

PRE-DISASTER PLANNING OF MITIGATION, RESPONSE AND RECOVERY  
DECISIONS: CASE OF A POSSIBLE EARTHQUAKE IN ISTANBUL

by

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## **ABSTRACT**

### **PRE-DISASTER PLANNING OF MITIGATION, RESPONSE AND RECOVERY DECISIONS: A CASE OF A POSSIBLE EARTHQUAKE IN ISTANBUL**

Over the past three decades, increasing natural disaster losses have raised the importance of emergency management. In this respect, an optimization model is constructed in order to analyze the probable results of an earthquake. The aim of the model is to minimize the sum of mitigation, recovery and transportation costs of relief items with limited mitigation budget and limited capacity of aid stations. The developed linear programming model is applied to a case study for the university campuses in Şişli and Beşiktaş districts of Istanbul. Thus, the linear optimization model is solved by using the real data. With the obtained results, the relationship between the relief item inventory and mitigation strategies, the mitigation choices and the expected recovery costs under different conditions are discussed. Finally, the model can be used as a decision support tool for the risk managers facing a serious earthquake threat.

## ÖZET

### **HAFİFLETME, TEPKİ VE DÜZELTME KARARLARININ AFET ÖNCESİ PLANLAMASI: İSTANBUL'DA OLASI DEPREM OLMA DURUMU**

Geçen otuz yılda, doğal afetlere bağlı kayıpların artması afet yönetiminin önemi arttırmıştır. Buna bağlı olarak büyük bir depremin olası sonuçlarını analiz etmek için bir lineer optimizasyon modeli oluşturulmuştur. Model, limitli hafifletme bütçesi ve yardım merkezlerinin limitli kapasiteleriyle hafifletme, düzeltme ve yardım malzelerinin taşıma maliyetlerinin toplamını en aza indirmeyi amaçlar. Oluşturulan bu lineer optimizasyon modeli İstanbul'un Şişli ve Beşiktaş bölgelerinden seçilmiş üniversite kampüsleri için hazırlanan örnek-olay çalışmasına uygulanmıştır. Böylece, oluşturulan lineer optimizasyon modeli gerçek hayat verileri ile çalıştırılmıştır. Elde edilen sonuçlarla, yardım malzemesi envanteri ve hafifletme stratejileri arasındaki ilişki, hafifletme seçenekleri ve farklı koşullarda altında beklenen düzeltme masrafları yorumlanmıştır. Son olarak, model ciddi bir deprem tehlikesi ile yüzleşen risk yöneticileri tarafından karar destek aracı olarak kullanılabilir.

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## 1. INTRODUCTION

Natural disasters such as earthquakes, tornados, typhoons, and tsunamis continuously lead to considerable number of deaths, injuries and substantial economic losses all over the world. The loss after these disasters depends on the resilience of the affected population. With the rapid growth in the population, the pressure on natural resources and environment has increased, and as a result, the risk associated with the human activities is raised. For instance, the number of natural disasters worldwide related to extreme weather conditions has increased about 50% on each decade between 1900 and 1990 with a dramatic acceleration since 1950s. Parallel to this increment, the damage caused by these natural disasters has also aggravated with nearly the same rate (Kreimer and Munasinghe, 1990). Balcik and Beamon (2008) stated that the average annual number of natural disasters between 2000 and 2004 was 55% higher than the number between 1995 and 1999. This increase also raised the number of affected people with a rate of 33% in this time period. These past studies show the significance of emergency management to make the impact of natural disasters smaller.

Emergency management is a field that deals with the protection of critical assets from disasters or catastrophes. Emergency management ensures the stability of an organization, country and city after a natural disaster. There are four phases of emergency management. These are mitigation, preparedness, response and recovery.

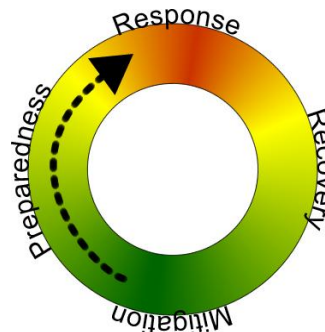


Figure 1.1. Phases of emergency management.

Mitigation is defined as the attempt to prevent the hazardous effects of the natural disasters or diminish them. By lessening the impact of disasters, mitigation efforts aim to reduce loss of life and property. The difference between the mitigation phase and the other phases is that mitigation efforts focus on long-term measures to eliminate the risk. Mitigation efforts take place in pre-event stages. Mitigation measures can be structural or non-structural. In this work, we concentrate on a specific structural mitigation measure which is building retrofitting for earthquakes.

Preparedness activities also take place in pre-event stages. These activities aim to develop plans to take action against the results of upcoming natural disasters. Preparedness activities include communication plans, training of emergency service teams, development of emergency population warning methods, encouraging volunteers to take action in the emergency conditions and train them and estimating required resources for every various emergency scenarios.

Response phase aims to take action immediately during and just after the disaster to prevent deaths and protect political and economic structures of the society. Transportation of relief items is a significant factor in the response phase. The shortest paths between the aid stations and the demand points have to be found in the preparedness phase and relief items have to be distributed to demand points as fast as possible during the disaster. Also, the prevention of shortage of relief items in aid stations is very important because an available relief item inventory at hand means to assist the victims of the disaster quicker. Another important issue in this phase is that the rescue teams have to be coordinated and trained perfectly before the disaster to react quickly during the disaster to save lives from building debris. Depending on the injuries, the hospitals and other medical centers must be ready to respond to serve quickly and successfully.

Recovery efforts simply aim to restore the damage area to its normality. These efforts include rebuilding, reemployment and repairing the infrastructure of the damaged area. It is logical to classify this phase into two major headlines. These are short-term recovery and long-term recovery. In this study we concentrate on the short-term recovery, namely the recovery actions that take place just after the disaster.

An earthquake is a sudden-onset disaster which can destroy commercial, industrial and housing stock, leaving societies homeless and also can harm the productive base of a country. It may cause long-term effects on the economy. The effects of earthquakes are more dramatic in developing countries because they are so vulnerable to earthquakes as well as to other natural disasters. Poverty and rapid population growth are the main reasons of weak resilience to earthquakes in developing countries.

Turkey is a rapidly developing country and political scientist and economists categorize it as the newly industrialized country as of 2011. The Marmara region is the most industrialized and crowded region of Turkey. The financial, cultural and economic center of Turkey, Istanbul, is also placed in this region. Istanbul is the third largest metropolitan area in Europe after London and Moscow with a population of 13.26 million people living in it as of December 2010. This population is equal to 18% of the total population of Turkey. With these bright features, this region is also one of the alarming seismic parts of the Turkey. According to historical documents on earthquakes, 55 destructive earthquakes were recorded during the last 2000 years (Ambraseys, 2002). In 1999, two catastrophic earthquakes occurred in Marmara region. On 17 August 1999, there were almost one million people trapped under debris, thousands of people were dead and a myriad number of people became homeless. Just after several months from this destructive disaster, on 12 November 1999, another huge earthquake hit the region in Duzce. There were 894 deaths and 4948 injuries (Bakir and Boduroglu, 2002). These two earthquakes drastically show that a better emergency management has to be applied to avoid these fatal results.

Istanbul has an important role in the education system in Turkey. The city houses many of the finest institutions of higher education in Turkey. There are eight public universities and 30 private universities active in the city of Istanbul. Most of the bright students around Turkey and from other parts of the world come to Istanbul to have high quality of education. The universities in Istanbul are located in many different parts of the city, but most of them are placed in Beşiktaş and Şişli district. In 2011, total university student population in these districts is 58272. It is known that Istanbul is seismically in danger, and for the safety of the bright futures of the country and the valuable academic

personals that provide priceless knowledge to these students, an active disaster response system has to be applied to the universities of Istanbul.

The specific concern of this thesis is to develop an optimization model for a disaster response system. The main aim is to minimize the sum of four different costs. These costs are the total mitigation cost, expected post-earthquake recovery cost, expected transportation cost of relief items from aid stations to demand points just after the earthquake and expected penalty cost due to limited relief item shortage. While these costs are minimized, the satisfaction of the demands and the completion of the retrofiting process are aimed to minimize the damage of the expected earthquake.

This thesis is organized as follows. The literature on regional earthquake mitigation strategies, quantitative tools for humanitarian relief process and earthquake probability estimation studies is reviewed in Chapter 2. In Chapter 3, we first give general information on mitigation and recovery phase of the emergency management and their role in our optimization model. Then we explain the distribution of relief items and its importance in the model. Finally, the model formulation and its explanation is given in Chapter 3. In Chapter 4, we present a case study for universities in Şişli and Beşiktaş district to run our model with real life data. Finally, we analyzed the results obtained from eight different cases and conclude in the last section.

## 2. LITERATURE SURVEY

There are three major points in literature, which directly form the basis of this thesis. These are studies on regional earthquake mitigation optimization, estimation of earthquake occurrence times and facility location problems. The research in the field of regional earthquake mitigation optimization is reviewed first with an emphasis on studies regarding the structural upgrading of buildings to reduce their vulnerability to damage. Previous researches on estimated earthquake probabilities are also used in this thesis to adapt the mathematical model with real life data. In particular, we focus on probability distributions with respect to the earthquake risk in Istanbul. We review the facility location problems in literature to work on post-disaster transportation and the shortage of relief items.

### 2.1. Regional Earthquake Mitigation Strategies

Generally, the communities have limited available budget for taking action to mitigate future losses, even though they recognize the earthquake risk. Therefore, they have to decide on an active regional earthquake mitigation planning, which is a systematic procedure to prioritize alternative mitigation strategies and to determine the spending on mitigation versus post-earthquake reconstruction (Dodo *et al.*, 2005). There are two significant issues in this planning stage: (i) the amount to spend on pre-earthquake mitigation that targets to diminish future losses versus waiting until after a major earthquake and paying for recovery, and (ii) the choice from the myriad possible mitigation activities to fund so as to minimize the overall risk (Dodo *et al.*, 2004). Structural upgrading, non-structural upgrading, public education, removing structures from hazardous locations, emergency planning, buying insurance and saving money are the examples of possible pre-earthquake investments (Dodo *et al.*, 2004).

Previous research related to earthquake mitigation planning can be grouped into four approaches. These are deterministic net present value analysis, stochastic net present value analysis, multiattribute utility models and optimization models (Vaziri *et al.*, 2010).

Deterministic net present value analysis is widely used in the literature and it is easier to use compared to other approaches. This type of analysis involves estimating the cost of implementing each mitigation alternative, estimating the benefits of each alternative, where benefits are losses avoided by implementing the alternative, comparing alternatives according to the net present value or a similar criterion (Dodo *et al.*, 2005) (Vaziri *et al.*, 2010). The deterministic net present value analysis is used by Kunreuther *et al.* (2001) to examine the way to utilize a cost benefit analysis to evaluate the attractiveness of mitigation for lifeline systems subject to earthquake ground motion. Altay *et al.* (2002) also used this approach to perform a cost benefit analysis on a common and vulnerable type of an apartment building located in Istanbul for implementation of various seismic retrofitting measures.

The difference between stochastic net present value analysis and deterministic net present value analysis is that the benefits of the mitigation alternatives are estimated by using a convenient probability density function. Mostafa and Grigoriu (2002) employed a 22000 gallon water tank on the twentieth floor of a hospital in New York City to show the potential of their methodology clearly based on fragility surfaces and cost benefit analysis. They generate myriad seismic events and compare the distributions of losses with and without mitigation activities.

Multi-attribute utility and some similar decision techniques have been used in small number of studies to choose from earthquake mitigation strategies. Tamura *et al.* (2000) assumed various alternative scenarios of earthquakes to calculate costs to improve buildings, probability of death and injury to restore damaged buildings for each scenario. They worked on a system methodology of decision analysis by using a decision tree for mitigating the risk of earthquakes which are low probability and high consequence events. Opricovic and Tzeng (2000) developed a fuzzy multicriteria model which was used for the post-earthquake reconstruction problem in Central Taiwan. They considered a variety of scenarios for reconstructing infrastructures and urban areas.

In optimization models approach, it is aimed to maximize the net present value with given some constraints such as limited budget (Dodo *et al.*, 2005). This approach is also

used in this thesis. Ermoliev *et al.* (2000) used Monte Carlo optimization to create a system approach for management of catastrophic risks. They applied this model to low probability and high consequence events in Russia. Dodo *et al.* (2004) presented three alternative optimization model formulations. Structural upgrading policies for group of buildings are considered in all these three formulations. Firstly, they grouped the buildings into categories such as their census tract locations, structural types, occupancy types and design levels. After that step, the mitigation alternatives are created by considering all possible combinations of these four categories. The first alternative model formulation aimed to minimize the expected post-earthquake recovery costs:

$$\min \sum_t \sum_i \sum_j \sum_k \sum_c \sum_d \sum_{c'} R_{ijkt}^{dcc'} y_{ijkt}^{dcc'} \quad (2.1)$$

where  $R_{ijkt}^{dcc'}$  is the per square foot recovery cost for buildings in census tract  $k$  that are of structural type  $I$  and occupancy type  $j$  which were designed to seismic code  $c$  and have entered damage state  $d$  to be repaired to condition  $c'$  during time period  $t$ , and  $y_{ijkt}^{dcc'}$  are the decision variables during time period  $t$ , the square footage in census tract  $k$ , of structural type  $I$  and occupancy type  $j$  that was in condition  $c$  prior to the earthquake and has entered damaged state  $d$  as a result of the earthquake and is to be repaired to seismic code  $c'$ . This model includes several constraints as well as nonnegativity constraint for decision variables and annual budget constraint. They also used this formulation in a case study, which focuses on some buildings in Los Angeles County, CA (Dodo *et al.*, 2004). The decision variables of the first alternative model formulation were also used in the second alternative model formulation. On the other hand, it was aimed to minimize the present value of the total mitigation and the expected post-earthquake recovery costs. Both first and second model formulations are linear programs and can be easily solved by a standard linear program solver (Dodo *et al.*, 2004). A stochastic programming formulation is used to trade-off expected net present value against the large probable losses in the third alternative model formulation (Dodo *et al.*, 2004).

Dodo *et al.* (2005) developed their optimization formulation. The objective of the formulation is similar with the second alternative model formulation in their previous study

and it is to minimize the present value of the total mitigation and expected post-earthquake recovery cost:

$$\min \sum_t \frac{1}{(1+r)^{t-1}} \sum_m \sum_c \sum_{c'} F_{mt}^{cc'} z_{mt}^{cc'} + \sum_d R_{mt}^{dcc'} y_{mt}^{dcc'} \quad (2.2)$$

where  $F_{mt}^{cc'}$  is per-square-foot cost to mitigate buildings in class  $m$ , during time  $t$ , that were upgraded from seismic level  $c$  to  $c'$ ,  $z_{mt}^{cc'}$  is square footage of buildings in class  $m$  that were in seismic design level  $c$  at the end of period  $t-1$  and were mitigated to seismic level  $c'$  at the beginning of period  $t$ , and  $r$  is an annual interest rate which is used to discount cash flows to the present value (Dodo *et al.*, 2005).  $R_{mt}^{dcc'}$  and  $y_{mt}^{dcc'}$  have the same definitions with the first alternative model formulation in their previous study. To simplify the notation they used  $m$  as a class of buildings in census tract  $k$  that are of structural type  $I$  and occupancy type  $j$ . This model includes a constraint for upgrading, a budget constraint and non-negativity constraints (Dodo *et al.*, 2005). They applied this model to ten census tracts in Los Angeles County, CA. After solving the case study, they concluded that the mitigation recommendations depend on the combinations of structural types and census tracts, and the various earthquake scenarios clearly affect the benefits, and an increment in total annual budget leads to spend more on mitigation and less on reconstruction.

Dodo *et al.* (2007) made some improvements in their model. They included several factors in their model such as life loss and soil amplification to focus on a more realistic case study. They also increase the area of their case study. Other than those improvements, they develop two efficient solution algorithms which are Dantzig-Wolfe decomposition algorithm and a greedy heuristic algorithm. They also compared those two solution algorithms. In this developed model, their aim is to minimize the net present value of the total mitigation and expected post-earthquake reconstruction expenditures.

Xu *et al.* (2007) developed another optimization model for resource allocation problem. Different from Dodo *et al.*'s optimization model, they defined risk. The reason why they included the concept of the risk is to avoid the possible losses that exceed some allowable threshold value. Their model had become a multi-objective optimization

formulation. One of their objectives is to minimize the net present value of the total mitigation and expected post-earthquake reconstruction expenditures like Dodo *et al.* did, and the other objective is to minimize the risk (Xu *et al.*,2007):

$$\min \sum_t \frac{1}{(1+r)^{t-1}} (\sum_m \sum_c \sum_{c'} F_{mt}^{cc'} z_{mt}^{cc'} + \sum_m \sum_c \sum_l \sum_d P^l R_{mt}^{dc} y_{mt}^{ldc} + \kappa \sum_l P^l \beta_t^l) \quad (2.3)$$

where  $\kappa \geq 0$  is the weight for the risk-based objective;  $r$  is an interest rate per period used to discount cash flows to the present value;  $F_{mt}^{cc'}$  is the per square foot cost to upgrade building area in class  $m$  from seismic code  $c$  to code  $c'$  during time  $t$ ;  $z_{mt}^{cc'}$  is the square footage of buildings in class  $m$  that were in seismic design level  $c$  at the end of period  $t - 1$  and were mitigated to seismic design level  $c'$  at the beginning of period  $t$ ;  $P^l$  is the per-period probability of earthquake  $l$ ;  $\beta^l$  is the excess reconstruction cost for earthquake  $l$ ;  $R_{mt}^{dc}$  is the per square foot reconstruction cost for building area in class  $m$  that enters damage state  $d$  and is repaired to code  $c$  during period  $t$ ; and  $y_{mt}^{ldc}$  is the square footage in class  $m$  that was in condition  $c$  prior to an earthquake  $l$ , enters damage state  $d$  as a result of the earthquake, and is repaired to seismic code  $c$  during time period  $t$  (Xu *et al.*, 2007). The constraints of the model are similar with Dodo *et al.*'s work. The case study of the work was also conducted to Central and Eastern part of the Los Angeles County, CA. After the case study, they concluded that as the risk aversion ( $\kappa$ ) increases, the mitigation expenditures increase and the reconstruction costs decrease.

In the previous studies on optimization model approach generally focus on developed countries such as USA and European countries. On the other hand, Vaziri *et al.* (2007) worked on a developing country, Iran. Compared with developed countries, Iran has more constrained economic resources and an earthquake in Iran may result in a widespread damage and higher death tolls. This model built on Dodo *et al.*'s work, but they expanded the model in some ways. For instance, in this model both upgrading a particular structure type and changing the structural type were mitigation alternatives. Like Xu *et al.*'s work, their model is also multi-objective.

## 2.2. Quantitative Tools for Humanitarian Relief Process

Most of the research on disaster management relates to social sciences. Generally, the studies on disaster management analyze the conclusions of disasters, psychological and economical impacts on societies and the response and communication system organizations. There are few but recently growing number of studies in this area, which use quantitative methods and principles such as Operational Research and Management Sciences for humanitarian relief process. Shortly, it is possible to define Operational Research as a scientific approach to the solution of problems in complex systems (Altay and Green, 2006).

Disaster response aims to exhibit some action in return to disasters as rapidly and effectively as possible by mobilizing resources such as people, money and other assets. For instance, the Red Cross and Red Crescent uses its network in a coordinated way to counter the initial effects of a disaster and meet the demands of affected people. In disaster response, the quantitative methods are used to design a supply network, facility locations and distribution of relief items. Quick response is very important in disaster response, because there is a little time to respond in inevitable occurrences. Quantitative methods such as operations research, computer science and engineering management have to be used in communication and computing technologies by emergency managers for an urgent need (Tufekci and Wallace, 1998).

Another significant issue in disaster response is the transportation of relief items. There are several issues in the literature that address this issue. Oh and Haghani (1996) used quantitative tools for emergency relief to analyze the transportation of various commodities such as food, medicine, clothing and personnel. The objective of their work was to minimize the loss of life and maximize the efficiency of the rescue operations. Barbarosoğlu *et al.* (2002) proposed a hierarchical multi-criteria methodology on an important logistical issue, which is to transport humanitarian relief items in an urgent condition and evacuate the affected people and transfer them from a disaster to hospitals quickly and safely by helicopters. They applied a two-level hierarchical decomposition to the problem and had the solutions during the initial response phase of disaster

management. Özdamar *et al.* (2004) propose a model on vehicle routing problem to plan logistics at a macro level. The model involves inter-city transportation of medical aid materials and personnel, specialized equipment, troops to keep order and conduct rescue activities, food and other various commodities used in relief processes. The aim of the work is coordinate logistics used in these relief processes. There are two sub-problems that had to be integrated. A Lagrangean relaxation is used to couple these two sub-problems. During an emergency response, Barbarosoğlu and Arda (2004) propose a two-stage stochastic programming model to provide a rapid transportation of first-aid commodities to places affected by a disaster. This model is distinct compared to previous studies since it includes survivability of connecting routes in the damaged area, amount of resources and an estimation of the demand for resources of first-aid commodities.

There are few quantitative tools used for inventory management in the literature. Beamon and Kortleba (2006) aimed to develop the inventory management policy of warehouses, which had a significant role in emergency aid operations. Their work did not focus on natural disasters, but on man-made disasters such as wars. They analyzed a case study of a single humanitarian agency operating a warehouse in the northwest Kenyan town of Lockichoggio, and responding to the south Sudan where a civil war has occurred for many years. For this case study, they assumed a continuous demand approximation and analyzed three different single-item inventory management strategies, which were mathematical, heuristic, and naïve models. Balcik and Beamon (2008) considered multi-item inventory management strategies and they integrated this multi-item inventory strategies and facility location. Furthermore, they considered budgetary constraints and capacity restrictions. Their model is based on the maximal covering location problem and they had various computational experiments on a realistic event to show the prolificness of their model. Döyen *et al.* (2011) developed a two-stage stochastic programming model for humanitarian relief logistics problem where decisions are made for pre- and post-disaster rescue centers, the amount of relief items to be stocked at the pre-disaster rescue centers, the amount of relief item flows at each echelon, and the amount of relief item shortage.

### 2.3. Earthquake Probability Estimation Studies

After two massive earthquakes that occurred in 1999 in the Marmara region, the scientists tried to forecast for the timing of next massive earthquake in Marmara region, which will affect the biggest city of Turkey, Istanbul. Probability seismic hazard analysis is a useful approach for forecasting the timing of earthquakes because it enables a basic conceptual structure to identify, quantify and combine the uncertainties in the size, location and the recurrence rate of an earthquake to provide a clear picture of the seismic hazard (Anbazhagan *et al.*, 2009). The time-dependent probability seismic hazard analysis and the time-independent probability seismic hazard analysis are two main probability seismic hazard analyses used in literature.

Time-independent probability seismic hazard analysis model is a classical approach and it is assumed that the earthquake events are independent both in time and space. In this classical approach, an earthquake occurrence follows a Poisson process. According to the Poisson process, the probability of a number of earthquakes having a magnitude equal or greater than a specific value during time interval  $t$  is

$$P(N = n | \lambda, t) = \frac{e^{-\lambda t} (\lambda t)^n}{n!} \quad (2.4)$$

The probability of at least one earthquake occurrence during time  $t$  is;

$$P(N \geq 1) = 1 - e^{-\lambda t} \quad (2.5)$$

where  $\lambda$  is the average number of earthquakes having a magnitude equal or greater than a specific value per unit time (Öztürk Yılmaz, 2008).

On the contrary, in time-dependent occurrence models, the probability of a future earthquake increases with the elapsed time since the last earthquake. These kinds of models are also called renewal models. In renewal models, the occurrence of a

characteristic earthquake is described as a sequence of events with independent and identically distributed inter-event times. The logic of these models date back to Reid's elastic rebound theory. In this theory, it is stated that an earthquake occurs whenever stress reaches a threshold on a fault. The occurrence of a characteristic earthquake releases the stored stress and the earthquake cycle begins anew. With the assumption in this theory of constant stress increments on faults, the recurrence times are perfectly periodic. In renewal models, the conditional probability, which is dependent on an assumed probability distribution of inter-event times, is used to enable the time dependency. Weibull distribution, lognormal distribution and the Brownian passage time distribution are the most common distributions in literature that are used to describe variability in recurrence time periods.

Cornell and Winterstein (1988) worked on both time-independent and time-dependent earthquake occurrence models. They made quantitative comparisons between the probability values for the earthquake occurrences for the Poisson model and non-Poisson models, where the inter-event times were distributed with Weibull distribution. They concluded that the Poisson estimate is insufficient for such cases in which the hazard is controlled by a single feature for which the elapsed time since the last significant event exceeds the average inter-event time. Matthews *et al.* (2002) proposed a time-dependent earthquake occurrence model. In their model, the inter-event times are distributed by Brownian passage time distribution. It is mentioned that in long-term earthquake forecasting, the Brownian passage time family reflects physical properties underlying earthquake generation, which makes it unique and different from other distributions such as log-normal and Weibull distributions for inter-event times. Abaimov *et al.* (2007) considered Brownian passage time, log-normal and Weibull distributions. They dealt with two different cases, which are the sequence of earthquakes on the Parkfield segment of the San Andreas Fault, and the sequence of earthquakes on the southern San Andreas Fault obtained from palaeoseismic studies at the Wrightwood site to compare these data with three distributions mentioned above of recurrence times.

In literature, there are also some studies for the faults near Istanbul in forecasting the probability of a characteristic earthquake in this region. Generally, the renewal models

have been used in these studies by observing the data of past characteristic earthquakes in the region. Parsons *et al.* (2000) combined the time-dependencies and stress transfer on a fault to calculate the probability of the next characteristic earthquake in Marmara region. They found a  $62 \pm 15\%$  probability of a characteristic earthquake in Istanbul during the next 30 years and  $32 \pm 12\%$  probability of a strong shaking event during the next decade in Marmara region in 2000. Parsons *et al.* (2004) made new probability calculations for the Marmara region. They included some new scientific findings into their analysis and found  $41 \pm 14\%$  probability of a characteristic earthquake in Istanbul.

### **3. FRAMEWORK OF THE EARTHQUAKE MITIGATION AND RESPONSE MODEL**

#### **3.1. Objectives and Scope**

The aims of the study is to determine the retrofitted area of buildings, the recovered area on the field of buildings, the amount of relief items demand transported from aid stations to buildings and the amount of shortage of relief item demands as to minimize costs of mitigation, recovery, the transportation of relief items and the penalty cost for shortage of relief items in aid stations. A linear programming model is constructed. This constructed linear programming model can be applied to several cases to support public regional planning process for upcoming earthquakes.

##### **3.1.1. Mitigation and Recovery Phase**

Pre-earthquake mitigation investments are significant because of several reasons. First of all, mitigation is definitely an important factor to minimize human losses, whereas post-earthquake spending is not even a factor to protect lives. Secondly, in most cases, avoiding the damage of a characteristic earthquake can be cheaper than repairing it, when the full range of losses are taken into consideration. Thirdly, mitigation investments have a positive psychological effect on people psychological, because they feel safe in their upgraded houses, work places and other public areas such as schools, universities and hospitals. For sure, earthquakes are the events whose occurrence times are uncertain. Accordingly, the discounting effect may cause mitigation investments less desirable than post-earthquake spending. Eventually, neither zero nor unlimited mitigation investments are likely to be optimal. An optimization model is a functional way to balance between those two extreme investments.

In this study, we focus on structural upgrading as a mitigation alternative. The initial seismic design levels of buildings in an observed area are determined and their seismic design levels are improved to prepare them for an upcoming earthquake. The

recovery phase is included in our model as an immediate response after an earthquake occurrence. For instance, if a laboratory is damaged after an earthquake, the spending for maintaining the functionality of that laboratory immediately is considered as a recovery cost in our model. Consequently, one of our objectives is to find the optimal spending for both pre-earthquake preparations and post-earthquake recoveries.

### **3.1.2. Transportation and Shortage of Relief Items**

Disaster relief operations are very substantial in order to help care-seeking people in damaged areas. These civilian activities can be classified as humanitarian aids and rescue actions in natural disasters. One of the objectives in this study is to design the transportation of food, equipment and first aid material to the affected areas from the aid stations that are geographically located close to the disaster region. It is possible to take action immediately after the receipt of an earthquake signal through rapid communication channels. The issue is to respond quickly after the disaster and less costly compared to other transportation activities by determining the shortest path possible to affected areas.

It is aimed to minimize the shortage of relief items in the stocks of aid stations. We assign a high penalty cost in our model to limit the shortage in the aid stations as much as possible. It is an important factor to be considered that everyone in the disaster region must utilize from the humanitarian aids.

## **3.2. Model Formulation**

Table 3.1 and Table 3.2 provide the definitions of all the parameters and the decision variables used in the model.

Table 3.1. Parameters used in the optimization model.

Parameters	Description
$z_k^c$	Area of building $k$ , seismic design level $c$ at time zero.
$B_t$	Available budget in period $t$ .
$\alpha_{kt}$	Population density (per $m^2$ ) of building $k$ , at time $t$ .
$c_{jk}(s)$	Unit transportation cost of relief items demand from facility $j$ to building $k$ under earthquake scenario $s$ .
$\lambda_d$	Demand parameter in damage type $d$ .
$\gamma_k^{dc}(s)$	Damage ratio of building $k$ in damage type $d$ , seismic design level $c$ under earthquake scenario $s$ .
$r_k^{c'c}$	Unit cost of mitigating a building from seismic design level $c'$ to seismic design level $c$ .
$v_k$	Unit cost of constructing a prefabricated house on the field of building $k$ .
$p_t(s)$	The conditional probability of earthquake scenario $s$ at time $t$ .
$q_{jt}(s)$	The maximum amount of relief items available at facility $j$ under scenario $s$ at time $t$ .
$u_t$	Inflation rate at time $t$
$g$	Interest rate

Table 3.2. Decision variables used in the optimization model.

Decision Variables	Description
$J_{kt}^c$	Floor area of building $k$ , with seismic design level $c$ at time $t$ .
$R_{kt}^{c'c}$	The retrofitted area from seismic design level $c'$ to seismic design level $c$ of building $k$ at time $t$ .
$I_{kt}$	The recovered area on the field of building $k$ at time $t$ .
$X_{jkt}(s)$	The amount of relief demand transported from aid station $j$ to building $k$ under scenario $s$ at time $t$ .
$W_{kt}(s)$	The amount of shortage of relief demand in building $k$ under scenario $s$ at time $t$
$D_{kt}(s)$	The level of relief items demand in building $k$ under scenario $s$ at time $t$

The parameters and decision variables that are defined in Table 3.1 and Table 3.2 respectively are used in the formulation of the linear programming model, which is constructed as follows:

$$\min \left( \sum_t \frac{(1+u_t)^{t-1}}{(1+g)^{t-1}} (\sum_k \sum_s p_t(s) a W_{kt}(s) + \sum_j \sum_k \sum_s p_t(s) c_{jk}(s) X_{jkt}(s) + \sum_s p_t(s) \sum_{t'=1}^t \sum_k \sum_{c'} \sum_{c \geq c'} r_k^{c'c} R_{kt'}^{c'c} + \sum_s \sum_k p_t(s) v_k I_{kt}) \right) \quad (3.1)$$

subject to

$$J_{kt}^c = z_k^c + \sum_{c'=1}^{c-1} R_{kt}^{c'c} - \sum_{c'=c+1}^{c_{max}} R_{kt}^{cc'} \quad \forall k, \forall c, t = 1 \quad (3.2)$$

$$J_{kt}^c = J_{kt-1}^c + \sum_{c'=1}^{c-1} R_{kt}^{c'c} - \sum_{c'=c+1}^{c_{max}} R_{kt}^{cc'} \quad \forall k, \forall c, t \geq 2 \quad (3.3)$$

$$I_{kt} \geq \sum_c J_{kt}^c \sum_{s=1}^{s_{max}} \sum_{d=1}^{d_{max}} p_t(s) \gamma_k^{dc}(s) \quad \forall k, \forall t \quad (3.4)$$

$$\sum_k \sum_{c'} \sum_{c \geq c'} r_m^{c'c} R_{kt}^{c'c} \leq B_t \quad \forall t \quad (3.5)$$

$$D_{kt}(s) = \sum_d \sum_c \lambda_d \gamma_k^{dc}(s) J_{kt}^c \alpha_{kt} \quad \forall k, \forall t, \forall s \quad (3.6)$$

$$D_{kt}(s) = \sum_j X_{jkt}(s) + W_{kt}(s) \quad \forall k, \forall t, \forall s \quad (3.7)$$

$$\sum_k X_{jkt}(s) \leq q_{jt}(s) \quad \forall j, \forall t, \forall s \quad (3.8)$$

$$J_{kt}^c \geq 0 \quad \forall c, \forall k, \forall t \quad (3.9)$$

$$R_{kt}^{c'c} \geq 0 \quad \forall c', \forall c, \forall k, \forall t \quad (3.10)$$

$$I_{kt} \geq 0 \quad \forall k, \forall t \quad (3.11)$$

$$X_{jkt}(s) \geq 0 \quad \forall j, \forall k, \forall t, \forall s \quad (3.12)$$

$$W_{kt}(s), D_{kt}(s) \geq 0 \quad \forall k, \forall t, \forall s \quad (3.13)$$

The objective (Equation 3.1) is to minimize the total mitigation cost, expected post-earthquake recovery cost, expected transportation cost of relief items from aid stations to demand points just after the characteristic earthquake and expected penalty cost due to limited relief item shortage. It is assumed that different areas of building  $k$  may be upgraded to various seismic design levels. The scalar value  $a$  is the unit penalty cost for shortage of relief demand. The logic of having the unit penalty cost in model is to reduce the shortage of relief items when a characteristic earthquake strikes the observed area. Lastly,  $u_t$  is an inflation rate per period and  $g$  is an interest rate used to discount cash flows to the present value.

Constraint sets (Equation 3.2) and (Equation 3.3) ensure that the total area of buildings does not change by mitigation. Total area is conserved through the time periods but the floor area at each code level may variate. These constraints state that building  $k$  at seismic design level  $c'$  can be retrofitted to a higher seismic design level. In a nutshell, it is assumed in the model that mitigation is only an improvement in seismic design level, so  $c > c'$ . Constraint set (Equation 3.2) shows the mitigation decisions in the first time period and constraint set (Equation 3.3) shows the mitigation decisions when  $t$  is equal or greater than 2.

Constraint set (Equation 3.4) points out the area that is to be recovered for building  $k$  when an earthquake occurs at time  $t$ . The total probability that the building  $k$  at seismic design level  $c$  has a damaged area is calculated by  $\sum_{s=1}^{s_{max}} \sum_{d=1}^{d_{max}} p_t(s) \gamma_k^{dc}(s)$ . The expected damaged area of a building  $k$  at time  $t$  is calculated by multiplying  $J_{kt}^c$  and  $\sum_{s=1}^{s_{max}} \sum_{d=1}^{d_{max}} p_t(s) \gamma_k^{dc}(s)$  and summing this result up every seismic design level. The

expected damaged area of a building  $k$  at time  $t$  is the minimum value of the recovered area of a building  $k$  at time  $t$ .

Constraint set (Equation 3.5) provides a limitation for retrofitting investments in each time period by a pre-determined mitigation budget per year.

Constraint set (Equation 3.6) states the amount of relief item needed in building  $k$  if an earthquake scenario  $s$  occurs in time period  $t$ . In this constraint, the calculation of  $\gamma_{km}^{dc}(s)J_{kt}^c$  is the expected floor area of building  $k$  at seismic design level  $c$ , which has a damage type  $d$  under earthquake scenario  $s$  in time period  $t$ . So, the expected number of residential people in building  $k$  facing a damage type  $d$  in time period  $t$  is found by  $\gamma_k^{dc}(s)J_{kt}^c\alpha_{kt}$ . Therefore, the amount of relief item needed is obtained by  $\lambda_d\gamma_k^{dc}(s)J_{kt}^c\alpha_{kt}$ . Finally, summing up for seismic design levels and damage types gives the total relief item demand in building  $k$  under earthquake scenario  $s$  at time  $t$ . The demand parameter provides an increment in demand level if the damage in buildings is higher. Constraint set (Equation 3.7) exhibits that the total relief item demand in building  $k$  under earthquake scenario  $s$  at time is the sum of the shortage of relief item demand in building  $k$  under earthquake scenario  $s$  at time  $t$  and the total amount of relief items transported from the aid stations to building  $k$ . Constraint set (Equation 3.8) limits the amount of relief items transported from the aid station  $j$  to buildings at time  $t$  under scenario by using the parameter  $q_{jt}(s)$ .

Lastly, constraint sets (Equation 3.9), (Equation 3.10), (Equation 3.11), (Equation 3.12) and (Equation 3.13) are non-negativity restrictions on the decision variables.

## 4. CASE STUDY

The case study in this section presents an illustration of the input data required and the type of results that the designed optimization model produces. This analysis is conducted for 11 university campuses located in Beşiktaş and Şişli districts of Istanbul. The results of the case study are also extensively discussed in this section.

### 4.1. Introduction

11 university campuses in Beşiktaş and Şişli districts in Istanbul are chosen for demand points in the optimization model. These campuses are Bahçeşehir University Beşiktaş campus, Bahçeşehir University Şişli Campus, Beykent University Ayazağa Campus, three campuses of Boğaziçi University (North, South and Hisar campuses), Galatasaray University Ortaköy Campus, Haliç University Mecidiyeköy Campus, Haliç University Bomonti Campus, Istanbul Technical University Maçka Campus, Marmara University Nişantaşı Campus, Mimar Sinan University Fındıklı Campus and Yıldız Technical University Yıldız Campus. As an important notice, we consider three campuses of Boğaziçi University as a single campus because these campuses are very near to each other. The buildings in these campuses are coded one by one. The total number of the buildings that are taken into consideration in these campuses are 37. Generally the structural type of these buildings is ferro concrete, however, apart from that there are limited number of stone buildings in some of these campuses. Table 4.1 exhibits each coded buildings in the chosen campuses. It is estimated that the population growth rate in the campuses is 1.3%. Also in Appendix A, an information about the chosen campuses is given.

There are three aid stations in this district that will send the relief items in an emergency situation. These aid stations are located in Etiler, Gültepe and Şişli. The first aid station is in Şaban Gündeş Sağlık Ocağı, which is located in Etiler. It is in Kültür Mahallesi, and close to both the coastal road and the two main highways of the city. The second aid station is in Şişli Etfal Hastanesi, which is located in Şişli. It is very central and

close to many demand points. The third aid station is in Gültepe ACS AP Dispanseri, which is located in Gültepe. Its location is close to one of the corniest avenues of Istanbul, Büyükdere Caddesi. This property makes this facility vital for the distribution of relief items.

Table 4.1. Coded buildings in university campuses.

<b>University Campuses</b>	<b>Buildings (k)</b>
Bahçeşehir University (Beşiktaş)	1
Bahçeşehir University (Şişli)	2
Beykent University	3
Boğaziçi University	4,5,6,7,8,9,10,11,12,13,14,15,16
Galatasaray University	17,18,19,20,21
ITU (Maçka)	22,23,24
Mimar Sinan University	25,26
YTU	27,28,29,30,31,32,33
Haliç University (Mecidiyeköy)	34
Haliç University (Bomonti)	35
Marmara University	36,37

## 4.2. Input Data

### 4.2.1. Distances between Aid stations and Demand Points

In order to find the optimal transportation cost of relief items during the characteristic earthquake, it is essential to obtain the distances between the aid stations and demand points. The Google Earth software is used to acquire the actual road distances between those points. The program also enables to find the shortest path between the aid stations and demand points. The Table 4.2 shows the distances in kilometers.

Table 4.2. Distance between aid stations and universities.

<b>Aid Station</b>	<b>Universities</b>	<b>Distance (km)</b>	
Etiler	Bahçeşehir University (Beşiktaş)	5.75	
	Bahçeşehir University (Şişli)	5.05	
	Beykent University	8.2	
	Boğaziçi University	3	
	Galatasaray University	4.84	
	ITU (Maçka)	7.16	
	Mimar Sinan University	7.89	
	YTU	5.62	
	Haliç University (Mecidiyeköy)	3.43	
	Haliç University (Bomonti)	5.26	
	Marmara University	5.79	
	<b>Aid Station</b>	<b>Universities</b>	<b>Distance (km)</b>
	Şişli	Bahçeşehir University (Beşiktaş)	3.32
Bahçeşehir University (Şişli)		1.37	
Beykent University		10.25	
Boğaziçi University		6.6	
Galatasaray University		4.15	
ITU (Maçka)		3.84	
Mimar Sinan University		3.78	
YTU		3.28	
Haliç University (Mecidiyeköy)		2.05	
Haliç University (Bomonti)		0.74	
Marmara University		2.22	
<b>Aid Station</b>		<b>Universities</b>	<b>Distance (km)</b>
Gültepe		Bahçeşehir University (Beşiktaş)	6.11
	Bahçeşehir University (Şişli)	2.75	
	Beykent University	6.28	
	Boğaziçi University	5.52	
	Galatasaray University	7.23	
	ITU (Maçka)	7.2	
	Mimar Sinan University	8.08	
	YTU	6.19	
	Haliç University (Mecidiyeköy)	1.92	
	Haliç University (Bomonti)	3.68	
	Marmara University	6.27	

#### 4.2.2. Computation of Earthquake Occurrence Probabilities

In this study, time-dependent probability seismic hazard analysis is employed to forecast the timing of the next earthquake in the given time period. In time-dependent probability seismic hazard analysis, it is assumed that the probability of the next earthquake increases with the elapsed time since the last earthquake.

The probability that a large earthquake occurs on a fault at time  $\tau$  in an interval  $(T, T + \Delta T)$ , assuming a probability density function for recurrence time  $f_T(t)$ , can be given by the integral;

$$P(T \leq \tau \leq T + \Delta T) = \int_T^{T + \Delta T} f_T(t) dt \quad (4.1)$$

Since the previous earthquake, if the elapsed time  $T_e$  is known on a specific fault, the conditional probability that the earthquake will occur in the next  $\Delta T$  years is given by the ratio:

$$P(T \leq \tau \leq T + \Delta T \mid \tau > T_e) = \frac{\int_T^{T + \Delta T} f_T(t) dt}{\int_T^{\infty} f_T(t) dt} \quad (4.2)$$

The Brownian passage time distribution is used to describe variability in recurrence time periods in this study. The Brownian passage time distribution is one of the most notable distributions that have been proposed and used in the literature. The probability density function of the Brownian passage time model is expressed as follows:

$$f_T(t) = \left(\frac{\mu}{2\pi\alpha^2 t^3}\right)^{\frac{1}{2}} \exp\left(-\frac{(t-\mu)^2}{2\alpha^2 \mu t}\right) \quad (4.3)$$

where  $\mu$  is the average inter-event time and  $\alpha$  is aperiodicity, which is conceptually similar to the coefficient of variance in normal distribution. The software ‘‘R’’ is used to show the

behavior of this distribution. For instance, if  $\mu$  is taken as 20 and  $\alpha$  is 0.5, then we obtain the following graph for  $f_T(t)$ .

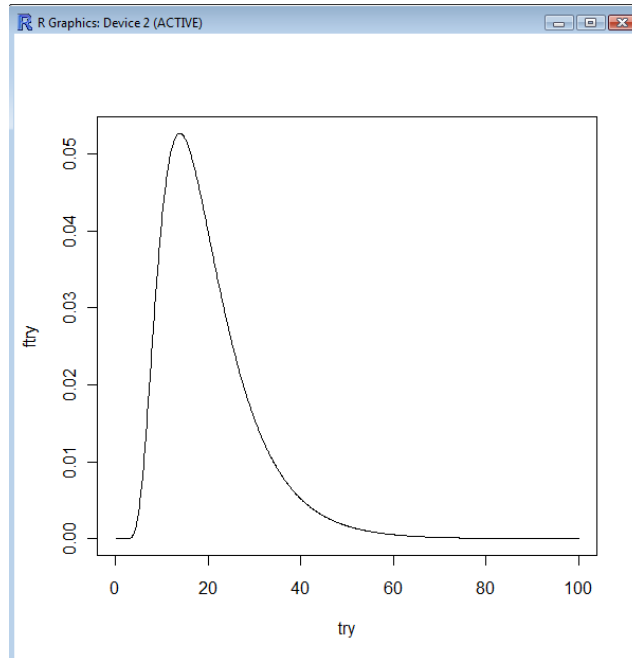


Figure 4.1. Probability distribution function of Brownian passage time distribution with  $\mu = 20$  and  $\alpha = 0.5$ .

As can be seen in this diagram, when  $t$  approaches the value of  $\mu$ , the function gets its maximum value. Then there is a sharp decreasing trend when  $t$  is getting closer to 40, and after that time, the probability distribution  $f_T(t)$  is getting asymptotically zero.

An important issue in such earthquake estimates is the reliable data of characteristic earthquake recurrence intervals. In literature, Ambraseys worked on the past earthquakes in Marmara region. He listed the characteristic earthquakes from the year zero to year two thousand. The earthquakes in the list have magnitudes 6.8 or larger than this value. This data can be used to calculate the conditional probability of the future characteristic earthquake in Marmara region. The data is given below (Ambraseys, 2000).

Table 4.3. Past characteristic earthquakes in Marmara region between 0 and 2000.

Year	Magnitude	Location	Year	Magnitude	Location	Year	Magnitude	Location
32	7	Nicaea	740	7.1	Marmara	1752	6.8	Edirne
68	7.2	Nicaea	860	6.8	Marmara	1754	6.8	Izmit
121	7.4	Nicomedia	869	7	CP	1766	7.1	Marmara
123	7	Cyzicus	967	7.2	Bolu	1766	7.4	Gonas
160	7.1	Hellespont	989	7.2	Marmara	1855	7.1	Bursa
180	7.3	Nicomedia	1063	7.4	Panio	1859	6.8	Saros
268	7.3	Nicomedia	1065	6.8	Nicaea	1893	6.9	Saros
358	7.4	Izmit	1296	7	Bithynia	1894	7.3	Izmit
362	6.8	Izmit	1343	6.9	Ganos	1912	7.3	Ganos
368	6.8	Persis	1343	7	Heraclea	1912	6.8	Ganos
368	6.8	Germe	1354	7.4	Hexamili	1944	6.8	Edremit
407	6.8	Hebdomon	1419	7.2	Bursa	1953	7.1	Gonen
437	6.8	Istanbul	1509	7.2	CP	1957	7.1	Abant
447	7.2	Nicomedia	1556	7.1	Gonen	1964	6.8	Manyas
460	6.9	Cyzicus	1625	7.1	Saros	1967	7.2	Mudurnu
478	7.3	Helenopolis	1659	7.2	Saros	1999	7.4	Izmit
484	7.2	Callipolis	1672	7	Biga	1999	7.1	Duzce
554	6.9	Nicomedia	1719	7.4	Izmit			
557	6.9	Silivri	1737	7	Biga			

In our case study, we created four different scenarios. The first scenario is for earthquakes with magnitudes of 6.8 and 6.9, the second scenario is for earthquakes with magnitudes 7.0 and 7.1, the third scenario is for earthquakes with magnitudes 7.2 and 7.3, and finally the fourth scenario is for earthquakes with magnitudes 7.4 or higher. To calculate the probability of each scenario, the average inter-event times of characteristic earthquakes in Marmara region is obtained from the data and it is 36.35 years. The aperiodicity is taken at a conservative value 0.5 in our model because there is no adequate catalog to estimate the coefficient of variance of inter-event time. As is mentioned before, this data is collected until the year 2000. We know that there was not any characteristic earthquake occurred in Marmara region until the beginning of 2011. So we calculated the conditional probabilities of a possible characteristic earthquake for the next 20 years from year 2011 by using Equation 4.2 and Equation 4.3 with the help of software “R”.  $\mu$  is equal to 36.35 years and  $\alpha$  is equal to 0.5.

Table 4.4. Conditional probabilities of a next characteristic earthquake.

Year	Conditional Probability	Year	Conditional Probability
2011	0.006497927	2021	0.0335555
2012	0.009047087	2022	0.03567483
2013	0.011837	2023	0.0376397
2014	0.01476	2024	0.03945679
2015	0.017726	2025	0.041124
2016	0.02066181	2026	0.04268
2017	0.023514	2027	0.044105
2018	0.026249	2028	0.0454162
2019	0.0288403	2029	0.046623
2020	0.03127756	2030	0.047734

Table 4.4 shows the conditional probabilities of the next characteristic earthquake in the Marmara region, which has a magnitude greater or equal to 6.8. By using the software “R” it is possible to draw a graph of these probabilities to see the behavior much clearly.

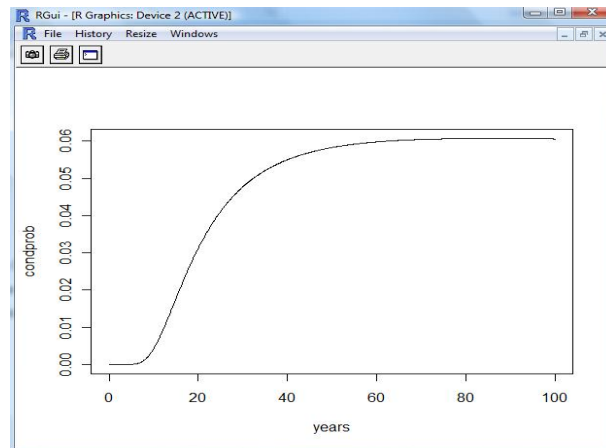


Figure 4.2. Graph of conditional probabilities.

In the next step we have to extend these probabilities by including the scenarios. In order to do this, we have to calculate the probabilities of each scenario. Ambraseys’ work states that there were 55 events that had occurred in Marmara region, 18 of these events had the magnitudes 6.8 or 6.9, 16 had the magnitudes 7.0 or 7.1, 14 had the the magnitudes 7.2

or 7.3 and lastly seven have the magnitude 7.4 or greater. Table 4.5 gives the probabilities of each scenario in Marmara region by dividing the number of each scenario occurrences into the total number of earthquakes.

Table 4.5. Earthquake scenario probabilities.

Scenarios	Probability
Scenario 1	0.3273
Scenario 2	0.291
Scenario 3	0.2545
Scenario 4	0.1273

For the last step, we have to calculate the conditional probabilities of each scenario in each time period. We multiply conditional probabilities in Table 4.4 with earthquake scenario probabilities in Table 4.5. Table 4.6 shows the calculated conditional probabilities of each scenario in the following 20 years.

#### 4.2.3. Determination of Cost Parameters

In this section, the definition of the mitigation, recovery, transportation and penalty costs for our model is given to determine the optimum total cost for preparing and facing the disaster risk.

The mitigation cost ( $r_k^{c'c}$ ) is per square meter cost of mitigating a building  $k$  from a seismic design level  $c'$  to an upgraded seismic design level  $c$ . These costs are given per unit area. The work of Altay *et al.* is used in our model as the data of mitigation costs. Table 4.7 shows the costs to mitigate from a specific seismic design level to upgraded design levels (Altay *et al.*, 2002).

The other significant parameter for our disaster response problem is the recovery cost. In our model, the definition of the recovery cost is the outlay for responding to damaged areas of the universities to pursue the education without any hitches due to the disaster.

Table 4.6. Conditional probabilities of each scenario in each year.

<b>Years</b>	<b>Scenarios</b>	<b>Conditional Probability</b>	<b>Years</b>	<b>Scenarios</b>	<b>Conditional Probability</b>
2011	Scenario 1	0.002126594	2021	Scenario 1	0.0109818
2011	Scenario 2	0.001890306	2021	Scenario 2	0.0097616
2011	Scenario 3	0.001654018	2021	Scenario 3	0.0085414
2011	Scenario 4	0.000827009	2021	Scenario 4	0.0042707
2012	Scenario 1	0.002960865	2022	Scenario 1	0.011675399
2012	Scenario 2	0.00263188	2022	Scenario 2	0.010378132
2012	Scenario 3	0.002302895	2022	Scenario 3	0.009080866
2012	Scenario 4	0.001151447	2022	Scenario 4	0.004540433
2013	Scenario 1	0.003873927	2023	Scenario 1	0.012318447
2013	Scenario 2	0.003443491	2023	Scenario 2	0.010949731
2013	Scenario 3	0.003013055	2023	Scenario 3	0.009581015
2013	Scenario 4	0.001506527	2023	Scenario 4	0.004790507
2014	Scenario 1	0.004830545	2024	Scenario 1	0.012913131
2014	Scenario 2	0.004293818	2024	Scenario 2	0.011478339
2014	Scenario 3	0.003757091	2024	Scenario 3	0.010043547
2014	Scenario 4	0.001878545	2024	Scenario 4	0.005021773
2015	Scenario 1	0.005801236	2025	Scenario 1	0.013458764
2015	Scenario 2	0.005156655	2025	Scenario 2	0.011963345
2015	Scenario 3	0.004512073	2025	Scenario 3	0.010467927
2015	Scenario 4	0.002256036	2025	Scenario 4	0.005233964
2016	Scenario 1	0.006762047	2026	Scenario 1	0.013968
2016	Scenario 2	0.006010708	2026	Scenario 2	0.012416
2016	Scenario 3	0.00525937	2026	Scenario 3	0.010864
2016	Scenario 4	0.002629685	2026	Scenario 4	0.005432
2017	Scenario 1	0.007695491	2027	Scenario 1	0.014434364
2017	Scenario 2	0.006840436	2027	Scenario 2	0.012830545
2017	Scenario 3	0.005985382	2027	Scenario 3	0.011226727
2017	Scenario 4	0.002992691	2027	Scenario 4	0.005613364
2018	Scenario 1	0.008590582	2028	Scenario 1	0.014863484
2018	Scenario 2	0.007636073	2028	Scenario 2	0.013211985
2018	Scenario 3	0.006681564	2028	Scenario 3	0.011560487
2018	Scenario 4	0.003340782	2028	Scenario 4	0.005780244
2019	Scenario 1	0.009438644	2029	Scenario 1	0.015258436
2019	Scenario 2	0.008389905	2029	Scenario 2	0.013563055
2019	Scenario 3	0.007341167	2029	Scenario 3	0.011867673
2019	Scenario 4	0.003670584	2029	Scenario 4	0.005933836
2020	Scenario 1	0.010236292	2030	Scenario 1	0.015622036

Table 4.6. Conditional probabilities of each scenario in each year. (cont.).

2020	Scenario 2	0.009098927	2030	Scenario 2	0.013886255
2020	Scenario 3	0.007961561	2030	Scenario 3	0.012150473
2020	Scenario 4	0.00398078	2030	Scenario 4	0.006075236

Table 4.7. Unit mitigation costs.

Structural Type	Current Seismic Design Level	Intended Seismic Design Level	Unit Cost (TL)
Ferro-Concrete	1	2	65
Ferro-Concrete	1	3	80
Ferro-Concrete	1	4	135
Ferro-Concrete	1	5	163
Ferro-Concrete	2	3	65
Ferro-Concrete	2	4	80
Ferro-Concrete	2	5	135
Ferro-Concrete	3	4	65
Ferro-Concrete	3	5	80
Ferro-Concrete	4	5	65
Stone	1	2	97
Stone	1	3	120
Stone	1	4	202
Stone	1	5	245
Stone	2	3	97
Stone	2	4	120
Stone	2	5	202
Stone	3	4	97
Stone	3	5	120
Stone	4	5	97

It is assumed that the structural type of the buildings does not affect the amount of the recovery cost and it is same for all of the buildings in the observed area. This cost is assumed to be 750 TL per unit area ( $m^2$ ).

The transportation cost is another important parameter in our model. It is the unit cost to transfer relief demand from aid stations to the buildings in the selected campuses under each scenario. In order to determine the transportation cost, the gas consumption of

an ordinary truck and the unit gas prices in Istanbul are considered. When an ordinary truck travels with a velocity of 66km/hr, the gas consumption of a truck is 30 liters in 126 km. The gas price in Istanbul is currently 4.21 TL per liter. So, the cost for an ordinary truck to travel 1 km is approximately 1.005 TL. In Section 4.3.1, the distances between the aid stations and the demand points are given. With those data, it is possible to calculate the unit transportation cost for the trucks to travel from one aid station to a demand point. The Table 4.8 shows the transportation costs that we used in our model.

Lastly, we have a high penalty cost, if there is a shortage in any stocks of the aid stations. The aim to assign a high value for this cost is to prevent any shortage in the model. Otherwise it is logical to have shortage in the model, because the objective of the model is to minimize the sum of the costs. Having a shortage in relief item stocks is not a desirable option under a disaster scenario.

#### **4.2.4. Determination of Damage Ratio and Demand Parameter**

In the model, it is assumed that there are three types of damages, which are light, moderate and heavy. In the determination of damage ratio, several points are considered. First of all, if a building has a seismic design level of 5, under any earthquake scenario that building decisively is not going to be damaged in any types. With this assumption, the model will try to retrofit the buildings to seismic design level 5 as much as possible to minimize the demand level. Secondly, when the magnitude of the expected earthquake increases, the damage risk in the buildings correspondingly increases, but as it is mentioned before the buildings with seismic design level 5 does not have any damage risk. Thirdly, the risk of heavy damage increases as the seismic design level of a building decreases. Fourthly, it is assumed that the stone buildings are more resistant to earthquakes than the ferro-concrete buildings, thus the damage risk in stone buildings are less than the damage risk in ferro-concrete buildings. Lastly, under same conditions, the sum of the damage ratios cannot be more than 1. For instance, under the first earthquake scenario, in a ferro-concrete building with seismic design level 1, sum of the probabilities of possible damage types (light, moderate, heavy) is not more than 1.

Table 4.8. Unit transportation costs.

<b>Aid Station</b>	<b>Universities</b>	<b>Unit Cost (TL)</b>
Etiler	Bahçeşehir University (Beşiktaş)	5.78
Etiler	Bahçeşehir University (Şişli)	5.07
Etiler	Beykent University	8.24
Etiler	Boğaziçi University	3.01
Etiler	Galatasaray University	4.86
Etiler	ITU	7.19
Etiler	Mimar Sinan University	7.93
Etiler	YTU	5.65
Etiler	Haliç University (Mecidiyeköy)	3.45
Etiler	Haliç University (Bomonti)	5.29
Etiler	Marmara University	5.82
<b>Aid Station</b>	<b>Universities</b>	<b>Unit Cost (TL)</b>
Şişli	Bahçeşehir University (Beşiktaş)	3.34
Şişli	Bahçeşehir University (Şişli)	1.38
Şişli	Beykent University	10.3
Şişli	Boğaziçi University	6.63
Şişli	Galatasaray University	4.17
Şişli	ITU	3.86
Şişli	Mimar Sinan University	3.8
Şişli	YTU	3.3
Şişli	Haliç University (Mecidiyeköy)	2.06
Şişli	Haliç University (Bomonti)	0.74
Şişli	Marmara University	2.23
<b>Aid Station</b>	<b>Universities</b>	<b>Unit Cost (TL)</b>
Gültepe	Bahçeşehir University (Beşiktaş)	6.14
Gültepe	Bahçeşehir University (Şişli)	2.76
Gültepe	Beykent University	6.31
Gültepe	Boğaziçi University	5.55
Gültepe	Galatasaray University	7.26
Gültepe	ITU	7.23
Gültepe	Mimar Sinan University	8.12
Gültepe	YTU	6.22
Gültepe	Haliç University (Mecidiyeköy)	1.93
Gültepe	Haliç University (Bomonti)	3.7
Gültepe	Marmara University	6.3

The demand parameter provides an increment in demand level if the damage in buildings is higher. The remarkable points for the determination of demand parameter are the damage types. Table 4.9 exhibits the demand parameters used in the model.

Table 4.9. Demand parameters.

Damage Type	Demand Parameter
Light	1
Moderate	2
Heavy	5

#### 4.2.5. Turkey Inflation Rate Forecast

In this study, we used exponential smoothing method to forecast the inflation rate of Turkey. This technique can be applied to time series data, a sequence of observations, to make forecasts. The application of this method is common in financial market and economic data. When the sequence of observations starts at  $t = 0$ , the simplest form of exponential smoothing is given by the formula

$$\hat{y}_{t+1} = \hat{y}_t + \alpha(y_t - \hat{y}_t)$$

where  $\hat{y}_t$  is the estimated rate at time  $t$  Istanbul  $y_t$  is the actual rate at time  $t$  and  $\alpha$  is the smoothing factor. In this study Istanbul we used the conservative value of 0.3 for  $\alpha$ . The following data in Table 4.10 are the inflation rates in Turkey from 2004 to 2010.

The inflation rate forecast in Turkey for next 20 years can be estimated by applying the exponential smoothing technique to the data in Table 4.10 The inflation rates derived from this method are given in Table 4.11.

Table 4.10. Inflation rates in Turkey between 2004 and 2010.

<b>Year</b>	<b>Inflation Rate</b>
2004	0.093
2005	0.082
2006	0.098
2007	0.087
2008	0.104
2009	0.063
2010	0.087

Table 4.11. Inflation rate forecasts for the next 20 years.

<b>Year</b>	<b>Inflation Rate Forecast</b>	<b>Year</b>	<b>Inflation Rate Forecast</b>
2011	0.064	2021	0.0957
2012	0.0108	2022	0.0965
2013	0.0878	2023	0.0959
2014	0.102	2024	0.0963
2015	0.0921	2025	0.0960
2016	0.099	2026	0.0962
2017	0.0941	2027	0.0961
2018	0.0975	2028	0.0962
2019	0.0952	2029	0.0961
2020	0.0968	2030	0.0962

The benchmark interest rate is taken constant value 9%.

### 4.3. Results

The linear optimization model constructed in this work was solved by using GAMS software. The results from the model can be used to answer various questions Istanbul including (i) What is the optimal budget to be spent on mitigation? (ii) Which time periods are optimal to retrofit the buildings? (iii) Which aid station is the most economical for transporting relief items to each of the buildings? (iv) What must be the optimum level of

relief items in each of the aid stations to avoid shortage? (v) What are the total expected recovery costs in each year? Analyzing the results and investigating these and other possible questions on the case study can enable acute observations in regional earthquake risk management problem. Eight cases under different conditions are created to analyze the problem more accurately. Finally, the general analysis for the case study will be given by using the results obtained from those cases.

#### **4.3.1. Case A**

In Case A, it is assumed that the capacity of each aid station is 10000 relief items in each year of 20 years time period. There are three aid stations and totally 30000 relief items are at hand for a single year. The penalty cost for the shortage is very high and it forces the model to obstruct any shortages. The penalty cost for the shortage is 1 billion TL for each building in each scenario and in every year. In Case A, an infinite mitigation budget is used to solve this optimization problem. The reason why the infinite budget is used in Case A is that we do not want to restrict the mitigation expenditures with any financial boundaries. It is also obvious that minimum value of the expected total cost will be same when the problem is solved by either infinite budget per year or optimum amount of budget per year. The optimum mitigation budget level of each year will be obtained for Case A and will be given in the results section of Case A.

4.3.3.1. Results for Case A. In this case, most of the buildings are retrofitted to the highest seismic design level at the end of the 20<sup>th</sup> time period. The total number of the buildings in the model is 37 and 27 of them is reached to the highest seismic design level in the first period by infinite budget per year. In Table 4.12 the buildings that are retrofitted to maximum seismic design level in 2011, their campuses and their initial seismic design levels are exhibited.

Table 4.12. Mitigation process completed buildings in 2011 in Case A.

Building No	University Campus	Initial Seismic Level	Total Area (m <sup>2</sup> )
1	Bahçeşehir University Beşiktaş Campus	1	18327.15
2	Bahçeşehir University Şişli Campus	3	3191.87
3	Beykent University Ayazağa Campus	1	23444.04
8	Boğaziçi University South Campus	4	2443.50
9	Boğaziçi University North Campus	4	18716.73
12	Boğaziçi University North Campus	4	4848.29
13	Boğaziçi University North Campus	4	2816.46
15	Boğaziçi University North Campus	4	3913.11
16	Boğaziçi University North Campus	4	6002.50
25	Mimar Sinan University Fındıklı Campus	1	19034.67
26	Mimar Sinan University Fındıklı Campus	1	2232.84
27	Yıldız Technical University Yıldız Campus	2	1420.14
28	Yıldız Technical University Yıldız Campus	2	6689.88
29	Yıldız Technical University Yıldız Campus	2	7503.66
30	Yıldız Technical University Yıldız Campus	2	8175.77
31	Yıldız Technical University Yıldız Campus	2	2807.87
33	Yıldız Technical University Yıldız Campus	2	2285.28
35	Haliç University Bomonti Campus	3	6333.33
36	Marmara University Nişantaşı Campus	2	4527.69
37	Marmara University Nişantaşı Campus	2	1687.70

In Table 4.12, it is observed that 20 buildings are retrofitted to the highest seismic design level in 2011. The mitigation processes of Bahçeşehir University Beşiktaş Campus, Bahçeşehir University Şişli Campus, Beykent University Ayazağa Campus, Mimar Sinan University Fındıklı Campus, Haliç University Bomonti Campus and Marmara University Nişantaşı Campus are completed in this period. These buildings are safe and there will not be any damages if an earthquake hits in following years.

In Case A, there are some buildings that are not retrofitted, until the end of 2030. Table 4.13 shows the buildings that are not retrofitted in this 20 years time period.

The mitigation of the other buildings in the model is done in 19 years period. Table 4.14 exhibits the years of mitigation of these buildings, the mitigated areas of the buildings and their new seismic design levels.

Table 4.13. Buildings not retrofitted in 20 years in Case A.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.3
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
23	ITU Maçka Campus	3	20995.8
34	Haliç University Mecidiyeköy Campus	2	12571.8

At the end of the year 2030, most of the buildings are retrofitted to the highest seismic design level. The pie chart below shows the total area in the model with their seismic design levels.

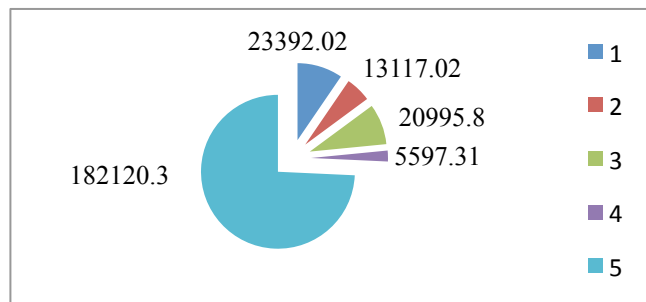


Figure 4.3. Floor areas (m<sup>2</sup>) with their seismic codes at the end of 2030 in Case A.

The total area under consideration is 245222.55 m<sup>2</sup>. 182120.30 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4.

20995.8 m<sup>2</sup> of the total area has a seismic design level of 3. 13117.02 m<sup>2</sup> of the total area has a seismic design level of 2. 23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. Eventually, 74.27% of the total area is retrofitted to the highest seismic design level.

Table 4.14. Buildings retrofitted in various years in Case A.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	4	Boğaziçi University Hisar Campus	4	5	5974.33	8712.02
2013	4	Boğaziçi University Hisar Campus	4	5	1386.52	8712.02
2015	4	Boğaziçi University Hisar Campus	4	5	1351.17	8712.02
2011	5	Boğaziçi University North Campus	4	5	6919.53	7493.20
2016	5	Boğaziçi University North Campus	4	5	573.67	7493.20
2011	10	Boğaziçi University North Campus	4	5	6012.29	7381.02
2014	10	Boğaziçi University North Campus	4	5	1368.73	7381.02
2011	11	Boğaziçi University North Campus	4	5	1719.92	1781.97
2012	11	Boğaziçi University North Campus	4	5	62.06	1781.97
2012	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2021	22	ITU Maçka Campus	3	5	1346.25	1743.16
2023	22	ITU Maçka Campus	3	5	396.91	1743.16
2022	24	ITU Maçka Campus	3	5	1328.97	2988.42
2023	24	ITU Maçka Campus	3	5	915	2988.42
2024	24	ITU Maçka Campus	3	5	744.44	2988.42
2016	32	Yıldız Technical University Yıldız Campus	2	5	243.68	4820.87
2017	32	Yıldız Technical University Yıldız Campus	2	5	422.09	4820.87
2018	32	Yıldız Technical University Yıldız Campus	2	5	416.67	4820.87
2019	32	Yıldız Technical University Yıldız Campus	2	5	411.33	4820.87
2020	32	Yıldız Technical University Yıldız Campus	2	5	406.05	4820.87
2024	32	Yıldız Technical University Yıldız Campus	2	5	163.95	4820.87
2025	32	Yıldız Technical University Yıldız Campus	2	5	380.65	4820.87
2026	32	Yıldız Technical University Yıldız Campus	2	5	375.77	4820.87
2027	32	Yıldız Technical University Yıldız Campus	2	5	370.95	4820.87
2028	32	Yıldız Technical University Yıldız Campus	2	5	366.19	4820.87
2029	32	Yıldız Technical University Yıldız Campus	2	5	361.49	4820.87
2030	32	Yıldız Technical University Yıldız Campus	2	5	356.85	4820.87

As it is mentioned before, there are no restrictions on the mitigation expenditures in Case A. Under these conditions, the mitigation expenditures per year is given in Table 4.15. These costs are also equal to the optimal mitigation budget per year for Case A.

Table 4.15. Mitigation expenditures per year for Case A.

<b>Year</b>	<b>Expenditures (TL)</b>	<b>Year</b>	<b>Expenditures (TL)</b>
2011	19318910	2021	104085
2012	90469	2022	102524
2013	89057	2023	101002
2014	87654	2024	89095
2015	86268	2025	73912
2016	84843	2026	72845
2017	83463	2027	71803
2018	82161	2028	70784
2019	80891	2029	69788
2020	79652	2030	68812

The mitigation cost in 2011 is very high when it is compared with the mitigation costs in other years. The reason is that the most of the retrofitting process is done in the first year. Another interesting point in Table 4.11 is the costs are decreasing as the years pass, but in 2021, 2022, 2023 and 2024 the costs are higher. In this four years period, the mitigation process takes place in ITU Maçka Campus. The initial seismic codes of these buildings are 3 and they are retrofitted to seismic design level of 5. The buildings are upgraded 2 levels, on the other hand, between 2012 and 2018, the mitigation process takes place in Boğaziçi University. The initial seismic design levels of these buildings are 4 and they are retrofitted to seismic design level of 5. These buildings are upgraded only 1 level. In years between 2025 and 2030, only one building in Yıldız Technical University Yıldız Campus is retrofitted. Total retrofitting process in 2021, 2022, 2023 and 2024 is more than other years except 2011, this is why the costs are higher in these years.

In Case A, the buildings that are retrofitted in the first time period, do not require any relief items from the aid stations in any time periods. The other 17 buildings from various university campuses require relief items in diverse time periods according to earthquake scenarios. It is obvious that the demand in these buildings increases, when the

magnitude of the earthquake increases. There is no shortage in the aid stations and every demand in every time period and earthquake scenario is satisfied. Table 4.16 shows the years that buildings require relief items and the aid stations that are used to satisfy the demand.

Table 4.16. Relief item transportation in Case A.

Building No	University Campus	Demand Years	Facility Point
4	Boğaziçi University Hisar Campus	2011-2014	Etiler
5	Boğaziçi University South Campus	2011-2015	Etiler
6	Boğaziçi University South Campus	2011-2030	Etiler
7	Boğaziçi University South Campus	2011-2030	Etiler
10	Boğaziçi University North Campus	2011-2013	Etiler
11	Boğaziçi University North Campus	2011	Etiler
14	Boğaziçi University North Campus	2011	Etiler
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
22	ITU Maçka Campus	2011-2022	Şişli
23	ITU Maçka Campus	2011-2030	Şişli
24	ITU Maçka Campus	2011-2023	Şişli
32	Yıldız Technical University Yıldız Campus	2011-2030	Şişli, Gültepe
34	Haliç University Mecidiyeköy Campus	2011-2030	Gültepe

The buildings in Galatasaray University require the highest demand, because among all of these buildings, the buildings in Galatasaray University have the lowest seismic design level of 1 and there is no mitigation process in 20 years. All three aid stations are used to send relief items to Galatasaray University to satisfy the demand in various earthquake scenarios. The demand in Boğaziçi University is satisfied by Etiler aid station. The demand in ITU Maçka campus is satisfied by Şişli aid station. The demand in Haliç University Mecidiyeköy campus is satisfied by Gültepe aid station. Both Şişli and Gültepe aid stations are used to meet the demand in Yıldız Technical University Yıldız campus.

In our model, we assume that when a building is mitigated to the highest seismic design level which is 5, there will not be any damage on that building to recover. In Case A, as it is mentioned before, 20 of the buildings are retrofitted in the first time period. There is not going to be any damaged areas in these buildings to recover. Table 4.17 shows the expected recovery costs per year in Case A.

Table 4.17. Expected recovery costs in Case A.

<b>Year</b>	<b>Expected Recovery Cost (TL)</b>	<b>Year</b>	<b>Expected Recovery Cost (TL)</b>
2011	2306	2021	53920
2012	4385	2022	59702
2013	7361	2023	65093
2014	11223	2024	70517
2015	15868	2025	76197
2016	21311	2026	81641
2017	27454	2027	86730
2018	34031	2028	91488
2019	40867	2029	95920
2020	47816	2030	100034

The expected recovery costs increase as the years pass. The reason of this increment in costs is the probability of an earthquake also increases in time.

#### **4.3.2. Case B**

In Case B, it is assumed that the capacity of each aid station is 500 relief items per year. Totally, 1500 relief items are at hand for a single year. The reason to decrease the capacities of the aid stations in this case is to force the model to retrofit more buildings. The penalty cost for the shortage in stocks is very high again, hence it is cheaper to retrofit buildings than having shortage in stocks of aid stations. It forces the model to obstruct any shortages. Like in Case A, this optimization problem is also solved by an infinite mitigation budget.

4.3.2.1. Results for Case B. In Case B, the retrofitting process in all of the buildings except 23<sup>rd</sup> building is completed in 2011. Table 4.18 shows the years of mitigation of 23<sup>rd</sup> building, the mitigated area of the building and its new seismic design level.

Table 4.18. Mitigation process of 23<sup>rd</sup> building in Case B.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	23	ITU Maçka Campus	3	5	14042.45	20995.8
2012	23	ITU Maçka Campus	3	5	89.23	20995.8
2013	23	ITU Maçka Campus	3	5	88.09	20995.8
2014	23	ITU Maçka Campus	3	5	86.96	20995.8
2015	23	ITU Maçka Campus	3	5	85.84	20995.8
2016	23	ITU Maçka Campus	3	5	84.74	20995.8
2017	23	ITU Maçka Campus	3	5	83.65	20995.8
2018	23	ITU Maçka Campus	3	5	82.58	20995.8
2019	23	ITU Maçka Campus	3	5	81.52	20995.8
2020	23	ITU Maçka Campus	3	5	80.47	20995.8
2021	23	ITU Maçka Campus	3	5	79.44	20995.8
2022	23	ITU Maçka Campus	3	5	78.42	20995.8
2023	23	ITU Maçka Campus	3	5	77.42	20995.8
2024	23	ITU Maçka Campus	3	5	76.42	20995.8
2025	23	ITU Maçka Campus	3	5	75.44	20995.8
2026	23	ITU Maçka Campus	3	5	74.47	20995.8
2027	23	ITU Maçka Campus	3	5	73.52	20995.8
2028	23	ITU Maçka Campus	3	5	72.57	20995.8
2029	23	ITU Maçka Campus	3	5	71.64	20995.8
2030	23	ITU Maçka Campus	3	5	70.72	20995.8

At the end of 2030, 15555.61 m<sup>2</sup> of this building has a seismic design level of 5 and 5440.19 m<sup>2</sup> of the building has a seismic design level of 3. At the end of 2030, most of the buildings are retrofitted to the highest seismic design level. Table 4.19 exhibits the total area in the model with their seismic design levels at the end of 20<sup>th</sup> period, if an earthquake does not occur.

Table 4.19. Floor area at the end of 2030 in Case B.

Seismic Design Level	Total Area (m <sup>2</sup> )
1	0
2	0
3	5440.19
4	0
5	239782.36

The mitigation expenditures of Case B is given in Table 4.20. Since the same reason as in Case A, these mitigation expenditures are also equal to the optimal mitigation budget per year for Case B.

Table 4.20. Mitigation expenditures per year in Case B.

Year	Expenditures (TL)	Year	Expenditures (TL)
2011	28678700	2021	9213
2012	10611	2022	9074
2013	10445	2023	8940
2014	10280	2024	8808
2015	10118	2025	8680
2016	9958	2026	8555
2017	9802	2027	8432
2018	9649	2028	8313
2019	9500	2029	8196
2020	9354	2030	8081

The mitigation expenditure in the first time period is distinctly higher than the expenditures in other time periods, because most of the retrofiting process is completed in this period. For other periods, as the years passed the mitigation expenditures decreases.

The buildings that their mitigation process is completed in the first time period, do not require any relief items from the aid stations. According to this, there is a demand only in the 23<sup>rd</sup> building. Under all earthquake scenarios, all three-aid stations satisfy the demand of residential people in this building definitively in the system in every year.

In Case B, the recovery costs are low, because 36 of 37 buildings are retrofitted in the first time period. The buildings are durable enough to face any characteristic earthquakes in following years, so the expected recovery costs are low. Table 4.21 shows the expected recovery costs per year for Case B.

Table 4.21. Expected recovery costs in Case B.

Year	Expected Recovery Cost (TL)	Year	Expected Recovery Cost (TL)
2011	180	2021	4234
2012	345	2022	4724
2013	584	2023	5192
2014	896	2024	5632
2015	1276	2025	6039
2016	1712	2026	6422
2017	2189	2027	6770
2018	2693	2028	7086
2019	3209	2029	7372
2020	3726	2030	7628

#### 4.3.3. Case C

In Case C, firstly, it is aimed to determine the total mitigation cost of the buildings in a single year. For this purpose, it is assumed that there are no relief items in the aid stations in each year. This pushed the model to retrofit every building in the first time period because the penalty cost of shortage is very high. In this case, the best option to minimize the total cost is to complete the mitigation process in the first time period. The total mitigation cost in this case is 29507680 TL. Secondly, the total mitigation cost is split up into equal amounts for each year and this new amount is assumed as the new mitigation budget per year. The new mitigation budget per year is 1475384 TL. By doing this, a limited mitigation budget will be used instead of an infinite mitigation budget, which makes the problem more realistic. After calculating the mitigation budget per year for Case C, the capacity of each aid stations and the penalty cost for shortage is set same as the values in Case A. In other words, the capacity of each aid station is 10000 relief items per year and the penalty cost for shortage is 1 billion TL for each building and each scenario in every year.

4.3.3.1. Results for Case C. In previous cases, most of the mitigation process is completed in 2011, because there is no boundary on mitigation budget in Case A and Case B. However, in Case C there is a limited budget per year. Table 4.22 shows the years of mitigation of the buildings and the mitigated area of the buildings.

Table 4.22. Mitigation process in Case C.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	1	Bahçeşehir University Beşiktaş Campus	1	5	2441.30	18327.15
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	9305.34	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	6580.52	18327.15
2011	2	Bahçeşehir University Şişli Campus	3	5	3191.87	3191.87
2018	3	Beykent University Ayazağa Campus	1	5	1022.70	23444.04
2019	3	Beykent University Ayazağa Campus	1	5	9494.99	23444.04
2020	3	Beykent University Ayazağa Campus	1	5	9518.88	23444.04
2021	3	Beykent University Ayazağa Campus	1	5	3407.48	23444.04
2022	4	Boğaziçi University Hisar Campus	4	5	4974.26	8712.02
2024	4	Boğaziçi University Hisar Campus	4	5	1378.10	8712.02
2025	4	Boğaziçi University Hisar Campus	4	5	1187.45	8712.02
2026	4	Boğaziçi University Hisar Campus	4	5	1172.21	8712.02
2023	5	Boğaziçi University South Campus	4	5	7493.20	7493.20
2022	8	Boğaziçi University South Campus	4	5	2443.50	2443.50
2023	9	Boğaziçi University North Campus	4	5	5549.41	18716.73
2024	9	Boğaziçi University North Campus	4	5	11320.94	18716.73
2027	9	Boğaziçi University North Campus	4	5	1157.17	18716.73
2028	9	Boğaziçi University North Campus	4	5	689.22	18716.73
2022	10	Boğaziçi University North Campus	4	5	7381.02	7381.02
2023	11	Boğaziçi University North Campus	4	5	1781.97	1781.97
2023	12	Boğaziçi University North Campus	4	5	4848.29	4848.29
2022	13	Boğaziçi University North Campus	4	5	2816.46	2816.46
2024	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2023	15	Boğaziçi University North Campus	4	5	3913.11	3913.11
2021	16	Boğaziçi University North Campus	4	5	79.82	6002.50
2022	16	Boğaziçi University North Campus	4	5	5922.68	6002.50
2029	22	ITU Maçka Campus	3	5	1214.08	1743.16
2030	22	ITU Maçka Campus	3	5	529.07	1743.16
2028	24	ITU Maçka Campus	3	5	487.82	2988.42

Table 4.22. Mitigation process in Case C. (cont.).

2030	24	ITU Maçka Campus	3	5	669.43	2988.42
2016	25	Mimar Sinan University Fındıklı Campus	1	5	6543.95	19034.67
2017	25	Mimar Sinan University Fındıklı Campus	1	5	7210.36	19034.67
2018	25	Mimar Sinan University Fındıklı Campus	1	5	5280.36	19034.67
2017	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2014	27	Yıldız Technical University Yıldız Campus	2	5	1420.14	1420.14
2014	28	Yıldız Technical University Yıldız Campus	2	5	6689.88	6689.88
2015	29	Yıldız Technical University Yıldız Campus	2	5	7503.66	7503.66
2013	30	Yıldız Technical University Yıldız Campus	2	5	452.68	8175.77
2014	30	Yıldız Technical University Yıldız Campus	2	5	697.21	8175.77
2015	30	Yıldız Technical University Yıldız Campus	2	5	3622.33	8175.77
2016	30	Yıldız Technical University Yıldız Campus	2	5	3403.55	8175.77
2013	31	Yıldız Technical University Yıldız Campus	2	5	2807.87	2807.87
2021	32	Yıldız Technical University Yıldız Campus	2	5	4820.87	4820.87
2014	33	Yıldız Technical University Yıldız Campus	2	5	2285.28	2285.28
2018	35	Haliç University Bomonti Campus	3	5	6333.33	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	4527.69	4527.69
2011	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

As can be seen in Table 4.22, there is mitigation process in 28 buildings in 20 years. The mitigation of 26 buildings is completed during 20 years. Only in two buildings of ITU Maçka campus, the mitigation process is not completed. Some parts of these buildings have retrofitted a seismic design level of 5 and some parts have a seismic design level of 3 at the end of 2030. In nine buildings, there is no mitigation process during 20 years period and Table 4.23 exhibits these buildings.

Figure 4.4 shows the total area in the model with their seismic design level, at the end of year 2030.

In this case, 180834.46 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4. 22826.96 m<sup>2</sup> of the total area has a seismic design level of 3. 12571.80 m<sup>2</sup> of the total area has a seismic design level of 2.

23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. Eventually, 73.74% of the total area is retrofitted to the highest seismic design level.

Table 4.23. Buildings not retrofitted in 20 years in Case C.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.3
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
23	ITU Maçka Campus	3	20995.80
34	Haliç University Mecidiyeköy Campus	2	12571.80

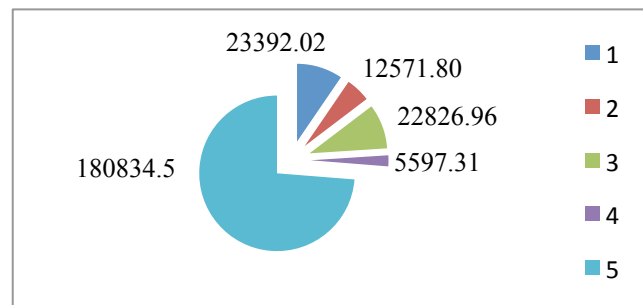


Figure 4.4. Floor area (m<sup>2</sup>) with seismic codes at the end of 2030 in Case C.

As specified before, there are financial boundaries for mitigation process in each year. Table 4.24 exhibits the mitigation expenditures in each year. This table provides to observe the amount of the budget spend in each year for retrofitting the buildings.

Table 4.24. Mitigation expenditures per year in Case C.

<b>Year</b>	<b>Expenditure (TL)</b>	<b>Year</b>	<b>Expenditure (TL)</b>
2011	1475384	2021	1475384
2012	1475384	2022	1475384
2013	1475384	2023	1475384
2014	1475384	2024	876687
2015	1475384	2025	74009
2016	1475384	2026	72941
2017	1475384	2027	71898
2018	1475384	2028	80018
2019	1475384	2029	92598
2020	1475384	2030	91303

In the first 13 years, the maximum amount is spent to retrofit the buildings. In the other periods, the model does not use the entire budget. The reason will be discussed in the analysis part of this section.

In Case C, the mitigation process is completed in a building in Bahçeşehir University Şişli Campus and two buildings in Marmara University Nişantaşı Campus in 2011. There is no demand from the residential people of these three buildings in any of the time periods. Table 4.25 exhibits the years that buildings require relief items, the aid stations that are used to satisfy the demand and the buildings that their demand cannot be satisfied in some scenarios and time periods.

In Table 4.25, it is observed that the demand of the residential people from Haliç University Mecidiyeköy and Bomonti Campuses can be satisfied fully under each earthquake scenario. The demand of residential people from Bahçeşehir University Beşiktaş Campus, Beykent University Ayazağa Campus and Mimar Sinan University Fındıklı Campus cannot get any relief items from any of the aid stations in years that they need relief items under each earthquake scenario. The demand in rest of the buildings is partially satisfied under various earthquake scenarios. After 2023, there is no shortage and the demand in every building in the following seven years is fully satisfied. Table 4.24 exhibits the demand levels in each year and earthquake scenario.

Table 4.25. Relief item transportation in Case C.

Building No	University Campus	Demand Years	Aid station	Shortage
1	Bahçeşehir University Beşiktaş Campus	2011-2012	-	Yes
3	Beykent University Ayazağa Campus	2011-2020	-	Yes
4	Boğaziçi University Hisar Campus	2011-2025	Etiler, Gültepe	Yes
5	Boğaziçi University South Campus	2011-2022	Etiler, Gültepe	Yes
6	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
7	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
8	Boğaziçi University South Campus	2011-2021	Etiler, Gültepe	Yes
9	Boğaziçi University North Campus	2011-2027	Etiler, Gültepe	Yes
10	Boğaziçi University North Campus	2011-2021	Etiler, Gültepe	Yes
11	Boğaziçi University North Campus	2011-2022	Etiler, Gültepe	Yes
12	Boğaziçi University North Campus	2011-2022	Etiler, Gültepe	Yes
13	Boğaziçi University North Campus	2011-2021	Etiler	Yes
14	Boğaziçi University North Campus	2011-2023	Etiler	Yes
15	Boğaziçi University North Campus	2011-2022	Etiler, Gültepe	Yes
16	Boğaziçi University North Campus	2011-2021	Etiler, Gültepe	Yes
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
22	ITU Maçka Campus	2011-2029	Şişli	Yes
23	ITU Maçka Campus	2011-2030	Şişli	Yes
24	ITU Maçka Campus	2011-2030	Şişli	Yes
25	Mimar Sinan University Fındıklı Campus	2011-2017	-	Yes
26	Mimar Sinan University Fındıklı Campus	2011-2016	-	Yes
27	Yıldız Technical University Yıldız Campus	2011-2013	Şişli	Yes
28	Yıldız Technical University Yıldız Campus	2011-2013	Şişli, Gültepe	Yes
29	Yıldız Technical University Yıldız Campus	2011-2014	Şişli, Gültepe	Yes
30	Yıldız Technical University Yıldız Campus	2011-2015	Şişli, Gültepe	Yes
31	Yıldız Technical University Yıldız Campus	2011-2012	Şişli	Yes
32	Yıldız Technical University Yıldız Campus	2011-2020	Şişli, Gültepe	Yes
33	Yıldız Technical University Yıldız Campus	2011-2013	Şişli, Gültepe	Yes
34	Haliç University Mecidiyeköy Campus	2011-2030	Gültepe	No
35	Haliç University Bomonti Campus	2011-2017	Gültepe	No

Table 4.26. Demand levels in Case C.

<b>Year</b>	<b>Scenario 1</b>	<b>Scenario 2</b>	<b>Scenario 3</b>	<b>Scenario 4</b>
2011	129313.69	133444.65	137575.61	144216.87
2012	118239.25	122105.02	125970.79	132180.19
2013	107614.89	111209.44	114803.99	120606.59
2014	98593.14	101913.78	105234.42	110711.66
2015	89286.76	92324.78	95362.80	100504.01
2016	79958.05	82754.40	85550.74	90339.75
2017	70460.35	73029.62	75598.89	80022.09
2018	61992.76	64332.78	66672.80	70611.00
2019	54947.78	57121.95	59296.12	62966.57
2020	47689.14	49692.25	51695.37	55089.63
2021	41202.92	43005.96	44809.00	47937.16
2022	35702.13	37142.28	38582.43	41123.47
2023	30038.88	31105.60	32172.32	34109.14
2024	26734.12	27578.21	28422.30	30000.00
2025	26765.11	27599.91	28434.72	30000.00
2026	26796.50	27621.89	28447.29	30000.00
2027	26828.29	27644.16	28460.03	30000.00
2028	26854.40	27663.92	28473.45	30000.00
2029	26871.56	27679.70	28487.84	30000.00
2030	26888.94	27695.68	28502.42	30000.00

The total capacity of the aid stations is 30000 relief items every year under each earthquake scenario. In Table 4.26, it is observed that total demand is more than 30000 relief items in every earthquake scenario until 2024. The full capacity of aid stations is used to satisfy the demand in the buildings in the fourth earthquake scenario between 2024 and 2030.

Table 4.27 shows the expected annual recovery costs in Case C. The expected annual recovery costs are increasing in time.

Table 4.27. Expected recovery costs in Case C.

Year	Expected Recovery Cost (TL)	Year	Expected Recovery Cost (TL)
2011	7213	2021	108124
2012	13411	2022	99765
2013	21925	2023	86016
2014	32280	2024	78140
2015	43938	2025	83378
2016	56515	2026	88206
2017	69282	2027	92508
2018	79872	2028	96285
2019	90502	2029	99529
2020	99467	2030	102321

#### 4.3.4. Case D

In Case D, the total mitigation cost of the buildings, which is calculated in Case C is divided into two parts by multiplying with 0.67 and 0.33 respectively. Both of the results are divided into ten. The first part, which is multiplied by 0.67 and divided into 10, is set for the mitigation budget of the first ten years. The second part, which is multiplied by 0.33 and divided into 10, is set for the mitigation budget for the last ten years. As a result, in the first ten years the mitigation budget is 1967179 TL and in the last ten years the mitigation budget is 983589 TL. The capacities of the aid stations are assigned with respect to Table 4.26. The level of demands in Table 4.26 is split up equally to three aid stations. The reason is to avoid shortage. It is assumed that the capacities alter according to earthquake scenarios and time periods. The penalty cost for shortage is very high like the previous cases.

4.3.4.1. Results for Case D. Like in Case C, there is a boundary in mitigation budget. Different from Case C, there is more amount available to spend for mitigation process in first ten years and less amount available in the following ten years. However, the total 20 years mitigation budget is same as Case C and Case D. Table 4.28 exhibits the years of

mitigation of the buildings, the retrofitted area of the buildings and their new seismic design levels.

Table 4.28. Mitigation process in Case D.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	1	Bahçeşehir University Beşiktaş Campus	1	5	2440.33	18327.15
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	9305.61	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	6581.22	18327.15
2011	2	Bahçeşehir University Şişli Campus	3	5	3191.87	3191.87
2020	3	Beykent University Ayazağa Campus	1	5	6974.56	23444.04
2021	3	Beykent University Ayazağa Campus	1	5	6360.87	23444.04
2022	3	Beykent University Ayazağa Campus	1	5	3720.74	23444.04
2023	3	Beykent University Ayazağa Campus	1	5	6387.87	23444.04
2019	4	Boğaziçi University Hisar Campus	4	5	677.37	8712.02
2020	4	Boğaziçi University Hisar Campus	4	5	8034.64	7493.20
2019	5	Boğaziçi University South Campus	4	5	7493.20	7493.20
2017	8	Boğaziçi University South Campus	4	5	2443.50	2443.50
2017	9	Boğaziçi University North Campus	4	5	1212.75	18716.73
2018	9	Boğaziçi University North Campus	4	5	13951.46	7381.02
2019	9	Boğaziçi University North Campus	4	5	3552.53	7381.02
2018	10	Boğaziçi University North Campus	4	5	7381.02	7381.02
2020	11	Boğaziçi University North Campus	4	5	103.37	1781.97
2024	11	Boğaziçi University North Campus	4	5	1678.60	4848.29
2019	12	Boğaziçi University North Campus	4	5	4848.29	4848.29
2019	13	Boğaziçi University North Campus	4	5	2816.46	2816.46
2018	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2019	15	Boğaziçi University North Campus	4	5	3913.11	3913.11
2019	16	Boğaziçi University North Campus	4	5	6002.50	6002.50
2024	22	ITU Maçka Campus	3	5	520.08	1743.16
2025	22	ITU Maçka Campus	3	5	1223.08	1743.16
2024	24	ITU Maçka Campus	3	5	2988.42	2988.42
2016	25	Mimar Sinan University Fındıklı Campus	1	5	6543.72	19034.67
2017	25	Mimar Sinan University Fındıklı Campus	1	5	8655.08	19034.67
2018	25	Mimar Sinan University Fındıklı Campus	1	5	3414.59	19034.67
2022	25	Mimar Sinan University Fındıklı Campus	1	5	421.28	19034.67
2022	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2016	27	Yıldız Technical University Yıldız Campus	2	5	1420.14	1420.14
2015	28	Yıldız Technical University Yıldız Campus	2	5	6689.88	6689.88

Table 4.28. Mitigation process in Case D. (cont.).

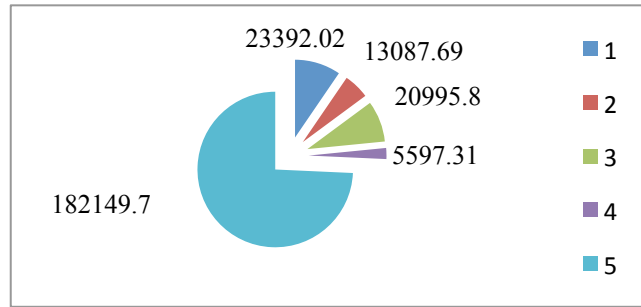
2013	29	Yıldız Technical University Yıldız Campus	2	5	1449.81	7503.66
2014	29	Yıldız Technical University Yıldız Campus	2	5	2916.98	7503.66
2015	29	Yıldız Technical University Yıldız Campus	2	5	1153.23	7503.66
2016	29	Yıldız Technical University Yıldız Campus	2	5	1983.65	7503.66
2014	30	Yıldız Technical University Yıldız Campus	2	5	8175.77	8175.77
2013	31	Yıldız Technical University Yıldız Campus	2	5	1810.15	8175.77
2015	31	Yıldız Technical University Yıldız Campus	2	5	997.71	2807.87
2024	32	Yıldız Technical University Yıldız Campus	2	5	2600.83	4820.87
2026	32	Yıldız Technical University Yıldız Campus	2	5	339.33	4820.87
2027	32	Yıldız Technical University Yıldız Campus	2	5	338.62	4820.87
2028	32	Yıldız Technical University Yıldız Campus	2	5	338.12	4820.87
2029	32	Yıldız Technical University Yıldız Campus	2	5	346.07	4820.87
2030	32	Yıldız Technical University Yıldız Campus	2	5	342	4820.87
2015	33	Yıldız Technical University Yıldız Campus	2	5	2285.28	2285.28
2019	35	Haliç University Bomonti Campus	3	5	1510.91	6333.33
2020	35	Haliç University Bomonti Campus	3	5	4822.42	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	4527.69	4527.69
2011	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

As it is seen in Table 4.28, the mitigation process is done in 28 buildings in 20 years. The mitigation of 27 buildings is completed during 20 years and only a building in Yıldız Technical University Yıldız Campus is not fully retrofitted. 4303.97 m<sup>2</sup> of this building has retrofitted to seismic design level of 5 and 515.89 m<sup>2</sup> of the building have a seismic design level of 2 at the end 2030. There is no mitigation process during 20 years period in nine buildings and Table 4.29 exhibits these buildings.

Figure 4.5 chart shows the total area in the model with their seismic design level, at the end of year 2030.

Table 4.29. Buildings not retrofitted in 20 years in Case D.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.30
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
23	ITU Maçka Campus	3	20995.80
34	Haliç University Mecidiyeköy Campus	2	12571.80

Figure 4.5. Floor area (m<sup>2</sup>) with seismic codes at the end of 2030 in Case D.

182149.73 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4. 20995.80 m<sup>2</sup> of the total area has a seismic design level of 3. 13087.69 m<sup>2</sup> of the total area has a seismic design level of 2. 23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. At the end of 2030, 74.28% of the total area is retrofitted to the highest seismic design level.

The following table shows the mitigation expenditures in each year. The mitigation budget per year in the first ten periods is 1967179 TL and it is 983589 TL in the last ten years.

Table 4.30. Mitigation expenditures per year in Case D.

<b>Year</b>	<b>Expenditures (TL)</b>	<b>Year</b>	<b>Expenditures (TL)</b>
2011	1475230	2021	983589
2012	1475426	2022	983589
2013	1475416	2023	983589
2014	1475417	2024	880296
2015	1475398	2025	93822
2016	1475379	2026	65781
2017	1584317	2027	65546
2018	1967179	2028	65359
2019	1967179	2029	66811
2020	1967179	2030	65949

Between 2018 and 2023, the mitigation budget is used fully. In the first ten years, the total mitigation expenditure is more than the total mitigation expenditure in the last ten years. This shows that the total retrofitting process in the first ten years is higher than the total retrofitting process in the last ten years.

Like in Case C, in Case D, the mitigation process is completed in a building in Bahçeşehir University Şişli Campus and two buildings in Marmara University Nişantaşı Campus. There is no demand from the residential people of these three buildings in any of the time periods. Table 4.31 exhibits the years that buildings require relief items and the aid stations that are used to satisfy the demand.

In Case D, there is no shortage in any of the aid stations. The residential people in these 34 buildings are fully satisfied by all three of the aid stations under each scenario and every year.

Table 4.32 exhibits the expected recovery costs in Case D. There is an increasing trend in the first eight years in expected recovery costs. Then there is a drop in 2019, and it is followed by another increasing trend ended in 2024. From 2025 to 2030, there is the third increasing trend.

Table 4.31. Relief item transportation in Case D.

Building No	University Campus	Demand Years	Aid station
1	Bahçeşehir University Beşiktaş Campus	2011-2012	Etiler, Şişli
3	Beykent University Ayazağa Campus	2011-2022	Etiler, Gültepe
4	Boğaziçi University Hisar Campus	2011-2019	Etiler
5	Boğaziçi University South Campus	2011-2018	Etiler
6	Boğaziçi University South Campus	2011-2030	Etiler
7	Boğaziçi University South Campus	2011-2030	Etiler
8	Boğaziçi University South Campus	2011-2016	Etiler
9	Boğaziçi University North Campus	2011-2018	Etiler
10	Boğaziçi University North Campus	2011-2017	Etiler
11	Boğaziçi University North Campus	2011-2023	Etiler
12	Boğaziçi University North Campus	2011-2018	Etiler
13	Boğaziçi University North Campus	2011-2018	Etiler
14	Boğaziçi University North Campus	2011-2017	Etiler
15	Boğaziçi University North Campus	2011-2018	Etiler
16	Boğaziçi University North Campus	2011-2018	Etiler
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
22	ITU Maçka Campus	2011-2024	Şişli
23	ITU Maçka Campus	2011-2030	Şişli
24	ITU Maçka Campus	2011-2023	Şişli
25	Mimar Sinan University Fındıklı Campus	2011-2021	Şişli
26	Mimar Sinan University Fındıklı Campus	2011-2021	Şişli
27	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe
28	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe
29	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe
30	Yıldız Technical University Yıldız Campus	2011-2013	Etiler, Gültepe
31	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe
32	Yıldız Technical University Yıldız Campus	2011-2030	Etiler, Şişli, Gültepe
33	Yıldız Technical University Yıldız Campus	2011-2014	Şişli, Gültepe
34	Haliç University Mecidiyeköy Campus	2011-2030	Şişli, Gültepe
35	Haliç University Bomonti Campus	2011-2019	Şişli, Gültepe

Table 4.32. Expected recovery costs in Case D.

Year	Expected Recovery Cost (TL)	Year	Expected Recovery Cost (TL)
2011	7213	2021	68567
2012	13412	2022	71421
2013	21926	2023	72724
2014	32280	2024	71391
2015	43938	2025	76030
2016	56515	2026	81504
2017	68093	2027	86623
2018	71384	2028	91411
2019	66985	2029	95860
2020	64236	2030	99992

#### 4.3.5. Case E

The approach of Case E is similar with Case D. The capacities of the aid stations are same with the capacities in Case D. The penalty cost for shortage is very high again. The difference between Case D and Case E is the mitigation budget per year. In Case E, the total mitigation cost of the buildings calculated in Case C is divided into two parts by multiplying with 0.75 and 0.25 respectively. The mitigation budget per year of the first ten years is calculated by dividing the 0.75 of the total mitigation expenditure into ten and the mitigation budget per year of the last ten years is calculated by dividing the 0.25 of the total mitigation cost into ten. In the first ten years the mitigation budget is 2213076 TL and in the last ten years the mitigation budget is 737692 TL.

4.3.5.1. Results for Case E. Like in Case C and Case D, there is a boundary in mitigation budget in this case. There is more amount available to spend for mitigation process in first ten years than in Case C and Case D. On the other hand, there is less amount available in the following ten years than in Case C and Case D. The total 20 years mitigation budget is same as in Case E with the total 20 years mitigation budget in Case C and Case D. Table 4.33 shows the years of mitigation of the buildings according to their university campuses,

the retrofitted area of the buildings, their initial seismic design levels and their new seismic design levels.

Table 4.33. Mitigation process in Case E.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	1	Bahçeşehir University Beşiktaş Campus	1	5	2440.33	18327.15
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	9305.61	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	6581.22	18327.15
2011	2	Bahçeşehir University Şişli Campus	3	5	3191.87	3191.87
2019	3	Beykent University Ayazağa Campus	1	5	99.65	23444.04
2020	3	Beykent University Ayazağa Campus	1	5	14278.32	23444.04
2021	3	Beykent University Ayazağa Campus	1	5	2852.57	23444.04
2022	3	Beykent University Ayazağa Campus	1	5	1412.18	23444.04
2023	3	Beykent University Ayazağa Campus	1	5	4551.34	23444.04
2024	3	Beykent University Ayazağa Campus	1	5	249.99	23444.04
2017	4	Boğaziçi University Hisar Campus	4	5	93.99	8712.02
2018	4	Boğaziçi University Hisar Campus	4	5	6827.49	8712.02
2019	4	Boğaziçi University Hisar Campus	4	5	1790.54	8712.02
2019	5	Boğaziçi University South Campus	4	5	7493.20	7493.20
2019	8	Boğaziçi University South Campus	4	5	2443.50	2443.50
2019	9	Boğaziçi University North Campus	4	5	18716.73	18716.73
2018	10	Boğaziçi University North Campus	4	5	7381.02	7381.02
2018	11	Boğaziçi University North Campus	4	5	1781.97	1781.97
2018	12	Boğaziçi University North Campus	4	5	4848.29	4848.29
2018	13	Boğaziçi University North Campus	4	5	2816.46	2816.46
2018	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2018	15	Boğaziçi University North Campus	4	5	3913.11	3913.11
2017	16	Boğaziçi University North Campus	4	5	6002.50	6002.50
2025	22	ITU Maçka Campus	3	5	1223.08	1743.16
2026	22	ITU Maçka Campus	3	5	520.08	1743.16
2026	24	ITU Maçka Campus	3	5	677.39	2988.42
2027	24	ITU Maçka Campus	3	5	1194.96	2988.42
2028	24	ITU Maçka Campus	3	5	1116.07	2988.42
2016	25	Mimar Sinan University Fındıklı Campus	1	5	4310.89	19034.67
2017	25	Mimar Sinan University Fındıklı Campus	1	5	8129.31	19034.67
2018	25	Mimar Sinan University Fındıklı Campus	1	5	1067.86	19034.67

Table 4.33. Mitigation process in Case E. (cont.).

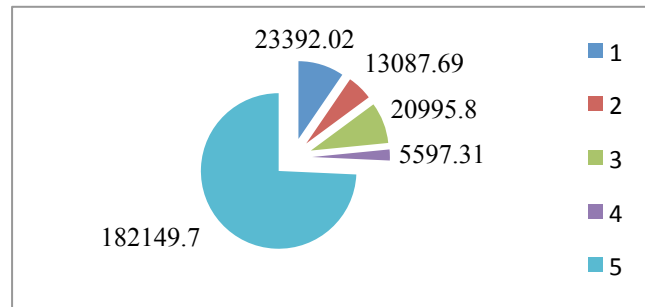
2021	25	Mimar Sinan University Fındıklı Campus	1	5	1918.08	19034.67
2022	25	Mimar Sinan University Fındıklı Campus	1	5	3368.96	19034.67
2023	25	Mimar Sinan University Fındıklı Campus	1	5	239.56	19034.67
2016	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2015	27	Yıldız Technical University Yıldız Campus	2	5	158.27	1420.14
2016	27	Yıldız Technical University Yıldız Campus	2	5	1261.87	1420.14
2013	28	Yıldız Technical University Yıldız Campus	2	5	58.6	6689.88
2014	28	Yıldız Technical University Yıldız Campus	2	5	6631.27	6689.88
2014	29	Yıldız Technical University Yıldız Campus	2	5	4461.48	7503.66
2015	29	Yıldız Technical University Yıldız Campus	2	5	900.27	7503.66
2016	29	Yıldız Technical University Yıldız Campus	2	5	2141.91	7503.66
2013	30	Yıldız Technical University Yıldız Campus	2	5	3201.36	8175.77
2015	30	Yıldız Technical University Yıldız Campus	2	5	4974.41	8175.77
2015	31	Yıldız Technical University Yıldız Campus	2	5	2807.87	2807.87
2024	32	Yıldız Technical University Yıldız Campus	2	5	3595.05	4820.87
2028	32	Yıldız Technical University Yıldız Campus	2	5	21.86	4820.87
2029	32	Yıldız Technical University Yıldız Campus	2	5	346.07	4820.87
2030	32	Yıldız Technical University Yıldız Campus	2	5	342	4820.87
2015	33	Yıldız Technical University Yıldız Campus	2	5	2285.28	2285.28
2018	35	Haliç University Bomonti Campus	3	5	2783.39	6333.33
2019	35	Haliç University Bomonti Campus	3	5	3549.94	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	4527.69	4527.69
2011	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

Similar with Case D, the mitigation process is done in 28 buildings in 20 years. The mitigation of 27 buildings is completed during 20 years and only a building in Yıldız Technical University Yıldız Campus is not retrofitted fully. 4303.97 m<sup>2</sup> of this building has retrofitted to seismic design level of 5 and 515.89 m<sup>2</sup> of the building have a seismic design level of 2 at the end 2030. The difference between Case D and Case E is that the most retrofitting process is done earlier in Case E. There are no mitigation process during 20 years period in nine buildings and Table 4.34 exhibits these buildings.

Table 4.34. Buildings not retrofitted in 20 years in Case E.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.30
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
23	ITU Maçka Campus	3	20995.80
34	Haliç University Mecidiyeköy Campus	2	12571.80

Figure 4.6 shows the total area in the model with their seismic design level. at the end of year 2030.

Figure 4.6. Floor area (m<sup>2</sup>) with seismic codes at the end of 2030 in Case E.

The mitigated areas are exactly same with the mitigated areas in Case E with the mitigated areas in Case D. 182149.73 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4. 20995.80 m<sup>2</sup> of the total area has a seismic design level of 3. 13087.69 m<sup>2</sup> of the total area has a seismic design level of 2. 23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. At the end of 2030, 74.28% of the total area is retrofitted to the highest seismic design level.

Table 4.35 shows the mitigation expenditures in each year. The mitigation budget in the first ten periods is 2213076 TL and it is 737692 TL in the last ten years.

Table 4.35. Mitigation expenditures in Case E.

Year	Expenditures (TL)	Year	Expenditures (TL)
2011	1475230	2021	737692
2012	1475426	2022	737692
2013	1475416	2023	737692
2014	1475417	2024	737692
2015	1475398	2025	93822
2016	1475379	2026	91708
2017	1657058	2027	91380
2018	2213076	2028	89454
2019	2213076	2029	66811
2020	2213076	2030	65949

Between 2018 and 2024, the mitigation budget is fully spent. In the first ten years, the total mitigation expenditure is more than the total mitigation expenditure in the last ten years. This shows that the total retrofitting process in the first ten years is higher than the total retrofitting process in the last ten years.

Like in Case C and Case D, the mitigation process is completed in a building in Bahçeşehir University Şişli Campus and two buildings in Marmara University Nişantaşı Campus in 2011 in Case E. There is no demand from the residential people of these three buildings in any of the time periods. Table 4.36 exhibits the years that buildings require relief items and the aid stations that are used to satisfy the demand.

In Case E, there is no shortage in any of the aid stations. The residential people in these 34 buildings are fully satisfied by all three of the aid stations under each scenario and every year.

The expected recovery costs in Case E is exhibited in Table 4.37. The expected recovery costs are almost same with the expected recovery costs in Case D.

Table 4.36. Relief item transportation in Case E.

Building No	University Campus	Demand Years	Aid station
1	Bahçeşehir University Beşiktaş Campus	2011-2012	Etiler, Şişli
3	Beykent University Ayazağa Campus	2011-2023	Etiler, Gültepe
4	Boğaziçi University Hisar Campus	2011-2018	Etiler
5	Boğaziçi University South Campus	2011-2018	Etiler
6	Boğaziçi University South Campus	2011-2030	Etiler
7	Boğaziçi University South Campus	2011-2030	Etiler
8	Boğaziçi University South Campus	2011-2018	Etiler
9	Boğaziçi University North Campus	2011-2018	Etiler
10	Boğaziçi University North Campus	2011-2017	Etiler
11	Boğaziçi University North Campus	2011-2017	Etiler
12	Boğaziçi University North Campus	2011-2017	Etiler
13	Boğaziçi University North Campus	2011-2017	Etiler
14	Boğaziçi University North Campus	2011-2017	Etiler
15	Boğaziçi University North Campus	2011-2017	Etiler
16	Boğaziçi University North Campus	2011-2016	Etiler
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe
22	ITU Maçka Campus	2011-2025	Şişli
23	ITU Maçka Campus	2011-2030	Şişli
24	ITU Maçka Campus	2011-2027	Şişli
25	Mimar Sinan University Fındıklı Campus	2011-2022	Şişli
26	Mimar Sinan University Fındıklı Campus	2011-2015	Şişli
27	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe
28	Yıldız Technical University Yıldız Campus	2011-2013	Etiler, Şişli, Gültepe
29	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe
30	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe
31	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe
32	Yıldız Technical University Yıldız Campus	2011-2030	Etiler, Şişli, Gültepe
33	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe
34	Haliç University Mecidiyeköy Campus	2011-2030	Şişli, Gültepe
35	Haliç University Bomonti Campus	2011-2018	Şişli, Gültepe

Table 4.37. Expected recovery costs in Case E.

<b>Year</b>	<b>Expected Recovery Cost (TL)</b>	<b>Year</b>	<b>Expected Recovery Cost (TL)</b>
2011	7213	2021	64669
2012	13412	2022	68536
2013	21926	2023	71207
2014	32280	2024	74434
2015	43938	2025	79336
2016	56515	2026	83849
2017	67300	2027	87832
2018	66977	2028	91411
2019	59645	2029	95860
2020	59684	2030	99992

#### 4.3.6. Case F

In Case F, it is aimed to reduce the mitigation budget to observe the effects of this reduction on the model. The mitigation budget per year in Case F is 70% of 1475384 TL, which is the mitigation budget per year in Case C. The mitigation budget in Case F is 1032769 TL in every time period. The capacities of the aid stations are same with the capacities in Case D and Case E. There is a very high penalty cost to prevent shortage in the aid stations.

4.3.6.1. Results for Case F. In Case F, the aim is to observe the mitigation process with a reduction in mitigation budget per year, and having a same level of relief items at the aid stations. Table 4.38 shows the years of mitigation of the buildings, the mitigated area of the buildings and their new seismic design levels.

Table 4.38. Mitigation process in Case F.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	6170.60	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	6532.13	18327.15
2014	1	Bahçeşehir University Beşiktaş Campus	1	5	5624.43	18327.15
2011	2	Bahçeşehir University Şişli Campus	3	5	2505.58	3191.87
2012	2	Bahçeşehir University Şişli Campus	3	5	686.28	3191.87
2022	3	Beykent University Ayazağa Campus	1	5	5206.78	23444.04
2023	3	Beykent University Ayazağa Campus	1	5	6707.27	23444.04
2024	3	Beykent University Ayazağa Campus	1	5	6719.95	23444.04
2025	3	Beykent University Ayazağa Campus	1	5	4810.05	23444.04
2026	4	Boğaziçi University Hisar Campus	4	5	1460.05	8712.02
2027	4	Boğaziçi University Hisar Campus	4	5	765.33	8712.02
2028	4	Boğaziçi University Hisar Campus	4	5	4769.20	8712.02
2030	4	Boğaziçi University Hisar Campus	4	5	1717.44	8712.02
2030	5	Boğaziçi University South Campus	4	5	7493.20	7493.20
2028	8	Boğaziçi University South Campus	4	5	2443.50	2443.50
2028	9	Boğaziçi University North Campus	4	5	2050.97	18716.73
2029	9	Boğaziçi University North Campus	4	5	16665.76	18716.73
2028	10	Boğaziçi University North Campus	4	5	7381.02	7381.02
2027	11	Boğaziçi University North Campus	4	5	1781.97	1781.97
2026	12	Boğaziçi University North Campus	4	5	4848.29	4848.29
2027	13	Boğaziçi University North Campus	4	5	2816.46	2816.46
2027	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2027	15	Boğaziçi University North Campus	4	5	3913.11	3913.11
2027	16	Boğaziçi University North Campus	4	5	6002.50	6002.50
2030	22	ITU Maçka Campus	3	5	1743.16	1743.16
2030	24	ITU Maçka Campus	3	5	1167.87	2988.42
2018	25	Mimar Sinan University Fındıklı Campus	1	5	2958.72	19034.67
2019	25	Mimar Sinan University Fındıklı Campus	1	5	4413.66	19034.67
2020	25	Mimar Sinan University Fındıklı Campus	1	5	6663.22	19034.67
2021	25	Mimar Sinan University Fındıklı Campus	1	5	4999.08	19034.67
2019	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2018	27	Yıldız Technical University Yıldız Campus	2	5	1420.14	1420.14
2017	28	Yıldız Technical University Yıldız Campus	2	5	4946.80	6689.88
2018	28	Yıldız Technical University Yıldız Campus	2	5	1743.08	6689.88
2016	29	Yıldız Technical University Yıldız Campus	2	5	4616.10	7503.66
2017	29	Yıldız Technical University Yıldız Campus	2	5	2887.56	7503.66
2015	30	Yıldız Technical University Yıldız Campus	2	5	7788.19	8175.77
2016	30	Yıldız Technical University Yıldız Campus	2	5	387.58	8175.77
2016	31	Yıldız Technical University Yıldız Campus	2	5	2807.87	2807.87

Table 4.38. Mitigation process in Case F. (cont.).

2025	32	Yıldız Technical University Yıldız Campus	2	5	1518.30	4820.87
2026	32	Yıldız Technical University Yıldız Campus	2	5	3302.57	4820.87
2014	33	Yıldız Technical University Yıldız Campus	2	5	1098.76	2285.28
2018	33	Yıldız Technical University Yıldız Campus	2	5	1186.52	2285.28
2021	35	Haliç University Bomonti Campus	3	5	3359.69	6333.33
2022	35	Haliç University Bomonti Campus	3	5	2973.64	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	4527.69	4527.69
2011	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

As it is seen in the table, the mitigation process is taken action in 27 buildings in 20 years. The mitigation of 26 buildings is completed during 20 years and only 24<sup>th</sup> building in ITU Maçka Campus is not retrofitted fully. 2911.03 m<sup>2</sup> of this building has retrofitted to seismic design level of 5 and 77.39 m<sup>2</sup> of the building have a seismic design level of 3 at the end 2030. There are no mitigation process during 20 years period in ten buildings and Table 4.39 exhibits these buildings.

Table 4.39. Buildings not retrofitted in 20 years in Case F.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.30
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
23	ITU Maçka Campus	3	20995.80
34	Haliç University Mecidiyeköy Campus	2	12571.80

The next pie chart shows the total area in the model with their seismic design level, at the end of year 2030.

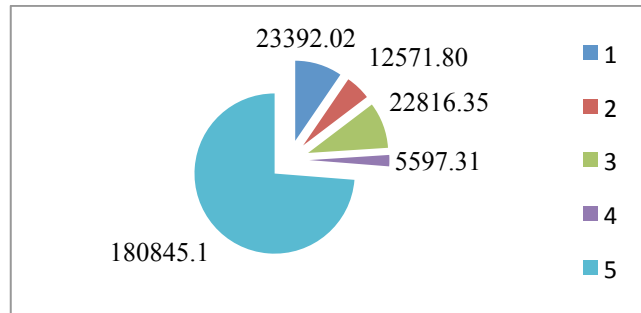


Figure 4.7. Floor area (m<sup>2</sup>) with the seismic codes at the end of 2030 in Case F.

180845.07 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4. 22816.35 m<sup>2</sup> of the total area has a seismic design level of 3. 12571.80 m<sup>2</sup> of the total area has a seismic design level of 2. 23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. At the end of 2030, 73.75% of the total area is retrofitted to the highest seismic design level.

Table 4.40 shows the mitigation expenditures in each year. The mitigation budget per year is 1032769 TL in 20 years time period.

Table 4.40. Mitigation expenditure in Case F.

Year	Expenditure (TL)	Year	Expenditure (TL)
2011	1032769	2021	1032769
2012	1032769	2022	1032769
2013	1032769	2023	1032769
2014	1032769	2024	1032769
2015	1032769	2025	1032769
2016	1032769	2026	1032769
2017	1032769	2027	1032769
2018	1032769	2028	1032769
2019	1032769	2029	1032769
2020	1032769	2030	791879

In the first 19 years, the maximum amount is spent to retrofit the buildings. Only in the last time period, the model does not use all of the budget. The reason will be discussed in the analysis section.

In Case F, the mitigation process is completed in two buildings of Marmara University Nişantaşı Campus in 2011. There is no demand from the residential people of these two buildings in any of the time periods. Table 4.42 shows the years that buildings require relief items, the aid stations that are used to satisfy the demand and the buildings that their demand cannot be satisfied in some scenarios and time periods.

In Table 4.42, it is observed that the demand of the residential people from 14 buildings in the model can be satisfied fully under each earthquake scenario. The demand in rest of the buildings is partially satisfied under various earthquake scenarios. After 2029, there is no shortage and only the demand in every building in the last time period is fully satisfied. This is why the mitigation budget in 2030 is not fully used. Table 4.43 exhibits the demand levels in each year and earthquake scenario.

In Case F, to avoid a shortage in aid stations, Table 4.43 also shows the required amount of relief items has to be stocked in the aid stations under each scenario and year.

Table 4.41. Expected recovery costs in Case F.

<b>Year</b>	<b>Expected Recovery Cost (TL)</b>	<b>Year</b>	<b>Expected Recovery Cost (TL)</b>
2011	7311	2021	133852
2012	13753	2022	143545
2013	22858	2023	152671
2014	34444	2024	159928
2015	47844	2025	166017
2016	62506	2026	166420
2017	77708	2027	153488
2018	93063	2028	137022
2019	108201	2029	117253
2020	122377	2030	102303

Table 4.42. Relief item transportation in Case F.

Building No	University Campus	Demand Years	Facility Point	Shortage
1	Bahçeşehir University Beşiktaş Campus	2011-2013	Etiler, Şişli	No
2	Bahçeşehir University Şişli Campus	2011	Gültepe	No
3	Beykent University Ayazağa Campus	2011-2024	Gültepe	Yes
4	Boğaziçi University Hisar Campus	2011-2029	Etiler, Gültepe	Yes
5	Boğaziçi University South Campus	2011-2029	Etiler, Gültepe	Yes
6	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
7	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
8	Boğaziçi University South Campus	2011-2027	Etiler, Gültepe	Yes
9	Boğaziçi University North Campus	2011-2028	Etiler, Gültepe	Yes
10	Boğaziçi University North Campus	2011-2027	Etiler, Gültepe	Yes
11	Boğaziçi University North Campus	2011-2026	Etiler, Gültepe	Yes
12	Boğaziçi University North Campus	2011-2025	Etiler	Yes
13	Boğaziçi University North Campus	2011-2026	Etiler	Yes
14	Boğaziçi University North Campus	2011-2026	Etiler, Gültepe	Yes
15	Boğaziçi University North Campus	2011-2026	Etiler, Gültepe	Yes
16	Boğaziçi University North Campus	2011-2026	Etiler, Gültepe	Yes
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
22	ITU Maçka Campus	2011-2029	Şişli	No
23	ITU Maçka Campus	2011-2030	Şişli	No
24	ITU Maçka Campus	2011-2030	Şişli	No
25	Mimar Sinan University Fındıklı Campus	2011-2020	Şişli	Yes
26	Mimar Sinan University Fındıklı Campus	2011-2018	Şişli	Yes
27	Yıldız Technical University Yıldız Campus	2011-2017	Etiler, Şişli, Gültepe	No
28	Yıldız Technical University Yıldız Campus	2011-2017	Etiler, Şişli, Gültepe	No
29	Yıldız Technical University Yıldız Campus	2011-2016	Etiler, Şişli, Gültepe	No
30	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe	No
31	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe	No
32	Yıldız Technical University Yıldız Campus	2011-2025	Etiler, Şişli, Gültepe	No
33	Yıldız Technical University Yıldız Campus	2011-2017	Etiler, Şişli, Gültepe	No
34	Haliç University Mecidiyeköy Campus	2011-2030	Gültepe	No
35	Haliç University Bomonti Campus	2011-2021	Gültepe	No

Table 4.43. Demand levels in Case F.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2011	133223.74	137459.05	141694.36	148532.38
2012	125882.74	129939.60	133996.46	140516.38
2013	118448.73	122331.57	126214.41	132450.60
2014	111044.76	114748.53	118452.29	124408.44
2015	105076.68	108600.54	112124.40	117872.92
2016	98912.15	102250.12	105588.08	111121.69
2017	92547.31	95693.26	98839.21	104150.50
2018	86103.04	89073.88	92044.72	97123.69
2019	79611.84	82431.04	85250.23	90086.05
2020	72917.92	75580.54	78243.17	90086.05
2021	66569.09	69068.44	71567.78	75826.71
2022	61683.52	64057.71	66431.90	70432.81
2023	56645.47	58904.53	61163.59	64979.27
2024	51454.83	53595.08	55735.33	59359.82
2025	46434.93	48444.98	50455.02	53888.81
2026	42269.62	44085.29	45900.97	49062.89
2027	38271.98	39820.25	41368.51	44098.63
2028	34156.94	35430.12	36703.31	38989.21
2029	29922.52	30912.83	31903.15	33732.21
2030	26886.00	27692.63	28499.27	29996.55

#### 4.3.7. Case G

Like in Case F, in Case G, it is aimed to reduce the mitigation budget to observe the effects of this reduction on the model. The mitigation budget per year in Case G is 50% of 1475384 TL, which is the mitigation budget per year in Case C. So, the mitigation budget in Case G is 737692 TL in every time period. The capacities of the aid stations are same with the capacities in Case D, Case E and Case F. There is a very high penalty cost to prevent shortage in the aid stations.

4.3.7.1 Results for Case G. In Case G, the aim is to observe the mitigation process with a reduction in mitigation budget per year, and having a same level of relief items at the aid stations. Table 4.44 shows the years of mitigation of the buildings, the mitigated area of the buildings and their new seismic design levels.

Table 4.44. Mitigation process in Case G.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	2453.23	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	4665.80	18327.15
2014	1	Bahçeşehir University Beşiktaş Campus	1	5	4679.65	18327.15
2015	1	Bahçeşehir University Beşiktaş Campus	1	5	4693.78	18327.15
2016	1	Bahçeşehir University Beşiktaş Campus	1	5	1834.69	18327.15
2012	2	Bahçeşehir University Şişli Campus	3	5	3191.87	3191.87
2026	3	Beykent University Ayazağa Campus	1	5	1799.81	23444.04
2027	3	Beykent University Ayazağa Campus	1	5	4823.31	23444.04
2028	3	Beykent University Ayazağa Campus	1	5	4829.93	23444.04
2029	3	Beykent University Ayazağa Campus	1	5	4836.05	23444.04
2030	3	Beykent University Ayazağa Campus	1	5	4841.69	23444.04
2021	25	Mimar Sinan University Fındıklı Campus	1	5	2237.52	19034.67
2022	25	Mimar Sinan University Fındıklı Campus	1	5	4781.14	19034.67
2023	25	Mimar Sinan University Fındıklı Campus	1	5	4790.90	19034.67
2024	25	Mimar Sinan University Fındıklı Campus	1	5	2567.13	19034.67
2025	25	Mimar Sinan University Fındıklı Campus	1	5	4657.97	19034.67
2024	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2019	27	Yıldız Technical University Yıldız Campus	2	5	1420.14	1420.14
2018	28	Yıldız Technical University Yıldız Campus	2	5	4768.63	6689.88
2019	28	Yıldız Technical University Yıldız Campus	2	5	1921.25	6689.88
2016	29	Yıldız Technical University Yıldız Campus	2	5	3405.22	7503.66
2017	29	Yıldız Technical University Yıldız Campus	2	5	3255.38	7503.66
2018	29	Yıldız Technical University Yıldız Campus	2	5	843.06	7503.66
2017	30	Yıldız Technical University Yıldız Campus	2	5	2340.59	8175.77
2020	30	Yıldız Technical University Yıldız Campus	2	5	5640.82	8175.77
2021	30	Yıldız Technical University Yıldız Campus	2	5	194.37	8175.77
2021	31	Yıldız Technical University Yıldız Campus	2	5	2807.87	2807.87
2019	33	Yıldız Technical University Yıldız Campus	2	5	2285.28	2285.28
2025	35	Haliç University Bomonti Campus	3	5	300.69	6333.33

Table 4.44. Mitigation process in Case G. (cont.).

2026	35	Haliç University Bomonti Campus	3	5	6032.64	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	3812.43	4527.69
2012	36	Marmara University Nişantaşı Campus	2	5	715.26	4527.69
2012	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

As it is seen in the table, the mitigation process is taken action in 14 buildings in 20 years. The mitigation of 13 buildings is completed during 20 years and only a building in Beykent University Ayazağa Campus is not retrofitted fully. 21130.78 m<sup>2</sup> of this building has retrofitted to seismic design level of 5 and 2313.27 m<sup>2</sup> of the building have a seismic design level of 1 at the end 2030. There is no mitigation process during 20 years period in 23 buildings and Table 4.45 exhibits these buildings.

Table 4.45. Buildings not retrofitted at the end of 2030 in Case G.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
4	Boğaziçi University Hisar Campus	4	8712.02
5	Boğaziçi University South Campus	4	7493.20
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
8	Boğaziçi University South Campus	4	2443.50
9	Boğaziçi University North Campus	4	18716.73
10	Boğaziçi University North Campus	4	7381.02
11	Boğaziçi University North Campus	4	1781.97
12	Boğaziçi University North Campus	4	4848.29
13	Boğaziçi University North Campus	4	2816.46
14	Boğaziçi University North Campus	4	1342.49
15	Boğaziçi University North Campus	4	3913.11
16	Boğaziçi University North Campus	4	6002.50
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.30
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
22	ITU Maçka Campus	3	1743.16
23	ITU Maçka Campus	3	20995.80
24	ITU Maçka Campus	3	2988.42
32	Yıldız Technical University Yıldız Campus	2	4820.87
34	Haliç University Mecidiyeköy Campus	2	12571.80

The next pie chart shows the total area in the model with their seismic design level, at the end of year 2030.

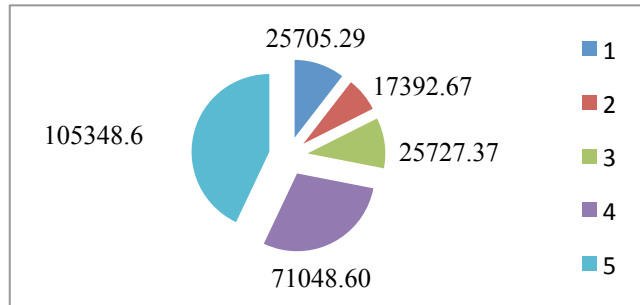


Figure 4.8. Floor area (m<sup>2</sup>) with seismic codes at the end of 2030 in Case G.

105348.61 m<sup>2</sup> of the total area has a seismic design level of 5. At the end of 2030, 42.96% of the total area is retrofitted to the highest seismic design level.

Table 4.46 shows the mitigation expenditures in each year. The mitigation budget per year is 737692 TL in 20 years time period and it is fully used in each year.

Table 4.46. Mitigation expenditures in Case G.

Year	Expenditures (TL)	Year	Expenditures (TL)
2011	737692	2021	737692
2012	737692	2022	737692
2013	737692	2023	737692
2014	737692	2024	737692
2015	737692	2025	737692
2016	737692	2026	737692
2017	737692	2027	737692
2018	737692	2028	737692
2019	737692	2029	737692
2020	737692	2030	737692

In Case G, the maximum amount of mitigation budget per year is used in every time period.

Table 4.47. Relief item transportation in Case G.

Building No	University Campus	Demand Years	Facility Point	Shortage
1	Bahçeşehir University Beşiktaş Campus	2011-2015	Etiler, Şişli	No
2	Bahçeşehir University Şişli Campus	2011	Gültepe	No
3	Beykent University Ayazağa Campus	2011-2030	Gültepe	Yes
4	Boğaziçi University Hisar Campus	2011-2030	Etiler, Gültepe	Yes
5	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
6	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
7	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
8	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	Yes
9	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
10	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
11	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
12	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
13	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
14	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
15	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
16	Boğaziçi University North Campus	2011-2030	Etiler, Gültepe	Yes
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
22	ITU Maçka Campus	2011-2030	Şişli	Yes
23	ITU Maçka Campus	2011-2030	Şişli	Yes
24	ITU Maçka Campus	2011-2030	Şişli	Yes
25	Mimar Sinan University Fındıklı Campus	2011-2024	Şişli	Yes
26	Mimar Sinan University Fındıklı Campus	2011-2023	Şişli	Yes
27	Yıldız Technical University Yıldız Campus	2011-2018	Etiler, Şişli, Gültepe	No
28	Yıldız Technical University Yıldız Campus	2011-2018	Etiler, Şişli, Gültepe	No
29	Yıldız Technical University Yıldız Campus	2011-2017	Etiler, Şişli, Gültepe	No
30	Yıldız Technical University Yıldız Campus	2011-2020	Etiler, Şişli, Gültepe	No
31	Yıldız Technical University Yıldız Campus	2011-2020	Etiler, Şişli, Gültepe	No
32	Yıldız Technical University Yıldız Campus	2011-2030	Etiler, Şişli, Gültepe	No
33	Yıldız Technical University Yıldız Campus	2011-2018	Şişli, Gültepe	No
34	Haliç University Mecidiyeköy Campus	2011-2030	Gültepe	No
35	Haliç University Bomonti Campus	2011-2025	Gültepe	No

Table 4.47. Relief item transportation in Case G. (cont.).

36	Marmara University Nişantaşı Campus	2011	Şişli	No
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In Case G, the mitigation process is completed in a building of Marmara University Nişantaşı Campus in 2011. There is no demand from the residential people of this building in any of the time periods. Table 4.47 shows the years that buildings require relief items, the aid stations that are used to satisfy the demand and the buildings that their demand cannot be satisfied in some scenarios and time periods.

Table 4.48. Demand levels in Case G.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2011	136549.71	140898.66	145247.61	152356.77
2012	130978.40	135162.66	139346.91	146073.84
2013	126202.21	130278.89	134355.56	140906.73
2014	121260.23	125225.34	129190.44	135559.36
2015	116148.29	119997.74	123847.18	130027.19
2016	111727.20	115459.48	119191.75	125218.25
2017	107714.87	111327.52	114940.16	120834.82
2018	103563.79	107052.58	110541.38	116299.16
2019	99271.56	102632.22	105992.88	111608.64
2020	94835.87	98064.03	101292.18	106760.71
2021	90352.32	93461.72	96571.12	101885.18
2022	85835.97	88843.52	91851.07	97003.02
2023	81175.16	84077.39	86979.62	91963.87
2024	76367.59	79160.98	81954.36	86765.23
2025	71462.91	74143.72	76824.53	81449.97
2026	68037.76	70614.92	73192.09	77530.41
2027	64499.98	67000.10	69500.21	73715.28
2028	60852.58	63273.04	65693.51	69781.13
2029	57093.68	59431.87	61770.05	65725.97
2030	53221.40	55474.62	57727.84	61547.72

In Table 4.47, it is observed that the demand of the residential people from 12 buildings in the model can be satisfied fully under each earthquake scenario. The demand in rest of the 24 buildings is partially satisfied under various earthquake scenarios. Between 2011 and 2030, there is a shortage in every time period and the total demand is never fully satisfied in 20 years. Table 4.48 exhibits the demand levels in each year and earthquake scenario.

In Case G, for avoiding a shortage in aid stations, Table 4.48 shows the required amount of relief items has to be stocked in the aid stations under each scenario and year.

Table 4.49 exhibits the expected recovery costs in Case G.

Table 4.49. Expected recovery costs in Case G.

<b>Year</b>	<b>Expected Recovery Cost (TL)</b>	<b>Year</b>	<b>Expected Recovery Cost (TL)</b>
2011	7412	2021	152691
2012	13982	2022	168028
2013	23445	2023	181960
2014	35689	2024	194353
2015	50369	2025	204847
2016	66759	2026	210104
2017	84143	2027	217337
2018	101958	2028	222986
2019	119576	2029	227116
2020	136505	2030	229802

#### 4.3.8. Case H

The mitigation budget per year in Case H is reduced to 90% of 1475384 TL, which is the mitigation budget per year in Case C. Thus, the mitigation budget in Case G is 1327846 TL in every time period. The capacities of the aid stations are same with the capacities in Case D, Case E, Case F and Case G.

4.3.8.1. Results for Case H. In Case H, the aim is to observe the mitigation process with a reduction in mitigation budget per year, and having a same level of relief items at the aid stations. Table 4.50 shows the years of mitigation of the buildings, the mitigated area of the buildings and their new seismic design levels.

Table 4.50. Mitigation process in Case H.

Year	Building No	University Campus	Previous Seismic Code	New Seismic Code	Retrofitted Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )
2011	1	Bahçeşehir University Beşiktaş Campus	1	5	1513.15	18327.15
2012	1	Bahçeşehir University Beşiktaş Campus	1	5	8374.81	18327.15
2013	1	Bahçeşehir University Beşiktaş Campus	1	5	8398.45	18327.15
2014	1	Bahçeşehir University Beşiktaş Campus	1	5	40.74	18327.15
2011	2	Bahçeşehir University Şişli Campus	3	5	3191.87	3191.87
2019	3	Beykent University Ayazağa Campus	1	5	2068.83	23444.04
2020	3	Beykent University Ayazağa Campus	1	5	8566.99	23444.04
2021	3	Beykent University Ayazağa Campus	1	5	8587.19	23444.04
2022	3	Beykent University Ayazağa Campus	1	5	4221.04	23444.04
2024	4	Boğaziçi University Hisar Campus	4	5	8095.79	8712.02
2025	4	Boğaziçi University Hisar Campus	4	5	616.22	8712.02
2025	5	Boğaziçi University South Campus	4	5	7493.20	7493.20
2025	8	Boğaziçi University South Campus	4	5	2443.50	2443.50
2023	9	Boğaziçi University North Campus	4	5	17002.42	18716.73
2025	9	Boğaziçi University North Campus	4	5	554.12	18716.73
2027	9	Boğaziçi University North Campus	4	5	1160.19	18716.73
2025	10	Boğaziçi University North Campus	4	5	7381.02	7381.02
2026	11	Boğaziçi University North Campus	4	5	1781.97	1781.97
2024	12	Boğaziçi University North Campus	4	5	4848.29	4848.29
2025	13	Boğaziçi University North Campus	4	5	2816.46	2816.46
2024	14	Boğaziçi University North Campus	4	5	1342.49	1342.49
2024	15	Boğaziçi University North Campus	4	5	978.47	3913.11
2028	15	Boğaziçi University North Campus	4	5	2242.83	3913.11
2024	15	Boğaziçi University North Campus	4	5	691.81	3913.11
2024	16	Boğaziçi University North Campus	4	5	6002.50	6002.50
2028	24	ITU Maçka Campus	3	5	481.88	2988.42
2029	24	ITU Maçka Campus	3	5	1219.48	2988.42
2030	24	ITU Maçka Campus	3	5	1209.66	2988.42
2016	25	Mimar Sinan University Fındıklı Campus	1	5	935.87	19034.67

Table 4.50. Mitigation process in Case H. (cont.).

2017	25	Mimar Sinan University Fındıklı Campus	1	5	8498.88	19034.67
2018	25	Mimar Sinan University Fındıklı Campus	1	5	6289.92	19034.67
2019	25	Mimar Sinan University Fındıklı Campus	1	5	3310.00	19034.67
2018	26	Mimar Sinan University Fındıklı Campus	1	5	2232.84	2232.84
2016	27	Yıldız Technical University Yıldız Campus	2	5	1420.14	1420.14
2014	28	Yıldız Technical University Yıldız Campus	2	5	6689.88	6689.88
2014	29	Yıldız Technical University Yıldız Campus	2	5	2797.43	7503.66
2016	29	Yıldız Technical University Yıldız Campus	2	5	4706.24	7503.66
2014	30	Yıldız Technical University Yıldız Campus	2	5	447.66	8175.77
2015	30	Yıldız Technical University Yıldız Campus	2	5	7728.11	8175.77
2016	31	Yıldız Technical University Yıldız Campus	2	5	2807.87	2807.87
2022	32	Yıldız Technical University Yıldız Campus	2	5	3464.70	4820.87
2023	32	Yıldız Technical University Yıldız Campus	2	5	1356.16	4820.87
2015	33	Yıldız Technical University Yıldız Campus	2	5	2285.28	2285.28
2019	35	Haliç University Bomonti Campus	3	5	6333.33	6333.33
2011	36	Marmara University Nişantaşı Campus	2	5	4527.69	4527.69
2011	37	Marmara University Nişantaşı Campus	2	5	1687.70	1687.70

As can be seen in the table, the mitigation process is taken action in 28 buildings in 20 years. The mitigation of 26 buildings is completed during 20 years and two buildings in ITU Maçka Campus is not retrofitted fully. 1209.66 m<sup>2</sup> of 22<sup>nd</sup> building has retrofitted to seismic design level of 5 and 533.49 m<sup>2</sup> of the building have a seismic design level of 3 and 1701.36 m<sup>2</sup> of 24<sup>th</sup> building has retrofitted to seismic design level of 5 and 1287.05 m<sup>2</sup> of the building have a seismic design level of 3 at the end 2030. There is no mitigation process during 20 years period in nine buildings and Table 4.51 shows these buildings.

Figure 4.9 shows the total area in the model with their seismic design level, at the end of year 2030.

180845.07 m<sup>2</sup> of the total area has a seismic design level of 5. 5597.31 m<sup>2</sup> of the total area has a seismic design level of 4. 22816.35 m<sup>2</sup> of the total area has a seismic design level of 3. 12571.80 m<sup>2</sup> of the total area has a seismic design level of 2. 23392.02 m<sup>2</sup> of the total area has a seismic design level of 1. At the end of 2030, 73.75% of the total area is retrofitted to the highest seismic design level.

Table 4.51. Buildings not retrofitted in 20 years in Case H.

Building No	University Campus	Seismic Code	Total Area (m <sup>2</sup> )
6	Boğaziçi University South Campus	4	3180.75
7	Boğaziçi University South Campus	4	2416.56
17	Galatasaray University Ortaköy Campus	1	7175.34
18	Galatasaray University Ortaköy Campus	1	697.3
19	Galatasaray University Ortaköy Campus	1	3364.45
20	Galatasaray University Ortaköy Campus	1	5140.34
21	Galatasaray University Ortaköy Campus	1	7014.59
22	ITU Maçka Campus	3	1743.17
23	ITU Maçka Campus	3	20995.80
34	Haliç University Mecidiyeköy Campus	2	12571.80

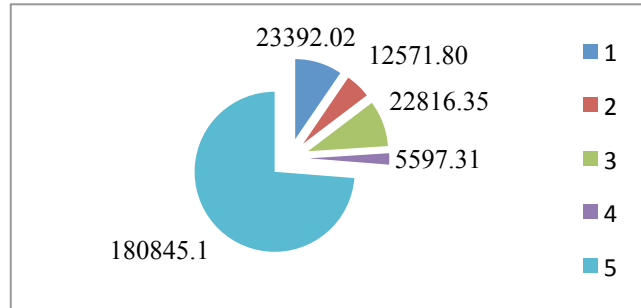
Figure 4.9. Floor area (m<sup>2</sup>) with seismic codes at the end of 2030 in Case H.

Table 4.52 shows the mitigation expenditures in each year. The mitigation budget per year is 1327846 TL in 20 years time period.

In the first 15 years, the maximum amount is spent to retrofit the buildings. In the other periods, the model does not use all of the budget. The reason will be discussed in the analysis section.

Table 4.52. Mitigation expenditures in Case H.

<b>Year</b>	<b>Expenditures (TL)</b>	<b>Year</b>	<b>Expenditures (TL)</b>
2011	1327846	2021	1327846
2012	1327846	2022	1327846
2013	1327846	2023	1327846
2014	1327846	2024	1327846
2015	1327846	2025	1327846
2016	1327846	2026	250446
2017	1327846	2027	72086
2018	1327846	2028	79725
2019	1327846	2029	93010
2020	1327846	2030	92153

In Case H, the mitigation process is completed in a building of Bahçeşehir University Şişli Campus and in two buildings of Marmara University Nişantaşı Campus in 2011. There is no demand from the residential people of these three buildings in any of the time periods. Table 4.53 shows the years that buildings require relief items, the aid stations that are used to satisfy the demand and the buildings that their demand cannot be satisfied in some scenarios and time periods.

In Table 4.53, it is observed that the demand of the residential people from 24 buildings in the model can be satisfied fully under each earthquake scenario. The demand in rest of the 10 buildings are partially satisfied under various earthquake scenarios. After 2025, there is no shortage and the demand in every building in the following five years is fully satisfied. Table 4.54 exhibits the demand levels in each year and earthquake scenario.

Table 4.53. Relief item transportation in Case H.

Building No	University Campus	Demand Years	Aid station	Shortage
1	Bahçeşehir University Beşiktaş Campus	2011-2013	Etiler, Şişli	No
3	Beykent University Ayazağa Campus	2011-2021	Gültepe	Yes
4	Boğaziçi University Hisar Campus	2011-2024	Etiler, Gültepe	Yes
5	Boğaziçi University South Campus	2011-2024	Etiler, Gültepe	No
6	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	No
7	Boğaziçi University South Campus	2011-2030	Etiler, Gültepe	No
8	Boğaziçi University South Campus	2011-2024	Etiler, Gültepe	No
9	Boğaziçi University North Campus	2011-2026	Etiler, Gültepe	No
10	Boğaziçi University North Campus	2011-2024	Etiler, Gültepe	No
11	Boğaziçi University North Campus	2011-2025	Etiler	No
12	Boğaziçi University North Campus	2011-2023	Etiler, Gültepe	No
13	Boğaziçi University North Campus	2011-2024	Etiler, Gültepe	No
14	Boğaziçi University North Campus	2011-2023	Etiler, Gültepe	No
15	Boğaziçi University North Campus	2011-2027	Etiler, Gültepe	No
16	Boğaziçi University North Campus	2011-2023	Etiler, Gültepe	No
17	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
18	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
19	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
20	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
21	Galatasaray University Ortaköy Campus	2011-2030	Etiler, Şişli, Gültepe	Yes
22	ITU Maçka Campus	2011-2030	Şişli	No
23	ITU Maçka Campus	2011-2030	Şişli	No
24	ITU Maçka Campus	2011-2030	Şişli	No
25	Mimar Sinan University Fındıklı Campus	2011-2018	Şişli	Yes
26	Mimar Sinan University Fındıklı Campus	2011-2017	Şişli	No
27	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe	No
28	Yıldız Technical University Yıldız Campus	2011-2013	Etiler, Şişli, Gültepe	No
29	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe	No
30	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe	No
31	Yıldız Technical University Yıldız Campus	2011-2015	Etiler, Şişli, Gültepe	No
32	Yıldız Technical University Yıldız Campus	2011-2022	Etiler, Şişli, Gültepe	No
33	Yıldız Technical University Yıldız Campus	2011-2014	Etiler, Şişli, Gültepe	No
34	Haliç University Mecidiyeköy Campus	2011-2030	Gültepe	No
35	Haliç University Bomonti Campus	2011-2018	Gültepe	No

Table 4.54. Demand levels in Case H.

<b>Year</b>	<b>Scenario 1</b>	<b>Scenario 2</b>	<b>Scenario 3</b>	<b>Scenario 4</b>
2011	130569.64	134732.00	138894.35	145586.63
2012	120787.07	124716.54	128646.01	134958.91
2013	110695.26	114384.26	118073.26	123994.46
2014	102743.67	106192.02	109640.36	115277.24
2015	94550.05	97750.02	100949.99	106293.63
2016	86135.49	89086.28	92037.06	97077.03
2017	77771.82	80523.87	83275.93	87996.16
2018	69149.14	71696.13	74243.13	78633.34
2019	61933.68	64282.50	66631.32	70585.57
2020	55563.15	57763.12	59963.08	63677.22
2021	48999.39	51045.80	53092.22	56558.65
2022	42954.41	44825.67	46696.93	49922.22
2023	37884.85	39453.71	41022.57	43775.38
2024	32780.45	34011.50	35242.56	37449.07
2025	27527.07	28410.64	29294.21	30938.74
2026	26798.01	27623.51	28449.00	30000.00
2027	26829.00	27644.91	28460.83	30000.00
2028	26856.00	27665.58	28475.17	30000.00
2029	26871.71	27679.85	28488.00	30000.00
2030	26886.00	27692.63	28499.27	29996.55

In Case H, to avoid a shortage in aid stations, Table 4.54 shows the required amount of relief items has to be stocked in the aid stations under each scenario and year.

Table 4.55 exhibits the expected recovery costs in Case H.

Table 4.55. Expected recovery costs in Case H.

<b>Year</b>	<b>Expected Recovery Cost (TL)</b>	<b>Year</b>	<b>Expected Recovery Cost (TL)</b>
2011	7242	2021	115169
2012	13525	2022	123376
2013	22272	2023	118080
2014	33002	2024	104944
2015	45240	2025	87000
2016	58309	2026	88214
2017	71997	2027	92512
2018	85319	2028	96294
2019	95769	2029	99530
2020	106359	2030	102303

#### **4.4. Analysis of The Case Study**

There are four important points to be mentioned for analyzing the case study more accurately. These are the relationships between the relief item inventory and mitigation strategies, the mitigation choices, the recovery expenditures and the total cost analysis.

##### **4.4.1. Relationships Between Relief Item Inventory and Mitigation Strategies**

In our optimization model, the prime purpose is to minimize the sum of four costs which are total mitigation cost, expected post-earthquake reconstruction cost, expected transportation cost of relief items from aid stations to demand points just after the characteristic earthquake and expected penalty cost due to limited relief items. Among these costs, the most expensive one is the expected penalty cost for shortage of relief items. For this reason, the common tendency in the model is to eliminate relief item shortage as soon as possible, if it exists. This can be done by retrofitting buildings to the highest seismic design level as fast as possible depending on the available mitigation budget. On the other hand, the mitigation process will continue, even if there is no relief item shortage, because the population in the demand points is continuously increasing as the years pass. Furthermore, the relief item demand will never reduce below the capacity of aid stations, because the retrofitting a building is more costly than distributing relief items. In other

words, the distribution of relief items is more preferable than retrofitting as far as the minimum total cost is concerned.

For instance, in Case A and Case B, it is assumed that there is an infinite mitigation budget to retrofit buildings. The difference in these two cases is the amount of relief item inventory in aid stations. In Case A, it is given that the capacity of each aid station is 10000 relief items in each year. On the other hand, the capacity of each aid station is 500 relief items per year in Case B. Despite infinite mitigation budget, nine buildings are not retrofitted in 20 years in Case A. The main reason is that the demand of residential people in these buildings can be met with the available relief item inventory in aid stations. Table 4.54 shows the total demand under four scenarios in Case A.

Table 4.56. Demand levels in Case A.

<b>Year</b>	<b>Scenario 1</b>	<b>Scenario 2</b>	<b>Scenario 3</b>	<b>Scenario 4</b>
2011	26706.28	27580.71	28455.13	30000.00
2012	26736.91	27602.44	28467.97	30000.00
2013	26767.93	27624.45	28480.98	30000.00
2014	26799.35	27646.75	28494.15	30000.00
2015	26831.19	27669.34	28507.50	30000.00
2016	26845.07	27678.18	28511.29	30000.00
2017	26845.28	27676.53	28507.79	30000.00
2018	26845.48	27674.86	28504.25	30000.00
2019	26845.69	27673.17	28500.65	30000.00
2020	26845.91	27671.46	28497.02	30000.00
2021	26856.07	27680.13	28504.20	30000.00
2022	26873.26	27696.12	28518.99	30000.00
2023	26890.66	27712.32	28533.97	30000.00
2024	26908.29	27728.72	28549.15	30000.00
2025	26909.32	27727.73	28546.14	30000.00
2026	26910.36	27726.73	28543.09	30000.00
2027	26911.42	27725.71	28540.01	30000.00
2028	26912.48	27724.68	28536.88	30000.00
2029	26913.57	27723.64	28533.71	30000.00
2030	26914.66	27722.58	28530.51	30000.00

In Table 4.56, it is observed that if any earthquake of any scenario hits, there are adequate relief items in aid stations to meet the demand. Another interesting point in this table is the demand levels are nearly same every year while a risk of earthquake occurrence and the population increase in time. The reason is that the model stabilizes by retrofitting some buildings as years pass.

In Case B, there is also an infinite mitigation budget to retrofit buildings, but as distinct from Case A, the capacity of aid stations is lower. It is assumed that the capacity of each aid station is 500 relief items per year. Totally, 1500 relief items are available for a single year. The retrofitting is nearly completed in the first year to avoid shortage. Only one building is not fully retrofitted in 2011. Although the mitigation budget is unlimited, this building's mitigation process continues during the 20 years period and cannot be completed at the end of 2030. The existence of 1500 relief items per year in the inventories is the reason of incompleting mitigation process. Table 4.57 exhibits the demand levels in each year and earthquake scenario.

Finally, it is significant to examine the cases which have shortage incidence to analyze the relationships between relief item inventory and mitigation strategies. There is a shortage in relief item inventory in Case C, Case F, Case G and Case H. In Case C, there is a shortage under some scenarios in the first 13 years time period. In this time period, the mitigation budget is fully used. The reason is that the capacity in aid stations is not enough to meet the demand of residential people. Thus, it is aimed to retrofit as much as possible to decrease the demand level. In the following seven years, the mitigation budget is not fully used, because the relief item inventory in aid stations is adequate to satisfy the demand. This pattern is same in the other three cases.

Taking everything into consideration, since it is a minimization problem and the transportation cost is the cheapest, the first option is to satisfy the demand with the relief item inventory. If the relief item inventory at hand is not sufficient enough to meet the demand, the second option is to retrofit the buildings for decreasing the demand level. Finally, if the relief item inventory is not adequate and the mitigation budget is too low for upgrading buildings, there has to be a shortage, which is undesirable.

Table 4.57. Demand levels in Case B.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4
2011	1236.49	1290.54	1344.60	1500.00
2012	1236.49	1290.54	1344.60	1500.00
2013	1236.49	1290.54	1344.60	1500.00
2014	1236.49	1290.54	1344.60	1500.00
2015	1236.49	1290.54	1344.60	1500.00
2016	1236.49	1290.54	1344.60	1500.00
2017	1236.49	1290.54	1344.60	1500.00
2018	1236.49	1290.54	1344.60	1500.00
2019	1236.49	1290.54	1344.60	1500.00
2020	1236.49	1290.54	1344.60	1500.00
2021	1236.49	1290.54	1344.60	1500.00
2022	1236.49	1290.54	1344.60	1500.00
2023	1236.49	1290.54	1344.60	1500.00
2024	1236.49	1290.54	1344.60	1500.00
2025	1236.49	1290.54	1344.60	1500.00
2026	1236.49	1290.54	1344.60	1500.00
2027	1236.49	1290.54	1344.60	1500.00
2028	1236.49	1290.54	1344.60	1500.00
2029	1236.49	1290.54	1344.60	1500.00
2030	1236.49	1290.54	1344.60	1500.00

#### 4.4.2. Mitigation Choices

In Case C, as a first step, the mitigation expenditures of all buildings in a single year is calculated by assuming that there are no relief items in stocks of aid stations in each year and there is an infinite mitigation budget. The total mitigation expenditure of retrofitting all of the buildings in the model in a single year is 29507680 TL. In Case C and the following cases, this total cost is fully or partially allotted in years in various ways as mitigation budget per year.

In Case C, Case D and Case E, the total mitigation budget for 20 years period, 29507680 TL, is fully allotted in years. The decomposition of this budget into years is different in each of these cases. In Case C, this amount is equally allotted in years as mitigation budget per year. In Case D, the amount of mitigation budget per year is higher

in the first ten years and lower in the second ten years than the amount of mitigation budget per year in Case C. In Case E, the amount of mitigation budget per year is higher in the first ten years and lower in the second ten years than the amount of mitigation budget per year in Case D. Figures 4.4, 4.5 and 4.6 show that the total area retrofitted to highest seismic design level 5 in Case D and Case E is 1315.27 m<sup>2</sup> more than the total area retrofitted to highest seismic design level 5 in Case C at the end of 2030, if an earthquake does not occur in 20 years period. Table 4.58 exhibits the total area in the model with their seismic design levels, at the end of year 2020, if an earthquake does not occur in the first ten years.

Table 4.58. Comparison of floor areas (m<sup>2</sup>) in Case C, Case D and Case E in 2020.

<b>Seismic Code</b>	<b>Case C</b>	<b>Case D</b>	<b>Case E</b>
1	26799.50	42515.62	37984.71
2	17392.67	16876.77	16876.77
3	25727.37	26243.27	26243.27
4	71048.60	7275.91	5597.31
5	104254.41	152310.98	158520.48

At the end of ten years time period, the results are interesting. When there is a lower mitigation budget per year in the first ten years period, the model tends to improve the buildings with lowest seismic design level. On the other hand, when the mitigation budget per year is escalating, the total area of highest seismic design level is increasing. To analyze the incident more detailed, it is better to focus on Case C and Case E. The total area of seismic design level 1 in Case E is 11185.21 m<sup>2</sup> which is more than the total area of seismic design level 1 in Case C, but the total area of seismic design level 5 in Case E is 54266.07 m<sup>2</sup> which is more than the total area of seismic design level 5 in Case C at the end of 2020. There is a risk of an earthquake occurrence in first ten years period, so it is logical to improve the area of buildings as much as possible to the highest seismic design level. The advisable decision here is to invest more money for mitigation expenditures in early years, because at the end of 20 years the total mitigation is almost same in both cases.

In Case F, Case G and Case H, the total mitigation budget for 20 years period, 29507680 TL, is multiplied with 0.7, 0.5 and 0.9 respectively and then the new results are equally allotted in years as mitigation budget per year. Figure 4.20 shows that the mitigation budget per year is very inadequate in Case G and only 105348.61 m<sup>2</sup> of the total area is retrofitted to highest seismic level 5 at the end of 2030. On contrary, in Case F and Case H with a less mitigation budget per year compared to mitigation budget per year in Case C, the total area which has a seismic design level of 5 at the end of 2030 is similar with the total area of seismic design level of 5 at the end of 2030 in Case C. The problem in these cases is the shortage of relief items in various years under different earthquake scenarios.

#### 4.4.3. Recovery Expenditures

Figure 4.10 exhibits the expected recovery costs of each of the cases as years pass.

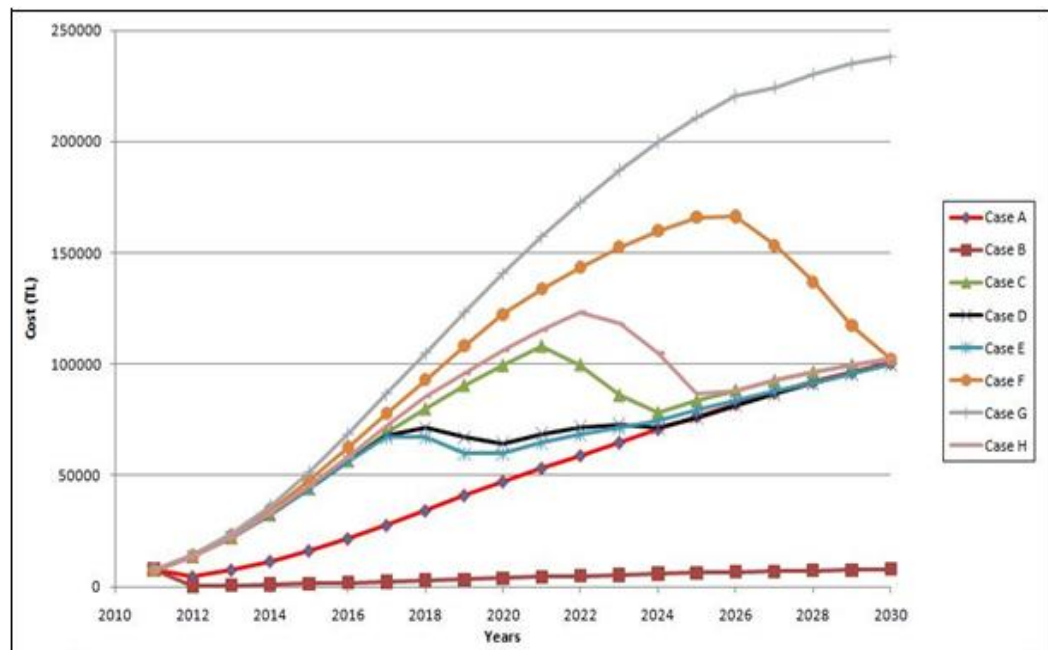


Figure 4.10. Comparison of expected recovery costs (TL) in every case.

As it is seen in Figure 4.10, the expected recovery costs in Case B is clearly lower than the expected recovery costs in other cases. The reason is that most of the mitigation process is completed in 2011. Mostly, the buildings are durable enough to face any characteristic earthquakes in following years. However, there is an infinite mitigation budget and the capacities of aid stations are unrealistically low in Case B.

On the contrary, the expected recovery costs in Case G is distinctly higher than the expected recovery costs in other cases. The mitigation budget per year in Case G is very limited, so deficient mitigation process leads to high recovery costs.

In Case F, the mitigation budget per year is higher than the mitigation budget per year in Case G but lower than the mitigation budget per year in Case C and Case H. The mitigation budget per year in Case C is higher than the mitigation budget per year in Case H. The expected recovery costs in Case F are more than the expected recovery costs in Case C and Case H between 2011 and 2029, especially, are very high between 2019 and 2029. Generally, the expected recovery costs in Case C and Case H are similar, but in years between 2021 and 2025, the expected costs in Case C are a little bit lower.

Total mitigation budget over 20 years are same in Case C, Case D and Case E, but more money is invested in first ten years as a mitigation budget per year in Case D and Case E than in Case C. Figure 4.22 shows that higher investments in early years to mitigation budget per year provide less expected recovery costs. More financial investments in early years will provide more safer buildings and low amount of recovery expenditures.

#### **4.4.4. Total Expected Cost Analysis**

In this section, Case C, Case E and Case H are chosen to analyze the total expected costs when a characteristic earthquake occurs in 2015, 2020, 2025 and 2030. Table 4.59 shows the total mitigation cost until 2015, the expected recovery cost if an earthquake occurs at the beginning of 2015, the expected transportation cost of relief items in 2015,

penalty cost for the shortage of relief items and the total expected cost in 2015 for Cases C, E and H.

Table 4.59. Minimized costs of possible 2015 earthquake.

Case	Total Mitigation Cost (TL)	Recovery Cost (TL)	Transportation Cost (TL)	Penalty Cost (TL)	Expected Total Cost (TL)
Case C	8393963	62495	54491	0	8510949
Case E	8393899	62495	54490	0	8510884
Case H	7554569	64347	53043	137621038336	137628710295

The costs in Case C and E are very similar. Total mitigation cost for Case H is lower than Cases C and E, but the recovery cost is higher. Thus, there is a penalty cost in Case H, because if an earthquake hits in 2015, the capacities are not enough to satisfy the demand of the residential people. Table 4.60 shows the total area that is retrofitted to the highest seismic design level in Cases C, E and H.

Table 4.60. Upgraded Areas at the end of 2015.

Case	Total Area with Seismic Code 5 (m <sup>2</sup> )
Case C	42087.48
Case E	42087.13
Case H	37669.38

Table 4.60 also shows that the total mitigation process in Case C and Case E is almost same, but it is less in Case H.

If an earthquake occurs in 2020, the costs in Cases C, E and H are shown in Table 4.61.

Table 4.61. Minimized Costs of possible 2020 earthquake.

Case	Total Mitigation Cost (TL)	Recovery Cost (TL)	Transportation Cost (TL)	Penalty Cost (TL)	Expected Total Cost (TL)
Case C	30505216	228511	71216	0	30804943
Case E	34311971	137116	69966	0	34519053
Case H	27454702	244344	71219	58349846108	58377616373

The total mitigation costs in Case E is higher than Case C and Case H. On the contrary, the expected recovery cost in Case E is less than Case C and Case H. Transportation costs are similar in all three cases. It is logical because the capacities of relief items are same in these cases and it is forced to distribute every relief item to the demand points. In Case H, still there is a shortage in relief items inventory, so there is a high penalty cost in Case H. The expected total cost in Case E is higher than the expected total cost in Case C, on the contrary, Table 4.62 shows that the total mitigated area in Case E is markedly higher than the total mitigated area in Case C.

Table 4.62. Upgraded areas at the end of 2020.

Case	Total Area with Seismic Code 5 (m <sup>2</sup> )
Case C	104254.41
Case E	158520.48
Case H	86286.69

If an earthquake occurs in 2025, the costs in Cases C, E and H are shown in Table 4.63.

Table 4.63. Minimized costs of possible 2025 earthquake.

Case	Total Mitigation Cost (TL)	Recovery Cost (TL)	Transportation Cost (TL)	Penalty Cost (TL)	Expected Total Cost (TL)
Case C	72399866	300976	80940	0	72781782
Case E	72553800	286385	80779	0	72920964
Case H	67104938	314051	79725	122053000000	122120498714

It is seen that, the total mitigation costs in Case C and Case E are almost same, but in Case H it is lower. Still, the relief item inventory in Case H does not satisfy the demand of residential people, so there is a high penalty cost. The expected total cost in Case E is slightly higher than the expected total cost in Case C, but like in 2015, Table 4.64 exhibits that the total mitigated areas in cases, and the total mitigated area in Case E is higher than Case C and Case H.

Table 4.64. Upgraded areas at the end of 2025.

Case	Total Area with Seismic Code 5 (m <sup>2</sup> )
Case C	173728.03
Case E	176708.23
Case H	151444.54

If an earthquake occurs in 2030, the costs in Cases C, E and H are shown in Table 4.65.

Table 4.65. Minimized costs of possible 2030 earthquake.

Case	Total Mitigation Cost (TL)	Recovery Cost (TL)	Transportation Cost (TL)	Penalty Cost (TL)	Expected Total Cost (TL)
Case C	117015339	585538	149468	0	117750345
Case E	117498067	572212	148969	0	118219248
Case H	116813975	585436	149470	0	117548881

The total mitigation cost in Case E is slightly higher than the total mitigation costs in Case C and Case H, adversely the expected recovery cost and the expected transportation cost in Case E is slightly less than the expected recovery cost and the expected transportation cost in Case C and Case H. In 2030, the demand of residential people is satisfied in every case and there is no penalty cost for a shortage in relief item inventory. The expected total cost in Case E is slightly higher than the expected total costs in other two cases, but Table 4.66 shows that the total mitigated area in Case E is still higher than the total mitigated area in Case C and Case H.

Table 4.66. Upgraded areas at the end of 2030.

<b>Case</b>	<b>Total Area with Seismic Code 5 (m<sup>2</sup>)</b>
Case C	180834.98
Case E	182149.74
Case H	180845.1

A brief summary of this case study can be given as follows. The expected total costs of Case E is slightly higher than the expected total cost of Case C in 2015, 2020, 2025 and 2030, and also it is higher than the expected total cost of Case H in 2030. On the contrary, the total mitigated area to the highest seismic design level in Case E is higher than the total mitigated area to the highest seismic design level in Case C and Case H. This is a vital point to take into account.

This problem cannot be only based on the costs, because earthquakes are random events that can cause fatal effects on society. The mitigation process has to be considered to decide on the best option to choose. Taking all aspects of these cases into consideration, Case E seems like a best option to choose for this case study. It is a little bit costly but the total safe area is more than the other cases, and the expected recovery costs are less than the other cases. In conclusion, the local and general government have to invest more money on early years' mitigation budget by taking account to their financial power as an effective strategy in emergency management.

## 5. CONCLUSION AND FURTHER STUDIES

In this thesis, a linear programming model is developed and applied to disaster response operations. The objective of the optimization problem is to minimize the sum of various costs that are directly related with the emergency management. These costs are the mitigation cost, expected reconstruction expenditures, the costs for transporting relief items and the penalty cost for the shortage of relief items in stocks of aid stations.

The model is applied to the most populated city of Turkey, Istanbul. 11 university campuses in downtown area of Istanbul are chosen, and the properties of the buildings in these campuses are studied carefully. The data of these campuses such as the total living space of the buildings and the population of the campuses are collected. Three aid stations that are close to these campuses are identified, and the shortest path between the campuses and aid stations are reckoned. Moreover, from the past earthquake occurrence data of Marmara region, the probabilities of a next characteristic earthquake occurrence are calculated. The unit costs of retrofitting a building and recovering a building are obtained from the past studies. The gas consumption of an ordinary truck is investigated to calculate the unit transportation cost of distributing relief items by ordinary trucks.

In the Case Study section, eight distinctive cases are formed by using different values of key parameters such as the mitigation budget and capacity of aid stations. By running all of the eight different cases and carefully analyzing the results, we explored some valuable tradeoffs between mitigation activities, the transportation of relief items and the expected reconstruction activities. The model is also helpful to understand the investment plans for constituting a mitigation budget. At the end of the Case Study section, we proposed a best solution for a problem like this.

In this study, we made our investigations under some assumptions. Of course, changing these always lead to areas of further research. With some modifications, the problem studied here can be applied to two-stage stochastic programming and various solution algorithms can be used to solve. Besides the mitigation of buildings, the

mitigation of transportation network can be added to the problem. The shortest path between the aid stations and the demand points can be changed if the transportation network is damaged after an earthquake, thus, the total cost will increase. Furthermore, the case study part may be extended with more sufficient data.

## APPENDIX A: THE UNIVERSITY CAMPUSES CONSIDERED IN THE STUDY

### A.1. Bahçeşehir University Beşiktaş Campus

The campus of this university is located in the center of Beşiktaş district between the piers of seabus and boats. There are many available ways of reaching to the campus because of its central location. Total student population of the campus is 7750 students. There is a single building on the campus, and the total used area in the building is 18327.15 m<sup>2</sup>. The population density is 0.42 person/m<sup>2</sup>. The structural type of the building is ferro-concrete.



Figure A.1. Bahçeşehir University Beşiktaş Campus.

In Figure 4.2, it clear that there is a single large building in this campus, so we coded this building by assigning number one to the value of k. So,  $k=1$  means the main building in Bahçeşehir University Beşiktaş campus.

### A.2. Bahçeşehir University Şişli Campus

This campus of the Bahçeşehir University is located in Şişli district and is very close to D100 highway of Istanbul. The location of this campus is also central and there are many available options to arrive this campus by using overland route. Total student population of the campus is 1265 students. There is a single building on the campus, and the total used area in the building is  $3191.87 \text{ m}^2$ . The population density is  $0.40 \text{ person/m}^2$ . The structural type of the building is ferro-concrete.



Figure A.2. Bahçeşehir University Şişli Campus.

This Figure 4.3 shows the building coded 2 (  $k=2$  ) in Bahçeşehir University Şişli campus.

### A.3. Beykent University Ayazağa Campus

This campus of the Beykent University is located in Ayazağa district and is nearly far away from the main districts of Istanbul. Like the campuses of Bahçeşehir University there is one building in the campus. Total student population of the campus is 5463 students. There is a single building on the campus, and the total used area in the building is  $23444.04\text{m}^2$ .



Figure A.3. Beykent University Ayazağa Campus.

The building that is coded 3 is in Beykent University Ayazağa campus. The population density is  $0.23 \text{ person/m}^2$ . The structural type of the building is ferro-concrete.

#### A.4. Boğaziçi University Hisar, South and North Campuses

There are three campuses of Boğaziçi University which are so close to each other, therefore it can be considered as a single large campus in this study. These campuses are located on the uphill of Bebek district. The campuses are close to Trans-European Motorway (TEM), which makes the transportation to these campuses easy. Total student population of these campuses is 12646 students. In these campuses, 13 buildings are considered in the model and the total used area in these buildings is 59387.2 m<sup>2</sup>. The population density is 0.18 person/m<sup>2</sup>. 6<sup>th</sup> and 7<sup>th</sup> buildings are stone buildings, the structural type of the other buildings are ferro-concrete.

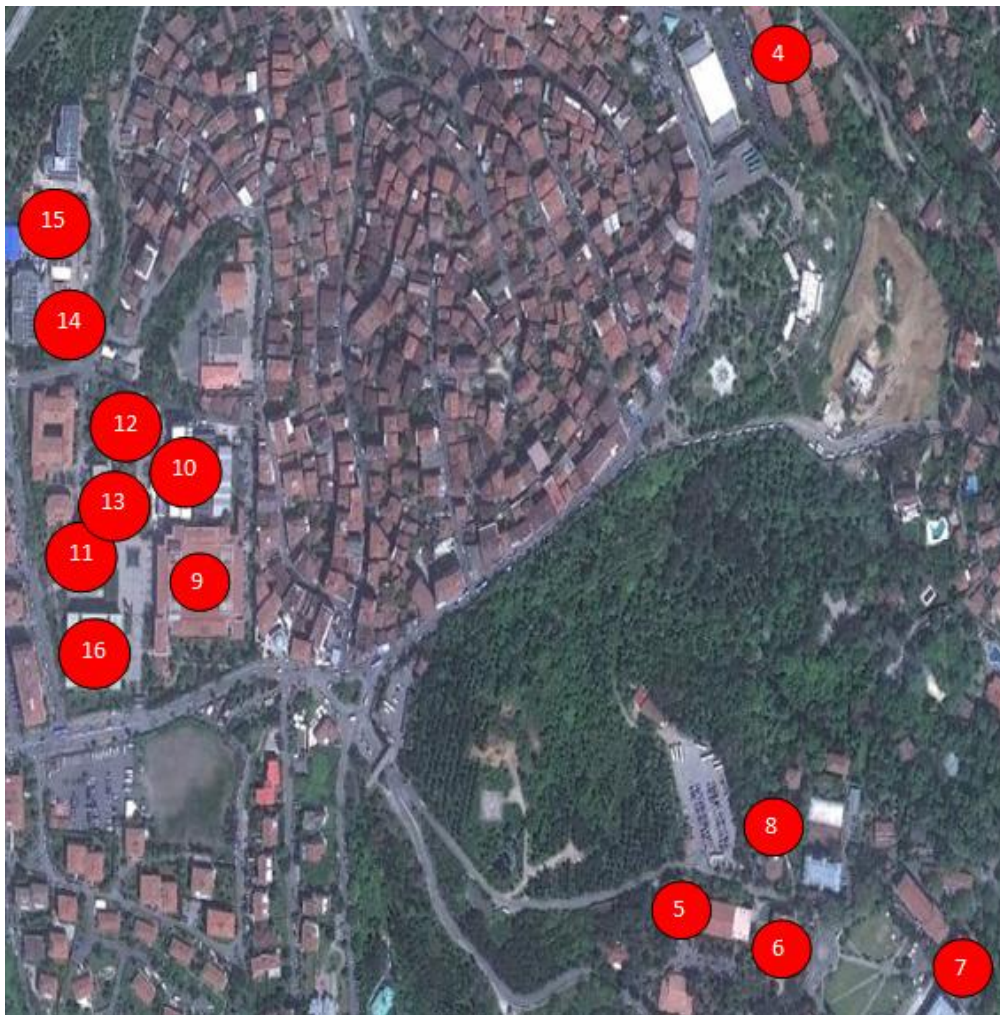


Figure A.4. Boğaziçi University Hisar, South and North Campuses.

### A.5. Galatasaray University Ortaköy Campus

This campus is located just near the Bosphorus between Ortaköy and Ciragan districts. The only way to reach the campus is the coastal road. This makes the overland transportation limited. Total student population of this campus is 3394 students. In this campus, five buildings are considered in the model and the total used area in these buildings is 21030.61m<sup>2</sup>. The population density is 0.15 person/m<sup>2</sup>. The structural type of the buildings is ferro-concrete.



Figure A.5. Galatasaray University Ortaköy Campus.

### A.6. Istanbul Technical University Maçka Campus

This campus is located in Maçka district. The location is very good for the transportation because it is located at the center of three important districts of Istanbul, which are Beşiktaş, Nişantaşı and Beyoğlu. This provides the multiple choice overland transportation. Total student population of this campus is about 2500 students. In this campus, three buildings are considered in the model and the total used area in these buildings is 25727.37 m<sup>2</sup>. The population density is 0.10 person/m<sup>2</sup>. 23<sup>rd</sup> building is a stone building, the structural type of the other buildings are ferro-concrete.



Figure A.6. ITU Maçka Campus.

### A.7. Mimar Sinan University Fındıklı Campus

Like the campus of Galatasaray University this campus is also located near the Bosphorus between Karaköy and Kabataş districts. Because of a similar location with Galatasaray University, the only overland transportation to this campus is the coastal road. Total student population of this campus is 6863 students. In this campus, two buildings are considered in the model and the total used area in these buildings is 19034.67 m<sup>2</sup>. The population density is 0.32 person/m<sup>2</sup>. The structural type of the buildings is ferro-concrete.

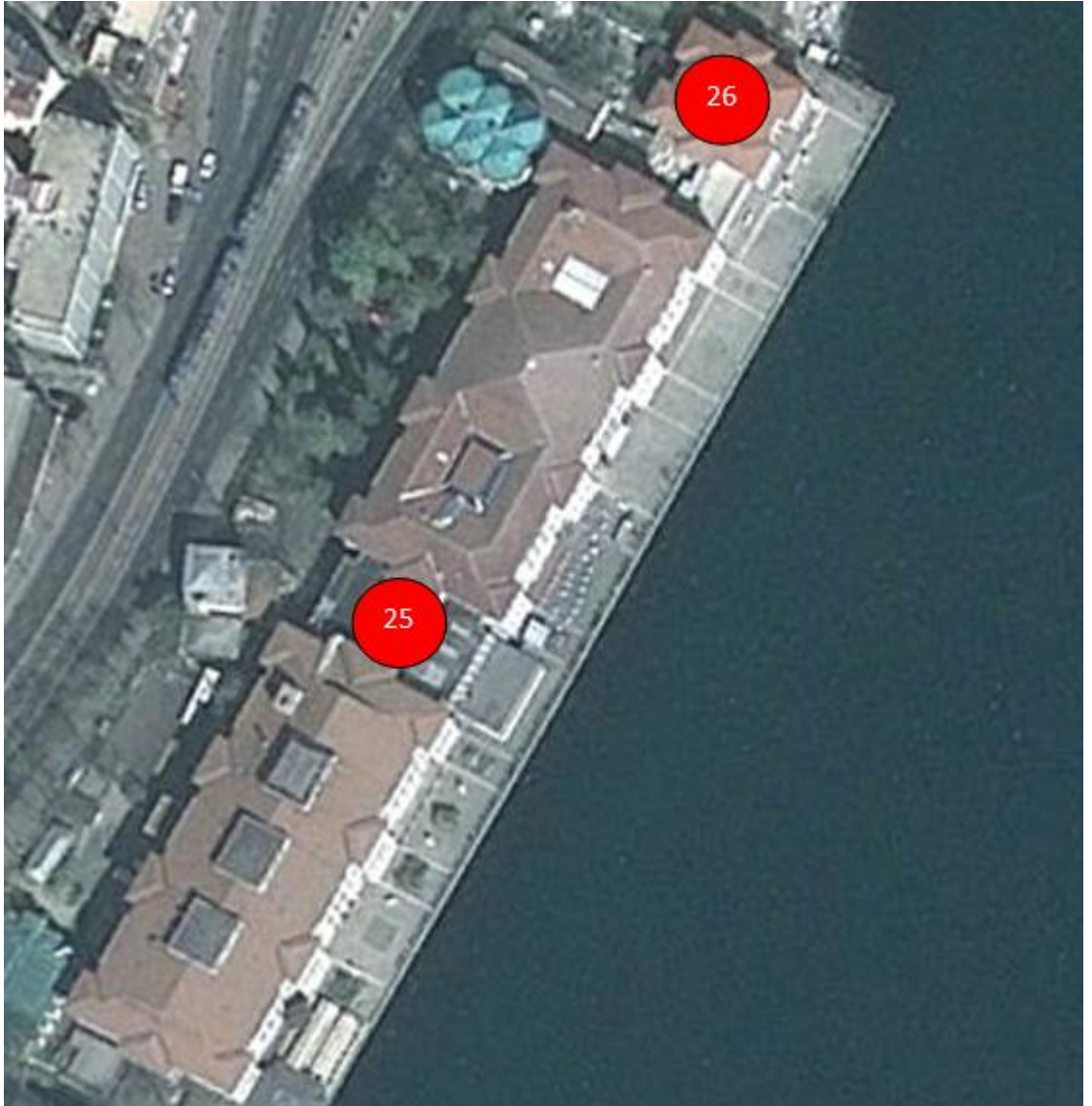


Figure A.7. Mimar Sinan University Fındıklı Campus.

### A.8. Yıldız Technical University Yıldız Campus

This campus is located in Yıldız district. The overland transportation to the campus is ideal, because one of the most living boulevard of Istanbul is located next to this campus. Total student population of this campus is 11715 students. In this campus, seven buildings are considered in the model and the total used area in these buildings is 34385.26 m<sup>2</sup>. The population density is 0.35 person/m<sup>2</sup>. 32<sup>nd</sup> building is a stone building, the structural type of the other buildings are ferro-concrete.



Figure A.8. Yıldız Technical University Yıldız Campus.

### A.9. Haliç University Mecidiyeköy Campus

This campus is located in Mecidiyeköy district. The location of the campus is very central and there are many available options to arrive this campus by using the overland transportation. Total student population of this campus is 1904 students. In this campus, there is only one building and the total used area in this building is 12571.8 m<sup>2</sup>. The population density is 0.15 person/m<sup>2</sup>. The structural type of the building is ferro-concrete.



Figure A.9. Haliç University Mecidiyeköy Campus.

### A.10. Haliç University Bomonti Campus

This campus is located in Bomonti district and it is very close to the centre of Şişli district. The location of the campus is central. Total student population of this campus is 1057 students. There is only one building in this campus and the total used area in this building is 6333.33m<sup>2</sup>. The population density is 0.17 person/m<sup>2</sup>. The structural type of the building is ferro-concrete.



Figure A.10. Haliç University Bomonti Campus.

#### **A.11. Marmara University Nişantaşı Campus**

This campus is located in Nişantaşı district. There are various ways for overland transportation to arrive this campus. Two buildings are located in this campus, one is used for dentistry faculty and the other one is used for the communication faculty. Total student population of this campus is 3715 students. There are two buildings in this campus and the total used area in this building is 6215.39 m<sup>2</sup>. The population density is 0.60 person/m<sup>2</sup>. The structural type of the buildings is ferro-concrete.



Figure A.11. Marmara University Nişantaşı Campus.

**APPENDIX B: THE MAP OF UNIVERSITY CAMPUSES AND AID STATIONS OBSERVED IN THE STUDY**

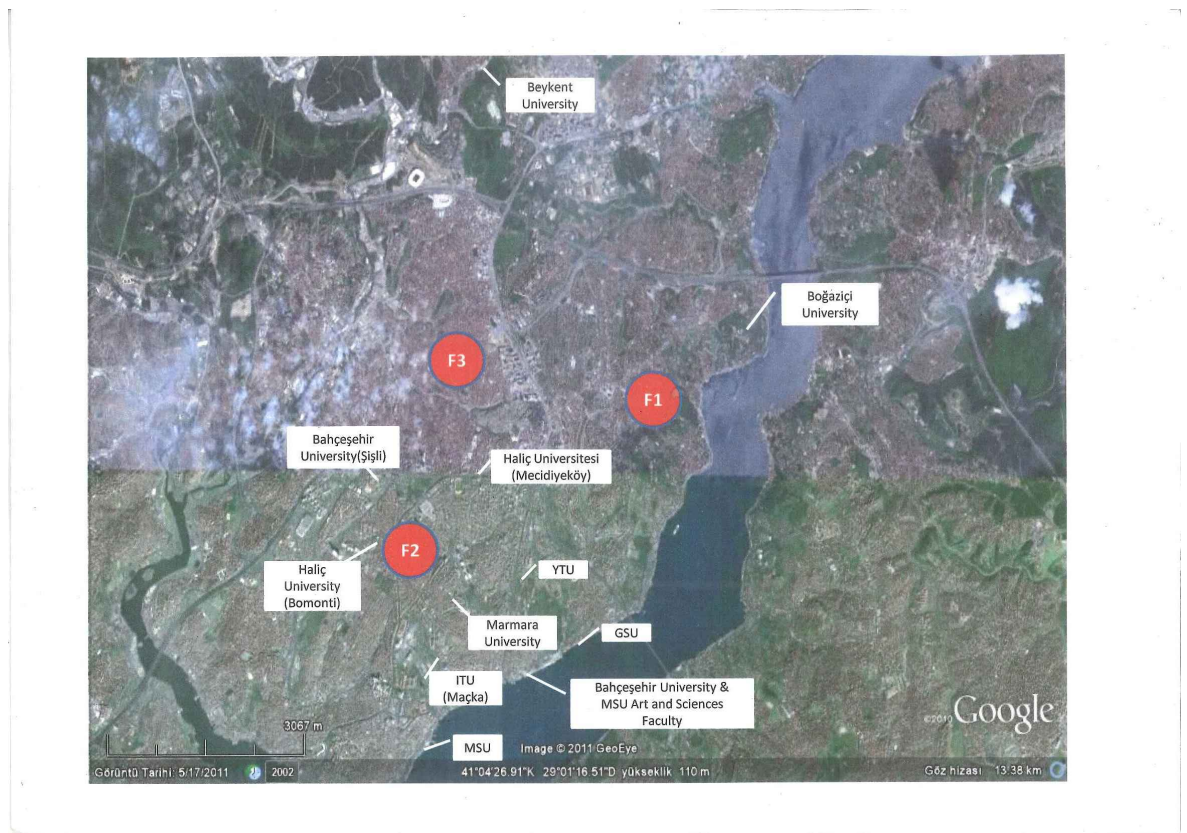


Figure B.1. Chosen university campuses and aid stations in Şişli and Beşiktaş.

## APPENDIX C: OPTIMIZATION MODEL GAMS CODE

```

Set t      time      / 1*20 /

      k      demandpoints / 1*37 /

      sbar   scenarios / 1*4/

      m      buildingtype      / 1*2 /

      d      damage type      / light , moderate ,
heavy /

      j      facilitypoints      / 1*3 /

      s      seismiccode      / 1*5 /;

alias(s,sp);
alias(t,tp);

Parameters
rm(m,sp,s) unit cost of mitigation (rs per m^2)/
$include "mitnewww.txt"
/
V(k) unit cost of building a prefabricated house (rs per
m^2)/
$include "prefabrication5.txt"
/
lamda(d) demand parameter/
$include "demandparam.txt"
/
gamma(d,s,k,m,sbar) damage ratio (inches)/
$include "dr16.txt"

```

```
/
c(j,k,sbar) unit transportation cost (rs per m)/
$include "transporter.txt"
/
P(t,sbar) scenarioprobability /
$include "condprob.txt"
/
alfa(k,m,t) populationofbuilding /
$include "newpop1.txt"
/
B(t) budget /
$include "sonsuzbudget.txt"
/
Z(m,k,s) initialarea /
$include "universityinitial1.txt"
/
q(j,t,sbar) capacityoffacility /
$include "denemerelief11.txt"
/
bud(t) optimal budget /
$include "bud.txt"
/
recovery(t) optimal recovery /
$include "recovery.txt"
/
retrofit(t) optimal retrofit /
$include "retrofit.txt"
/
retro(t) retro /
$include "retro.txt"
/
demand(t,sbar) dmand /
$include "d.txt"
/
```

```
infla(t) inflation /
$include "inflationdata1.txt"
/
transportation(t) transport /
$include "transportt.txt"
/
shortage(t) shorta /
$include "shortage.txt"
/
totalcost(t) tcost /
$include "totalcost.txt"
/
;

Scalar a penaltycost /1000000000
/;
Scalar g interestrate/ 0.09
/;
parameter top;

top=0;

parameter pot;

pot=0;

parameter tpo;

tpo=0;

parameter pto;

pto=0;
```

```
parameter top2;
```

```
top2=0;
```

```
parameter ara_top;
```

```
ara_top=0;
```

```
parameter gec_top;
```

```
gec_top=0;
```

```
Positive Variables
```

```
X(j,k,t,sbar) relief item sent
```

```
DL(k,t,sbar) demand level
```

```
W(k,sbar,t) shortage
```

```
JF(m,k,t,s) floorarea
```

```
I(k,t) prefabricatedarea
```

```
R(m,k,tp,sp,s) retrofittedarea
```

```
;
```

```
Variable
```

```
tcost totalcost
```

```
;
```

```
Equations
```

```
obj totalcost
```

```
floorarea(m,k,t,s) 1stfloorarea constraint
```

```
floorarea2(m,k,t,s) 2ndfloorarea constraint
```

```
prefab(k,t) 1stprefabricatedarea constraint
```

```
budget(t) budget constraint
```

```
demand1(k,t,sbar) demand1 constraint
```

```
demand2(k,t,sbar) demand2 constraint
```

```
rlfitem(j,t,sbar) reliefitem constraint;
```

```

obj..
tcost=e=sum((t),power(((1+infla(t))/(1+g)),(1-
ord(t)))*(sum((k,sbar),P(t,sbar)*a*W(k,sbar,T))+sum((j,k,sbar
),P(t,sbar)*c(j,k,sbar)*X(j,k,t,sbar))+sum((sbar),P(t,sbar)*s
um(tp$(ord(tp)<=ord(t)), sum(m, sum(k, sum(sp, sum(s$(ord(s)
GE ord(sp)),rm(m,sp,s)*R(m,k,tp,sp,s)))))))+sum(k, sum(sbar,
P(t,sbar)* V(k)* I(k,t)))));
    floorarea(m,k,t,s$(ord(t)=1)..
JF(m,k,t,s)=e=Z(m,k,s)+sum(sp$( ord(sp) <= (ord(s)-
1)),R(m,k,t,sp,s))-sum(sp$( ord(sp)
>=(ord(s)+1)),R(m,k,t,s,sp));;
    floorarea2(m,k,t,s$(ord(t)>=2)..
JF(m,k,t,s)=e=JF(m,k,t-1,s)+sum(sp$( ord(sp) <= (ord(s)-
1)),R(m,k,t,sp,s))-sum(sp$( ord(sp)
>=(ord(s)+1)),R(m,k,t,s,sp));
    prefab(k,t).. I(k,t)=g=sum(m, sum(s,
sum(d$(ord(d)<=3), sum(sbar$(ord(sbar)<=5),
JF(m,k,t,s)*P(t,sbar)*gamma(d,s,k,m,sbar)))));
    budget(t).. B(t)=g=(1-
sum(sbar,P(t,sbar)))*sum(m,sum(k, sum(sp, sum(s$(ord(s) GE
ord(sp)),rm(m,sp,s)*R(m,k,t,sp,s)))));
    demand1(k,t,sbar).. DL(k,t,sbar) =e=
sum((d,m,s), lamda(d)*gamma(d,s,k,m,sbar)*JF(m,k,t,s)*alfa(k,m
,t));
    demand2(k,t,sbar).. DL(k,t,sbar) =e=
sum(j,X(j,k,t,sbar))+W(k,sbar,t);
    rlfitem(j,t,sbar)..
q(j,t,sbar)=g=sum(k,X(j,k,t,sbar));

Model murat /all/;

R.L(m,k,t,sp,s)=0;

```

```
I.L(k,t)=0;
```

```
W.L(k,sbar,t)=0;
```

```
X.L(j,k,t,sbar)=0;
```

```
DL.L(k,t,sbar)=0;
```

```
JF.L(m,k,t,s)=0;
```

```
Solve murat minimizing tcost using lp;
```

```

loop(m,loop(k,loop(t,loop(tp$(ord(tp)<=(ord(t)-
1)),loop(s,loop(sp$(ord(sp)<=(ord(s))),loop(sbar,top = top +
top + (P(t,sbar)*rm(m,sp,s)*R.L(m,k,tp,sp,s))))))));
loop((k,t,sbar),pot = pot + (P(t,sbar)*V(k)*
I.L(k,t))););
loop((k,sbar,t),tpo = tpo +
(P(t,sbar)*a*W.L(k,sbar,t))););
loop((j,k,t,sbar),pto = pto +
(P(t,sbar)*c(j,k,sbar)*X.L(j,k,t,sbar))););
loop(t,
recovery(t)=0;
loop(sbar,loop(k,
recovery(t)=recovery(t)+(P(t,sbar)*V(k)*I.L(k,t))););
retrofit(t)=0;
gec_top=0;
loop(sbar,gec_top=gec_top+(P(t,sbar))););
loop(k,loop(m,loop(sp,loop(s$(ord(s)>=(ord(sp))),
retrofit(t)=retrofit(t)+(rm(m,sp,s)*R.L(m,k,t,sp,s)))));
retro(t)=(1-gec_top)*retrofit(t);
bud(t)=recovery(t)+((1-gec_top)*retrofit(t))););
loop(t,loop(sbar,
```

```

demand(t,sbar)=0;
loop(k,loop(d,loop(m,loop(s,
demand(t,sbar)=demand(t,sbar)+(lamda(d)*gamma(d,s,k,m,sbar)*J
F.L(m,k,t,s)*alfa(k,m,t)))))););
loop(t,
transportation(t)=0;
loop(j,loop(k,loop(s,loop(sbar,
transportation(t)=transportation(t)+(P(t,sbar)*c(j,k,sbar)*X.
L(j,k,t,sbar)))))););
loop(t,
shortage(t)=0;
loop(k,loop(sbar,
shortage(t)=shortage(t)+(P(t,sbar)*a*W.L(k,sbar,T))))););
loop(t,
totalcost(t)=0;
totalcost(t)=totalcost(t)+shortage(t)+transportation(t)+
recovery(t)+retrofit(t)););
display
R.L,I.L,W.L,X.L,DL.L,JF.L,top,pot,tpo,pto,bud,recovery,retro,
demand,transportation,shortage,totalcost;

```

**APPENDIX D: R CODE**

```
dbrown<-function(x,mu,alpha){
  c1<-mu/(2*pi*(alpha^2)*(x^3))
  c2<-exp(-(x-mu)^2)/(2*mu*(alpha^2)*x)
  sqrt(c1)*c2
}
mus<-20;alphas<-0.5;
condbrown<-function(x,mus,alphas){
  fintegrand<-function(x){
    dbrown(x,mus,alphas)
  }
  integrate(fintegrand,x,x+1,rel.tol=1.e-
10)$value/(integrate(fintegrand,x,Inf,rel.tol=1.e-10)$value)
}
try<-seq(1.e-6,100,length.out=1000);
hrtry<-0
for(i in 1:length(try)){
  hrtry[i]<-condbrown(try[i],mus,alphas)
}
plot(try,hrtry,type="l")
```

## REFERENCES

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