Cost Estimation of Reinforced Concrete Buildings by Using Neural Network and Multi Regression Analysis

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Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
June 2021
Gazimağusa, North Cyprus

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ABSTRACT

In this study, an Artificial Neural Network and Multi Regression Analysis have been used to evaluate the strengthening cost and total cost of reinforced concrete buildings. To obtain strengthening cost, 377 reinforced concrete buildings which have been designed according to the 1975, 1997 and 2007 Turkish Earthquake Codes have been checked and strengthened according to the new code (2018 Turkish Earthquake Code). After that, to obtain the total cost of the buildings according to the new code, 84 different reinforced concrete buildings have been designed according to the 2018 Turkish Earthquake Code. 4 different places at 4 different earthquake zones in İstanbul have been chosen to make the study. The professional program Sta4CAD has been used to model, analyze and strengthening those reinforced concrete buildings. The parameters which affect the cost of the buildings will represent the input and the strengthening cost and total cost of the buildings will represent the output.

When the old buildings will be checked according to the new code, they may not satisfy the conditions of the code. Since the new code has more general rules. According to that, those old buildings will need strengthening. Section enlargement method, addition of shear wall and other methods described in chapter 4 will be used so that the old buildings will satisfy the new code.

For strengthening cost of Reinforced Concrete buildings, 13 parameters have been chosen accordingly. These parameters are: Number of Storey (N), Concrete Class (C), Steel Class (S), Plan Area (A), Shear Wall Ratio (SWR), Column Ratio (CR), Earthquake Code (EQ), Stirrup Spacing, Soil Type (ST), Earthquake Zone (EZ) Torsional Irregularity, Weak Column-Strong Beam and Soft Storey. The output parameter for the study is the strengthening cost, which are in Turkish Lira according to the unit prices of materials in Turkey. For total cost according to TEC 2018 8 parameters have been used. Those parameters are: Plan Area (A), Number of Storey (N), Concrete Class (C), Steel Class (S), Shear Wall Ratio (SWR), and Column Ratio (CR). Finally the input parameters of the strengthening cost will be sorted accordingly to the importance.

According to the study, the prediction accuracy of the Artificial Neural Network that has been trained, found 94% accuracy for the strengthening cost calculations of buildings. However for the Multi Regression Analysis Method, 71% accuracy has been found for strengthening cost. For total cost, Artificial Neural Network gave 97% accuracy and for Multi Regression Analysis Method 95% accuracy has been found.

Keywords: Artificial Neural Network, Strengthening, Cost, Earthquake, Regression Analysis.

ÖZ

Bu çalışmada, betonarme binaların güçlendirme maliyetini ve toplam maliyetini değerlendirmek için Yapay Sinir Ağı ve Çoklu Regresyon Analizi kullanılmıştır. Güçlendirme maliyetini elde etmek için 1975, 1997 ve 2007 Türk Deprem Yönetmeliğine göre projelendirilen 377 betonarme bina yeni yönetmelik 2018 Türkiye Deprem Yönetmeliğine göre kontrol edilerek güçlendirildi. Daha sonra binaların yeni yönetmeliğe göre kaba inşaat maliyetini elde etmek için 2018 Türk Deprem Yönetmeliği'ne göre 84 farklı betonarme bina tasarlanmıştır. Çalışmayı yapmak için İstanbul'da 4 farklı deprem bölgesinde 4 farklı yer seçilmiştir. Bu betonarme binaları modellemek, analiz etmek ve güçlendirmek için profesyonel program Sta4CAD kullanılmıştır. Binaların maliyetini etkileyen parametreler girdiyi, binaların güçlendirme maliyeti ise çıktıyı temsil edecektir.

Eski binalar yeni yönetmeliğe göre kontrol edileceği zaman, yönetmeliğin şartlarını karşılamayabilir. Yeni kodun daha genel kuralları olduğundan dolayı karşılamayabilir. Buna göre eski binaların güçlendirilmesi gerekecek. Eski binaların yeni yönetmeliği karşılaması için kesit büyütme yöntemi, perde duvar ekleme ve 4. bölümde açıklanan diğer yöntemler kullanılacaktır.

Betonarme binaların güçlendirme maliyeti için 13 parametre seçilmiştir. Bu parametreler: Kat Sayısı (N), Beton Sınıfı (C), Çelik Sınıfı (S), Plan Alanı (A), Perde Duvar Oranı (SWR), Kolon Oranı (CR), Deprem Kodu (EQ), Etriye Aralığı , Zemin Tipi (ST), Deprem Bölgesi (EZ) Burulma Düzensizliği, Zayıf Kolon-Kuvvetli Kiriş ve Yumuşak Kat. Çalışmanın çıktı parametresi, Türkiye'deki malzeme birim fiyatlarına göre Türk Lirası cinsinden olan güçlendirme maliyetidir. TEC 2018'e göre kaba inşaat maliyeti için 8 parametre kullanılmıştır. Bu parametreler şunlardır: Plan Alanı (A), Kat Sayısı (N), Beton Sınıfı (C), Çelik Sınıfı (S), Perde Duvar Oranı (SWR) ve Kolon Oranı (CR). Son olarak güçlendirme maliyetinin girdi parametreleri önem sırasına göre sıralanacaktır.

Çalışmaya göre, eğitilen Yapay Sinir Ağının tahmin doğruluğu, binaların güçlendirme maliyeti hesaplamalarında %94 doğruluk buldu. Ancak Regresyon Analizi yöntemi için %71 doğruluk bulunmuştur. Kaba inşaat maliyeti için Yapay Sinir Ağı %97, Regresyon Analizi yöntemi için %95 doğruluk bulunmuştur.

Anahtar Kelimeler: Yapay Sinir Aglari, Guclendirme, Maliyet, Deprem, Regresyon Analizi.

DEDICATION

I would like to dedicate this thesis to my family and all of my friends whom they support me and help me through all my study.

ACKNOWLEDGEMENT

I would like to thank all of my family and my friend because of their positive motivation and full energy. After that I would like to thank my supervisor Asst. Prof. Dr. Giray Özay for his support and guidance in the studying of this thesis. With the help of him, I would be able to finish my thesis on time and get well experienced in this topic.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ao	The Effective Ground Acceleration
I	Importance Factor of Building
Rc	Reinforced Concrete
TEC-2007	Turkish Earthquake Code 2007
TEC-1997	Turkish Earthquake Code 1997
TEC-1975	Turkish Earthquake Code 1975
To	Soil Ruling Period
TRNC	Turkish Republic of Northern Cyprus
TS-500	Requirements for Design of Reinforced Concrete Buildings

Chapter 1

INTRODUCTION

1.1 General

Artificial Neural Networks are commonly used to solve the problems that may be complicated or there are difficult in modeling by using other techniques like mathematical modeling. ANN's are used in many problems in structural engineering. An Artificial Neural Network is based on a collection of nodes called artificial neurons, which loosely model the neurons in a biological brain. On the other hand neural networks can store, memorize, analyze, and process a huge amount of data gleaned from experiments and numerical analysis. Artificial neural networks are basically used in solving some problems that might be complicated or they may be difficult to be modeled. The operation of the ANN is easy, simple and precise.

Multi Regression Analysis is an extension of simple linear regression. It is commonly used to estimate the value of a variable based on the value of two or more other variables. Multi regression requires two or more predictor variables, and this is why it is called multi regressions.

Cost is one of the major criteria in decision making at the early stages of a building in design process. In today's globally competitive world, diminishing profit margins and decreasing market shares, cost control plays an important and major role for being competitive while maintaining high quality levels [1]. The cost estimate becomes one of the main elements of information for decision making at the beginning stage of construction. Thus, improved cost estimation techniques will facilitate more effective control of time and costs in construction projects.

Strengthening of building is also very important in the construction life. If the structure is strong enough then the peoples or others that are using that structure are at safe position. During past earthquakes, many reinforced concrete (RC) buildings have either collapsed or suffered distinct degrees of damage. Several inquiries have been conducted on buildings earthquakes have destroyed or broken them. Safety is also one of the most important considerations which should be taken before any construction project gets underway. Buildings are legally required to meet certain codes and rules that set minimum safety standards. These codes are important because when it gets applied, the building will be safer.

1.2 Aim and Objective

The objective of this study is to prepare a Neural Network and Multi Regression Analysis software for quick strengthening cost and total cost estimation of buildings with different structures. The buildings will be designed according to 1975, 1997, 2007 and 2018 Turkish Earthquake codes. After that the buildings will be strengthened according to the last earthquake code which is 2018 Turkish Earthquake Code and strengthening will be done to those old buildings that are not satisfying the standards of the new code. Another ANN and MRA will be created to calculate the total cost of the structures according to 2018 TEC. The input parameters of the strengthening cost will be sorted accordingly to the importance. The study aims to provide all the reinforced concrete buildings in the most economical way without affecting their strength and sustainability.

1.3 Significance of the Study

For the buildings that are designed according to the old codes, the total cost for each of them will be calculated. After that those buildings will be strengthening according to the 2018 code which is the new code that is used. After strengthening done the cost of strengthening will be calculated for each building. Since in this way when too many structures have been strengthen, in the future if a new earthquake code have been introduced it will be easier to strengthen the buildings according to that code. After this study, there will be buildings stock for reinforced concrete structures before analysis will get strengthened. There has been a lot of difficulty in the cost calculation method for several reinforced concrete buildings and it has been detected that neural network is an appropriate method to make all of these calculations. One of the important methods used in computer aided cost estimation is the artificial neural network and multi regression analysis. It has a highly useful tool in estimating building cost that may face. Today, it's easier to reach many artificial neural networks software since it's easier to model the cost by using this software and by regression modeling. This software is very useful in cost calculations, especially in preliminary exploration of the projects and in modeling different options. This is a great advantage for the engineer in terms of time provided. Artificial neural network is complex and dynamic process as shown in figure 1.

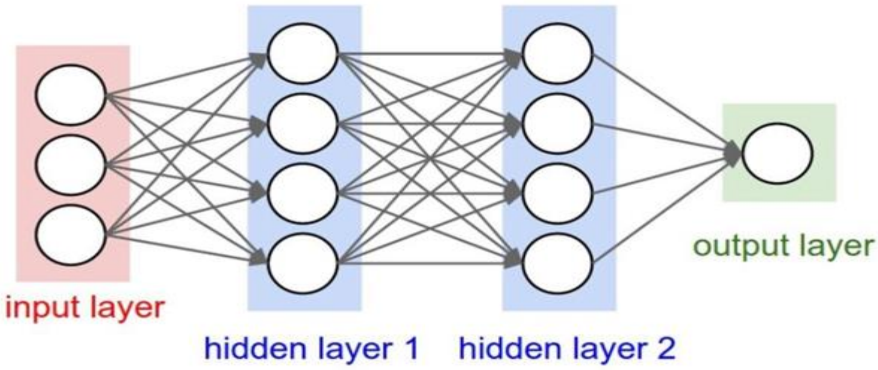


Figure 1: Application of neural network [10]

1.4 Previous Work Done

In the past, many researches study about cost calculations, earthquake, neural network and multi regression analysis. Several studies are listed below.

In the study of Alshaer [52], ANN have been developed for evaluation the collapse vulnerability of RC buildings. In his study, 260 RC buildings were chosen with 16 input parameters. ANN has been used and the outputs of the system represent the performance of the structures. As a result, 90% accuracy has been found for nonlinear performance analysis and 89% accuracy for linear performance analysis.

In the study of Arslan [51], a total of 256 RC buildings with between 4 and 7 floors were modeled. Modal analysis and pushover analysis have been applied to each of the capacity curves for each structure. 2007 Turkish Earthquake Code has been used in the analyzing of data. The effect and importance of each parameter have been tested in his study and he found that short column formation and shear wall ratio are the most important structural component that affects the performance of the structures. As a result the performance has been determined using ANN.

Another study that have been done by Arslan, Ceylan and Koyuncu [37] which was the analytical method developed for analyzing the earthquake performance of Reinforced concrete buildings by using Neural Network. In this study 66 RC buildings with 4 to 10 storey were designed by using the IDE Static software according to the linear analysis method in the 2007 Turkish Earthquake Code. 66 buildings have been selected and 18 input parameters have been chosen. As a result, the performance of RC buildings was determined.

Angin (2018), in his thesis he use buildings stock before 1990s constructed without horizontal loads and he work with performance analysis within TEC-2018 regulations by using non-linear analysis method. Sta4cad have been used for the modeling of the structures and through this study.

Furtado, Rodrigues, Varum, Costa and Anibal (2014) study is to prepare a numerical analysis and possible solutions to strengthen existing reinforced concrete buildings and to have the full potential governed by soft-story mechanisms. In their study they use concrete buildings which are located in the South European Countries. They analyses the seismic response of the buildings with masonry infill panels, upper stories and ground floor. They use different techniques for strengthening such as RC column jacketing, addition of RC shear wall and steel bracing. Finally they compared the strengthened buildings results with original structures and detect about the improvement in the performance of each type of strengthening technique.

In their building projects in Philippines, Roxas and Ongpeng (2014) used 30 different project data’s for their building cost estimation of construction Project. 18 of them are for training the network, 6 of them for the performance verification and the other 6 for the network to be tested completely independent. 6 input parameters are determined for the network. These are; number of basements, floor area, and number of floors, concrete volume, and formwork area and reinforced concrete reinforcement weight. The output layer is defined as the total building cost. The network is simulated in MATLAB software. As a result of the study, from the ANN model respectively; from training data 0.96812, from the verification data 0.70199 and from test data's 0.9548 correlation coefficients were obtained. Mean square error (MSE) value was found to be as 2.98 multiply by 10 to the power of 15. Nevertheless, artificial neural network has concluded with a good cost estimate in this model.

Aydinli and Oral (2017) in their research they use different parameters and properties such as gross total floor area, gross ground floor area, gross floor area, total structural height, gross total floor perimeter, foundation type and basement type. All of that has been calculated using neural network. Data have been collected from 68 building projects. They compare the results they find in Matlab with regression analysis method. Results show that average of 10% error obtained by neural network. However this values is 34% for the regression analysis method.

According to M. Arafa (2011) developing an efficient model to estimate the cost of building construction project at early stages gives accurate results using artificial neural network. A database of 71 building projects are collected from the construction industry and several parameters were identified for the structural skeleton cost of the project. The results they obtained from the trained models indicated that neural network reasonably succeeded in predicting the cost of the buildings without the need for a more detailed design.

M. Rodriguez and M. Eeri work on strengthening of reinforced concrete buildings in seismic areas by repairing and strengthening the columns of the structures. They make experimental results and its provide that there is further information on the strength, ductility and seismic behavior of reinforced concrete columns repair by adding longitudinal reinforcement placed through the floor structure. The structure they used was built between 1970 and 1980.

Elhab and Boussabaine (1998) in their study, they developed a neuro-fuzzy system for forecasting cost and duration of construction projects. They use 13 influencing model factors in the school building development, however in the second model only 4 determinant variables were provided. After they use the neural network system, they achieve overall accuracy of 82.2% and 79.3% as average respectively.

1.5 Thesis Outline

This thesis is mainly discussed of seven chapters. In this chapter, aim and objective of the study will be described and basic information regarding the neural network, multi regression analysis and strengthening method with previous work done is presented.

Chapter 2 presents a wide range background regarding the cost calculation of reinforced concrete buildings and the usage of regression analysis with artificial neural network in predicting the strengthening cost for the reinforced concrete structures.

Chapter 3 explains in details all of the strengthening methods with different structures. Also the importance and the way of strengthening for different types of buildings are presented in this chapter.

Chapters 4 represent and discuss the Turkish Earthquake codes including 1975, 1997, 2007 and 2018. After explaining in details each code, the codes are compared with each other. Because sometimes the buildings that are designed according to the old codes may not satisfy the new code, all the changes and the updates of the new code are presented in details.

Chapter 5 will be the methodology chapter of this study. The aim of the methodology is to understand the significant of the work done and to explain the importance of the study. The definition of Seismic analysis method plans of the study, parameters used and their importance will be explained in details.

In chapter 6, case studies will be studied. Structural plans are chosen and buildings are designed using those plans. After the input parameters have been chosen, the cost of strengthening and the total cost for each structure has been calculated accordingly. After that, neural network will be used to find the accuracy of the buildings and multi regression analysis will be done in order.

Chapter 7 will discuss about the conclusion and the recommendations for the future studies.

Chapter 2

NEURAL NETWORK AND MUTLI REGRESSION ANALYSIS

2.1 Introduction

In this chapter, the detailed explanation and importance of Neural Network and Multi Regression Analysis will be discussed in details. The important of ANN and MRA, advantages, disadvantages and other important applications will also take place.

2.2 Definition and Terminology of Artificial Neural Networks

An artificial neural network is a part of a computer processing system which is designed to simulate the way how a human brain can analyzes and processes information. On the other hand it is an ensemble of a large series of processing units, called nodes and neurons that are strongly connected. By connections, the neurons are linked. Numerical values reflect the frequency of the relations between the neuron.

From a biological brain paradigm, the terminology of artificial neural networks has emerged. The neurons receive signals from either input cells or other neurons and carry out some sort of control conditions and relay the result to other neurons or output cells. The neural networks are constructed from related neuron layers such that one layer collects input from the previous neuron layer and transfers the output to the subsequent layer. The definitions of the terms that take place in the layer of Artificial Neural Network are:

Neuron: They receive impulses from either input cells or other neurons and show the degree of value that is added to that input by this neuron, and it is often called nodes.

Input: It is a real function of a neuron. It activates the information that come from outside.

Output: Obtained with a function which is typically sigmoid or logistic. It activates the information that comes to output.

Hidden Layer: It is positioned between the algorithm's input and output, in which the function adds weights to the inputs and guides them as output by a learning algorithm. In brief, nonlinear transformations of the inputs entered into the network are performed by the hidden layers.

2.3 Definition of Multi Regression Analysis

Multi regression analysis is a technique that is used to estimates a single regression model with more than one outcome variable. Multi linear regression attempts to model the linear relationship between the independent and dependent variables. The parameter that is used to measure the dependent variable or consequence is known as the independent variable. The coefficient of determination (R-squared) is a statistical metric for determining how much difference in the independent variables can be explained by variation in the result. As a result, R-squared alone cannot be used to determine which predictors should be included and which should be omitted from a model. R-squared can only be between 0 and 1, with 0 indicating that none of the independent variables can predict the outcome and 1 indicating that the independent variables can predict the outcome without error.

2.4 Cost Estimation in Construction Projects

Decision making for civil engineering in cost estimation for building design processes points to a need for an estimation tool for both designers and project managers construction practitioners are aware of uncertainty, incompleteness, unknown circumstances and complex relationships of factors affecting cost and duration of construction projects [4].

Cost is defined as the some of the values spent in production until a good is obtained. As Unsal (2017) states construction costs are the sum of the items formed by multiplying the production amount by the price determined for that manufacturing.

The cost estimation for a construction project should be determined by using the resource needs of the project to be realized and by using the previous projects. Unsal (2017) explained that the main purpose of cost estimation is to assist in making decisions about pre-planning by providing reliable information about potential costs as soon as the project idea is outlined.

With the increase in the use of computer software in the field of civil engineering and project management, it is observed that the use of artificial intelligence applications has also increased. It has been determined in the literature review that artificial neural networks are the most frequently used tools among artificial intelligence applications.

The more data enter to the construction project whose cost will be estimated are included in the Artificial Neural Network, the better the network created based on these data that will be yield. Keeping the data set wide is a great of importance for the work to be done on this subject.

2.5 Cost Estimation and Regression Analysis with Statistical Methods

Statistical methods are not given realistic results as unit price method. But it is a practical way to find the parametric results based on the past construction cost data.

The most common statistical methods that may come across [13];

Unit Method

Volume Method

Area Method

Coat Shell Method

Regression Analysis Method

Expected Value Method

Range Method

Simulation Method.

The common feature of the statistical methods listed above is that the building cost is calculated based on the data obtained from the past parameters.

2.6 Applications of Artificial Neural Networks and Multi Regression Analysis in Civil Engineering

Nowadays Artificial neural networks have gained an important interest in civil engineering problems. They can be used as regression and statistical method including the optimization methods as well as in combination with numerical simulation systems and statistical cost problems. Application areas in civil engineering are such as forecasting, water management, building materials, structural engineering, heat transfer problems, transportation, controls, cost calculation and building services issues. It is used to calculate the earthquake-induced liquefaction potential which is essential for the civil engineers in the design procedure. Artificial Neural Network model is further applied in examining of the geotechnical engineering in their site work since the site materials and equipment's can be order accordingly [9].

Neural Network is used in civil engineering in project management and planning. Also resource analysis, set bid price and delayed programs also used to get done with it.

2.7 Factors Affecting the Performance of Artificial Neural Network

Artificial neural network is very widely and it has been used in systems such as system's modeling, forecasting, control, image processing and recognition, and many more. The improvement of multi-layered artificial neural network model for a particular application subsumes some causes which affect its demonstration. Artificial neural network performance depends mainly upon the following factors [10]:

1. Network
2. Problem complexity
3. Learning Complexity.

The quality and amount of training data are often the single most dominant factor that determines the performance of a model. The amount of data that is needed for a machine learning algorithm depends on the complexity of the problem and on the complexity of the chosen algorithm. Therefore, reasoning by analogy is a way to determine the amount of data that is probably needed.

In the supervised learning process of an artificial neural network, the learning process is based on datasets which ensure both input and output values. While the output value is ordinarily determined by the objective of the model, the choice of inputs to be considered in the model is at the commendation of the modeler.

2.8 Limitations of Artificial Neural Network

Neural Network programs may sometimes become ambivalent when applied to big and difficult problems. The solution for the time being may be to train and test these intelligent systems much as it is done for humans.

On the other hand there may cause some practical problems like it cannot easily pick up the resolution as it is the native polity of the network. We need much time and great computational resources to train the network since the system may never converge on an answer if pattern is not present in training data. Moreover, the network can’t easily take out the solution as it is the native state of the network.

Conversely Artificial Neural Network does not work well and give accurate results by tasks that are not done well by people. The network has lack of explanation capabilities. As a last thing, training time can be excessive and it usually requests a large quantity of training and test data.

2.9 Properties of Artificial Neural Network

Artificial neural network enable the human brain to generate new information through learning and it has the ability to create and discover information. With the developing software technology, artificial neural networks such as face recognition, text detection with complex network structures, are widely used today for many aims up to the purpose.

Artificial neural networks are a system of many artificial nerve cells consists together as in the biological system. Multiples of data input to artificial neural cell are transmitted. The outputs of those generated data are obtained after the processing method is activated. The artificial cell model consists of 5 components [22]:

Inputs

Weights

Merge function

Activation Function

Output.

The Artificial Neural cell model of Neural Network is shown in figure 1.2.

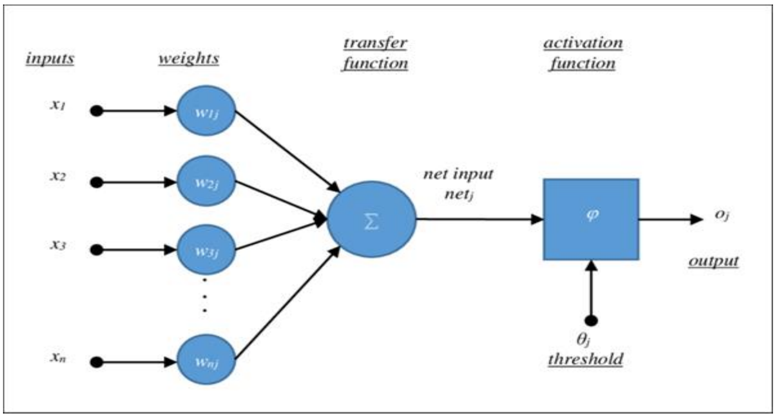


Figure 2: The Artificial Neural cell model [25]

2.10 Advantages and Disadvantages of Artificial Neural Networks

Neural Networks have the ability to find the error mistake in the study and to fins the accuracy of the work done. The input is stored in its own networks instead of a database, hence the loss of data do not affect its working. They're a classification of the clustering layer that sits on top of the data you store and handle. Also, if a neuron is not responding or a piece of information is missing, the network can detect the fault and still produce the output. Moreover, they can run more than one tasks in parallel at the same time without affecting performance of the system [11].

As neural network is very useful and have many usage areas, it also has some disadvantages. The first thing is the hardware dependence. Artificial neural networks require parallel processing driven processors, according to their structure. It is for this reason that the equipment realization is based. After that another important problem of neural network is that when the system produces a probing solution, it does not give a clue as to why and how. Therefore this reduces confidence in the network.

Hereafter as it known, neural networks works with numerical information. There is a difficulty in displaying the problems to the network because the problems have to be translated into numerical values before being introduced to neural network. The display mechanism to be set here will directly affect network output. The last thing is about the duration of the network. The network reduces the error on the sample to a certain amount, meaning that the training was completed. This value does not give an optimum result and difficulties may face [7].

2.11 Types of Artificial Neural Network

There are basically two types of neural network. The first is Feed Forward Artificial Neural network, the second is called Feedback Artificial neural network. In the feed forward Artificial Neural network there is no feedback loop. The data flow is only happening forwardly. The behavior of feed forward artificial neural network do not relies on the information of historical data. However in feedback artificial neural network, there are loops that carry information from exit to input.

The feed forward Artificial neural network are divided into two as single layer feed forward and multi-layer feed forward as shown in figure 2 and figure 3. In single layer feed forward there is only one compute layer. Here the calculation is only made in the output layer. Also there is only single weight layer since it connects the entries directly to the output layer with a certain weight vector. In multi-layer feed forward, one or more hidden layer is available. The data which are coming to the input layer are first transmitted to the first hidden layer. The hidden layer is the layer which carries out the intermediate calculations before passing the inputs to the output layer.

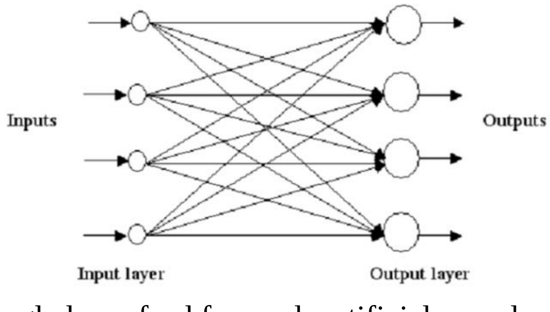


Figure 3: Single layer feed forwards artificial neural network [10]

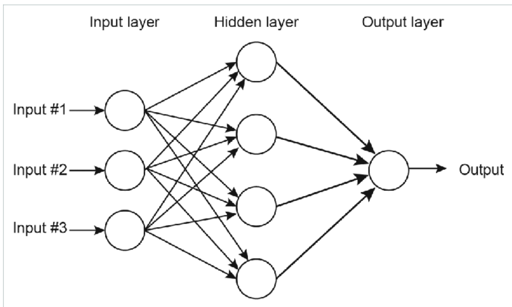


Figure 4: Multi-Layer Feed Forward Artificial neural network [10]

As seen in figure 4, feedback artificial neural network contains at least one feedback cycle.

Some of the properties of feedback Artificial neural networks [11]:

Feedback must be provided to all biological neural networks;

Mathematically they are dynamic systems;

There are many learning algorithms available;

They have problems in philosophy and reality.

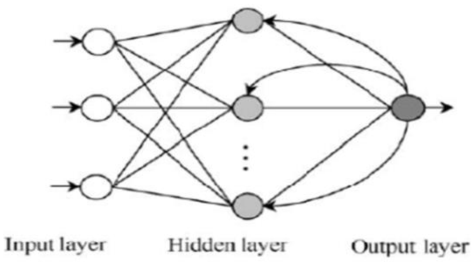


Figure 5: Feedback Artificial neural network [10]

2.12 Advantages and Disadvantages of Multi Regression Analysis

There are too many advantages of regression analysis. The first is the possibility of creating one or more predictor variables' relative effect on the criterion value. The ability to detect outliers, or anomalies, is the second advantage of the system. For example, a human resources manager reviewing data on management compensation might discover that the number of hours employed, the size of the department, and its budget all had a strong connection to salaries, while seniority did not.

The disadvantages of regression analysis is the under fitting. Multi regression fails to suit complex datasets because it assumes a linear relationship between the input and output variables. In such cases, a more complex function will more efficiently capture the data. As a result, the accuracy of most multi regression models is low.

Chapter 3

STRENGTHENING OF BUILDINGS

3.1 Background of the Study

Strengthening is the process of enlarging a structure's load-carrying capability. It is important for a structure to be both strong and stable. It will crack and collapse if it is not strong enough. When the building is designed according to the old code, this problem may face. The reason is that every few years a new earthquake code is introduced. Since when an earthquake happen, the engineers will face something new. For example when a big earthquake happens and if the building collapse this means that more regulations should be considered in the design. So it is very important to follow the new regulations and get read of them.

Before any strengthening is attempted, a thorough review should be conducted to assess the existing error in the system and correctly define the issues to be solved. The need to strengthen the ability of an existing building to withstand seismic forces typically emerges from proof of damage during a recent earthquake and bad conduct. Strong earthquakes have destroyed a significant number of reinforced concrete buildings in the past, and some of these structures have been restored and strengthened (M. Rodriguez). Naturally, the method of repair and reinforcement relies very much on the structural system and for the materials used for the buildings construction. Regularly, strengthening is implemented by adding a new material to the system such as adding an element like shear walls or may be section enlargement can be considered too. There should first be a thorough examination before any strengthening is applied and those investigations are such as errors in the design, incomplete part in the building and unconsidered standards.

3.2 The Importance of Strengthening

In the past many earthquakes happens and due to this many buildings have either collapsed or suffered distinct levels of damage. The most important point is that the existing structures that will be strengthen have to obey more recent and topical code necessity. Most of the old buildings in the environment are constructed before the introduction of those modern building codes that have been occurred in the last years [22]. Since no one knows when the world will be faced with a very strong earthquake, all the precautions should be taken in advance. When the building is protected, it means that the peoples or whoever is using this building are in safe position. Brittle structures are subject to high displacement demands due to low lateral stiffness and strength, which cannot be adequately met as they have low ductility [30].

3.3 Causes of Strengthening

The most important reason for strengthening is to improve the performance of the structure under existing load or to increase the strength to carry additional loads. If the building is not satisfying this condition it causes strengthening. By doing this, there will be change in design codes and limitations. Another important cause for strengthening a structure is the alteration in the use of the structure. For example if a building is used as a dormitory and it suddenly change to a school then it will led to increase in the live loads on the building. Therefore this structure has to be strengthening in order to carry these extra loads. The most significant aim for a structure to be strengthened is to reduce the effect of the internal forces and to make the building safe for everyone.

3.4 Method of Strengthening

3.4.1 Introduction

Most of the strengthening techniques have recently been focused on global reinforcement schemes, which typically reinforce the system to limit lateral displacements to satisfy for low ductility. Some strengthening strategies that were introduced to fix/eliminate the vertical stiffness irregularity induced by the presence of the soft ground floor story, which contributes to a soft-story mechanism, were suggested to enhance the structural actions [19].

3.4.2 Addition of Shear Wall

It is critical that the new members that are to be added to the structure are few in number for a building that is already used and are built to ensure a substantial improvement in the load capacity and stiffness of the structure. Improving their lateral load bearing ability or fixing anomalies is the main aim of fixing and reinforcing shear walls. Two shear wall addition in both x and y direction that is the most frequently applied system based strengthening methods. Those are infill shear walls and external shear walls. The most common method to increase the seismic resistance of existing structures is the installation of new reinforced concrete shear walls. In managing global drifts and structural damage in frame systems, this technique has been proven more effective [25].

According to the global strengthening methods, adding of shear wall to the building is one of the most popular one. Infill shear walls enhance the potential of lateral load and stiffness of the texture. The existing partition walls in the building are replaced in the reinforcing process with infill walls and high-strength shear walls of reinforced concrete structures are constructed instead of those old ones. To be applied to the structure, reinforced concrete walls must be positioned in such a way that torsional effects on the structure are not induced and irregularities in the structure are avoided, as found in the construction of new buildings [30].

An alternative possible way of strengthening with infill depends on precast panels. Those elements can be constructed speedily and with major quality control. On the other hand, they help to prevent the practical implications of cast-in-place walls, such as parasite with occupants and functions of the building, extended construction period and man ability [14]. In figure 1 it can be seen how shear wall can be included to the building and how it can be fixed.

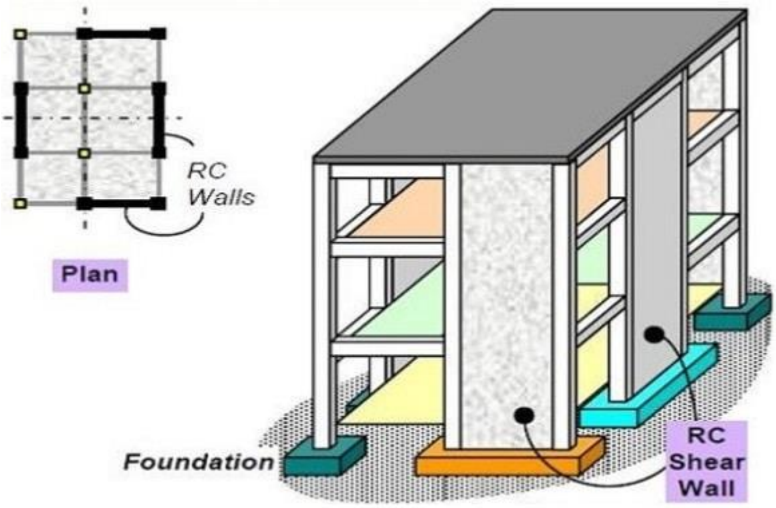


Figure 6: Adding of shear wall to strengthen the building [25]

While the use of shear walls is common due to the fact that they are efficient reinforcement materials, certain problems are often known to result in them so they involve a lot of demolition and renovation work in the existing structure. The use of external shear walls is an approach adopted to minimize such problems [30]. The application where they are mounted in parallel with the structure is the most desired type of the exterior shear walls. The design stage and the application field of external shear walls are easier compared with those infill walls.

3.4.3 Section Enlargement Method

Section enlargement is a method of strengthening where extra concrete is applied in order to increase the strength and stiffness of the member where steel is applied to an existing structural member, such as slabs, beams, columns, and walls. This method is also done to increase the shear capacity of beams and columns. Because of available ducts and pipes adjoining to the member, section enlargement may not always be necessary. As the member in use is a monolithic member, the original segment and the enlargement method will work accordingly. Unless those loads are withdrawn prior to the operation of the extension, the enlarged section cannot tolerate current dead loads. The extended portion, where current loads are not replaced, will resist only live loads and new superimposed loads [31]. Example for section enlargement is shown in figure 3.2 for column enlargement.

Figure 7: Column section enlargement method [28]

This procedure entails installing additional reinforced concrete in the shape of a jacket over an existing structural member. The composition of the current construction is extensively roughened during jacketing by sand blasting to strengthen bonding and reinforce bonding between old and new concrete. When section enlargement method applied, some changes will also be occurred in the moment capacity of the member that has been enlarged. By jacketing method the jacketed section will be sure to achieve sufficient shear and axial load strength. Jacketing of the columns is to produce the best results if the jacketing is applied from all the 4 sides of the column. Depends on the column, sometimes 3 sides can also be acceptable but it is not recommended to jacket the column from 1 or 2 sides since no changes will be occurred in terms of strength [27].

3.4.4 Supplemental Supports

Supplemental strengthening of assistance is a strategy under which the load impacts lowered to a current structural member. The design strength of a current structural member is strengthened by connecting the current structure with one or more additional structural members. It is also possible to use this reinforcement method to reduce deflections and to enhance the vibration characteristics of an established floor structure. This strengthening method is a system that it can consist of several beams and columns, bracing members or a single column [31]. The placement of new supports will have a significant impact on the allocation of the load effects of a current member. It is normal to add a supplementary member with a slight distance between it and the current member. So it will achieve a gap between this and existing member. To fill the gap, it is normal to add a supplementary member with a slight distance between it and the current member.

3.4.5 Strengthening of Joints and Corner Columns

According to D.C. Rai 2005, to overcome weak construction and design for reinforcement, joints should be sealed with hoop rings for defects in the beam-column joints. In portal frame systems, the ductility of reinforced concrete columns without requiring extra stiffness, it is possible to rise. Columns are an integral part of a building's construction and, in the case of an earthquake, represent the most significant protection measure. In figure 3.3 it shows the failure that may happen in the corner joints of a structure.

(a) (b)

Figure 8: Failure of the corner joints of reinforced concrete structures [26]

3.4.6 Strengthening with Steel Bracing

Steel bracing or shear walls are often used in order to improve the seismic resilience of framed buildings. Possibility for the use of steel bracing in reinforced concrete buildings have been popular in recent years. Steel bracing tends to be an appealing alternative to other shear-resistant elements such as concrete and masonry shear walls or a rigid frame structure, given the ease of installation and the comparatively low cost [29]. Steel bracings in reinforced concrete buildings can be designed to provide strength, stiffness, ductility, energy dissipation, or sometimes it provide some combination of these. The braces are mounted directly onto or connected to the concrete frame by a steel frame. There are advantages and disadvantages for steel bracing [18].

Advantages:

There is massive rise in lateral resistance. By choosing the number and height of the braces, the degree of strength and stiffness can be changed reasonably quickly. Steel bracing is efficient, simple to erect, takes up much less space and can be built flexibly to match the strength and stiffness necessary. Lowest possible loss of residential spaces and adjustment of the building's structural function is archived and easy to be constructed.

Disadvantages:

The relationship between modern steel and established concrete structures is hard to manage. It is responsive to brace specification and localized buckling and post-buckling failure contacts. It involves professional labor to create these frames.

3.5 Foundation

It is very important for a structure to have a strong foundation. The foundation, since it carries all sorts of loads, is a vital aspect of a structure. When the implemented loads are more than their capacity, it requires strengthening. The foundation of a building is what everything else depends on. In the construction, the foundation will pass the load to the earth. In this scenario, a new foundation is attached to each reinforced column to indicate that the load is well distributed to the earth [38]. The creation of cracks is perhaps the most frequent symptom of a broken foundation. Usually, noticeable cracks arise after concealed ones, suggesting the issue is actually more extensive than it looks. Many occasions, damage to the foundation results from water. This will build a weakened foundation if water will not drain sufficiently away from the building. Concrete foundations will only accumulate too much moisture until they tend to crack.

3.5.1 How Can Foundations Strengthened?

1) Jacketing of Foundation

Where there are columns that need to be strengthening, this method will be available to use. When the foundation will be jacketed, the seismic capacity of all the columns and shear strength will be increased accordingly. This is a typical need as additional load, such as by extensions, is applied to the wall. After that the weight of the columns will not be increased and construction time will be saved. It could be appropriate to enlarge or apply additional support to the base which is already established in order to ensure the wall is rigid enough to support this. In figure 4 it shows clearly how a foundation can be jacketed.

Figure 9: Jacketing of foundation [39]

2) Underpinning

In construction, the technique of reinforcing the foundation of a current building or other structure is underpinning. This procedure is used either to raise the foundation depth or to restore the foundation if there is substantial damage to it. Here the loads of the foundation will be transferred to a greater depth and stronger soil layers. The decision of underpinning requirement should be taken on the basis of findings. Underpinning could be necessary when the foundation of the structure is not strong enough as shown in figure 5. Then the characteristic of the soil that is supporting the foundation may alter through soil erosion or was misquoted during construction. Finally it is necessary because it is more sustainable and economical due to land price and to work on the current structure's foundation than to create a new one.

Figure 10: Underpinning of foundation if structure is not strong enough [40]

3.6 Base Isolation

Base isolation is one of the most effective means of defending a structure from any seismic forces. Base isolation is a nation approach in which by adding a suspension structure between the base and the main frame, the structure is isolated from the foundation. The aim of base isolation is to defend the structure from the motion of the earth to make it turn while and there is an earthquake and so there is not any structural damage. Base isolation can improve the seismic efficiency of both a system and its seismic sustainability considerably as shown in figure 11.

Figure 11: Base isolation for a structure from the foundation [41]

The overall benefit of base isolation is the restriction of criteria on the basis of the structure elements. This approach is more effective for comparatively rigid low rise buildings with large density compared to compact, flexible structures.

However, base isolation is mentally impressive and cost very expensive to incorporate and can be used for historical structures or where there is a requirement for a performance standard greater than life safety.

3.7 Fiber Reinforced Plastics (FRP)

For about 25 years, fiber-reinforced polymer (FRP) composites have been used in the United States for structural reinforcement. Acceptance of FRP composites as a mainstream building material has increased during this time, and so has the number of FRP reinforcement projects completed. FRP composite materials consist of high-strength composite materials trapped in a polymer matrix, such as glass, carbon, or steel wires. Although the polymer matrix (epoxy resins) serves as a binder, covers the fibers, and passes loads to and between the fibers, the fibers provide the main reinforcing components. In figure 7 and 8 it can be seen the FRP method for beam and column respectively.

Figure 12: FRP for beam [42]

Figure 13: FRP for column [42]

There are procedures for the installation of FRP. The first thing is that the surface of the concrete should be in a good condition before FRP sheets are linked to it. Otherwise irregularity will happen and it will cause problems. Both sharp edges are rounded to a minimal radius of 13 mm in order to minimize stress concentration and voiding between the FRP and the concrete base. When the coarse aggregates are exposed, the beam surface is usually roughened by grinding. If it is necessary, a protective coating will be applied over the FRP to resist the impact due to the moisture, radiation and other chemicals.

Chapter 4

EARTHQUAKE CODES

4.1 Introduction

Earthquake is the most feared and most damaging natural disaster among natural disasters. Building structures are totally made out of earthquake resistant starting from the foundation. Throughout this way, after an earthquake happen, the buildings are likely to experience the least damage. The earthquake code is the system of laws that guarantee the design of buildings in an earthquake-resistant condition. Within that way, from the start to the finish, the structures are guaranteed to abide with the earthquake requirements. To meet this process, audits are always made accordingly. In order to ensure that the buildings or structures to be designed in areas defined as unsafe within the scope of the earthquake are immune to earthquakes, the measurement takes into account all considerations such as calculations, construction stages, construction laws, the value of buildings and structures and local ground conditions. This situation is called earthquake regulation.

Due to normal causes and varying influences, modifications may be observed within the framework of the law. The laws will be updated in accordance with the reasons for the adjustment in the general earthquake law, the requirements that exist in tandem with the advancement of construction and information technology. Around the same time, where a large portion of the current building stock is made of non-durable material, amendments to the earthquake Code may be made to the law in order to reinforce these structures. Earthquake laws prioritize people's lives and aim to be firmly designed. Here is a list for the earthquake regulation that has been used in Turkey from the past until present [34]:

1940 –The Building Instructions for Italian Construction in Earthquake Districts,

1944 - Earthquake Districts Provisional Building Instructions,

1949 - Turkish Ground Movement Region Building Regulation,

1953 - Regulation on Structures to Be Built In Ground Movement Regions,

1962- Regulation on structures in disaster zones,

1968 - Regulation on structures in disaster zones,

1975 - Regulation on structures to be built in disaster zones,

1998 - Regulation on structures in disaster zones,

2007 - Regulation on buildings in earthquake zones,

2018 - Turkey building earthquake regulation.

4.2 1975 Turkish Earthquake Code

In 1975 earthquake codes, the country is divided into 1st, 2nd, 3rd and 4th degree earthquake zones. In that code, reinforced concrete buildings dominate the building population. Shear force and ductility were first described and used in this code. For reinforced concrete components, the dimensions and reinforcement values given are at a level that can be said to be adequate in earthquakes. This code has been used for more than 20 years and many buildings are designed according to that code. In this code it is involved the minimum reinforcement level and minimum cross sectional area of the buildings. Calculations of earthquake forces are rendered according to several criteria in detail. Several flaws in the previous specification, which caused heavy damage during earthquakes, have been found and have been resolved in this legislation.

The structural coefficients value, K for 1975 Turkish Earthquake code is given in table 4.

Table 1: Structure coefficient values, K according to 1975 regulations

Structure Type	**K[1]**
Ductile frame[2]	(a) 0.60, (b) 0.80, (c) 1.00
Non-ductile frame[2]	(a) 1.20, (b) 1.50, (c) 1.50
Steel frames with bracing[2]	(a) 1.20, (b) 1.50, (c) 1.60
Shear wall-ductile frames[2.3]	(a) 0.80, (b) 1.00, (c) 1.20
Shear wall structures with frames	1.33
Masonry buildings	1.5
Other	1

Blow counts or shear wave velocity were used to classify soil types, and values were assigned to each type. Shear wave velocities were set at greater than 700 m/sec for soil types I through IV, 400 to 700 m/sec for soil types II and III, 200 to 400 m/sec for soil type IV, and less than 200 m/sec for soil type IV.

Details for the beams and columns were modified in the 1975 earthquake code. For the beam design the minimum dimensions were 20cm width by 30cm depth. For the columns it is the story height multiply by 0.05 and 25cm accordingly. Maximum spacing was 30cm and minimum slab thickness was 10cm in advance. Figure 1 shows details for columns according to 1975 earthquake code.

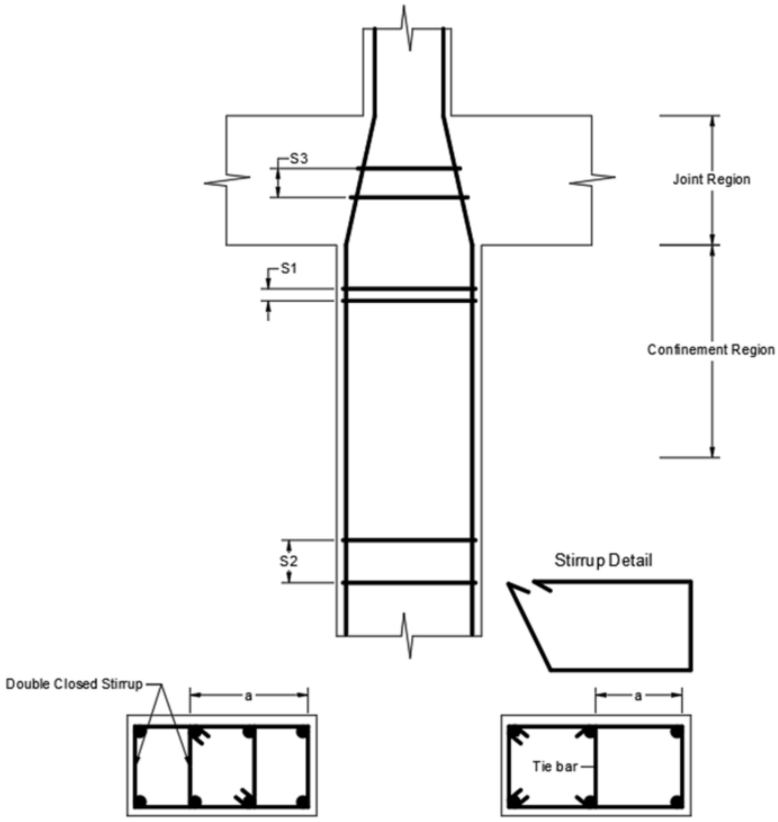


Figure 14: Detail for column according to 1975 [44]

Particular attention is assigned to column-beam junction areas and areas of column and beam containment in this legislation. Under the direction of 1975, generally BS20 concrete, longitudinal ST III and transverse reinforcement ST I were used for column walls and beams. With this regulation, four different soil classes are defined. This classification is made according to the "Soil Dominance Period". This classification is given in table 4.1 [39].

Table 2: Soil ruling period [47]

Soil Type		Soil Ruling Period To	To avg (s)
I	a b c	0.2 0.25 0.3	0.25
II	a b c	0.35 0.4 0.5	0.42
III	a b c	0.55 0.60 0.65	0.6
IV	a b c	0.7 0.8 0.9	0.8

4.3 1997 Turkish Earthquake Code

The 1997 Earthquake Law uses the advancement of information and technology and all necessary calculations and tables related to the measurement of earthquakes in the construction of buildings. With the amendments made in 1998, the legislation for a large amount of earthquake-resistant building design was completed. With this regulation, general rules were given and it was requested to comply with these rules. When 20 years pass through the old code a new code was introduced with improved formulas and regarding more seismic activity. One of the most important improvements in this code is the elastic design spectrum. The shear capacity in the beams, columns and shear wall should be higher than the bending capacity in the seismic design. Concrete with strength more than C20 should be used. In order to meet the seismic zone, concrete quality conditions should be meted. For steel reinforcement, S420 and lower steel class can be used but the reinforcement should not exceed the satisfying condition for steel buildings. Figure 2 shows the details of the columns connection with beam according to 1997 codes.

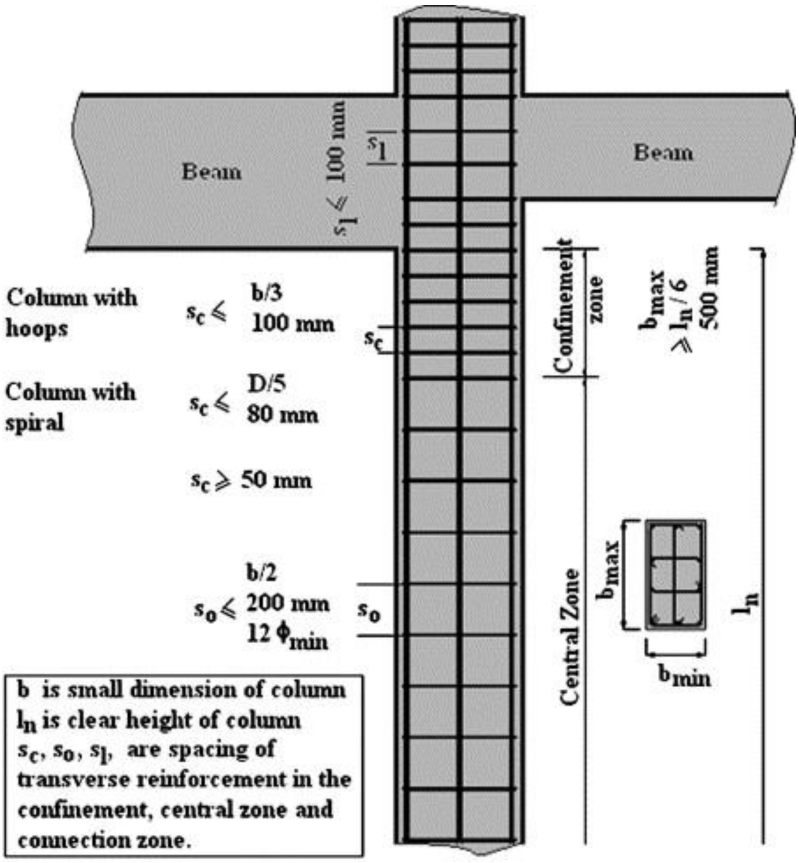


Figure 15: Column and beam reinforcement details for 1997 code [46]

The detailing specifications for high and nominal ductility columns are nearly identical. The cross-sectional measurements must be at least 25 cm by 30 cm. At a beam-column joint, the sum of the column strengths must be greater than 120 percent of the sum of the beam strengths. A column's shear strength must be greater than the shear force associated with the column's plastic moments. The overall spacing of the transverse reinforcement between the confinement zones is increased by a factor of two for columns in frames with nominal ductility. The smaller of 0.067 times the story height and 200 mm is the minimum wall thickness for shear walls.

The horizontal and vertical irregularities of the building have been identified, and these rules were demanded during the design to be followed. It must first be regular in terms of proportions and location of the components in order for the loads to come to the structure to be calculated in a practical way. In order to assess the earthquake forces that will influence the structure, the law determines the effective ground acceleration coefficient, building value coefficient and spectrum coefficient. Then, means of calculation are quoted. They are classified under three headings: equal method of earthquake load, combination method of mode, and methods of time-history calculation. Table 3 shows the characteristic spectrum period of the local site class according to 1997 regulation.

Table 3: Characteristic Spectrum Periods of the local site class according to 1997 regulation

Local site class	**T_A (s)**	**T_B (s)**
Z1	0.10	0.30
Z2	0.15	0.40
Z3	0.15	0.60
Z4	0.20	0.90

4.4 2007 Turkish Earthquake Code

After 1999 Gölcük earthquake that happen in Kocaeli in Turkey, a new earthquake regulation has been published in 2007. The aim of this code is to evaluate the buildings regarding seismic safety assessment and retrofitting. Seismic safety and retrofitting harder the life of the engineers because they had no choice to rely and thus results in appropriate design. The code was written to demonstrate the seismic inspection and retrofitting of existing buildings. In this code, a longer chapter involving the seismic safety assessment and retrofitting has been added in advance. On the other hand pushover and nonlinear time history analysis have been introduced in this code. So the performance level of reinforced concrete buildings for different structures can be obtained easily.

The Turkish earthquake code of 2007 was issued, stressing the seismic inspection and retrofitting of existing buildings. The major changes made to this code include a linear elastic approach for seismic safety evaluation that takes into account inelastic behavior in terms of estimated permissible demand/capacity ratios, depending on the degree of damage.

4.4.1 Major Innovations of 2007 Turkish Earthquake Code

The main principle of the 2007 earthquake regulation, as in the TDY-97 regulation, is that "structural and non-structural system elements in buildings are not affected in mild earthquakes, the damage that may occur in the structural and non-structural elements in moderate earthquakes is minimal and repairable, and in extreme earthquakes the hazard It is the limitation of significant structural damage in order to ensure its safety.

In compliance with the American Earthquake Law IBC (International Building Code), the Regulation on Buildings to be built in Earthquake Zones, which was issued in 2007 and entered into effect, has been updated with a performance strategy, in particular in the evaluation and stabilization of existing buildings. The key aim of the 2007 Earthquake Management is to determine the efficiency of existing buildings which have not been designed in compliance with the 1998 Regulations in relation to the potential impact of earthquakes and to identify the rules needed for the reinforcement of buildings with inadequate resistance to earthquakes.

4.5 2018 Turkish Earthquake Codes

The Seismic Code of 2018 has strengthened the Seismic Code of 2007 with an enlarged content. The key changes are the concept of site-specific ground construction shifts, and the seismic design of high towers, isolated base buildings and foundations of piles. In specific cases, non-linear analysis methods are used as compulsory, but are recommended for performance assessment of non-standard techniques. In this code, the earthquake hazard maps for all the cities have been updated and new approaches in parameters calculation have been introduced accordingly. By static and dynamic approaches, the forces impacting structures during the earthquake can be calculated. However the method of spectral analysis, which is the static method, is commonly used in order to make the analyses more practical. This approach is referred to in earthquake codes as a design continuum.

4.5.1 The Significant Changes in 2018 Turkish Earthquake Code

The previous Seismic Hazard Map of Turkey (1996) was a seismic zonation map, which divides the region into 5 hazard zones. It was based on the PGA values on very stiff soil. The new Seismic Hazard Map is not a seismic zonation map, but it is a geographic coordinate-based contour map. Seismic hazard is not summarized in terms of PGA; however it is expressed in terms of spectral acceleration. Site-specific spectral acceleration maps at T=0.2 s and T=1 s are developed for stiff soil sites, and for return periods of 2475, 475, 72 and 43 years [34]. A PGA contour map is also developed for the advance. In the figure below it shows the seismic hazard map for the 2018 codes.

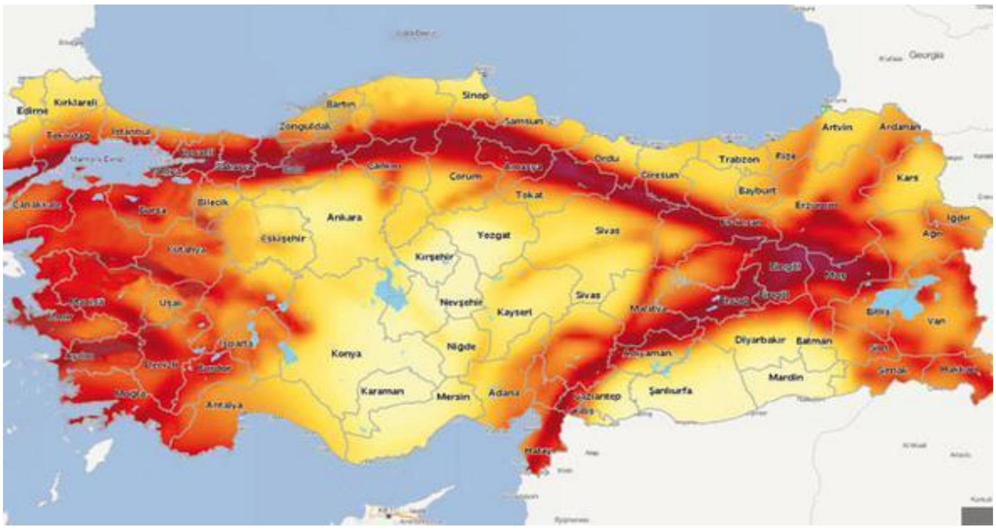


Figure 16: 2018 seismic hazard map [34]

4.6 Differences in 2007 and 2018 Turkish Earthquake Codes

Four separate earthquake areas were included in the 2007 earthquake regulations. However in the latest 2018 earthquake rules, the regions of the earthquake zone are defined in a different way. The precise site of earthquake risk and location based soil activity of structures became the subject of the new regulation. It is targeted at achieving accurate outcomes in predefined areas. Changes related to earthquake ground motion are also present. The earthquake acceleration coefficient was taken as a mere unit value according to the place of the structure in the 2007 Earthquake Law. The current regulation adopts various principles, such as the coefficients of earthquake acceleration for short and long periods. Differences in soil type descriptions are also present. The soil classes were graded into 4 classes in the previous regulation as Z1, Z2, Z3, and Z4 accordingly. However in the new regulation, the soil divisions are classified into 6 classes in the current law. There is also a shift in the coefficient of building importance. The coefficient of construction significance used in the previous earthquake legislation was modified from 1.4 to 1.5 values. Criteria for earthquake design classes and building level classes are included in the current legislation. The use of the attitude coefficient and the strength coefficient were one of the most noticeable improvements in the existing legislation. The level of construction performance in the 2007 Legislation is linked to the level of harm that can occur in the building and has been debated in three separate classes. Immediate use performance level, life safety performance level and collapse performance level. According to the 2018 regulations, construction performance standards are defined in four separate ways. Continuous usage performance level, limited damage performance level, controlled damage performance level and collapse performance level.

C20 /C25, C25/C30, C30/C37, C35/C45, C40/C50, C45/C55, C50/C60 concrete classes are used in reinforced concrete structures for the building in earthquake zones under 2007 regulation. However for the 2018 regulations, between C25 and C80 concrete class should be used and limitations that are stated in TS500 will be considered. For steel reinforcement, S220 and S420 both were used in the structures. In the 2018 regulation, it is stipulated that B420C and B500C rebar reinforcement steel will be used in the reinforced concrete structure to be built under the effect of an earthquake. Also S420 steel can be used if the design and strength criteria of the building are meeting the conditions.

Chapter 5

METHODOLOGY

5.1 Introduction

This chapter deals with designing of 377 reinforced concrete buildings according to the old earthquake codes and then to be strengthening according to the new code (TEC 2018). 84 different RC buildings will be chosen to calculate the total cost of the structures according to the 2018 Turkish Earthquake Code. Explanation of the input parameters used in the study which also represent the input of the study will be explained accordingly. Plans of RC buildings, performance, neural network and multi regression analysis will be presented as well.

On the other hand in this chapter pushover analysis, linear and nonlinear analysis will be discussed and brief information will be given.

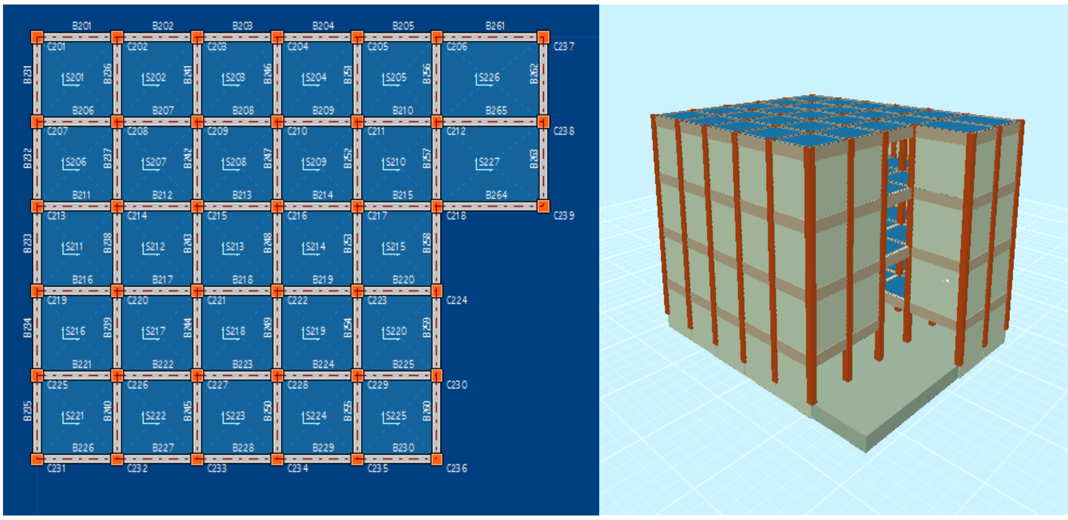
5.2 Parameters Considered in the Study

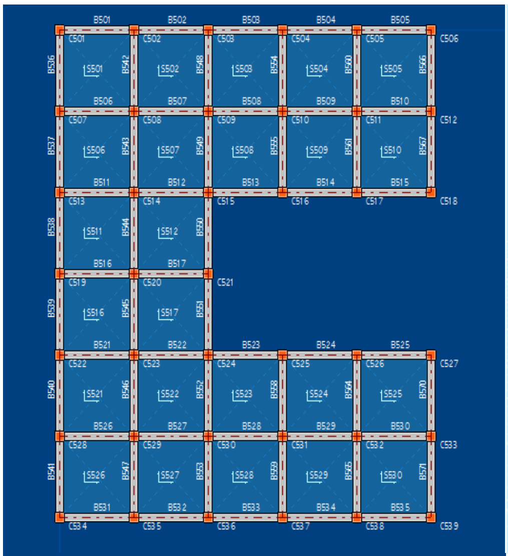
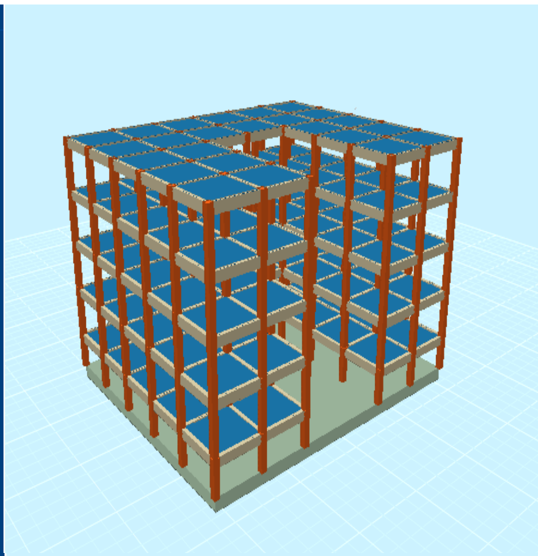
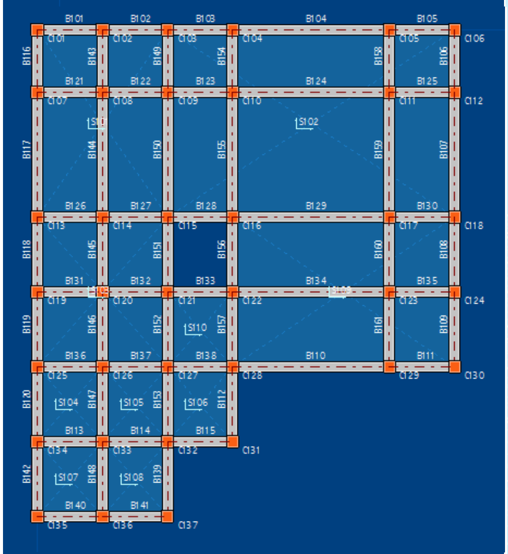
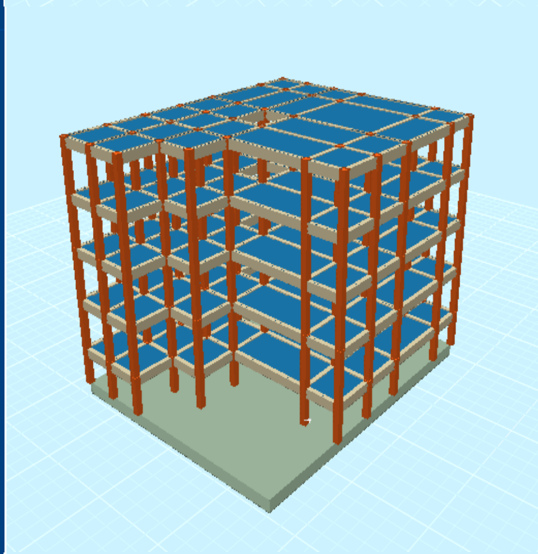
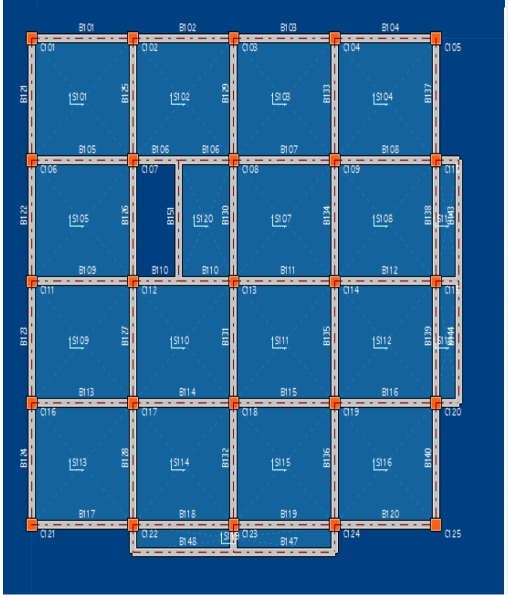
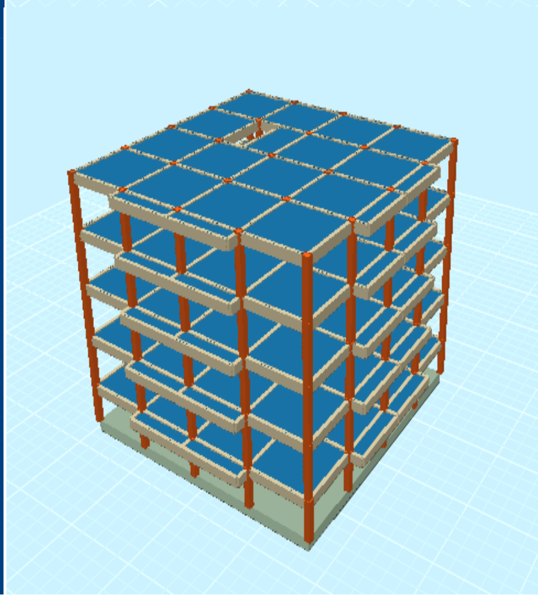
For the strengthening cost of RC buildings several parameters will be considered. The parameters that affect the cost present the input and the strengthening cost will present the output. The commercial program Sta4cad is used for modeling and analyzing the buildings which are designed according to 1975, 1997 and 2007 Turkish Earthquake Code. Those building will be analyzed according to the last code which is 2018 Turkish Earthquake Code. The detailed information for the cost are discussed in section 6.2 with 377 reinforced concrete buildings with 4 and 5 stories that are chosen to present the existing reinforced concrete buildings. For the total cost 8 of those parameters as discussed in the abstract will be considered. Table 6.2 indicates the input parameters and their variation intervals of those 377 and 84 buildings which are selected for this study. For the strengthening methods as it explained in chapter 3, there are many methods. In this study addition of shear wall and section enlargement method have been used for the structures.

Table 4: Parameters considered in the study

Parameter	1	2	3	4
Number of Story	4	5		
Concrete Class	16	20	25	
Steel Class	220	420		
Area (m2)	576(min)	2016(max)		
Shear Wall Ratio	0 (min)	0.01 (max)		
Column Ratio	0.01(min)	0.03(max)		
Earthquake Code	1975	1997	2007	
Weak Column-Strong Beam	Exist	None		
Soil Type (Z)	Z1	Z2	Z3	
Earthquake Zone (EZ)	0.4	0.3	0.2	0.1
Stirrup Spacing	Ok	Not Ok		
Torsional Irregularity	Exist	None		
Interstorey Stiffness Irregularity (Soft Storey)	Exist	None		

5.3 Plans for Buildings



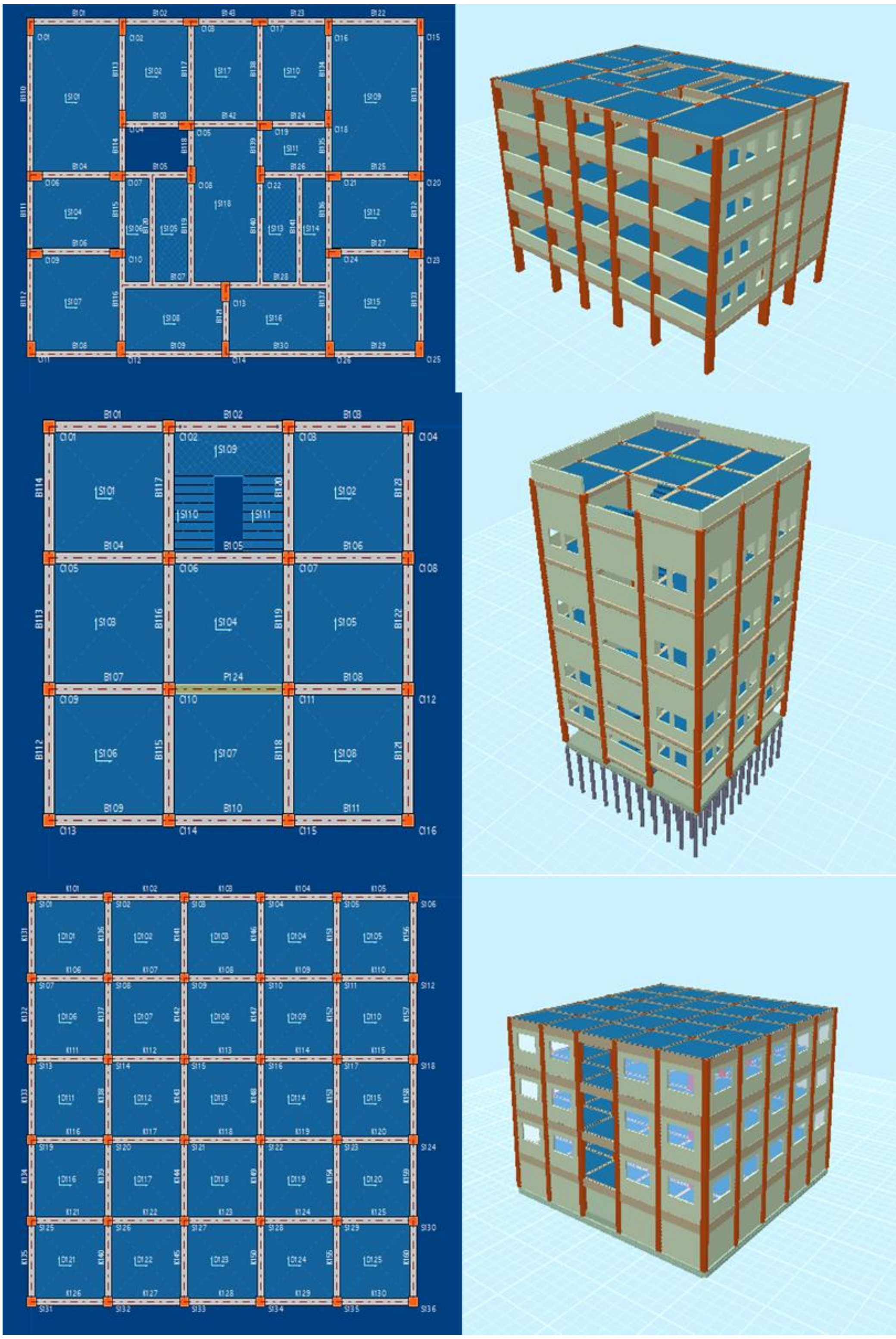


Figure 17: Different Plans of building models used in this study

5.4 Definition and Importance of the Parameters in the Study

1) Number of Storey

Number of storey is important in the cost calculation and also increases the earthquake force on the structure. In this study, the number of storey for the reinforced concrete buildings will be 4 and 5 storey.

2) Concrete Class

Concrete quality is important because it guarantees the productivity of the structures. To prevent potential failure, it also helps to achieve the best strength for any structure. The concrete class also receives their strength through concrete and its stability. In this study concrete with compression strength of 16 MPa, 20 MPa and 25 MPa will be used to represent concrete class of existing buildings.

3) Steel Class

In this study S220 and S420 which means yield strength of 220 MPa and 420 MPa will be used for transverse and longitudinal reinforcement in existing buildings.

4) Area of the building

To calculate the strengthening cost of a building, it's very important to know the area and the specific parameters of the building. The area calculation will also be considered in column, shear wall and beams ratio. The area of the structures used in the study will be as 576 meter square minimum and 2016 meter square maximum.

5) Shear wall ratio

The shear wall ratio in the structures increases the stiffness and the strength. Moreover it reduces the lateral away. The shear wall ratio for each plan will be calculated for x and y direction separately. The small value will be considered. The equation is the total area of the direction divided by the area of the shear wall in that direction. Some of the buildings will not have shear wall and in the strengthening point shear walls will be added according to the rules to make the building stronger.

6) Column Ratio

Column ratio for the structures will be calculated by dividing the total cross-sectional area of all the columns divided by the normal floor area.

7) Earthquake Code

1975, 1997 and 2007 Turkish earthquake codes will be used in the design. After that this codes will be checked according to the last code which is 2018 Turkish Earthquake code. The details and specific information for each code is given in chapter 4.

8) Weak Column-Strong Beam

Columns that are weaker than beams are unable to avoid the development of plastic hinges at column ends. This type of plastic hinge mechanism causes high inelastic deformations at the story stage, resulting in frame system instability, which can lead to failure.

In this study Exist and Non Exist representing existing or non-existing Weak Column- Strong Beam respectively. Figure 18 shows an example of how Weak Column-Strong Beam condition occurs.

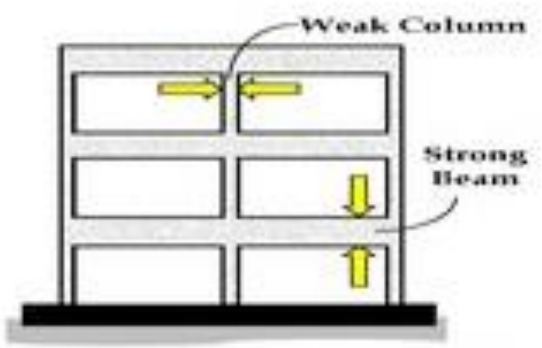


Figure 18: Weak Column-Strong Beam Condition

9) Soil Type (Class)

There are 6 different soil types used in 2018 Turkish Earthquake Code. For this study only 3 of them will be considered which the most used ones are. ZB, ZC and ZD classes will be used. ZB is few decomposed, medium strong rock. ZC is very hard sand, gravel and hard clay layers. ZD is medium tight sand gravel and hard clay. Since the old codes classes are different in terms of symbols, the research has been made and it found the responses for each class in terms of allowable pressure for each class.

10) Earthquake Zone

For the seismic zone the map in figure 6.1 will be considered. 4 different points with 4 different zones in İstanbul (Turkey) will be considered accordingly. Z1, Z2, Z3 and Z4 will be used. Where Z1 is the first earthquake zone and it is the most dangerous place for an earthquake to happen. The 2, 3 and 4 zones are classified accordingly as shown in figure 5.2.

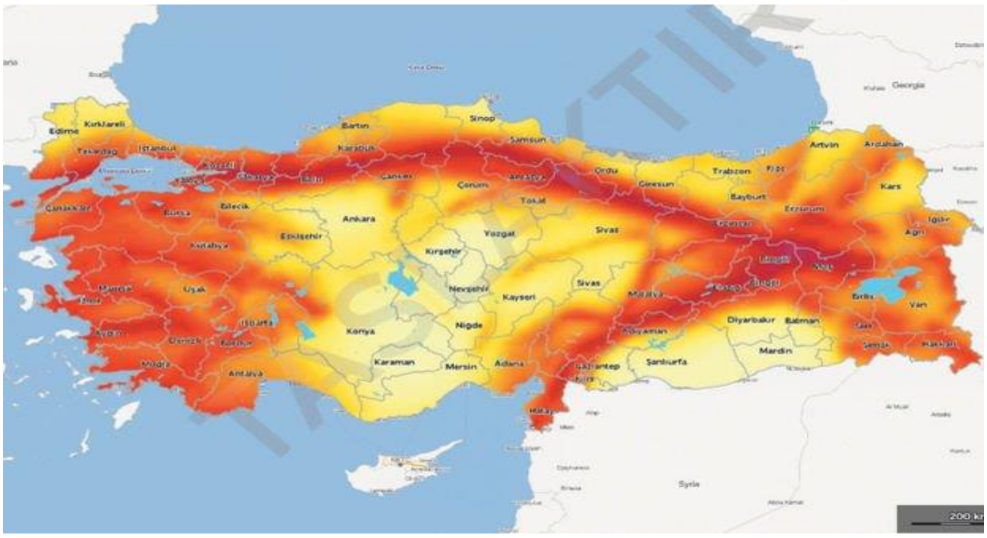


Figure 19: Seismic hazard zonation map of Turkey 2018 [34]

Earthquake Zone: The ground acceleration is higher than 0.4g

Earthquake Zone: The ground acceleration change between 0.3g and 0.4g

Earthquake Zone: The ground acceleration change between 0.2g and 0.3g

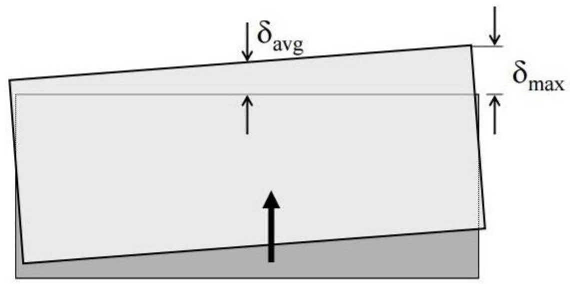
Earthquake Zone: The ground acceleration change between 0.1g and 0.2g.

11) Stirrup Spacing

Reinforcement with a diameter smaller than 8 mm will not be used. Stirrup spacing should not be taken less than 5 cm. In the study if the stirrup spacing is according to the code, it is presented as OK and if it is not satisfying the code requirements, it is presented as Not Ok.

12) Torsional Irregularity

The asymmetrical distribution of rigidity causes torsional irregularity in buildings. Torsional irregularity occurs if d max over δ average is greater than 1.2. Where δ max is the maximum story drift at that story of the structure and δ average is the average story drift at that story of the structure.



$$\delta_{max} < 1.2\delta_{avg} \quad \text{No irregularity}$$

$$1.2\delta_{avg} \leq \delta_{max} \leq 1.4\delta_{avg} \quad \text{Irregularity}$$

$$\delta_{max} > 1.4\delta_{avg} \quad \text{Extreme irregularity}$$

Figure 20: Torsional irregularities in structure

13) Soft Storey

Soft story configuration in structures refers to a type of structures in which one story of a building is more flexible and less stiff than the others. This will happen where stiffness irregularity factor nki is greater than 2. Where nki: Stiffness irregularity factor at that storey of the building. In most of the structures the ground floor of the buildings is designed to be greater than the other floors of those buildings. The reason is that the ground floor is used to be workplaces for shops. In this cases ground floor will cause soft storey and higher storey drift so that the upper floors will move such as diaphragm. As such, it happens when one story has fewer walls and columns than the one above it.

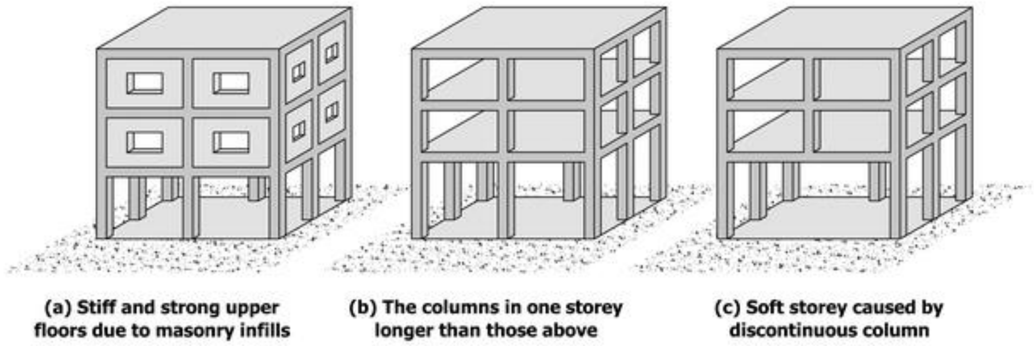


Figure 21: Buildings with soft storey due to large openings in ground floor

5.5 Method of Analysis

In this study linear performance analysis and nonlinear performance analysis have been used. A linear static analysis is an analysis where a linear relation holds between applied forces and displacements. A nonlinear analysis is an analysis where a nonlinear relation holds between applied forces and displacements.

5.5.1 Linear Analysis

Linear static analysis is dependent on strength analysis when the elastic potential of structural elements exceeds the demands of loading situations. Response spectra are used as a common seismic study for design purposes. It has the potential to speed up time by demonstrating only the full answer without having to justify it. The adequacy of each variable is shown by strength-based demand-capacity ratios. Since only the elastic stiffness properties are used for the model, this method is the simplest and least time consuming method.

However the linear static analysis has some limitations. These are: If the ratio of a story's horizontal dimension to the same dimension a neighboring storey exceeds 1.4. If the buildings torsional stiffness is very irregular in every storey, it will not give the result. This occurs if the diaphragm over the storey is rigid. Appears if the structure is very rigid and has an irregular vertical mass.

5.5.2 Definition of Nonlinear Analysis Method

The aim of non-linear analysis methods is to determine the structural strength and retrofitting analysis of existing buildings under the influence of seismic loads. The member's and the building's structural efficiency levels are assessed.

The nonlinear analysis methods are: Incremental Equivalence Seismic Load Method, Increment Mode Combination Method, measurement within the Scope of Time Definition Method.

The incremental and increment mode combination method can be used for the pushover analysis which is needed for the performance and strengthening measurements.

5.5.3 Pushover Analysis Method

Pushover analysis is a static method that estimates seismic structural deformations using a simplified nonlinear technique. During earthquakes, structures re-design themselves. The dynamic forces on a building are transferred to other components as individual components of a system yield or fail.

Pushover analysis is a popular method for determining the seismic ability of existing structures, and it is mentioned in several recent guidelines for seismic retrofit design. It can also help with performance-based design of new buildings that rely on ductility or redundancy to withstand earthquake forces.

Before using the pushover analysis, a nonlinear static analysis must be performed, taking into account the vertical loads that are in compliance with the masses. The analysis' findings must be used as the pushover analysis' primary conditions.

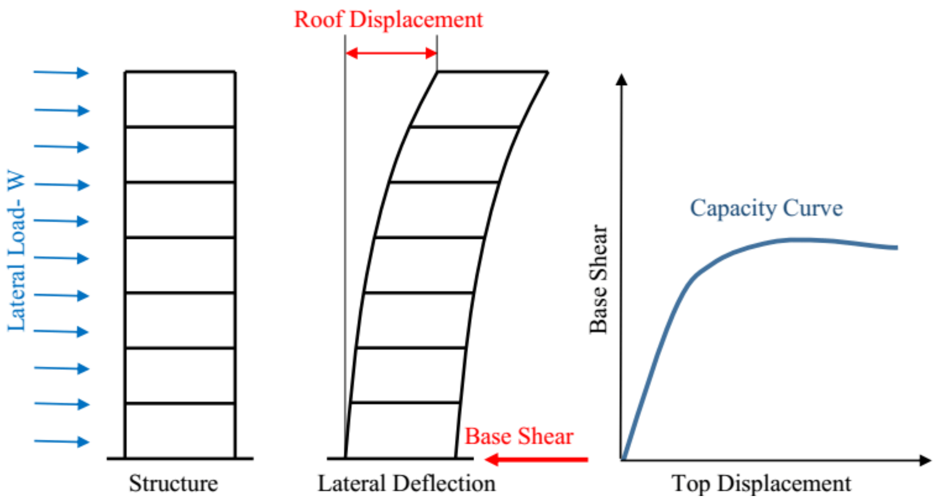


Figure 22: Pushover analysis method

5.6 Performance Level of Structures

Performance-based design aids in explaining the inelastic behavior of a building's structural portion. This method allows for a more reliable estimation of a building's actual behavior during a given ground motion. The performance level of a building is directly related to the damage level likely to appear in that building under the influence of earthquake.

Building seismic safety is determined by the amount of damage that may occur in the structure as a result of the applied seismic load. Four building performance level with their details will be presented.

5.6.1 Continuous Usage Performance Level

This level of performance refers to the situation in which structural damage does not occur in the building bearing system elements or the damage remains negligible.

The buildings can still be used since very limited structural damage has been occurred.

The structure has been damaged by light. There is no permanent drift. The structure retains a significant amount of its initial strength and stiffness. There is slight hairline cracking in the concrete frame, minimal yielding in a few locations, and no crashing.

5.6.2 Limited Damage Performance Level

Overall, the structure sustains moderate damage. The building will face some permanent drift. Concrete frame beams are severely damaged, ductile columns suffer from shear cracking and cover spall off, and conductive columns suffer from mild cracking.

5.6.3 Controlled Damage Performance Level

This level of performance building carrier system not too heavy in its elements and mostly controlled damage that can be repaired corresponds to the level.

5.6.4 Collapse Prevention Performance Level

This degree of building efficiency is primarily concerned with the vertical load carrying system and the structure's ability to remain stable only when subjected to vertical loads. The structure is subjected to significant permanent drifts. The structure is in danger of collapsing.

5.6.5 Collapse Performance Level

When the building is not satisfying the regulations of collapse prevention level, than it is accepted to be collapse level structure. It is no longer available to use the building and the building will not be permitted.

Chapter 6

CASE STUDIES

6.1 Introduction

In this chapter, different types of reinforced concrete buildings will be considered with their input parameters. The buildings will be designed according to 1975, 1997 and 2007 Turkish Earthquake Code and those buildings will be checked according to TEC 2018. Since old buildings usually do not satisfy the 2018 Turkish Earthquake Code, strengthening will be done. After strengthening, the performance of the building will be improved and the structure will become safer than before. Most of the buildings have 4 to 5 floors. In the case studies buildings with 4 and 5 floors will be considered. After the strengthening done and the buildings start to satisfy the new code, cost of strengthening will be considered for every building. Finally an artificial neural network and multi regression analysis system will be used in order to find the efficiency with strengthening of building with the lowest price. The input parameters of the strengthening cost will be sorted accordingly.

6.2 Strengthening Cost of Buildings

Strengthening of the buildings will be done as discussed in the details section 6.5. When all the buildings will be designed according to the old coeds, they will be strengthening according to the new code. The cost of strengthening will be the output. To find the total cost or strengthening cost the unit price for concrete and steel should be determined. Since the study will take place in İstanbul, the unit prices for İstanbul have been determined. In figure 6.1 it shows the unit prices of İstanbul. 4

different earthquake zones at 4 different places in İstanbul have been chosen and their point of location is shown in table 6.2.

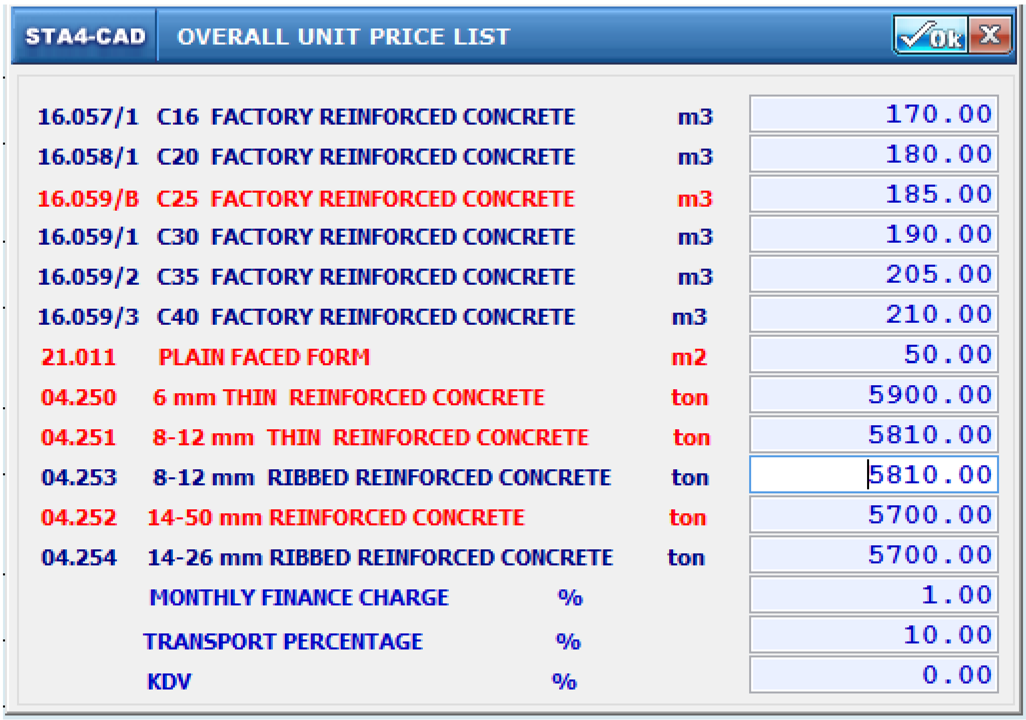


Figure 23: Unit price in Istanbul (TL) [48]

Table 5: Coordinates of four different locations used for earthquake zone [48]

Point	Coordinates
1-Avcilar	40.94925 / 28.63551
2-Çatalca	41.17664 / 28.35657
3-Sultangazi	41.14327 / 28.82973
4-Çerkezköy	41.28706 / 27.99832

6.3 Strengthening Cost for Each Structure

In the study, 377 different projects have been designed and analyzed. The projects have been designed according to 1975, 1997 and 2007. After that all of these projects have been checked according to the last code 2018 Turkish Earthquake Code. Table 5.3 shows the strengthening cost for each structure with their input parameters.

Table 6: The strengthening cost for each structure with their input parameters

No	No of Story (N)	Concrete Class (C)	Steel Class (S)	Area (A)	Shear Wall Ratio (SWR)	Column Ratio (CR)	Earthquake Code (EQ)	Stirrup Spacing	Soil Type (ST)	Earthquake Zone (EZ)	Weak Column-strong beam	Torsional Irregularity	Soft Storey	Strengthening Cost(TL)
1	5	16	220	2000	0	0.015	1975	0	2	3	0	0	0	79,891
2	5	16	220	2000	0	0.015	1997	0	2	3	0	0	0	79,891
3	5	16	220	2000	0	0.015	2007	0	2	3	0	0	0	67,026
4	5	16	220	2000	0	0.015	1975	1	2	1	1	0	0	144,472
5	5	16	220	2000	0	0.015	1997	1	2	1	1	0	0	137,468
6	5	16	220	2000	0	0.015	2007	1	2	1	1	0	0	125,899
7	5	16	220	2000	0	0.015	1975	1	2	3	0	0	0	93,702
8	5	16	220	2000	0	0.015	1997	1	2	3	0	0	0	88,621
9	5	16	220	2000	0	0.015	2007	1	2	3	0	0	0	82,144
10	5	20	220	2000	0	0.015	1975	0	2	3	0	0	0	75,505
11	5	20	220	2000	0	0.015	1997	0	2	3	0	0	0	75,505
12	5	20	220	2000	0	0.015	2007	0	2	3	0	0	0	69,982
13	5	20	220	2000	0	0.015	1975	1	2	2	1	0	0	139,341
14	5	20	220	2000	0	0.015	1997	1	2	2	1	0	0	133,743
15	5	20	220	2000	0	0.015	2007	1	2	2	1	0	0	118,552
16	5	20	220	2000	0	0.015	1975	1	2	3	0	0	0	81,808
17	5	20	220	2000	0	0.015	1997	1	2	3	0	0	0	74,151
18	5	20	220	2000	0	0.015	2007	1	2	3	0	0	0	72,063
19	4	16	220	1600	0	0.015	1975	0	1	3	0	0	0	66,574
20	4	16	220	1600	0	0.015	1997	0	1	3	0	0	0	66,574
21	4	16	220	1600	0	0.015	2007	0	1	3	0	0	0	58,486
22	4	16	220	1600	0	0.015	1975	1	1	3	0	0	0	77,357
23	4	16	220	1600	0	0.015	1997	1	1	3	0	0	0	69,994
24	4	16	220	1600	0	0.015	2007	1	1	3	0	0	0	66,102
25	4	16	220	1600	0	0.015	1975	0	1	3	0	0	1	82,369
26	4	16	220	1600	0	0.015	1997	0	1	3	0	0	1	80,741
27	4	16	220	1600	0	0.015	2007	0	1	3	0	0	1	73,187
28	4	20	220	1600	0	0.015	1975	0	1	3	0	0	0	61,173
29	4	20	220	1600	0	0.015	1997	0	1	3	0	0	0	60,446
30	4	20	220	1600	0	0.015	2007	0	1	3	0	0	0	58,301
31	4	20	220	1600	0	0.015	1975	0	1	3	1	0	0	99,364
32	4	20	220	1600	0	0.015	1997	0	1	3	1	0	0	99,364

33	4	20	220	1600	0	0.015	2007	0	1	3	1	0	0	78,202
34	4	20	220	1600	0	0.015	1975	1	1	3	0	0	0	68,427
35	4	20	220	1600	0	0.015	1997	1	1	3	0	0	0	61,114
36	4	20	220	1600	0	0.015	2007	1	1	3	0	0	0	58,489
37	4	16	220	1600	0	0.015	1975	0	2	2	0	0	0	87,348
38	4	16	220	1600	0	0.015	1997	0	2	2	0	0	0	81,202
39	4	16	220	1600	0	0.015	2007	0	2	2	0	0	0	73,207
40	4	16	220	1600	0	0.015	1975	1	2	2	1	0	0	117,268
41	4	16	220	1600	0	0.01	1997	1	2	2	1	0	0	111,154
42	4	16	220	1600	0	0.01	2007	1	2	2	1	0	0	111,154
43	4	16	220	1600	0	0.01	1975	0	2	2	0	0	1	88,300
44	4	16	220	1600	0	0.01	1997	0	2	2	0	0	1	84,500
45	4	16	220	1600	0	0.01	2007	0	2	2	0	0	1	79,478
46	4	20	220	1600	0	0.01	1975	0	2	2	0	0	0	73,478
47	4	20	220	1600	0	0.01	1997	0	2	2	0	0	0	70,376
48	4	20	220	1600	0	0.01	2007	0	2	2	0	0	0	64,472
49	4	20	220	1600	0	0.01	1975	0	2	2	0	1	0	84,200
50	4	20	220	1600	0	0.01	1997	0	2	2	0	1	0	84,200
51	4	20	220	1600	0	0.01	2007	0	2	2	0	1	0	67,649
52	4	20	220	1600	0	0.01	1975	1	2	2	1	0	0	108,347
53	4	20	220	1600	0	0.01	1997	1	2	2	1	0	0	105,004
54	4	20	220	1600	0	0.01	2007	1	2	2	1	0	0	92,836
55	4	20	220	1600	0	0.01	1975	0	2	1	0	0	0	83,478
56	4	20	220	1600	0	0.01	1997	0	2	1	0	0	0	80,376
57	4	20	220	1600	0	0.01	2007	0	2	1	0	0	0	73,472
58	4	20	220	1600	0	0.01	1975	1	2	1	0	0	1	86,348
59	4	20	220	1600	0	0.01	1997	1	2	1	0	0	1	86,348
60	4	20	220	1600	0	0.01	2007	1	2	1	0	0	1	76,823
61	4	20	220	1600	0	0.01	1975	1	2	1	1	1	0	160,847
62	4	20	220	1600	0	0.01	1997	1	2	1	1	1	0	160,847
63	4	20	220	1600	0	0.01	2007	1	2	1	1	1	0	128,579
64	4	16	220	1600	0	0.015	1975	1	2	1	0	1	0	99,736
65	4	16	220	1600	0	0.015	1997	1	2	1	0	1	0	89,736
66	4	16	220	1600	0	0.015	2007	1	2	1	0	1	0	85,008
67	4	16	220	1600	0	0.015	1975	0	2	1	0	0	0	99,274
68	4	16	220	1600	0	0.01	1997	0	2	1	0	0	0	88,624
69	4	16	220	1600	0	0.01	2007	0	2	1	0	0	0	81,725
70	4	16	220	1600	0	0.01	1975	0	2	1	0	0	0	101,926
71	4	16	220	1600	0	0.01	1997	1	2	1	1	0	0	95,378
72	4	16	220	1600	0	0.01	2007	1	2	1	1	0	0	86,193
73	5	16	220	1245	0	0.02	1975	0	2	3	0	0	0	56,435
74	5	16	220	1245	0	0.02	1997	0	2	3	0	0	0	53,317

75	5	16	220	1245	0	0.02	2007	0	2	3	0	0	0	42,414
76	5	16	220	1245	0	0.02	1975	1	2	2	1	0	1	157,333
77	5	16	220	1245	0	0.02	1997	1	2	2	1	0	1	157,333
78	5	16	220	1245	0	0.02	2007	1	2	2	1	0	1	141,616
79	5	16	220	1245	0	0.02	1975	1	2	3	0	1	0	91,801
80	5	16	220	1245	0	0.02	1997	1	2	3	0	1	0	75,738
81	5	16	220	1245	0	0.02	2007	1	2	3	0	1	0	75,738
82	5	20	220	1245	0	0.02	1975	0	2	3	0	0	0	47,745
83	5	20	220	1245	0	0.02	1997	0	2	3	0	0	0	38,968
84	5	20	220	1245	0	0.02	2007	0	2	3	0	0	0	36,699
85	5	20	220	1245	0	0.02	1975	1	2	3	0	0	0	56,742
86	5	20	220	1245	0	0.02	1997	1	2	3	0	0	0	56,742
87	5	20	220	1245	0	0.02	2007	1	2	3	0	0	0	56,742
88	5	20	220	1245	0	0.02	1975	0	2	3	1	0	0	78,389
89	5	20	220	1245	0	0.02	1997	0	2	3	1	0	0	78,389
90	5	20	220	1245	0	0.02	2007	0	2	3	1	0	0	72,205
91	4	16	220	996	0	0.02	1975	0	1	3	0	0	0	48,485
92	4	16	220	996	0	0.02	1997	0	1	4	0	0	0	46,928
93	4	16	220	996	0	0.02	2007	0	1	4	0	0	0	39,537
94	4	16	220	996	1	0.02	1975	0	1	4	0	0	0	47,348
95	4	16	220	996	1	0.02	1997	0	1	4	0	0	0	42,349
96	4	16	220	996	1	0.02	2007	0	1	4	0	0	0	28,930
97	4	16	220	996	0	0.02	1975	0	1	4	1	0	0	76,714
98	4	16	220	996	0	0.02	1997	0	1	4	1	0	0	71,222
99	4	16	220	996	0	0.02	2007	0	1	4	1	0	0	62,288
100	4	20	220	996	0	0.02	1975	0	1	4	0	0	0	38,364
101	4	20	220	996	0	0.02	1997	0	1	4	0	0	0	32,957
102	4	20	220	996	0	0.02	2007	0	1	4	0	0	0	31,645
103	4	20	220	996	1	0.02	1975	0	1	4	0	0	0	39,764
104	4	20	220	996	1	0.02	1997	0	1	4	0	0	0	31,489
105	4	20	220	996	1	0.02	2007	0	1	4	0	0	0	30,075
106	4	20	220	996	0	0.02	1975	0	1	4	1	0	0	75,274
107	4	20	220	996	0	0.02	1997	0	1	4	1	0	0	70,271
108	4	20	220	996	0	0.02	2007	0	1	4	1	0	0	67,755
109	4	16	220	2016	1	0.02	1975	0	2	2	0	0	0	28,973
110	4	16	220	2016	1	0.02	1997	0	2	2	0	0	0	28,847
111	4	16	420	2016	1	0.02	2007	0	2	2	0	0	0	27,103
112	4	16	220	2016	0	0.02	1975	0	2	2	0	0	0	25,734
113	4	16	220	2016	0	0.02	1997	0	2	2	0	0	0	25,983
114	4	16	420	2016	0	0.02	2007	0	2	2	0	0	0	25,726
115	4	16	220	2016	0	0.02	1975	1	2	2	0	0	0	27,159
116	4	16	220	2016	0	0.02	1997	1	2	2	0	0	0	24,724

117	4	16	420	2016	0	0.02	2007	1	2	2	0	0	0	23,997
118	4	20	220	2016	0	0.02	1975	0	2	2	0	1	0	38,779
119	4	20	220	2016	0	0.02	1997	0	2	2	0	1	0	38,779
120	4	20	220	2016	0	0.02	2007	0	2	2	0	1	0	38,779
121	4	20	220	2016	0	0.02	1975	0	2	2	0	0	0	25,780
122	4	20	220	2016	0	0.02	1997	0	2	2	0	0	0	25,780
123	4	20	220	2016	0	0.02	2007	0	2	2	0	0	0	25,780
124	4	20	220	2016	0	0.02	1975	1	2	2	0	0	0	42,634
125	4	20	220	2016	0	0.02	1997	1	2	2	0	0	0	42,634
126	4	20	220	2016	0	0.02	2007	1	2	2	0	0	0	37,409
127	4	20	220	2016	0	0.02	1975	0	2	1	0	0	0	35,928
128	4	20	220	2016	0	0.02	1997	0	2	1	0	0	0	33,250
129	4	20	220	2016	0	0.02	1975	0	2	1	1	0	0	69,455
130	4	20	220	2016	0	0.02	1997	0	2	1	1	0	0	69,455
131	4	20	220	2016	0	0.02	2007	0	2	1	1	0	0	69,455
132	4	20	220	2016	0	0.02	1975	0	2	1	0	1	0	62,622
133	4	20	220	2016	0	0.02	1997	0	2	1	0	1	0	62,622
134	4	20	220	2016	0	0.02	2007	0	2	1	0	1	0	56,285
135	4	16	220	2016	0	0.02	1975	0	2	1	0	0	0	39,328
136	4	16	220	2016	0	0.02	1997	0	2	1	0	0	0	39,328
137	4	16	220	2016	0	0.02	2007	0	2	1	0	0	0	35,827
138	4	16	220	2016	0	0.02	1975	0	2	1	1	0	0	65,666
139	4	16	220	2016	0	0.02	1997	0	2	1	1	0	0	65,666
140	4	16	220	2016	0	0.02	2007	0	2	1	1	0	0	65,666
141	4	16	220	2016	0	0.02	1975	0	2	1	0	1	0	60,089
142	4	16	220	2016	0	0.02	1997	0	2	1	0	1	0	60,089
143	4	16	220	2016	0	0.02	2007	0	2	1	0	1	0	56,736
144	4	16	220	768	1	0.01	1975	0	2	3	0	0	0	46,000
145	4	16	220	768	1	0.01	1997	0	2	3	0	0	0	46,000
146	4	16	220	768	1	0.01	2007	0	2	3	0	0	0	41,160
147	4	16	220	768	0	0.01	1975	0	2	3	0	0	0	47,440
148	4	16	220	768	0	0.01	1997	0	2	3	0	0	0	46,977
149	4	16	220	768	0	0.01	2007	0	2	3	0	0	0	41,683
150	4	16	220	768	0	0.01	1975	1	2	3	0	0	0	50,999
151	4	16	220	768	0	0.01	1997	1	2	3	0	0	0	50,813
152	4	16	220	768	0	0.01	2007	1	2	3	0	0	0	48,387
153	4	20	220	768	0	0.01	1975	0	2	3	0	0	0	41,681
154	4	20	220	768	0	0.01	1997	0	2	3	0	0	0	41,073
155	4	20	220	768	0	0.01	2007	0	2	3	0	0	0	34,861
156	4	20	220	768	1	0.01	1975	0	2	3	0	0	0	40,088
157	4	20	220	768	1	0.01	1997	0	2	3	0	0	0	40,080
158	4	20	220	768	1	0.01	2007	0	2	3	0	0	0	40,080

159	4	20	220	768	0	0.01	1975	1	2	3	0	0	0	40,725
160	4	20	220	768	0	0.01	1997	1	2	3	0	0	0	40,725
161	4	20	220	768	0	0.01	2007	1	2	3	0	0	0	40,725
162	5	16	220	960	0	0.01	1975	0	1	4	0	0	0	61,888
163	5	16	220	960	0	0.01	1997	0	1	4	0	0	0	60,361
164	5	16	220	960	0	0.01	2007	0	1	4	0	0	0	60,361
165	5	16	220	960	0	0.01	1975	0	1	3	0	0	0	57,873
166	5	16	220	960	0	0.01	1997	0	1	3	0	0	0	59,736
167	5	16	220	960	0	0.01	2007	0	1	3	0	0	0	53,128
168	5	16	220	960	0	0.01	1975	0	1	4	1	0	0	87,360
169	5	16	220	960	0	0.01	1997	0	1	4	1	0	0	87,360
170	5	16	220	960	0	0.01	2007	0	1	4	1	0	0	81,100
171	5	20	220	960	0	0.01	1975	0	1	4	0	0	0	52,360
172	5	20	220	960	0	0.01	1997	0	1	4	0	0	0	51,475
173	5	20	220	960	0	0.01	2007	0	1	4	0	0	0	45,836
174	5	20	220	960	0	0.01	1975	1	1	4	0	0	0	55,367
175	5	20	220	960	0	0.01	1997	1	1	4	0	0	0	50,930
176	5	20	220	960	0	0.01	2007	1	1	4	0	0	0	45,238
177	5	20	220	960	0	0.01	1975	1	1	4	0	1	0	88,653
178	5	20	220	960	0	0.01	1997	1	1	4	0	1	0	82,629
179	5	20	220	960	0	0.01	2007	1	1	4	0	1	0	80,889
180	5	16	220	960	0	0.01	1975	0	2	2	0	0	0	73,457
181	5	16	220	960	0	0.01	1997	0	2	2	0	0	0	67,397
182	5	16	220	960	0	0.01	2007	0	2	2	0	0	0	61,306
183	5	16	220	960	0	0.01	1975	0	1	2	0	0	0	71,645
184	5	16	220	960	0	0.01	1997	0	1	2	0	0	0	64,593
185	5	16	220	960	0	0.01	2007	0	1	2	0	0	0	59,930
186	5	16	220	960	0	0.01	1975	0	2	1	0	0	0	68,845
187	5	16	220	960	0	0.01	1997	0	2	1	0	0	0	68,845
188	5	16	220	960	0	0.01	2007	0	2	1	0	0	0	59,675
189	5	20	220	960	0	0.01	1975	1	2	2	0	0	0	57,485
190	5	20	220	960	0	0.01	1997	1	2	2	0	0	0	53,284
191	5	20	220	960	0	0.01	2007	1	2	2	0	0	0	49,324
192	5	20	220	960	0	0.01	1975	0	1	2	0	0	0	58,239
193	5	20	220	960	0	0.01	1997	0	1	2	0	0	0	52,583
194	5	20	220	960	0	0.01	2007	0	1	2	0	0	0	50,385
195	5	20	220	960	0	0.01	1975	0	2	1	0	0	0	65,389
196	5	20	220	960	0	0.01	1997	0	2	1	0	0	0	62,590
197	5	20	220	960	0	0.01	2007	0	2	1	0	0	0	45,092
198	5	16	220	960	0	0.01	1975	0	3	1	0	0	0	89,034
199	5	16	220	960	0	0.01	1997	0	3	1	0	0	0	78,478
200	5	16	220	960	0	0.01	2007	0	3	1	0	0	0	73,039

201	5	16	220	960	0	0.01	1975	0	3	1	1	0	0	107,453
202	5	16	220	960	0	0.01	1997	0	3	1	1	0	0	107,453
203	5	16	220	960	0	0.01	2007	0	3	1	1	0	0	92,658
204	5	16	220	960	0	0.01	1975	1	3	1	0	0	0	81,998
205	5	16	220	960	0	0.01	1997	1	3	1	0	0	0	73,001
206	5	16	220	960	0	0.01	2007	1	3	1	0	0	0	66,836
207	4	16	220	1348	0	0.02	1975	0	2	3	0	0	0	26,711
208	4	16	220	1348	0	0.02	1997	0	2	3	0	0	0	26,711
209	4	16	220	1348	0	0.02	2007	0	2	3	0	0	0	26,711
210	4	16	220	1348	0	0.02	1975	0	1	3	0	0	0	29,486
211	4	16	220	1348	0	0.02	1997	0	1	3	0	0	0	29,486
212	4	16	220	1348	0	0.02	2007	0	1	3	0	0	0	24,074
213	4	16	220	1348	0	0.02	1975	0	2	1	0	0	0	31,150
214	4	16	220	1348	0	0.02	1997	0	2	1	0	0	0	26,711
215	4	16	220	1348	0	0.02	2007	0	2	1	0	0	0	26,711
216	4	20	220	1348	0	0.02	1975	0	2	3	0	0	0	22,626
217	4	20	220	1348	0	0.02	1997	0	2	3	0	0	0	22,626
218	4	20	220	1348	0	0.02	2007	0	2	3	0	0	0	22,626
219	4	20	220	1348	0	0.02	1975	0	1	3	0	0	0	23,789
220	4	20	220	1348	0	0.02	1997	0	1	3	0	0	0	23,789
221	4	20	220	1348	0	0.02	2007	0	1	3	0	0	0	23,789
222	4	20	220	1348	0	0.02	1975	0	2	1	0	0	0	26,338
223	4	20	220	1348	0	0.02	1997	0	2	1	0	0	0	25,155
224	4	20	220	1348	0	0.02	2007	0	2	1	0	0	0	25,155
225	5	16	220	1685	0	0.02	1975	0	1	4	0	0	0	30,839
226	5	16	220	1685	0	0.02	1997	0	1	4	0	0	0	30,839
227	5	16	220	1685	0	0.02	2007	0	1	4	0	0	0	30,839
228	5	16	220	1685	0	0.02	1975	0	1	2	0	0	0	36,858
229	5	16	220	1685	0	0.02	1997	0	1	2	0	0	0	36,858
230	5	16	220	1685	0	0.02	2007	0	1	2	0	0	0	30,093
231	5	16	220	1685	0	0.02	1975	0	1	3	0	0	0	38,938
232	5	16	220	1685	0	0.02	1997	0	1	3	0	0	0	33,389
233	5	16	220	1685	0	0.02	2007	0	1	3	0	0	0	33,389
234	5	20	220	1685	0	0.02	1975	0	1	4	0	0	0	28,283
235	5	20	220	1685	0	0.02	1997	0	1	4	0	0	0	28,283
236	5	20	220	1685	0	0.02	2007	0	1	4	0	0	0	28,283
237	5	20	220	1685	0	0.02	1975	0	1	3	0	0	0	25,252
238	5	20	220	1685	0	0.02	1997	0	1	3	0	0	0	25,252
239	5	20	220	1685	0	0.02	2007	0	1	3	0	0	0	22,945
240	5	20	220	1685	0	0.02	1975	0	1	2	0	0	0	30,736
241	5	20	220	1685	0	0.02	1997	0	1	2	0	0	0	28,034
242	5	20	220	1685	0	0.02	2007	0	1	2	0	0	0	25,936

243	5	16	220	1685	0	0.02	1975	0	2	2	0	0	0	39,458
244	5	16	220	1685	0	0.02	1997	0	2	2	0	0	0	37,047
245	5	16	220	1685	0	0.02	2007	0	2	2	0	0	0	37,047
246	5	16	220	1685	0	0.02	1975	1	2	2	0	0	0	45,800
247	5	16	220	1685	0	0.02	1997	1	2	2	0	0	0	45,800
248	5	16	220	1685	0	0.02	2007	1	2	2	0	0	0	45,800
249	5	16	220	1685	0	0.02	1975	0	2	2	1	0	0	57,717
250	5	16	220	1685	0	0.02	1997	0	2	2	1	0	0	57,717
251	5	16	220	1685	0	0.02	2007	0	2	2	1	0	0	57,717
252	5	20	220	1685	0	0.02	1975	0	2	2	0	0	0	39,677
253	5	20	220	1685	0	0.02	1997	0	2	2	0	0	0	39,677
254	5	20	220	1685	0	0.02	2007	0	2	2	0	0	0	38,458
255	5	20	220	1685	0	0.02	1975	1	2	2	0	0	0	39,677
256	5	20	220	1685	0	0.02	1997	1	2	2	0	0	0	39,677
257	5	20	220	1685	0	0.02	2007	1	2	2	0	0	0	38,458
258	5	20	220	1685	0	0.02	1975	0	2	2	1	0	0	63,192
259	5	20	220	1685	0	0.02	1997	0	2	2	1	0	0	63,192
260	5	20	220	1685	0	0.02	2007	0	2	2	1	0	0	60,738
261	5	20	220	1685	0	0.02	1975	0	2	1	0	1	0	52,300
262	5	20	220	1685	0	0.02	1997	0	2	1	0	1	0	52,300
263	5	20	220	1685	0	0.02	2007	0	2	1	0	1	0	52,300
264	5	20	220	1685	0	0.02	1975	0	2	1	0	0	1	47,847
265	5	20	220	1685	0	0.02	1997	0	2	1	0	0	1	47,847
266	5	20	220	1685	0	0.02	2007	0	2	1	0	0	1	47,847
267	5	20	220	1685	0	0.02	1975	1	2	1	0	1	0	60,466
268	5	20	220	1685	0	0.02	1997	1	2	1	0	1	0	60,466
269	5	20	220	1685	0	0.02	2007	1	2	1	0	1	0	59,331
270	4	16	220	952	0	0.01	1975	1	2	3	0	0	0	63,021
271	4	16	220	952	0	0.01	1997	1	2	3	0	0	0	63,021
272	4	25	420	952	0	0.01	2007	0	2	3	0	0	0	52,260
273	4	16	220	952	0	0.01	1975	0	2	1	0	0	0	84,578
274	4	16	220	952	0	0.01	1997	0	2	1	0	0	0	84,578
275	4	25	420	952	0	0.01	2007	0	2	1	0	0	0	59,122
276	4	16	220	952	0	0.01	1975	0	2	2	0	0	0	71,791
277	4	16	220	952	0	0.01	1997	0	2	2	0	0	0	71,791
278	4	25	420	952	0	0.01	2007	0	2	2	0	0	0	52,664
279	5	16	220	1190	0	0.01	1975	0	2	4	0	0	0	65,389
280	5	16	220	1190	0	0.01	1997	0	2	4	0	0	0	65,389
281	5	25	420	1190	0	0.01	2007	0	2	4	0	0	0	42,904
282	5	16	220	1190	0	0.01	1975	0	2	3	0	0	0	82,222
283	5	16	220	1190	0	0.01	1997	0	2	3	0	0	0	82,222

284	5	25	420	1190	0	0.01	2007	0	2	3	0	0	0	65,324
285	5	16	220	1190	0	0.01	1975	0	2	1	0	0	0	111,119
286	5	16	220	1190	0	0.01	1997	0	2	1	0	0	0	104,017
287	5	25	420	1190	0	0.01	2007	0	2	1	0	0	0	86,826
288	5	16	220	1190	0	0.01	1975	0	2	2	0	0	0	101,227
289	5	16	220	1190	0	0.01	1997	0	2	2	0	0	0	101,227
290	5	25	420	1190	0	0.01	2007	0	2	2	0	0	0	71,912
291	5	16	220	1190	0	0.01	1975	1	2	4	0	0	0	73,379
292	5	16	220	1190	0	0.01	1997	1	2	4	0	0	0	73,379
293	5	25	420	1190	0	0.01	2007	1	2	4	0	0	0	60,298
294	5	16	220	1190	0	0.01	1975	0	2	3	1	0	0	91,198
295	5	16	220	1190	0	0.01	1997	0	2	3	1	0	0	80,827
296	5	25	420	1190	0	0.01	2007	0	2	3	1	0	0	69,190
297	5	16	220	1190	0	0.01	1975	1	2	1	0	1	0	123,887
298	5	16	220	1190	0	0.01	1997	1	2	1	0	1	0	123,887
299	5	25	420	1190	0	0.01	2007	0	2	1	0	1	0	75,004
300	5	16	220	1190	0	0.01	1975	0	2	2	0	0	1	104,108
301	5	16	220	1190	0	0.01	1997	0	2	2	0	0	1	104,108
302	5	25	420	1190	0	0.01	2007	0	2	2	0	0	1	76,983
303	5	16	220	1190	0	0.01	1975	1	2	4	1	0	0	81,219
304	5	16	220	1190	0	0.01	1997	1	2	4	1	0	0	73,379
305	5	25	420	1190	0	0.01	2007	1	2	4	1	0	0	56,928
306	4	16	220	576	1	0.02	1975	0	1	3	0	0	0	40,278
307	4	16	220	576	1	0.02	1997	0	1	3	0	0	0	40,278
308	4	25	420	576	1	0.02	2007	0	1	3	0	0	0	31,942
309	4	16	220	576	1	0.02	1975	1	1	1	0	1	0	91,866
310	4	16	220	576	1	0.02	1997	1	1	1	0	1	0	91,866
311	4	25	420	576	1	0.02	2007	1	1	1	0	1	0	91,866
312	4	16	220	576	1	0.02	1975	0	1	2	1	0	0	108,317
313	4	16	220	576	1	0.02	1997	0	1	2	1	0	0	108,317
314	4	25	420	576	1	0.02	2007	0	1	2	1	0	0	108,317
315	5	16	220	720	1	0.02	1975	0	1	4	0	0	0	33,144
316	5	16	220	720	1	0.02	1997	0	1	4	0	0	0	33,144
317	5	25	420	720	1	0.02	2007	0	1	4	0	0	0	20,771
318	5	16	220	720	1	0.02	1975	0	1	3	0	0	0	50,347
319	5	16	220	720	1	0.02	1997	0	1	3	0	0	0	50,347
320	5	25	420	720	1	0.02	2007	0	1	3	0	0	0	39,928
321	5	16	220	720	1	0.02	1975	0	1	1	0	0	0	62,960
322	5	16	220	720	1	0.02	1997	0	1	1	0	0	0	62,960
323	5	25	420	720	1	0.02	2007	0	1	1	0	0	0	47,105
324	5	16	220	720	1	0.02	1975	0	1	2	0	0	0	65,659
325	5	16	220	720	1	0.02	1997	0	1	2	0	0	0	63,860

326	5	25	420	720	1	0.02	2007	0	1	2	0	0	0	51,111
327	5	16	220	720	1	0.02	1975	1	1	4	0	0	0	37,250
328	5	16	220	720	1	0.02	1997	1	1	4	0	0	0	37,250
329	5	25	420	720	1	0.02	2007	1	1	4	0	0	0	20,771
330	5	16	220	720	1	0.02	1975	0	1	3	1	0	0	85,772
331	5	16	220	720	1	0.02	1997	0	1	3	1	0	0	85,772
332	5	25	420	720	1	0.02	2007	0	1	3	1	0	0	85,772
333	5	16	220	720	1	0.02	1975	0	1	1	0	1	0	74,408
334	5	16	220	720	1	0.02	1997	0	1	1	0	1	0	74,408
335	5	25	420	720	1	0.02	2007	0	1	1	0	1	0	67,379
336	5	16	220	720	1	0.02	1975	0	1	2	0	0	1	68,293
337	5	16	220	720	1	0.02	1997	0	1	2	0	0	1	66,827
338	5	25	420	720	1	0.02	2007	0	1	2	0	0	1	54,103
339	5	16	220	720	1	0.02	1975	1	1	4	1	0	0	85,772
340	5	16	220	720	1	0.02	1997	1	1	4	1	0	0	85,772
341	5	25	420	720	1	0.02	2007	1	1	4	1	0	0	70,321
342	4	16	220	1176	1	0.02	1975	1	1	3	0	0	0	59,780
343	4	16	220	1176	1	0.02	1997	1	1	3	0	0	0	59,780
344	4	25	420	1176	1	0.02	2007	1	1	3	0	0	0	41,993
345	4	16	220	1176	1	0.02	1975	0	1	1	1	0	0	100,355
346	4	16	220	1176	1	0.02	1997	0	1	1	1	0	0	100,355
347	4	25	420	1176	1	0.02	2007	0	1	1	1	0	0	84,597
348	4	16	220	1176	1	0.02	1975	0	1	2	0	0	0	81,025
349	4	16	220	1176	1	0.02	1997	0	1	2	0	0	0	81,025
350	4	25	420	1176	1	0.02	2007	0	1	2	0	0	0	50,109
351	5	16	220	1470	1	0.02	1975	1	1	4	0	0	0	68,192
352	5	16	220	1470	1	0.02	1997	1	1	4	0	0	0	61,382
353	5	25	420	1470	1	0.02	2007	1	1	4	0	0	0	43,671
354	5	16	220	1470	1	0.02	1975	0	1	3	0	1	0	106,143
355	5	16	220	1470	1	0.02	1997	0	1	3	0	1	0	106,143
356	5	25	420	1470	1	0.02	2007	0	1	3	0	1	0	106,143
357	5	16	220	1470	0	0.02	1975	1	1	1	0	0	1	129,639
358	5	16	220	1470	0	0.02	1997	1	1	1	0	0	1	126,938
359	5	25	420	1470	0	0.02	2007	1	1	1	0	0	1	126,938
360	5	16	220	1470	1	0.02	1975	0	1	2	0	0	0	108,384
361	5	16	220	1470	1	0.02	1997	0	1	2	0	0	0	103,029
362	5	25	420	1470	1	0.02	2007	0	1	2	0	0	0	62,901
363	5	16	220	1470	1	0.02	1975	1	1	4	1	0	0	101,670
364	5	16	220	1470	1	0.02	1997	1	1	4	1	0	0	101,670
365	5	25	420	1470	1	0.02	2007	0	3	4	0	0	0	51,038
366	5	16	220	1470	1	0.02	1975	0	3	3	0	0	0	83,829
367	5	16	220	1470	1	0.02	1997	0	3	3	0	0	0	78,375

368	5	25	420	1470	1	0.02	2007	0	2	3	0	0	0	59,002
369	5	16	220	1470	0	0.02	1975	1	1	1	1	1	0	164,379
370	5	16	220	1470	0	0.02	1997	1	1	1	1	1	0	164,379
371	5	25	420	1470	0	0.02	2007	1	1	1	1	1	0	127,410
372	5	16	220	1470	1	0.02	1975	0	1	2	0	0	1	108,655
373	5	16	220	1470	1	0.02	1997	0	1	2	0	0	1	104,858
374	5	25	420	1470	1	0.02	2007	0	1	2	0	0	1	65,511
375	5	16	220	1470	1	0.02	1975	0	1	4	0	0	0	78,417
376	5	16	220	1470	1	0.02	1997	0	1	4	0	0	0	78,417
377	5	25	420	1470	1	0.02	2007	0	1	4	0	0	0	50,481

6.4 Total Cost for Each Buildings According to 2018 Turkish Earthquake Code

Table 7: Total cost of buildings according to TEC 2018

No	Area	No of Storey	Concrete Class	Steel Class	Shear Wall Ratio	Column Ratio	Total Cost 2018
1	2000	5	25	420	0	0.02	584,381
2	2000	5	25	420	0	0.03	632,932
3	2000	5	25	420	0.01	0.02	596,334
4	2000	5	30	500	0	0.02	592,489
5	2000	5	30	500	0	0.03	641,039
6	2000	5	30	500	0.01	0.02	599,198
7	1600	4	25	420	0	0.02	463,848
8	1600	4	25	420	0	0.03	488,500
9	1600	4	25	420	0.01	0.02	482,919
10	1600	4	30	500	0	0.02	467,248
11	1600	4	30	500	0	0.03	493,350
12	1600	4	30	500	0.01	0.02	486,874
13	1245	5	25	420	0	0.02	454,058
14	1245	5	25	420	0	0.03	488,932
15	1245	5	25	420	0.01	0.02	471,625
16	1245	5	30	500	0	0.02	458,438

17	1245	5	30	500	0	0.03	491,334
18	1245	5	30	500	0.01	002	477,773
19	996	4	25	420	0	0.02	383,511
20	996	4	25	420	0	0.03	402,372
21	996	4	25	420	0.01	0.02	388,329
22	996	4	30	500	0	0.02	386,435
23	996	4	30	500	0	0.03	404,390
24	996	4	30	500	0.01	0.02	395,313
25	768	4	25	500	0	0.02	332,347
26	768	4	25	420	0.01	0.02	334,499
27	768	4	25	420	0	0.02	329,238
28	768	4	30	500	0	0.03	351,961
28	768	4	30	420	0.01	0.02	342,128
30	768	4	30	420	0	0.03	343,230
31	960	5	25	420	0	0.02	401,534
32	960	5	25	500	0	0.03	425,747
33	960	5	25	500	0.01	0.02	414,249
34	960	5	30	420	0.01	0.02	418,222
35	960	5	30	500	0	0.02	416,953
36	960	5	30	500	0.01	0.03	438,494
37	1348	4	25	500	0	0.02	471,311
38	1348	4	25	500	0.01	0.02	484,965
39	1348	4	25	500	0	0.03	488,104
40	1348	4	30	420	0	0.02	482,107
41	1348	4	30	420	0.01	0.02	488,740
42	1348	4	30	420	0	0.03	494,009
43	1685	5	30	420	0	0.02	534,547
44	1685	5	30	500	0	0.03	571,395
45	1685	5	30	500	0.01	0.02	560,531
46	1685	5	25	420	0	0.03	545,618
47	1685	5	25	500	0	0.02	527,476
48	1685	5	25	500	0.01	0.03	555,698
49	952	4	25	420	0	0.02	365,150

50	952	4	25	420	0	0.03	388,587
51	952	4	25	420	0.01	0.02	377,580
52	952	4	30	500	0.01	0.03	404,101
53	952	4	30	500	0	0.03	392,486
54	952	4	30	500	0.01	0.02	389,404
55	1190	5	25	420	0.01	0.02	467,002
56	1190	5	25	420	0	0.02	453,634
57	1190	5	25	500	0	0.03	478,866
58	1190	5	30	420	0.01	0.02	476,500
59	1190	5	30	420	0	0.02	470,455
60	1190	5	30	500	0	0.03	489,149
61	576	4	25	500	0.01	0.02	293,690
62	576	4	25	420	0.01	0.02	284,968
63	576	4	25	420	0.01	0.03	299,674
64	576	4	30	500	0.01	0.03	313,239
65	576	4	30	420	0.01	0.02	298,543
66	576	4	30	420	0.01	0.03	310,583
67	720	5	25	500	0	0.02	344,910
68	720	5	25	420	0	0.02	342,659
69	720	5	25	420	0	0.03	357,591
70	720	5	30	500	0	0.02	351,956
71	720	5	30	420	0	0.02	354,302
72	720	5	30	420	0	0.03	367,105
73	1176	4	25	500	0	0.02	428,664
74	1176	4	25	500	0.01	0.03	450,500
75	1176	4	25	420	0.01	0.02	433,484
76	1176	4	30	500	0.01	0.03	459,932
77	1176	4	30	500	0	0.02	435,683
78	1176	4	30	420	0.01	0.03	452,377
79	1470	5	25	420	0	0.02	504,239
80	1470	5	25	420	0.01	0.03	518,004
81	1470	5	25	500	0	0.02	506,771
82	1470	5	30	420	0	0.02	510,677

83	1470	5	30	420	0.01	0.03	523,459
84	1470	5	30	500	0	0.02	513,019

6.5 Strengthening Cost for each Building According to Gravity Force

Table 8: Strengthening cost of structures according to gravity force

No	No of Story	Concrete Class	Steel Class	Area	Shear Wall Ratio	Column Ratio	Stirrup Spacing	Weak Column Strong Beam	Torsional Irregularity	Soft Storey	Strengthening Cost	Percentage to total cost with gravitational force %	Percentage to total cost with Earthquake Codes %
1	5	16	220	2000	0	0.015	0	0	0	0	79,891	13.68	13.68
2	5	16	220	2000	0	0.015	0	1	0	0	159,923	27.38	24.74
3	5	20	220	2000	0	0.015	0	0	0	0	75,505	12.93	12.93
4	5	20	220	2000	0	0.015	0	1	0	0	159,923	27.38	23.86
5	5	20	220	2000	0	0.015	1	0	0	0	86,244	14.77	14.01
6	4	16	220	1600	0	0.015	0	0	0	0	68,822	14.86	14.38
7	4	16	220	1600	0	0.015	1	1	0	0	116,580	25.18	16.71
8	4	16	220	1600	0	0.015	0	0	0	1	91,003	19.66	17.79
9	4	20	220	1600	0	0.015	0	1	0	0	109,473	23.64	21.46
10	4	20	220	1600	0	0.01	1	0	1	1	155,777	33.65	22.51
11	5	16	220	1245	0	0.02	0	0	0	0	64,201	14.14	12.43
12	5	16	220	1245	0	0.02	1	1	0	1	187,814	41.37	34.65
13	5	16	220	1245	0	0.02	1	0	1	0	117,559	25.89	20.22
14	5	20	220	1245	0	0.02	0	0	0	0	55,329	12.19	10.52
15	5	20	220	1245	0	0.02	0	1	0	0	97,425	21.46	17.27
16	4	16	220	996	0	0.02	0	0	0	1	61,606	16.09	12.66
17	4	16	220	996	0	0.02	1	1	0	0	89,742	23.43	20.03
18	4	16	220	996	1	0.02	1	1	1	0	111,400	29.09	23.06
19	4	20	220	996	0	0.02	0	0	1	0	49,877	13.02	10.13
20	4	20	220	996	0	0.02	1	1	0	0	86,625	22.62	18.13
21	4	16	220	768	0	0.02	0	1	1	0	102,769	30.95	22.79
22	4	16	220	768	1	0.01	0	0	0	0	58,252	17.55	13.86
23	4	16	220	768	0	0.01	1	0	1	0	87,108	26.24	18.07
24	4	20	220	768	0	0.01	0	0	0	0	52,700	15.87	12.55

25	4	20	220	768	0	0.01	1	0	0	1	88,312	26.60	17.27
26	5	16	220	960	0	0.01	0	0	0	0	62,067	15.48	12.43
27	5	16	220	960	0	0.01	0	1	0	0	100,108	24.96	21.79
28	5	20	220	960	0	0.01	1	0	0	0	69,727	17.39	13.81
29	5	20	220	960	0	0.01	1	0	1	0	105,792	26.38	22.11
30	4	16	220	1348	0	0.02	1	1	0	0	119,341	25.34	17.42
31	5	16	220	1685	0	0.02	0	0	0	0	42,619	12.76	9.23
32	5	20	220	1685	0	0.02	0	0	0	0	38,500	11.53	8.47
33	5	16	220	1685	0	0.02	1	0	0	0	59,241	17.74	13.71
34	5	16	220	1685	0	0.02	0	1	0	0	68,778	20.59	17.28
35	5	20	220	1685	0	0.02	0	0	1	0	61,714	18.48	15.66
36	5	20	220	1685	0	0.02	0	0	0	1	56,800	17.01	14.33
37	5	20	220	1685	0	0.02	1	0	1	0	77,054	23.07	18.10
38	4	16	220	952	0	0.01	1	0	0	1	107,495	29.45	17.27
39	4	16	220	952	0	0.01	1	1	1	0	164,578	45.09	30.57
40	5	16	220	1190	0	0.01	0	0	0	0	77,179	16.53	14.00
41	5	16	220	1190	0	0.01	1	0	0	0	86,682	18.56	15.71
42	5	16	220	1190	0	0.01	0	1	0	0	117,623	25.19	19.53
43	5	16	220	1190	0	0.01	1	0	1	0	141,846	30.37	26.53
44	5	16	220	1190	0	0.01	0	0	0	1	107,348	22.99	22.29
45	5	16	220	1190	0	0.01	1	1	0	0	105,455	22.58	17.39
46	4	16	220	576	1	0.02	0	0	0	0	48,278	16.48	13.75
47	4	16	220	576	1	0.02	1	1	1	0	138,500	47.27	31.35
48	4	16	220	576	1	0.02	1	1	0	0	119,111	40.65	36.97
49	5	16	220	720	1	0.02	0	0	0	0	48,280	14.90	10.23
50	5	16	220	720	1	0.02	1	1	0	0	104,933	32.39	29.56
51	5	16	220	720	1	0.02	1	0	1	0	98,408	30.37	22.97
52	5	16	220	720	1	0.02	1	0	0	1	99,771	30.79	21.08
53	5	16	220	720	1	0.02	1	1	1	0	138,226	42.66	26.47
54	4	16	220	1176	1	0.02	1	0	0	0	69,780	16.30	13.97
55	4	16	220	1176	1	0.02	0	1	0	0	117,228	27.39	23.45
56	4	25	420	1176	1	0.02	0	1	0	0	98,721	23.07	19.77
57	5	16	220	1470	1	0.02	1	0	0	0	72,755	14.44	13.53
58	5	16	220	1470	1	0.02	1	0	1	0	128,810	25.56	21.06
59	5	16	220	1470	1	0.02	1	0	0	1	138,639	27.51	25.72
60	5	16	220	1470	1	0.02	1	1	0	0	134,033	26.59	20.17
61	5	16	220	1470	1	0.02	1	1	1	0	192,629	38.22	32.61
Average												**23.70**	**18.92**

6.6 Discussion of Strengthening Between Earthquake Code and Gravity Force

First of all, 377 different models have been analyzed according to earthquake codes. After that 61 of those models have been chosen and analyzed according to gravity load design. Strengthening cost for earthquake design and gravity loaded design has been calculated separately. Then the percentage of the strengthening cost to the total cost of buildings according to TEC 2018 have been found for both earthquake and gravity load design. From the results it have been seen that the average for the strengthening cost with earthquake loaded design divided by total cost of that buildings found as 18.92%. However the average for the gravity loaded design divided by the total cost has been found as 23.70%. This means that the strengthening cost with gravity force is 25% more expensive than the strengthening against earthquakes loaded design.

6.7 Details of the Cases

1) Plan 1

Buildings type with no irregularity and no weak column-strong beam condition.

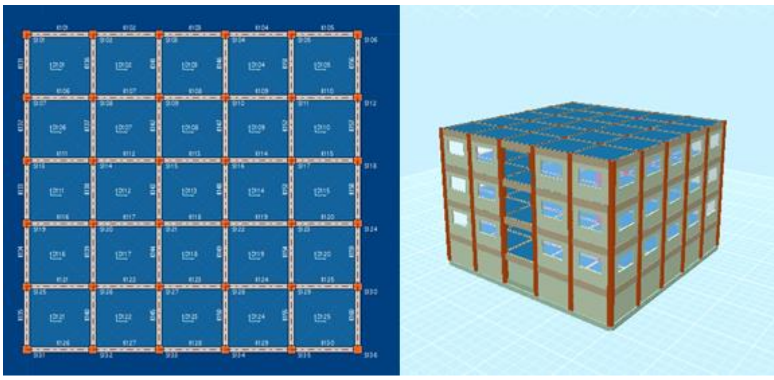


Figure 24: Regular building 1

Table 9: Regular building 1 specifications

Specifications		
No of Storey	5 (15m)	4 (12m)
Column Size	40x40	35x35
	45x45	40x40
Beam Size	25x55	20x50
Slab Thickness	12,15,17	12,15,17

2) Plan 2

Buildings type with no irregularity and no weak column-strong beam condition.

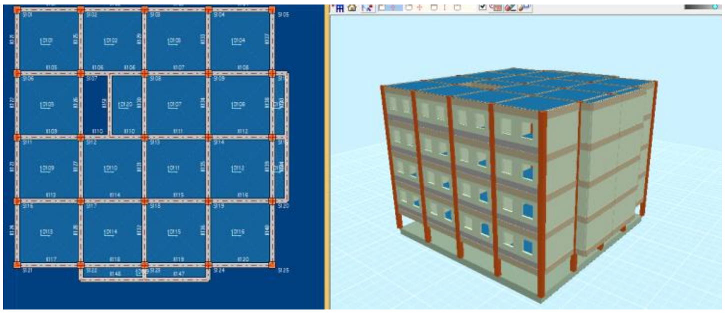


Figure 25: Regular building 2

Table 10: Regular building 2 specifications

Specifications		
No of Storey	5 (15m)	4 (12m)
Column Size	40x40	40x40
	45x45	40x40
Beam Size	25x55	25x55
Slab Thickness	17,15	12,15

3) Plan 3

Buildings type with soft storey condition.

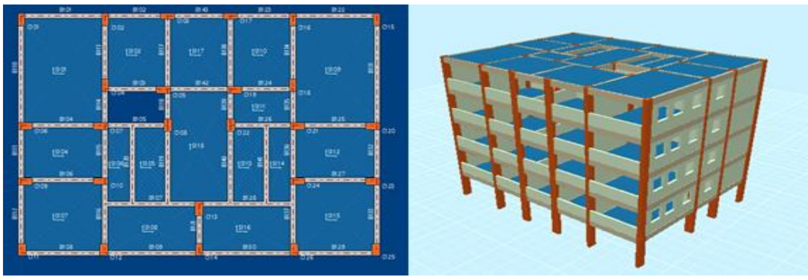


Figure 26: Soft storey building

Table 11: Soft Storey building specifications

Specifications		
No of Storey	5 (15m)	4 (12m)
Column Size	30x60	25x55
	25x60	30x55
Beam Size	20x50	20x45
Slab Thickness	12	12

4) Plan 4

Buildings type with torsional irregularity condition.

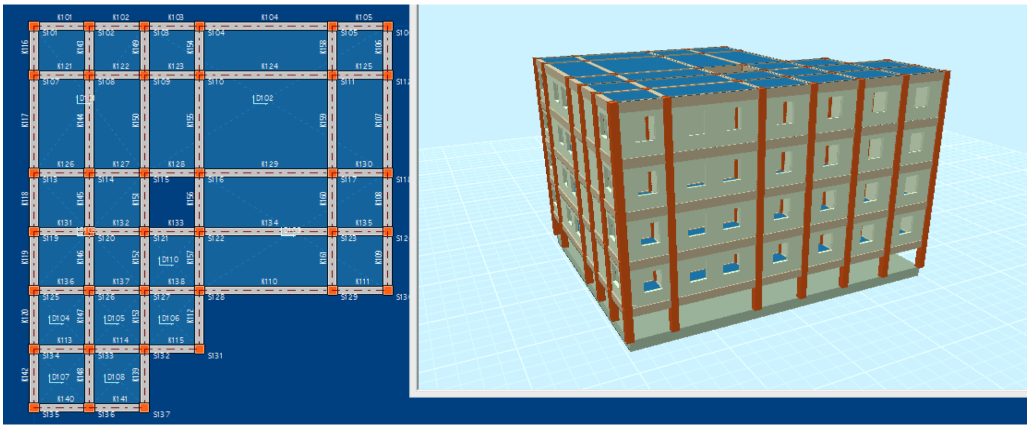


Figure 27: Torsional irregularity

Table 12: Torsional irregularities building specifications

Specifications		
No of Storey	5 (15m)	4 (12m)
Column Size	40x40	35x35
	35x35	40x40
Beam Size	30x55	25x55
Slab Thickness	15,17	15,17

5) Plan 5

Buildings type with weak column-strong beam condition.

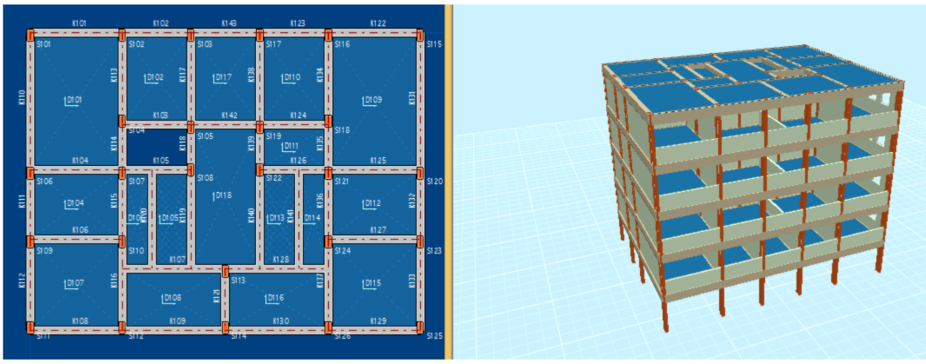


Figure 28: Weak column strong beam

Table 13: Weak Column strong Beam specifications

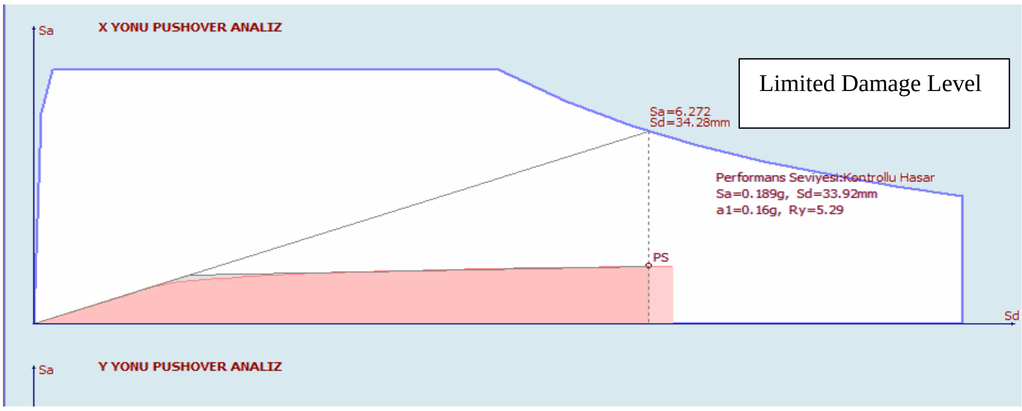
Specifications		
No of Storey	5 (15m)	4 (12m)
Column Size	20x45	20x40
	20x50	25x40
Beam Size	30x60	25x55
Slab Thickness	15	15

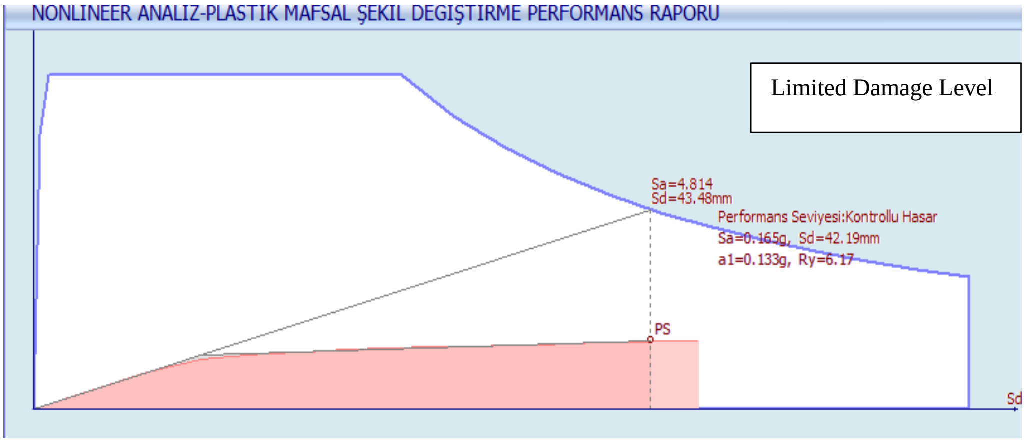
6.8 Contribution of Pushover Curves for Each Plan

The performance level of the structures is increasing in many of the strengthening. For the buildings that designed according to old codes after they analyzed and strengthen according to the new codes their performance level increases. For some of the old buildings the performance is enough. However little strengthening is needed so that the building will satisfy the new condition. For example in the case where the building has no irregularity and only the concrete class is weak, the building only need some strengthening in some of the columns and beams. In this part of the study, pushover curve with performance level for some of the buildings will be represented in a before strengthening and after strengthening style.

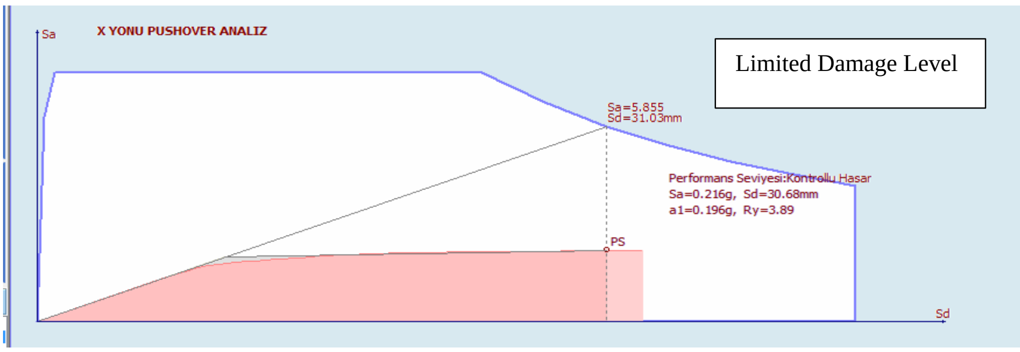
6.8.1 Case 1 Pushover Curve Before and After Strengthening for Regular Building 1

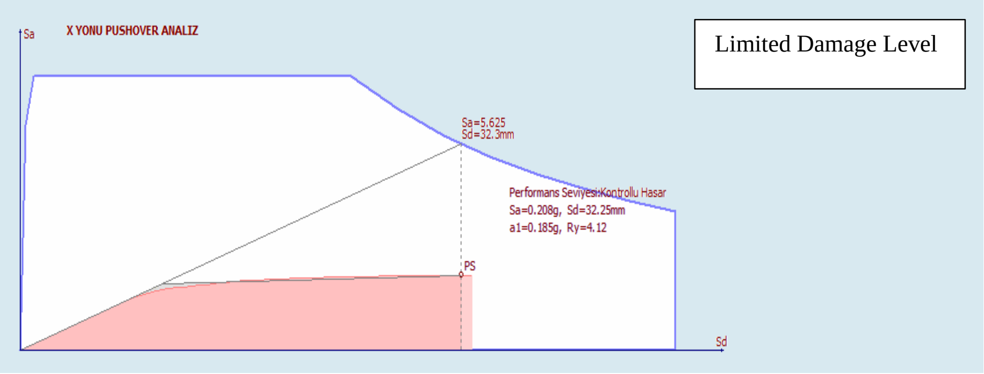
TEC 1975



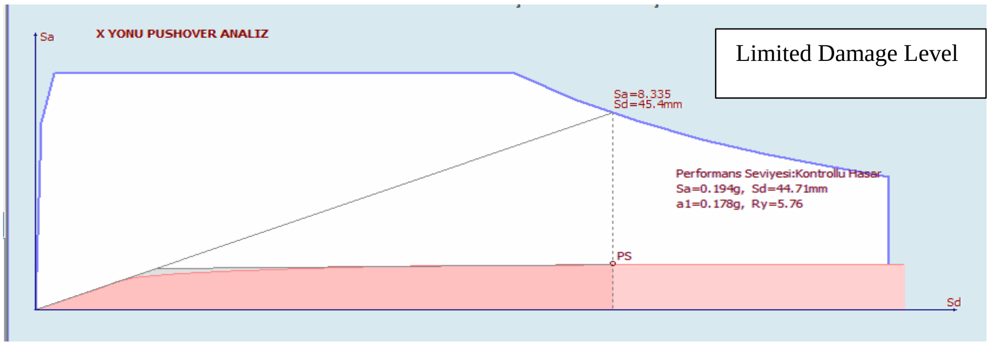


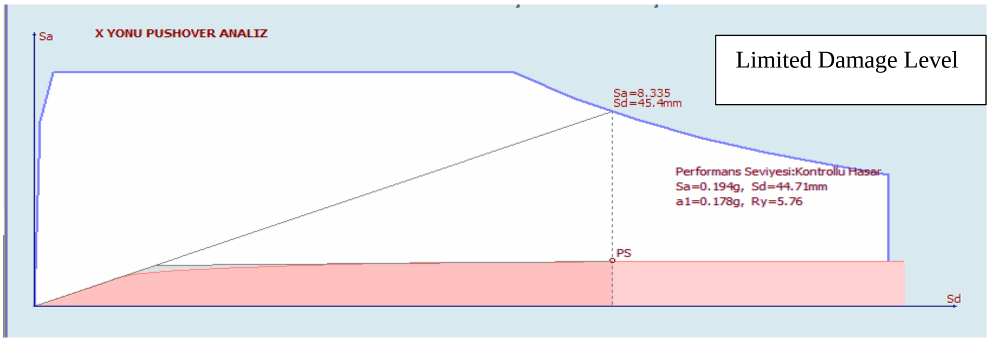
TEC 1997




Sa
X YONU PUSHOVER ANALIZ
Limited Damage Level
Sa=5.625
Sd=32.3mm
Performans Seviyesi:Kontrollu Hasar
Sa=0.208g, Sd=32.25mm
a1=0.185g, Ry=4.12
PS
Sd

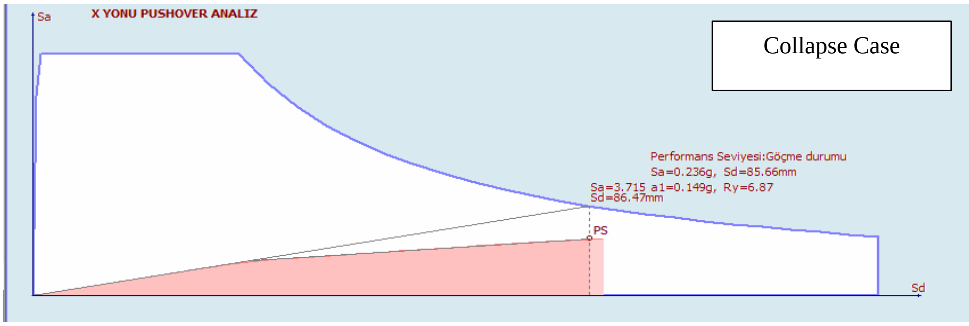
TEC 2007

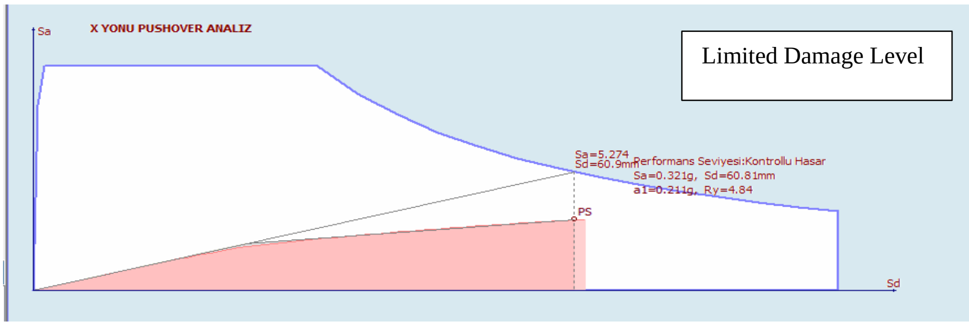

Sa
X YONU PUSHOVER ANALIZ
Limited Damage Level
Sa=8.335
Sd=45.4mm
Performans Seviyesi:Kontrollu Hasar
Sa=0.194g, Sd=44.71mm
a1=0.178g, Ry=5.76
PS
Sd


Sa
X YONU PUSHOVER ANALIZ
Limited Damage Level
Sa=8.335
Sd=45.4mm
Performans Seviyesi:Kontrollu Hasar
Sa=0.194g, Sd=44.71mm
a1=0.178g, Ry=5.76
PS
Sd

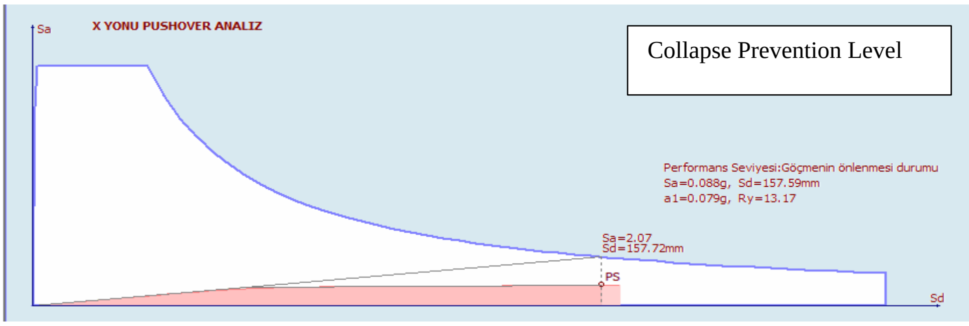
6.8.2 Case 3 Pushover Curve Before and After Strengthening for Soft Storey

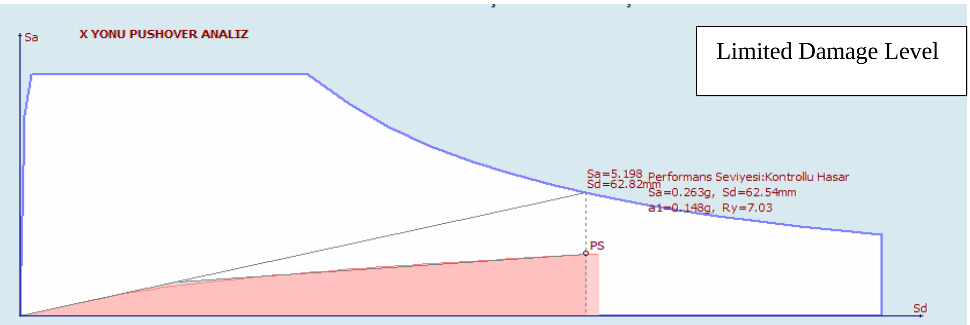
TEC 1975



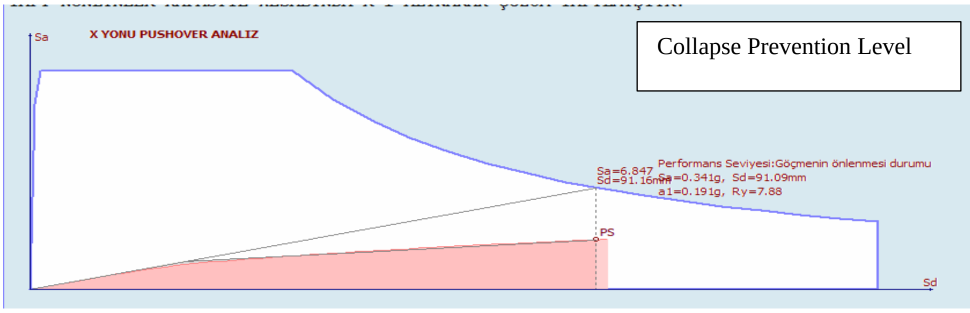


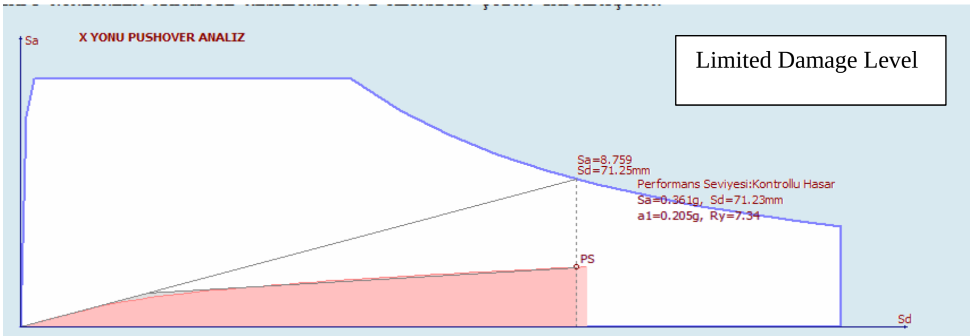
TEC 1997





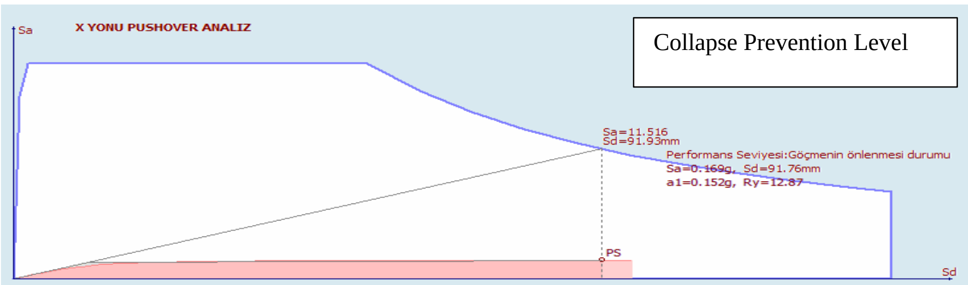
TEC 2007

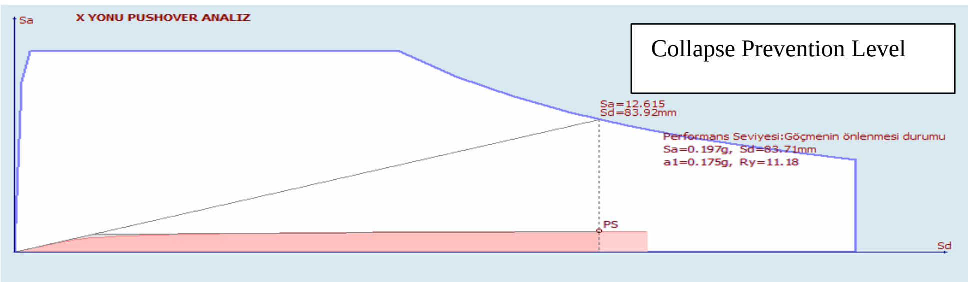




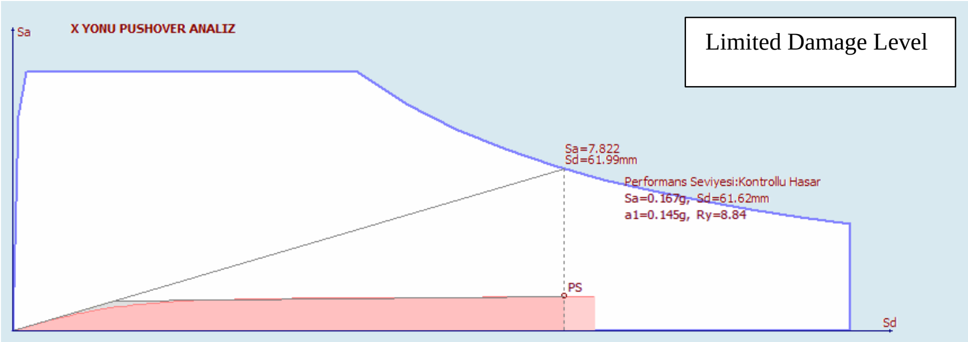
6.8.3 Case 4 Pushover Curve Before and After Strengthening for Torsional Irregularity

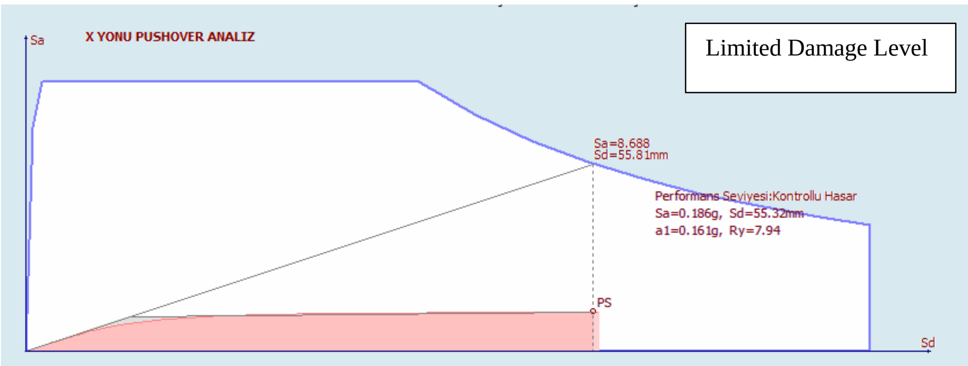
TEC 1975



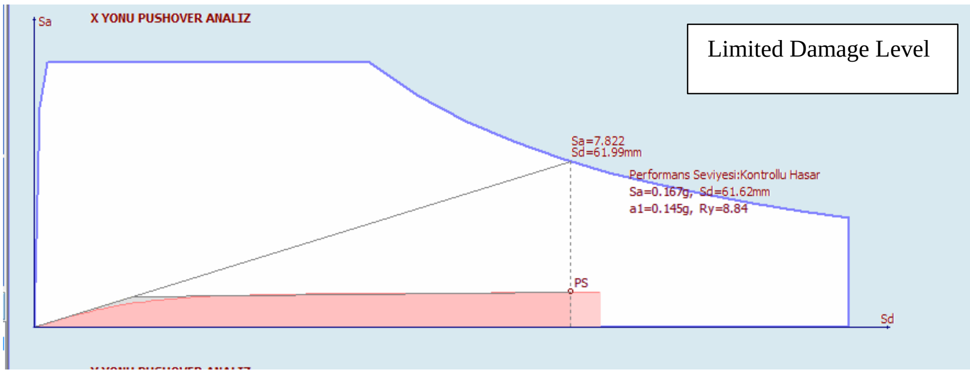


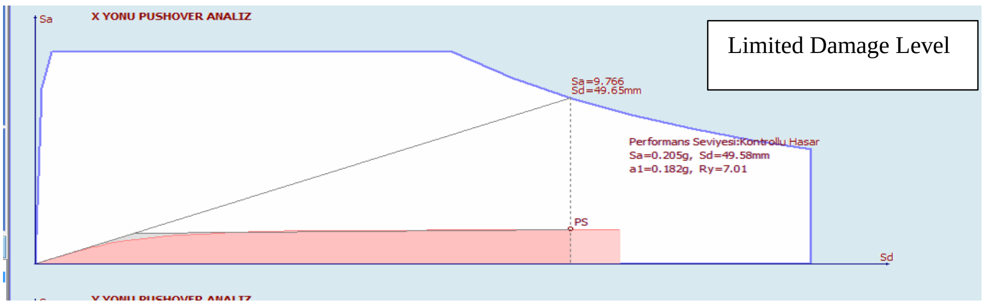
TEC 1997





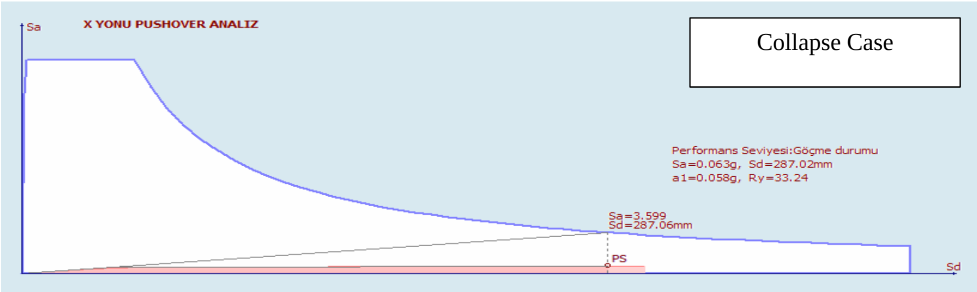
TEC 2007

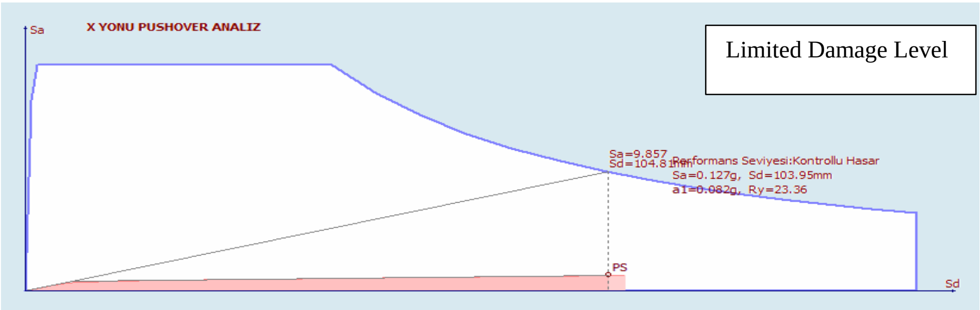




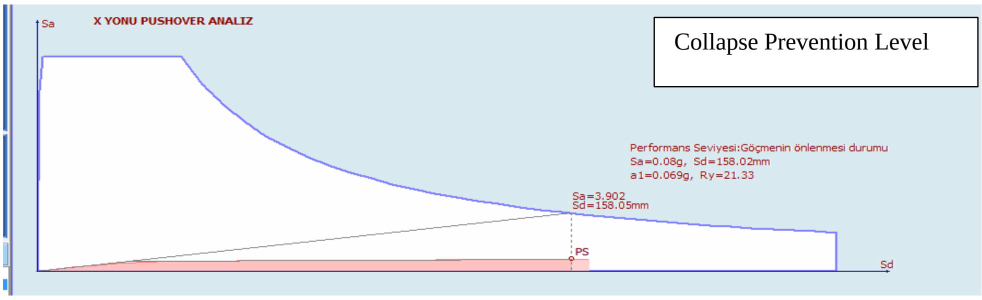
6.8.4 Case 5 Pushover Curve Before and After Strengthening for Weak Column-Strong Beam

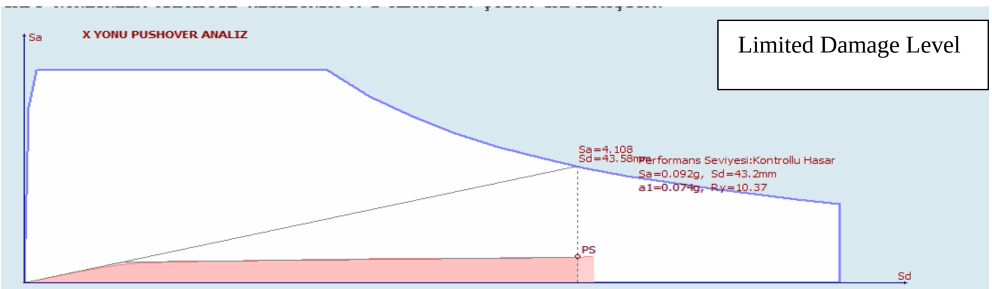
TEC 1975



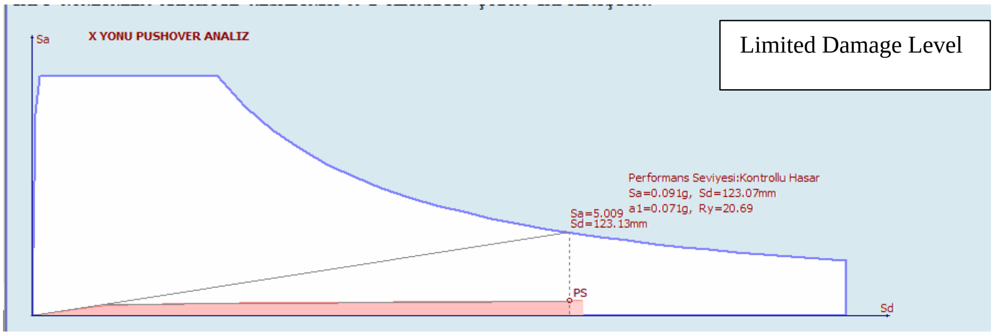


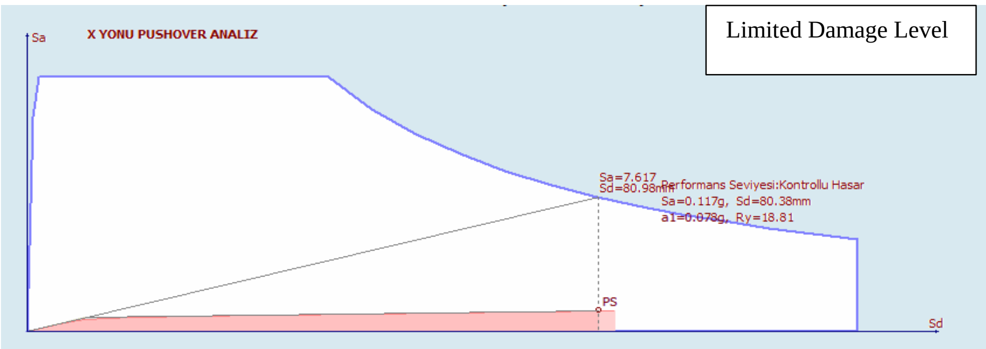
TEC 1997





TEC 2007





6.9 Details of Strengthening in the Study

6.9.1 Introduction

Since the buildings that have been analyzed in the study are old buildings, they have been strengthening according to the new code. Depends on the type and life of the buildings, some building need more strengthening however some of them do not. This will be discussed in details.

6.9.2 Details for Strengthening

Since the conditions of every structure are different, the price is changing. But in the structures there are some common properties. The columns strengthened with concrete cover of 10 cm -15 cm with 1.4 cm for the longitudinal reinforcement. In the study the concrete class was 16 and 20. For strengthening method, minimum of

C25 have been used. For the weak column strong beam situations the following concrete/form and reinforcement details were used.

Summary	Concrete m^3	Formwork m^2	Ө8 ton	Ө14 ton
Beams	0	779	-	-
Columns	49.1		-	-
Reinforcement	0		2.6	5.6
Total	49.1	779	2.6	5.6

6.9.3 Strengthening with Section Enlargement Method

Section enlargement method is happen where the section (column, beam etc.) of the building is increasing so that the building will meet the requirements. In the study, for the columns jacketing have been added for strengthening of the buildings which have weak column size. In the study 10 cm or 15 cm thickness jacketing have been added to these columns to make them strong enough.

On the other hand for the buildings with torsional irregularities since on one side of the structure the column sizes are bigger or there are more columns on one side of the building. In this type of buildings the irregularities should be ignored by increasing the column size of the other side of the building which have weaker column. By doing this, balancing will happen in the building and the irregularities will disappear. This can be visible in the irregularities report of the sta4cad program.

After that in the case study, there are some cases where the buildings have weak column and strong beam. Here the columns sizes are also increases by jacketing method so that the columns will become strong enough. Because in the past earthquakes, it can be obviously seen that building collapse like pancake and one of the reason is that the columns are very weak.

This method is also possible for the case where there is soft storey. Due to stores that are at the bottom floor of the structures, soft storey may occur. Prevention of this is to increase the column size at the bottom floor since there are less windows and more opening in this floor. All the weight of the building is on that floor.

Finally even irregularities and other factors do not exist, in the structure usually in the old ones cracking happens in columns and beams. The reason may be due to old concrete or corrosion. Also since the concrete class is poor in the old buildings, section enlargement can be also done so that the weakness will be negligible.

6.9.4 Addition of Shear Wall

The most important strengthening element against earthquakes is the shear wall. The last element to collapse during an earthquake is the shear wall. For the strengthening shear wall should be more than 200cm.

In this study external shear walls have been added to the structures. In the cases where jacketing is not enough and where the performance of the building is poor, shear wall is added. The shear walls have been arranged in close dimension and rigidity to each other as it has to be. In the study, they have been located close to the edges of the structure, close to the center of rigidity and center of gravity in both directions. Figure 28 shows an example for the study of how external shear walls have been added to the buildings.

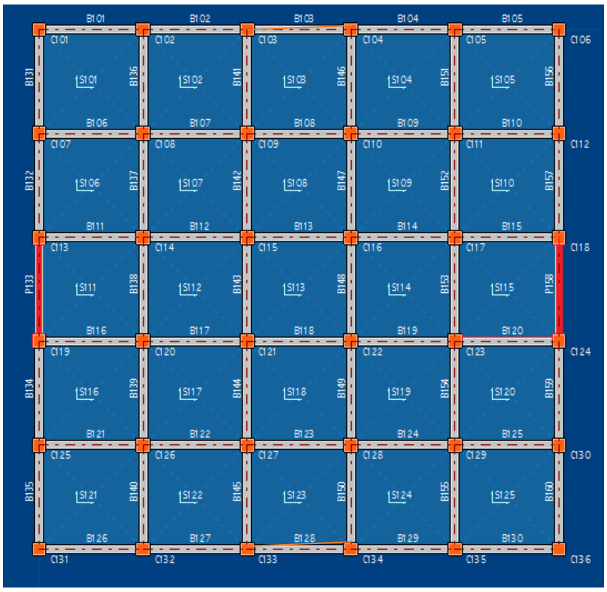


Figure 29: The placing of External Shear Walls to the building

Figure 30: Placing jacketing to the end edge of the shear wall

6.10 Summary of the Structural Characteristics of the Models and Design

For the study, 377 different buildings have been analyzed for strengthening cost and 84 for total cost according to TEC 2018. Most of these buildings have common characteristics. Details of these characteristics will be discussed and also characteristics of each design code will be represented.

6.10.1 General Buildings Data Used in the Study

Table 14: General Information for the buildings used in the study

Storey Number	4, 5
Structural Behaviour Factor Rx/Ry	4
Over strength Factor, D	2.5
Seismic Importance Factor, I	1, 1.4
Live load Seismic Reduction Factor, n	0.3
Slab Thickness	12cm, 15cm, 17cm
Storey Height	12-15 m

Table 15: Reinforcement and stirrup details for the study

Name	Stirrups	Reinforcements			Reinforcement Ratio
Column	Ө8/10-15	Ө816	10Ө16	12Ө16	0.013-0.027
Beam	Ө8/15-20	3Ө14 top	2Ө14 bent	3Ө14 bottom	0.0135-0.0203

Table 16: Size for columns and beams

Name	Size
Column	40x40 , 35x35 , 105x30
Beam	25x55 , 20x50
Panels	40x300, 40x350

6.10.2 Features of each Design Code

Explanation	1975	1997	2007	2018
Earthquake zone	0.1, 0.08,0.06,0.03	0.4, 0.3, 0.2, 0.1	0.4, 0.3, 0.2, 0.1	Map
Load coefficient, n	0.3, 0.6, 0.8	0.3, 0.6, 0.8	0.3, 0.6, 0.8	0.3, 0.6, 0.8
Importance Factor	1.5, 1.0, 1.2, 1.4	1.5, 1.0, 1.2, 1.4	1.5, 1.0, 1.2, 1.4	1, 1.2, 1.5
Concrete Class	C12, C16, C22	C16, C20, C25	C20-C50	C25-C80
Steel Class	S220	S220, S420	S420	S420
Structural Behaviour, K	1.0	R= 4, 6, 7, 8	R= 4, 6, 7, 8	R= 8,7,6,5,4,2.5,3

6.11 Total Cost of Each Building According to 2018 Turkish Earthquake Code

For the total cost of the structures, 2018 Turkish Earthquake regulation have been used. Concrete class, steel class, minimum dimensions, column ratio and reinforcement ratio have been used according to 2018. The aim is to see that when the building do not need strengthen and it is according to the new code, the total cost can be found. Before any buildings strengthen, those steps should be following. First the strengthen cost will be calculated, and then the cost of the building to be constructed again should be calculated and compared with each other. On this way 84 buildings have been analyzed and the total price according to TEC 2018 regulations have been calculated. Different neural network and multi regression analysis have been created so that the results will be compared with each other.

In the total cost part current concrete and steel class have been used. In the calculation part after the design finish, the buildings have been analyzed and the total amount for the steel, concrete and formwork have been found. After that those amount have been multiply by the current price so that rough construction cost of the structures according to 2018 have been calculated.

6.12 MATLAB Neural Network Toolbox

Neural network toolbox can be found in MATLAB program 2018. In this study an Artificial Neural Network has been created in order to study the results. MATLAB program can easily be performed and it has a high range of problem solving when the data become tested.

6.13 Training Strategy of Artificial Neural Network

For the Artificial Neural Network, back propagation is one of the most important and successful method for the engineers. The input parameters have some limits. For the number of story there is 4 and 5 story. The concrete class for each building change with C16, C20 and C25. The steel class also has S220 and S420 respectively. The shear wall ratio is 0 as minimum and 0.01 as maximum. For the slab thickness, it is vary between 12 and 17. For the soil type, 1 is used for ZC and 2 have been used for ZD class. Finally for the earthquake zone, it changes from 1 to 4 according to the place of the earthquake. Since this study takes place in İstanbul, the following table shows the details for the 4 different locations that have been chosen for earthquake zone.

Table 17: Location chosen for earthquake zone

Location	North Coordinates	South Coordinates	Zone
1	40.94925	28.63551	1
2	41.17664	28.35657	2
3	41.14327	41.28973	3
4	41.28706	27.99832	4

6.14 Strengthening Cost Using Artificial Neural Network

In the study there are 13 input parameters; Number of Story (N), Concrete Class (C), Steel Class (S), Area (A), Shear Wall Ratio (SWR), Column Ratio (CR), Earthquake Code (EQ), Strong Column-Weak Beam, Soil Type (ST), Earthquake Zone (EZ) Stirrup Spacing, Torsional irregularity and Soft Storey. The output parameter is the total strengthening cost of the building.

6.15 Artificial Neural Network for Total Cost

For the total cost of the structure according to 2018 Turkish Earthquake code has been constructed differently since the parameters are different. For the total cost Number of storey, concrete class, steel class, column ratio, shear wall ratio and area for each structure. The output parameter is the total cost of the structure according to the new code.

6.16 Performance of Artificial Neural Network

Table 5.3 shows the comparisons of the Strengthening costs from experiments and those obtained from the trained neural network for 377 testing data.

From this comparison it is obvious that the cost calculation for the structures is in a good agreement with the experimental results as 94% accuracy found in the program.

Another neural network has been created for the total cost of each building. From this comparison it has been found an accuracy of 97 %.

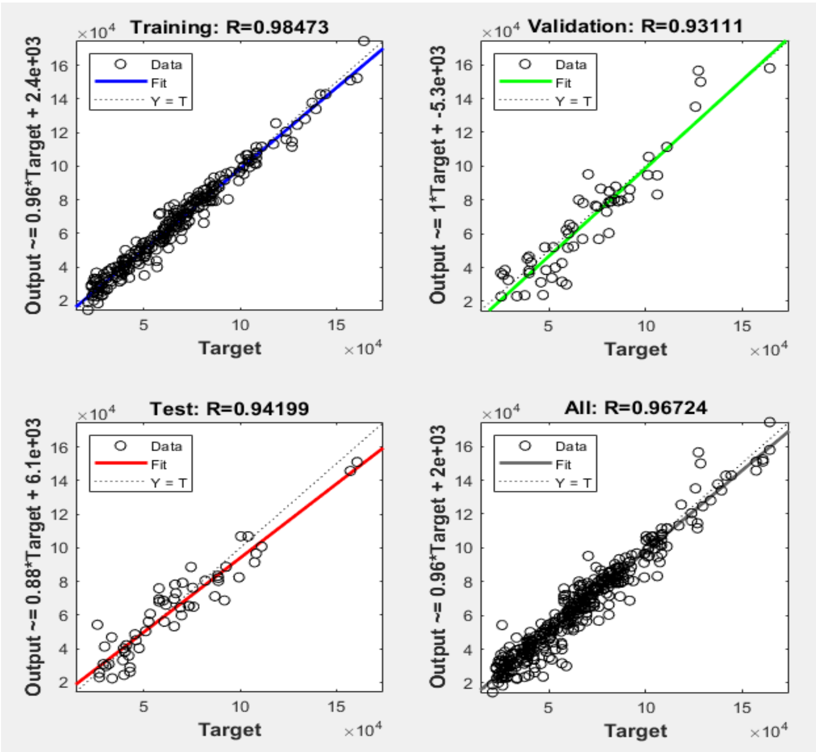


Figure 31: Performance of ANN for the strengthening cost

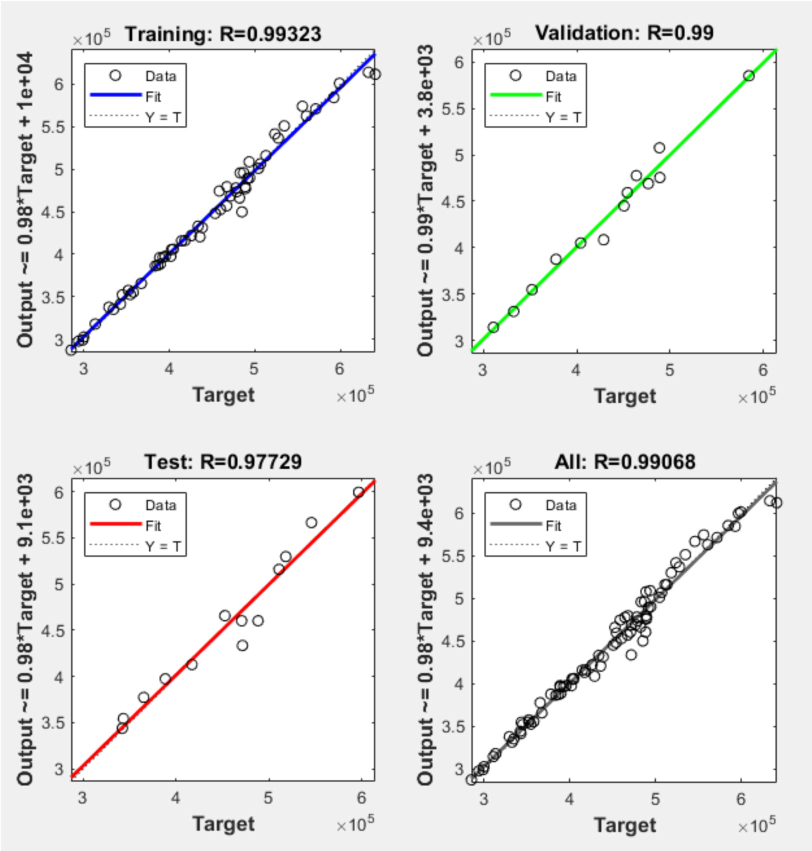


Figure 32: Performance of ANN for the total cost

6.17 Training Algorithms, Input layers and Training Parameters

After many searching and making some trials and errors in MATLAB, topology for the strengthening cost calculation of the buildings is considered as Multi-layer feed forward and the number of layers which are hidden plus output is 2. In table 5.3 the number of neurons and transfer function type is showed.

Table 18: Number of neurons and transfer function for data

Name of Layer	Number of Neurons	Transfer Function
First Hidden Layer	28	Logsig
Output Layer	1	Purlin

Data Division: Random

Training: Levenberg-Marquardt

Training algorithm used in the study: Multi-Layer Feed Forward

Performance function of the network: Mean Square Error.

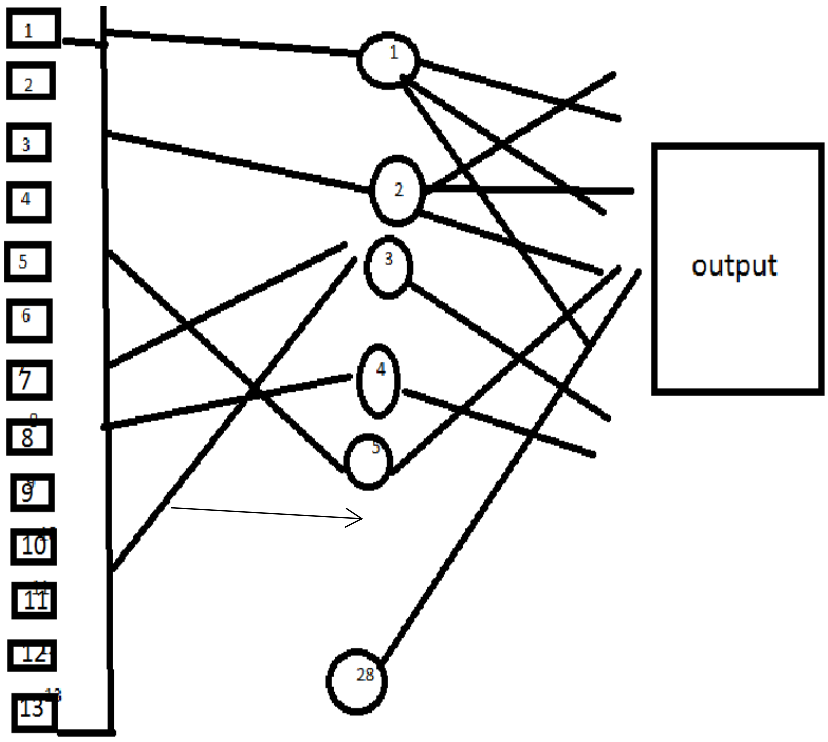


Figure 33: Architecture Model of Neural Network

6.18 Results of Artificial Neural Network

According to the study, the prediction accuracy of the Artificial Neural Network that has been trained, found 94% accuracy for the strengthening cost calculations of buildings.

Another neural network has been created for the total cost and accuracy of 97% has been calculated for the total cost of the structures according to 2018 TEC.

6.19 Testing of Artificial Neural Network

For the correction of results, with other words to find the ability of the neural network system for the strengthening cost calculation that has been used, 7 different models of buildings which are not used in the analysis have been used in comparison between the predicted costs and the cost of the data that has been used. The developed neural network that has been used predict the cost calculation for 6 of these buildings correctly. The results show that the chosen parameters and the strengthening cost for each building have been done in advance.

6.20 Multi Regression Analyses

For the multi regression analysis, the following figure has been created after analysing the data by using Minitab software.

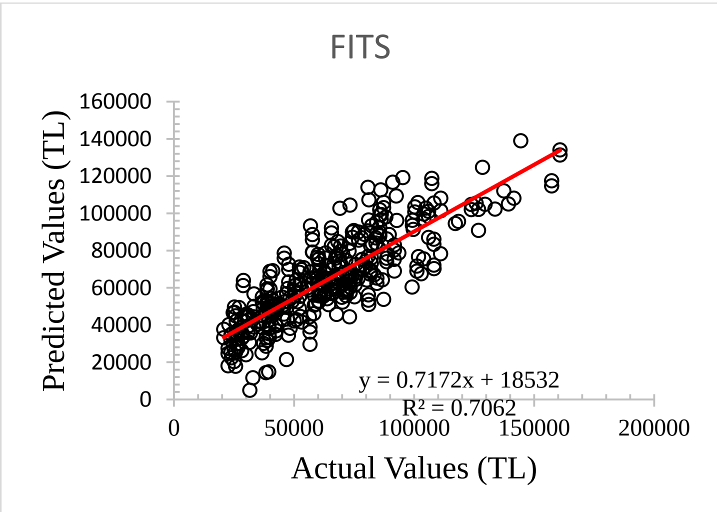


Figure 34: Multi regression analysis for strengthening cost of buildings

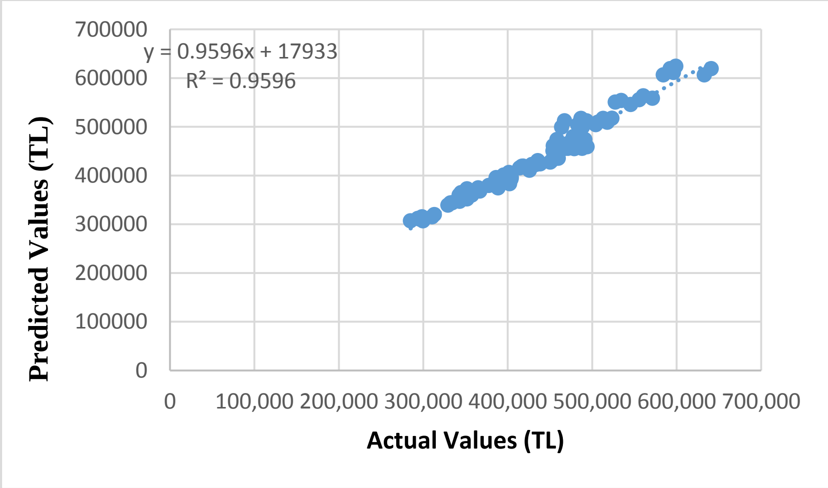


Figure 35: Multi regression analysis for total cost of buildings

Regression analysis on the basis of the mean square error is conducted to calculate the strengthening cost calculations and total cost of each structure through multiple variables analysis.

According to the figure above, Minitab 2019 is used to construct the multivariable regression analysis of the total and strengthening cost of the buildings.

The accuracy for the fitting of results are always calculated through coefficient of determination which is shows as R2 where the fitting is best as R2 approaches values close to one. The coefficient of determination is calculated in accordance with equation below:

$$R2=1-\Sigma(yi-\hat{yi})2\Sigma(yi-\bar{y})2$$

In the equation of R2 yi is the measured output, $\hat{yi}$ is the predicted output and y is the average of the measured output.

When the result calculated is less than 0.4 then the study will have a very weak effective model. However if the result calculated is between 0.4 and 0.5 than the result will be considered as normal results. If the result will be more than 0.7 which is 70%, then the result will be accepted as strong results according to the study.

6.21 Sorting of the Input Parameters

1) Earthquake Code

According to figure 36, it can be seen that the strengthening is lightly decreases as the earthquake code is becoming new.

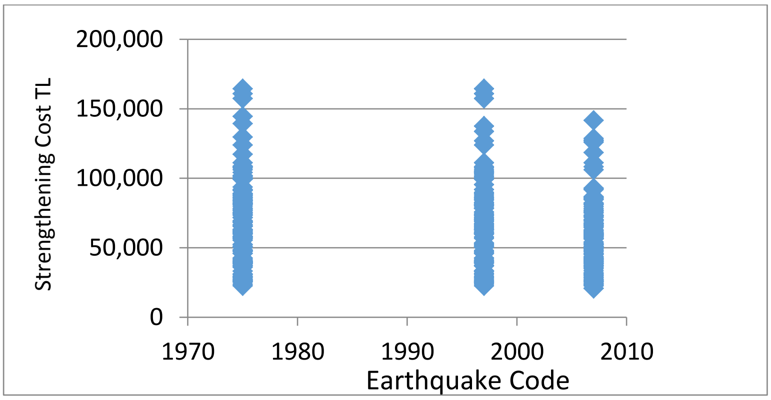


Figure 36: The effect of earthquake code on strengthening cost

2) Earthquake Zone

Figure 37 shows that as the earthquake zones are increasing the strengthening cost are decreasing. Since 1 is the highest and most dangerous zone and 4 is the lowest zone.

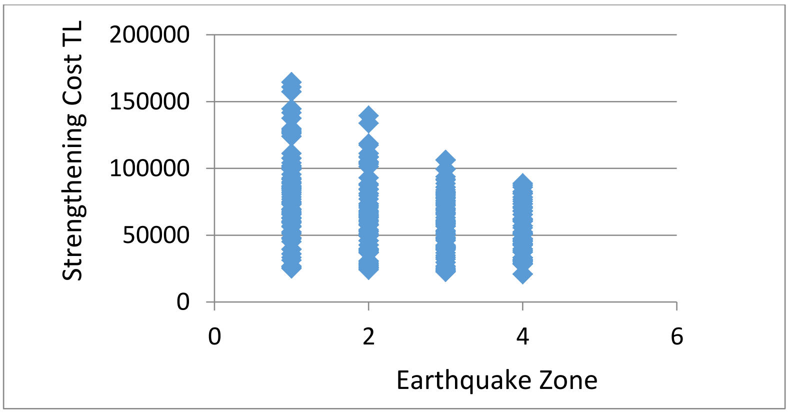


Figure 37: The effect of earthquake zone on strengthening cost

3) Soil Type

It can be noticed from figure 38 that, in type 1 and 2 with full effect from the rest of the parameters, soil type has no effect. But in type 3 it can be seen that the strengthening cost is level-headed.

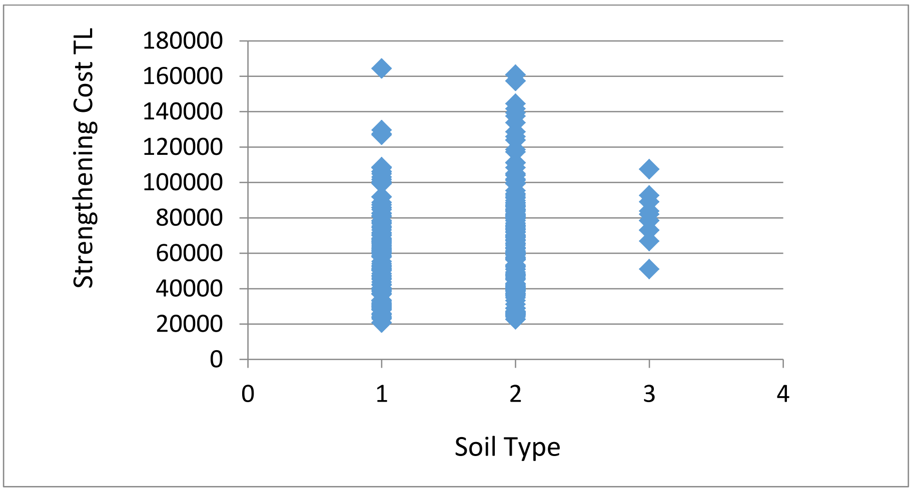


Figure 38: The effect of soil type on strengthening cost

4) Column Ratio

Figure 39 shows that the average column ratio has a significant effect on the cost, since when the column ratio is enough, the strengthening cost is remaining in an admissible level.

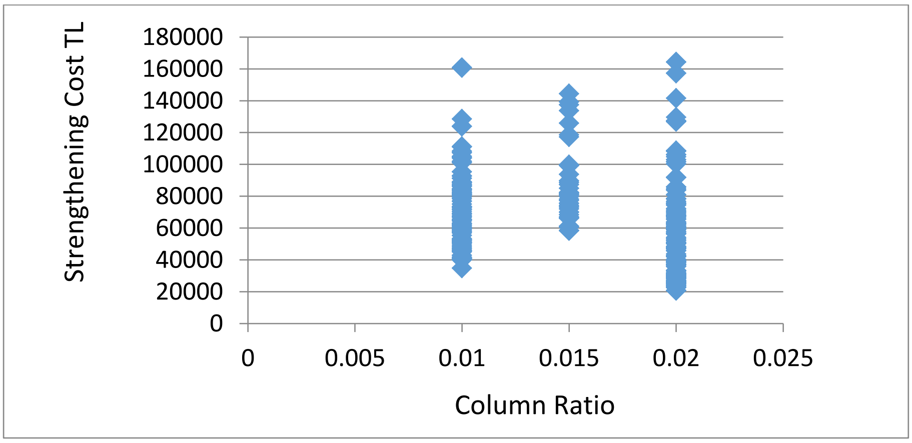


Figure 39: The effect of column ratio on strengthening cost

5) Shear Wall Ratio

It can be noticed from figure that the cost of strengthening is decreasing with addition of shear wall to the structure. This means that the shear wall ratio is one of the important parameters affecting cost of strengthening.

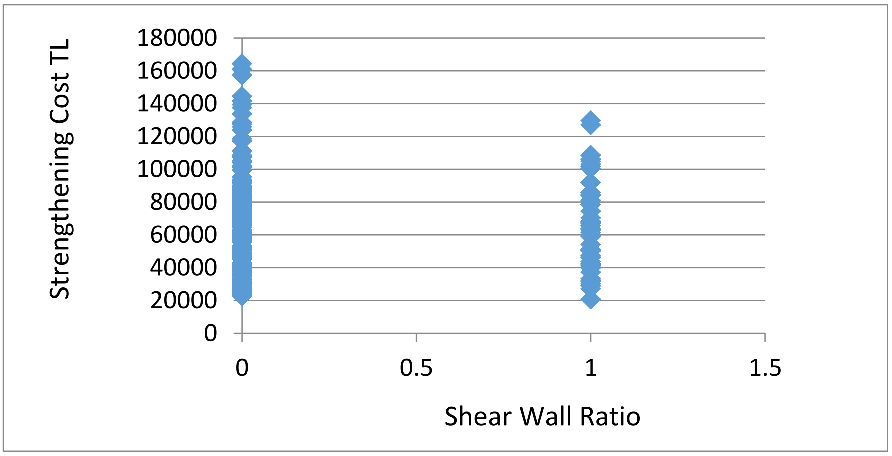


Figure 40: The effect of shear wall ratio on strengthening cost

6) Stirrup Spacing

With a low proportion it can be seen that the cost of strengthening is increasing when the stirrup spacing of the structure is not OK. The stirrup spacing has no big effect on the performance of the buildings.

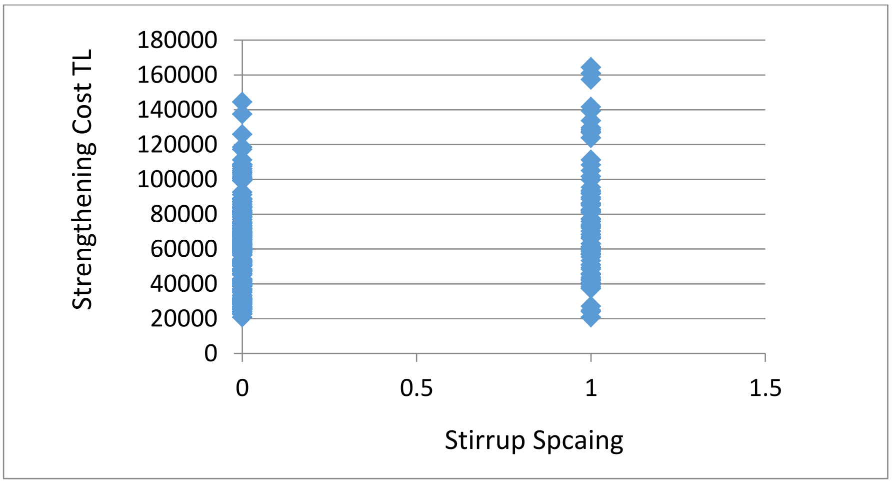


Figure 41: The effect of stirrup spacing on strengthening cost

7) Steel Class

According to figure 42, the strengthening cost is decreasing by increasing the steel tension strength.

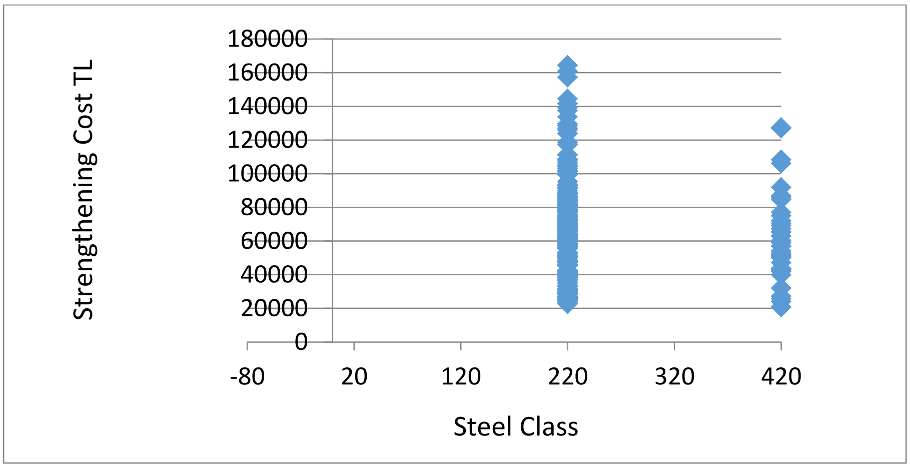


Figure 42: The effect of steel class on strengthening cost

8) Concrete Class

According to figure 43, the strengthening cost is decreasing by increasing the concrete compression strength.

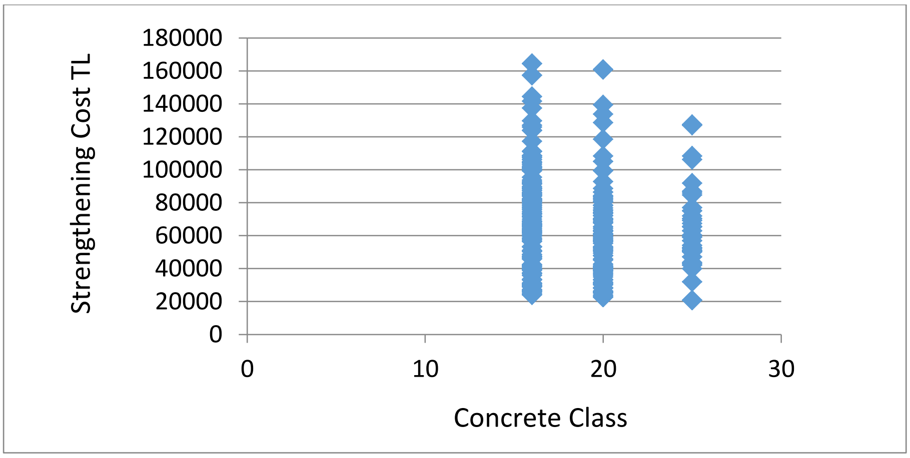


Figure 43: The effect of concrete class on strengthening cost

9) Area

From figure 44, it can be seen that the area has no direct effect on the cost of strengthening. Because the area of buildings are changing according to the parameters of the design.

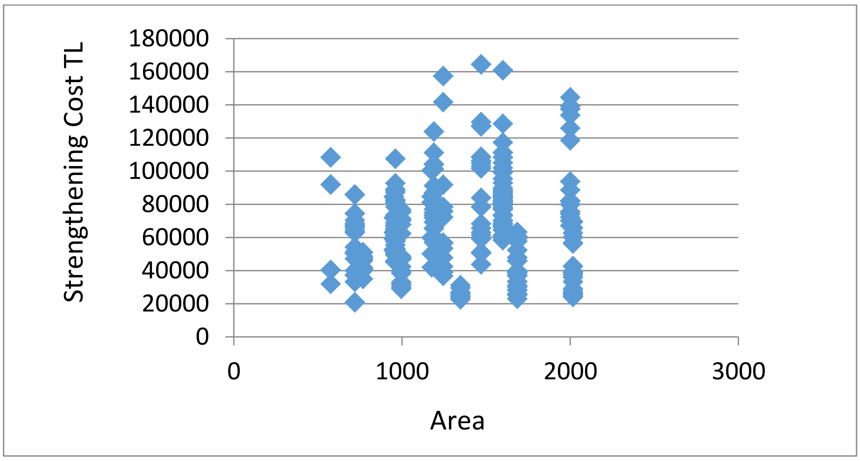


Figure 44: The effect of area on strengthening cost

10) Weak Column Strong Beam

From figure 45, it is obviously visible that when the buildings have weak columns and strong beams the strengthening price is increasing. The reason is that when the columns are weak, they need more cost to be satisfied.

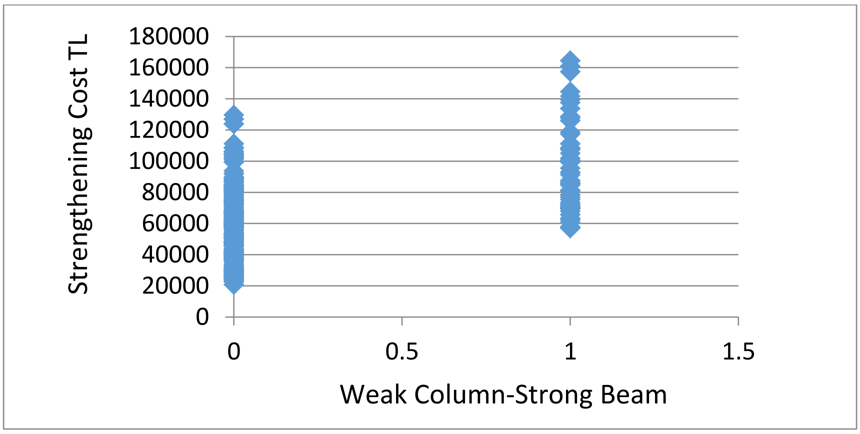


Figure 45: The effect of weak column strong beam on strengthening cost

11) Torsional Irregularity

The cost of strengthening increases when torsional irregularities have been existing in the structures.

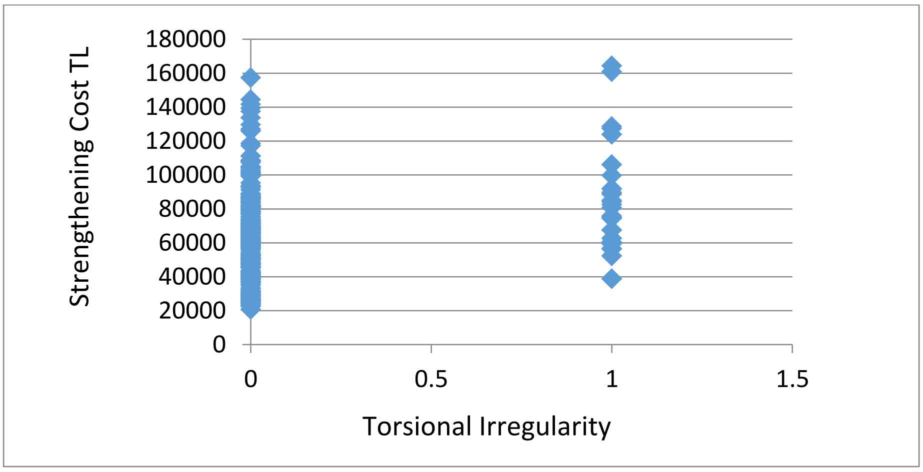


Figure 46: The effect of torsional irregularity on strengthening cost

12) Soft Storey

The strengthening price is lower where there is no soft storey in the structure. The reason is that when there is soft storey, the bottom ground needs to be strengthening strongly because it carries all the load of the structure.

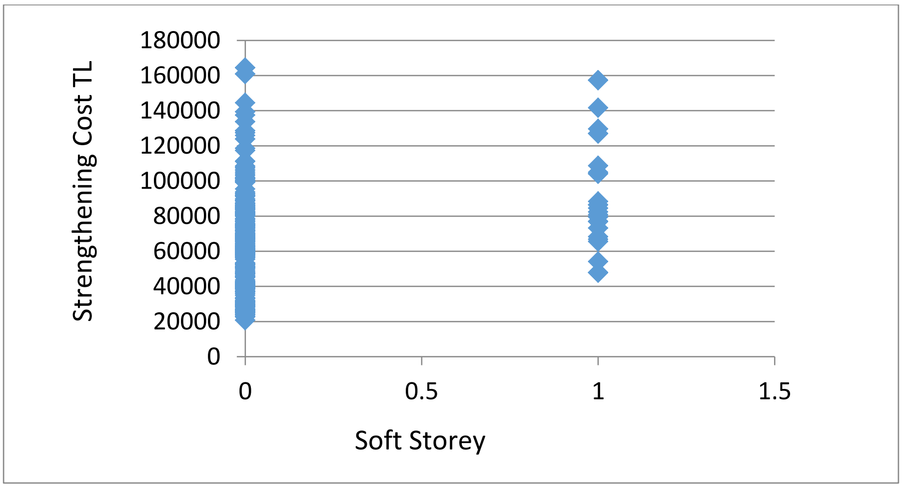


Figure 47: The effect of soft storey on strengthening cost

13) No of Storey

It can be visible from figure 48 that the cost of strengthening is not changing when the no of storey is changing.

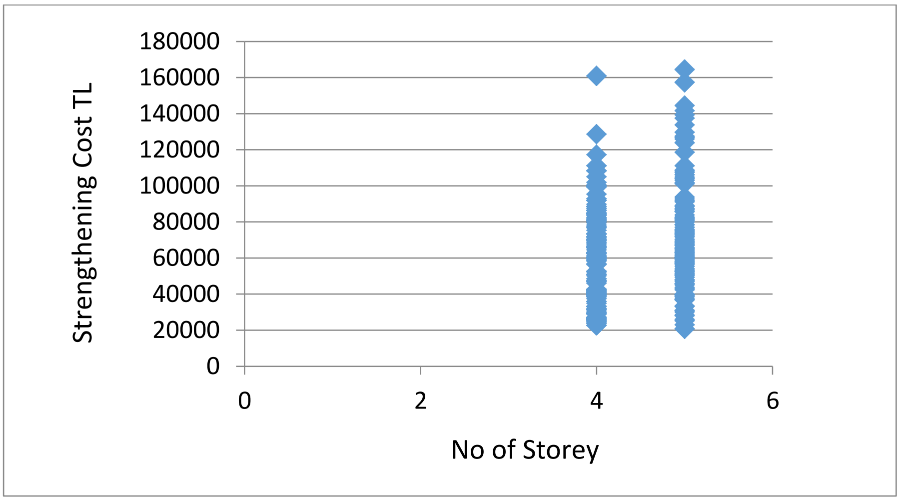


Figure 48: The effect of no of storey on strengthening cost

The input parameters for the strengthening cost of 377 RC buildings have been sorted accordingly. From the graphs, the relation between the parameters and the strengthening cost have been discussed.

Chapter 7

CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This research explored the use of Artificial Neural Networks to test the cost of reinforced concrete buildings for strengthening. Using the available test data of 377 RC buildings that have been modelled with the commercial software STA4cad, an artificial neural network model is designed according to 1975, 1997 and 2007 and strengthened according to 2018 regulation. After that 84 RC buildings have been tested to calculate the total cost according to 2018. 51 of those buildings have been designed according to gravity load design. The percentage of the difference between earthquake code and gravity load design have been discussed and have been found that gravity loaded design is 25% more expensive than earthquake code design.

In order to determine the effects of the variables on earthquake results, which are the preferred output parameter, the ANN model was used to conduct parametric analysis.

7.2 Conclusion on the Use of Neural Network in Cost Calculation

The Artificial Neural Network is a very strong, powerful and high potential method in learning the relationship between the input and output parameters in order to predict the accuracy for the study.

On the other hand the Artificial Neural Network takes place in many civil engineers problems and this study will play important role since the Artificial Neural Network system has been used accordingly. Because by adding new training examples to the network, the system can be updated for getting better result.

7.3 Conclusion on the Use of Artificial Neural Network in Strengthening Cost of Reinforced Concrete Buildings

To find the accuracy of the results, Neural Network has been created. The type for the architecture used was the multi-layer feed forward method. The input layer is containing 11 neurons and the first hidden layer contains 28 neurons however in the output layer there were only 1 neuron. For the training of data, back probation algorithm was used.

The neural network model that have been created predict the strengthening cost of the buildings with 94% accuracy and for the total cost according to 2018 of each building the accuracy was about 97% in the system.

7.4 Conclusion on the Case Study

When reviewing the studies on the use of ANNs for strength cost estimation issues relevant to the topic of this study, it is shown that there is an emphasis on ANN models made with highly complex structures containing computer software. The explanation for this was known to be that both forms of ANN were very abundant and that their reasoning was focused on quite complex mathematical relationships. By using this technique, it was possible to work on the parameters for each cost calculation that will be done. When the buildings that have been designed according to 1975, 1997 and 2007 codes do not pass through the new code, strengthening method like adding shear wall and section enlargement method have been used. For the studies, by adding of shear wall and by increasing the section which is calling jacketing, increase the strength and the performance of the structures.

Performance decreases and strengthening cost increases when torsional irregularities exist in the structure. Also where there is weak column strong beam, the cost of strengthening is also high because more columns need to get enlarged.

The average column ratio which was one of the input parameters in the study has a significant effect on the performance of the project together with the shear wall ratio. Structures that have high column and shear wall ratio will cost less for strengthening.

By increasing the strength and concrete class, the cost of strengthening is decreasing. The reason is that the new and high classes have more ability to perform more. For the new materials, the strengthen cost of the structures is affected directly.

Finally the earthquake zone takes important part in strengthening method. For the structures which are checked according to the 1st and 2nd degree which are the less effective places for earthquake costs less for strengthening. But for the 3rd and 4th cases, the strengthening cost is more expensive since more addition shear wall and better section enlargement method is needed because the earthquake will appear more dangerous in this places.

7.5 Comparison of Neural network and Multi Regression Analysis

In neural network, the accuracy for the study has been found 94% for strengthening cost and 97% for total cost. While in multi regression analysis this result became around 71% for strengthening cost and 95% for total cost. There is a different in both method and the reason is that the two methods have different working strategy.

There is a greater variation in a more sensitive algorithm, which would result in more model variations and, in turn, the model's predictions and evaluation. A less sensitive algorithm, on the other hand, has a lower variance and would result in less variation with different training data in the resulting model, and in turn, less difference in the resulting predictions and model evaluation.

7.6 Recommendation for Future Studies

This study let us know that the cost calculation of reinforced concrete buildings play important role in neural network. The strengthening cost of each building is calculated. These recommendations are needed for the future studies for this study:

1-One of the artificial intelligence techniques, artificial neural networks can be used in the management of strength less buildings projects within the framework of this thesis research. It was investigated and a modeling was carried out and the results can be used accordingly.

2-Pattern recognition, classification, learning and other artificial intelligence techniques such as programming can be used to compare these results together.

3-On the other hand, more and different data can be obtained from different studies and those data can be trained as well. By doing this, the training process for the cost calculation can be improved accordingly.

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