948
EQ Loss	-	**1.855**	**4.755**	**6.800**	**11.776**
Scenario 3	3.949	1.414	19.608	19.922	41.979
EQ Loss	-	**3.122**	**8.785**	**10.035**	**17.745**
Scenario 4	3.949	1.414	19.608	20.362	42.741
EQ Loss	-	**3.122**	**8.785**	**9.595**	**16.983**
Scenario 5	3.949	723	17.837	18.381	39.312
EQ Loss	-	**3.813**	**10.556**	**11.576**	**20.412**
Scenario 6	3.949	723	17.837	18.671	39.813
EQ Loss	-	**3.813**	**10.556**	**11.286**	**19.911**

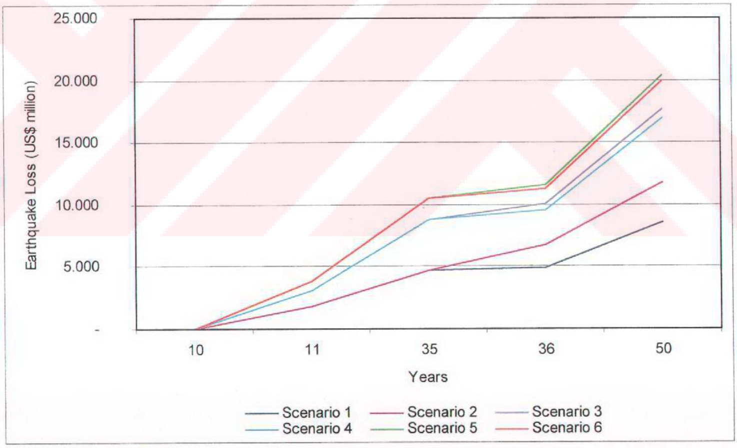


Figure 5.20 EQL (2^{nd} EQ year=35, RP=1 year, i=4%, UB)

Table 5.32 FW and EQL (2^{nd} EQ year=35, RP=6 years, i=4%, UB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	3.949	7.842	28.393	38.771	59.724
Scenario 1	3.949	4.819	22.023	30.712	48.253
EQ Loss	-	**3.023**	**6.370**	**8.059**	**11.471**
Scenario 2	3.949	4.819	22.023	27.689	43.950
EQ Loss	-	**3.023**	**6.370**	**11.082**	**15.774**
Scenario 3	3.949	3.262	18.191	24.363	39.005
EQ Loss	-	**4.580**	**10.202**	**14.408**	**20.719**
Scenario 4	3.949	3.262	18.191	25.047	39.978
EQ Loss	-	**4.580**	**10.202**	**13.724**	**19.746**
Scenario 5	3.949	2.474	16.529	22.786	36.760
EQ Loss	-	**5.368**	**11.864**	**15.985**	**22.964**
Scenario 6	3.949	2.474	16.529	23.207	37.359
EQ Loss	-	**5.368**	**11.864**	**15.564**	**22.365**

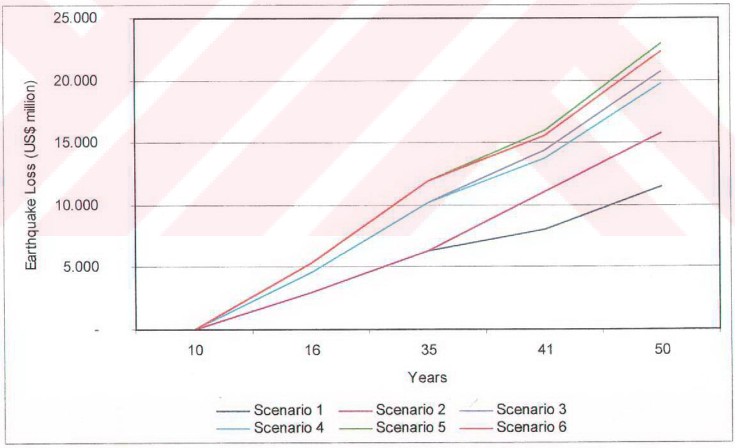


Figure 5.21 EQL (2^{nd} EQ year=35, RP=6 years, i=4%, UB)

Table 5.33 FW and EQL (2nd EQ year=35, RP=1 year, i=12%, LB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	5.006	6.036	142.310	159.817	794.938
Scenario 1	5.006	5.664	136.654	153.481	763.975
EQ Loss	-	**372**	**5.656**	**6.336**	**30.963**
Scenario 2	5.006	5.664	136.654	153.108	762.154
EQ Loss	-	**372**	**5.656**	**6.709**	**32.784**
Scenario 3	5.006	4.682	119.385	133.947	667.864
EQ Loss	-	**1.354**	**22.925**	**25.870**	**127.074**
Scenario 4	5.006	4.682	119.385	134.034	668.286
EQ Loss	-	**1.354**	**22.925**	**25.783**	**126.652**
Scenario 5	5.006	4.561	117.548	131.953	658.115
EQ Loss	-	**1.475**	**24.762**	**27.864**	**136.823**
Scenario 6	5.006	4.561	117.548	132.008	658.386
EQ Loss	-	**1.475**	**24.762**	**27.809**	**136.552**

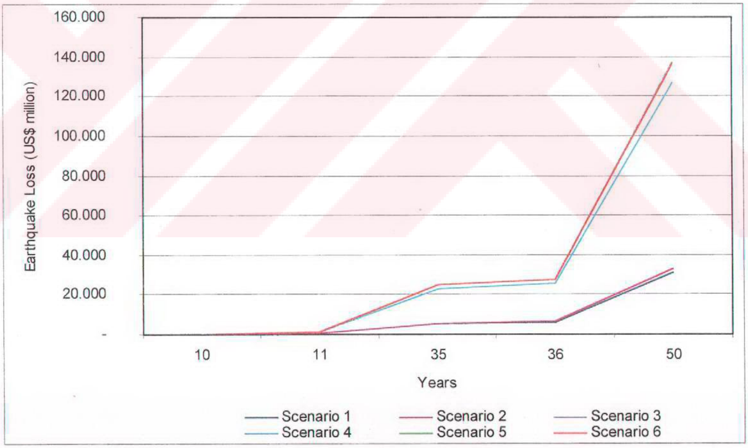


Figure 5.22 EQL (2nd EQ year=35, RP=1 year, i=12%, LB)

Table 5.34 FW and EQL (2nd EQ year=35, RP=6 years, i=12%, LB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	5.006	13.363	142.310	284.377	794.938
Scenario 1	5.006	12.306	133.204	266.402	745.092
EQ Loss	-	**1.057**	**9.106**	**17.975**	**49.846**
Scenario 2	5.006	12.306	133.204	265.345	742.160
EQ Loss	-	**1.057**	**9.106**	**19.032**	**52.778**
Scenario 3	5.006	10.721	118.281	236.326	661.393
EQ Loss	-	**2.642**	**24.029**	**48.051**	**133.545**
Scenario 4	5.006	10.721	118.281	236.555	662.028
EQ Loss	-	**2.642**	**24.029**	**47.822**	**132.910**
Scenario 5	5.006	10.542	116.739	233.476	653.491
EQ Loss	-	**2.821**	**25.571**	**50.901**	**141.447**
Scenario 6	5.006	10.542	116.739	233.609	653.858
EQ Loss	-	**2.821**	**25.571**	**50.768**	**141.080**

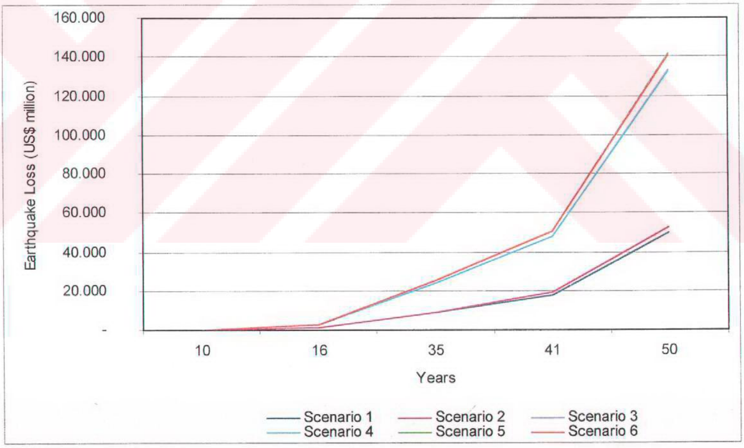


Figure 5.23 EQL (2nd EQ year=35, RP=6 years, i=12%, LB)

Table 5.35 FW and EQL (2nd EQ year=35, RP=1 year, i=12%, UB), US$ million

Scenarios	Years				
	10	11	35	36	50
Non-EQ	5.006	6.036	142.310	159.817	794.938
Scenario 1	5.006	4.171	114.004	128.114	640.002
EQ Loss	-	**1.865**	**28.306**	**31.703**	**154.936**
Scenario 2	5.006	4.171	114.004	126.249	630.888
EQ Loss	-	**1.865**	**28.306**	**33.568**	**164.050**
Scenario 3	5.006	2.904	92.410	103.024	516.737
EQ Loss	-	**3.132**	**49.900**	**56.793**	**278.201**
Scenario 4	5.006	2.904	92.410	103.466	518.897
EQ Loss	-	**3.132**	**49.900**	**56.351**	**276.041**
Scenario 5	5.006	2.213	81.921	91.581	460.813
EQ Loss	-	**3.823**	**60.389**	**68.236**	**334.125**
Scenario 6	5.006	2.213	81.921	91.871	462.231
EQ Loss	-	**3.823**	**60.389**	**67.946**	**332.707**

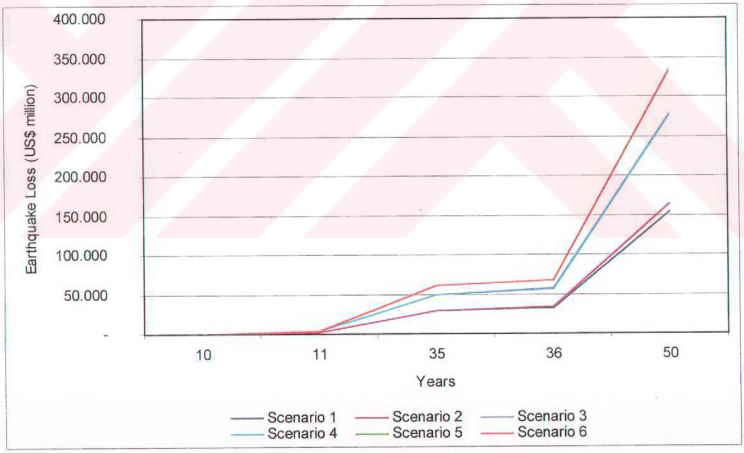


Figure 5.24 EQL (2nd EQ year=35, RP=1 year, i=12%, UB)

Table 5.36 FW and EQL (2nd EQ year=35, RP=6 years, i=12%, UB), US$ million

Scenarios	Years				
	10	16	35	41	50
Non-EQ	5.006	13.363	142.310	284.377	794.938
Scenario 1	5.006	9.380	108.000	216.654	607.137
EQ Loss	-	**3.983**	**34.310**	**67.723**	**187.801**
Scenario 2	5.006	9.380	108.000	212.670	596.090
EQ Loss	-	**3.983**	**34.310**	**71.707**	**198.848**
Scenario 3	5.006	7.373	89.446	178.071	499.849
EQ Loss	-	**5.990**	**52.864**	**106.306**	**295.089**
Scenario 4	5.006	7.373	89.446	178.970	502.342
EQ Loss	-	**5.990**	**52.864**	**105.407**	**292.596**
Scenario 5	5.006	6.350	80.642	161.389	453.587
EQ Loss	-	**7.013**	**61.668**	**122.988**	**341.351**
Scenario 6	5.006	6.350	80.642	161.940	455.117
EQ Loss	-	**7.013**	**61.668**	**122.437**	**339.821**

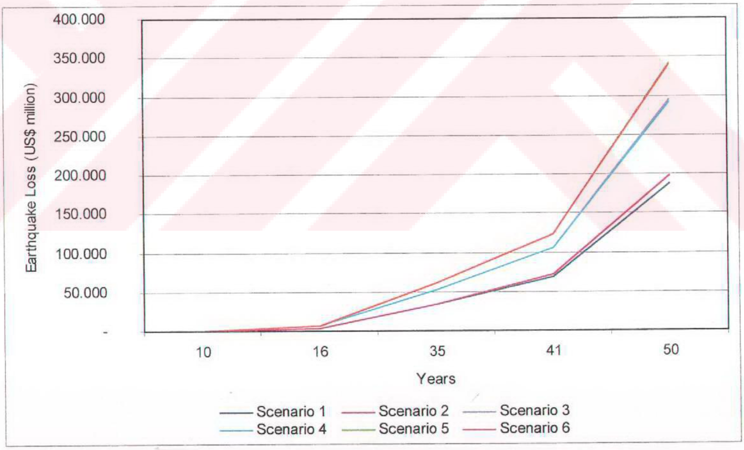


Figure 5.25 EQL (2nd EQ year=35, RP=6 years, i=12%, UB)

5.3. Results

In the application of the model to an actual case of Adapazarı, six scenarios are created to analyze the earthquake loss on the cost of the town. Each scenario is evaluated for the lower and upper bounds of input parameters since there are no exact cost values available. Recovery periods of 1 and 6 years are considered to observe the effects of recovery period on the earthquake loss. For all scenarios earthquake losses are determined at year 50. Earthquake loss of Scenario 2 having recovery period of 1 year, an interest rate of 8 per cent and the occurrence of the second earthquake at year 25 is accepted as a special case. In the comparison of the earthquake losses of each scenario against recovery period, interest rate and the occurrence year of the second earthquake, this special case is accepted as a base. The ratios to show the increases in earthquake losses are determined by dividing the earthquake loss of each scenario to earthquake loss of the special case. The increases in the lower and upper bounds of earthquake losses are presented in Table 5.37. The results are as follows:

- In all scenarios longer recovery periods result in high earthquake losses.
- The occurrence year of the second earthquake at late stage of the analysis period decreases the earthquake losses at the end of 50 years.
- In the comparison of the scenarios with each other, Scenario 5 (2 EQs; retrofitting and soil improvement after the first EQ and repairing after the Second EQ) produces the highest earthquake loss.
- Interest rates, 4, 8 and 12 per cent are considered for the effects of interest rates. Assuming the special case as a base it is seen that high interest rates increase the earthquake losses (see Tables 5.38 and 5.39).

Table 5.37 Ratios of Increases in Earthquake Losses, i=8%

Year of the Second EQ	Scenarios	Recovery Periods, years			
		Lower Bound		Upper Bound	
		1	6	1	6
25	1	0,76	1,28	0,76	0,97
	2	**1,00***	1,68	**1,00****	1,27
	3	3,38	3,73	1,49	1,66
	4	3,32	3,65	1,43	1,59
	5	3,59	3,88	1,73	1,86
	6	3,55	3,83	1,70	1,82
30	1	0,76	1,28	0,76	0,97
	2	0,92	1,56	0,92	1,17
	3	3,34	3,68	1,45	1,62
	4	3,30	3,62	1,41	1,57
	5	3,56	3,85	1,71	1,83
	6	3,54	3,81	1,68	1,80
35	1	0,76	1,28	0,76	0,97
	2	0,87	1,47	0,87	1,11
	3	3,32	3,64	1,43	1,59
	4	3,29	3,60	1,40	1,56
	5	3,55	3,83	1,69	1,81
	6	3,53	3,80	1,68	1,79
40	1	0,76	1,28	0,76	0,97
	2	0,84	1,41	0,84	1,06
	3	3,30	3,61	1,41	1,57
	4	3,28	3,59	1,39	1,54
	5	3,54	3,81	1,68	1,80
	6	3,53	3,80	1,67	1,79

* Earthquake Loss=US$ 9.792 million.

** Earthquake Loss=US$ 49.207 million

Table 5.38 Ratios of Increases in Earthquake Losses, i=4%

Year of the Second EQ	Scenarios	Recovery Periods, years			
		Lower Bound		Upper Bound	
		1	6	1	6
35	1	0,17	0,31	0,17	0,23
	2	0,24	0,42	0,24	0,32
	3	0,85	0,98	0,36	0,42
	4	0,84	0,95	0,35	0,40
	5	0,90	1,01	0,41	0,47
	6	0,89	0,99	0,40	0,45

Table 5.39 Ratios of Increases in Earthquake Losses, i=12%

Year of the Second EQ	Scenarios	Recovery Periods, years			
		Lower Bound		Upper Bound	
		1	6	1	6
35	1	3,16	5,09	3,15	3,82
	2	3,35	5,39	3,33	4,04
	3	12,98	13,64	5,65	6,00
	4	12,93	13,57	5,61	5,95
	5	13,97	14,45	6,79	6,94
	6	13,95	14,41	6,76	6,91

CHAPTER 6

CONCLUSIONS

This research work is undertaken to estimate earthquake loss for a town in seismic zone using a life cycle cost model. A town is accepted as an asset in national economics' point of view, with its revenues and expenditures. However, the aim is not to consider a town as an asset, which is worth for investment. It is intended to provide optimum solution for a town to recover from earthquakes with the least earthquake loss.

Earthquakes cause economic and social impacts in society. This study concerns only the economic aspect of earthquakes. However, as far as human life is concerned, the social aspect of earthquakes is more important than its economical effect. Saving human life during an earthquake is primary concern of all parties involved in the mitigation of earthquake damages. Building codes and regulations are designed to prevent human loss even in heavy earthquakes.

A life cycle cost model is developed in this study to compute earthquake loss for a town under earthquake, so that, decision-makers define a strategy to cope with earthquakes at minimum economic loss. Nevertheless, social aspect should not be ignored in making a decision. The LCC model combines all the costs and benefits of a town under earthquake risk. Initial cost and annual expenditures are considered as costs and economic value as benefits of a town without concerning the occurrence of an earthquake. Recovery cost and disaster cost are introduced to the model when an earthquake occurs.

Initial cost of a town, in the model, refers to the land and construction cost of the technical and social facilities required accommodating a certain population.

Annual expenditures are needed for the growth of a town and consist of public and private investments and maintenance cost. Economic value, for the survival of a town, includes revenues from different sources.

Earthquakes cause direct and indirect losses. The cost of these losses are considered in the model as disaster cost which includes supply cost (emergency aids, temporary accommodation etc.), economic loss due to disruption in enterprises and physical damage cost due to damage on structures. It is desired that the recovery from the earthquakes should be as quick as possible for the sake of resuming normal life. Recovery cost in the model concerns all the cost required for the recovery of the damaged structures. The length of recovery period depends on the resources available for the recovery. In the model, damaged structures are classified as lightly, moderately and heavily damaged and they are recovered by either repairing or retrofitting or reconstructing. In addition, in the case of that structures are damaged by ground failure such as liquefaction, the cost of soil improvement is also included in the model.

The LCC model analyzes the benefits and costs (revenues and expenditures) of a town for an analysis period of 50 years which is long enough to cover two earthquakes. In Turkey, it is observed that there is approximately 30 years period of time between two major earthquakes. A time of 50 years satisfactorily covers this period with sufficient beginning and final time lengths. However, the model allows the user to change the analysis period. Cost effective parameters in this study are accepted as recovery period, initial cost, interest rate and earthquake pattern (occurrence year of the second earthquake). Although the earthquake loss can be computed at any year of the analysis period, the earthquake loss at year 50 is taken into consideration in the evaluation of the parameters and the case study.

In the evaluation of the parameters four cases are created in order to analyze earthquake loss for different situations. All cases assume that the first earthquake occurs at year 10. The first case considers the occurrence of only one earthquake while the second case includes two earthquakes throughout the analysis period. In both cases the structures damaged after the earthquakes are only repaired, i.e. they are brought to their previous conditions. The third and fourth cases also cover two earthquakes. But, in the third case the damaged structures are retrofitted, i.e. they are brought to better conditions, while the fourth case considers retrofitting and soil improvement after the first earthquake. Both cases assume that damaged structures are only repaired after the second earthquake. The results of the evaluation show that;

- Longer recovery periods increase the earthquake loss. For example, in Case 1 and Case 2, a recovery period of 6 years increases the earthquake loss as 67 per cent when it is compared with a recovery period of 1 year. This increase is 56 per cent in Case 3 and 48 per cent in Case 4. Figure 6.1 shows average ratios of increases in earthquake loss for all cases against recovery periods. For example, increasing recovery period from 1 to 6 years causes an increase in earthquake loss as 1.60 times (60 per cent).

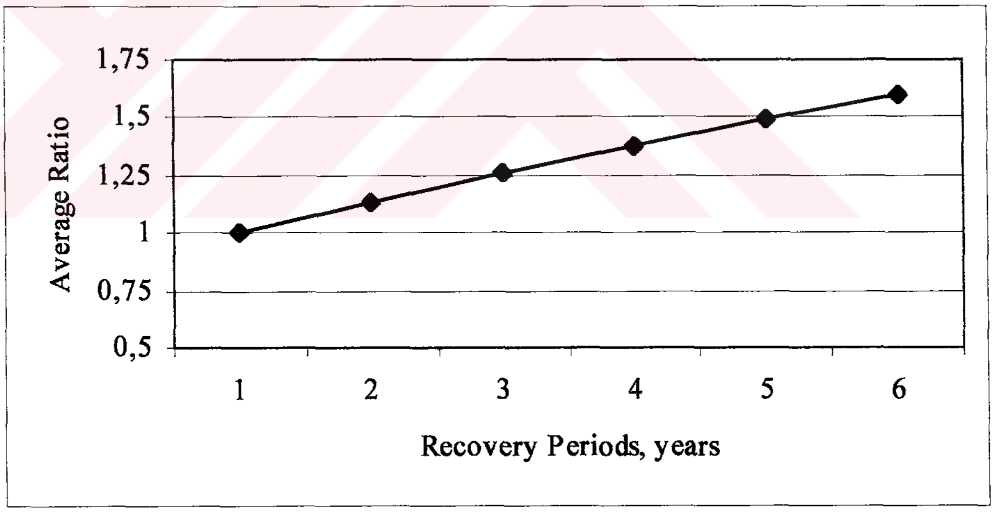


Figure 6.1 Average Ratio of Increases in EQ Loss against Recovery Period

- An increase in initial cost means the construction of more resistant structures and new developments with more open areas and results in less earthquake cost. If the initial cost is increased as 25 per cent or 50 per cent, the earthquake cost is reduced as 50 percent or 75 percent, respectively. Earthquake loss for the initial cost of US$ 2.000 million is assumed to be 1,0 and average ratio of decreases in earthquake loss against initial cost is shown in Figure 6.2.

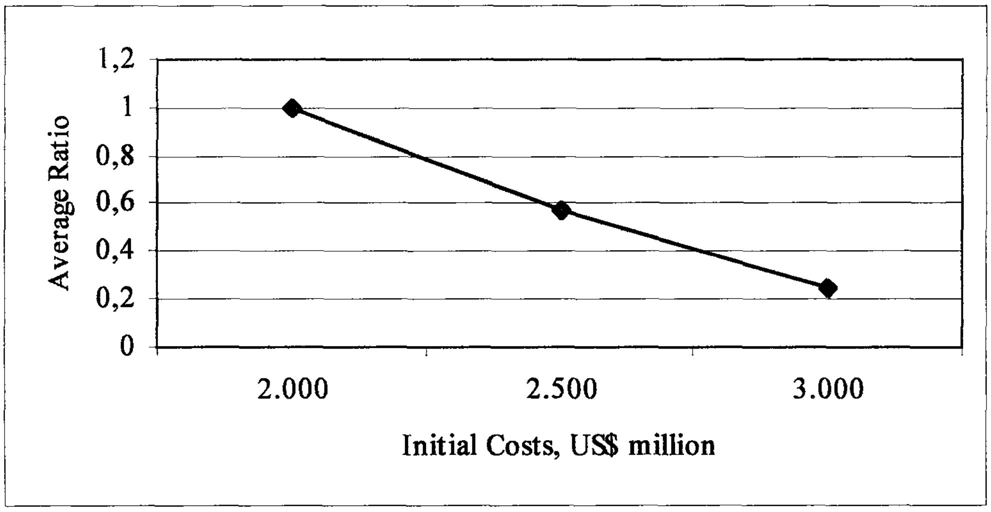


Figure 6.2 Average Ratio of Decreases in EQ Loss against Initial Cost

- Higher interest rates also increase the earthquake loss. The increase in the earthquake loss for an interest rate of 12 per cent is about 16 times higher than the earthquake loss for 4 per cent. Assuming that earthquake loss for the interest rate of 4 per cent is 1,0, Figure 6.3 presents average ratios of increases in earthquake loss against interest rate.

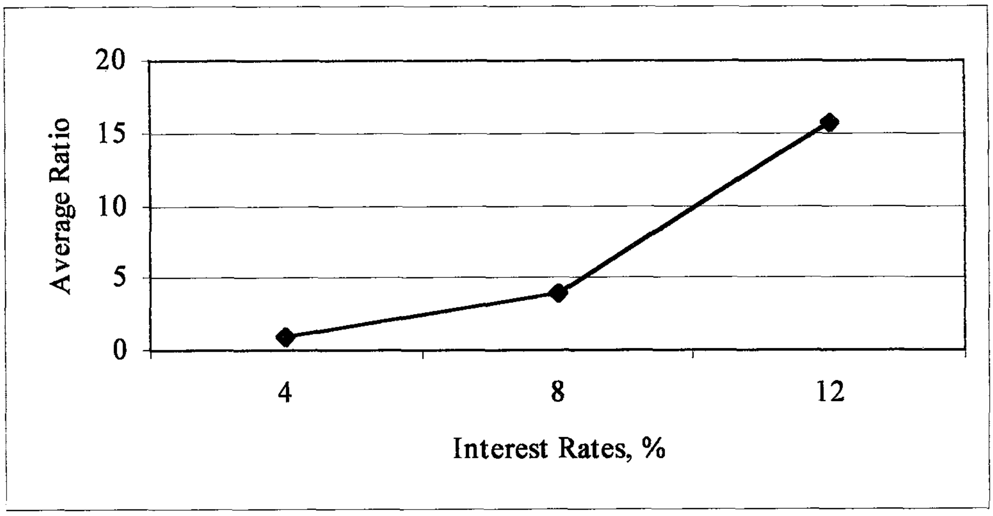


Figure 6.3 Average Ratio of Increases in EQ Loss against Interest Rate

- The occurrence year of the second earthquake is also effective on the earthquake loss. A late occurrence of the second earthquake decreases the earthquake loss at the end of the analysis period. If the second earthquake occurs at year 40 the earthquake loss decreases about 84 to 96 per cent for different cases when earthquake loss of 25th year is assumed to be 1,0. This decrease is about 92 to 98 per cent at year 30. Figure 6.4 shows average ratios of decreases in earthquake Loss against earthquake pattern.

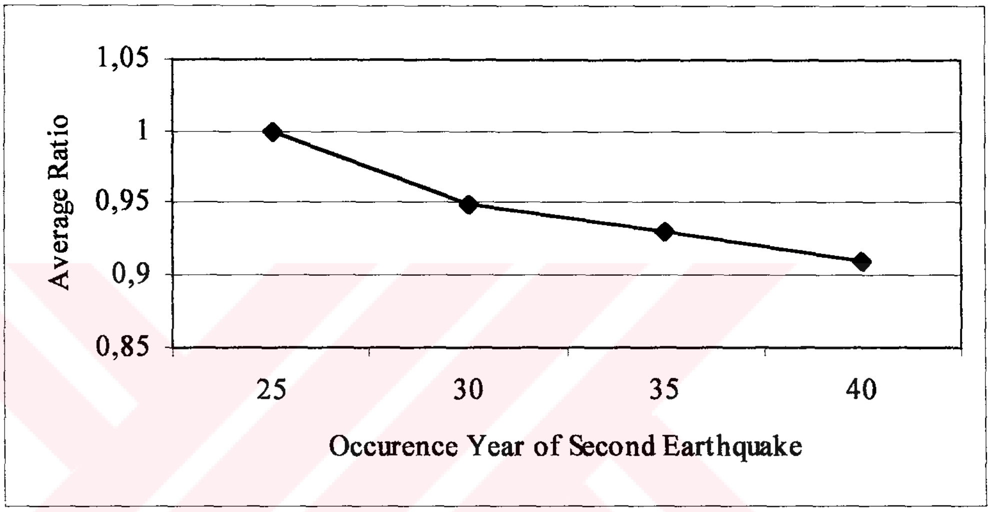


Figure 6.4 Average Ratio of Decreases in EQ Loss against EQ Pattern.

A case study is also carried out to apply the model to an actual case and Adapazarı is chosen as a pilot area. Data required by the model is collected from Adapazarı. Because of the difficulties in finding reliable exact data as required by the model, it is preferred to use lower and upper values of input data obtained from various sources to have a boundary of the results.

Six scenarios are created in order to analyze earthquake losses against cost-effective parameters. Scenario 1 includes 1 earthquake, which occurs at year 10 of the analysis period and structures damaged after the earthquake are only repaired. All other scenarios assume the occurrence of two earthquakes within the analysis period. It is also assumed that the first earthquake occurs at year 10 and the structures damaged after the second earthquake are only repaired. In Scenario 2 the structures damaged after the first earthquake is also repaired while they are retrofitted in

Scenarios 3 and 4. However, in Scenario 4, the magnitude of the second earthquake is smaller than that in Scenario 3. The fifth and sixth scenarios consider the retrofitting and soil improvement of the structures after the first earthquake. The second earthquake in Scenario 6 has a smaller magnitude than that in Scenario 5. The results of the case study are given below. These results are valid as far as input values in this case study are concerned. One may get different results for different input values.

- A recovery period of 6 years increases the earthquake loss as 68 per cent in lower bounds of Scenarios 1 and 2 and as about 10 per cent in other scenarios when compared to a recovery period of 1 year. This increase in upper bounds is 27 per cent in Scenarios 1 and 2, and about 10 per cent in other Scenarios.

- The occurrence year of the second earthquake does not have a significant effect on the earthquake loss at year 50 although late occurrence decreases earthquake loss. However, if earthquake loss at any other time of analysis period, for example, at the end of the second recovery period, is considered, this effect may be more significant.

- In the comparison of the scenarios with each other, as it is seen in Tables 6.1 and 6.2, average ratio of increases in the earthquake loss for retrofitting is 3,48 when earthquake loss for repairing is taken as 1,0. This ratio for retrofitting + soil improvement is 3,69. Retrofitting + soil improvement increases the earthquake loss by 6 per cent in lower bound compared to retrofitting only. In upper bound average ratio of increases in the earthquake loss for retrofitting is 1,51 times of earthquake loss for only repairing. The average ratio of increases for retrofitting + soil improvement is 1,76 times higher than the earthquake loss of repairing. Retrofitting + soil improvement increases the earthquake loss by 17 per cent in lower bound compared to retrofitting only.

Table 6.1 Ratios of Increases in EQ Loss, Lower Bound

Occurrence Year of The Second EQ	Repair	Retrofit	Retrofit + Soil Improvement
25	1	3,52	3,71
30	1	3,49	3,69
35	1	3,46	3,68
40	1	3,44	3,67
Average	1	3,48	3,69

Table 6.2 Ratios of Increases in EQ Loss, Upper Bound

Occurrence Year of The Second EQ	Repair	Retrofit	Retrofit + Soil Improvement
25	1	1,54	1,78
30	1	1,51	1,76
35	1	1,50	1,74
40	1	1,48	1,74
Average	1	1,51	1,76

- An interest rate of 8 per cent is used in the comparison of different situations. An interest rate of 4 per cent outstandingly decreases the earthquake loss while an interest rate of 12 per cent increases when compared to 8 per cent. Tables 6.3 and 6.4 present ratios of increases in earthquake loss against interest rate in lower and upper bounds. The earthquake loss for retrofitting + soil improvement is about 7 per cent higher than retrofitting only in lower bound and 18 per cent in upper bound when repairing is accepted as a base.

Table 6.3 Ratios of Increases in EQ Loss against Interest Rate, LB

Interest Rate, %	Repair	Retrofit	Retrofit + Soil Improvement
4	1	3,79	3,97
8	1	14,53	15,42
12	1	55,72	59,55

Table 6.4 Ratios of Increases in EQ Loss against Interest Rate, UB

Interest Rate, %	Repair	Retrofit	Retrofit + Soil Improvement
4	1	1,60	1,82
8	1	6,24	7,28
12	1	24,24	28,62

This study provides a general approach for earthquake loss estimation of a town in seismic zone using life cycle cost model. It is suggested in further research that,

- Each parameter in the model can be investigated in detail. For example,
    - Recovery period can be considered in monthly base and more precise data can be used,
    - Economic value and annual expenditures can be different at any time throughout the analysis period.
- A data collection method can be developed in order to provide data required by the model.
- The LCC model developed in this study is flexible to any change. Therefore, depending on the situation encountered, modifications can be made in the model.

APPENDIX A

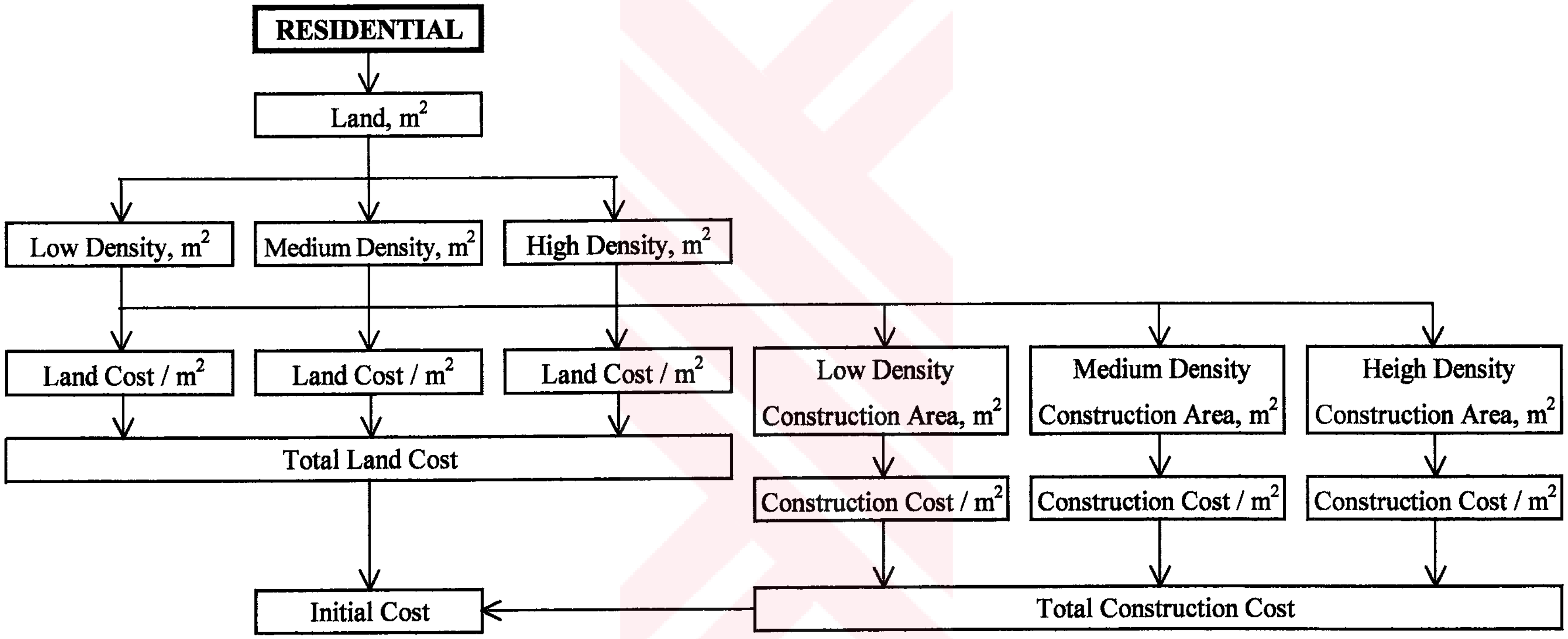


Figure A.1 Flowchart for the Initial Cost of Residential

Table A.1 An Example of the Initial Cost Computation for Residential

Population	250.000

LAND, m^2	1.728.000		
	Low Density	Medium Density	High Density
Land Area, m^2	300.000	580.000	848.000
Land Cost / m^2, US$	120	130	170
Construction Area, m^2	360.000	1.050.000	3.450.000
Construction Cost / m^2, US$	264	176	165
Total Land Cost, US$	36.000.000	75.400.000	144.160.000
Total Construction Cost, US$	95.040.000	184.800.000	569.250.000
Initial Cost, US$	**1.104.650.000**		

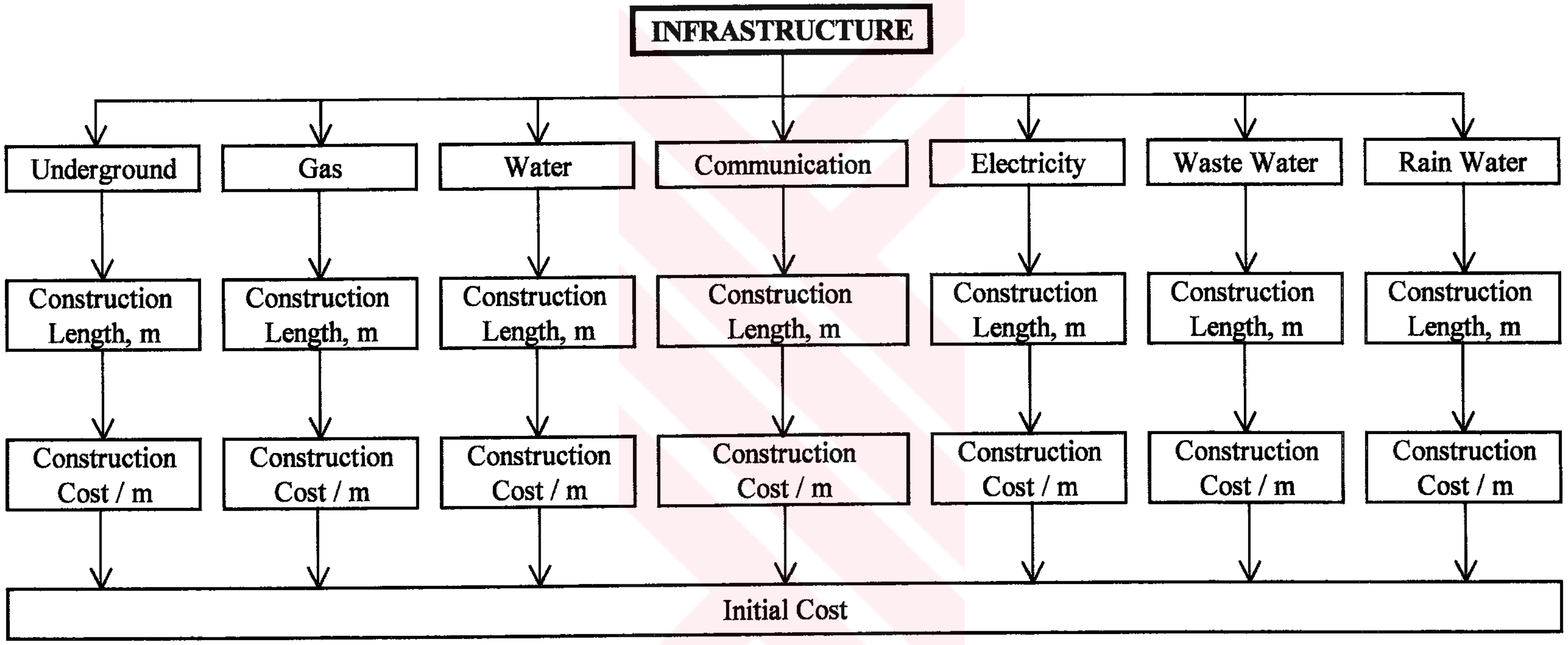


Figure A.2 Flowchart for the Initial Cost of Infrastructure

Table A.2 An Example of the Initial Cost Computation for Infrastructure

Population	250.000

	Underground	Gas	Water	Communication	Electricity	Waste Water	Rain Water
Construction Length, m	600	190.000	142.000	150.000	190.000	142.000	135.000
Construction Cost / m, US$	1200	450	460	420	420	460	440
Total Construction Cost, US$	720.000	85.500.000	65.320.000	63.000.000	79.800.000	65.320.000	59.400.000
Initial Cost, US$							**419.060.000**

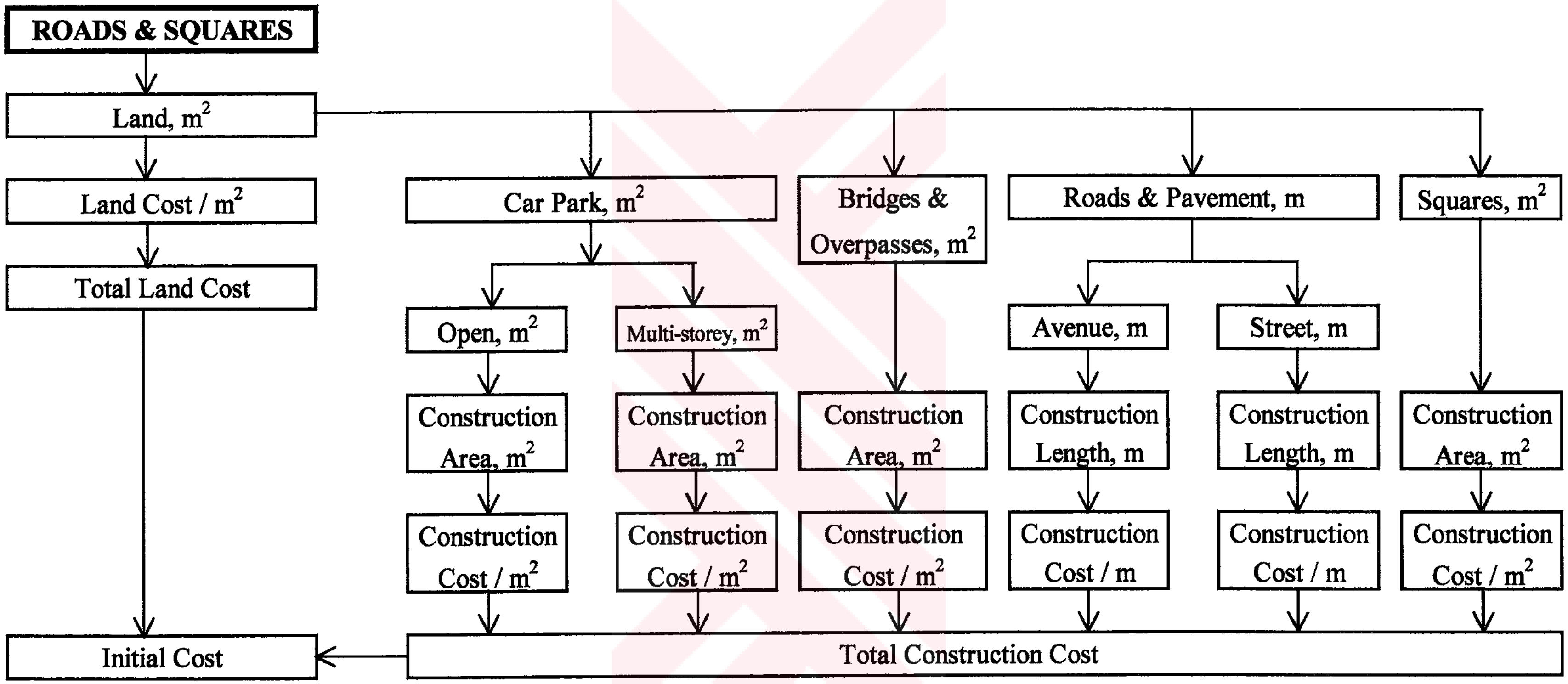


Figure A.3 Flowchart for the Initial Cost of Roads & Squares

Table A.3 An Example of the Initial Cost Computation for Roads & Squares

Population	250.000

	Open	Multi-storey	Bridges&Overpass	Avenue	Street	Squares
Land Area, m^2	33.500	60.000	-	480.000	980.000	75.385
Land Cost / m^2, US$	150					
Construction Area, m2/length	33.500	120.000	-	24.000	49.000	75.385
Construction Cost/m^2/m, US$	40	176	-	1250	750	120
Total Land Cost, US$	244.332.750					
Total Construction Cost, US$	1.340.000	21.120.000	-	30.000.000	36.750.000	9.046.200
Initial Cost, US$	**342.588.950**					

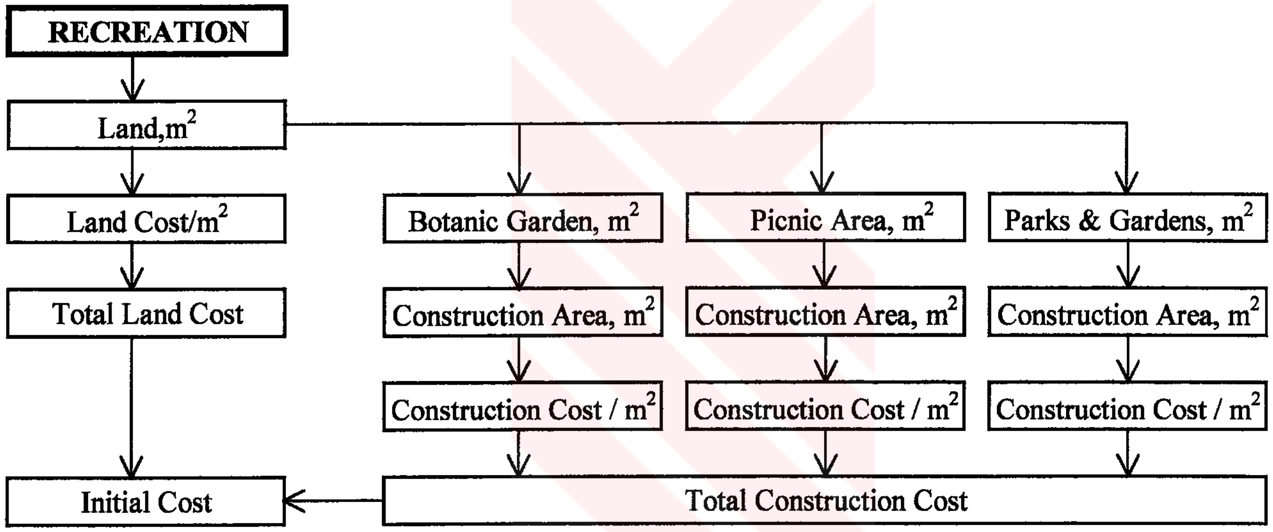


Figure A.4 Flowchart for the Initial Cost of Recreation

Table A.4 An Example of the Initial Cost Computation for Recreation

Population	250.000

	Botanic Garden	Picnic Area	Parks & Gardens
Land Area, m^2	-	31.985	47.510
Land Cost / m^2, US$	120		
Construction Area, m^2	-	31.985	47.510
Construction Cost / m^2, US$		100	120
Total Land Cost, US$	9.539.400		
Total Construction Cost, US$	-	3.198.500	5.701.200
Initial Cost, US$	**18.439.100**		

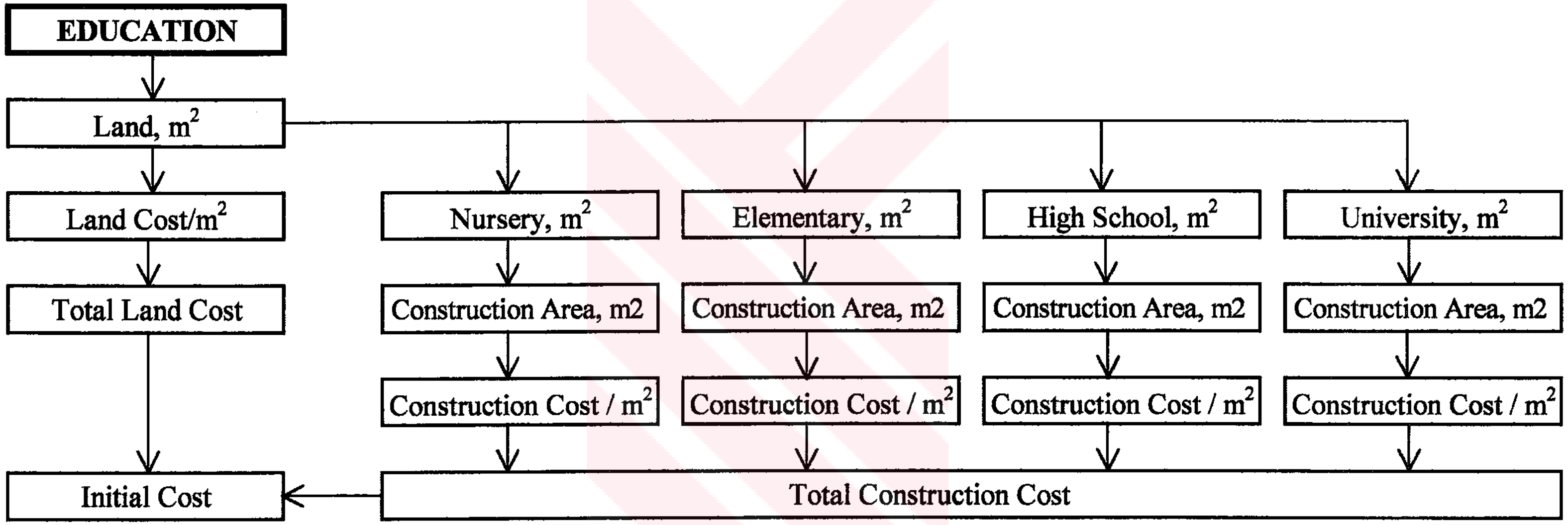


Figure A.5 Flowchart for the Initial Cost of Education

Table A.5 An Example of the Initial Cost Computation for Education

Population	250.000

	Nursery	Elementary	High School	University
Land Area, m^2	9.800	32.000	28.000	-
Land Cost / m^2, US$	120			
Construction Area, m^2	13.230	19.200	16.800	-
Construction Cost / m^2, US$	198	176	176	-
Total Land Cost, US$	8.376.000			
Total Construction Cost, US$	2.619.540	3.379.200	2.956.800	-
Initial Cost, US$	17.331.540			

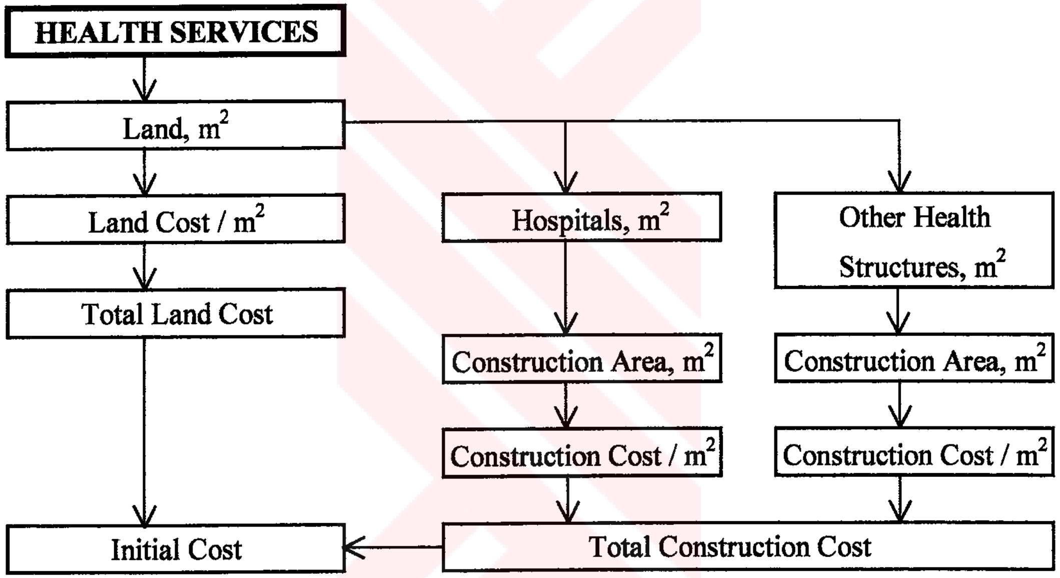


Figure A.6 Flowchart for the Initial Cost of Health Services

Table A.6 An Example of the Initial Cost Computation for Health Services

Population	250.000

	Hospitals	Other Health Structures
Land Area, m^2	14.500	9.800
Land Cost / m^2, US$	120	
Construction Area, m^2	19.575	13.230
Construction Cost / m^2, US$	320	264
Total Land Cost, US$	2.916.000	
Total Construction Cost, US$	6.264.000	3.492.720
Initial Cost, US$	**12.672.720**	

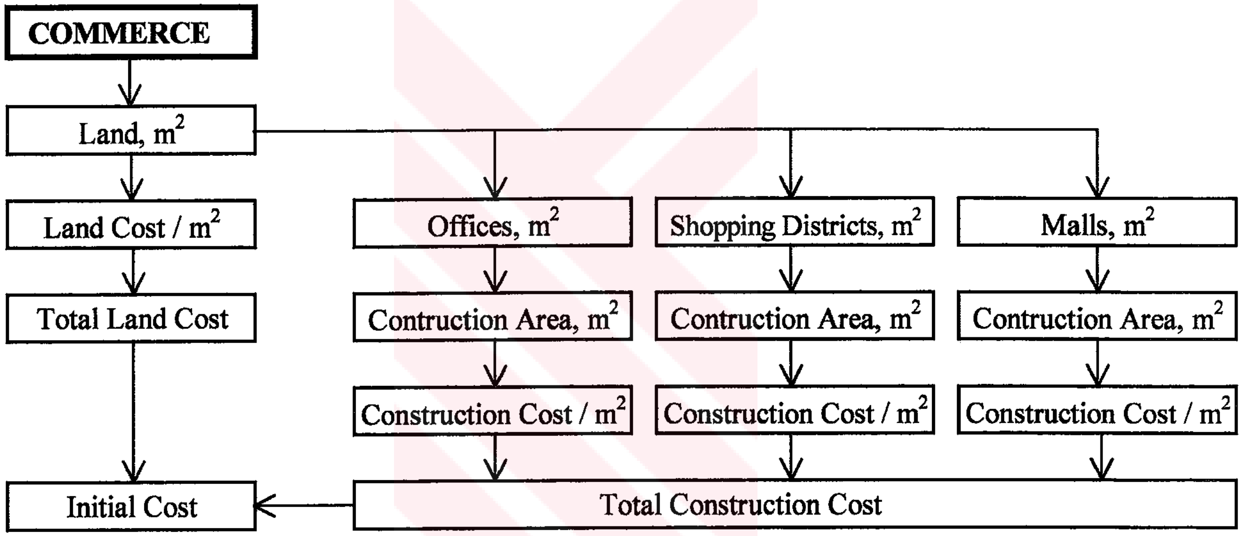


Figure A.7 Flowchart for the Initial Cost of Commerce

Table A.7 An Example of the Initial Cost Computation for Commerce

Population	250.000

	Office	Shopping District	Malls
Land Area, m^2	11.500	16.200	13.000
Land Cost / m^2, \$	120		
Construction Area, m^2	15.525	21.870	17.550
Construction Cost / m^2, \$	220	330	420
Total Land Cost, \$	4.884.000		
Total Construction Cost, \$	3.415.500	7.217.100	7.371.000
Initial Cost, \$	**22.887.600**		

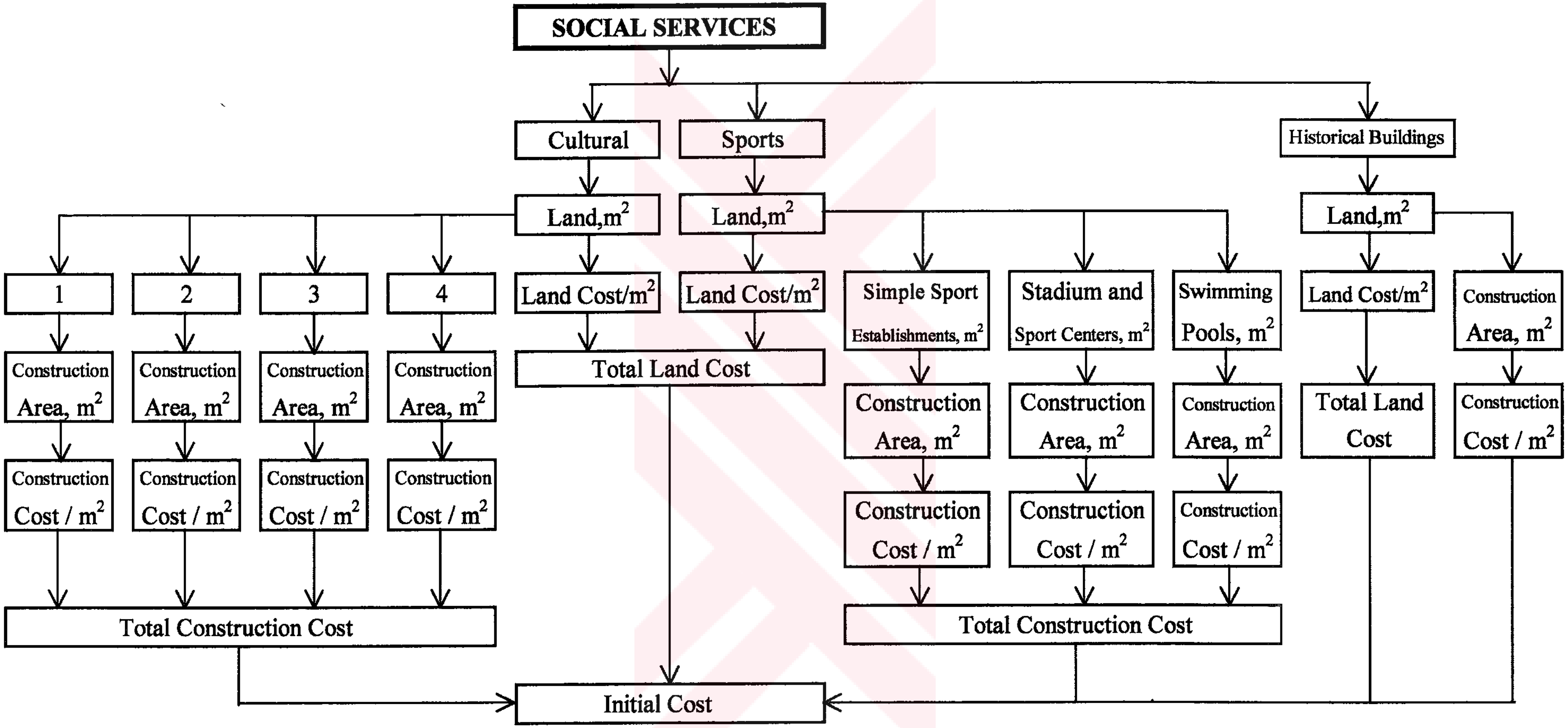


Figure A.8 Flowchart for the Initial Cost of Social Services

1 Fairs, District Libraries, Cultural Establishments
2 City Libraries, Cultural Structures, Cinema
3 Convention Centers, Museums, Exhibition Halls, Library Complexes
4 Opera, Theatre and Concert Halls, Religious Buildings

Table A.8 An Example of the Initial Cost Computation for Social Services

Population	250.000							
	1	2	3	4	Simple Sport Es.	Stadiums	Swimming Pools	Historical Buildings
Land Area, m^2	-	9.200	8.200	22.500	8.500	-	-	13.200
Land Cost, US$	120				120			120
Construction Area, m^2	-	12.420	11.070	30.375	11.475	-	-	17.820
Construction Cost/m^2, US$	-	264	395	541	154	-	-	541
Total Land Cost, US$	4.788.000				1.020.000			1.584.000
Total Construction Cost, US$	-	3.278.880	4.372.650	16.432.875	1.767.150	-	-	9.640.620
Initial Cost, US$	**42.884.175**							

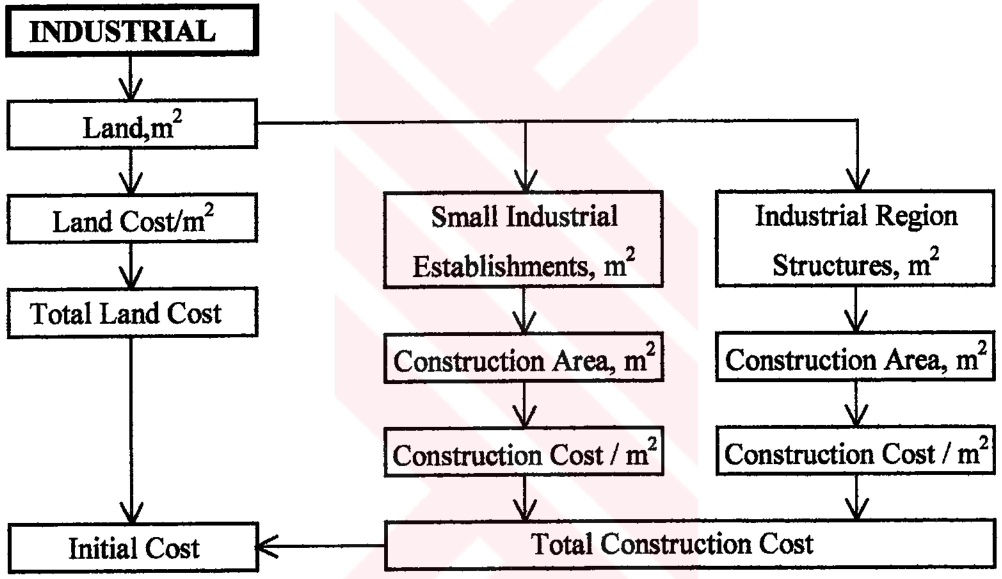


Figure A.9 Flowchart for the Initial Cost of Industrial

Table A.9 An Example of the Initial Cost Computation for Industrial

Population	250.000

	Small Industrial	Industrial Region
Land Area, m^2	18.000	-
Land Cost / m^2, US$	120	
Construction Area, m^2	24.300	-
Construction Cost / m^2, US$	176	-
Total Land Cost, US$	2.160.000	
Total Construction Cost, US$	4.276.800	-
Initial Cost, US$	**6.436.800**	

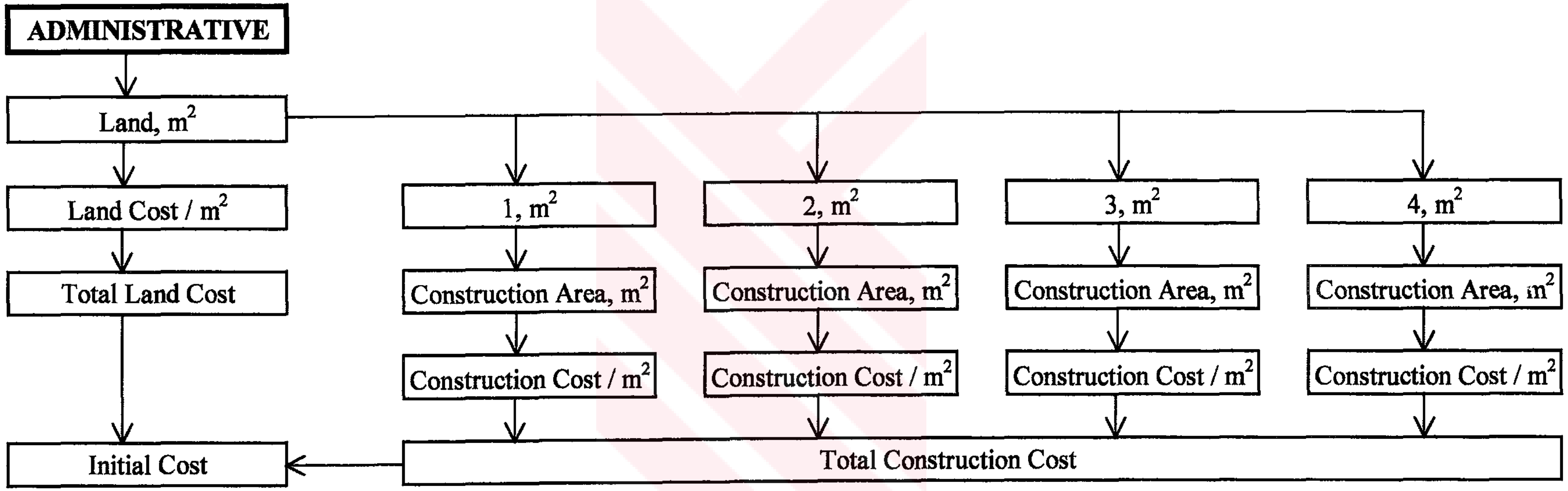


Figure A.10 Flowchart for the Initial Cost of Administrative

1 Security Buildings, Normal Administrative Buildings
2 Government Offices, Big Administrative Buildings
3 Bank and Stock-Exchange Buildings, Central Post Offices, Bus Terminals, Railway Station Buildings
4 Buildings for Courts of Justice

Table A.10 An Example of the Initial Cost Computation for Administrative

Population	250.000

	1	2	3	4
Land Area, m^2	7.600	8.700	9.500	6.890
Land Cost / m^2, $	120			
Construction Area, m^2	10.260	11.745	12.825	9302
Construction Cost / m^2, $	176	198	198	264
Total Land Cost, $	3.922.800			
Total Construction Cost, $	1.805.760	2.325.510	2.539.350	2.455.728
Initial Cost, $	**13.049.148**			

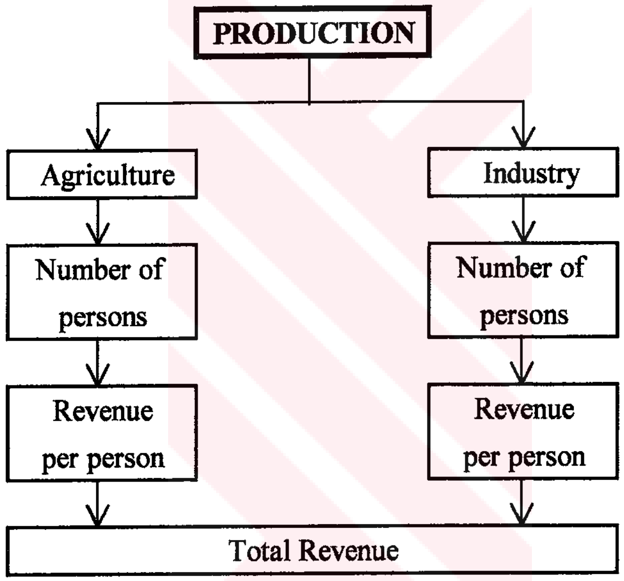


Figure A.11 Flowchart for the Economic Value of Production

Table A.11 An Example of the Economic Value Computation for Production

	Agriculture	Industry
Number of Persons	20000	17000
Revenue per Person, US$	4785	3620
Total Revenue, US$	95.700.000	61.540.000
Total Production Revenue, US$	157.240.000	

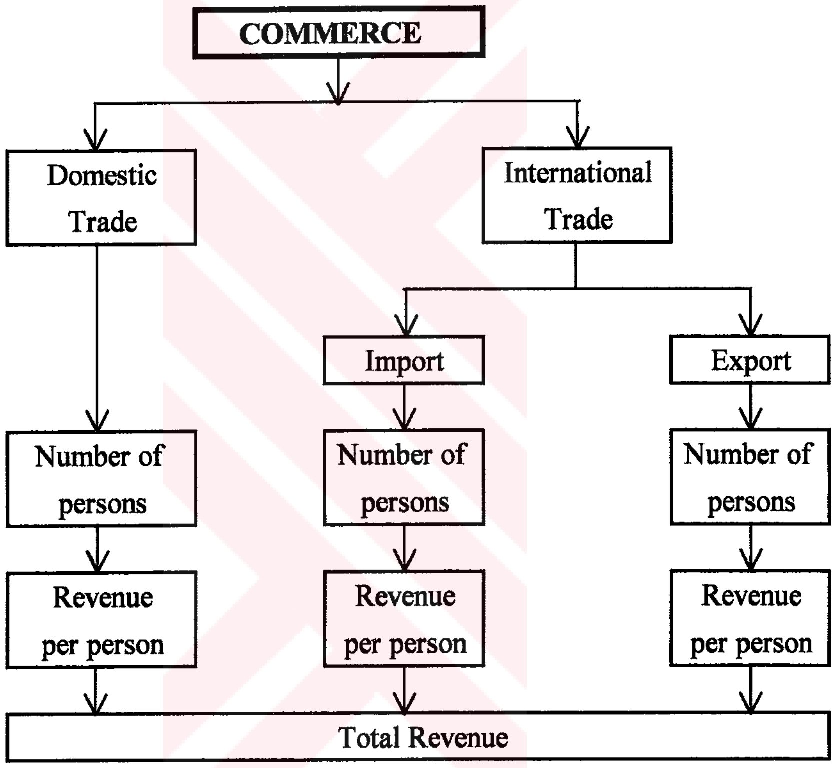


Figure A.12 Flowchart for the Economic Value of Commerce

Table A.12 An Example of the Economic Value Computation for Commerce

	Domestic Trade	Import	Export
Number of Persons	30.000	25.000	15.000
Revenue per Person, US$	2495	2810	3485
Total Revenue, US$	74.850.000	70.250.000	52.275.000
Total Commerce Revenue, US$			197.375.000

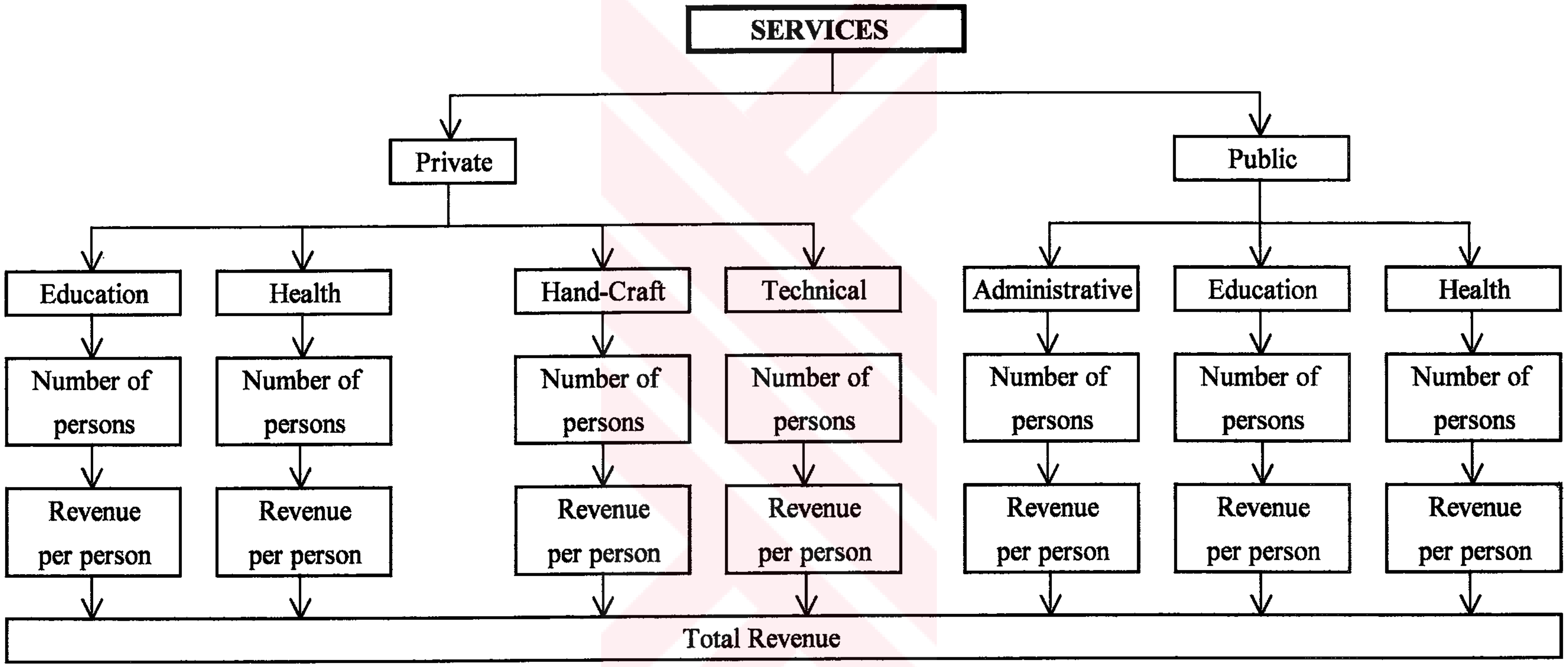


Figure A.13 Flowchart for the Economic Value of Services

Table A.13 An Example of the Economic Value Computation for Services

	Private				Public		
	Education	Health	Hand-Craft	Technical	Administrative	Education	Health
Number of Persons	5.000	4.200	2.000	6.000	12.000	18.000	15.000
Revenue per Person, US$	18.570	28.460	22.374	30.270	4.280	3.850	5.265
Total Revenue, US$	92.850.000	119.532.000	44.748.000	181.620.000	51.360.000	69.300.000	78.975.000
Total Services Revenue, US$							638.385.000

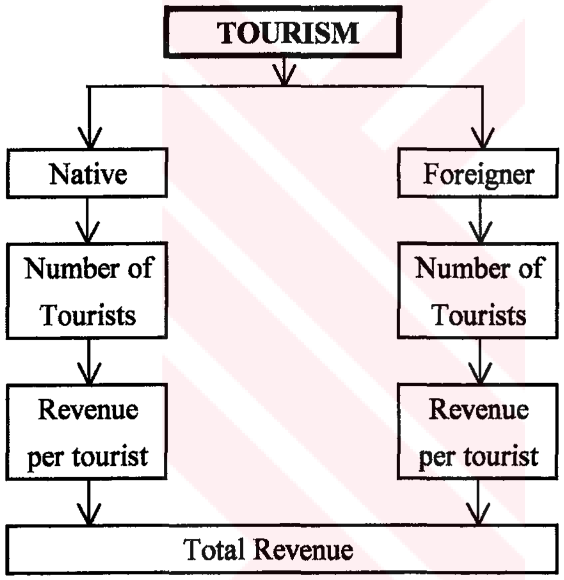


Figure A.14 Flowchart for the Economic Value of Tourism

Table A.14 An Example of the Economic Value Computation for Tourism

	Native	Foreigner
Number of Tourists	60000	25000
Revenue per Tourist, US$	1200	2200
Total Revenue, US$	72.000.000	55.000.000
Total Tourism Revenue, US$		127.000.000

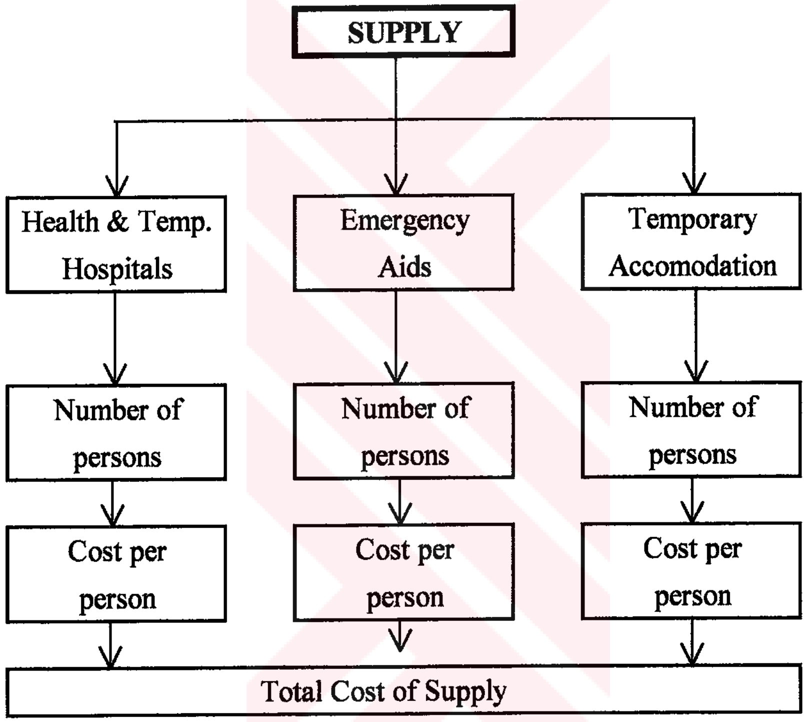


Figure A.15 Flowchart for the Disaster Cost of Supply

Table A.15 An Example of the Disaster Cost Computation for Supply

	Health & Temp. Hospitals	Emergency Aids	Temporary Accomodation
Number of persons	35000	40000	40000
Cost per person, US$	1200	950	1500
Total Cost, US$	42.000.000	38.000.000	60.000.000
Total Supply Cost, US$	140.000.000		

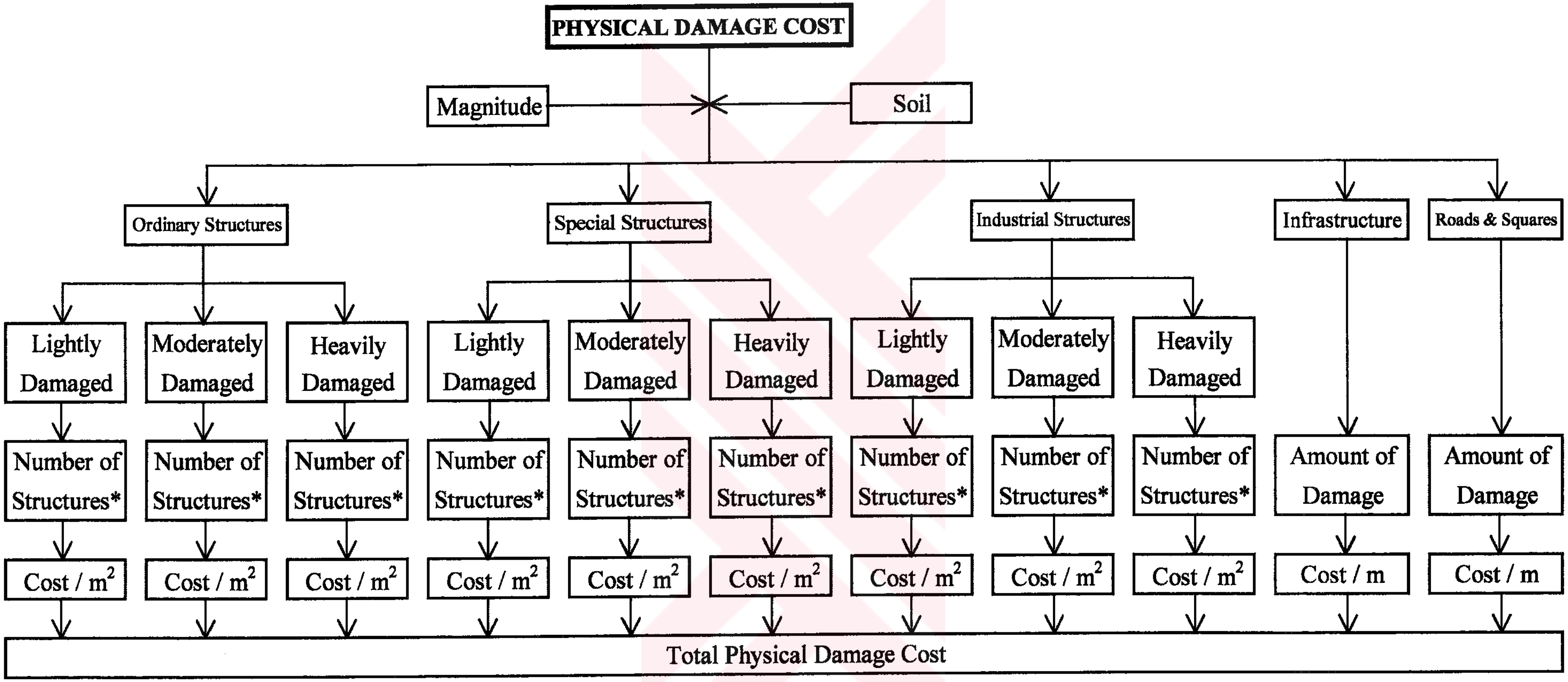


Figure A.16 Flowchart for the Disaster Cost of Physical Damage

* Number of structures and their total area, m^2

Table A.16 An Example of the Disaster Cost Computation for Physical Damage

Magnitude	
Soil	

	Ordinary Structures			Special Structures			Industrial Structures			Infrastructure	Roads	Squares
	Lightly Damaged	Moderately Damaged	Heavily Damaged	Lightly Damaged	Moderately Damaged	Heavily Damaged	Lightly Damaged	Moderately Damaged	Heavily Damaged	Amount of Damage	Amount of Damage	Amount of Damage
Number of Structures*	650.870	450.650	315.560	250.340	200.180	150.580	120.800	93.580	64.590	128.000	200.000	57.350
Cost / m^2,US$	90	130	180	130	260	580	150	350	600	-	-	120
Cost / m,US$	-	-	-	-	-	-	-	-	-	450	900	-
Total Cost, US$	58.578.300	58.584.500	56.800.800	32.544.200	52.046.800	87.336.400	18.120.000	32.753.000	38.754.000	57.600.000	180.000.000	6.882.000
Total Physical Damage Cost, US$	680.000.000											

* Number of structures and their total area, m^2

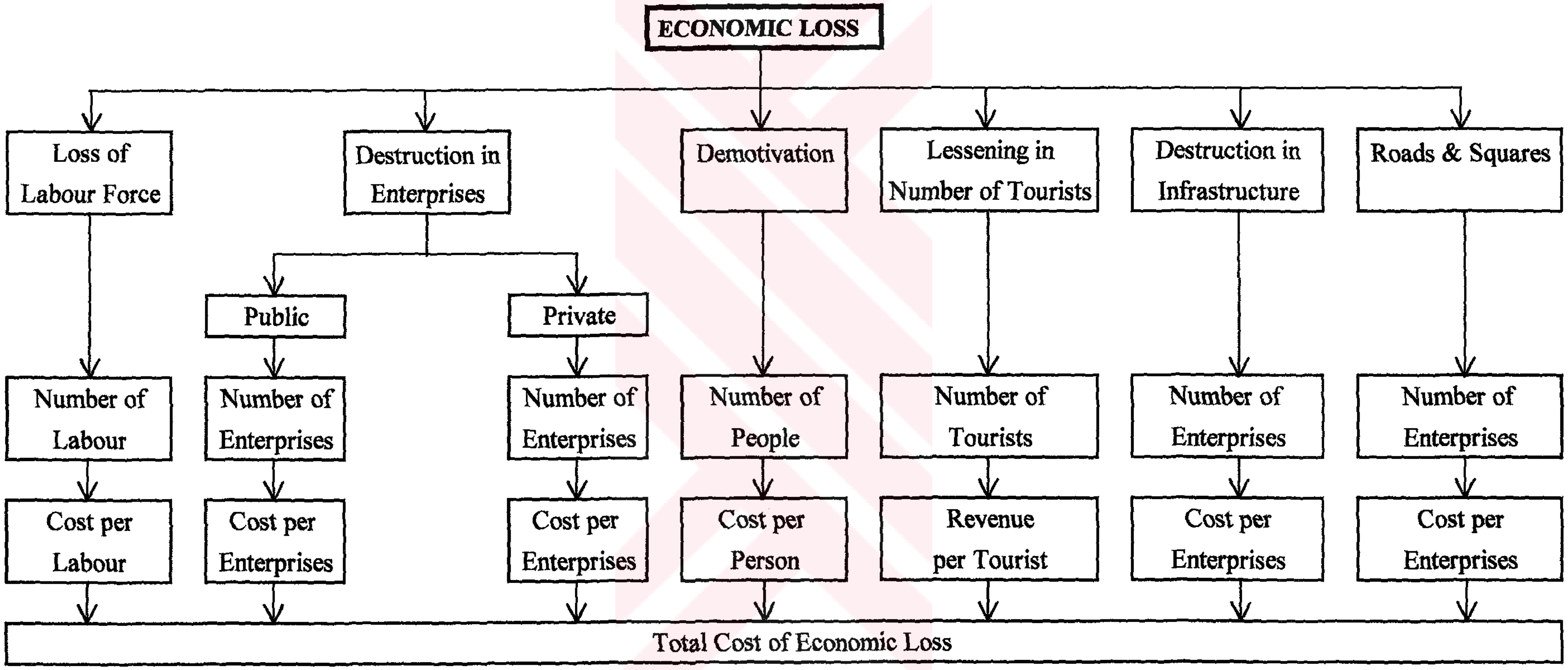


Figure A.17 Flowchart for the Disaster Cost of Economic Loss

Table A.17 An Example of the Disaster Cost Computation for Economic Loss

	Loss of Labour Force	Destruction in Public Enterprises	Destruction in Private Enterprises	Demotivation Num. of people	Lessenning in Num. of Tourists	Destruction in Infrastructure	Destruction in Roads & Squares
Number of Units	3.000	60	120	8.000	12.000	128.000	200.000
Cost per Unit, US$	1.210	183	325	1.450	2.260	450	900
Total Cost, US$	3.630.000	10.980	39.000	11.600.000	27.120.000	57.600.000	180.000.000
Total Cost of Economic Loss, US$	280.000.000						

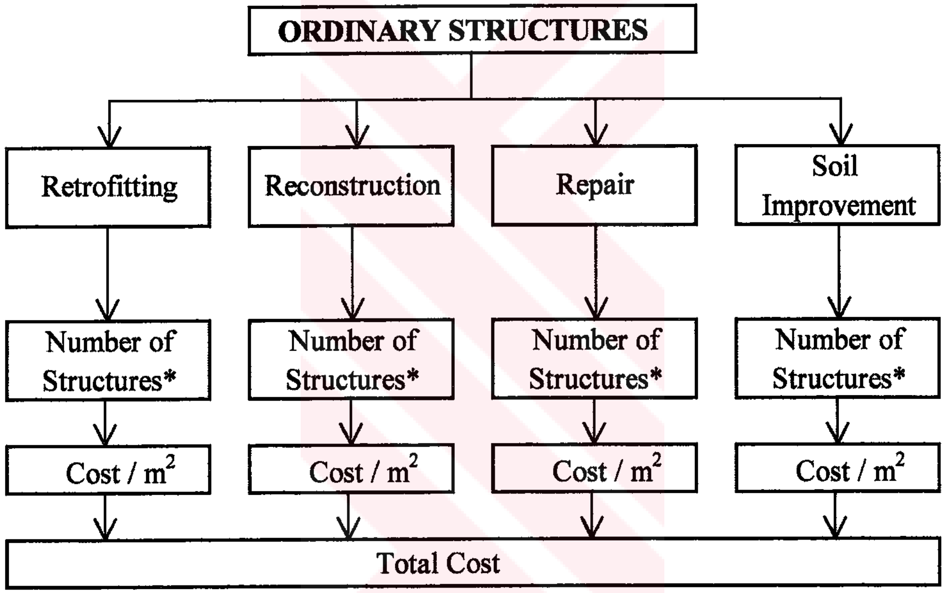


Figure A.18 Flowchart for the Recovery Cost of Ordinary Structures

* Number of structures and their total area,m^2

Table A.18 An Example of the Recovery Cost Computation for Ordinary Structures

Ordinary Structures	
Number of Structures for Retrofitting/Total Area, m^2	
Number of Structures for Reconstruction/Total Area, m2	315.560
Number of Structures for Repairing/Total Area, m2	1.101.520
Number of Structures for Soil Improvement/Total Area, m2	
Retrofitting Cost / m^2, US$	
Reconstruction Cost / m^2, US$	110
Repair Cost / m^2, US$	134
Soil Improvement Cost / m^2, US$	
Total Cost, US$	182.315.280

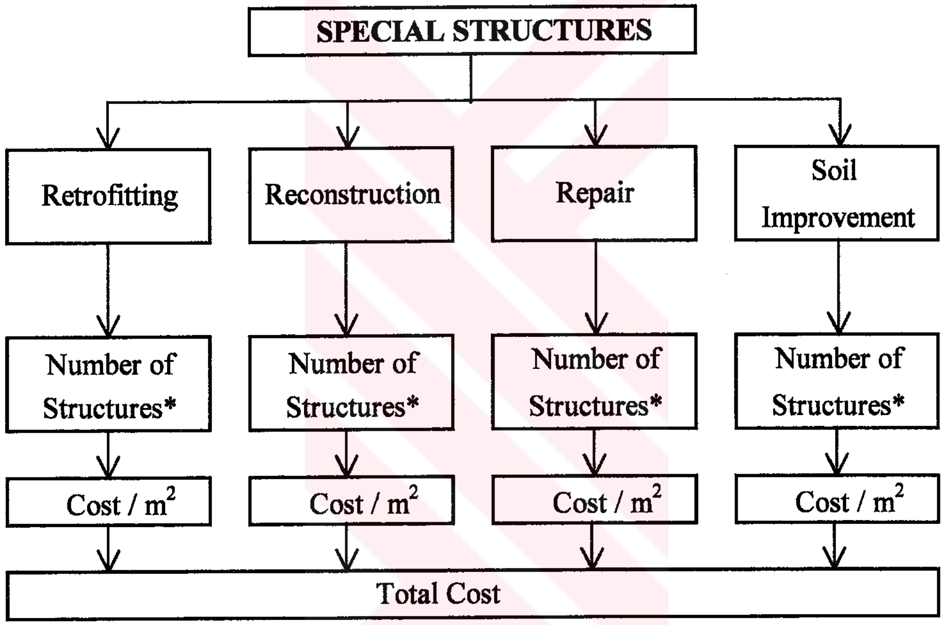


Figure A.19 Flowchart for the Recovery Cost of Special Structures

* Number of structures and their total area,m^2

Table A.19 An Example of the Recovery Cost Computation for Special Structures

Special Structures	
Number of Structures for Retrofitting/Total Area, m^2	
Number of Structures for Reconstruction/Total Area, m2	150.580
Number of Structures for Repairing/Total Area, m2	450.520
Number of Structures for Soil Improvement/Total Area, m2	
Retrofitting Cost / m^2, US$	
Reconstruction Cost / m^2, US$	580
Repair Cost / m^2, US$	195
Soil Improvement Cost / m^2, US$	
Total Cost, US$	175.187.800

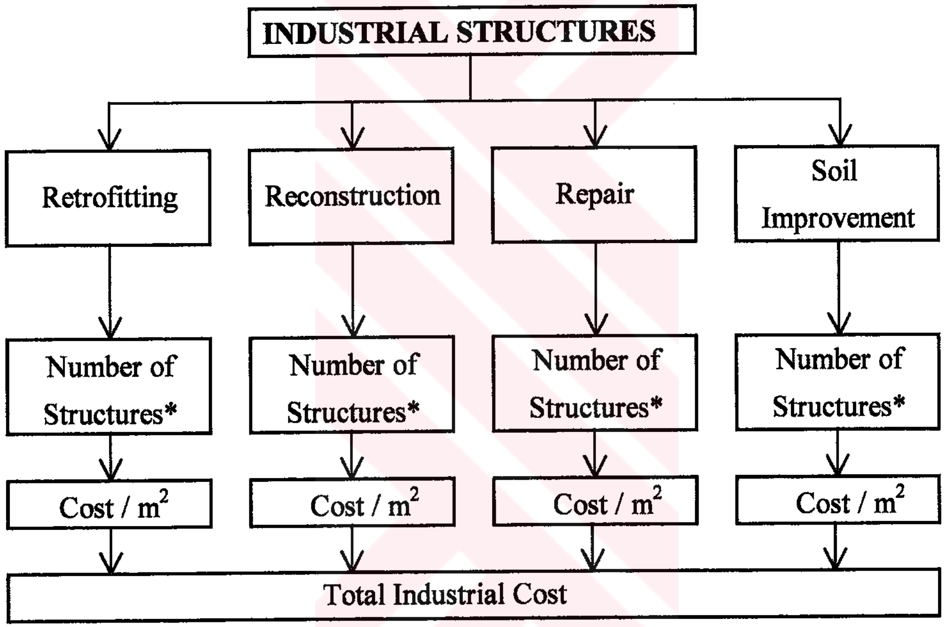


Figure A.20 Flowchart for the Recovery Cost of Industrial Structures

* Number of structures and their total area,m^2

Table A.20 An Example of the Recovery Cost Computation for Industrial Structures

Industrial Structures	
Number of Structures for Retrofitting/Total Area, m^2	
Number of Structures for Reconstruction/Total Area, m2	64.590
Number of Structures for Repairing/Total Area, m2	214.380
Number of Structures for Soil Improvement/Total Area, m2	
Retrofitting Cost / m^2, US$	
Reconstruction Cost / m^2, US$	600
Repair Cost / m^2, US$	250
Soil Improvement Cost / m^2, US$	
Total Cost, US$	92.349.000

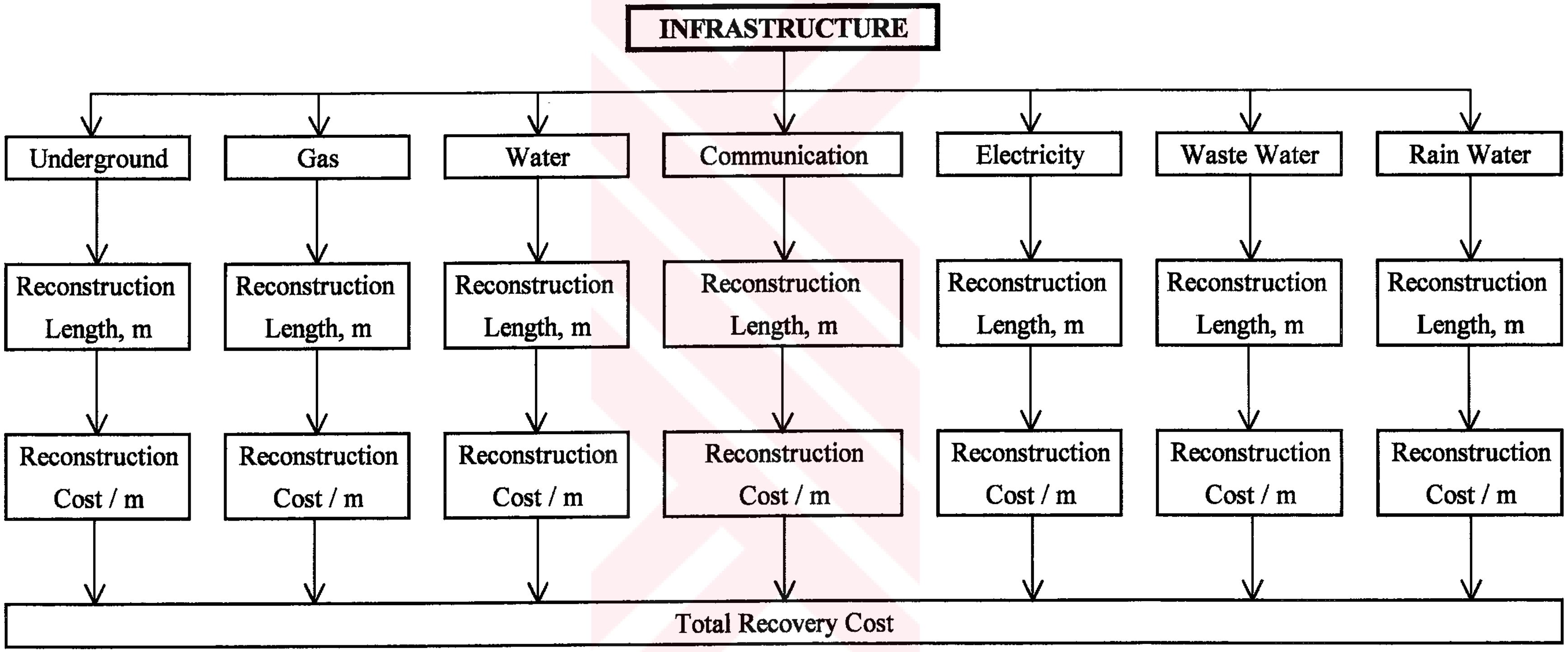


Figure A.21 Flowchart for the Recovery Cost of Infrastructure

Table A.21 An Example of the Recovery Cost Computation for Infrastructure

	Infrastructure						
	Underground	Gas	Water	Communication	Electricity	Waste Water	Rain Water
Reconstruction Length, m	450	32.000	22.050	18.000	10.000	30.500	15.000
Reconstruction Cost / m, US$	1.200	450	460	420	420	460	440
Cost, US$	540.000	14.400.000	10.143.000	7.560.000	4.200.000	14.030.000	6.600.000
Total Cost, US$							57.600.000

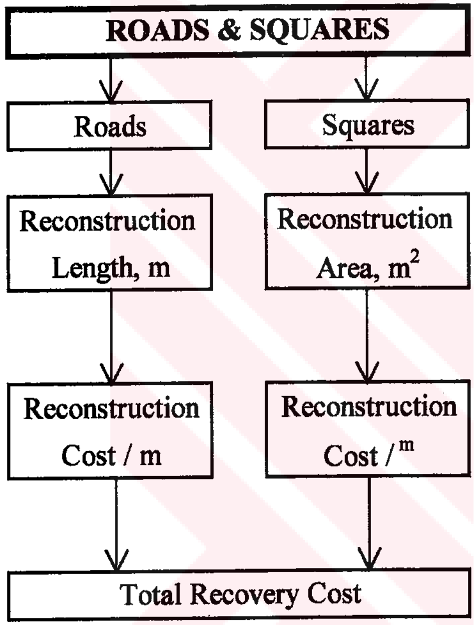


Figure A.22 Flowchart for the Recovery Cost of Roads & Squares

Table A.22 An Example of the Recovery Cost Computation for Roads & Squares

	Roads	Squares
Reconstruction Length/Area, m, m^2	200.000	57.350
Reconstruction Cost / m, m^2,US $	900	120
Cost, $	180.000.000	6.882.000
Total Cost, $	-	186.882.000

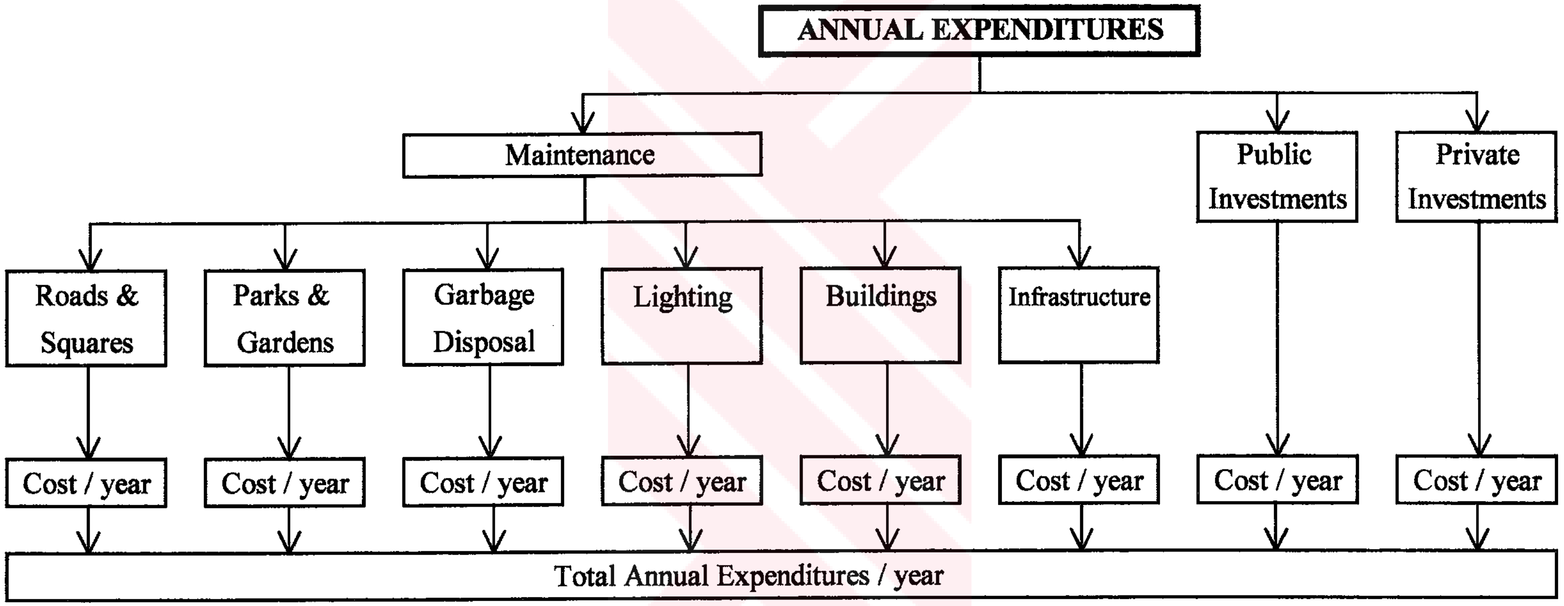


Figure A.23 Flowchart for the Annual Expenditures

Table A.23 An Example of the Annual Expenditures Computation

	Roads &Squares	Parks & Gardens	Garbage Disposal	Lighting	Buildings	Infrastructure	Public Investments	Private Investments
Cost / year, US$	4.300.000	2.200.000	1.200.000	1.200.000	1.800.000	4.300.000	33.000.000	40.000.000
Total Annual Expenditure, US$	88.000.000							

APPENDIX B

Table B.1 Earthquake Loss Computations for Recovery Periods

INPUT

Initial Cost, US$ million	2.000
Economic Value, US$ million	1.120
Economic Loss, US$ million	280
Recovery Cost, US$ million	680
Supply Cost, US$ million	140
Annual Expenditure, US$ million	88
Interest Rate, %	8

OUTPUT (US$ million)

Case 1 (1 EQ, repairing)

Recovery Periods, years	Years				
	10	16	30	36	50
Non-EQ	10.632	24.443	96.783	161.153	498.328
1	10.632	23.221	93.196	155.461	481.608
EQ Loss	-	**1.222**	**3.587**	**5.692**	**16.720**
2	10.632	23.040	92.664	154.617	479.129
EQ Loss	-	**1.403**	**4.119**	**6.536**	**19.199**
3	10.632	22.869	92.159	153.816	476.777
EQ Loss	-	**1.574**	**4.624**	**7.337**	**21.551**
4	10.632	22.706	91.680	153.056	474.545
EQ Loss	-	**1.737**	**5.103**	**8.097**	**23.783**
5	10.632	22.551	91.226	152.334	472.425
EQ Loss	-	**1.892**	**5.557**	**8.819**	**25.903**
6	10.632	22.404	90.764	151.649	470.412
EQ Loss	-	**2.039**	**6.019**	**9.504**	**27.916**

Case 2 (1st EQ repairing, 2nd EQ repairing)

Recovery Periods, years	Years				
	10	16	30	36	50
Non-EQ	10.632	24.443	96.783	161.153	498.328
1	10.632	23.221	93.196	154.239	478.021
EQ Loss	-	**1.222**	**3.587**	**6.914**	**20.307**
2	10.632	23.040	92.664	153.214	475.010
EQ Loss	-	**1.403**	**4.119**	**7.939**	**23.318**
3	10.632	22.869	92.159	152.242	472.154
EQ Loss	-	**1.574**	**4.624**	**8.911**	**26.174**
4	10.632	22.706	91.680	151.319	469.443
EQ Loss	-	**1.737**	**5.103**	**9.834**	**28.885**
5	10.632	22.551	91.226	150.442	466.868
EQ Loss	-	**1.892**	**5.557**	**10.711**	**31.460**
6	10.632	22.404	90.764	149.610	464.422
EQ Loss	-	**2.039**	**6.019**	**11.543**	**33.906**

Table B.1 continued

Case 3 (1st EQ retrofitting, 2nd EQ repairing)

Recovery Periods, years	Years				
	10	16	30	36	50
Non-EQ	10.632	24.443	96.783	161.153	498.328
1	10.632	23.022	92.609	153.961	477.202
EQ Loss	-	**1.421**	**4.174**	**7.192**	**21.126**
2	10.632	22.846	92.092	153.070	474.585
EQ Loss	-	**1.597**	**4.691**	**8.083**	**23.743**
3	10.632	22.678	91.601	152.224	472.102
EQ Loss	-	**1.765**	**5.182**	**8.929**	**26.226**
4	10.632	22.520	91.135	151.422	469.746
EQ Loss	-	**1.923**	**5.648**	**9.731**	**28.582**
5	10.632	22.370	90.694	150.661	467.509
EQ Loss	-	**2.073**	**6.089**	**10.492**	**30.819**
6	10.632	22.227	90.274	149.938	465.386
EQ Loss	-	**2.216**	**6.509**	**11.215**	**32.942**

Case 4 (1st EQ retrofitting+soil improvement, 2nd EQ repairing)

Recovery Periods, years	Years				
	10	16	30	36	50
Non-EQ	10.632	24.443	96.783	161.153	498.328
1	10.632	22.842	92.081	153.371	475.469
EQ Loss	-	**1.601**	**4.702**	**7.782**	**22.859**
2	10.632	22.670	91.576	152.536	473.019
EQ Loss	-	**1.773**	**5.207**	**8.617**	**25.309**
3	10.632	22.507	91.098	151.745	470.695
EQ Loss	-	**1.936**	**5.685**	**9.408**	**27.633**
4	10.632	22.353	90.645	150.995	468.491
EQ Loss	-	**2.090**	**6.138**	**10.158**	**29.837**
5	10.632	22.207	90.215	150.283	466.399
EQ Loss	-	**2.236**	**6.568**	**10.870**	**31.929**
6	10.632	22.068	89.806	149.607	464.415
EQ Loss	-	**2.375**	**6.977**	**11.546**	**33.913**

Table B.2 Earthquake Loss Computations for Initial Costs

INPUT

Initial Cost, US$ million	2.000	2.500	3.000
Economic Value, US$ million	1.120	1.120	1.120
Economic Loss, US$ million	280	140	70
Recovery Cost, US$ million	680	340	170
Supply Cost, US$ million	140	70	35
Annual Expenditure, US$ million	**88**	**88**	**88**
Interest Rate, %	**8**	**8**	**8**

OUTPUT (US$ million)

Initial Cost = US$2.000 million

Cases	Years				
	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
Case 1	10.632	15.494	92.159	118.445	476.777
EQ Loss	-	**1.250**	**4.624**	**6.824**	**21.551**
Case 2	10.632	15.494	92.159	118.195	472.154
EQ Loss	-	**1.250**	**4.624**	**7.074**	**26.174**
Case 3	10.632	15.343	91.601	118.181	472.102
EQ Loss	-	**1.401**	**5.182**	**7.088**	**26.226**
Case 4	10.632	15.208	91.098	117.801	470.695
EQ Loss	-	**1.536**	**5.685**	**7.468**	**27.633**

Initial Cost = US$2.500 million

Cases	Years				
	10	13	30	33	50
Non-EQ	9.553	15.384	91.752	118.931	474.877
Case 1	9.553	14.759	89.440	116.019	464.102
EQ Loss	-	**625**	**2.312**	**2.912**	**10.775**
Case 2	9.553	14.759	89.940	115.394	461.790
EQ Loss	-	**625**	**1.812**	**3.537**	**13.087**
Case 3	9.553	14.684	89.161	115.387	461.764
EQ Loss	-	**700**	**2.591**	**3.544**	**13.113**
Case 4	9.553	14.624	88.951	114.976	460.245
EQ Loss	-	**760**	**2.801**	**3.955**	**14.632**

Initial Cost = US$3.000 million

Cases	Years				
	10	13	30	33	50
Non-EQ	8.473	14.024	86.720	112.593	451.426
Case 1	8.473	13.712	85.564	111.137	446.038
EQ Loss	-	**312**	**1.156**	**1.456**	**5.388**
Case 2	8.473	13.712	85.564	110.824	444.883
EQ Loss	-	**312**	**1.156**	**1.769**	**6.543**
Case 3	8.473	13.674	85.425	110.821	444.869
EQ Loss	-	**350**	**1.295**	**1.772**	**6.557**
Case 4	8.473	13.646	85.320	110.753	444.620
EQ Loss	-	**378**	**1.400**	**1.840**	**6.806**

Table B.3 Earthquake Loss Computations for Interest Rates

INPUT

Initial Cost, US$ million	2.000
Economic Value, US$ million	1.120
Economic Loss, US$ million	280
Recovery Cost, US$ million	680
Supply Cost, US$ million	140
Annual Expenditure, US$ million	88
Interest Rate, %	8

OUTPUT (US$ million)

Case 1 (1 EQ, repairing)

Interest Rate, 4%	Years				
	10	13	30	33	50
Non-EQ	9.430	13.829	51.393	61.031	143.339
With EQ	9.430	12.655	49.107	58.461	138.331
EQ Loss	-	**1.174**	**2.286**	**2.570**	**5.008**

Interest Rate, 8%	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
With EQ	10.632	15.494	92.159	118.445	476.777
EQ Loss	-	**1.250**	**4.624**	**6.824**	**21.551**

Interest Rate, 12%	10	13	30	33	50
Non-EQ	11.899	20.199	189.135	269.204	1.898.814
With EQ	11.899	18.870	180.010	256.383	1.810.787
EQ Loss	-	**1.329**	**9.125**	**12.821**	**88.027**

Case 2 (1st EQ repairing, 2nd EQ repairing)

Interest Rate, 4%	Years				
	10	13	30	33	50
Non-EQ	9.430	13.829	51.393	61.031	143.339
With EQ	9.430	12.655	49.107	57.287	136.046
EQ Loss	-	**1.174**	**2.286**	**3.744**	**7.293**

Interest Rate, 8%	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
With EQ	10.632	15.494	92.159	118.195	472.154
EQ Loss	-	**1.250**	**4.624**	**7.074**	**26.174**

Interest Rate, 12%	10	13	30	33	50
Non-EQ	11.899	20.199	189.135	269.204	1.898.814
With EQ	11.899	18.870	180.010	255.054	1.801.662
EQ Loss	-	**1.329**	**9.125**	**14.150**	**97.152**

Table B.3 continued

Case 3 (1st EQ retrofitting, 2nd EQ repairing)

Interest Rate, 4%	Years				
	10	13	30	33	50
Non-EQ	9.430	13.829	51.393	61.031	143.339
With EQ	9.430	12.512	48.828	57.620	136.694
EQ Loss	-	**1.317**	**2.565**	**3.411**	**6.645**

Interest Rate, 8%	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
With EQ	10.632	15.343	91.601	118.181	472.102
EQ Loss	-	**1.401**	**5.182**	**7.088**	**26.226**

Interest Rate, 12%	10	13	30	33	50
Non-EQ	11.899	20.199	189.135	269.204	1.898.814
Two EQ (Retrofitted,20%)	11.899	18.711	178.920	254.257	1.796.188
EQ Loss	-	**1.488**	**10.215**	**14.947**	**102.626**

Case 4 (1st EQ retrofitting+soil improvement, 2nd EQ repairing)

Interest Rate, 4%	Years				
	10	13	30	33	50
Non-EQ	9.430	13.829	51.393	61.031	143.339
With EQ	9.430	12.383	48.577	57.575	136.606
EQ Loss	-	**1.446**	**2.816**	**3.456**	**6.733**

Interest Rate, 8%	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
With EQ	10.632	15.208	91.038	117.801	470.695
EQ Loss	-	**1.536**	**5.745**	**7.468**	**27.633**

Interest Rate, 12%	10	13	30	33	50
Non-EQ	11.899	20.199	189.135	269.204	1.898.814
With EQ	11.899	18.568	177.939	253.148	1.788.572
EQ Loss	-	**1.631**	**11.196**	**16.056**	**110.242**

Table B.4 Earthquake Loss Computations for Earthquake Pattern

INPUT

Initial Cost, US$ million	2.000
Economic Value, US$ million	1.120
Economic Loss, US$ million	280
Recovery Cost, US$ million	680
Supply Cost, US$ million	140
Annual Expenditure, US$ million	88
Interest Rate, %	8

OUTPUT (US$ million)

Year of the Second EQ=25

Cases	Years				
	10	13	25	28	50
Non-EQ	10.632	16.744	61.748	81.135	498.328
Case 1	10.632	15.494	58.602	77.172	476.777
EQ Loss	**-**	**1.250**	**3.146**	**3.963**	**21.551**
Case 2	10.632	15.494	58.602	75.922	469.984
EQ Loss	**-**	**1.250**	**3.146**	**5.213**	**28.344**
Case 3	10.632	15.343	58.222	76.132	471.129
EQ Loss	**-**	**1.401**	**3.526**	**5.003**	**27.199**
Case 4	10.632	15.208	57.879	75.955	470.161
EQ Loss	**-**	**1.536**	**3.869**	**5.180**	**28.167**

Year of the Second EQ=30

Cases	Years				
	10	13	30	33	50
Non-EQ	10.632	16.744	96.783	125.269	498.328
Case 1	10.632	15.494	92.159	119.445	476.777
EQ Loss	**-**	**1.250**	**4.624**	**5.824**	**21.551**
Case 2	10.632	15.494	92.159	118.195	472.154
EQ Loss	**-**	**1.250**	**4.624**	**7.074**	**26.174**
Case 3	10.632	15.343	91.601	118.181	472.102
EQ Loss	**-**	**1.401**	**5.182**	**7.088**	**26.226**
Case 4	10.632	15.208	91.038	117.801	470.695
EQ Loss	**-**	**1.536**	**5.745**	**7.468**	**27.633**

Table B.4 continued

Year of the Second EQ=35

Cases	Years				
	10	13	35	38	50
Non-EQ	10.632	16.744	148.260	190.116	498.328
Case 1	10.632	15.494	141.467	181.558	476.777
EQ Loss	-	**1.250**	**6.793**	**8.558**	**21.551**
Case 2	10.632	15.494	141.467	180.308	473.631
EQ Loss	-	**1.250**	**6.793**	**9.808**	**24.697**
Case 3	10.632	15.343	140.646	179.964	472.764
EQ Loss	-	**1.401**	**7.614**	**10.152**	**25.564**
Case 4	10.632	15.208	139.908	179.286	471.058
EQ Loss	-	**1.536**	**8.352**	**10.830**	**27.270**

Year of the Second EQ=40

Cases	Years				
	10	13	40	43	50
Non-EQ	10.632	16.744	223.897	285.396	498.328
Case 1	10.632	15.494	213.915	272.822	476.777
EQ Loss	-	**1.250**	**9.982**	**12.574**	**21.551**
Case 2	10.632	15.494	213.915	271.573	474.636
EQ Loss	-	**1.250**	**9.982**	**13.823**	**23.692**
Case 3	10.632	15.343	212.710	270.743	473.214
EQ Loss	-	**1.401**	**11.187**	**14.653**	**25.114**
Case 4	10.632	15.208	211.625	269.629	471.305
EQ Loss	-	**1.536**	**12.272**	**15.767**	**27.023**

APPENDIX C

Table C.1. Initial Cost of Adapazari (Centre)

Total Town Area, m^2 1.920.000

FACILITIES	Land Area, m^2	%	Construction Area, m^2	KAKS	Construction Cost, US$ / m^2	Total Land Cost, US$	Total Construction Cost, US$	Total Cost US$
RESIDENTIAL	1.212.687		1.940.299			**145.522.440**	**341.492.659**	**487.015.099**
Low Density			-				-	-
Medium density	1.212.687	63,16	1.940.299	1,6	176	145.522.440	341.492.659	487.015.099
High Density			-				-	-
INFRASTRUCTURE							**156.000.000**	**156.000.000**
Gas						-	-	-
Water						-	-	-
Communication						-	-	-
Electricity						-	-	-
Waste Water						-	-	-
Rain Water								
Underground						-	-	-
ROADS & SQUARES	582.130	30,32				**69.855.600**	**48.102.500**	**117.958.100**
Open Carpark	11.730	0,61	11.730		40	1.407.600	469.200	1.876.800
Multi-storey Carpark	19.650	1,02	39.300	2	176	2.358.000	6.916.800	9.274.800
Bridges & Overpasses		-				-	-	-
Avenue, m	117.920	6,14	5.896		1250	14.150.400	7.370.000	21.520.400
Street, m	413.180	21,52	41.318		750	49.581.600	30.988.500	80.570.100
Squares	19.650	1,02	19.650		120	2.358.000	2.358.000	4.716.000
Railway		-				-	-	-

Table C.1 continued

RECREATION	29.043					**3.485.160**	**3.485.160**	**6.970.320**
Botanic Garden						-	-	-
Picnic Area						-	-	-
Parks & Gardens	29.043	1,51	29.043		120	3.485.160	3.485.160	6.970.320

EDUCATION	**27.675**	**1,44**	**16.605**			**3.321.000**	**2.940.630**	**6.261.630**
Nursery	1.375	0,07	825	0,6	198	165.000	163.350	328.350
Elementary	15.700	0,82	9.420	0,6	176	1.884.000	1.657.920	3.541.920
High School	10.600	0,55	6.360	0,6	176	1.272.000	1.119.360	2.391.360
University						-	-	-

HEALTH SERVICES	**7.000**	**0,36**	**9.450**			**840.000**	**2.494.800**	**3.334.800**
Hospitals						-	-	-
Other Health Services	7.000	0,36	9.450	1,35	264	840.000	2.494.800	3.334.800

COMMERCE	18.305	0,95	24.712			**2.196.600**	**7.003.260**	**9.199.860**
Office	7.755	0,40	10.469	1,35	220	930.600	2.303.235	3.233.835
Shopping District	10.550	0,55	14.243	1,35	330	1.266.000	4.700.025	5.966.025
Malls		-	-			-	-	-

Table C.1 continued

SOCIAL SERVICES	26.057	1,20	35.177			**3.126.840**	**14.121.306**	**17.248.146**
CULTURAL	17.365	0,90	23.443			2.083.800	10.777.192	12.860.992
1		-	-			-	-	-
2	4.070	0,21	5.495	1,35	264	488.400	1.450.548	1.938.948
3	1.945	0,10	2.626	1,35	395	233.400	1.037.171	1.270.571
4	11.350	0,59	15.323	1,35	541	1.362.000	8.289.473	9.651.473
								-
SPORTS	5.750	0,30	7.763			690.000	1.195.425	1.885.425
Simple Sport Estab.	5.750	0,30	7.763	1,35	154	690.000	1.195.425	1.885.425
Stadium & Sport Center		-	-			-	-	-
Swimming Pools		-	-			-	-	-
Historical Buildings	2.942	0,15	3.972	1,35	541	353.040	2.148.690	2.501.730

INDUSTRY	6.980	0,36	9.423			**837.600**	**1.658.448**	**2.496.048**
Small Industrial Estab.	6.980	0,36	9.423	1,35	176	837.600	1.658.448	2.496.048
Industrial Region. Str.						-	-	-

ADMINISTRATIVE	12.975	0,68	17.516			**1.557.000**	**3.512.471**	**5.069.471**
1	5.170	0,27	6.980	1,35	176	620.400	1.228.392	1.848.792
2	5.585	0,29	7.540	1,35	198	670.200	1.492.871	2.163.071
3		-	-	1,35		-	-	-
4	2.220	0,12	2.997	1,35	264	266.400	791.208	1.057.608

TOTAL COST, US$	**230.742.240**	**580.811.234**	**811.553.474**

Table C.2. Initial Cost of Karaman (New Development)

Total Town Area, m^2 1.509.600

FACILITIES	Land Area, m^2	%	Construction Area, m^2	KAKS	Construction Cost, US$/$m^2$	Total Land Cost, US$	Total Construction Cost, US$	Total Cost US$
RESIDENTIAL	749.000		599.200			**44.940.000**	**105.459.200**	**150.399.200**
Low Density			-			-	-	-
Medium density	749.000	49,62	599.200	0,8	176	44.940.000	105.459.200	150.399.200
High Density			-			-	-	-
INFRASTRUCTURE	11.500						**122.650.000**	**122.650.000**
Gas						-	-	-
Water						-	-	-
Communication						-	-	-
Electricity						-	-	-
Waste Water						-	-	-
Rain Water								
Underground						-	-	-
ROADS & SQUARES	373.900	24,77				**22.434.000**	**28.042.500**	**50.476.500**
Open Carpark		-				-	-	-
Multi-storey Carpark		-				-	-	-
Bridges & Overpasses		-				-	-	-
Avenue, m		-				-	-	-
Street, m	373.900	24,77	37.390		750	22.434.000	28.042.500	50.476.500
Squares		-				-	-	-
Railway		-				-	-	-

Table C.2 continued

RECREATION	274.900	18,21				**16.494.000**	**32.988.000**	**49.482.000**
Botanic Garden						-	-	-
Picnic Area	212.300	14,06	212.300		120	12.738.000	25.476.000	38.214.000
Parks & Gardens	62.600	4,15	62.600		120	3.756.000	7.512.000	11.268.000

EDUCATION	**36.400**	**2,41**	**18.200**			**2.184.000**	**3.303.300**	**5.487.300**
Nursery	9.100	0,60	4.550	0,5	198	546.000	900.900	1.446.900
Elementary	18.300	1,21	9.150	0,5	176	1.098.000	1.610.400	2.708.400
High School	9.000	0,60	4.500	0,5	176	540.000	792.000	1.332.000
University						-	-	-

HEALTH SERVICES	**25.300**	**1,68**	**34.155**			**1.518.000**	**9.016.920**	**10.534.920**
Hospitals						-	-	-
Other Health Services	25.300	1,68	34.155	1,35	264	1.518.000	9.016.920	10.534.920

COMMERCE	24.700	1,64	39.520			**1.482.000**	**13.041.600**	**14.523.600**
Office		-	-			-	-	-
Shopping District	24.700	1,64	39.520	1,6	330	1.482.000	13.041.600	14.523.600
Malls		-	-			-	-	-

Table C.2 continued

SOCIAL SERVICES	35.400	2,34	17.700			**2.124.000**	**4.426.800**	**6.550.800**
CULTURAL	13.300	0,88	6.650			798.000	2.725.100	3.523.100
1		-	-			-	-	-
2	6.300	0,42	3.150	0,5	264	378.000	831.600	1.209.600
3		-	-			-	-	-
4	7.000	0,46	3.500	0,5	541	420.000	1.893.500	2.313.500
								-
SPORTS	22.100	1,46	11.050			1.326.000	1.701.700	3.027.700
Simple Sport Estab.	22.100	1,46	11.050	0,5	154	1.326.000	1.701.700	3.027.700
Stadium & Sport Center		-	-			-	-	-
Swimming Pools		-	-			-	-	-
Historical Buildings		-	-			-	-	-

INDUSTRY	-	-	-			-	-	-
Small Industrial Estab.		-	-			-	-	-
Industrial Region. Str.						-	-	-

ADMINISTRATIVE	28.500	1,89	22.800			**1.710.000**	**4.012.800**	**5.722.800**
1	28.500	1,89	22.800	0,8	176	1.710.000	4.012.800	5.722.800
2		-	-			-	-	-
3		-	-			-	-	-
4		-	-			-	-	-

TOTAL COST, US$	**92.886.000**	**322.941.120**	**415.827.120**

Table C.3. Initial Cost of Camili (New Development)

Total Town Area, m^2 1.840.793

FACILITIES	Land Area, m^2	%	Construction Area, m^2	KAKS	Construction Cost/m^2	Total Land Cost, US$	Total Construction Cost, US$	Total Cost US$
RESIDENTIAL	477.960	25,96	382.368			**28.677.600**	**67.296.768**	**95.974.368**
Low Density			-			-	-	-
Medium density	477.960	25,96	382.368	0,8	176	28.677.600	67.296.768	95.974.368
High Density			-			-	-	-
INFRASTRUCTURE	11.978						**150.000.000**	**150.000.000**
Gas						-	-	-
Water						-	-	-
Communication						-	-	-
Electricity						-	-	-
Waste Water						-	-	-
Rain Water								
Underground						-	-	-
ROADS & SQUARES	469.141	25,49				**28.148.460**	**28.042.500**	**56.190.960**
Open Carpark		-				-	-	-
Multi-storey Carpark		-				-	-	-
Bridges & Overpasses		-				-	-	-
Avenue, m		-				-	-	-
Street, m	469.141	25,49	37.390		750	28.148.460	28.042.500	56.190.960
Squares		-				-	-	-
Railway		-				-	-	-

Table C.3 continued

RECREATION	535.816	29,11				**32.148.960**	**64.297.920**	**96.446.880**
Botanic Garden						-	-	-
Picnic Area	98.071	5,33	98071		120	5.884.260	11.768.520	17.652.780
Parks & Gardens	437.745	23,78	437745		120	26.264.700	52.529.400	78.794.100

EDUCATION	**118.925**	**6,46**	**59.463**			**7.135.500**	**10.586.972**	**17.722.472**
Nursery	11.052	0,60	5.526	0,5	198	663.120	1.094.148	1.757.268
Elementary	54.151	2,94	27.076	0,5	176	3.249.060	4.765.288	8.014.348
High School	53.722	2,92	26.861	0,5	176	3.223.320	4.727.536	7.950.856
University						-	-	-

HEALTH SERVICES	**32.206**	**1,75**	**43.478**			**1.932.360**	**11.478.218**	**13.410.578**
Hospitals						-	-	-
Other Health Services	32.206	1,75	43.478	1,35	264	1.932.360	11.478.218	13.410.578

COMMERCE	49.557	2,69	79.291			**2.973.420**	**26.166.096**	**29.139.516**
Office		-	-			-	-	-
Shopping District	49.557	2,69	79.291	1,6	330	2.973.420	26.166.096	29.139.516
Malls		-	-			-	-	-

Table C.3 continued

SOCIAL SERVICES	53.286	2,89	26.643			**3.197.160**	**6.604.448**	**9.801.608**
CULTURAL	31.288	1,70	15.644			1.877.280	4.910.602	6.787.882
1		-	-			-	-	-
2	25.652	1,39	12.826	0,5	264	1.539.120	3.386.064	4.925.184
3		-	-			-	-	-
4	5.636	0,31	2.818	0,5	541	338.160	1.524.538	1.862.698
								-
SPORTS	21.998	1,20	10.999			1.319.880	1.693.846	3.013.726
Simple Sport Estab.	21.998	1,20	10.999	0,5	154	1.319.880	1.693.846	3.013.726
Stadium & Sport Center		-	-			-	-	-
Swimming Pools		-	-			-	-	-
Historical Buildings		-	-			-	-	-

INDUSTRY	-	-	-			-	-	-
Small Industrial Estab.		-	-			-	-	-
Industrial Region. Str.						-	-	-

ADMINISTRATIVE	85.184	4,63	68.147			**5.111.040**	**11.993.907**	**17.104.947**
1	85.184	4,63	68.147	0,8	176	5.111.040	11.993.907	17.104.947
2		-	-			-	-	-
3		-	-			-	-	-
4		-	-			-	-	-

TOTAL COST, US$	**109.324.500**	**376.466.830**	**485.791.330**

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