ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EARTHQUAKE PERFORMANCE AND PROJECT BUDGET COMPARISON OF A CONVENTIONAL BUILDING AND A SEISMICALLY ISOLATED BUILDING

M.Sc. THESIS

Oğuzcan ÇATLIOĞLU

Disaster Management Instıtute

Earthquake Engineering Programme

JUNE 2021

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

EARTHQUAKE PERFORMANCE AND PROJECT BUDGET COMPARISON OF A CONVENTIONAL BUILDING AND A SEISMICALLY ISOLATED BUILDING

M.Sc. THESIS

Oğuzcan ÇATLIOĞLU
(802181230)

Disaster Management Institute

Earthquake Engineering Programme

Thesis Advisor: Assoc. Prof. Dr. Arcan YANIK
Thesis Co-Advisor: Assist. Prof. Dr. Senem BİLİR MAHÇİÇEK

JUNE 2021

ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

KONTROLSÜZ BİNA İLE SİSMİK İZOLATÖRLÜ BİNANIN DEPREM PERFORMANSI VE MALİYET AÇISINDAN KARŞILAŞTIRILMASI

YÜKSEK LİSANS TEZİ

Oğuzcan ÇATLIOĞLU
(802181230)

Afet Yönetimi Enstitüsü

Deprem Mühendisliği Programı

Tez Danışmanı: Doç. Dr. Arcan YANIK
Eş Danışman: Dr. Ögr. Üyesi Senem BİLİR MAHÇİÇEK

HAZİRAN 2021

Oğuzcan Çatlıoğlu, a M.Sc. student of İTU Graduate School student ID 802181230, successfully defended the thesis entitled "EARTHQUAKE PERFORMANCE AND PROJECT BUDGET COMPARISON OF A CONVENTIONAL BUILDING AND A SEISMICALLY ISOLATED BUILDING", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Assoc. Prof. Dr. Arcan YANIK** Istanbul Technical University	.....
Co-advisor :	**Assist. Prof. Dr. Senem BİLİR MAHÇİÇEK** Istanbul Technical University	.....
Jury Members :	**Prof. Dr. Şenol ATAOĞLU** Istanbul Technical University	.....
	Assoc. Prof. Dr. G. Emre GÜRCANLI Istanbul Technical University	.....
	Prof. Dr. Ersin AYDIN Niğde Ömer Halisdemir University	.....

Date of Submission : 09.06.2021
Date of Defense : 29.06.2021

To humanity,

FOREWORD

I would like to thank to my advisors Assoc. Prof. Dr. Arcan Yanık and Asist. Prof. Dr. Senem Bilir Mahçiçek who supported me during my work on earthquake performance and project budget comparison of conventional and seismically isolated buildings.

Also, I would like to thank to Senior Civil Engineers Sami Arı and Çağatay Tahaoğlu for their contribution to my works.

Lastly, I would like to thank to my colleague and my friend Civil Engineer Mehmet Mert Genç for his efforts and contributions to my thesis.

June 2021

Oğuzcan ÇATLIOĞLU
(Civil Engineer)

TABLE OF CONTENTS

Page

FOREWORD ..... **ix**
TABLE OF CONTENTS ..... **xi**
ABBREVIATIONS ..... **xiii**
SYMBOLS ..... **xv**
LIST OF TABLES ..... **xvii**
LIST OF FIGURES ..... **xix**
SUMMARY ..... **xxxii**
ÖZET ..... **xxiii**
1. INTRODUCTION **1**
1.1 Purpose of Thesis 1
1.2 Seismic Isolation 2
1.2.1 Seismic isolation systems 3
1.2.1.1 Elastomeric bearings 5
1.2.1.2 Sliding isolation systems 5
2. LITERATURE REVIEW **7**
3. NUMERICAL EXAMPLE **19**
3.1 Structural Material 19
3.2 Number of Story, Dimensioning and Floor Plan 20
3.3 Earthquake Used for the Analysis 22
3.3.1 Earthquake record processing 22
3.3.2 Forming response spectrum 26
4.DYNAMIC ANALYSIS UNDER EARTHQUAKE EXCITATION **29**
4.1 Modal Periods and Frequencies 29
4.2 Story Displacements 31
5. COST ANALYSIS **37**
5.1 Activity-Base Cost Calculation 37
5.2 Establisihing Work Breakdown Structure for the Case Project 37
5.3 Market Research and Pricing 39
6. CONCLUSIONS AND RECOMMENDATIONS **47**
REFERENCES **49**
CURRICULUM VITAE **53**

ABBREVIATIONS

SI **:** Seismically isolated
STMD : Single Tuned Mass Damper
MTMD : Multiple Tuned Mass Damper
D-MTMD : Distributed Multiple Tuned Mass Damper
FB **:** Fixed base
TFPB : Triple Friction Pendulum Bearing
DDBD : Direct Diplacement Base Design
LRB : Lead Rubber Bearing
HDRB : High Damping Rubber Bearings
MIDR : Maximum Interstory Drift Ratio
MBS : Maximum Base Shear
WBS **:** Work Breakdown Structure
TBDY **:** Turkish Building Earthquake Code
TCMB **:** Turkish Republic Central Bank
TCÇŞB **:** Turkish Republic Ministry of Environment and Urbanization
RC **:** Reinforced concrete
TH **:** Time History
PGA **:** Peak Ground Acceleration
PGV **:** Peak Ground Velocity
PGD **:** Peak Ground Displacement
IMs **:** Intensity measures

SYMBOLS

₺ **:** Turkish Lira

LIST OF TABLES

Page

Table 2.1 : Literature review. **9**
Table 4.1 : Modal periods and frequencies of FB building. **29**
Table 4.2 : Modal periods and frequencies of SI building **30**
Table 4.3 : Maximum story displacement of FB building **32**
Table 4.4 : Maximum story displacement of SI building **33**
Table 4.5 : Relative story drifts of FB and SI buildings **34**
Table 5.1 : Cost calculation. **40**
Table 5.2 : Total and m^2 costs. **44**
Table 5.3 : Seismic isolation / Total cost. **45**

LIST OF FIGURES

Page

Figure 1.1 : General design spectrum **3**
Figure 1.2 : Comparison of different methods **4**
Figure 1.3 : Prof. Dr. Süleyman Yalçın city hospital **6**
Figure 1.4 : Prof. Dr. Cemil Taşcıoğlu city hospital **6**
Figure 3.1 : 3D View of 5 story fixed-base building **20**
Figure 3.2 : Plan View of 5 story fixed-base building **21**
Figure 3.3 : Raw accelaration time history **23**
Figure 3.4 : Processed acceleration time history **24**
Figure 3.5 : Raw velocity time history **24**
Figure 3.6 : Processed velocity time history **25**
Figure 3.7 : Raw displacement time history. **25**
Figure 3.8 : Processed displacement time history **26**
Figure 3.9 : Horizontal elastic design spectrum **26**
Figure 3.10 : Comparison design spectrum with Duzce EW spectrum **27**
Figure 4.1 : Deformed shape of FB building mode 1 ..... **30**
Figure 4.2 : Deformed shape of FB building **31**
Figure 4.3 : Deformed shape of SI building **32**
Figure 4.4 : Comparison of maximum story displacement **33**
Figure 4.5 : Comparison of the relative story drifts **34**
Figure 4.6 : Displacement of the fifth story of FB building **35**
Figure 4.7 : Displacement of the fifth story of SI building **35**
Figure 5.1 : Work breakdown structure **38**

EARTHQUAKE PERFORMANCE AND PROJECT BUDGET COMPARISON OF A CONVENTIONAL BUILDING AND A SEISMICALLY ISOLATED BUILDING

SUMMARY

In the structural design process, various design methods are used all around the world. Seismic isolation is a relatively new method for designing earthquake-resistant structures in comparison with the conventional design approaches. Basically, all the design methodologies specified in the codes and specifications aim to protect life safety of the residents in the building by resisting the forces that may be occured by earthquakes. The energy released by the earthquake must be absorbed by structural elements before the structural failure occurs.

While the structures that are designed according to conventional design approaches dissipate the earthquake energy by the help of the possible damages that may be occurred in its structural elements, the aim of base isolation usage is to diminish the effect of the forces that are transmitted to the structure from the ground. Therefore, in base-isolated buildings, the structural elements would be less damaged, and the structure may not lose its functionality after being exposed to different earthquake excitations. Seismic isolation devices are placed into the base of a structure to enhance the ability of energy dissipation. The energy is absorbed by the displacement of the isolation level. This reduces the earthquake effects that the building experiences.

In this study, a five-storey structure is chosen to be analyzed from both earthquake safety and cost perspectives. Time history analysis are carried out with SAP 2000 software. The building's width and height are chosen as 40 m and 15 m, in a respective way. The buildings that have same width and height are modelled for two cases. One with fixed base and the other with base-isolation. Time History analysis are performed for both cases by using the same earthquake record to determine the earthquake performance of the buildings. In Case I, the fixed-base building is used. The earthquake performance of the building is obtained by the help of time history analysis. Secondly, a base isolated building is modeled and analyzed. In addition to the comparison of earthquake performance, this study evaluates the cost of these two cases.

With no doubt during an earthquake the life safety is the primary concern however financial situation must also be taken into account during the design process. Cost estimation plays a prominent role for financial project budget. It aims to maintain the project with the available resourses. These resources, of course, have limitations since every project have its own budget and time-limit. The method of design has a great impact on the project budget of the building. Design method affects not only the construction cost of project, but also service-life of the project. The costs of both conventional and seismically isolated buildings are calculated. Then, the seismically isolated and conventional buildings are compared in terms of their seismic performance and the project budget.

Finally, the result of seismic performance and the cost benefit are presented and discussed according to findings of the analysis. It is obtained from this thesis that, although the initial construction cost of the seismically isolated structure is obviously more than the conventional building, eventually in a possible earthquake scenario seismic isolation may provide financial advantage over the conventional building case.

KONTROLSÜZ BİNA İLE SİSMİK İZOLATÖRLÜ BİNANIN DEPREM PERFORMANSI VE MALİYET AÇISINDAN KARŞILAŞTIRILMASI

ÖZET

Yapısal tasarım sürecinde dünyanın her yerinde çeşitli tasarım yöntemleri kullanılmaktır. Şüphesiz ki her yöntem gibi yapısal tasarım yöntemleri de günden güne gelişmeye devam etmektedir. Son yıllarda oldukça yaygın kullanılmaya başlayan sismik yalıtım da yapısal tasarım yöntemlerinden biridir. Sismik yalıtım, depreme dayanıklı yapıların tasarlaması için geleneksel tasarım yaklaşımlarına kıyasla nispeten yeni bir yöntemdir.

Dünya'da depremlerin etkin olduğu coğrafyalarda depreme dayanıklı binaların tasarımı ülkelerin deprem yönetmeklerine göre yapılmaktadır. Bu yönetmelikler ülkelerden ülkelere bazı değişiklikler gösterse de temel prensip olarak aynı misyonu amaçlamaktadır. Yönetmeliklerde yer alan tüm tasarım metodolojileri ilk olarak depremin bina üzerinde oluşturacağı kuvvetlere direnerek bina içerisinde ikamet eden insanların can güvenliğini korumayı hedeflemektedir. İnsanların can güvenliğini sağlamak için depremin açığa çıkardığı enerji, yapısal göçme meydana gelmeden absorbe edilmelidir. Bu prensip doğrultusunda geleneksel tasarım yaklaşımlarına göre dizayn edilen yapılar, depremin enerjisini yapısal elemanlarına hasar alarak sömümlerken taban izolasyonu zeminden yapıya iletilen kuvvetlerin azaltılmasına neden olarak yapısal elemanlarda oluşacak hasarı en aza indirmeyi sağlamaktadır. Bu nedenle yapının tasarımı sırasında sismik isolasyon kullanılması kararlaştırılmışsa yapı elemanları farklı deprem uyarımları sonucu oluşmuş kuvvetlere maruz kaldıktan sonra daha az hasar alır ve yapının işlevi kaybolmayarak kesintisiz kullanım sağlanır.

Sismik izolasyon mekanizması basitçe deprem sonucu oluşan ve zeminden binaya aktarılacak olan kuvvetlerin taban kısmına yerleştirilen izolatörler tarafından sönümlenmesi şeklinde açıklanabilir. Bu kuvvetler taban seviyesinde bulunan izolatörlerin yer değiştirmesi ile absorbe edilir. Bir başka deyişle deprem sonucu oluşan binaya etki edecek kuvvetler izolasyon katmanında kullanılan izolatörün deforme olmasıyla emilir. Bu sayede yapının üst katlarındaki taşıyıcı sistem elemanlarında oluşacak hasar minumum seviyede kalacaktır. Katlar arası deplasmanlar istenilen düzeyde sınırlandırılabilecek ve kontrol edilebilecektir. Bu çalışma özelinde kullanılacak bina 5 katlı betonarme bir yapı olarak seçilmiştir. Binanın plandaki eni ve boyu 40 m'dir. Her kat yüksekliği aynı ve 3 m'dir. Aynı boyutlandırmaya sahip iki bina ayrı ayrı olarak SAP 2000 programında analiz yapılmak üzere modellenmiştir. SAP 2000 programında binaların deprem performansını belirlemek amacıyla aynı deprem kaydı kullanılarak her iki durum için Zaman-Tanım alanında analiz yapılmıştır. Birinci analizde bina geleneksel yöntemle sabit tabanlı olarak modellenerek incelenmiş ve yerdeğiştirme gibi deprem performansını gösteren değerler elde edilmiştir. Yönetmeliklerin ortak amacı yeni yapılacak binaların depreme dayanıklı tasarımının ana ilkesi; hafif şiddetteki depremlerde binalardaki yapısal ve yapısal olmayan sistem elemanlarının herhangi bir hasar görmemesi, orta şiddetteki depremlerde yapısal ve yapısal olmayan elemanlarda

oluşabilecek hasarın sınırlı ve onarılabilir düzeyde kalması, şiddetli depremlerde ise can güvenliğinin sağlanması amacı ile kalıcı yapısal hasar oluşumunun sınırlanması şeklinde özetlenebilirken maliyet ile alakalı herhangi bir kısıtlama içermez.

Öte yandan, can güvenliği bina tasarımın en önemli amacı olmakla beraber finansal etkenler de bina tasarımı yapılırken hesaba katılmalıdır. Finansal bağımsızlık hiçbir projede mümkün olmadığı gibi inşaat projelerinde de mümkün değildir. Binanın tasarım yöntemi gibi maliyet analizi de inşaat sürecinin kilometre taşlarından birisidir. Maliyet tahmini yapılırken dikkat edilmesi gereken hususların başında kaynakları verimli şekilde kullanılması gelmektedir. Bir başka deyişle proje başında belirlenmiş olan kısıtlı imkanlarla istenilen projenin çıkarılması amaçlanmaktadır. Maliyet tahmini, binanın proje bütçesini hesaplamada önemli rol oynamaktadır. Her projenin kendine özel bütçesi ve zaman kısıtı olduğu için bu kaynaklar sınırlı olmakla beraber projeyi mevcut kaynaklarla sürdürmeyi amaçlamaktadır.

Mühendislik süreci; yapının malzemesi, temel sistemi ve yapının tasarım metodu gibi unsurların belirlendiği yer olduğu için inşaat sırasında ve sonrasında hem yapısal hem finansal olarak önem arz etmektedir. Tasarım yöntemi ise binanın proje bütçesi üzerinde en büyük etkiye sahip olan kriterlerden biridir. Tasarım yöntemi sadece projenin inşaat maliyetini değil, aynı zamanda projenin servis ömrünü de etkiler. Aynı yapısal özelliklere sahip iki referans binalardan sismik izolatör yerleştirelerek yapısal tasarımı yapılmış olan binanın maliyetinin daha fazla olduğu oldukça açıktır. Ancak uzun vadeli düşünüldüğünde sismik izolasyonlu binanın geleneksel binaya kıyasla daha avantajlı olacağı beklenmektedir. İki farkı yöntemle tasarlanan binaların proje maliyetleri aktivite tabanlı maliyet analizi yöntemi kullanılarak hesaplanmıştır. Daha sonra bu iki bina için yapılan deprem analizi ve hesaplanan proje maliyeti elde edilen bulgular ışığında karşılaştırılmıştır. Karşılaştırmalar sonuç kısmında sunulacaktır.

1. INTRODUCTION

One of the most important challenge in civil engineering is to control the structural vibrations. The major aim of the earthquake codes and the specifications is protecting the structures from the hazards caused by earthquakes. There may be a loss of the serviceability of the building due to extreme accelerations and displacements that the structure may experience. These accelerations and displacements may exceed the limitations that are specified by the codes. Some types of structures are more crucial than the others. Important structures such as hospitals, power plants, municipality buildings, and fire stations have to be operational both during and after the earthquake movement. The usage of seismic isolation has been more common in these kinds of structures. Furthermore, in Turkey seismic isolation is mandatory for the state hospitals according to Turkish Building Earthquake Code 2018 (TBDY-2018). Although the usage of seismic isolation is also advantegous for residential buildings, in Turkey seismic isolation implementation to those kinds of buildings recently started.

1.1 Purpose of Thesis

Past earthquake experiences showed that many reinforced concrete structures experience damages partially or entirely during an earthquake. Safety standards are stated in the earthquake codes. These codes aim to raise the resistance capacity of the structures. This study concentrates on two different parameters that are earthquake performance and the project budget of a building. Initially, a 5-story reinforced concrete building is modeled according to TBDY 2018 which is the current earthquake code valid in Turkey. The seismic behaviour of the structures is analyzed to determine the earthquakes parameters including lateral displacements, inter-story drifts for the different cases with and and without seismic isolation. A well-known structural engineering software SAP 2000 is used for testing the models.

On the other hand, this research focuses on the financial part of the structure as a secondary perspective. It is recommended that cost estimation should be performed before the start of a construction. Since every construction project is unique,

estimations differ from project to project. In the very beginning of a project, the design method has to be determined. The design method is directly related to the project budget. The difference on the selection of the building material as steel, reinforced concrete or timber has a huge impact on the material cost of the project. Moreover, the usage of relatively new methods such as implementation of dampers and seismic isolators may significantly change the project budget. In this study, the project budget is calculated for both cases which are conventional and seismically isolated building. The approach for cost estimation is chosen as activity-based cost analysis.

1.2 Seismic Isolation

Seismic isolation is a recently used method for eliminating the earthquake hazards to the structures. It is mainly used in operational structures that functionality must be continued even during and after most considerable earhquakes. Examples of these structures are municipality buildings, fire stations, hospitals, power plants, bridges, and airports. Newly, seismic isolation is being applied to the residential buildings.

The primary idea behind the design of the structure at the seismically active region is basically to reduce the destructive effects of earthquakes. Seismic isolation simply creates an interface between the superstructure and the base of the building. The interface must be stiff enough to carry the weight of the building in the vertical direction. However, it has a very low horizontal stiffness to allow the lateral displacement.

Seismic isolation system inhibits the shear force transmission from ground to the superstructure. Therefore, the less inter-story drifts will be obtained. It is an undeniable fact that the natural vibration period of the structure plays a prominent role in the seismic behaviour of the building. If seismic isolation is applied to a structure, the natural vibration period will be increased without a doubt.

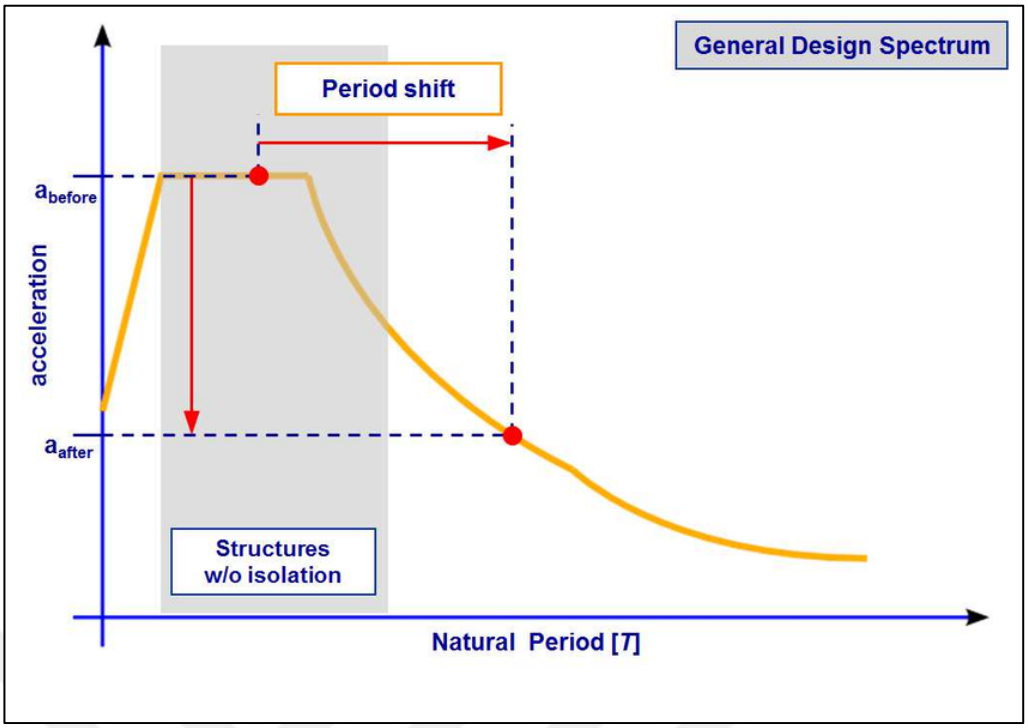

Figure 1.1 : General design spectrum.

Design spectra differ from one specification to another. However, the general shape is similar for all specifications. How the seismic isolation affects the structure is shown in Figure 1.1 that is taken from Galindo et al. (2012). Seismic isolation shifts the period of the building from plato to curve. The acceleration will be decreased corresdonping to the period change. Due to these changes, the forces that the structure is being exposed after the earthquake, are being reduced dramatically.

Figure 3.9 shows the horizontal elastic design acceleration spectrum from TBDY 2018. It can be clearly seen that the structures that have longer periods will experience low spectral accelerations. In other words, lengthening the natural vibration period results in the less internal forces that the structural elements expose. Design spectra are almost the same for different countries. There might be slight changes, but the general trends are identical.

1.2.1 Seismic isolation systems

Recently, the usage of seismic isolation is started for designing earthquake-resistant structures together with the conventional design approaches. Seismic isolation concept aims to dissipate the earthquake energy by the deformation of the isolators. Seismic isolation systems are classified into two main categories despite the variety of the sub-types.

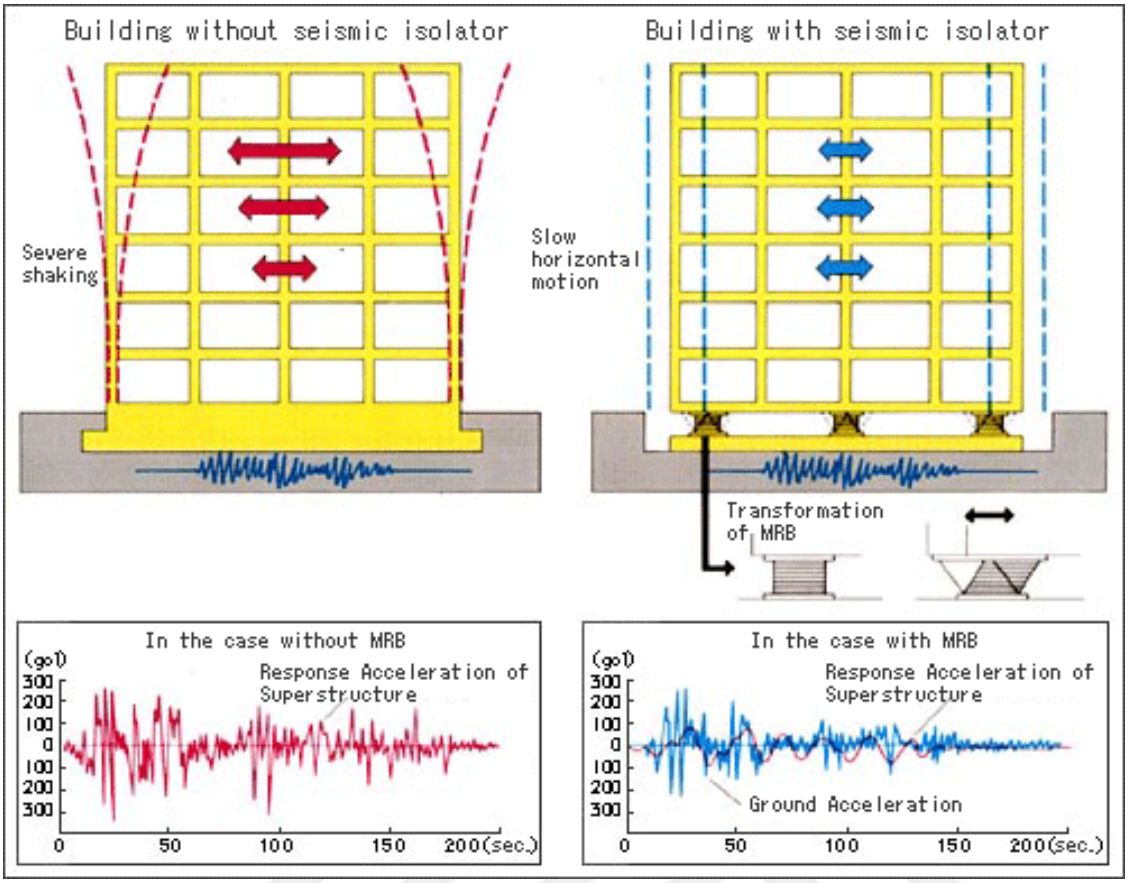

Figure 1.2 : Comparison of different methods.

To identify the difference, Figure 1.2 (It is taken from Bridgestone website) shows both design methodologies. Civil Engineers design the structures to experience damages during earthquakes. Earthquake energy is dissipated by the deformation of the structural elements. Previous methods increase the rigidity of the structure to resist earthquake forces. In reinforced concrete structures, shear walls are being implemented to the frame of the building to increase the rigidity. Normally, frame structures have only columns and beams. In the seismically active regions, frames do not provide enough rigidity. Braced frames are used for the same reason in the steel structures. Seismic isolation is a flexible approach for isolating the structure from the ground. The aim of base isolation usage is to diminish the seismic shock propagation that may effect the structure negatively. Therefore, in base-isolated buildings, the structural elements would experince less damage, and the structure may not lose its functionality after being exposed to different earthquake excitations.

1.2.1.1 Elastomeric bearings

One of the most used seismic isolation system type is elastomeric bearings. Elastomeric bearings are composed of various steel plates layers and elastomeric rubber material mounted on top of each other. The high pressure and heat are applied to the steel and rubber plates to stick them together. While the necessary vertical stiffness and load capacity are satisfied by the multiple steel plates, low horizontal stiffness are provided by rubber layers.

Low-damping rubber bearings (LDRB) and High-damping rubber bearings (HDRB) are two main types of elastomeric bearings. Thanks to its natural characteristics, rubber is a material with low viscousity. The bearigns that consists of rubber and steel plates are known as low-damping rubber bearings (LDRB). If some different materials such as carbon, resin and oil is added, the damping ratio will be increased. Therefore, this process makes possible to produce high-damping rubber bearings. Elastomeric bearings might contain lead cores. After the earthquakes, rubber layers recenter the seismic isolator while lead core dissipates the energy.

1.2.1.1 Sliding isolation systems

Another seismic isolation system type is called as sliding bearings. If isolation systems are compared in terms of ecomomical perspective, the sliding bearings are cheaper than the elastomeric ones. Because this type of isolation system depends on the friction phenomena. Basically, energy is being dissipated by friction.

There is a common problem about the tradional sliding bearing. They fail to recenter the isolation system after the earthquakes. In order to enhance the recentering capabilitiy, sliding bearings are needed to be supported by supplementary materials. If the geometry of the bearings alters to concave, it can provide enough force to recenter the isolator. Then the structure will return to their original position inherently due to the gravitational effect.

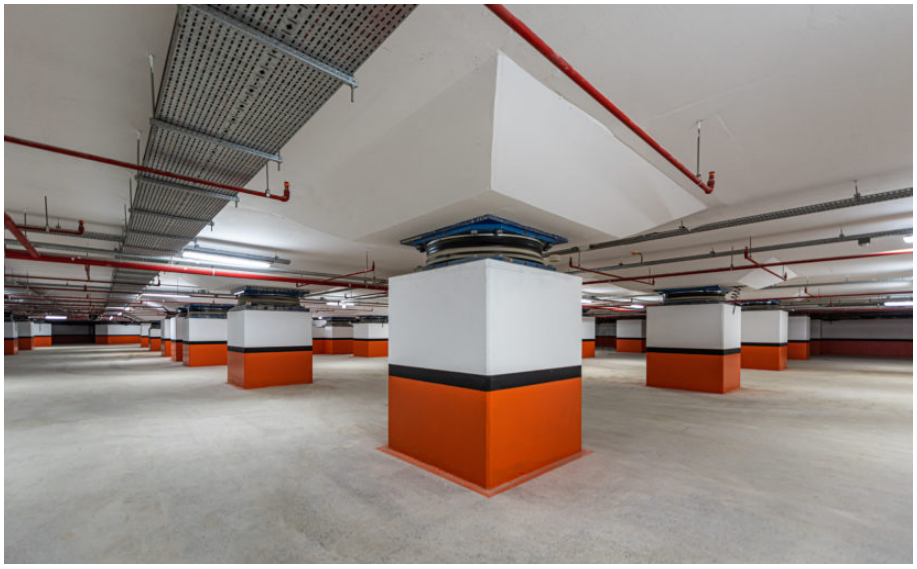

Figure 1.3 : Prof. Dr. Süleyman Yalçın city hospital.

Seismic isolation devices are placed into the base of a structure to enhance the ability of energy dissipation. Devices should be placed on each column. These two photos are taken from the city hospitals in Turkey. Figure 1.3 shows the isolation system in Prof. Dr. Süleyman Yalçın City Hospital in the Asian side of Istanbul while in Figure 1.4 the seismic isolator in Prof. Dr. Cemil Taşcıoğlu City Hospital located in Okmeydanı can be seen. In Turkey, Seismic isolation is mandatory for the state hospitals according to the regulations. In seismic isolation concept energy is absorbed by the displacement of the isolation level. This reduces the earthquake effects that the building experiences.

Figure 1.4 : Prof. Dr. Cemil Taşcıoğlu city hospital.

2. LITERATURE REVIEW

The literature was reviewed for this study by regarding some key parameters related to the content. Initially, the seismic isolation for structures is used as a preliminary parameter. Generally speaking, the seismic isolation concept is relatively new compared to the conventional design method. Because of this fact, we focused on the recent studies, especially published after 2015. Approximately 40 papers have been investigated for this study recently. More specifically, the research was conducted in terms of seismic and cost performance of seismically isolated structures and the conventional structures. The classification of the articles can be defined as;

- whether they cover cost-analysis or not
- the number of stories of the structures
- the software used for analyzing earthquake performance of the structures.

In this section, the reviewed studies that are listed in Table 2.1 will be evaluated. Thanks to the literature review, the results show that the seismic isolation is used for different types of structures such as nuclear power plants, bridges, hospitals and buildings. More than 30 papers that are reviewed for this research analyze the buildings that have various number of stories ranging from a single story to 15 story. The core objective of performance-based design of buildings is to transfer earthquake demands on the structural elements (Amjadian and Agrawal, 2019). To achieve this, the predominant period of the structure should be long. For the high-rise building, the implementation of the seismic isolation is not beneficial and feasible because of the fact that the natural predominant vibration period of the high-rise buildings is already long. Seismic isolation is a commonly applied technique to reduce structural and nonstructural damage during severe earthquake excitation (Yang and Zhang, 2019). External energy dissipation devices and base isolators extend the natural period of the buildings and add additional damping for the building. The usage of seismic base isolation can significantly mitigate the horizontal seismic demand on the structures (Yu et al., 2018). In other words, this provides the reduction of shear forces that are being transmitted from the ground to the superstructure.

In the scope of this research, we investigated the research that contain the analysis of 5 to 10 story buildings in terms of not only the earthquake performance but also the cost analysis. There are a few studies that cover the cost effectiveness of the utilization of the seismic isolation among the reviewed literature. Ryan et al. (2019) stated that the improvement of the design codes results in the necessity of additional requirements for the seismic isolation systems. Although this makes the increase in the cost of the isolation method, Ryan et al. mentioned an example study that investigated a fixed base and isolated building subjected to the same performance criteria. The result of this case study shows that the isolation system is 6% less expensive than conventional design method. Plenty of studies only deal with the initial and construction cost of the studies. The study of Dong and Frangopol (2015) shows that the cost benefit of base isolation is barely discoverable because of the high initial cost. Moreover, Dang et al. (2014) propose an indicator of structural seismic performance based on life-cycle cost for a 7-story hospital building. In the light of the literature review, despite the papers related to the seismic isolation, there is no concrete knowledge on direct comparison of seismically isolated and fixed base residential building in terms of earthquake and cost performance. On the other side, Mitropoulou – Lagaros (2016), Cardone et al. (2017) and Han et al. (2017) were the valuable references for this review. While the two of them, Mitropoulou – Lagaros (2016) and Han et al. (2017), focused on the comparison of the base isolated three and six-story reinforced concrete buildings, the other one, Cardone et al. (2017), analyzed the earthquake performance and retrofitting cost of the base isolated 4, 6, and 8 story reinforced concrete buildings.

As a result of the literature review, it can easily be realized that the knowledge regarding to the comparison of fixed-based and isolated buildings in terms of both earthquake performance and cost benefit is still limited. According to this outcome, this thesis focuses on the lack of knowledge stated above. This study will compare two different types of buildings by considering the earthquake performance and cost.

Table 2.1 : Literature review.

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
1	Ryan et al., (2018)	Nonlinear response history analysis, seismic isolation, lateral force distribution, equivalent lateral force method	It explains analysis procedures and dynamics parameters to develop the lateral force equations.	To predict the allocation of lateral forces over the base isolated structures, equations were formed for the seismically isolated building design.	2-story and 3-story braced frame structure	Etabs	Does not cover
2	Sayani and Ryan, (2009)	Base isolation, response spectra, nonlinear analysis, ductility, seismic effects, performance characteristics, structural response, acceleration	It examines the superstructures of seismically isolated buildings in terms of in- elastically response in comparison with the fixed base buildings.	After the response history analysis, findings show that force reduction factors for seismically isolated building are less than the fixed-base ones.	Single-story building	Does not mentioned	Testing cost, construction cost, repair cost
3	Calabrese et al., (2019)	Recycled rubber – fiber reinforced bearings, low-cost seismic protection systems, base isolation,	In the developing countries recycled rubber-fiber reinforced bearings as seismic isolation devices for low-cost residential buildings.	Seismic isolation with rubber-fiber reinforced bearings are applied to a low-cost housing. It is obtained that there is a dramatic reduction in the seismic demand on the superstructure.	4-story reinforced concrete frame structure	Msc software	Low-cost seismic isolation system
4	Ryan et al., (2011)	Base isolation, response spectra, nonlinear analysis, ductility, performance characteristics, structural response, acceleration	Two steel frame buildings are investigated in terms of multihazard response. While one of them is code designed conventional, the other one is a base-isolated steel frame building.	Code designed conventional building meets the performance objectives. If the response of earthquake is weak, stronger design is recommended. New approaches to control and to limit the isolator deformation are needed.	3-story moment resisting frame buildings	Opensees	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
5	Cancellara and Angelis, (2019)	Dynamic analysis, base isolated structures, nonlinear, isolation devices, dynamic assessment of structures,	The dynamic analysis of seismically isolated multistory structures that have high irregularity in plan is performed. High damping rubber bearings and friction sliders isolaters are placed in parallel direction.	Thanks to the base isolation, structural elements face less stress and bending moments. Results show that lower stress in columns, lower bending moment at supports of the beams and lower shear force at mid span of the beams.	A five-story reinforced concrete (rc) structure	Sap2000	Does not cover
6	Yang et al., (2019)	Engineering demand parameters, seismically isolated rc tall building, intensity measures, pulse-like ground motion	It evaluates the predictive capability of various intensity measures (IM) for forecasting significant engineering demand parameters.	The resilience of the structures are affected by some earthquake parameters. According to this study, some of them are story drift ratio, maximum floor acceleration, roof displacement, bearing displacement	Rc tall buildings	Etabs	Does not cover
7	Dong and Frangopol, (2015)	Structural damage Seismic hazard, base-isolated building, resilience, non-structural damage,	In order to discover the performance difference among buildings in terms of ecomomic, social and environmental, a new approach is proposed.	Repair cost, fatalities and impact to the environment can be reduced by the help of base isolation	3-story steel buildings	Opensees	Initial construction cost, repair cost, cost-effectiveness
8	Gazi and Alhan, (2019)	Monte carlo simulation method, Reliability analysis, base isolation uncertainty, seismic performance, forward directivity effects near-fault earthquakes	This study focuses on the seismic reliability of multi-story of structures. These structures with the nonlinear isolation system are evaluated under near-fault earthquakes.	Ground motion characteristics have more impact on the seismic reliabilities of base-isolated buildings. They are sensitive to the nearest fault, ground motion amplitudes, pga/pgv ratios and pulse periods.	3-story reinforced concrete structure with steel braces	Sap2000	Does not cover
9	Stanikzai et al., (2019)	Base-isolated building, bearing displacement, earthquake, hybrid vibration control,	Analytical models of 5-, 10-, and 15-storey base-isolated buildings equipped with the single tuned mass damper (STMD), multiple tuned mass dampers (MTMDs), and distributed multiple tuned mass dampers (d-MTMDs) are used in the numerical study.	It is possible to reduce the roof acceleration by installing the mtmds and d-mtmds. Therefore, it decreases the design seismic force.	5-, 10-, and 15-story shear type building		Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
10	Amjadian and Agrawal, (2019)	Semi-active control, Seismic base isolation, stick-slip motion, energy dissipation, electromagnetic force, friction,	Electromagnetic friction damper is one type of the semi active dampers that is commonly used in seismic control of structures. In this article, multi-story base-isolated buildings are evaluated for the control of structure.	Electromagnetic friction damper enables to limit the base floor displacement by reducing inter-story drifts and absolute acceleration.	6-story building	Comsol multiphysics	Does not cover
11	Yang and Zhang, (2019)	Lead-rubber bearing (lrb), seismic isolation, seismic safety assessment	For the purpose of the study, two prototype structures are established to analyze the seismic performance. They have different periods, axial loads and isolation geometry.	The axial and shear couple force influenced the behavior of lead rubber bearing dramatically. The analysis result shows that base-isolated buildings fail due to earthquakes.	5 and 15-story building	Opensees	Does not cover
12	Clemente and Martelli, (2017)	Seismic behavior, base isolation, seismically isolated structures, seismic monitoring	This paper focuses on the seismically-isolated strategic and municipal structures. These types of structures are compared with the residential building in terms of their earthquake performance under real strong ground motion excitation.	By the monitoring of the base isolated structures, it can be obtained that development of isolation is needed in implementation of structures in future.	4-story R. C. residential buildings	Does not mentioned	Construction cost, intervention cost, retrofit cost
13	Zhao et al., (2019)	Floor response spectrum, dynamic analysis Isolation system, mainshock-aftershock,	To analyze behavior of the nuclear power plant called as AP 1000, a finite element model is used for seismic isolation by using main and aftershock of earthquake event.	The results show that the displacement and acceleration response of seismically isolated structures are far less than the fixed base structures under both earthquake excitations.	Ap1000 nuclear power plant buildings (nppb)	Does not mentioned	Does not cover
14	Lee and Kelly, (2019)	Damping, bilinear model, base isolation, elastomeric bearings	In order to determine the response of the isolated superstructure which has an isolation system using a linear spring and linear viscous damper.	It is not certain that if the analysis results are accurate. The reponse may not be predicted. The isolation system can fail if the superstructure is experiencing high-frequency vibration.	The 2 dof model using linear spring and linear viscous damper isolation system	Does not mentioned	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
15	Kohiyama et al., (2019)	Base isolation, lqg control, semi-active damper, system identification	According to the strong ground motion record of 2011 Tohoku, the structural models are updated to perform a dynamic response analysis by the help of the fragility curve.	For minimizing the probability of hazards, dampers especially semi active ones are used. These dampers reduce the hazards probability by 4%.	9-story (2 below ground) steel, steel-r.c., and concrete-filled steel tube	Does not mentioned	Does not cover
16	Almusbahi and Güngor, (2018)	Structural analysis, Ansys, isolation system, seismic wave, hybrid composite, seismic wave	Hybrid isolation system is analyzed and implemented to a 40-story structure for retrofitting structures.	It can be preferred to use isolation system for enhancing the performance of a 40 story strcuture.	40-story structure	Ansys	Does not cover
17	Ye et al., (2019)	Direct displacement-based, second degree of freedom model, base-isolated building structures, lead rubber bearings (lrbs), 2dof model	A direct-displacement based design (ddbd) procedure is proposed in order to satisfy the performance objectives prescribed by displacement thresholds.	It can be easily seen that the proposed procedure helps to reach the performance objectives.	3-story building modeled as 2 dof	Sap2000	Does not cover
18	Amin et al., (2019)	Story-drift, Base isolation system, response spectrum, drift, displacement, base shear	Eurocode (EC8) is a specification that is used as guidelines for seismic design of structures. According to this specification, 10-story structures are designed by using standard design of BS8110	Benefit of seismic isolation usage is improvement in the seismic behaviour. By using isolation technique, there are reductions in story drifts, lateral displacement and base shear	10-story rc structure	Staadpro software.	Does not cover
19	Xu et al., (2019)	Friction pendulum, high-rise building, dynamics analysis, optimization, triple friction pendulum bearing	There are different pendulum paramaters that affects the earthquake behaviour. To find an optimal solution, an equation is established according to the study results.	For high-rise buildings, isolation with triple friction pendulum bearing (tfpb) is recommeded to get better results. In terms of story drift, acceleration, response of hysteresis loop, the performance of tfpbs is better than using sfpbs.	33-story rc building	Sap2000	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
20	Ahmad et al., (2019)	Hysteretic model, high damping rubber bearing, hdrb, base isolation,	How to preliminary design high damping rubber bearings is presented by a simple method, this method is convenient with design specification of ASCE 7-16.	The stiffness decreased by about 70% at the maximum lateral displacement capacity. It is observed that only rubber materials with their damping can enhance the isolation system's damping.	3-story reinforced concrete moment frame structure	Seismostruct	Unit cost
21	Naderpour et al., (2019)	Base isolation; structural pounding; seismic gap; non-linear analysis	2 separated 5-story and 8-story seismic-isolated and fixed base buildings aligned in three different axes have collapsed together. This study analyses this case.	If the gap size increases, the behavior of the base-isolated building has smaller response, and this trend is observed up to the gap size large enough to prevent collision. The increase in the response is bigger as the heights of both colliding structures are close to each other.	5-story and 8-story buildings	Does not mentioned	Does not cover
22	Kitayama and Constantinou, (2019)	Base isolation, friction pendulum isolator, moat walls, displacement restraint, collapse probability	The article mainly concentrates on seismically isolated structures collapse performance.	A balance between the value of r_I and the displacement capacity of the isolators are needed for proper design. This work indicates that some form of drift restraint is significant in isolation systems to inhibit collapse of the seismic isolators and the possibility of failure of the base isolated building.	6-story steel buildings	Opensees	Does not cover
23	Mazza (2018)	Elastomeric bearings, ageing effects, air temperature effects, seismic analysis, fragility curves, nonlinear sliding bearings	Seasonal thermal variations change the temperatures, this paper investigated properties that are affected by these changes. According to nonlinear dynamic analysis, fragility curves are formed for seismic isolation.	The ductility demand rises for increasing values of the ageing time of the elastomeric isolation system. The response of the high-damping rubber bearings (hdrb) are affected by the process of ageing leading to a decrease of seismic and total shear strains and a rise of the critical buckling load.	6-story–reinforced concrete building	Spector	Does not cover
24	Dao et al., (2018)	Isolation system model of computation, isolation system, test table, shear-frame model, triple friction pendulum bearing	The ability of simplified superstructure models are evaluated by using two shear frame models and a single-story model. Global responses of a full-scale five-story steel moment-frame buildings are analyzed	The response of the shear model and 3d model are compared. Results are almost identical. The computational models forecast that the peak displacement subjected to x-y motions are better than 3-D motions.	5-story steel moment-frame building	Opensees	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
25	Fujii (2019)	Modal response, seismic-isolated building; pushover analysis, member force	The study aims to predict the highest earthquake member force of 5- and 14-story RC base-isolated frame buildings by performing pushover analysis.	After the pushover analysis, the maximum predictive member forces are satisfactorily accurate, only the first mode is inaccurate.	5- and 14-story reinforced concrete frame building	Does not mentioned	Does not cover
26	Bhandari et al., (2019)	Seismic isolation; lead rubber bearing, near-field earthquakes; incremental dynamic analysis, fragility analysis, hazards states.	By conducting a fragility analysis, the current examination focus on probabilistic seismic risk assessment of a seismically-isolated building frame under near- and far-field earthquakes.	The seismic isolation frame is very susceptible to near-field earthquakes. Basic isolation is very effective in reducing interstory drift ratio (MIDR), maximum base shear (MBS) in far-field earthquakes, but it is less effective in near-field earthquakes.	10-story reinforced concrete frame	Sap2000	Does not cover
27	Dang et al., (2014)	Seismic behavior, seismic isolation, life-cyle cost	This document proposes a seismic performance index based on the life cycle cost of a building. It is expressed as the relationship between the damage loss during the useful life and the life cycle cost and determines the seismic behavior of isolated buildings.	The initial cost of the isolated case is 1% higher than the initial cost of the corresponding fixed base case. The expected loss of isolated buildings is only 37% of fixed base buildings. In addition, the life cycle cost of isolated buildings is reduced to nearly 1% of fixed base buildings.	7-story hospital building with a reinforced-concrete frame	Does not mentioned	Life-cycle cost, initial investment cost, maintenance cost, repair cost
28	Mousazadeh et al., (2020)	Full factorial design, life cycle cost analysis, base isolation, cost model, multi-objective optimization, , analysis of variance, endurance time method	The purpose of the framework is to minimize the initial and life cycle costs of construction, while improving the seismic performance of the base isolation structure.	The optimization results show that the initial cost and the life cycle cost may be different. If the initial cost is slightly increased, the life cycle cost can be greatly reduced. The provided examples emphasize on the importance of correct design, and the proposed method can be used to deal with these issues systematically.	6-story steel moment-resisting frame	Opensees	Life-cycle cost model, initial cost, total cost, cost-benefit analysis, detailed cost component evaluation
29	Mitropoulou and Lagaros (2016)	Seismic isolation, life-cycle cost analysis, performance-based design, optimization for structure, probabilistic dynamic loading,	This study carried out a critical evaluation of optimized fixed and insulated base reinforced concrete buildings, taking into account the initial and total life cycle costs.	Compared with the fixed structure, the isolated structure shows a more flexible response, in which the frequency is lower. Compared with the corresponding structure with high damping bearing, the initial cost of the isolation structure with lead rubber bearing is lower.	3 and 6-story rc frame	Opensees	Initial cost, life-cycle cost, operational cost, construction cost, potential damage cost

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
30	Li et al., (2019)	Bearing models, base isolation, hybrid base-isolated system	A novel framework based on dynamic substructures is developed to analyze bi-mixed systems with integer and fractional order differential equations. To demonstrate the framework, the seismic response of the multiple degrees of freedom construction model and the fractional derivative state space model of the control base isolator were obtained.	The fractional derivative Zener (fdz) system is compared with the fıx and elastomeric systems. Compared with the fıx system, these two systems can significantly reduce the natural frequency, and the damping ratio of the fdz system is even higher than that of the ela system. The evaluation standard data shows that the fdz system can simultaneously achieve smaller lateral structural response and horizontal displacement of smaller supports.	8-story benchmark building with 92 high-damping bearings	Does not mentioned	Does not cover
31	Fukasawa and Kanno, (2019)	Pounding, seismic-isolated building, non-smooth mechanics, linear complementarity problem, programming, measure differential inclusion	They proposed a formula and a numerical simulation method for earthquake-induced collisions between the seismically isolated building structure and the surrounding moat wall	It can be seen that the difference in the coefficient of restitution has little effect on the mechanical energy of the structure. Therefore, a rough estimate of the coefficient of restitution can be used in the numerical simulation of earthquake effects.	N-story shear building model	Does not mentioned	Does not cover
32	Kapasakalis et al., (2019)	Base isolation, kdamper, stiffness, seismic protection, vibration absorption, damping	The realization of kdamper is considered a seismic absorption base (kdab). The performance of kdab is evaluated in three typical test cases, namely a rigid body and two flexible buildings with basic periods of 0,5 and 1,0 s, respectively.	The kdamper can be used as an alternative to the traditional base isolation system, or as a "rigid absorption base", to overcome the shortcomings of the isolation method, leading to new seismic technology.	5-story and 10-story concrete building structures	Seismoartif	Does not cover
33	Karimi and Geneş, (2019)	Hazard limit, two-factor factorial design, lead core, rubber bearing, seismically isolated building	The specific purpose of this study is to evaluate the seismic response of multistory buildings with insulated base with lead rubber bearings (lcrbs) and non-insulated buildings when subjected to different types of ground movements with different components.	Compared to the fixed base building, the top displacement of the three pga / pgv values is significantly reduced. As the number of stories increases, the ratio of base insulator displacement to pgd is inversely proportional to the ratio of top story displacement to pgd. For different high-rise base insulation buildings, in the three pga / pgv cases, the acceleration of the insulation system with reference to pga is reduced by about 55%.	5, 10, 15, 20, 25, 30 and 35-story steel building	Matlab	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
34	Li and Conte, (2019)	Prototype bridge; base isolation; track-structure interaction; soil-structure interaction; probabilistic seismic response analysis; uncertainty quantification	This article compares the probabilistic seismic response of the California High Speed Rail (chsr) prototype bridge with and without seismic isolation. The uncertainty of the seismic response of the isolated bridge and the non-isolated bridge was quantified and compared to explore the influence of each other when considering the uncertainty of the seismic input.	The advantages and disadvantages identified in probabilistic terms need to be weighed when applying to hsr bridges.	Prototype bridge	Opensees	Does not cover
35	Xu et al., (2019)	Base isolation, floor response spectra, isolation characteristic parameters, nuclear power plant, performance spaces	The finite element method is used to simulate the new generation of passive nuclear power plant model. The acceleration response, deformation, damping efficiency and response degree of freedom of nuclear structures with different characteristic isolation parameters are analyzed.	The results show that the isolation system greatly reduces the average and dispersion of the seismic response of the nuclear structure.	New generation passive nuclear power plant model	Abaqus	Does not cover
36	Najafijozan et al., (2020)	Earthquake, seismic risk, seismic protection, equipment isolation, equipment fragility	This work aims to evaluate the benefits of adaptive vertical isolation systems for components, especially in nuclear power plants (NPP).	Due to the high-frequency component of the vertical component of ground motion, regardless of the lrb design, the equipment at the highest level of the internal structure of the nuclear power plant will experience greater vertical acceleration.	Nuclear power plants	Opensees	Does not cover
37	Arı, S. (2019)	Aashto guide specifications, design of bridges, seismic isolation design	The pathways given in the aashto has been followed to design of a seismically isolated posttensioned girder bridge.	It has been showed that analysis with elastic methods (after some iterations) produces close results with time history analysis. It shows that elastic solution methods are beneficial tools in design process and quite trustworthy for non-complex structures.	Bridge	Sap2000, seismomatch	Does not cover

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
38	Çavdar, E. (2019)	Base isolation, LRB (lead rubber bearing), scaling of ground motion, mass eccentricity, ground motion excitation angle	This study focuses on the parameters that are involved in the applied scaling procedure of ground motions, in order to determine the variation in amplitude of scale factors. Then, sensitivity of these parameters was examined by means of nonlinear dynamic analyses.	Determining the number of spectral values as 3, 5, and 10 within the period range in which the scaling will change the mid values by a maximum of 4%.	3-story steel frame	Opensees	Does not cover
39	Gazi, H (2015)	Earthquake engineering, seismic base isolation, probabilistic analysis, reliability analysis, performance tests, monte carlo simulation technique, 3-D basis	The aim of this dissertation is to investigate the dynamic response and reliability of the three-dimensional base isolated buildings, which are modeled by considering the probable variances in the nominal design values of the mechanical parameters of nonlinear isolation systems	It is observed that the probability of failure in terms of displacement monotonically increases as the magnitude of the earthquake increases, the distance of the fault line decreases, the isolation periods increase, and the characteristic force ratios decrease. As the earthquake magnitude of the failure probabilities in terms of acceleration increases, the fault line distance decreases, the isolation system period decreases and the characteristic force ratios increase, the failure probability increases.	3-story rc structure with steel braces	3d-basıs, sap2000	Does not cover
40	Kök, S. (2014)	Base isolation, structural design, earthquake resistant design	In their study, after giving general information about earthquakes, isolation systems were introduced, and the regulations and some applications used in the countries that are pioneers in the application of this system in the world were introduced.	As a result of the examinations, the performance targets expected from the isolator were determined by taking into account the architectural design aspect. Cost, time and design analysis of isolated structures were made.	11 seismically isolated structures	Does not mentioned	Does not cover
41	Cardone et al., (2017)	Seismic rehabilitation; base isolation; masonry infills and partitions; fragility function; loss functions; expected annual loss; breakeven point	In this study, alternative modernization strategies were investigated to reduce monetary losses in RC frame buildings. According to the time-based evaluation method proposed in the fema guideline p-58, the expected annual loss (eal) of some buildings with a rc structure was evaluated before and after the restoration.	Regardless of the number of floors in the building and the type of isolation system considered, seismic isolation can reduce the expected direct loss by approximately 80-90%. The cost of seismic isolation pays for itself over a period of 7 to 13 years, depending on the height of the building.	4,6 and 8 story archetype rc frame buildings	Sap2000	Cost-benefit analysis, initial cost, unit repair cost, repair/replacement cost

No	Reference	Study parameters	Focus	Findings	Structural type	Software used	Cost
42	Yu et al., (2017)	Nuclear plants, base isolation, seismic probabilistic risk assessment, cost	Perform a probabilistic seismic risk assessment to calculate the average annual frequency of unacceptable performance. The cost of handling seismic loads is estimated for the general nuclear facility(gnf) in the traditional foundation and the isolated gnf with foundation	The two potential benefits of seismic isolation considered here are 1) increased safety (or reduced risk) and 2) lower cost of overnight capital cost and structures, systems and components. The GNF benchmark cost, excluding consideration of the effects of seismic vibration, was approximately US $ 550 million in 2016.	2-story rc building (generic nuclear facility)	Does not mentioned	Construction cost, capital cost,
43	Han et al., (2017)	Probabilistic analysis; seismic behaviour assessment; uncertainties; risk; loss; downtime; fatality; mainshock; seismic isolation; RC frame building	One possible transformation strategy is basic insulation, which has many advantages, but due to its high cost, it has not been used routinely in the United States. Determine if foundation insulation is economical by comparing benefits and costs	The benefits may outweigh the cost of the upgrade. The impact of indirect losses caused by downtime and death on the results is quantified and shows a huge impact.	3-story and 6-story buildings	Opensees	Cost-benefit analysis, retrofit cost, repair cost

3. NUMERICAL EXAMPLE

In this section, information on the numerical example is presented. The example building performance is evaluated in terms of earthquake behavior and project cost.

The model is composed to analyze the earthquake behavior according to the specifications in the TBDY 2018 which is the current earthquake code in Turkey.

Moreover, structural system does not include shear walls. The model can be considered as frame system. Frame system is basically defined as a structural system that contains only colums and beams. Effective stiffness factors of reinforced concrete structural system elements are chosen for columns and beams as 0,7 and 0,35 in a respective way.

The building is modelled and time history analysis is performed in SAP 2000 software. Figure 3.1 indicates the 3D view of the model.

3.1 Structural Material

Concrete is being used for a long time and it will continue to be used in the coming years as structural material in the Turkish construction sector. The structural material of the buildings is mostly preferred as reinforced concrete since Turkey has a strong cement industry which ranks as the first in Europe and the sixth in world in terms of production capacity. Therefore, the building material is chosen as reinforced concrete.

The usage of concrete with a compressive strength less than 25 MPa (C25 concrete) is prohibited by the TBDY 2018 specification for all type of structures that are going to be build in Turkey. In this study the compressive strength of concrete is chosen as 30 MPa. In other words, C30 concrete is used for the building model. The elasticity modulus of C30 concrete is defined as 32000 N/mm^2 in SAP2000. Additionally, specification forces the design engineers to apply a safety factor to the structural

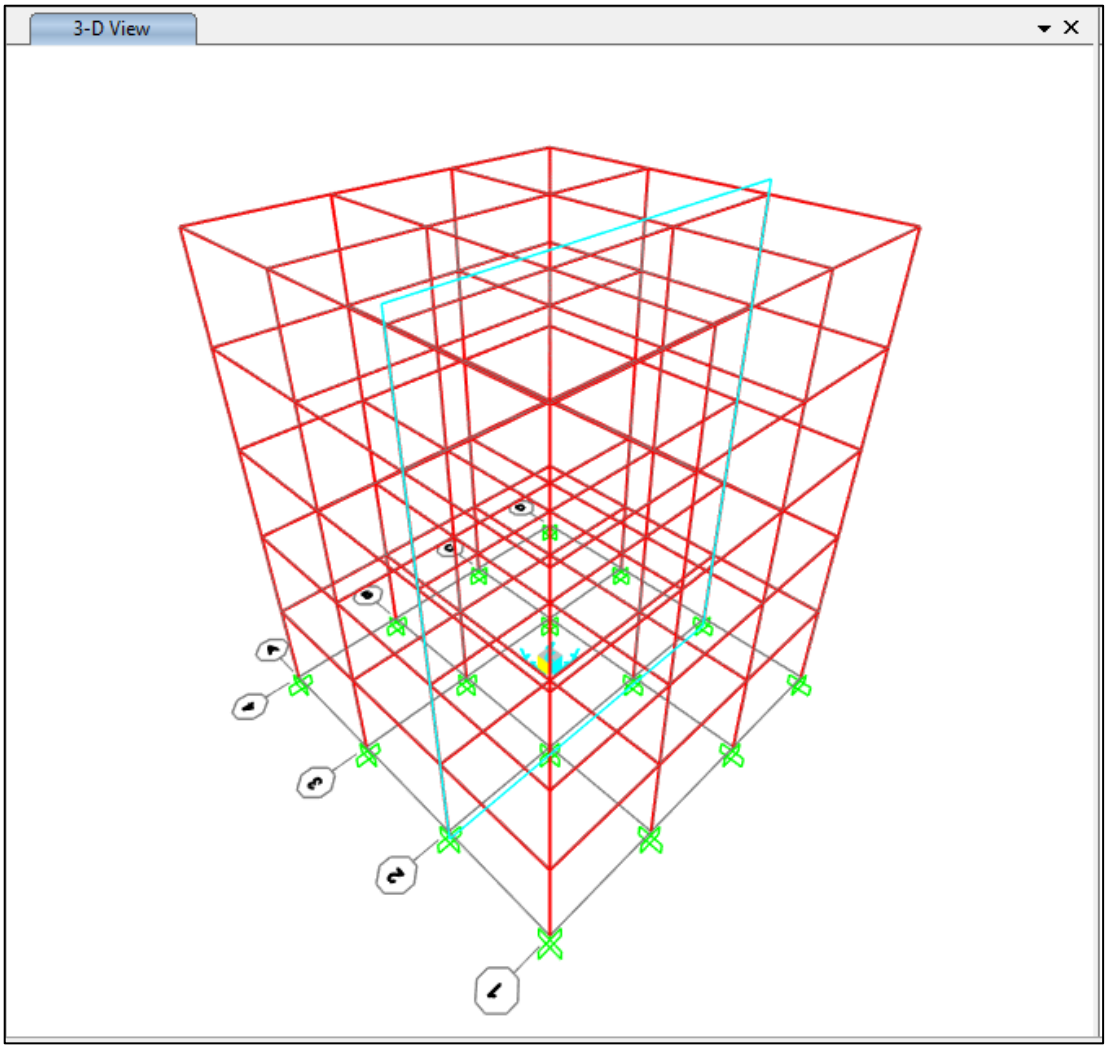

Figure 3.1 : 3D View of 5 story fixed-base building.

material. The safety factor for concrete is defined as 1,5 in the code. During the definition of the material properties in SAP 2000, this value is used. For the seismically isolated case, lead rubber isolators are chosen and modelled in SAP2000 as link/support properties. The rubber diameter of seismic isolator is 500 mm. Total overall height including external plates is 167 mm. Overall plate size is 550x550 mm. Total rubber thickness 77 mm. While the vertical stifness is 885 kN/mm, the effective horizontal stiffness 1,6 kN/mm.

3.2 Number of Story, Dimensioning and Floor Plan

Majority of the buildings especially in the city of Istanbul are five or six-story residential buildings. This is a challenging situation for engineers who are responsible of designing earthquake resistant structures. Considering the seismicity of these buildings, clearly it can be seen that five or six-story buildings are affected by the

earthquakes significantly due to their natural periods. The primary parameters that are related with the natural periods are mass and rigidity. Rigidity depends on the height of the structural elements. Factors mentioned above are directly and indirectly related with the natural period of the building. In addition, this concept highly influences the seismic behaviour of the structure. Therefore, the building that is analyzed in this section is chosen as five-story residential reinforced concrete structure.

Dimensions of the structure are chosen as 12x12 meters in plan. There are 4 axes in both x and y-direction. The distance between axes is 4 meters. Figure 3.2 shows the floor plan of the building.

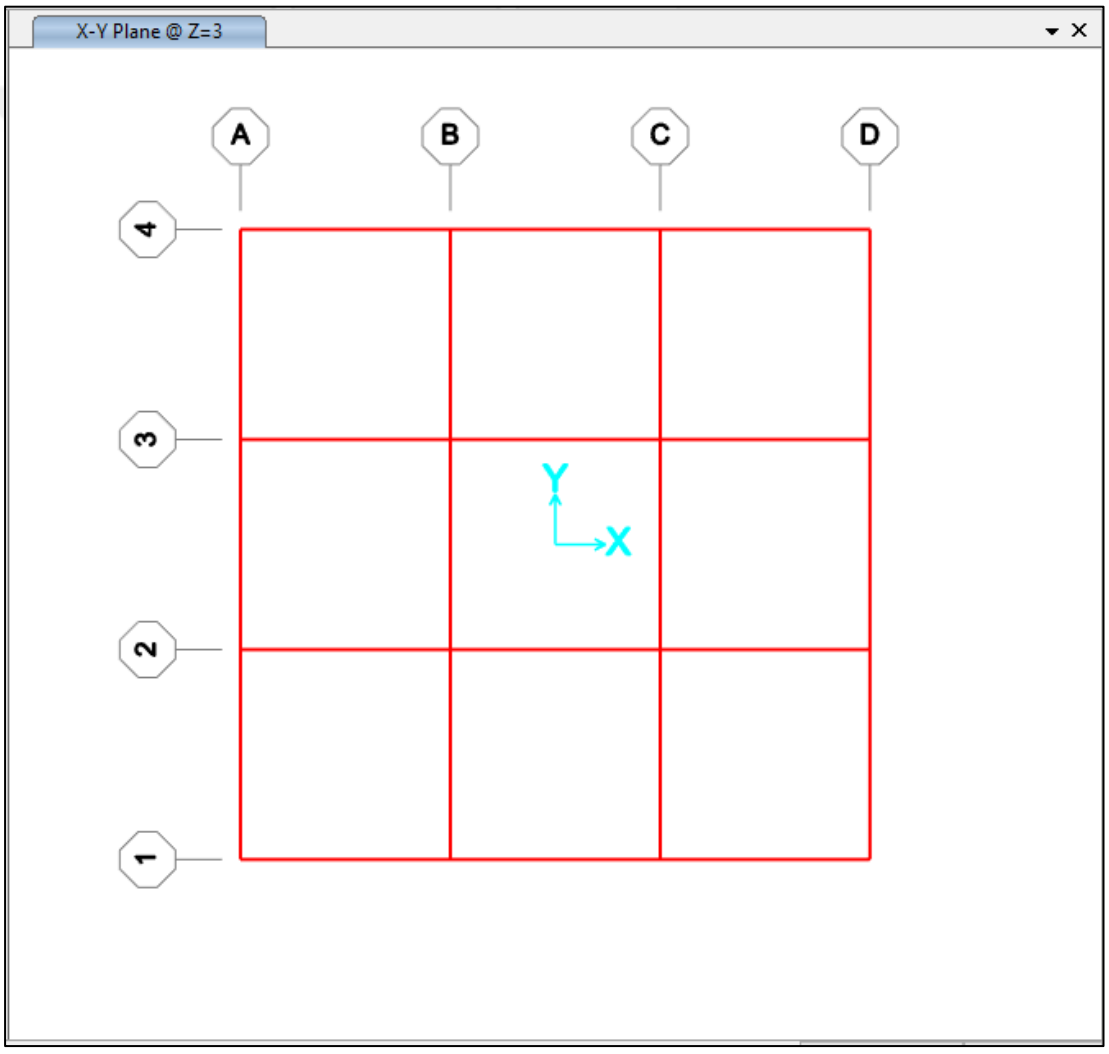

Figure 3.2 : Plan view of 5 story fixed-base building.

TBDY 2018 informs that the structure plan should be simple to foresee the seismic behaviour of the building. Besides simplicity, it is also recommended that eccentries in terms of mass, rigidity and strength should be avoided. Moreover, a predictable earthquake behaviour can be achieved by alining the structural system basically and

symmetrically. So, symmetricity is being preferred to eliminate eccentricity, the dimensional and directional effets. While the dimesions of columns is selected as 60x60 cm, beams are modelled as 30x60 cm. Lastly thickness of the slab is chosen as 15 cm.

3.3 Earthquake Used in the Analysis

In this section, information about the earthquake used in the analysis will be given. Turkey is located on a seismically active region that has plenty of different types of faults. One of them is very well-known North Anatolian Fault (NAF) that generates very destructive earthquake. Düzce Earthquake that occured on 12 November 1999 with a moment magnitute of 7,2 is used in this section. Since the NAF fault is a right-lateral strike-slip fault, East-West component of this earthquake is chosen for the time history analysis.

3.3.1 Earthquake record processing

Earthquake records have to be processed due to several reasons before the analysis. Databases have mostly raw motions, and they include some parts that needs to be revised by primary processing operations. Processing of an acceleration record is necessary to eliminate the numerical errors because of integration. It is not entirely possible to identify undesirable parts which are called noise. It is also not possible to remove these parts from the actual ground motion record.

To cope with this situation, those portions can be identified by frequency content. And contaminated frequencies can be removed by data processing operations. It should be mentioned that these operations do not correct the ground motion data, the most useful information is retrieved through a suitable processing.

First step of strong ground motion processing is baseline correction. After the ground shaking, it is an undeniable fact that the ground velocity must be zero. However, it is not valid for the final displacement because the ground can experience permanent deformation. Figures 3.3, 3.5 and 3.7 show raw data time histories which are acceleration velocity and displacement.

Secondly, frequency filtering is being employed to eliminate spectral noise that can be defined as unwanted frequency component from a chosen accelerogram. There are

mainly three types of filtering methods for engineering seismology purposes. These are Low-Pass Filtering, High-Pass filtering and Band-Pass Filtering. Band-Pass (BP) Filtering is used in this study. BP Filtering allows the stated frequency range to pass through. Thanks to the Fourier Amplitude Spectrum, spectral noise can be investigated in a desirable way. Final versions of applied BP filtering to the baseline corrected record time histories are shown in Figures 3.4, 3.6, and 3.8.

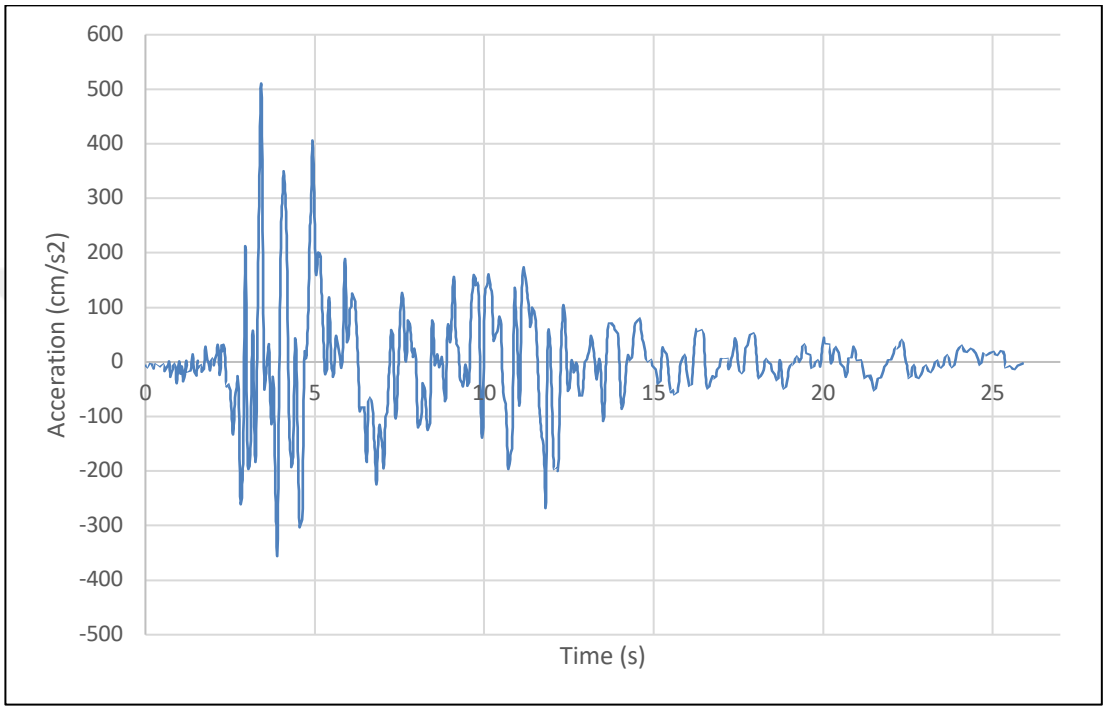

Figure 3.3 : Raw acceleration time history.

Strong ground motions record of Düzce Earthquake is taken from General Directorate of Disaster Affairs (AFAD) website. Number of data is 5182. Sample interval is 0.005 second.

For engineering purposes, Ground motion intensity measures are very useful parameters. Time series are the most common tools to define the earthquake ground motion. There are three peak values for acceleration, velocity, and displacement. These numbers enable us to rough evaluation of the earthquakes. The peak ground acceleration (PGA) measure as 513,78 cm/sec^2 in the raw form. Corrosponding peak ground velocity and displacement are 90,78 cm/sec, 422,36 cm respectively.

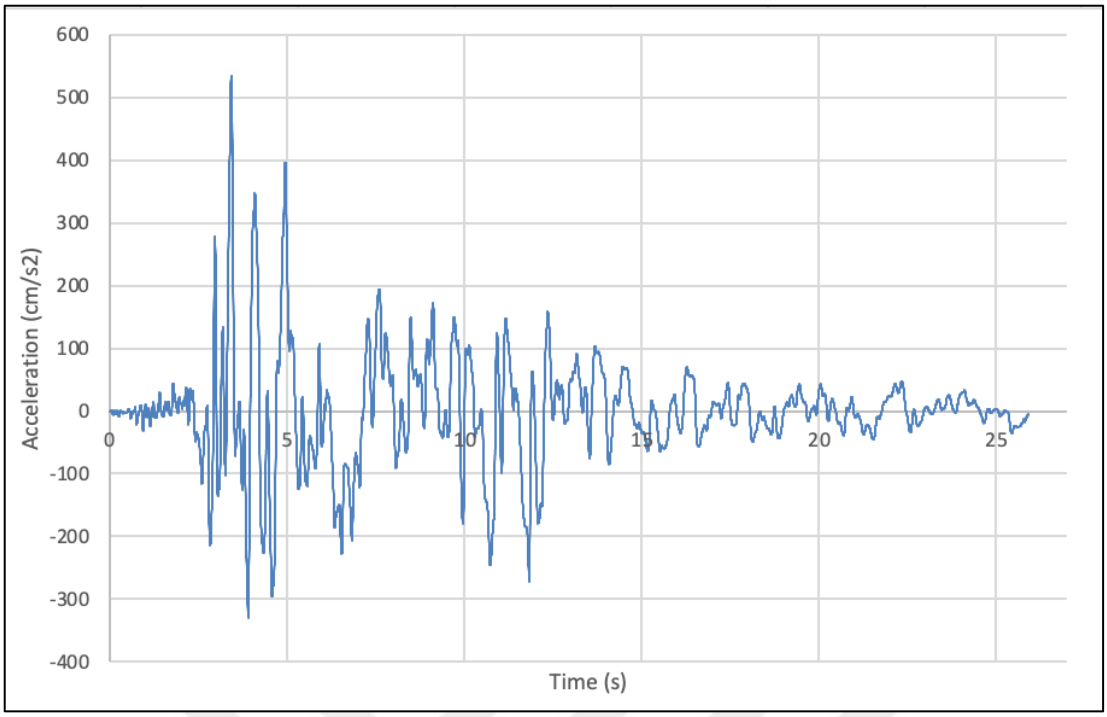

Figure 3.4 : Processed acceleration time history.

As mentioned before, some numerical errors must be eliminated wtih suitable operations. After these opereations are processed, we got the new peak ground values. Ground velocity needs to be returned to zero after the earthquake shaking is stopped. It can be clearly seen at Figure 3.6 that the PGV decreased from 90,78 cm/sec to 82,29 cm/sec after integration.

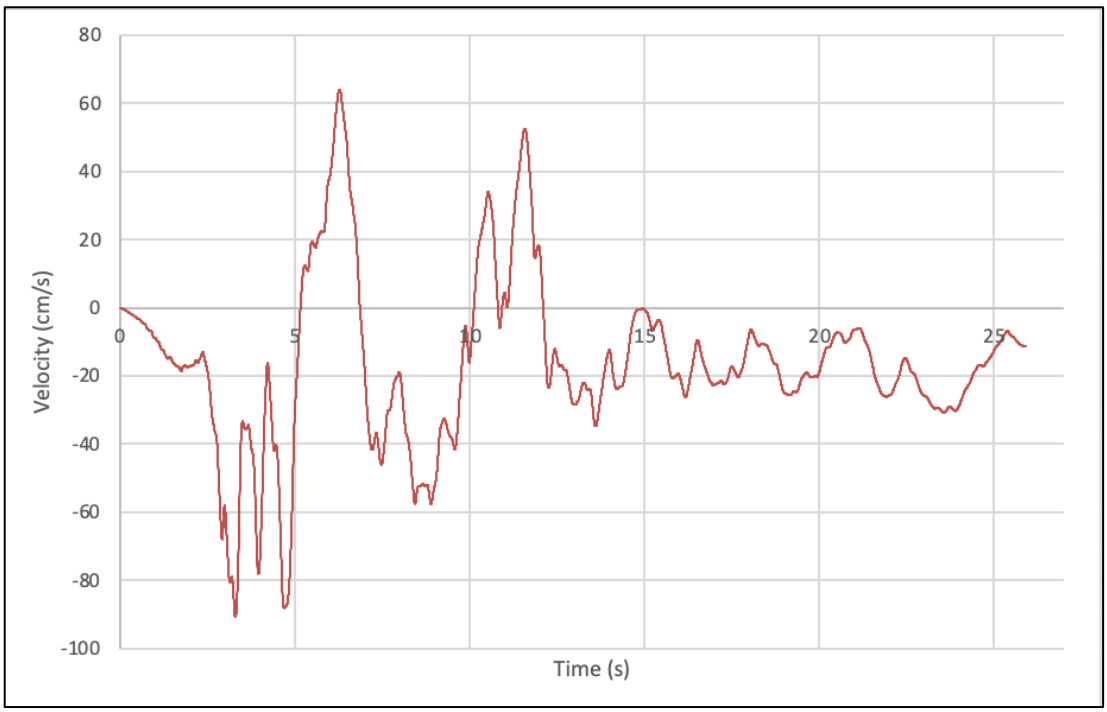

Figure 3.5 : Raw velocity time history.

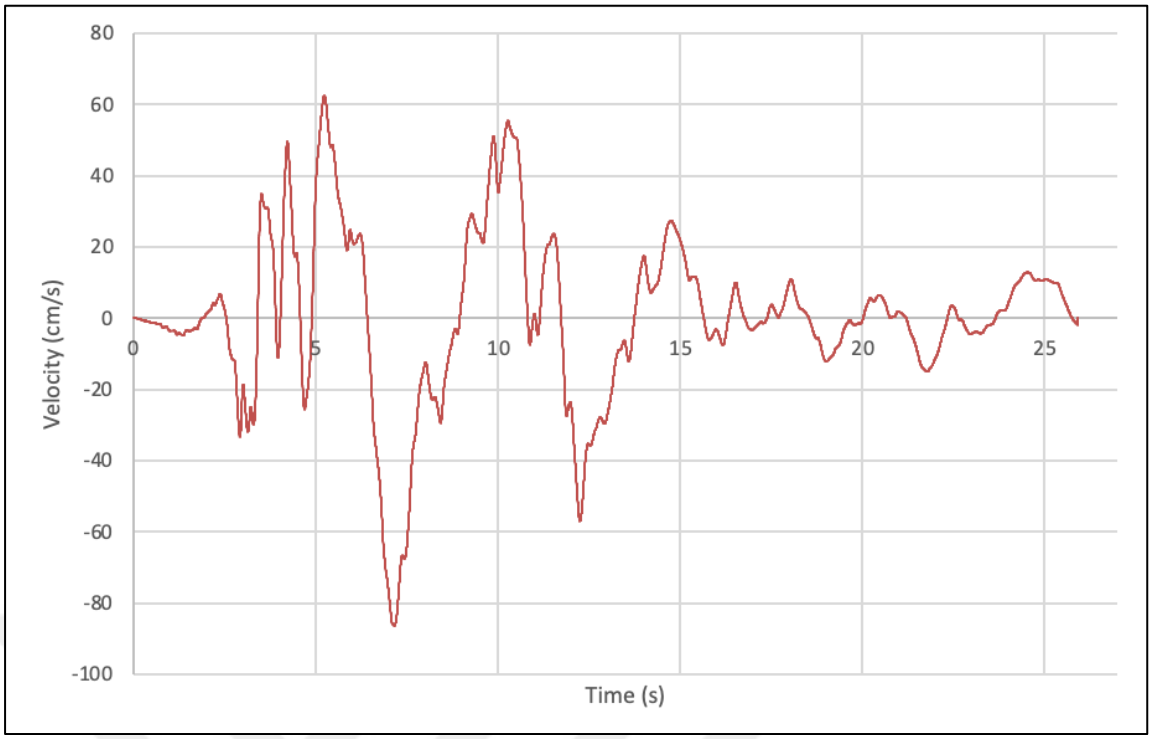

Figure 3.6 : Processed velocity time history.

Basically, displacement time history gives us information for deformation of the ground. In contrast to the ground velocity, it can be returned to zero. If the ground undergoes permanent deformation, the final ground displacement will be non-zero as seen at Figure 3.8.

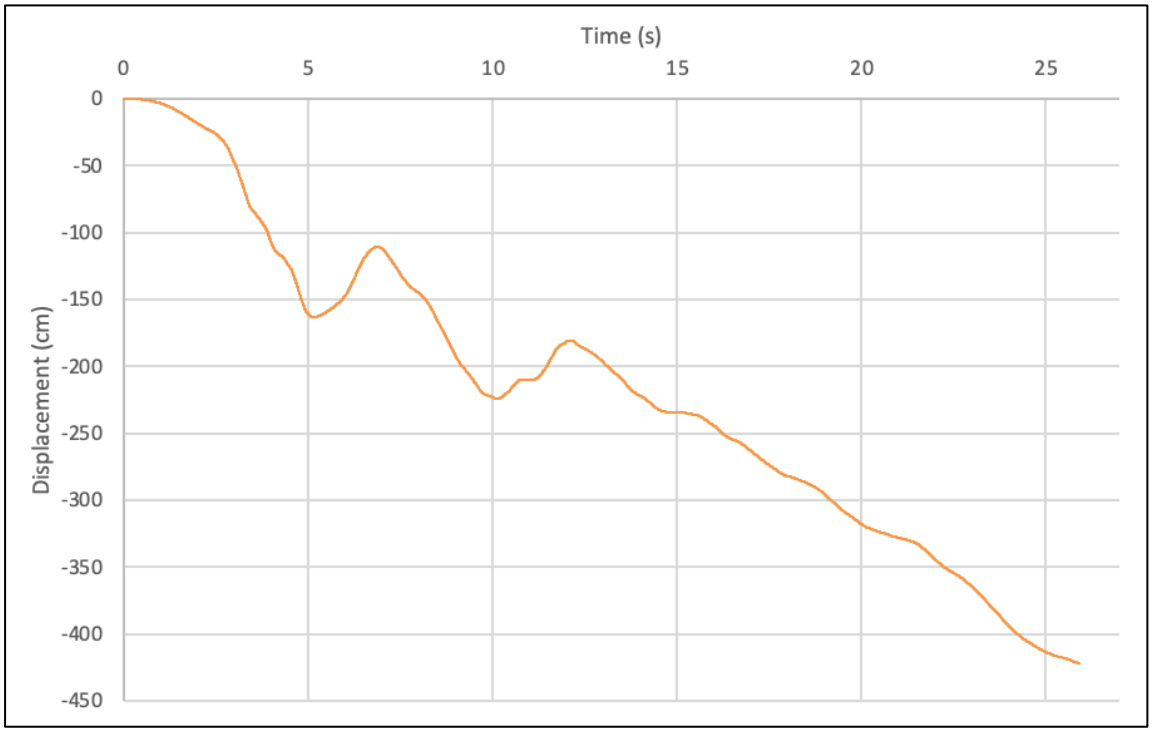

Figure 3.7 : Raw displacement time history.

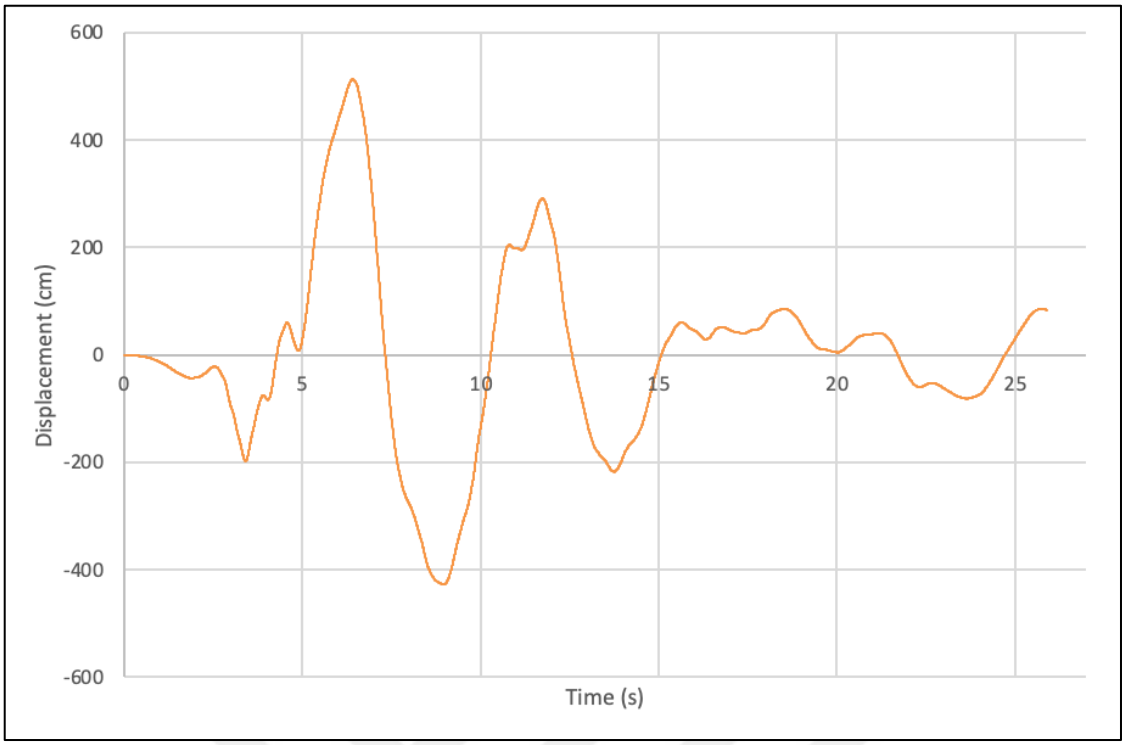

Figure 3.8 : Processed displacement time history.

3.3.2 Forming response spectrum

The standard response spectrum forming procedure is explained in the TBDY 2018. Unitless spectral acceleration coefficients are described for four different earthquake ground motion levels. These levels are DD-1, DD-2, DD-3 and DD-4 in the scope of Turkey Earthquake Danger Maps. In addition, local soil effect coefficents are defined for short term period and 1,0 s period. By directly multiplying these two coefficients design spectral acceleration coefficients are obtained.

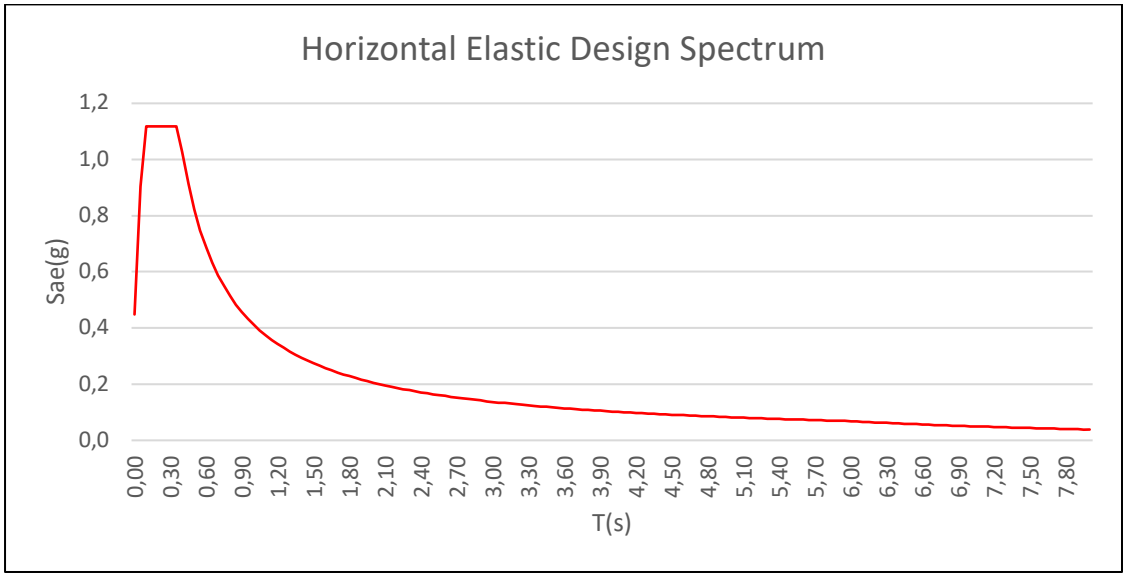

Figure 3.9 : Horizontal elastic design spectrum.

Cooradinates of 41,013962° and 28,925446° are chosen as the location of the structure. This location's local soil class is ZC. This class refers to very tight layers of sand, gravel and hard clay or weathered, weak rocks with very cracks. In the light of these information, horizontal elastic response spectrum is established for DD-2 earhquake ground motions level.

TBDY 2018 indicates that earthquake records should be scaled or transformed to match horizontal elastic spectrum. Scaled time history of Düzce Earthquake is created as suggested by the code. It is shown in Figure 3.10. This record is used for both conventional and sesimically-isolated buildings to analyze the earthquake behaviour.

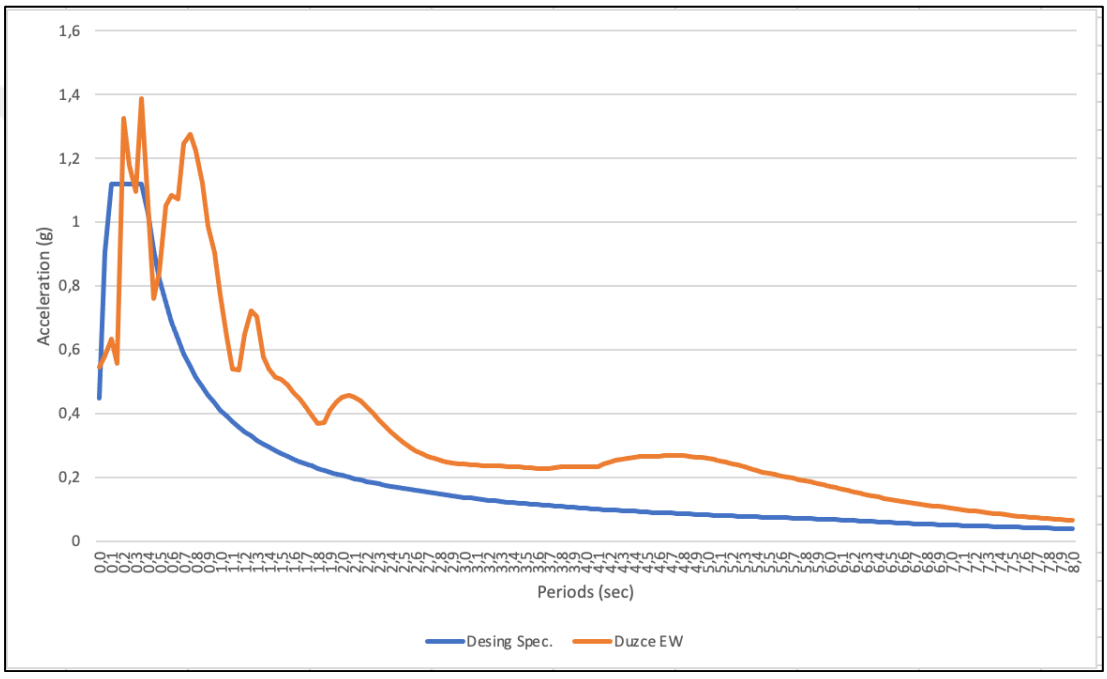

Figure 3.10 : Comparison design spectrum with Duzce EW spectrum.

4. DYNAMIC ANALYSIS UNDER EARTHQUAKE EXCITATION.

As stated before, two cases are compared within the scope of this thesis. The numerical examples are identical except the base condition. While the support condition is modelled as fixed support in Case 1, link support is preferred for modeling seismic isolation case which is Case 2. Fixed support restraints all degrees of freedoms. These freedoms are translations and rotations in 3 directions. For Case 2, model is revised by alternating support condition. This support is modelled as rubber isolator in SAP 2000.

4.1 Modal Periods and Frequencies

Earthquake analysis section covers the results of the analysis of the two different structure model in SAP 2000. The model is presented in a detailed way in the previous part. In earthquake engineering, the first phenomenon to take into account is the modal periods of the modelled structure. Table 4.1 shows the first 3 modal periods and the frequencies of the 5-story fixed base building, Table 4.2 presents the modal periods and frequencies of seismically isolated building.

Table 4.1 : Modal periods and frequencies of the FB building.

	Period (sec)	Frequency (sec^{-1})
Mode 1	0,4535	2,2049
Mode 2	0,4535	2,2049
Mode 3	0,3972	2,5178

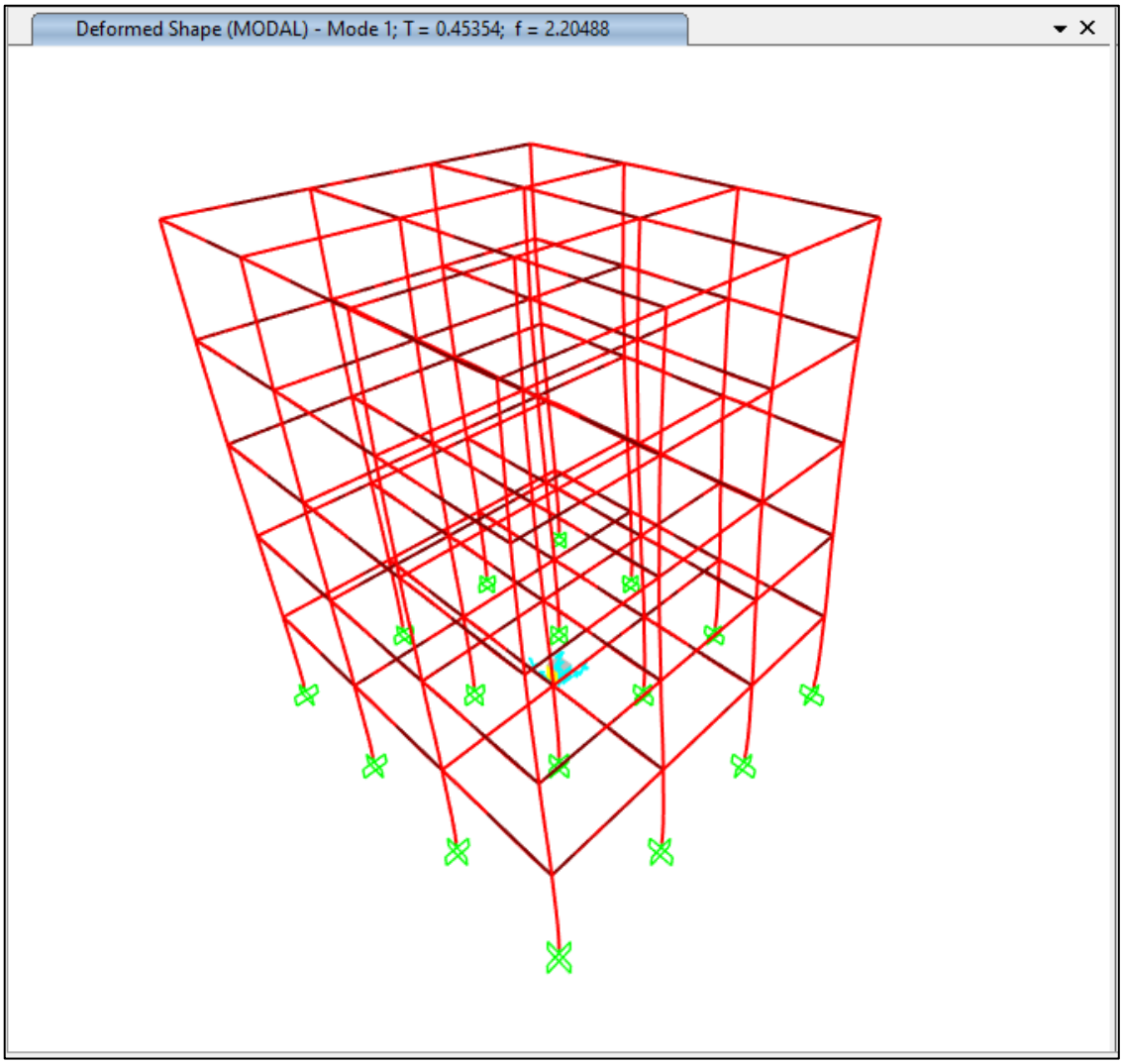

Figure 4.1 : Deformed shape of the FB building mode 1.

While the fundamental period of the FB building is approximately 0,45 sec, it is about 1,99 for the SI case. It was predicted before the analysis that the seismic isolator makes the period of the building enlarged. This is proved with the modal periods results given in Table 4.1 and 4.2.

Table 4.2 : Modal periods and frequencies of the SI building.

	Period (sec)	Frequency (sec^{-1})
Mode 1	1,9890	0,5028
Mode 2	1,9890	0,5028
Mode 3	1,8088	0,5528

4.2 Story Displacements

One of the key parameters in analyzing a structure for earthquake engineering discipline is the diplacement of the structure under an earthquake. To ensure the life safety of the residants, the story drift must be under control. Design engineers have to check the displacements to make sure if they are in the tolerable limits or not. The story drifts that are obtained from the analysis must not exceed the limits that are stated in the earthquake codes and specifications. After both models are analyzed, the results are obtained and reported in the following tables. The deformed shape of FB building is shown in Figure 4.2. Maximum Story Displacements of the fixed base (FB) and seismically isolated (SI) buildings are presented in Table 4.3 and 4.4 respectively.

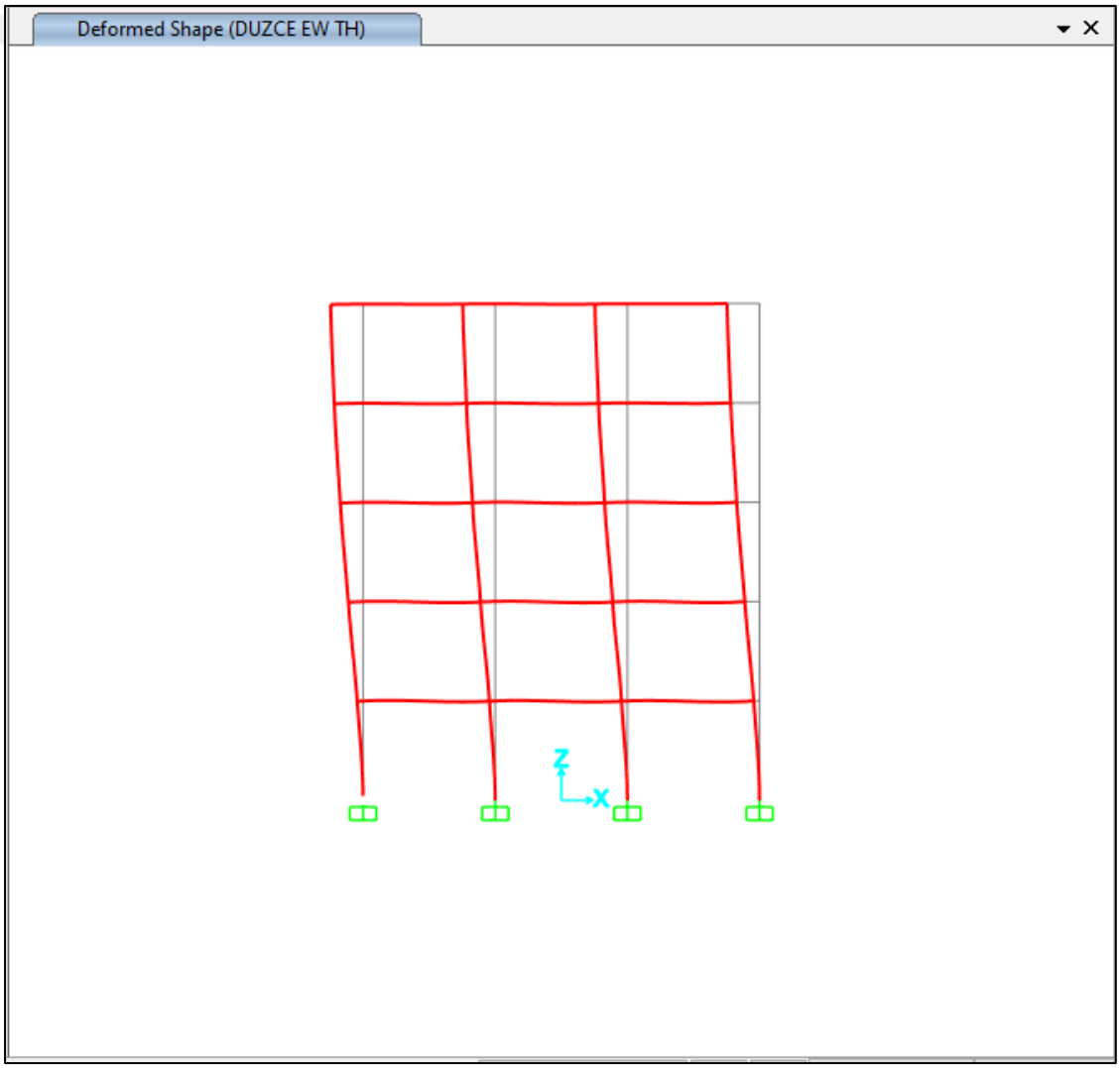

Figure 4.2 : Deformed Shape of the FB Building.

Table 4.3 : Maximum story displacements of the FB building.

Story Number	Maximum Story Displacements (cm)
1	1,7706
2	4,4643
3	6,8904
4	8,7193
5	9,8350

In seismically isololated design approach, it is expected that the maximum diplacement occurs in the isolation level. It can be clearly seen in Figure 4.3 that the isolators are displaced more than the other stories. The peak ground displacement of the East-West component of Düzce Earthquake measured as 427,7 cm.

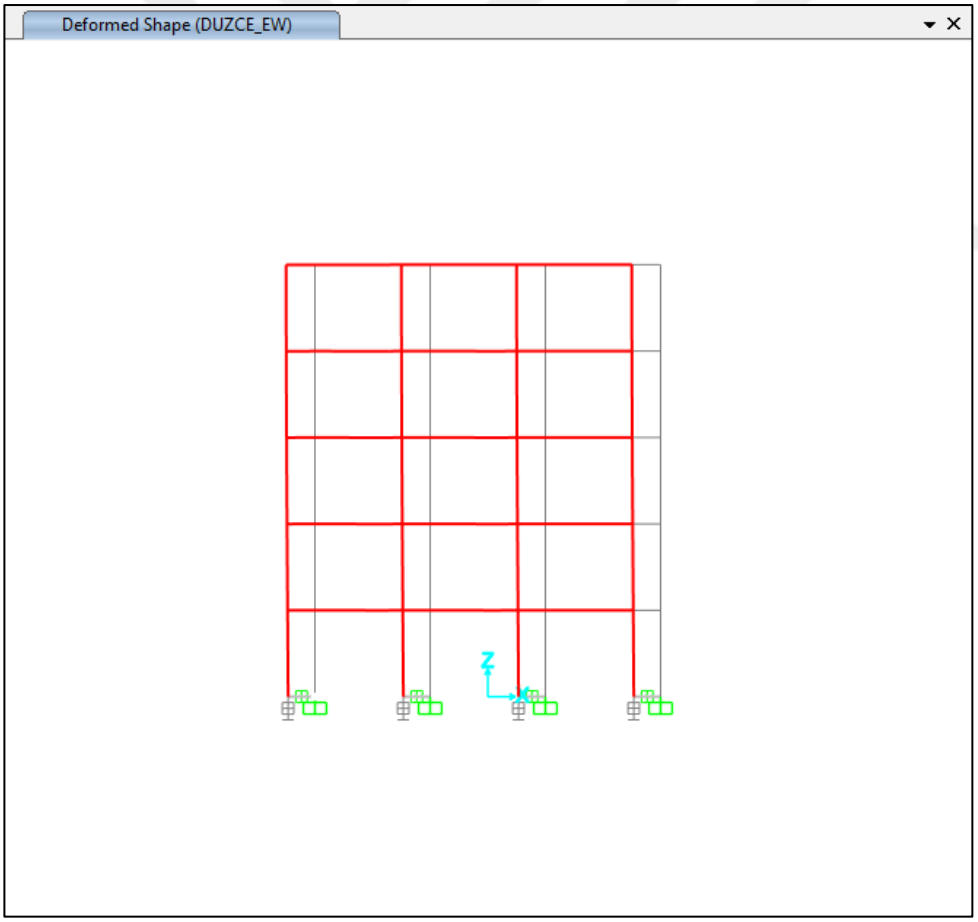

Figure 4.3 : Deformed shape of the SI building.

According to the results of the analysis, the displacement of the isolation level is 93 cm. Figure 4.4 shows the displacement comparison for both cases. The isolation level displacement is substracted from each story while constructing this figure.

Table 4.4 : Maximum story displacements of the SI building.

Story Number	Maximum Story Displacements (cm)
1	94,8764
2	96,8397
3	98,4442
4	99,5697
5	100,2303

As expected, the changes between each story displacement are not the same. The difference in the first story is about 8%. This ratio is increasing while elevating from the first to fifth story. The change between fifth story displacements is 41%.

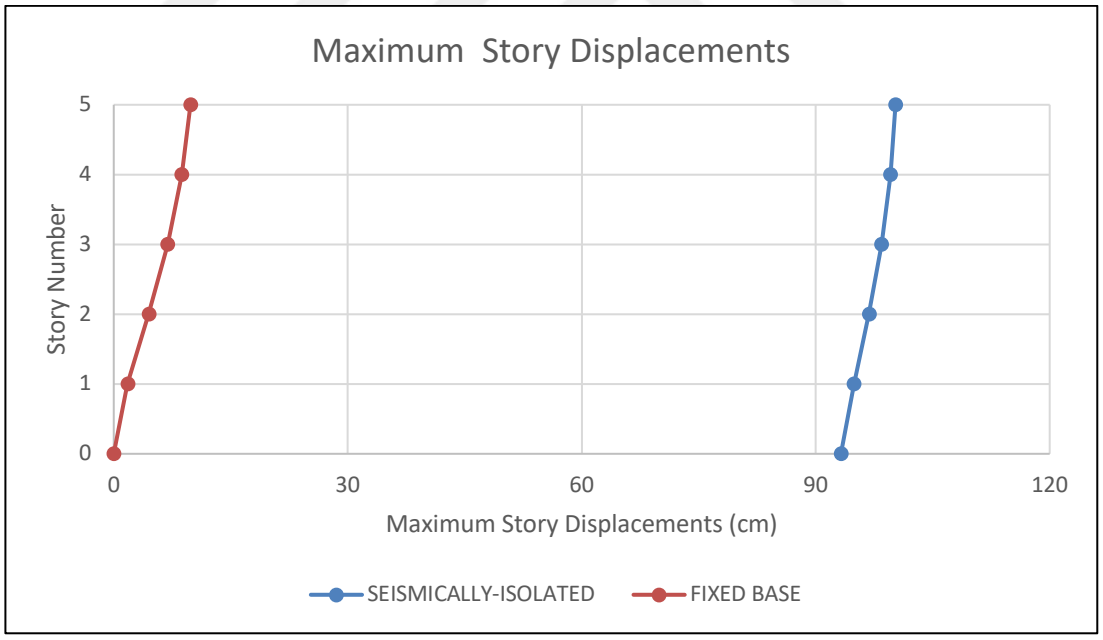

Figure 4.4 : Comparison of maximum story displacement.

Another significant parameter for evaluating the analysis results is the inter storey drifts. Inter storey drifts for FB and SI buildings are presented in Table 4.5.

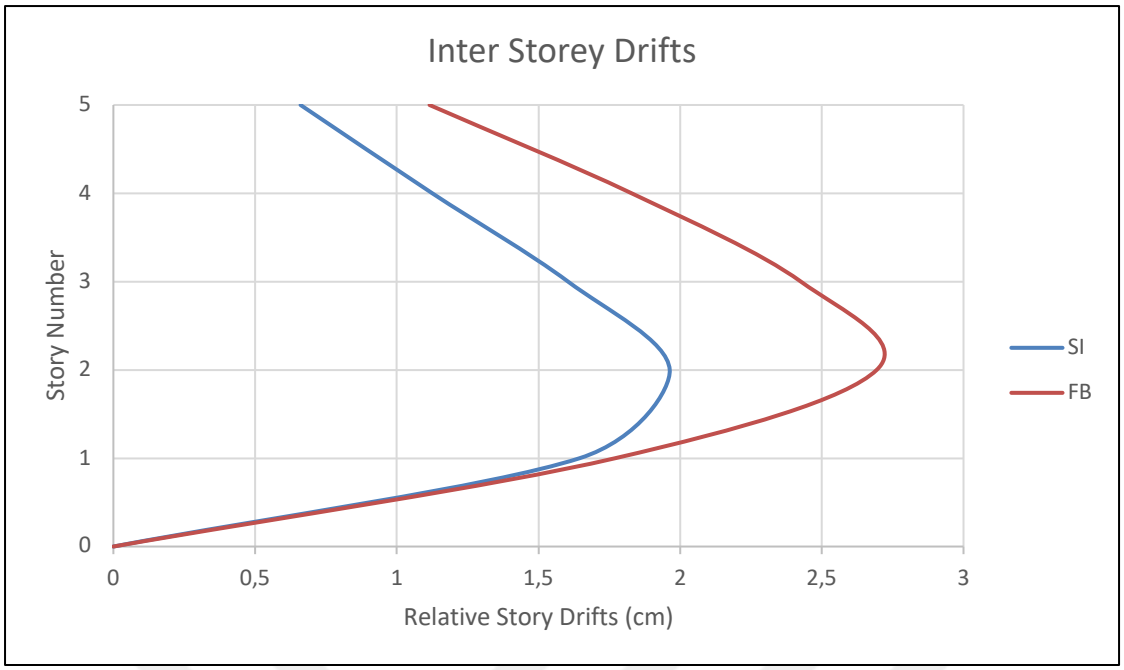

Figure 4.5 : Comparison of the inter storey drifts.

The reductions in the drifts are also shown at the Table 4.5 as percentage change. This change is 8% for the first story. For upper stories, it increases to 70 %.

Table 4.5 : Inter storey drifts of FB and SI buildings.

Story Number	Inter Storey Drifts of FB (cm)	Inter Storey Drifts of SI (cm)	Change Percent (%)
1	1,7706	1,6452	8
2	2,6937	1,9633	37
3	2,4261	1,6045	51
4	1,8289	1,1255	62
5	1,1157	0,6606	69

Seismic Isolation has great impact on decreasing inter storey drifts as it can be seen in tables and figures given above. Inter storey drifts are compared in Figure 4.5.

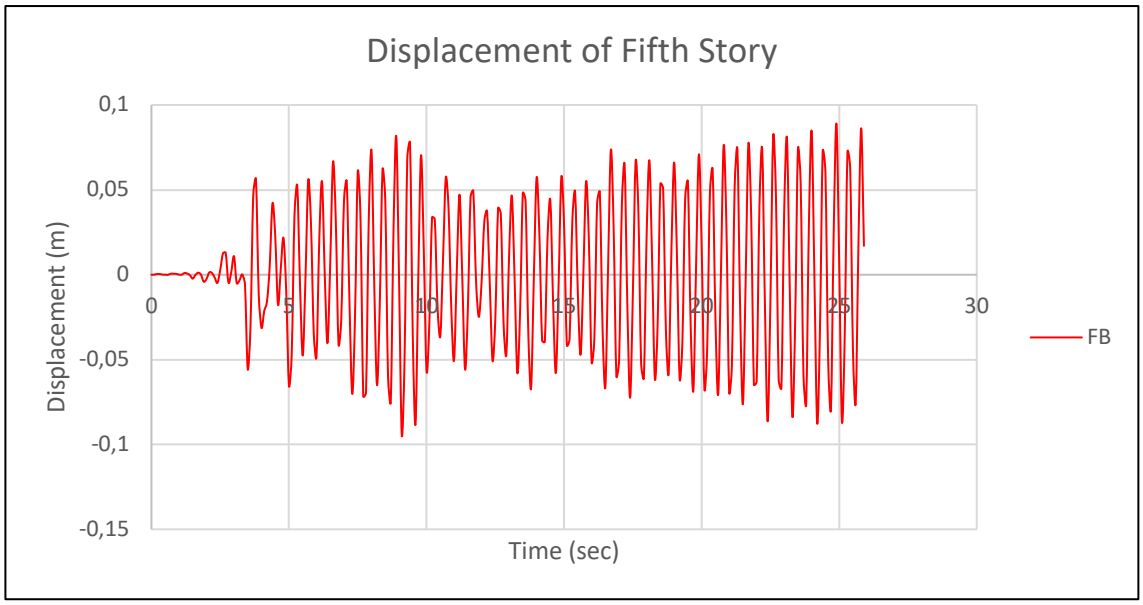

Figure 4.6 : Diplacement of the fifth story of the FB building.

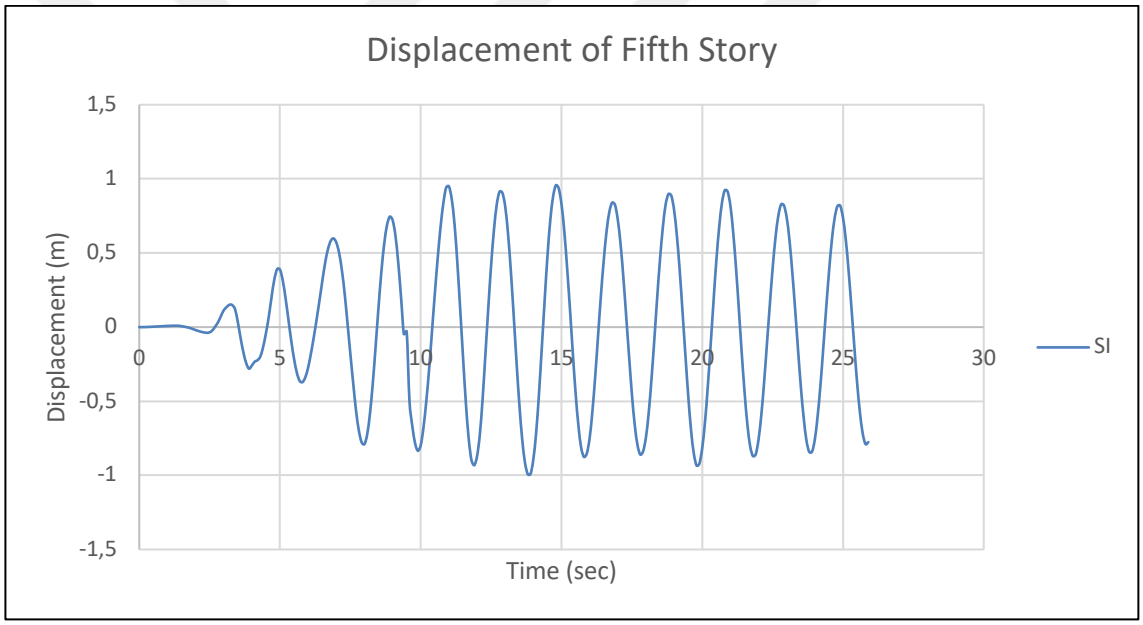

Figure 4.7 : Diplacement of the fifth story of the SI building.

To understand the behaviour of the structure under the earthquake excitation, another parameter that helps us is the roof displacement to follow the trace. Figure 4.6 shows the displacement time history of the top story (roof). The maximum roof displacement of FB is 9,8350 cm around 9,12 sec. It can be claimed that there is residual deformation because the graphic did not result in zero value after the dynamic analysis ends. On the other hand, the roof displacement of SI structure is reaching maxiumum which is approximately 1.02 meters at 13,85 sec. It seems that the cumulative displacement of SI building is more than the FB building. However, the design methodology of seismically isolated structure focuses on controlling the displacement of the structure.

The maximum displacement is expected to occur on the isolation level of the structure. The results are consistent with expectations. Maximum displacement of the isolation is about 93 cm.

5. COST ANALYSIS

Without a doubt, cost is one of the most important phenomena all around the world in all sorts of business. Finance affects decisions significantly on different sectors. As well as the other industries, it is also important for the construction sector. It is not possible to construct a building without considering its financial part. In this section of the thesis, the information about the cost analysis is presented. As it was performed for the earthquake analysis part, cost comparison is made for two different cases which are the conventional and seismically isolated building. It is known that there are several methods for cost calculation. In this thesis the activity base costing technique is chosen for comparison purposes.

5.1 Activity-Base Cost Calculation

Activity-Base Cost Calculation is one of the most important costing approaches that are used for the calculation of a construction project. In contrast to the problems related to the traditional cost methods, activity-based costing system has been developed as an alternative approach and has become widespread in time with the developing technology. The most important benefit of this system is that activity-based costing systems provide more realistic product cost information in comparison with the traditional cost methods. Thanks to the reasons that are mentioned above, activity-base costing is decided to be used for this thesis.

5.2 Establisihing the Work Breakdown Structure of the Case Project

Before the market research of unit prices, work breakdown structure is established for the 5-story residential building. To form the work breakdown structure, the construction process is divided into 3 main parts. First part includes the design, modeling parts and preparing documents for plans and drawings. It starts with preliminary design which covers the dimensions of structure, the structural material used, number of the stories and building significance coefficient etc. Next, the highly

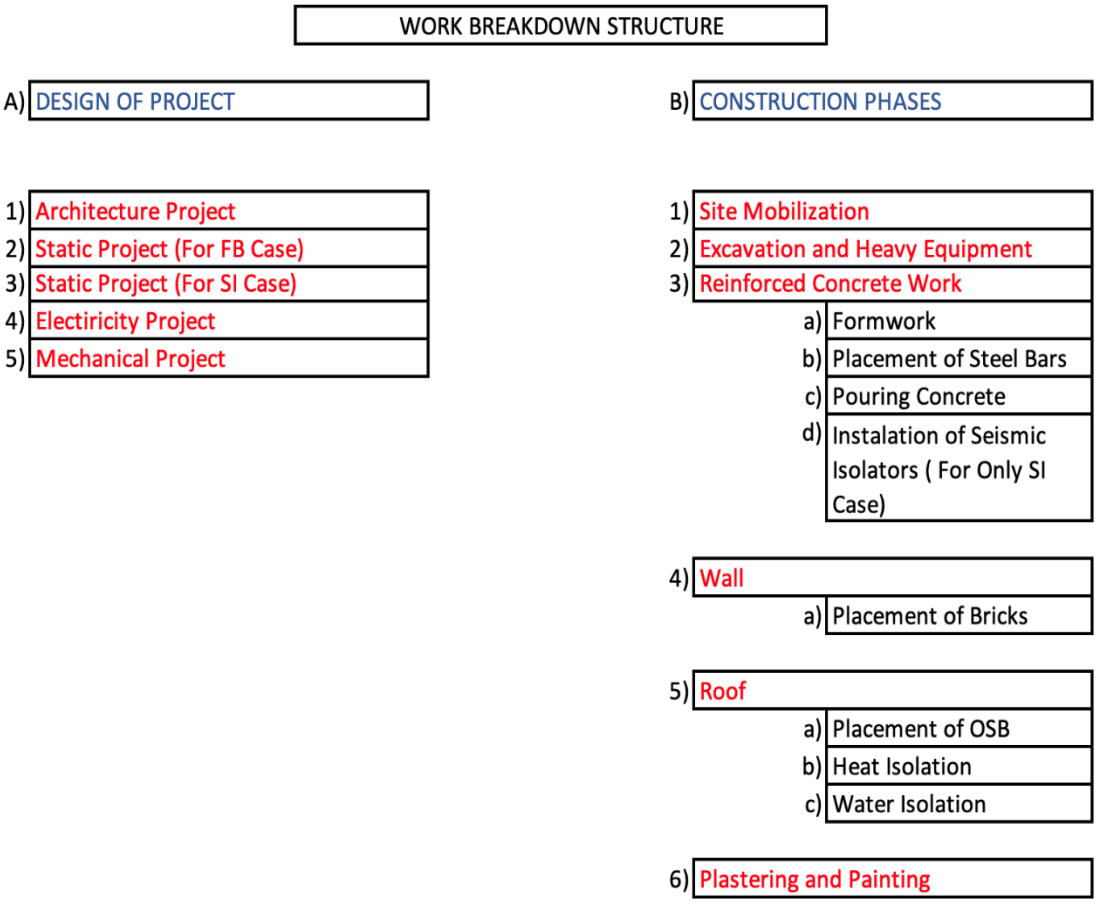

Figure 5.1 : Work breakdown structure (WBS).

important part is deciding the structural system of the building. That means whether to implement the seismic isolators to the structure or not. Undoublty, applying seismic isolation has financial consequences. However, it is very benefical to enhance the earthquake performance of structures. On the other hand, it increases the cost of the construction due to its advanced technology underneath. Design of the structure covers 4 different disciplines. These are architectural, static, mechanical, and electrical projects. Each one is prepared by experts in the related field. One of them is the most important among the others. It can easily be predicted that static design is the key parameter that effects the total project costs. Static project cost for seismically isolated building is higher than fixed base building because the design engineers that work on seismically isolated buildings are rare. In addition, the design of a structure with seismic isolation requires more efforts. Static project cost is calculated for both cases (FB and SI) and presented in Figure 5.1.

Second part contains the activities of structural construction. Structural construction activities start from preparing construction site and conclude with plastering and

paintings. First part of structural construction is Site Mobilization. It covers site landscaping, containers, and main resources such as site water and electricity. Also, we consider wastewater cost in this section. Next part is the excavation and heavy equipment. We calculated the cost of a m^3 excavation. This cost covers the digging of soil and the transport of the soil with related heavy equipment to the excavation dump site. Thirdly, this part included the reinforced concrete works. Formwork, placement of reinforcement bars and pouring concrete are milestones activities of the construction of reinforced concrete building. The only difference between the FB case and SI case is the installation of the seismic isolators to the related level of building. Seismic isolators must be placed on each column above the foundation level. Basically, SI structure needs 16 seismic isolators for installation. Furthermore, two more isolators are needed for the prototype testing before the construction starts. After the reinforced concrete structural elements are built, the construction of outer walls is being started by placing the bricks. Just before the final part, roof works which are placement of Oriented Strand Board (OSB), heat and water isolation are completed. Lastly, plastering and painting are completed to finish the structural construction part.

5.3 Market Research and Pricing

After the work breakdown structure is completed, market research is carried out for determining the unit prices. Firstly, we considered the Current Price List for Construction Labor – Tools and Equipment prepared by Turkish Republic Ministry of Environment and Urbanization. Although it is a guideline for both labor and tools-equipment unit prices, these prices seemed in comparison with the real sector prices. Due to the unstable conditions in the Turkish economy and fluctuations in exchange rates, unit prices vary from place to place or project to project. In order to make a more accurate cost estimation, a real example building that is constructed in 2020 is examined in a very detailed way and the cost calculation is given in Table 5.1. It can be easily seen that these prices are more appropriate than the prices that are recommended by the Turkish Republic Ministry of Environment and Urbanization. However, it is not feasible to directly use the real case prices because of the time difference. To eliminate the issue and improve the accuracy of the cost prediction, the inflation rate is also taken into account. In other words, unit prices are updated by multiplying with the inflation rate announced by the Turkish Republic Central Bank.

Table 5.1 : Cost calculation.

			UNIT PRICE			COST		
			Ministry	Private Sector	Updated	Ministry	Private Sector	Updated
DESIGN OF PROJECT								
		m^2	Unit Price (₺)					
	Architecture Project	720,00	9,00	10,00	11,71	6.480,00	7.200,00	8.434,08
	Static Project	720,00	7,00	10,00	11,71	5.040,00	7.200,00	8.434,08
	Static Project (For Addition of SI)	720,00	5,50	5,50	5,50	3.960,00	3.960,00	3.960,00
	Electiricity Project	720,00	4,50	5,00	5,86	3.240,00	3.600,00	4.217,04
	Mechanical Project	720,00	4,50	5,00	5,86	3.240,00	3.600,00	4.217,04
						21.960,00	**25.560,00**	**29.262,24**
SITE INSTALLATION						**40.490,00**	**46.795,00**	**54.815,66**
EXCAVATION AND HEAVY EQUIPMENT		m^3	₺/m^3					
		360,00	31,74	54,00	63,26	**11.426,40**	**19.440,00**	**22.772,02**

			UNIT PRICE			COST		
			Ministry	Private Sector	Updated	Ministry	Private Sector	Updated
REINFORCED CONCRETE								
	Piece	₺/Piece						
Seismic Isolator	18,00	25625,00				461250,00	461250,00	461250,00
	m^3	₺/m^3						
C30	338,40	205,00	240,00	281,14		69372,00	81216,00	95136,42
C30 (For Isolation Rigit Slab)	21,60	205,00	240,00	281,14		4428,00	5184,00	6072,54
	ton	₺/ton						
Reinforcement Steel	30,00	4790,00	6200,00	7262,68		143700,00	186000,00	217880,40
	m^2	₺/m^2						
Formwork	748,80	79,00	90,00	105,43		59155,20	67392,00	78942,99
	m^2	₺/m^2						
L. Cost for Formwork and C. Pouring	720,00	39,00	61,00	71,46		28080,00	43920,00	51447,89
Labor Cost for Rebar	720,00	12,00	14,28	16,73		8640,00	10281,60	12043,87
						308947,20	**388809,60**	**455451,57**

			UNIT PRICE			COST		
			Ministry	Private Sector	Updated	Ministry	Private Sector	Updated
WALL								
		Piece	Unit Price					
	Brick	25.000	0,50	0,69	0,81	12.500,00	17.250,00	20.206,65
		m^2	₺/m^2					
	Labor Cost for Brick	720,00	12,00	16,00	18,74	8.640,00	11.520,00	13.494,53
						21.140,00	**28.770,00**	**33.701,18**
ROOF								
		Piece	Unit Price					
	OSB	80,00	45,00	85,00	99,57	3.600,00	6.800,00	7.965,52
		m^2	₺/m^2					
	Heat Isolation	200,00	34,20	37,00	43,34	6.840,00	7.400,00	8.668,36
		m^2	Unit Price					
	Water Isolation	300,00	21,00	25,00	29,29	6.300,00	7.500,00	8.785,50
						16.740,00	**21.700,00**	**25.419,38**
PLASTERING AND PAINTING								
		m^2	₺/m^2					
	Plastering	360,00	56,86	20,79	24,35	20.469,60	7.484,40	8.767,23
	Painting	360,00	40,95	21,00	24,60	14.742,00	7.560,00	8.855,78
						35.211,60	**15.044,40**	**17.623,01**

As mentioned above, unit prices are determined for the resources which are materials and labor. Quantity calculations are made for structural construction activities. Unit prices are multiplied by their related quantities to obtain the cost of each activity. In contrast with the structural construction, fine construction cost estimation is not carried out in a very detailed way. It is not completely possible to calculate the cost of each fine construction activities. According to the investigation of the real building project, the ratio between the structural construction and fine construction is calculated.

Moreover, Gürcanlı (2012) stated that the structural construction cost is about 35% - 40% of the total construction cost. Both findings are consistent with each other. Therefore, fine construction cost is determined by the help of the ratio and the structural construction cost. Three different approaches that are mentioned just before are applied to estimate the cost of the reference building. While the total cost of the building is ₺1.139.788,00 according to the Turkish Republic Ministry of Environment and Urbanization's Unit Price Chart, it costs ₺1.365.297,50 by referring to the private sector prices. These prices were calculated by considering the economic conditions in April 2020. To make the cost up to date, the inflation rate of 17,14% that was announced by Turkish Central Bank is used. The effect of inflation is included in the cost estimation. Updated cost estimation is obtained as ₺1.597.612,63.

There are additional costs for making the structure seismically isolated. These are mentioned in the WBS. It is predictable that the number of the seismic isolators affected the project budget dramatically. Due to the seismic design procedure, prototpyes are manfactured and tested before the installation. As the structural system has 16 columns on each floor,18 pieces of seismic isolator are needed to fulfill the requirements. Price of an isolator is 2500 EUR. It corresponds to the ₺25.625,00 by taking the EUR/₺ rate as 10,25 on 24 May 2021. Another cost that is added is the design of the static project cost. It can be known that the design of SI structure is more expensive than the design of FB structure. The difference between the design cost prices for each metersquare is ₺5,50. These differences are added to the FB project cost. It should be noted here that there is an additional cost for shoring in the seismically isolated case. This cost is being excluded in this thesis. The comparison of the total and m^2 costs is shown at Table 5.2.

Özcanlı (2021) stated that lead core rubber isolators do not require maintenance as they contain natural rubber. No moving parts are included in these systems since they don't have any interaction with the atmosphere. Therefore, the isolators are not prone to corrosion which happens in some other types of materials due to the water and humidity. However only the steel plates and connecting bolts which are attachment elements to the superstructure and the substructure should be checked periodically. In addition, since it does not affect the UV rays under the buildings, the rubber does not have any disadvantage depending on its UV resistance. For these reasons, the maintenance cost of lead core rubber isolators is dramatically lower than the other construction costs. Therefore, the maintenance cost of isolators is being excluded in this thesis. It can be advised that the visual inspection shall be carried out after major earthquakes or in 10-year periods.

Table 5.2 : Total and m^2 costs.

Type of Building	Cost Type	Ministry	Private Sector	Updated
FB	Total Cost	₺1.139.788,00	₺1.365.297,50	₺1.597.612,63
FB	M^2 Cost	₺1.583,04	₺1.896,25	₺2.218,91
SI	Total Cost	₺1.609.426,00	₺1.835.691,50	₺2.068.895,17
SI	M^2 Cost	₺2.235,31	₺2.549,57	₺2.873,47

It can be seen from Table 5.2 that if we implement seismic isolators to the structure, total cost of the project rises to ₺2.068.895,17. Also seismic isolator is increasing the m^2 cost of the structure to ₺2.873,47. The important change ratio that is being obtained from this work is the additional cost of the the seismic isolation into the total cost of structure. According to the ministry price list, seismic isolator cost is approximately 28% of the total construction cost. If the private sector prices are considered, the share of the isolation is being 25%. Lastly, seismic isolation is 22% of the total cost if the updated prices are being taken into account. Although the total construction area is relatively less and the number of the seismic isolator is 18, the ratio of SI Cost/Total Cost of 22% seems to be feasible.

Table 5.3 : Seismic isolation / Total cost.

Cost Type	Seismic Isolation/Total Cost
Ministry	28,66%
Private Sector	25,13%
Updated	22,29%

6. CONCLUSIONS AND RECOMMENDATIONS

In this thesis, two 5-Story RC Building dimensions with and without seismic isolators are analyzed. Both of the buildings has the same structural system, element sizes, material quality etc. These buildings are assumed to be located in the European part of Istanbul. The only difference between them is, in one of them the seismic isolators are implemented into each column in the isolation level. The results obtained in this study are coming from two different structural analysis.

One of them is the dynamic analysis of the structure under earthquake excitation and the other is project budget analysis. Firstly, time history analysis under the effect of an earthquake is performed for the fixed base and for the building with seismic isolators. Thanks to the time history analysis the maximum story displacements of these two cases are compared. In comparison with the fixed base building, implementation of seismic isolators decreased the inter storey drifts of each story. For this study the most critical floor in terms of earthquake effects is found as the top floor of the building. Therefore, response comparison of the top story is pointed out. Top story relative drift is reduced from 112 cm to 66 cm. The reduction of the top story displacement is about 69 %. Although it is an expected outcome of seismic isolator usage, and similar results have been reported in numerous studies in the literature before, the response reduction percentage obtained in this study may still be considered remarkable.

Secondly, the project budgets are calculated by using 3 different approaches for both buildings. Financial results shows that seismic isolation increases the total project cost by 29,12% according to up-to-date prices. For the example building with seismic isolators although the cost of the project is increased by 29,12%, the top story relative displacement is reduced by 69% under the seismic excitation. The cost increase is relatively high, however it should be noted that the benefit of seismic isolation usage is very clear. The decrease in the inter storey drift of each story shows that the structural elements are not experiencing any serious damages. Therefore, the failure of the structure due to the earthquake excitations is prevented. In addition, the functionality of the structure is sustained, and the residents of the building may not

even feel the earthquake shaking. Furthermore, the reduction of the structural vibrations may save the equipment, electronical devices or valuable things that are in the building. These are considered as secondary advantages of seismic isolation usage. Another advantage is that the seismic isolation not only may prevent the collapse of the structural system but also may save the house furniture and valuable goods.

For further studies, a study may be performed on the investigation of size reduction of structural elements when seismic isolators are implemented to the building. As expected, the sizes of structural elements might be smaller in comparison with the fixed base case. Therefore, the usage of primary construction materials such as concrete and reinforcement steel bars would be decreased. This would result in the project cost reduction of seismically isolated building. In addition, another future research topic could be on analyzing the secondary benefits of the isolation system. If we consider a fixed base well-designed building which may provide life safety of its residents, which is its main purpose, most of the valuables inside the building may become unusable after an earthquake. These economic losses can be estimated in future studies. If both recommendations are researched in future, the feasibility of seismic isolation usage may be understood more clearly.

REFERENCES

Ahmad, N., Shakel H. and Masoudi, M. (2020). Design and development of low-cost HDRBs seismic isolation of structures, Bulletin of Earthquake Engineering (2020) 18:1107–1138 https://doi.org/10.1007/s10518-019-00742-w.

Almusbai, S. and Gungor, A. (2019). A composite building isolation system for earthquake protection, Engineering Science and Technology, an International Journal 22 (2019) 399–404.

Amin, N. M., Ayub N., and Alisibramulisi A. (2019). Design of base isolated reinforced concrete building subjected to seismic excitation using EC 8, International Journal of GEOMATE, Nov. 2019 Vol.17, Issue 63, pp. 23 - 28 ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2019.63.4672 Geotechnique, Construction Materials and Environment.

Amjadian, M. and Agrawal A. K. (2019). Seismic response control of multi-story base-isolated buildings using a smart electromagnetic friction damper with smooth hysteretic behavior, Mechanical Systems and Signal Processing 130 (2019) 409–432.

Arı, S. (2019). *AASHTO Rehber Teknik Şartnamesine (AASHTO-GSID) Göre Köprülerde Sismik Yalıtım Tasarımı* (Yüksek Lisans Tezi) İstanbul Teknik Üniverstesi, İSTANBUL

Bhandari, M., Bharti S. D., Shrimali M. K., and Datta T. K. (2019). Seismic Fragility Analysis of Base-Isolated Building Frames Excited by Near- and Far-Field Earthquakes, American Society of Civil Engineers.

Calabresea, A., Losannob, D., Spizzuocob, M., Stranoc S., and Terzoc, M. (2019). Recycled Rubber Fiber Reinforced Bearings (RR-FRBs) as base isolators for T residential buildings in developing countries: The demonstration building of Pasir Badak, Indonesia, Engineering Structures 192 (2019) 126–144.

Cancellara, D., and Angelis, F. D. (2019). Dynamic assessment of base isolation systems for irregular in plan T structures: Response spectrum analysis vs nonlinear analysis, Composite Structures 215 (2019) 98–115.

Cardone, D., Gesualdi G., and Perrone, G. (2019). Cost- Benefit Analysis of Alternative Retrofit Strategies for RC Frame Buildings, Journal of Earthquake Engineering, 23:2, 208-241, DOI: 10.1080/13632469.2017.1323041

Clementea, P. and Martellib, A. (2017). Seismically isolated buildings in Italy: State-of-the-art review and T applications, Soil Dynamics and Earthquake Engineering 119 (2019) 471–487.

Dang, Y., Han, J., and Li, Y., (2015). Analysis of the Seismic Performance of Isolated Buildings according to Life-Cycle Cost, Hindawi Publishing Corporation Computational Intelligence and Neuroscience Volume 2015, Article ID 495042, 7 pages.

Dao, N. D., Ryan, K. L., and Nguyen-Van, H. (2018). Evaluating simplified models in predicting global seismic responses of a shake table–test building isolated by triple friction pendulum bearings Earthquake Engineering Structural Dynamics (2019) 48:594–610.

Dong, Y., and Frangopol, D. M. (2016). Performance-based seismic assessment of conventional and base- isolated steel buildings including environmental impact and resilience, Earthquake Engineering Structural Dynamics 2016; 45:739–756.

Fujii, K. (2019). Prediction of the Maximum Seismic Member Force in a Superstructure of a Base-Isolated Frame Building by Using Pushover Analysis, Buildings 2019, 9, 201; doi:10.3390/buildings9090201

Fukasawa, S., and Kanno, Y. (2005). Numerical simulation of base-isolated buildings in collisions with surrounding moat walls during earthquakes: a nonsmooth mechanics approach, Optimization and Engineering https://doi.org/10.1007/s11081-019-09481-y.

Gazi, H., and Alhan C. (2019). Reliability of elastomeric-isolated buildings under historical earthquakes T with/without forward-directivity effects, Engineering Structures 195 (2019) 490–507.

Galindo, M. C., Spuler, T., Moor, G., and Stirnimann, F. (2012). Design, Full-scale Testing and CE Certification of Anti-seismic Devices According to the New European Norm EN 15129: Elastomeric Isolators.

Gürcanlı, G. E. (2012). Konut Projelerinde Süresel Planlama Teknikleri Yardımıyla İş Güvenliği Risk ve Maliyet Tahmini, TÜBİTAK Projesi (Proje No: 112M033).

Han, R., Li, Y., and Lindt, J. (2017). Probabilistic Assessment and Cost-Benefit Analysis of Nonductile Reinforced Concrete Buildings Retrofitted with Base Isolation: Considering Mainshock–Aftershock Hazards, American Society of Civil Engineers (2017), DOI: 10.1061/AJRUA6.0000928.

Kapasakalis, A. K., Antoniadis, I. A., Sapountzakis, E. J. (2019). Performance assessment of the KDamper as a seismic Absorption Base, Structural Control Health Monitoring. 2020;27: e2482.

Karimi, M. R., and Genes, M. C. (2019). Probabilistic Behavior Assessment of Base-Isolated Buildings and Base Isolation Systems Subjected to Various Earthquakes with Different Components, Arabian Journal for Science and Engineering (2019) 44:8265–8288 https://doi.org/10.1007/s13369-019-03867-x

Kohiyama, M., Omura, M., Takahashi M., Yoshida, O., and Nakatsuka, K. (2019). Update of control parameters for semi-actively controlled base-isolated building to improve seismic performance, Japan Architectural Review July 2019 vol. 2 no. 3 226–237.

Lee J. J., and Kelly, M. J., (2018). The effect of damping in isolation system on the performance of base-isolated system, Journal of Rubber Research (2019) 22:77–89 https://doi.org/10.1007/s42464-019-00012-z.

Li Y., and Conte, J. P. (2019). Probabilistic Evaluation of Seismic Isolation Effects for a California High-Speed Rail Prototype Bridge, American Society of Civil Engineers, DOI: 10.1061/(ASCE)ST.1943-541X.0002387.

Li, H., Gomez, D., Dyke, S. J., and Xu, Z. (2019). Fractional Differential Equation Bearing Models for Base-Isolated Buildings: Framework Development, American Society of Civil Engineers, DOI: 10.1061/(ASCE)ST.1943-541X.0002508.

Mazza, F. (2018). Effects of the long-term behaviour of isolation devices on the seismic response of base-isolated buildings, Structural Control Health Monitoring. 2019;26: e2331,

Mitropoulou C., and Lagaros, N. D. (2016). Life-Cycle Cost Model and Design Optimization of Base-Isolated Building Structures, Frontiers in Built Environment, November 2016 Volume 2 Article 27.

İNŞAAT BİRİM FİYATLARINA ESAS İŞÇİLİK-ARAÇ VE GEREÇ RAYİÇ LİSTELERİ. *T.C. ÇEVRE VE ŞEHİRCİLİK BAKANLIĞI Yüksek Fen Kurulu Başkanlığı, Ankara*

Mousazadeh, M., Pourreza F., Basim M., and Chenaghlou, M. R. (2020). An efficient approach for LCC-based optimum design of lead-rubber base isolation system via FFD and analysis of variance (ANOVA), Bulletin of Earthquake Engineering (2020) 18:1805–1827

Naderpour H., Danaeifard P., Burkacki D., and Jankowski, R. (2019). Earthquake-Induced Pounding of Medium-to-High-Rise Base-Isolated Buildings, Applied Science 2019, 9, 4681; doi:10.3390/app9214681

Najafijozania, M., Beckerb, T. C., and Konstantinidis, D. (2020). Evaluating Adaptive Vertical Seismic Isolation for Equipment in Nuclear Power Plants, Nuclear Engineering and Design, 358.

Ryan, K. L., Button, M. R., and Mayes, R. L. (2018). Lateral Force Distribution Equations for Static Design of Seismically Isolated Buildings, Journal of Structural Engineering DOI: 10.1061/(ASCE)ST.1943-541X.0002249

Sayani, P. J. and Ryan, K. L. (2009). Comparative Evaluation of Base-Isolated and Fixed-Base Buildings Using a Comprehensive Response Index, ournal of Structural Engi- neering, Vol. 135, No. 6.

Sayani, P. J. Erduran, E., and Ryan, K. L. (2011). Comparative Response Assessment of Minimally Compliant Low-Rise Base-Isolated and Conventional Steel Moment-Resisting Frame Buildings, Journal of Structural Engineer- ing, Vol. 137, No. 10.

Stanikzai, M. H., Elias S., Matsagar, V. A., and Jain A. K. (2017) Seismic response control of base-isolated buildings using multiple tuned mass dampers, Struct Design Tall Spec Build. 2019;28: e1576.

Xu, Y., Guo, T., and Yan P. (2019) Design optimization of triple friction pendulums for base-isolated high-rise buildings, Advances in Structural Engineering 2019, Vol. 22(13) 2727–2740.

Yang, C., Xiea, L., Lia A., Jiaa, J., and Zeng, D. (2019) Ground motion intensity measures for seismically isolated RC tall buildings, Soil Dynamics and Earthquake Engineering 125 (2019) 105727.

Yang, T. Y., and Zhang, H., (2019). Seismic Safety Assessment of Base-Isolated Buildings Using Lead-Rubber Bearings, Earthquake Spectra, Volume 35, No. 3, pages 1087–1108.

Ye, K., Xiao, Y., and Hu, L. (2019). A direct displacement-based design procedure for base-isolated building T structures with lead rubber bearings (LRBs), Engineering Structures 197 (2019) 109402.

Zhao, C., Yu N., Peng T., Lippolis, V., Corona A., and Mo, Y.L. (2020). Study on the dynamic behavior of isolated AP1000 NIB under mainshock-aftershock sequences, Progress in Nuclear Energy 119 (2020) 103144.

Özcanlı, M., E. (2021). Personal interview. 26 June, ISTANBUL.

Örnek İnşaat Maliyet Raporu. *İnşaat Hesabı,* Retrieved November 14, 2020, from https://insaathesabi.com/wp-content/uploads/2020/11/Ornek-proje-raporu.pdf

30364 Sayılı TÜRKİYE BİNA DEPREM YÖNETMELİĞİ. *T. C. Resmi Gazete, 30364,* 18 Mart 2018 PAZAR

Url-1 <*https://www.bridgestone.com/products/diversified/antiseismic_rubber/method.html>, date retrieved 25.05.2021.*

CURRICULUM VITAE

Name Surname : Oğuzcan Çatlıoğlu

EDUCATION :

- **B.Sc. :** 2018, Özyeğin University, Engineering Faculty, Civil Engineering Department

PROFESSIONAL EXPERIENCE AND REWARDS:

- Concrete Canoe Competition Organized by Istanbul Technical University (2017, 2018)
- Design Together Competition Organized by Istanbul Technical University (2018)
- DASK Earthquake Resistant Building Design Competition (2018)