T.C.

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INSTITUTE OF GRADUATE STUDIES

A COMPARATIVE OF STUDY THE DESIGN SPECTRA DEFINED BY VARIOUS SEISMIC CODES

Masters of Applied Science Thesis

KHADAR ABDILAHI ELMI

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Department: Civil Engineering

Programme: Structural Engineering

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Members of Examining Committee:

Assist. Prof Dr. Gökhan YAZICI (IKÜ)

Prof Dr. Cenk ALHAN (İÜ.Cerrahpaşa)

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University: **İstanbul Kültür University**

Institute: **Institute of Graduate Studies**

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ABSTRACT

Earthquakes create numerous forces in a short period. It is very important for all structures to withstand small earthquakes without collapse. The main purpose of this study, Turkey Building Earthquake Code (TBDY-2018), India Code (IS 1893-1, 2016), Eurocode (EN1998-1: 2004), and USA Code of (ASCE7-) to compare the behavior spectrum models. The most common method in earthquake analysis is the linear analysis and is generally used in the design of new structures. A six-story moment frame model was considered in the study for comparison and the required model for design and analysis was created using SAP2000-v20 software. Analyzes were performed using response spectra and the equivalent horizontal force method. Results such as periods, horizontal displacement, and modal mass participation ratio are interpreted by comparing them with graphs and tables.

Keywords: Response spectrum, Comparative seismic codes, Lateral displacement, Equivalent lateral force, Modal analysis

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ÖZET

Depremler kısa sürede büyük kuvvetler oluştururlar. Büyüklüğü küçük olan depremlerde tüm yapıların çökmeden ayakta kalabilmesi oldukça önemlidir. Bu çalışmanın temel amacı, Türkiye Bina Deprem Yönetmeliği (TBDY-2018), Hindistan Yönetmeliği (IS 1893-1, 2016), Eurocode (EN1998-1: 2004) ve ABD Yönetmeliklerinin (ASCE7-), davranış spektrumu modellerini karşılaştırmaktır. Deprem analizinde en yaygın yöntem doğrusal analizdir ve genellikle yeni yapıların tasarımında kullanılır.

Çalışmada karşılaştırma yapmak amacıyla altı katlı moment çerçevesi modeli ele alınmış ve tasarım ve analizler için gerekli model SAP2000-v20 yazılımı kullanılarak oluşturulmuştur. Analizler, tepki spektrumları ve eşdeğer yatay kuvvet yöntemi kullanılarak yapılmıştır. Periyotlar, yatay yer değiştirme ve modal kütle katılım oranı gibi sonuçlar grafikler ve tablolarla karşılaştırılarak yorumlanmıştır.

Anahtar kelimeler: Tepki spektrumu, Deprem yönetmelikleri, Eşdeğer yatay kuvvet, Yanal yer değiştirme, Modal analiz

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST ABBREVIATIONS

ASCE: American Society of Civil Engineering

TSC: Turkish Seismic Code

EC8: Eurocode 8

IS1893, 2016: Indian Seismic code

SDOF: Single Degree of Freedom

PGA: Peak Ground Acceleration

MDOF: Multi Degree of Freedom

MCE: Maximum Consider Earthquake

SDC: Seismic Design Category

SPT: Standard Penetration Test

ABSSUM: Absolute Sum

SRSS: Square Root of the Sum Squares

CQC: Complete Quadratic Combination

RC: Reinforced Concrete

LIST SYMBOLS

ω_d = damped natural circular frequency

ω = natural frequency

ξ = damping ratio

C = damping coefficient

S_d = spectral displacement

S_v = spectral velocity

S_a = spectral acceleration

S_{pv} = pseudo velocity response spectrum

S_{pa} = pseudo acceleration response spectrum

M= mass of structure

K= stiffness of structure

Fa = short period of site coefficient

Fv= long period of site coefficient

S_S = short periods spectral acceleration

S_1 = long period of 1s

S_{DS} = short-period design response acceleration**,**

S_{D1} = one-second period design response acceleration

S_{MS} = Response acceleration for short period

S_{M1} = Response acceleration for long period

S_{ae} (T) = elastic spectral acceleration

I = importance factor

V= Base shear

W= weight of buildings

C_S= seismic response coefficient

Fx = lateral force in X direction

Wx = is total weight

k = an exponent associated to the configuration period

Ta = first natural period

T= fundamental period

TL= Long-period transition period

R= Reduction factor

S_a/g = structural response factor

Ah= lateral force coefficient

Qi = Design lateral force

Wi = weight of floors

P_{NCR} =Reference probability of exceedance in 50 years of the reference seismic

a_g = ground acceleration design

agR = reference peak ground acceleration

Se (T) = elastic response spectrum

η= damping correction factor

T_C = the upper limit of the period of the constant spectral acceleration

T_D = the value defining the beginning of the constant displacement response range of the spectrum

S = Soil factor

S_{ve} (T) = vertical elastic acceleration

q = behavior factor

γ = importance class

F_S and F_1 = local ground effect coefficients

g = gravitational acceleration

S_{de} (T) = Elastic displacement spectral acceleration

S_d (T) = design spectrum

LL= live load

DL= dead load

E = earthquake

Hi= height of building

Mi, Mj = storey masses

T_A, T_B= Spectrum characteristic period

CHAPTER ONE

1. Introduction

Earthquakes have become the main problem that devastated the structures and human beings. In the past decades, strong earthquakes caused by life and economic loss, these earthquakes, including Loma Prieta (1989), Northridge (1999) in California, Kobe (1995) in Japan, and Marmara (1999) in Turkey [1].

Turkey is one of the most active seismic regions in the world enclosed by the Arabian and Eurasian plate, the Anatolian plate caused and impacted most earthquakes occur in Turkey. Most Turkey regions are located in active faults, and most people live in this area. The strong earthquakes (Marmara region), caused more than 51,000 buildings collapsed or damaged. Also, 18,000 people lost their lives. Van earthquake in 2011, caused heavy damage to the structures, and approximately 604 dead and more than 1301 injured during this earthquake [2].

Furthermore, the primary purpose developed by codes is to minimize the earthquakes disastrous and to maintain that buildings can resist the earthquake loads. With the forces that an earthquake induces with a short period, it can resist without collapse. Even an earthquake has the least magnitude, which causes minor damage to the structure needs the least cost of maintenance. The most useful and standard procedure is linear analysis, which codes used for the new buildings.

With the lack of building codes, the design will become appropriate. However, to compare codes is very crucial when the building codes are developed. During earthquake design, it must define seismic loads to foresee the coming earthquakes for a particular site. In some places, seismic design is sensitive.

Nevertheless, the absence of building codes designers followed by international guidelines. Thus, once seismic codes established, it is imperious to compare other international building codes. To reduce and protect the earthquake hazards is the purpose established by seismic codes [3]. Several studies have compared the seismic code provisions to evaluate the diffidence between them. Tariq Nahass (2017) compared UBC 1997 code with a Saudi building code to evaluate the similarities and dissimilar among codes using response spectra and equivalent lateral force methods [4].

Linear and nonlinear analysis can be categorized the seismic analysis. The most useful and standard procedure is linear analysis, the primary seismic code application used for the new buildings. For assessment irregular buildings, linear analysis is useful, and dynamic flexibility is common in flexible structural systems. Flexibility impacted by the selection of the building height and structural systems. The prominence of higher modes depends on the relationship among the fundamental mode of the structure and the dynamic-ground shaking features of the site. Figure 1.1 shows the characteristics of different modes shapes.

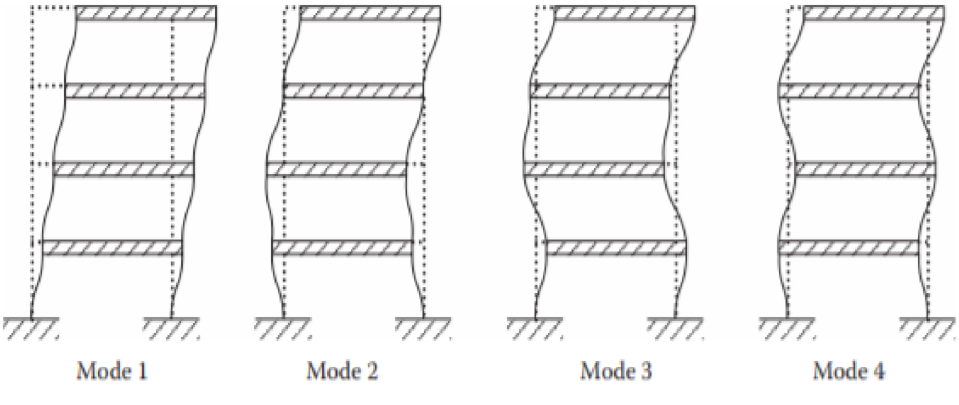


Figure 1.1: Mode shapes [5]

Earthquake engineers use a mathematical relationship to compute the earthquake intensity known as the response spectrum. The response spectrum founded by Boit and developed by Housner. The concept of dynamic linear analysis engineers adopts to evaluate the peak response of structures. Seismic hazard analysis used by engineers to measure the probability of earthquakes that site experienced for high-intensity ground motion. It is difficult to predict the earthquake magnitude, duration, and the direction that earthquake will occur, but engineers use accelerograms recorded the past earthquakes. The primary purpose of this study is to compare the building codes include Turkish, Eurocode, and American code. To explore the difference triggered the earthquakes.

1.1 Turkish Seismic Code History

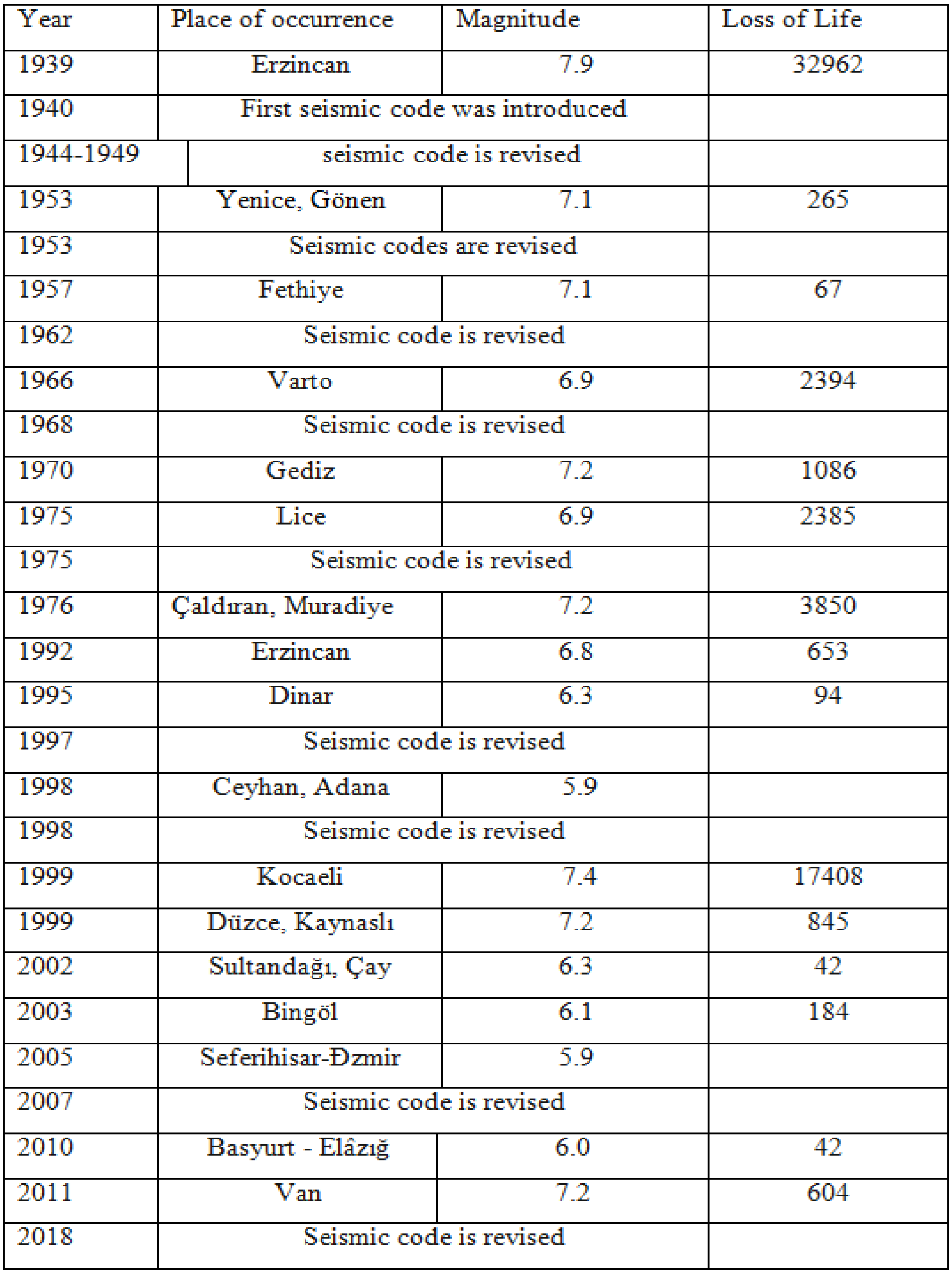
Commonly, seismic design codes updated and revised time to time depends on the developments in the illustration of ground motions, soils, and structures. In recent years, seismic codes revise more frequently, and Turkey started to publish the first seismic code in 1940 when a strong earthquake hit in Erzincan. Due to that event, more than 32,962 peoples recorded the number of fatalities, and approximately140,000 buildings collapsed or damaged.

Another significant earthquake again occurs in some areas in Turkey after only a few years later, the Erzincan earthquake in 1939 to 1944 for that code was the same as the Italian seismic code. In 1949, Turkish published another seismic building and is based on the Turkey Map and classified into three different seismic zones. The lateral force ranges from 0.01 to 0.03, the first zone, and the second zone, which is 0.02 to 0.04 [6].

The Turkish code published in 1998. To ensure the capacity structure, and the design principles of the capacity structure introduced. The return period is defined 475 earthquake designs for ordinary buildings, which have importance factor 1.0, and the importance of buildings (Importance factor 1.5) designed by 2475 years. In both cases, the probabilities of exceedance are 10 and 2% in 50 years, respectively. Earthquake code is defined effective seismic acceleration coefficient (Ao) 0.10 up to 0.40, and I, II, III, and IV categorized the seismic zones. The code also defined the 5% damping of elastic spectrum coefficient and the importance factor [7].

In 2007 Turkey was published another code when strong earthquakes occur in 1999 for Gölcük and Düzce in Kocaeli has magnitude 7.8 and 7.2, respectively. Some critical points highlighted as early reports described included that the quality of construction material was weak, structural mistakes, and insufficiencies due to the non-compliance with the seismic code. Table 1.1 covers the evaluation of Turkish seismic codes.

Table 1.1. Turkish seismic code evaluation and seismic events



Year	Place of occurrence	Magnitude	Loss of Life
1939	Erzincan	7.9	32962
1940	First seismic code was introduced		
1944-1949	seismic code is revised		
1953	Yenice, Gönen	7.1	265
1953	Seismic codes are revised		
1957	Fethiye	7.1	67
1962	Seismic code is revised		
1966	Varto	6.9	2394
1968	Seismic code is revised		
1970	Gediz	7.2	1086
1975	Lice	6.9	2385
1975	Seismic code is revised		
1976	Çaldıran, Muradiye	7.2	3850
1992	Erzincan	6.8	653
1995	Dinar	6.3	94
1997	Seismic code is revised		
1998	Ceyhan, Adana	5.9	
1998	Seismic code is revised		
1999	Kocaeli	7.4	17408
1999	Düzce, Kaynaslı	7.2	845
2002	Sultandağı, Çay	6.3	42
2003	Bingöl	6.1	184
2005	Seferihisar-Ðzmir	5.9	
2007	Seismic code is revised		
2010	Basyurt - Elâzığ	6.0	42
2011	Van	7.2	604
2018	Seismic code is revised		

1.2 Literature Review

Resatoglu (2016) compared a regular and irregular R.C. framed located by Nicosia city, the purpose of the study was to compare the difference among seismic codes TEC and EC8. The analysis is performed ETABS software [8]. Kumar (2017) compared dynamic linear analysis and static linear analysis. A regular and irregular plan has chosen for the design with different regions. Kumar results show that static linear is more drift than dynamic linear [9].

Landingin, Rodrigues, Varum, Arêde, and Costa (2012) analyze a structure using Eurocode, Philippine code (NSCP 2006), and American code (IBC 2009). The purpose is to investigate the variation caused by these codes [10].

Siah, Johinul, and Tameem (2016) carried out a moment resistance frame building using the Bangladesh National Code (BNBC 2006) [11]. The methods of response spectrum and equivalent lateral force were used for the design to compare. Bagheri, Firoozabad, and Yahyaei used different methods to evaluate the performance of the structure under seismic actions [12].

Their research described that time history analysis is more accurate than other methods. A. S Patil and P D Kumbhar (2013) defined a various earthquake intensity to explore and evaluate the different seismic behavior for the earthquake intensity, and the main objective is to compare the base shear and roof displacement [13]. Gizem Mestav Sarica Has had been used to three different ground motion data to make spectral matching, and this ground motions are the Düzce earthquake in 1999, Imperial Valley in 1976, and Chalfont earthquake in 1986 [14].

These real ground motion data obtained from the Pacific Earthquake Engineering Research Center. Khaled Ahmed Abdel-Raheem compared two different buildings using three different seismic approaches to demonstrate the seismic performance and to explore the difference and similarities. The main objective is to calculate the base shear, story drift, and displacement for each seismic method used in the study [15].

Amer Hassan and Shilpa Pal are compared to the time history analysis and response spectrum to evaluate the effects of soil conditions on the isolated base. The time-domain used to match response spectra and El Centro ground motion data used. The analysis carried out ETABS-2015 [16].

1.3 Objective of the Study

The main seismic codes established and enforced is to reduce damage and to ensure the life and economic loss. In some places, seismic design is sensitive. Nevertheless, the absence of building codes engineers followed by international guidelines. Thus, once seismic codes established, it is imperious to compare other international building codes. To reduce and protect the earthquake hazards is the purpose developed by seismic codes. Moreover, to compare different seismic codes defined by some earthquake resistance design techniques, mainly considered the response spectrum is the major purpose of this study. To achieve precious results with a case study of reinforced concrete moment frame has chosen for a particular site, and the result obtained by design compared similarity and dissimilarity among them, such as base shear and inter-story drift ratio.

1.4 Thesis Structures

Chapter one defines the background of the study, mainly focus on the earthquake history, scope and objectives of the study, as well as the literature review which summarized some article has already published but related to the comparison among seismic codes, and finally the structure of the thesis.

Chapter two describes the background of the response spectra using by a single degree of freedom to generate the equation of motion and concept of design response spectra discussed deeply. As well as factors that influenced the response spectra such as soil conditions looking deeply with reviewing some earthquake records, it also discussed the ground motion, and it is characteristics, such as amplitude, duration, and peak ground motion acceleration. Four different seismic design codes discussed their design response spectra.

Chapter Three describes the methodology reinforced concrete moment frame buildings have chosen to compare four different seismic codes, namely, American seismic code, Turkish, Eurocode, and Indian code. The main objective is to investigate differences and similarities according to their design response spectrum and equivalent lateral. The seismic analysis performed using SAP 2000.

Chapter Four describes the result obtained from seismic codes using the earthquake resistance design methods such as response spectrum, equivalent lateral force, and then compared them, such as base shear, story drift, and displacement.

Chapter Five highlighted conclusion of the thesis

CHAPTER 2

RESPONSE SPECTRUM

2.1 Background Response Spectrum

The Response spectrum is most useful method seismic design and Mr. Boit originated the response spectra in 1932, and then Housner improved it. The Response spectrum did not continue due to the conduct of research in the academic sphere for many years. There are two main reasons for this, and Irregular ground motion led to specific difficulties by computation of structural response, Second, response spectra could be adopted at that time only a few recorded accelerograms [17] [18] [19]. The arrival of digital computers and the availability of strong-motion accelerographs in the mid-1960 began to change all of this [20] [21]. Earlier the digital computer period, the response spectra computation was tough and time-consuming, and the results were defective, and several studies from that time, response spectrum amplitudes were using. The digitization of analog accelerographs was being recorded by in late 1960 and early 1970. The digital performing of ground motion and the response spectra were improved exclusively and verified for correctness. The response spectrum launched after the San Fernando earthquake in 1972, and more than 241 accelerograms recorded. Direct numerical integration and semi-graphical methods were being used before in 1940. Frank Neumann discovers the first mechanical analyzer, an oscillator, response to an earthquake. White and Byrane, proposed a technique that accelerograms can use directly to simulate mechanical analyzer [22]. Torsional pendulum analog had adopted by the first practical technique to compute the spectral amplitudes. Generally, the response spectrum is an instrument for engineers to compute the response of earthquake ground motion on the ability of buildings to withstand earthquakes. In Figure 2.1 describes the response spectrum scheme.

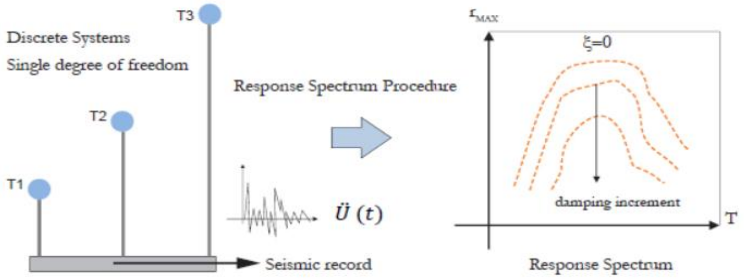


Figure 2.1: Response spectrum schemes [23]

2.1.2 Equation of Motion

The equation of motion is a fundamental mathematics expression derived from a single degree of freedom system. However, it is significant importance for earthquake design, and some basic fundamental parameters manage the structural response such as the acceleration, displacement as well as the force applied to the system. Figure 2.2 describes a single degree of freedom system SDOF for a portal frame connected by a rigid beam with lumped mass and supported two massless columns linked by constant lateral stiffness along with a massless column. Along with viscous damping, which losses energy due to system and causes to decrease the amplitude, this structure has only one degree of freedom. This system can be derived from the equation of motion when subjected to ground motion excitation.

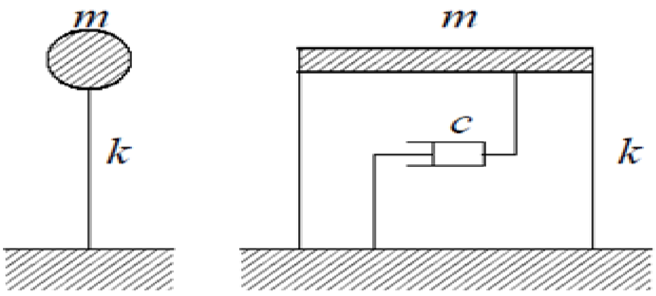


Figure 2.2: Single degree of freedom connected by a rigid beam with lumped mass and supported two massless columns [24]

M represented as the mass of the structure

K is the stiffness

C represents the viscous damper of the structure

The equation of motion can be express when subjected to the external force.

$$\mathrm{m}(\ddot{\mathrm{u}}) + \mathrm{c}(\dot{\mathrm{u}}) + [\mathrm{k}](\mathrm{u}) = \mathrm{p}(\mathrm{t}) \tag{2.1}$$

Where p (t) indicates the external applied force

If the equation of motion subject to the effects of ground motion can be written by

$$\mathrm{m}(\ddot{\mathrm{u}}) + \mathrm{c}(\dot{\mathrm{u}}) + \mathrm{k}(\mathrm{u}) = -\mathrm{m}\ddot{\mathrm{u}}_g(\mathrm{t}) \tag{2.2}$$

If divided m the equation of motion will be

$$\ddot{\mathrm{u}} + 2\xi\omega_n\dot{\mathrm{u}} + \omega_n^2\mathrm{u} = -\ddot{\mathrm{u}}_g(\mathrm{t}) \tag{2.3}$$

Where these expressions are represented by

M = indicates the mass of system, K = expresses the stiffness, U = Relative displacement $\dot{\mathrm{U}}$ = Relative velocity, C = Damping coefficient $\ddot{\mathrm{u}}_g$ = ground motion applied system

The natural frequency of the system can calculate

$$\omega_n = \sqrt{\frac{k}{m}} \tag{2.4}$$

Computing the response spectra needs Duhamel's integral solution [25].

$$u(t) = \frac{1}{\omega d}\int_0^t \ddot{\mathrm{u}}_g\, \mathrm{e}^{-\mathrm{i}\omega(\mathrm{t}-\tau)}\sin\omega_d(t_0 - \tau)\mathrm{d}\tau \tag{2.5}$$

The deformation of u (t) depends on the natural period and damping as well as the natural frequency, according to the equation of motion, the elastic force is an important part that can be obtained by the other relatives. In this study, the deformation of Düzce ground motion considered. The displacement of a different single degree of freedom system subjected to the components of Düzce ground motion has been plotted in Figure 2.3.

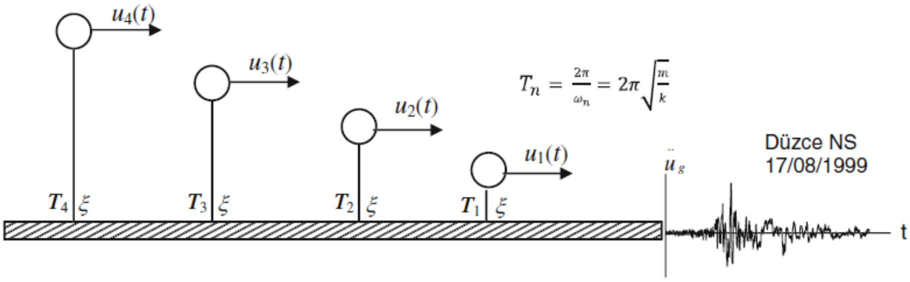


Figure 2.3: Different SDOF systems under earthquake ground excitation [26]

Figure 2.4 depict the response of each single degree of freedom system in terms of spectral acceleration and spectral displacement.

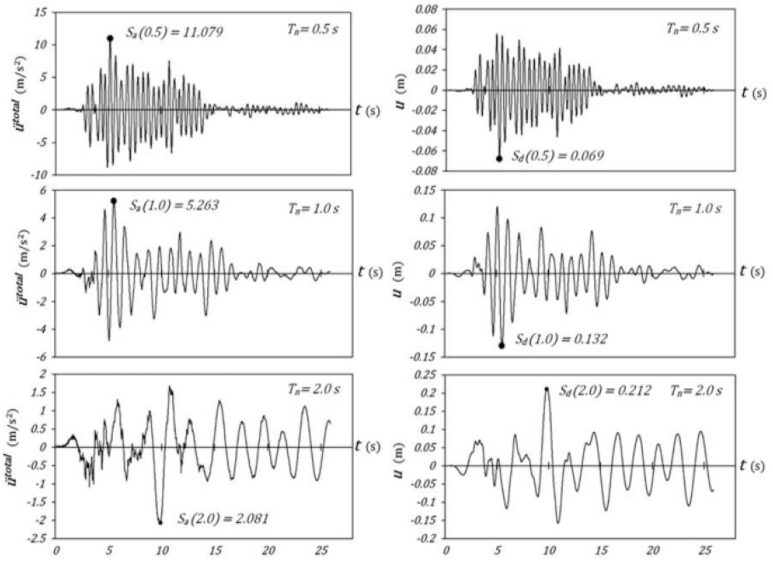


Figure 2.4: Displacement and acceleration responses of several SDOF subjected 1999 Düzce Ground motion [26]

The ground motion duration sometimes prolonged and almost lost the spectral information because the response spectrum only deals with peak response when it occurs. The ground motion long duration will cause low cycle fatigue and consequence degradation, and this information cannot obtain the response spectra. Figure 2.5 highlighted more detailed information about the characteristics of ground motion.

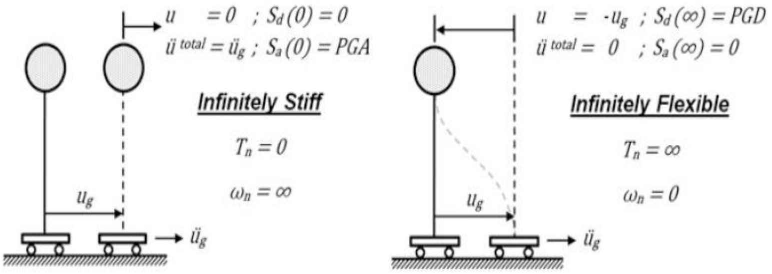


Figure 2.5: Response SDOF systems to ground excitation [26]

The above figure describes a single degree of freedom system subjected to the ground motion and emphasizes more details about the difference between two systems. For stiff structures, no deformation occurs, and a period of structure approaches zero, and natural frequency is infinite. The maximum spectral acceleration is identical to the peak ground acceleration of the system. For flexible structures, the mass of the top will remain rest but, the lower part of the structure moves, so there is no stiffness, and since there is no stiffness, it cannot be transmitted internal forces from the ground to the top. Furthermore, spectral displacement the same as the peak ground displacement, and the relative deformation can obtain the other two parameters.

The pseudo-spectral acceleration can obtain by this equation derived from the relative displacement.

$$\mathrm{P}S_a\ (\mathrm{T},\xi) = \omega^2 \mathrm{S_d} = \left(\frac{2\pi}{\mathrm{Tn}}\right)^2 \mathrm{S_d} = \omega \cdot \mathrm{PSV} \tag{2.6}$$

If the system is undamped, then the equation will become

$$\mathrm{m}\left(\dot{\mathrm{u}} + \ddot{u}_g\right) + k = 0 \tag{2.7}$$

Therefore if $\xi = 0$

$$mS_a = kS_d \quad \text{Or} \quad \mathrm{S_a} = \omega_n^2 \mathrm{S_d} \tag{2.8}$$

The restoring force developed during an earthquake will be computed Equation 2.9, as know when relative displacement maximum, Base shear is maximum

$$\mathrm{Vb_{max}} = \mathrm{Ku_{max}} = \mathrm{kS_d} = \mathrm{k}\left(\frac{\mathrm{S_a}}{\omega_n^2}\right) = \mathrm{m}S_a \tag{2.9}$$

Pseudo-spectral velocity describes the Maximum Strain Energy stored during the earthquake and obtained Equation 2.10

$$\mathrm{PS_v}(\mathrm{T}, \xi) = \omega \cdot \mathrm{S_d} = \frac{2\pi}{\mathrm{T_n}} \mathrm{S_d}\,(\mathrm{T}, \xi) \tag{2.10}$$

$$\mathrm{E_{Smax}} = \omega^2 \mathrm{S_d} = \frac{1}{2} \mathrm{m}(\mathrm{PS_v})^2 \tag{2.11}$$

Figure 2.6 illustrates the internal force and base shear developing in a single degree freedom system under earthquake ground motion excitation.

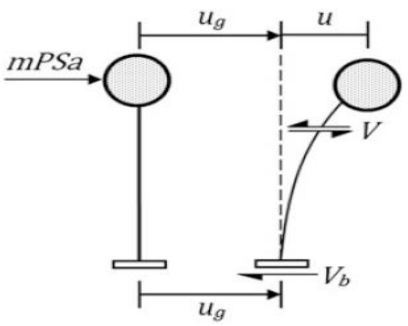


Figure 2.6: Base shear and internal force developed

2.2 Design Spectra

Most seismic codes use elastic design spectra, which derived from the response spectrum, and it is averaging and smoothing response spectra using for mean or mean plus one standard deviation, also called uniform hazard spectra. The concept of the elastic response spectrum started Boit, and Boit suggested that the construction of ordinary design spectra as an envelope can reach the availability of various accelerograms recorded in a different earthquake and soil sites.

Boit made a single degree of freedom system for a mechanical tool to understand the response of structure when subject to earthquake ground motion histories. Boit recommends that the smoothing response spectra could achieve real records. Boit and Housner are considering the founders of the elastic design spectrum, were theoretically understood that the response spectrum could use an earthquake resistance design instrument.

Housner used this theory and improved the design spectrum the first time in 1959. Smoothing and averaging response spectra with eight different ground motion records, these records obtained from of Olympia and in Taft respectively, and two horizontal components ground motion recorded El-Centro earthquake in 1934 and 1940. Housner proposed that the design spectrum only peak ground acceleration used to compute the possible devastation earthquakes.

Elastic design spectra suggest by Newmark and Hall employed in many building codes, particularly for dangerous structures, such as nuclear power plants. Newmark and Hall perceived in late 1960 and early 1970 that some spectral ordinates are influenced more by peak ground displacement or peak ground velocity than the peak ground acceleration [27]. The design spectrum recommended by Newmark and Hall encompassed three regions acceleration control region with high frequency, velocity control region with an intermediate frequency, and displacement control region with a low frequency. Tripartite plot develop by Newmark and Hall (1982) this method combined the peak ground acceleration, velocity, and displacement using soil amplification [28] [29]. Ground motion parameters and soil amplification used to construct the Newmark design spectra.

Newmark uses 14 vertical and 28 horizontal ground motions to define the probability distributions of vertical and horizontal amplification factors. PGA, PGV, and PGD are necessary to perform the Newmark design spectra. Figure 2.7 shows the tripartite plot developed by Newmark and Hall.

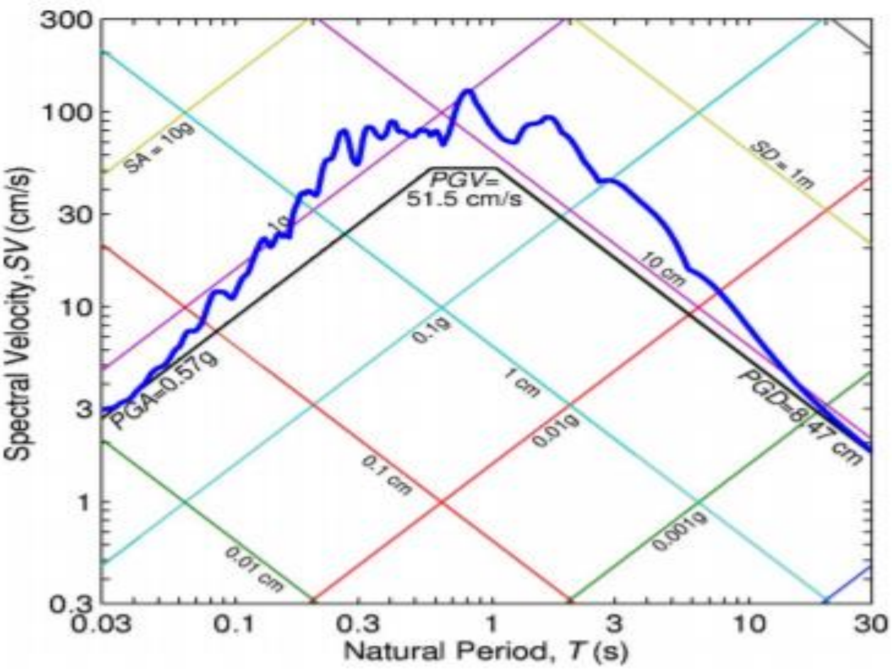


Figure 2.7: Tripartite plot response spectra [30]

The peak building ground acceleration for the building, closer to the peak ground acceleration for stiff structures, eventually the displacement will approach the peak ground displacement at low frequencies. The velocity control region is intermediate-range, and the first natural building occurs in the region between the low-frequency and high-frequency region. Therefore soil amplification factors suggested adopting the high, intermediate, and low frequency concerning the peak ground acceleration, velocity, and displacement. Generally, most seismic codes use elastic design spectra with 5% of damping as the design spectrum reference. The different soli classes that building codes adopt changes the spectral shapes and scaled PGA or spectral ordinate. The influence of soil conditions is essential to consider the design spectrum, and each of the soil classes provides soil amplification factors. The building codes often adopt the forced-based design.

2.3 Ground Motion

The number of applications using for nonlinear analysis techniques has been increased and aimed to evaluate the structural response and to assess the damage from seismic actions. For the earthquake analysis was necessary to have a ground motion, and time history analysis is commonly engineers use for accelerograms that recorded from past earthquakes. There are some limitations to use the recorded data to predict future ground motions because some regions are low seismicity. The recorded number of ground motions is not enough to consider earthquake ground motion variability. Commonly, the elastic design spectrum engineers use to match and scale records from other sites. For earthquake design, the ground motion is considered an essential tool for earthquake resistance design.

The ground motion parameters included amplitude, frequency content, and duration. The ground motion can define as acceleration and directly can use for ground motion time history. The ground motion can also describe velocity, and displacement but acceleration is standard. PGA is the most common parameter that seismic codes adopted.

The accelerograms of ground motion had recorded three directions since the PGA depends on the horizontal components recorded. Most seismic design codes adopted the peak ground acceleration rather than peak ground displacement, for designing earthquake resistance design for both response spectra and time history analysis. According to the Sokolov, the PGA is sternly counting on earthquake magnitude, distance, and local geological conditions.

The high peak acceleration offers more damage than lower peak acceleration, and the percentage of structural damages depending on the period of PGA [31]. Magnitude, distance, soil conditions, and local site effects can also affect ground motion. Local sites and soil conditions affected the intensity of ground movements and earthquake damage. The amount of local site impact depends on the type of soil deposit and site topography. The local site condition affects the amplitude and response spectral characteristics of ground motion. The earthquakes Hueneme in 1957, Parkfield in 1966, Northridge in 1994, and Kobe japan in 1995, and Marmara Turkey in 1999 recorded the near-field forward directivity ground motions. The engineering analysis to describe the design spectrum for near-field forward directivity ground motions [32]. The first seismic code defines the near-source effect for the design spectrum considered Uniform Building Code UBC. In the design spectrum period ranges, the UBC code demonstrates two near-fault factors Na and Nv to magnify the short, and long period ranges. The seismic activities are being dependent on these factors [33]. The sites near to the fault experienced impulsive characteristics, and the direction of propagation of fault are significant effects in near field areas [34]. The places near to the fault are very high velocity in such areas, and velocity is the most appropriate to define for the design than can replace for acceleration. In far-field sites, acceleration is the most common parameter used in the design.

The impact of soil amplification depends on the depth and soil type. Shear wave velocity, damping ratio, depth of soil layers, and the input of ground motion are significant parameters that impacted the soil amplification site, and according to these factors, input ground motion is the greatest that effected by soil site [35]. The effect of distance and spectral shape provided an example of the Loma Prieta earthquake in 1989 and reported that the recordings of spectral shape found on the rock for this earthquake decrease the high-frequency range and increases the long period range with increasing the distance [36].

The effects of spectral shape and distance are smaller than the magnitude effects. In the 1999 Chi-Chi earthquake, the significant factors resulted in are topography and geological conditions of the response of ground. Nearly 20 bridges were damaged hugely due to close the strong shaking areas, and soil liquefaction is another major factor that plays a significant role in the effects of the Chi-Chi earthquake. In Figure 218 demonstrates the peak ground motion recorded Chi-Chi and Kobe earthquakes.

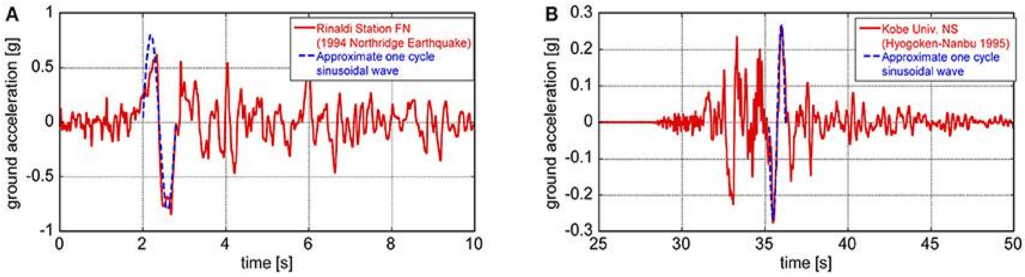


Figure 2.8: Near field ground motion recorded [37]

2.3.1 Factors Influence Response Spectra

Wave travel path, magnitude, distance from the source of energy, and soil condition characteristic plays a fundamental role in earthquake resistance design, and the response spectrum widely accepted techniques that adopted for earthquake design for elastic systems. However, the only basic parameters that affect spectra shape are magnitude, soil conditions, and distance. Nevertheless, the seismic codes commonly recommended that spectra depend on peak ground parameters and the soil conditions only.

The seismic codes identify typical spectral shapes for soil conditions differently to deal with the soil condition impact on the spectrum design. The factors of soil amplification are supported the site classes that seismic codes comprehend soil effects range for the short and long but only except the Indian seismic code is entirely overlook the consequence short period for soil amplification. The local site effects and soil conditions influenced the intensity of the movement of the ground and earthquake damage.

The factors such as magnitude, duration, soil conditions, and seismic source significantly influenced the earthquake ground motion in frequency content and amplitude. The nature of the soil can be influenced by the response spectra shape, which is very sensitive, and the waves traveled by the bedrock to the free field through sediments can affect the three surface motions as shown (Figure 2.9) [38]. Using by frequency content of ground motion can be studied by the site effects. Frequency depends on spectral amplitudes with increasing amplitude with increasing frequency content.

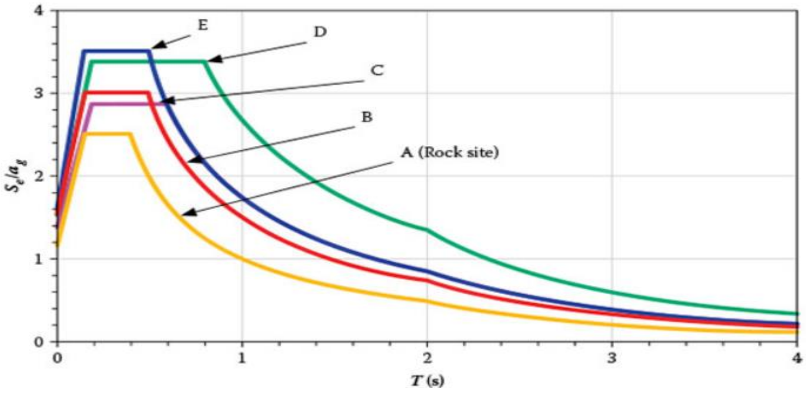


Figure 2.9: Effects of soil condition in design spectra [39]

Local site effects become more popular and crucial aspects contributing to the distinctions in strong ground motions [40]. To define the response of soil deposit to bedrock motion was the purpose of the analysis of ground response [41]. It is essential to assess the performance of the layer surface soil to compute response earthquake motion to structures as surface layers amplify earthquake motion [42].

The level of ground shaking results in soil stress-strain nonlinearity, and induce enormous strain caused by the high-intensity motion, these actions, decrease stiffness and increase hysteresis damping, and reduce the ability of soil. Seismic codes become predominately to prioritize the soil conditions in which each seismic code classifies different categories. The structural design will become vulnerable to the influence of soil conditions. Figure 2.10 describes the seismic site response.

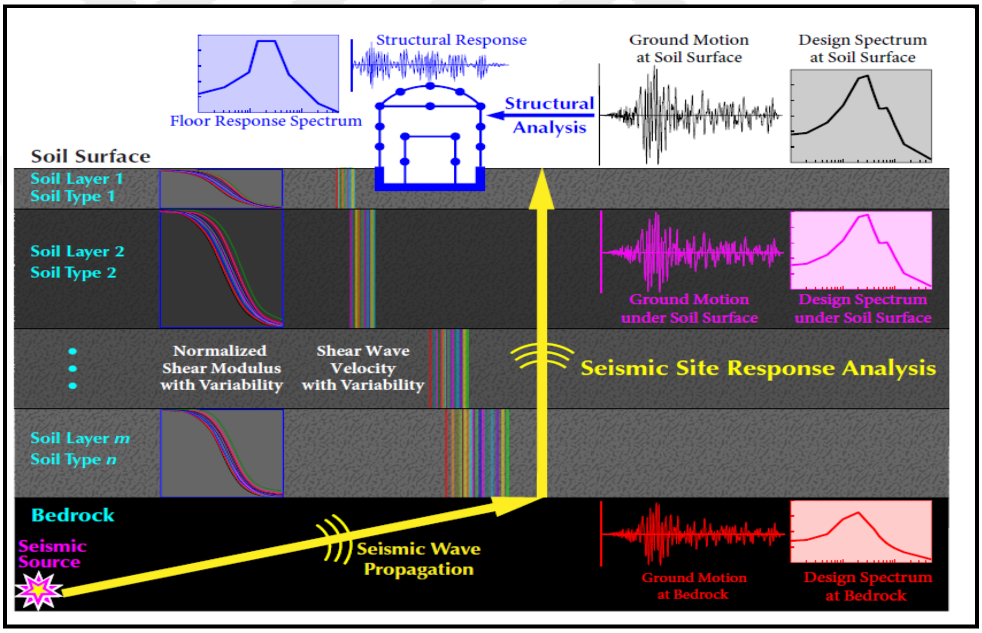


Figure 2.10: Design spectra of earthquake engineering [43]

Soil condition is very crucial as known that the response of structure will not be the same. For example, rock and soft soil, it also is taken into consideration using three different soil conditions. Generally, poor soil conditions increased resonance building. If the period of ground motion will match the natural period of building, it will undergo large oscillation possible and suffer significant damages. In Mexico City (1985), the frequency content of that earthquake matched the natural period of the building of 5 stories to 15 stories that were profoundly affected, where taller buildings remained safe (Figure 2.11). At that time, seismic codes changed and started looking at building frequency to pay attention to ground motion input and how it would affect the building. Generally, the bedrock has high frequency and lower amplitude and short period duration, while soft soils are long period duration, high amplitude, and lower frequency.

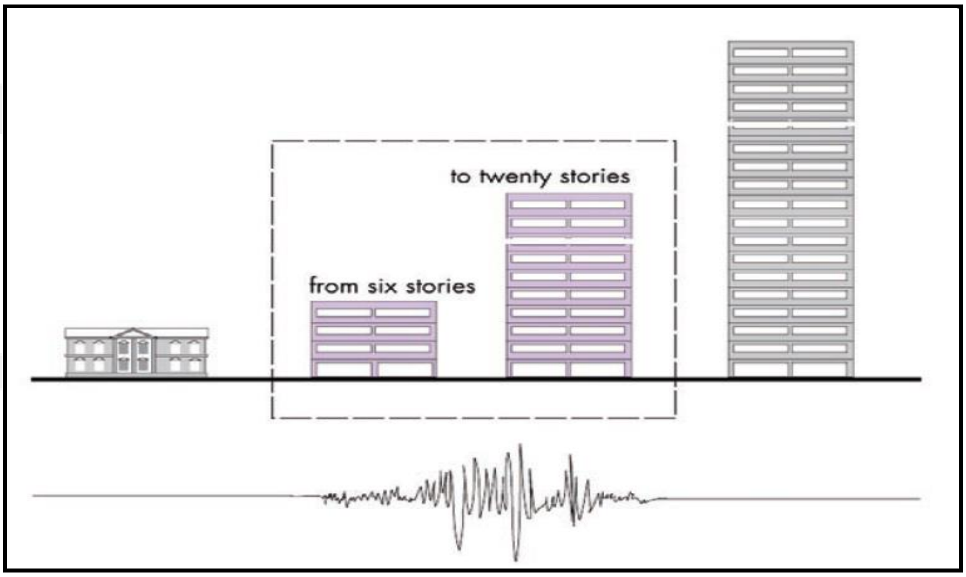


Figure 2.11: Mexico earthquake period of buildings [44]

The result can obtain by two sites that have the same distance from the earthquake epicenter will not be the same; maybe sites can experience different effects. One site can experience more damage, while another site is impacted little damage because of the variation site conditions. Generally, hard rock is less amplitude since waves travel faster than soft soil and medium soil. Soft soil has a strong amplitude and bigger waves, and the base shear obtained soft soil is more than other soil classes due to the higher amplification.

2.5 Reduction Factor

When a strong earthquake strike the structure, that structures experienced damage and behave in an inelastic manner. However, these strong earthquakes always a low probability and often do not happen. Therefore, most buildings are not remaining elastically under the strong motions. The aim purpose is to consider the inelastic is that buildings can undergo some damage but could not collapse this can endorse to prevent the loss of life. Another fundamental factor is the consideration of energy dissipation due to inelastic actions. For these phenomena, structures experienced to yield due to the cyclic loading repetition during the earthquake which leads to stiffness and strength degradation.

Seismic codes use a reduction or behavior factor to account for the inelastic deformation caused by strong ground motions. Also, this factor is used to reduce the design strength for the elastic force which is economical as shown in Figure 2.12 [45].

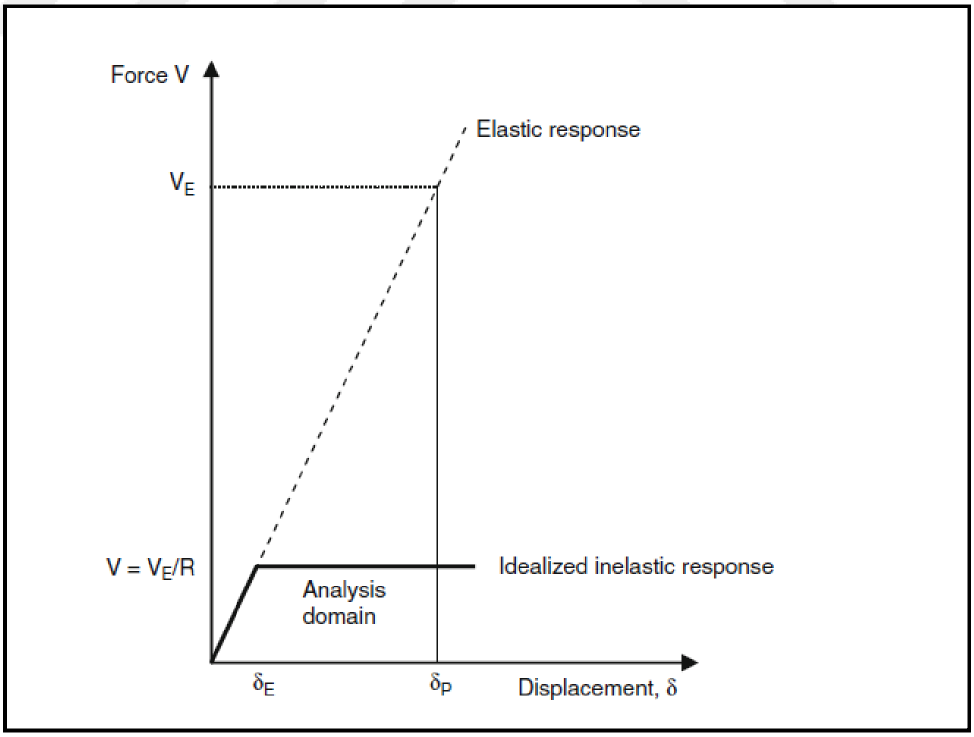


Figure 2.12: Reduction factor [46]

CHAPTER 3

METHODOLOGY

3.1 Introduction

To limit possible damage caused by the internal force that earthquakes induced is the main purpose adopted by earthquake resistance design. Weak earthquakes do not cause significant damage to the structural and non-structural of the building, and in moderate earthquakes, the structural and non-structural elements are limited and repairable. In high-intensity earthquakes, structural and non-structural elements are limited, and permanent structural destruction without collapse occurred. Seismic codes use a design based earthquake for a moderate earthquake for return period the probability of exceeding 50 years in 10% (475 years).

The most useful methods for earthquake resistance design are response spectrum, equivalent lateral force (limited height and usually used for lower and middle buildings). Engineers use response spectra to compute the earthquake force adopting the static force. In this study linear analysis procedure will be consider for the design.

3.2 Building Model

A six-story regular building considered for this study, and the longitudinal and transverse direction of the building both have four bays (20 m). The building geometry and 3D view presented Figure.3.2 and Figure 3.3 respectively. The overall building height is 18 m. The building has chosen Avclilar in Istanbul. The structure intended in a high seismic zone. The level ground motion design is assigned level DD-2, which defines a 10% probability of exceeding in 50 years, corresponding to a return period of 475 years for very stiff soil. The material properties are assumed the compressive strength of concrete M25 and reinforcement steel S420. The structural cross-section element used a column 500 mm x 500 mm, beam 300 mm x 500 mm, and the thickness of slab is assumed 150 mm. The values obtained from AFAD website for the construction elastic response spectrum curve are presented in Table 3.1 for soil class ZD.

Table 3.1 Design spectrum parameters obtained from AFAD

$\mathbf{S_S}$	1.080	$\mathbf{S_1}$	0.296
$\mathbf{S_{DS}}$	1.1534	$\mathbf{S_{D1}}$	0.5944
PGA	0.443g	**PGV**	26.666 cm/sec

40.9802 ° and 28.7207 ° are latitude and longitude of the site location coordinates and the spectral acceleration for short and long period S_S and S_1 found using by AFAD website. Figure 3.1 shown the location of the building. Table 3.2 are tabulated the details of the preliminary data considered for the design.

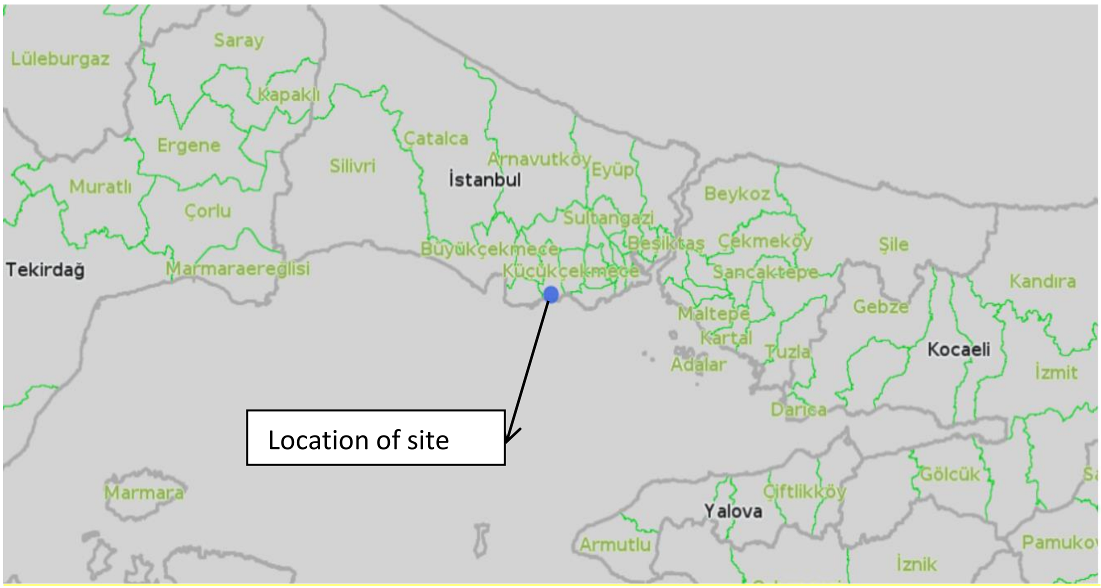


Figure 3.1 : Location site obtained AFAD website

Table 3.2 Preliminary data

Design parameters	ASC7-16	TSC-2018	EC8	IS 1893
Important factor	1.2			
Reduction factor/ behavior factor	5			
Load live reduction	25%	30%	30%	25%
Design category	III	BKS=2	II	II
Soil class type	D	D	C	II
Cross-section elements				
Beam	300 mm x 500 mm			
Slab	150 mm			
Column	500 mm x 500 mm			

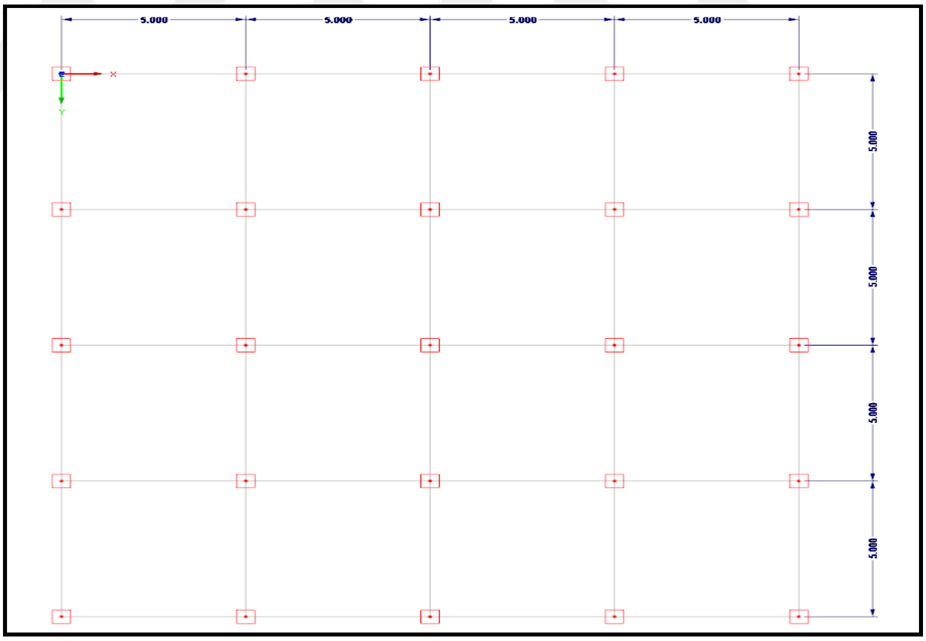


Figure 3.2: Typical Plan

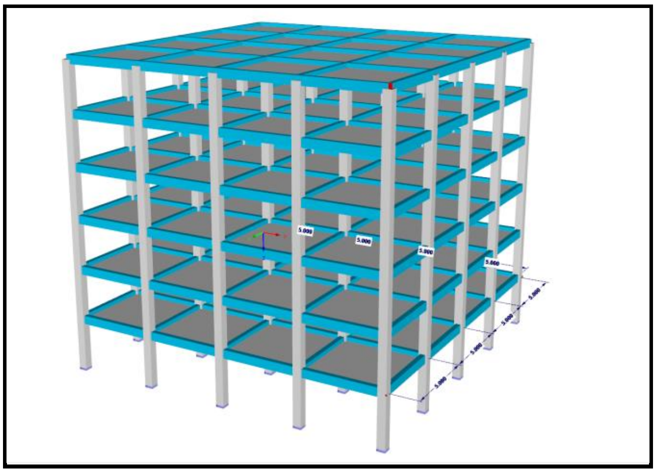
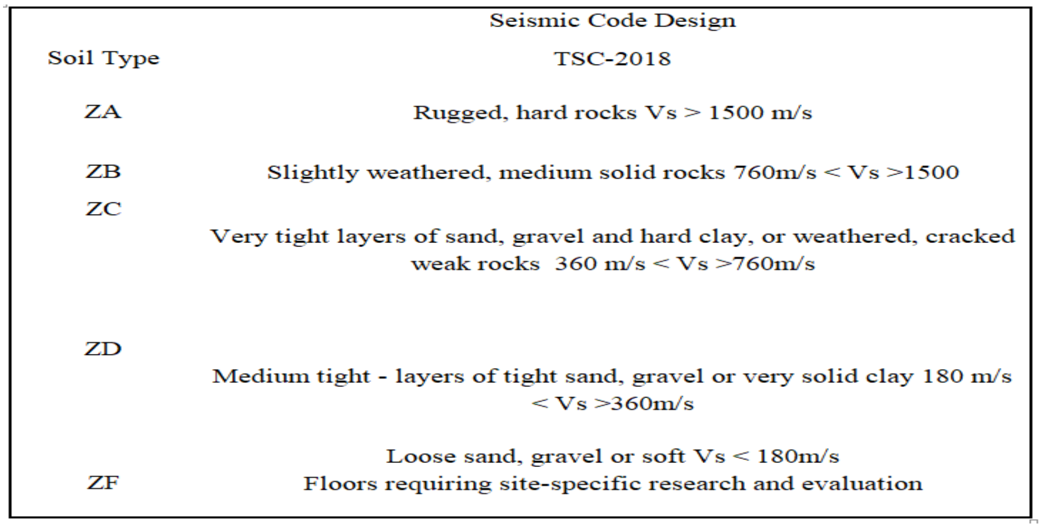


Figure 3.3**:** 3D view

3.3 Turkish Seismic Code (TSC-2018)

The effects of soil conditions recognized after the earthquakes, Kobe 1995, Northridge 1994 and Loma Prieta 1989. Earthquake codes acknowledged the prominence site conditions. The soft sediment and rock soil have different features that can nasty amplify the earthquake motions traveled from the earthquake source. If the structures made with a same material property, the building constructed by on the soft soils damaged more than the hard rock soils. The soil classes according to the Turkish code categorized A up to F as shown Table 3.3.

Table 3.3 Soil classification according to TSC-2018

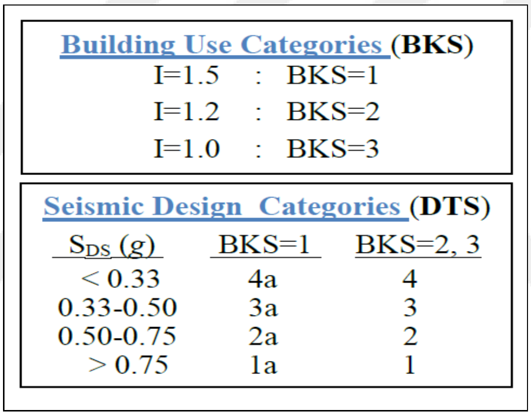


	Seismic Code Design
Soil Type	TSC-2018
ZA	Rugged, hard rocks Vs > 1500 m/s
ZB	Slightly weathered, medium solid rocks 760m/s < Vs >1500
ZC	Very tight layers of sand, gravel and hard clay, or weathered, cracked weak rocks 360 m/s < Vs >760m/s
ZD	Medium tight - layers of tight sand, gravel or very solid clay 180 m/s < Vs >360m/s
	Loose sand, gravel or soft Vs < 180m/s
ZF	Floors requiring site-specific research and evaluation

3.3.1 Building Usage Category

The Turkish seismic design code (2018) is classified the building use category that is assigned the importance of the building. The building use categorized in to three BKS=1, BKS=2 and BKS=3 as shown Table 3.4. However, The BKS=2 is assigned by the importance buildings such hospitals, schools and emergency farcicalities and the BKS=2 is assigned the buildings where overcrowded places such as malls, stadium and BKS=3 is all other remain buildings [47]. Table 3.5 illustrates the building height of category.

Table 3.4 Building use and seismic design category [48]



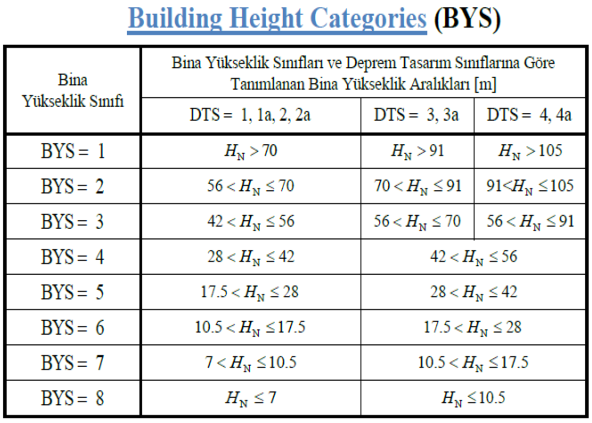
Building Use Categories (BKS)

I=1.5 : BKS=1
I=1.2 : BKS=2
I=1.0 : BKS=3

Seismic Design Categories (DTS)

S_{DS} (g)	BKS=1	BKS=2, 3
< 0.33	4a	4
0.33-0.50	3a	3
0.50-0.75	2a	2
> 0.75	1a	1

Table 3.5 Building height category [48]



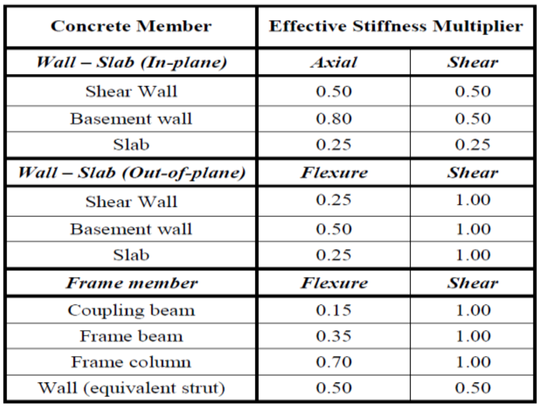
Building Height Categories (BYS)

Bina Yükseklik Sınıfı	Bina Yükseklik Sınıfları ve Deprem Tasarım Sınıflarına Göre Tanımlanan Bina Yükseklik Aralıkları [m]		
	DTS = 1, 1a, 2, 2a	DTS = 3, 3a	DTS = 4, 4a
BYS = 1	$H_N > 70$	$H_N > 91$	$H_N > 105$
BYS = 2	$56 < H_N \leq 70$	$70 < H_N \leq 91$	$91 < H_N \leq 105$
BYS = 3	$42 < H_N \leq 56$	$56 < H_N \leq 70$	$56 < H_N \leq 91$
BYS = 4	$28 < H_N \leq 42$	$42 < H_N \leq 56$	
BYS = 5	$17.5 < H_N \leq 28$	$28 < H_N \leq 42$	
BYS = 6	$10.5 < H_N \leq 17.5$	$17.5 < H_N \leq 28$	
BYS = 7	$7 < H_N \leq 10.5$	$10.5 < H_N \leq 17.5$	
BYS = 8	$H_N \leq 7$	$H_N \leq 10.5$	

3.3.2 Effects of Stiffness for Concrete Section Element

It is very crucial to estimate properly the flexural stiffness of each individual member to apprehend the dynamic behavior of the building and strength and deformation demands enforced on the structure. Throughout ground shaking, sections experienced substantial crack to that point it is challengeable for reinforced concrete to take an appropriate cross-section property. Low levels of flexural effects resulted, that reinforced concrete members experienced a crack, and it may cause to decrease in their stiffness. To account the effective stiffness, more accurate internal force distributions should be achieved the analysis if the reduced stiffness considers for linear analysis. American, Indian and Turkish codes are both similar of defining the effective stiffness for members 70% of gross of stiffness for columns and 35% for beams, while Eurocode describes 50% for both beams and columns as shown Table 3.6 [49]. Figure 3.4 describes the effect of stiffness for the fundamental period of structure.

Table 3.6 Effective stiffness modifiers



Concrete Member	Effective Stiffness Multiplier	
Wall – Slab (In-plane)	***Axial***	***Shear***
Shear Wall	0.50	0.50
Basement wall	0.80	0.50
Slab	0.25	0.25
Wall – Slab (Out-of-plane)	***Flexure***	***Shear***
Shear Wall	0.25	1.00
Basement wall	0.50	1.00
Slab	0.25	1.00
Frame member	***Flexure***	***Shear***
Coupling beam	0.15	1.00
Frame beam	0.35	1.00
Frame column	0.70	1.00
Wall (equivalent strut)	0.50	0.50

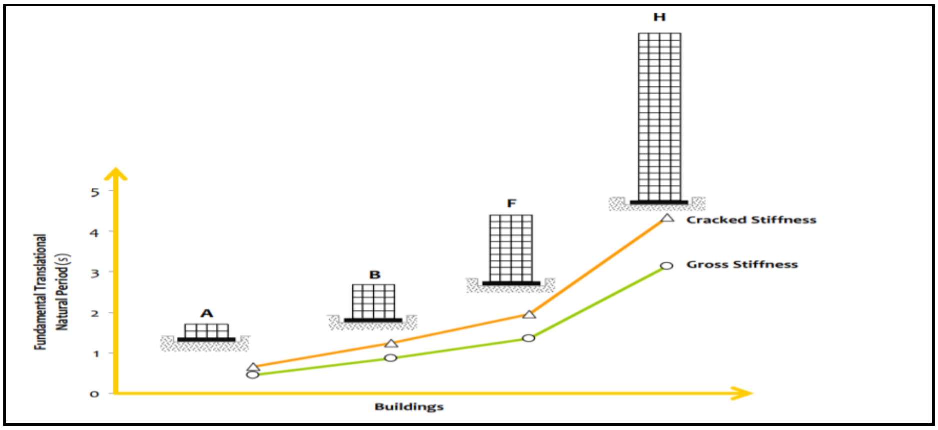


Figure 3.4 : Effects of stiffness [50]

3.3.3 Load Combination

In the design, all possible load combinations is applied on the structure should be considered and the load combination based on TSC 500. As shown the equations 3.1 up to 3.5.

$$1.2\ \mathrm{G} + 1.6\mathrm{Q} \tag{3.1}$$

$$1.0\ \mathrm{G} + 1.0\ \mathrm{Q} \pm 1.0\ \mathrm{EX} \tag{3.2}$$

$$1.0\ \mathrm{G} + 1.0\ \mathrm{Q} \pm 1.0\ \mathrm{EY} \tag{3.3}$$

$$0.9\ \mathrm{G} \pm 1.0\ \mathrm{EX} \tag{3.4}$$

$$0.9\ \mathrm{G} \pm 1.0\ \mathrm{EY} \tag{3.5}$$

3.3.4 Lateral Force Analysis TSC-2018

This method is incremental sequences loads subjected to the building and using horizontal coefficient acceleration and weight of the building can obtain the base shear. Employed with code defined base formulas for equivalent lateral force can distribute the forces into the floors of the building. Regular buildings usually adopted by this method, and the advantage of this method is simple to compute and less time-consuming. The maximum lateral force that earthquake generate is called by base shear. The computation of base shear predominantly depends on the weight of the building, local site conditions, ductility level, and natural period. Utilizing by empirical formulas defined by seismic codes can be calculated as the base shear force then distributed each floor of the building to balance the seismic loads [51].

The base shear force can be calculated according to the Turkish code using equation 3.6

$$V_t = m_t \cdot S_{aR}(T) \geq 0.04 m_t S_{DS} \cdot I \cdot g \tag{3.6}$$

$S_a(T)$ = reduced spectral acceleration

mt = is the total mass of the building

I = Important factor

The design spectral acceleration reduced can be used equation 3.7

$$S_{aR}(T) = \frac{S_{ae}(T)}{R_a(T)} \tag{3.7}$$

S_{ae} = Elastic acceleration design spectra

R= reduction factor

The fundamental period of structure can be calculated using the approximate empirical formula as described the equation 3.8

$$T = C_t H^{3/4} \tag{3.8}$$

Where C_t depends on the structural type of the building, for moment resistance steel frames 0.080 and moment resistance frames for concrete 0.10, and 0.070 for all other structures.

3.4 Response Spectrum Analysis

Seismic analysis can be classified to linear and non-linear analysis. The most and standard application for the design new structures is linear analysis and the response spectrum is most useful tool for linear analysis which is used to find the maximum stress which developed by the members. A response spectrum plots the maximum response for a single degree of freedom system, but in the case of multi-degree freedom system is carried out for modal analysis to find the modes shapes, modal participation factors and frequencies.

To construct response spectrum curve, it is necessary to have information concerning site conditions. The codes distinguish the soil classes into different categories rely on the soil profile. In this study, the soil class C regarding to Eurocode, site class D regarding to ASCE, site class D for TSC and site class III for Indian code is consider for the design.

3.4.1 Response spectrum TSC

Turkish code defines the spectral acceleration for short, and long $S_{S.}$ and S_1 respectively, and both obtained from hazard maps https://tdth.afad.gov.tr, the new Turkish code defines four ground motion levels, and this case, level two considered for the design which defines DD-2 10% probability of exceeding in 50 years, corresponding to a return period of 475 years. In building category one considered which defines the hospitals and main places. Figure 3.5 describes the data obtained from the AFAD website to construct elastic design spectra curve. The soil class is considered for soil class ZD. The short period and long period S_S and S_1 are mapped considerate spectral acceleration respectively and used to compute the design spectral acceleration. S_{DS} and S_{D1} are spectral design coefficient and define the upper and lower level of design spectrum curve.

The important factor is assigned 1.2 as described the new Turkish code for building use category BKS=2. Turkish code separates the lateral seismic resistance frames into three types the building system with high ductility level, building systems with mixed ductility and ductility with a limited ductility level. The systems are based on the material of the structure, the modification factors which are assigned to reduce the elastic force, overstrength and acceptable height category. In this study consider moment resistance frame. S_{DS} controls the seismic design category.

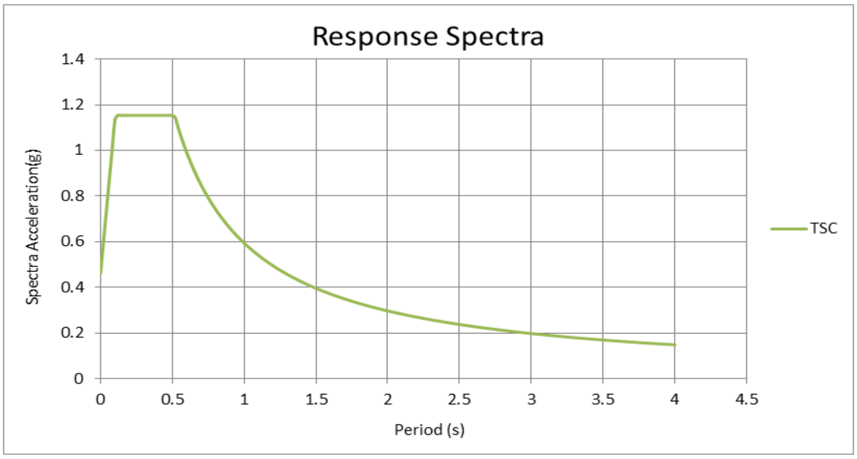


Figure 3.5: Response spectrum curve

The equation 3.9 and 3.10 describes the design spectral acceleration S_{DS} and S_{D1} respectively.

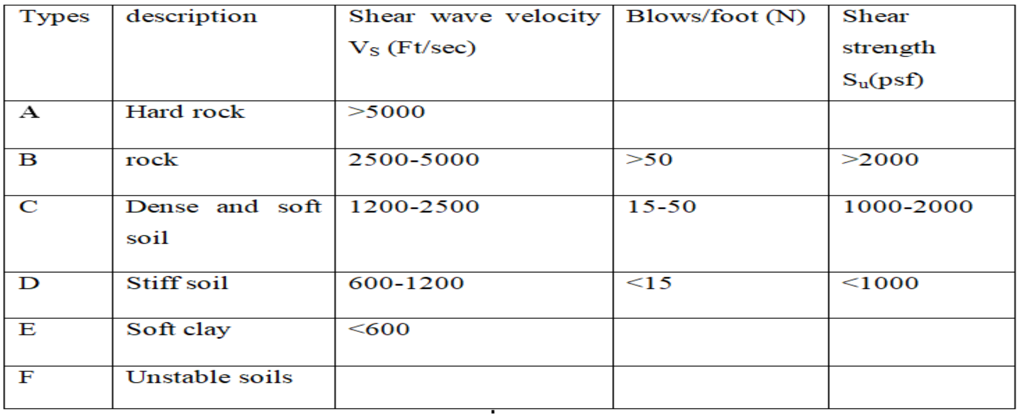
$$S_{DS} = S_S F_S \tag{3.9}$$

$$S_{DS} = S_S F_S \tag{3.10}$$

3.5 American Seismic Code ASCE7-16

American code defines six soil types as know that most buildings are not located on places matching the site condition reference related to the mapped values of S_S and S_1. ASCE7 explains the effects of the site on spectral shape through the assignment coefficient of the site which is based on the type of soil. Table 3.7 illustrates the soil classification according to ASCE7-16.

Table 3.7 Soil classifications ASCE7-16

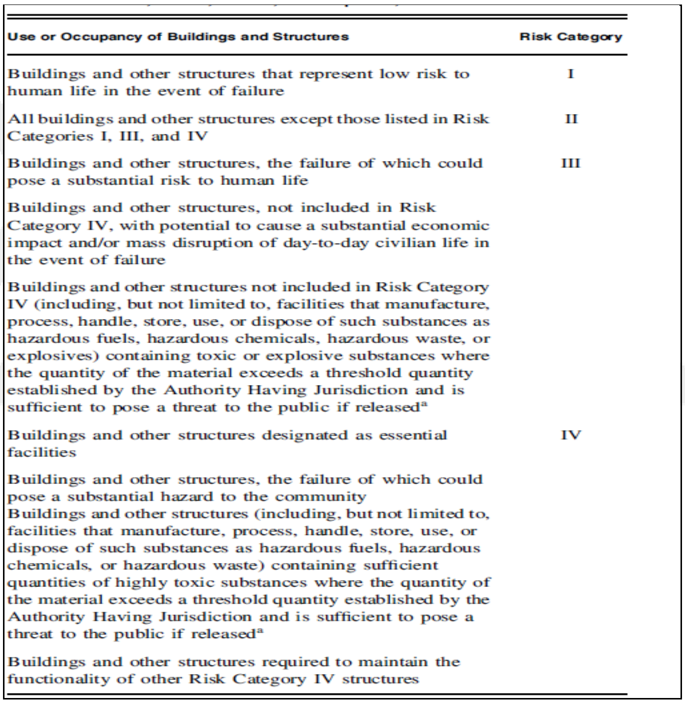


Types	description	Shear wave velocity V_S (Ft/sec)	Blows/foot (N)	Shear strength S_u(psf)
A	Hard rock	>5000		
B	rock	2500-5000	>50	>2000
C	Dense and soft soil	1200-2500	15-50	1000-2000
D	Stiff soil	600-1200	<15	<1000
E	Soft clay	<600		
F	Unstable soils			

3.5.1 Risk Category

Based on the importance of structures, the buildings are classified risk categories include consideration such as human risk life. According to the ASCE defines four risk categories, and the important factor is ranged from 1 to 1.5. The main purpose is to attain minimum levels of earthquake performance deemed suitable to individual occupancies. Table 3.8 depicts the risk category of each structure according to the American seismic code.

Table 3.8 Important factor [52]



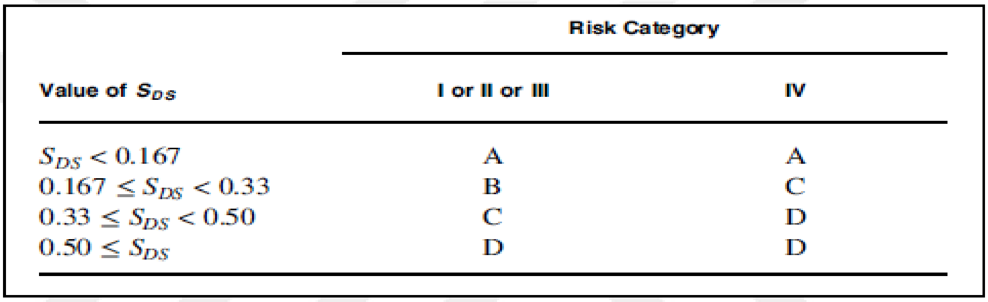
Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure	
Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures designated as essential facilities	IV
Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the Authority Having Jurisdiction and is sufficient to pose a threat to the public if released[a]	
Buildings and other structures required to maintain the functionality of other Risk Category IV structures	

3.5.2 Seismic Design Category

Seismic design category assigned by the structures to consider the allocated the design spectral acceleration parameters S_{DS} and S_{D1} and risk category. According to ASCE describes six design categories among from A to F. Structures assigned to design category A is not anticipated to experience destructive earthquake trembling. Not imperative to design a seismic resistance, however it must meet rudimentary structural criteria that should be capable to resists 1% of the building weight subjected to in each direction lateral force. The risk categories I, II, III are assigned the structures located low seismic regions, and it will be anticipated to experience VI or lesser according to the MMI. These categories belong to the seismic design category B and needed some detailing requirements. Seismic design categories C are assigned seismic regions where moderate earthquakes are expected to happen and needed some detailing requirements. Seismic design categories D are assigned high seismic regions and expected that earthquakes can be caused by damage and needed more detailing requirements.

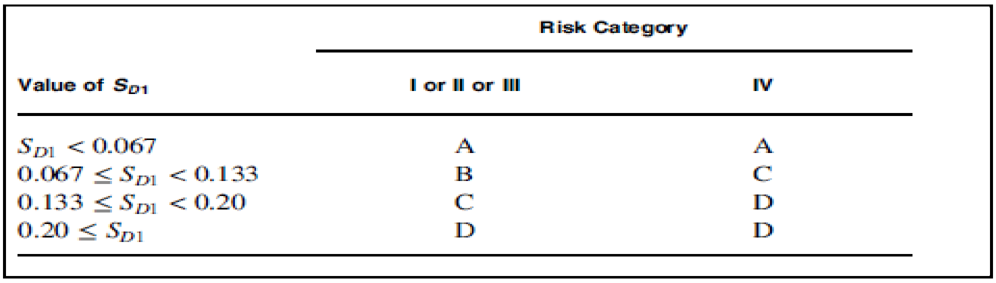
Table 3.9 and Table 3.10 demonstrate the seismic design category for short spectral acceleration and long spectral acceleration respectively.

Table 3.9 Seismic design category based on short spectral acceleration [52]



	Risk Category	
Value of S_{DS}	**I or II or III**	**IV**
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.50 \leq S_{DS}$	D	D

Table 3.10 Seismic design category based on long spectral acceleration [52]



	Risk Category	
Value of S_{D1}	**I or II or III**	**IV**
$S_{D1} < 0.067$	A	A
$0.067 \leq S_{D1} < 0.133$	B	C
$0.133 \leq S_{D1} < 0.20$	C	D
$0.20 \leq S_{D1}$	D	D

3.5.3 Load Combination

Below Equations describe the load combination according to the American code.

$$1.2\ DL + 1.6\ LL \tag{3.12}$$

$$1.2\ DL + 1.0EQ \tag{3.13}$$

$$0.9DL + 1.0EQ \tag{3.14}$$

3.5.4 Method of Analysis

The linear procedures, modal response spectrum and equivalent lateral force are considered for the design the structure.

3.5.4.1 Equivalent Linear Analysis ASCE7-16

The base shear of the structure is calculated using Equation 3.15. The base shear depends on the seismic weight of structure and seismic weight of building.

$$V_b = C_S W \tag{3.15}$$

The Equation 3.16 and Equation 3.17 are used to compute the seismic base shear coefficient. There are some important factors that seismic base shear coefficient depends on, these factors included the period of structure, importance factor, and the type of structural system used for the design.

The buildings with period smaller than the T_L value, then the seismic base shear coefficient used the lesser values. S_{DS} and S_{D1} are spectral design acceleration for short and long period defined by the design spectra.

$$C_S = \frac{S_{DS}}{\frac{R}{T}} \tag{3.16}$$

$$C_S = \frac{S_{D1}}{\left(\frac{R}{I}\right)T} \tag{3.17}$$

The seismic base shear coefficient should not be less than as describes Equation 3.18

$$C_S = 0.044 S_{DS} I_e \geq 0.01 \tag{3.18}$$

Equation 3.19 shall be determined the approximate period of the structure.

$$T_a = C_t h_n^x \tag{3.19}$$

Once computed the base shear of the structure, then the lateral force of structure shall be distributed at each floor using Equation 3.20.

$$F_i = \frac{w_i h_i^k}{\sum_{i=0}^{n} w_j h_i^k} V \tag{3.20}$$

3.5.4.2 Response Spectrum ASCE7-16

The displacement and internal forces of the structures caused by earthquakes can be determined response spectrum method which is the most useful instrument for earthquake resistance design and provides the peak response of spectral acceleration at any period. According to section 11.6, Table 11.6-1 describes that S_{DS} and S_{D1} control the seismic design category, and this study the design category III assigned the design.

Using Table 1.5-1, the building function is assigned to be a category III, and this study the important factor for seismic codes used the same important factor which is taken 1.2. The reduction factor is governed by the structural type, this study considered an ordinary moment frame and taken the reduction factor 5.

The mapped spectral acceleration for short and long periods S_S and S_1 respectively has been found using the AFAD database and then created elastic design spectra curve for as shown Figure 3.6. ASCE7-16 classifies the soil classes into five types and the type of soil has been chosen for medium soil (D). The return period ASCE proposed the probabilistic for the MCE_R earthquake is 2% in 50 years(2475year return period) and the earthquake design based on 10% in 50 years (475 return period) [53].

S_{MS} and S_{M1} are MCE_R for short period and long period and can be found using Equation 3.21 and 3.22 respectively.

$$S_{MS} = F_a S_s \tag{3.21}$$

$$S_{M1} = F_v S_1 \tag{3.22}$$

Fa and Fv are soil amplification a factor adopted to adjust the spectrum curve and depends on the soil type.

The design spectral acceleration for short S_{DS} and long period S_{D1} can be found using Equation 3.23 and Equation 3.24.

$$S_{DS} = \frac{2}{3} S_{Ms} \tag{3.23}$$

$$S_{D1} = \frac{2}{3} S_{M1} \tag{3.24}$$

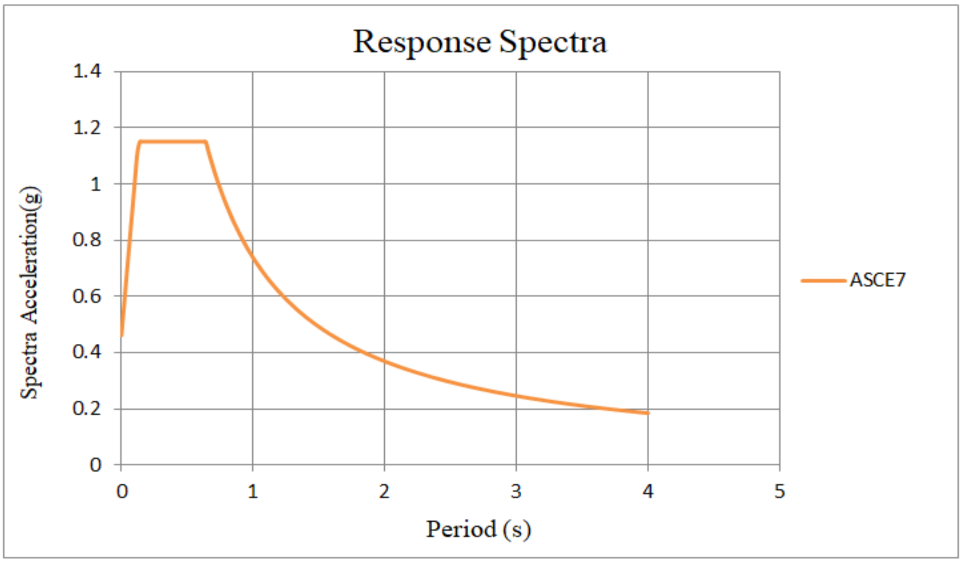


Figure 3.6: Repsone spectrum curve ASCE7-16

3.6 Indian Seismic Code IS 1893

Indian seismic code uses a seismic zone factor to establish the design shaking intensity. Four seismic zone map depict the Indian code to design four levels of effective peak ground acceleration (EPGA) normalized by soil factor. High seismic zone represents Zone IV for the design shaking intensity with maximum peak ground acceleration 0.36g. In moderate ground shaking represents by Zone III with 0.24g. Seismic zone I with 0.10g and zone II with 0.16g respectively and represents the lowest ground shaking design as presented Table 3.11[54].

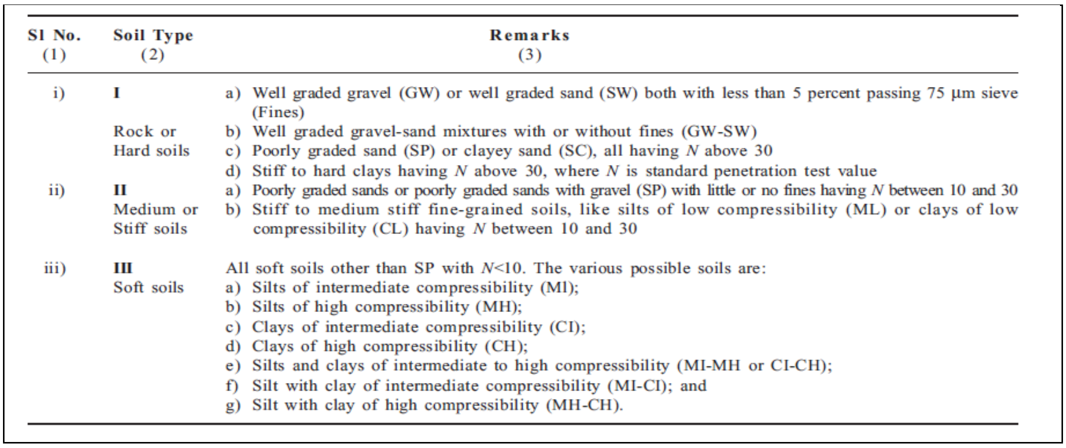
Table 3.11 Seismic zones IS 8193

Seismic zone	Ao
I	0.10g
II	0.16g
II	0.24g
IV	0.36g

3.6.1 Site Classes

In IS 1893, accounts three different soil classes and scaled by seismic zone factor. Type I, type and Type III which represent hard rock, medium and soft soil respectively. The soil classes is based on the standard penetration test (SPT) N-value, most codes use average shear wave velocity the major factor to classify the soil but Indian code not mentioned at all [55]. Table 3.12 depicts the soil description according to the IS1893-16.

Table 3.12 Soil descriptions [56]



Sl No. (1)	Soil Type (2)	Remarks (3)
i)	**I** Rock or Hard soils	a) Well graded gravel (GW) or well graded sand (SW) both with less than 5 percent passing 75 µm sieve (Fines) b) Well graded gravel-sand mixtures with or without fines (GW-SW) c) Poorly graded sand (SP) or clayey sand (SC), all having *N* above 30 d) Stiff to hard clays having *N* above 30, where *N* is standard penetration test value
ii)	**II** Medium or Stiff soils	a) Poorly graded sands or poorly graded sands with gravel (SP) with little or no fines having *N* between 10 and 30 b) Stiff to medium stiff fine-grained soils, like silts of low compressibility (ML) or clays of low compressibility (CL) having *N* between 10 and 30
iii)	**III** Soft soils	All soft soils other than SP with $N<10$. The various possible soils are: a) Silts of intermediate compressibility (MI); b) Silts of high compressibility (MH); c) Clays of intermediate compressibility (CI); d) Clays of high compressibility (CH); e) Silts and clays of intermediate to high compressibility (MI-MH or CI-CH); f) Silt with clay of intermediate compressibility (MI-CI); and g) Silt with clay of high compressibility (MH-CH).

3.6.2 Occupancy Category

To determine the seismic design forces, IS893 code considered for occupancy. As describes clause 7.2.3, the important factor which defines the usage of the building classified in to thee category as described Table 3.13.

Table 3.13 Important factor

No	Structure	Important Factor (I)
1	significant structures such as hospitals, schools, railways, metro rail buildings, shopping mall	1.5
2	Commercial and residential	1.2
3	Other buildings	1.0

3.6.3 Load Combination

For the design, the load combination that possible to applied on the structure should be used Equation 3.24 up to Equation 3.30. The load combination used the design are based on IS 456 2000.

$$1.2[\ \mathrm{DL} + \mathrm{LL} + (\mathrm{ELX} \pm 0.3\mathrm{ELY})] \qquad (3.25)$$

$$1.2[\ \mathrm{DL} + \mathrm{LL} + (\mathrm{ELY} \pm 0.3\mathrm{ELX})] \qquad (3.26)$$

$$1.5[\ \mathrm{DL} \pm (\mathrm{ELX} \pm 0.3\mathrm{ELY})] \qquad (3.27)$$

$$1.5[\ \mathrm{DL} \pm (\mathrm{ELY} \pm 0.3\mathrm{ELX})] \qquad (3.28)$$

$$0.9[\ \mathrm{DL} \pm 1.5(\mathrm{ELX} \pm 0.3\mathrm{ELY})] \qquad (3.29)$$

$$0.9[\ \mathrm{DL} \pm 1.5(\mathrm{ELY} \pm 0.3\mathrm{ELX})] \qquad (3.30)$$

3.6.4 Analysis Procedure

In the new building design, most codes use linear analysis. The most useful tool for earthquake resistance design is modal response spectrum, and equivalent lateral force, cannot be used any design such as modal response spectrum but restricted. In this study both procedure are used the design.

3.6.4.1 Equivalent Lateral Force

According to the Indian seismic code IS1893-16 the total base shear of the structures in each direction can be calculated by Equation 3.31.

$$V_b = A_h W \tag{3.31}$$

Where Vb is the base shear, Ah is horizontal seismic acceleration coefficient and w is the weight of structure.

The design horizontal seismic coefficient can be calculated Equation 3.32, and this factor depends on the seismic zone factor, reduction, importance factor, and the design acceleration coefficient.

$$V_b = \frac{ZI}{2R}\left(\frac{S_a}{g}\right)w \tag{3.32}$$

$\frac{S_a}{g}$ = ordinate design spectrum for period T

I = is the important factor that depends on the usage of the building

W = Mass of the building

Z = Seismic zone factor

Once calculated the base shear of structure then it is distrubed the storey shear for each floor using Equation 3.33. this method is only applicable for regular buidlings with less than heigh of 15 m in zone II.

$$F_i = F_b \cdot \frac{Z_i \cdot m_i}{\sum Z_j \cdot m_j} \qquad (3.33)$$

3.6.4.2 Response Spectrum

Most codes defined that sum of effective the modal effective masses should not be less than 90% of the total mass of the building obtained in each two horizontal directions. The accidental torsion effects have been considered for the design both positive and negative and taken 5%. IS 1893 distinguishes the lateral seismic resistance frames into four types. Shear wall, braced frame, moment resistance frame, and dual-system are the combinations of the above systems. The systems are based on the material of the structure, the modification factors which are assigned to reduce the elastic force. In this study moment resistance frame used particularly, ordinary moment resistance frame and modification factor is taken 5. The occupancy category has been assigned category II which is defined commercial and residential places and is taken 1.2. Figure 3.7 shown the elastic design spectra curve.

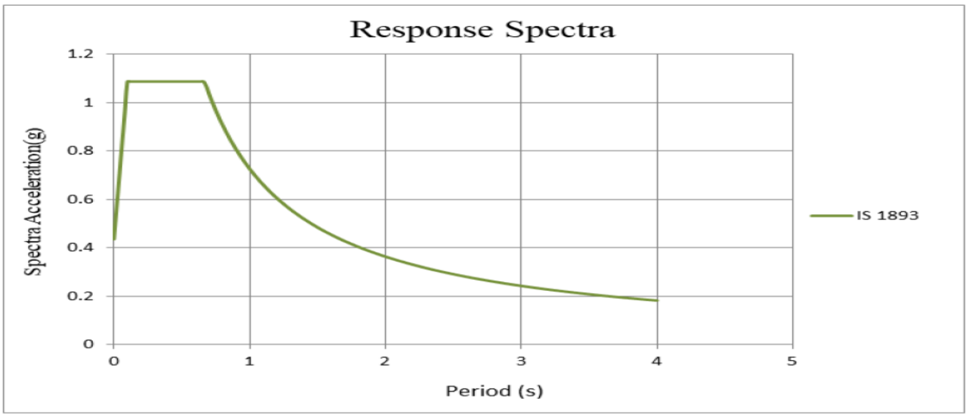


Figure 3.7 : Response spectrum IS 1893

3.7 Eurocode 8

To describe the seismic hazard, the most application Eurocode defines is a single parameter such as the reference peak ground acceleration on type A agR. This reference peak ground acceleration is corresponding to the return period T_{NCR} of seismic actions. The importance factor is multiplied reference peak ground acceleration to reach the design ground acceleration. The seismic codes define or classify the sites into a different category, and these categories called ground types, soil types, and subsoil classes, Eurocode defines five ground types and two soil factors based on the shear wave velocity Table 3.14 [57].

Table 3.14 Ground types

Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	_	_
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	_	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

3.7.1 Lateral Force Analysis EC8-2004

The base shear of the building Fb is obtained using Equation 3.35 according to the Eurocode building code. When computed the period of the building, the spectral acceleration Se is found from design spectrum.

$$F_b = S_d(T) \cdot m \cdot \lambda \tag{3.35}$$

$S_d(T)$ = ordinate design spectrum for period T

λ = is the important factor that depends on the usage of the building

$m =$ Mass of the building

The fundamental period of the structure should be determined using the expression based on the structural dynamic methods such as the Rayleigh method. The Equation 3.36 should be used to compute an approximate fundamental period for the structures with heights up to 40 m. Once compute the period of the building, it is possible to check that linear static analysis is acceptable to these requirements. The structure should satisfy the regularity criteria for EC8 code, and T_1 < 4TC and TC are defined as the end of the constant acceleration period for the design spectrum. If the structure should not meet these two conditions, the modal response spectrum method should be used. Then, It is distributed the horizontal loads over the building height using Equation 3.37.

$$T = C_t H^{3/4} \tag{3.36}$$

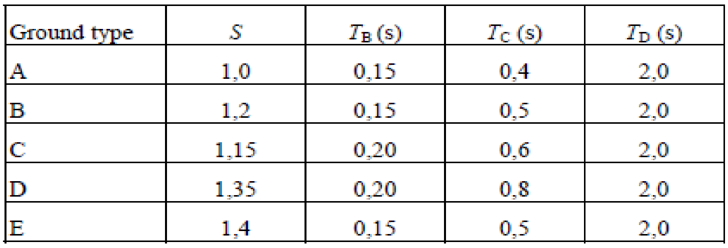
Where C_t depends on the structural type of the building, for moment resistance steel frames 0.085 and moment resistance frames for concrete 0.075, and 0.050 for all other structures.

$$F_i = F_b \cdot \frac{z_i \cdot m_i}{\sum z_j \cdot m_j} \tag{3.37}$$

3.7.2 Response Spectra Eurocode

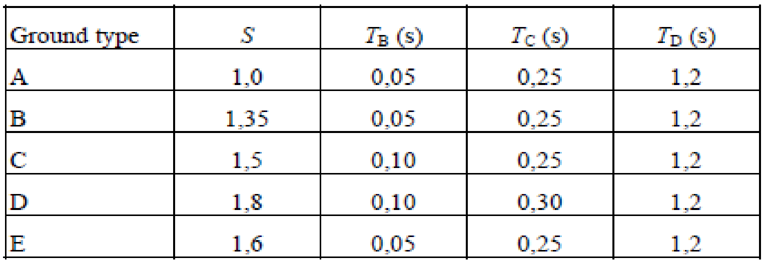
In earthquake resistance design, the response spectrum becomes the most useful technique used to design earthquake engineering, and most codes adopted. Ground shaking caused by earthquakes typically characterized acceleration or displacement response spectra. Epicentral distance, magnitude, local soil conditions are earthquake parameters and affect the shape of response spectra [58]. The design spectra describes both horizontal and vertical. T_B, T_C and T_D are control points. The elastic design spectrum describes two soil factors, which depend on the ground type and damping factor. Eurocode uses a behavior factor to reduce the elastic force to account for the inelastic design spectrum. The design spectra EC8 recommended two types of horizontal elastic spectra namely Type 1 is presented in Table 3.15 and Table 3.16 respectively and often used the higher seismic places, or regions that have a magnitude greater than 5.5, and Type 2, which commonly used for the less seismic places or where the magnitude of the earthquake is less than 5.5, as describes the probabilistic seismic hazard assessment.

Table 3.15 Elastic spectra Type 1



Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

Table 3.16 Elastic spectra Type 2



Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,05	0,25	1,2
B	1,35	0,05	0,25	1,2
C	1,5	0,10	0,25	1,2
D	1,8	0,10	0,30	1,2
E	1,6	0,05	0,25	1,2

Eurocode describes behavior factor to account the inelastic deformation caused by earthquakes and to reduce the elastic design force. In this study the soil class C which indicates the medium soil and the important factor which depends on the building usage is taken 1.2. Figure 3.8 depicts the elastic design spectra curve.

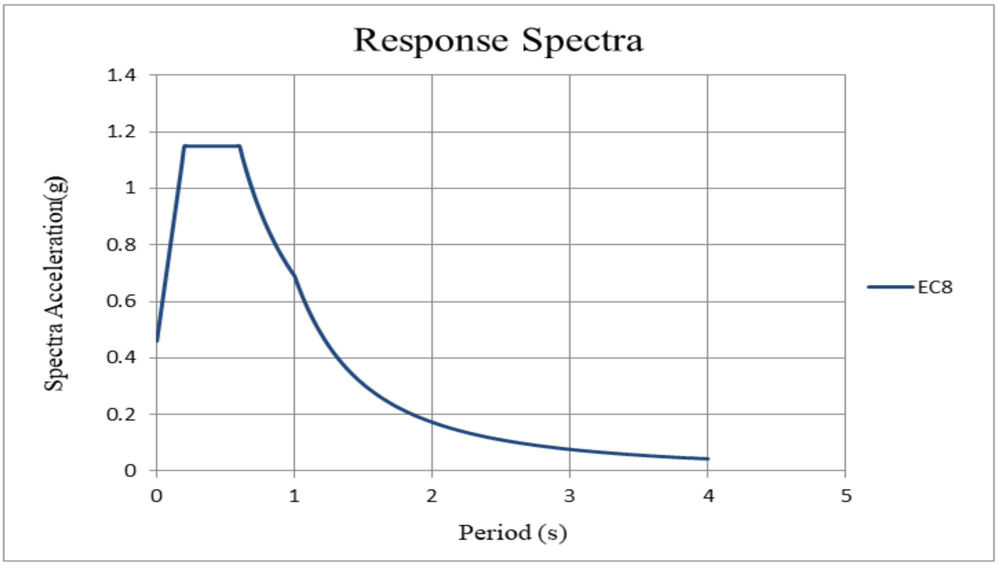


Figure 3.8 **:** Response spectrum curve EC8

3.8 Modal Analysis

The major purpose implemented by dynamic analysis is to assess the response of structure mode by mode and combined then the result from each mode as shown Figure 3.9 [59]. To find the spectral acceleration and period of each mode response spectrum method encompasses and to evaluate the structure response considered that for each mode is applied an equivalent static force that encompasses the spectral acceleration and modal mass. Codes use design spectra to obtain the mean of many earthquake actions in each mode. For a particular earthquake, the design spectra considered the peak values of the performance of each variation mode is a computed modal computation method. The maximum values obtained by each mode are combined using either SRSS or CQC. The CQC is considered in this study to combine the maximum modal contributions, 5% of damping will be assumed for all modes.

3.8.1 Modal Combination Rules

Complete quadratic combination (CQC) and the Square Root of the Sum of Squares (SRSS) are the most useful methods uses to combine the individual exaction spectra.

- Absolute Sum Method (ABSSUM), the peak of response all nodes are combined algebraically by taking the same time the contingency of modals.
- The Square Root of the Sum of Squares method (SRSS), the sum of maximum model response determined in each mode of vibration
- The complete quadratic combination method (CQC) is the calculation of maximum response from all the modes.

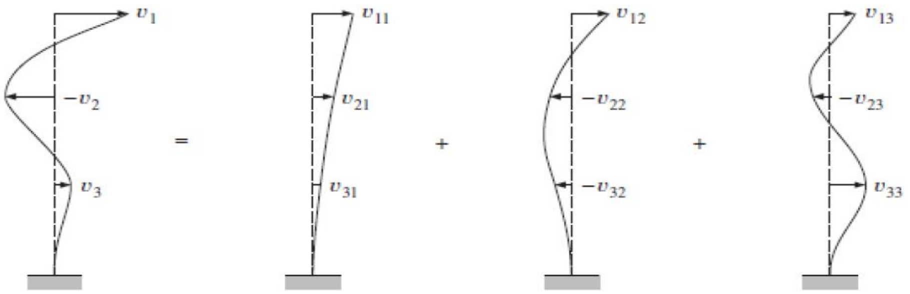


Figure 3.9 **:** Mode shapes of total response [60]

CHAPTER 4

ANALYSIS AND RESULTS

The main purpose of this chapter is to evaluate and review the results obtained from analysis using four seismic building is considered for the design to evaluate the performance for each seismic code and to highlight the similarity and differences.

Linear procedure analysis has been performed for the analysis, static linear analysis, and response spectrum method. This section, also demonstrated by the result obtained from the seismic codes used for the design, such as base shear, inter-story drift, and displacement with compared tables and graphs. As shown figures, each code defined by separately for it is base shear and inter-story drift and then combined with a graph to compare the similarity and dissimilarity among seismic codes.

The major purpose of this study is to compare various seismic codes included Turkish and American code, particularly evaluating the linear procedure analysis to make a conceivable comparison among seismic codes, the analyses have been used elastic response spectrum considered behavior and reduction factors to account the inelastic deformation caused by strong earthquakes. SAP 2000 program have been performed the analysis using the modal response spectrum and static equivalent lateral force. A structure of six-story floors will be used and applied for the seismic loading that seismic codes described to examine and compare their difference.

4.1 Fundamental Period

The natural period is a fundamental parameter that plays a significant role in the characteristics of the earthquake. In this study, a linear static analysis procedure has been calculated for approximate formulas that seismic codes define. There are differences between seismic codes and results show for the Turkish code 0.87s, American code 0.87s, and both for the Indian, and Eurocode 0.66 s respectively for approximate method. But the values obtained from SAP 2000 are more accurate than the approximated method. Table 4.1 shows the fundamental period for static linear analysis and dynamic linear analysis.

Table 4.1 Fundamental period of structure

Codes	Fundamental period (s) First mode	
	ELF	RSA
TSC-2018	0.87	0.78
EC8	0.66	0.80
ASCE7-16	0.87	0.78
IS1893-2016	0.66	0.78

4.2 Base Shear Scaling

Scaling base shear is a technique that most codes required to confirm that least strength of building considered by the response spectrum is same to the strength that building necessary if equivalent static procedure considered [61]. Most codes required the base shear obtained from the modal response spectrum method should be scaled the factor of equivalent lateral force base shear. Clause 12.9.4 refers to the ASCE7-16 states that the base shear of the modal response spectrum should be greater than 85% of ELFP. The result obtained from modal response spectra is more than 85% as shown Table 4.2. Figure 4.1 and Figure 4.2 describes the base shear obtained modal response spectra analysis and equivalent lateral force. Figure 4.3 depicts the combined base shear for response spectra and equivalent lateral force obtained from seismic codes.

Table 4.2 Base shear comparison ELF and RSA method

Codes	ELF	MSRA	Ratio
	VSx (Kn)	VDx (Kn)	(VDx / VSx)
TSC-2018	2820	2447	86%
EC8	2715	2361	87%
ASCE7-16	2497	2281	91.3%
IS1893-2016	2350	2183.5	93%

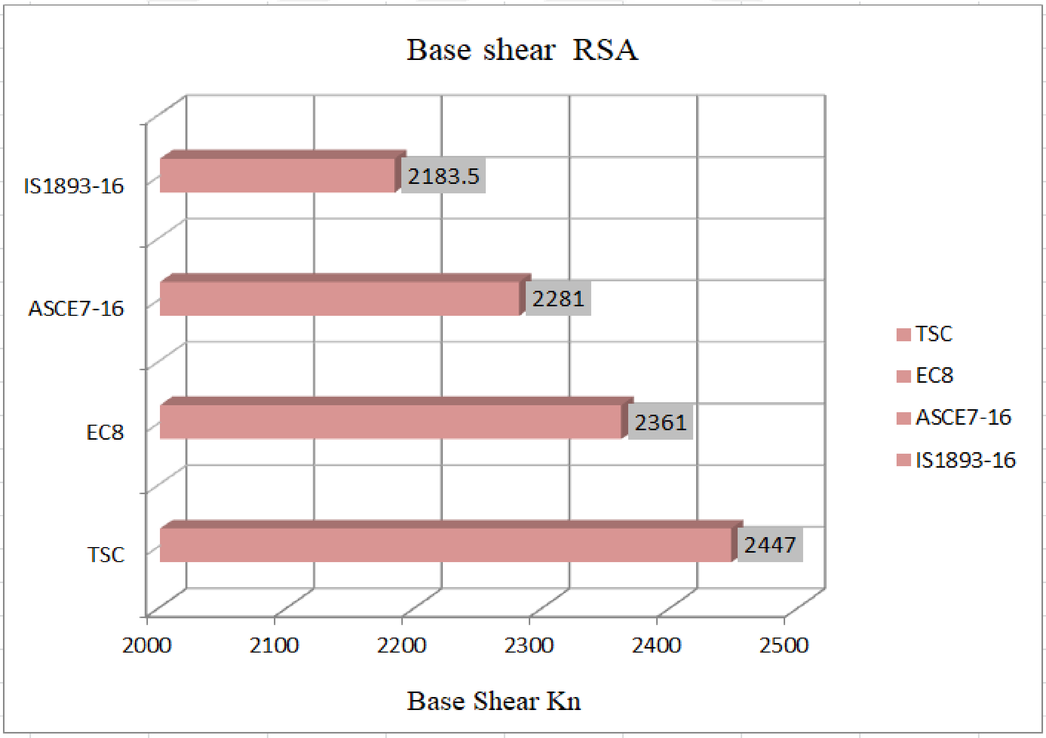


Figure 4.1: Base shear RSA

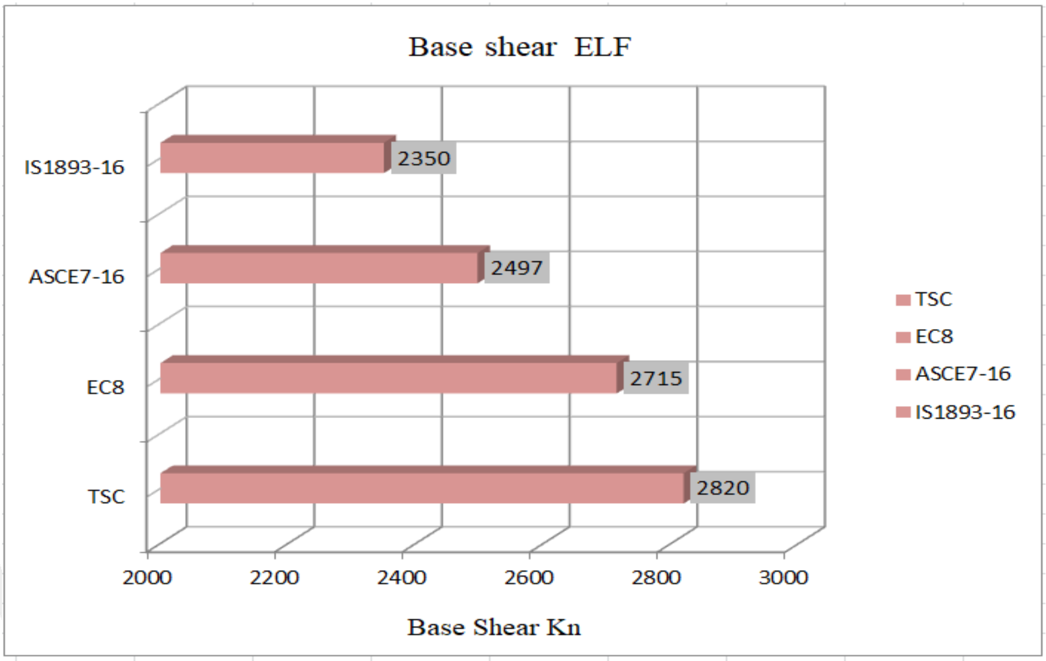


Figure 4.2: Base shear ELF

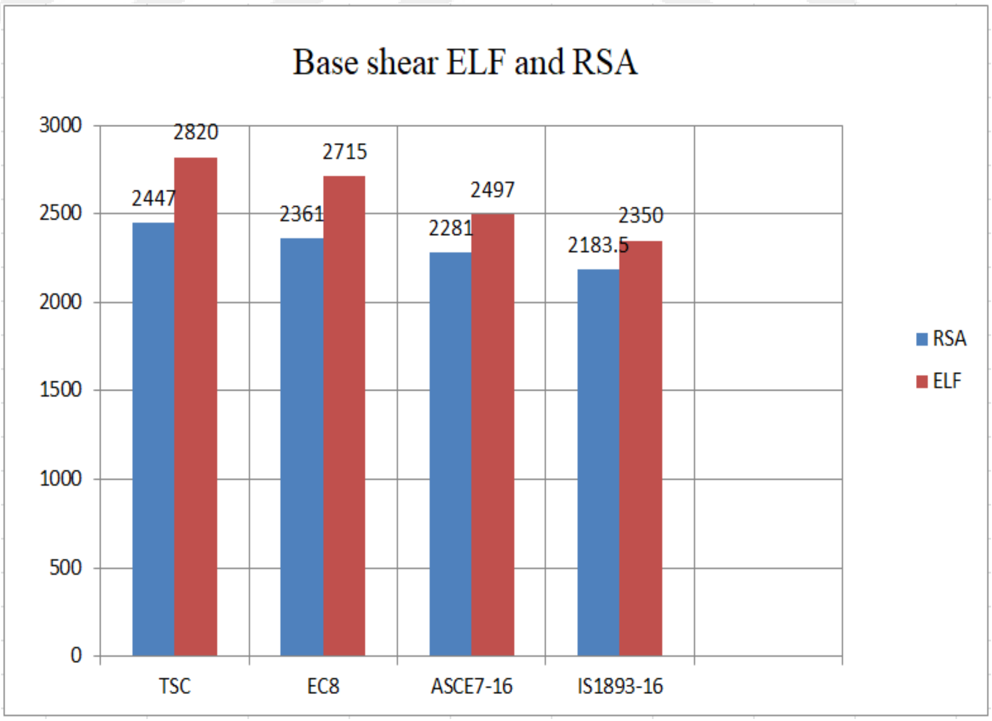


Figure 4.3**:** Base shear RSA and ELF

4.3 Mass Participation Ratio

The modal analysis used to obtain the mode shapes, frequencies, and modal participation factors. The important part is that how much the mass of the building is participating in each mode [62] [63]. Each mode is going to get it is own chunk of the mass of the building, the more mass gets the more that particular mode is participating. Cumulative effective mass participation is the sum of the effective mass participation factors.

According to TSC-2018 section 4.8.1, defines that the sum of the modal effective masses should not be less than 95% of the total mass of the building. Furthermore, the Eurocode also describes section 4.3.3.3, that the sum of the modal effective masses for modes should be at least 90%. The results obtained this study show that the effective of modal masses is more than 90% for the first ten modes shape and this is acceptable for the percentage requirements for building codes. Table 4.3 and Table 4.4 shows the first ten modes shape, period and cumulative sum for Eurocode and Turkish code.

Table 4.3 First ten-mode shapes and modal mass participation ratio EC8

Case	Mode	Period (s)	Cumulative sum %	
			X	Y
modal	1	0.799603	0	0.77527
modal	2	0.681543	0.78123	0.79086
modal	3	0.446354	0.78123	0.90230
modal	4	0.286156	0.91245	0.90351
modal	5	0.213461	0.91245	0.94237
modal	6	0.174332	0.95345	0.95359
modal	7	0.159083	0.95230	0.97671
modal	8	0.103542	0.9838	0.9823
modal	9	0.093730	0.9838	0.9823
modal	10	0.084312	0.9838	0.9823

Table 4.4 First ten-mode shapes and modal mass participation ratioTSC-2018

Case	Mode	Period (s)	Cumulative sum %	
			X	Y
modal	1	0.782357	0	0.65635
modal	2	0.65233	0.79314	0.79314
modal	3	0.423125	0.81246	0.88551
modal	4	0.27523	0.90483	0.90483
modal	5	0.16587	0.91649	0.94187
modal	6	0.152173	0.95353	0.95353
modal	7	0.120271	0.96074	0.97315
modal	8	0.116821	0.98035	0.98036
modal	9	0.10275	0.98035	0.98036
modal	10	0.084137	0.98036	0.98036

4.4 Inter Story Drift

The past decade's awareness of the prominence of building regularity and prevention of the non-structural damages for buildings located by the seismic area has grown, particularly after reflection on the disastrous caused by earthquakes. The inter-story drift described the structural performance of the structure, particularly the structural and non-structural elements. Story drift as well described the percentage among the two floors divided by the height of the floor.

However, it is imperative and fundamental to define the story drift. Codes provide procedures to reduce the probable devastation of buildings caused by the inelastic actions during the earthquake. However, the assessment and structure design shall be based on the earthquake demand for inelastic deformations.

Seismic codes highlight and limited the damage caused by minor and moderate earthquake and the building codes emphasize to limit non-structural damage.

Generally, building codes consider inelastic deformation caused by strong earthquakes. Thus, codes use a modification factor to reduce the design elastic forces; the elastic displacement obtained from the seismic analysis techniques such as modal response spectrum and equivalent lateral force are amplified by displacement amplification factor to compute the inelastic deformations of the building [64].

Building codes such as ASCE7-16 use deflection amplification factors while other codes such as Turkish a Eurocode use reduction factor or behavior factor to account inelastic deformations. Tables and figures below describes the comparison interstorey drift obtained for modal response spectrum and equivalent lateral force using four different building codes.

Based on section 4.9.1 in Turkish code, the results obtained inter storey drift both for modal response spectra and equivalent lateral force shows that is under the limit. In Figure 4.4 is plotted the inter storey drift both for response spectra and equivalent lateral force according to the Turkish code. Table 4.5 describes the detailed procedure obtained by interstorey drift according to the modal response spectrum method.

Table 4.5 Inter storey drift controls TSC-2018

Level	δ(m)	R	Δ_{i}	I	$\delta_{\mathrm{i}} = \frac{\mathrm{R}}{\mathrm{I}}\Delta_i$	$\lambda \frac{\delta_{i,max}}{h} \leq 0.008k$
Roof	0.028408	5	0.002293	1.2	0.0096	$0.0046 \leq 0.0080\mathrm{K}$
5	0.026115	5	0.003891	1.2	0.0162	
4	0.022224	5	0.005521	1.2	0.023	
3	0.016703	5	0.006627	1.2	0.0276	
2	0.010076	5	0.006537	1.2	0.0272	
1	0.003539	5	0.003539	1.2	0.0147	

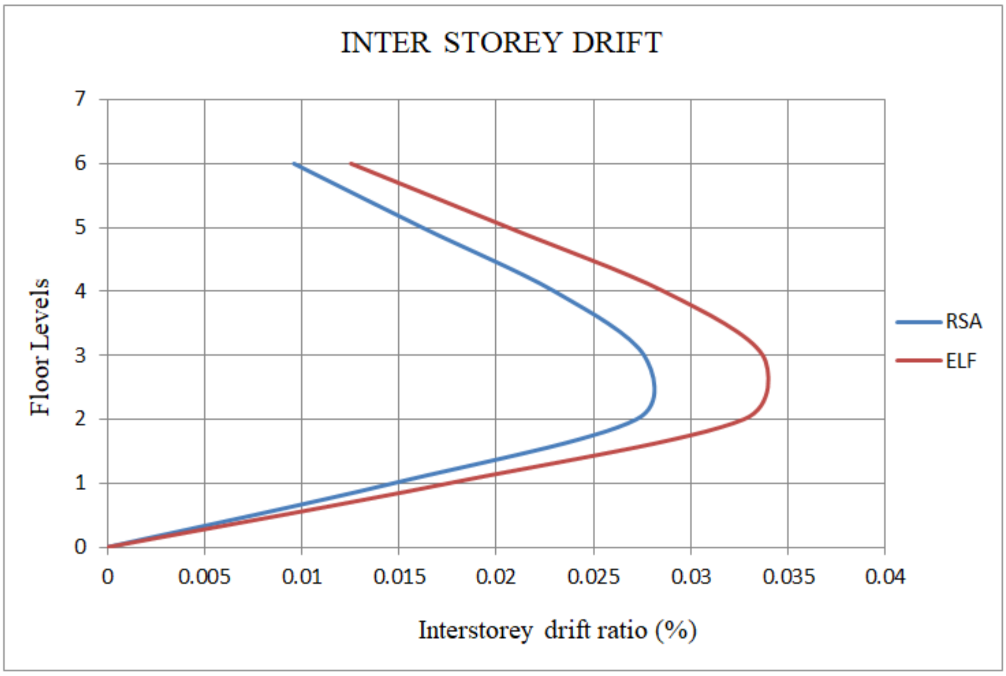


Figure 4.4 : Inter storey drift TSC-2018

The ASCE7 limited the inter-story drift ratio should not be less than 0.025h if the first period less than 0.7, and if the fundamental higher than that 0.020h will use. Table 4.6 defined the inter-story drift ratio based on the procedures and requirements for ASCE7-16. Figure 4.5 is tabulated the inter storey drift both for response spectra and equivalent lateral force according to the American seismic code.

Table 4.6 Inter storey drift controls ASCE7-16

Level	Δ(m)	C_d	δ_m	I	$\delta_{xe} = \frac{C_d \delta_m}{I}$	Δ_a
Roof	0.02280	5.5	0.00204	1.2	0.00935	0.020 h
5	0.02076	5.5	0.00291	1.2	0.0134	0.020 h
4	0.01785	5.5	0.00401	1.2	0.0184	0.020 h
3	0.01384	5.5	0.00491	1.2	0.0225	0.020 h
2	0.00893	5.5	0.00536	1.2	0.0246	0.020 h
1	0.00357	5.5	0.00357	1.2	0.0164	0.020 h

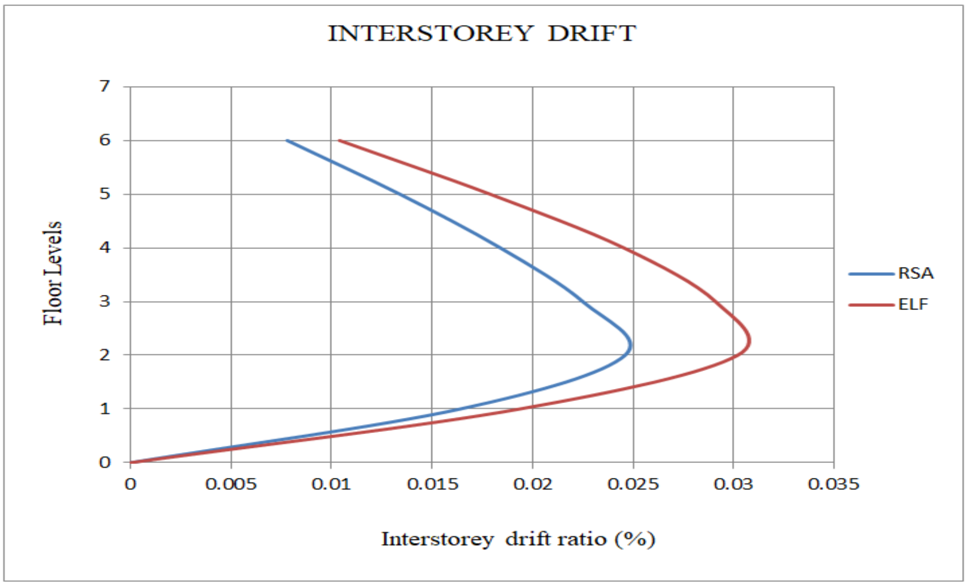


Figure 4.5: Inter storey drift ASCE7-16

According to clause 4.4.3.2 Eurocode describes the interstorey drift into three categories, structures having non-structural components with a brittle material limited by 0.5%, ductile material 0.075%, and 0.10%. Table 4.7 listed all the necessary parameters for the confirmation of inter storey limit and some storey exceeded the structures having a brittle material [65]. Figure 4.6 and Figure 4.7 is presented the inter storey drift both for response spectra and equivalent lateral force according to the Eurocode and Indian code respectively.

Table 4.7 Interstorey drift ratio EC8

Level	$d_r = d * q_d$ (m)	h (m)	v	$v\frac{d_r}{h}$	α		
					(a)	(b)	(c)
Roof	0.0105	3	0.5	0.00175			
5	0.0195	3	0.5	0.00325			
4	0.027	3	0.5	0.0045	0.005	0.0075	0.010
3	0.0305	3	0.5	0.0050			
2	0.031	3	0.5	0.0052			
1	0.0165	3	0.5	0.00275			

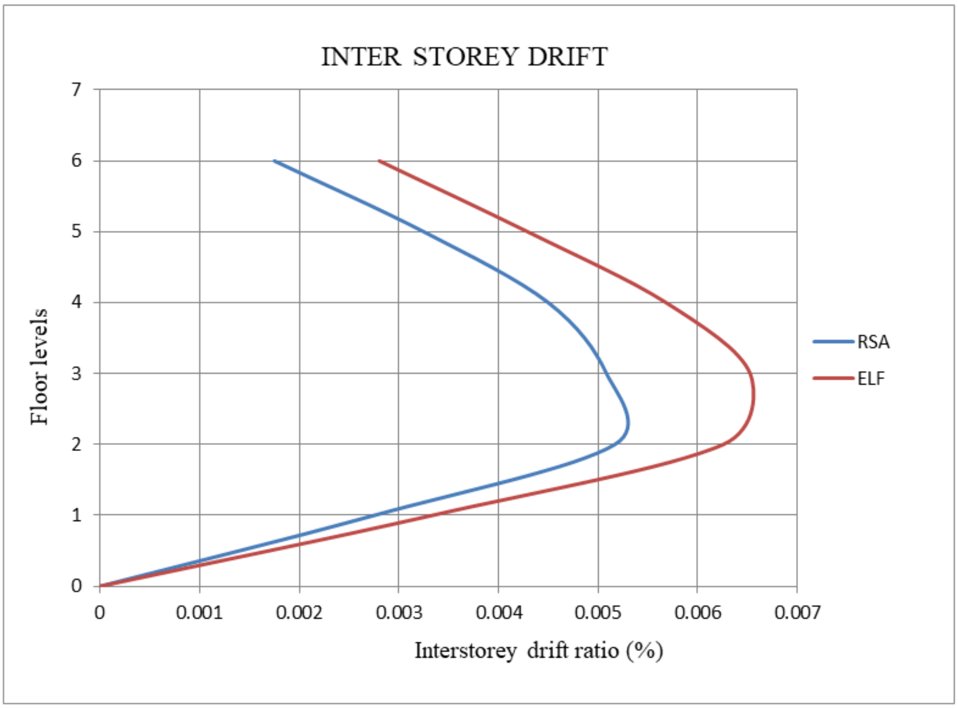


Figure 4.6: Inter storey drift EC8

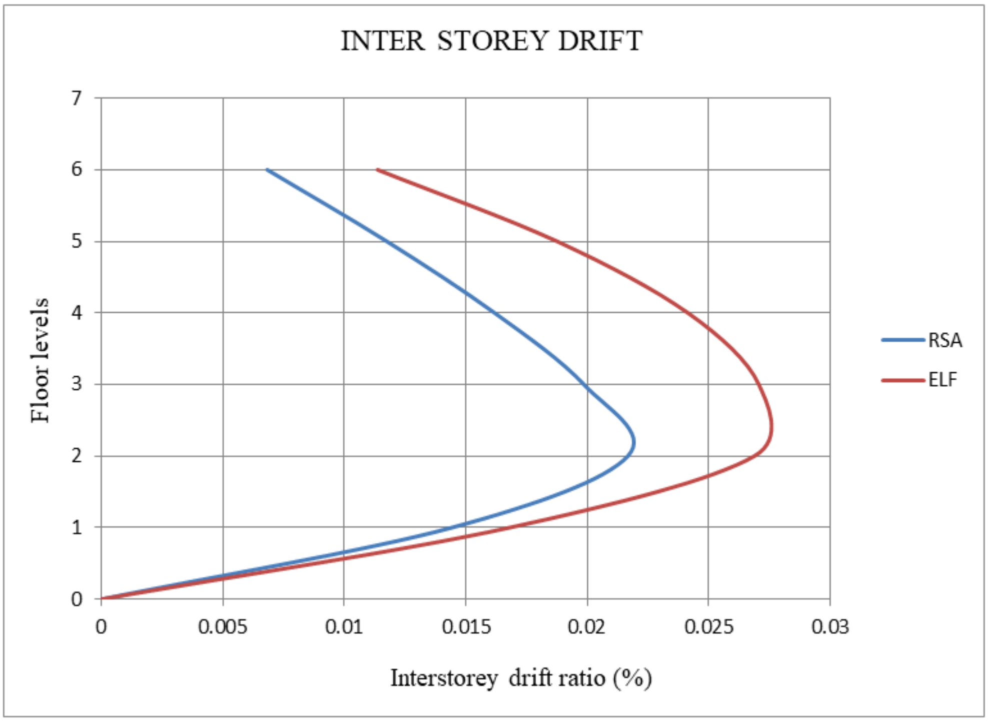


Figure 4.7: Inter storey drift IS 1893-16

4.5 Displacement

Generally, the significant difference between these standard building codes is the design spectra. The standard codes become clear when the displacement plotted. The main point that codes highlighted is the design of the corner period that amongst the velocity and displacement control region, the seismic codes provide different ranges for this period. The ASCE7 building code provides the corner period for 4 to 16 sec, and the Indian code only considered 4 sec for the design spectra, but not considered for the displacement.

The displacements obtained at the top of the building for each code presented the graphs below and combined a Table 4.8, these displacements are found both equivalent lateral force and spectral analysis considered CQC rule of modal analysis. The displacements are found the Turkish code is higher than other codes, the highest displacement both for dynamic (29.6 mm and static linear analysis (35 mm). The percentage of the highest and lowest displacement is 35.6%, despite the displacements obtained Eurocode using the elastic spectrum type 1 is nearby the displacement obtained by Turkish code. The lateral displacement obtained for seismic codes using response spectra and equivalent lateral force is presented the Figure 4.8 up to Figure 4.12 respectively. The combination displacement for RSA and EFL is tabulated Figure 4.13.

Table 4.8 Comparison displacement of seismic codes

Floor Levels	TSC-2018 (mm)		ASCE7-16(mm)		EC8(mm)		IS1893-16(mm)	
	RSA	ELF	RSA	ELF	RSA	ELF	RSA	ELF
6	28.4	35.0	22.48	28.7	27.86	34.6	21.8	29.9
5	26.2	31.9	20.71	26.4	24.9	31.3	20.1	27.3
4	22.2	27.02	17.85	22.5	20.9	27.0	17.3	22.8
3	16.7	20.15	13.84	17	15.67	20.2	13.4	16.9
2	10.07	12.07	8.9	10.8	9.47	12.1	8.6	10.5
1	3.54	4.23	3.56	4.2	3.353	4.2	3.4	4.02

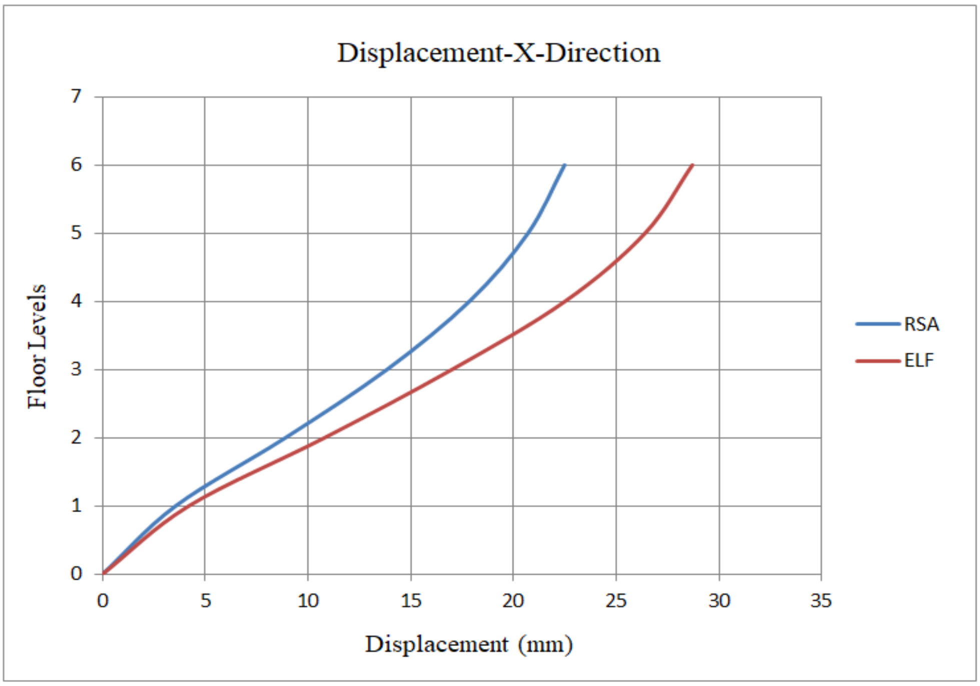


Figure 4.8: Displacement ASCE7-16

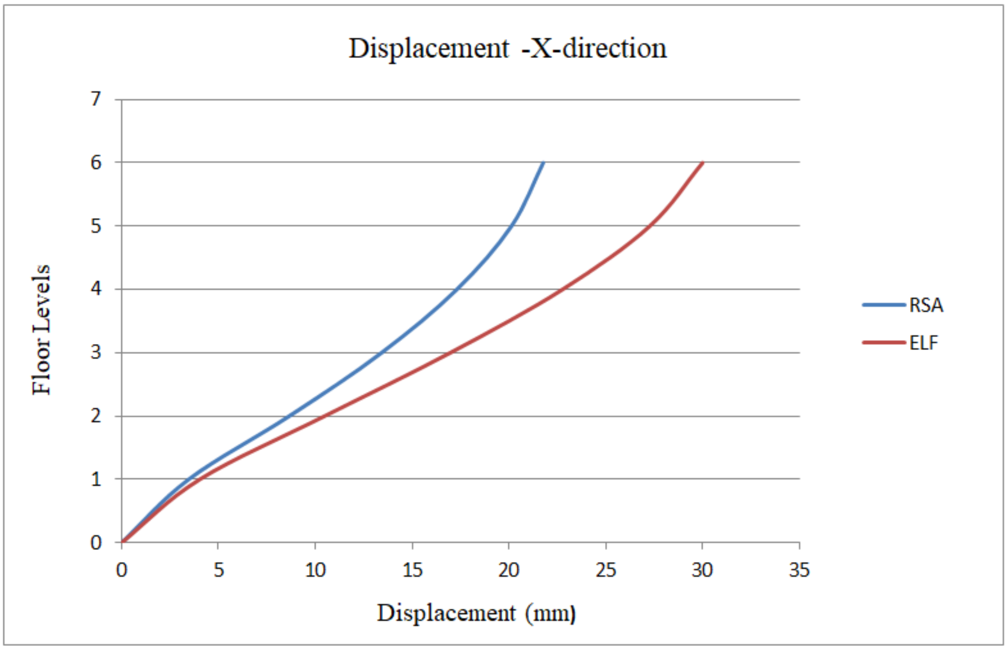


Figure 4.9: Displacement IS1893-2016

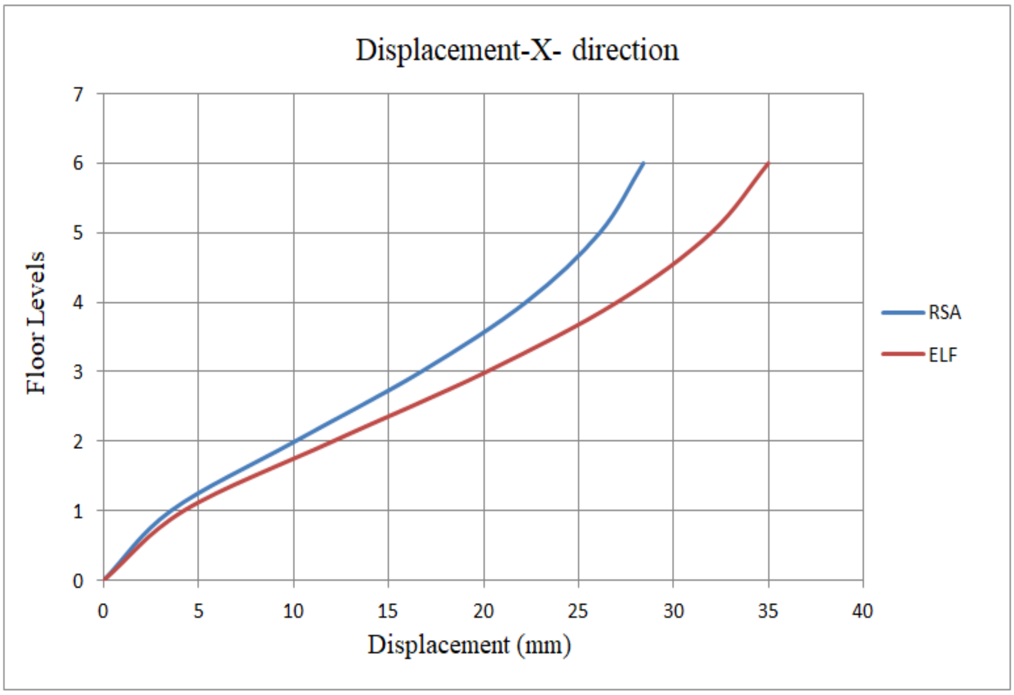


Figure 4.10: Displacement TSC-2018

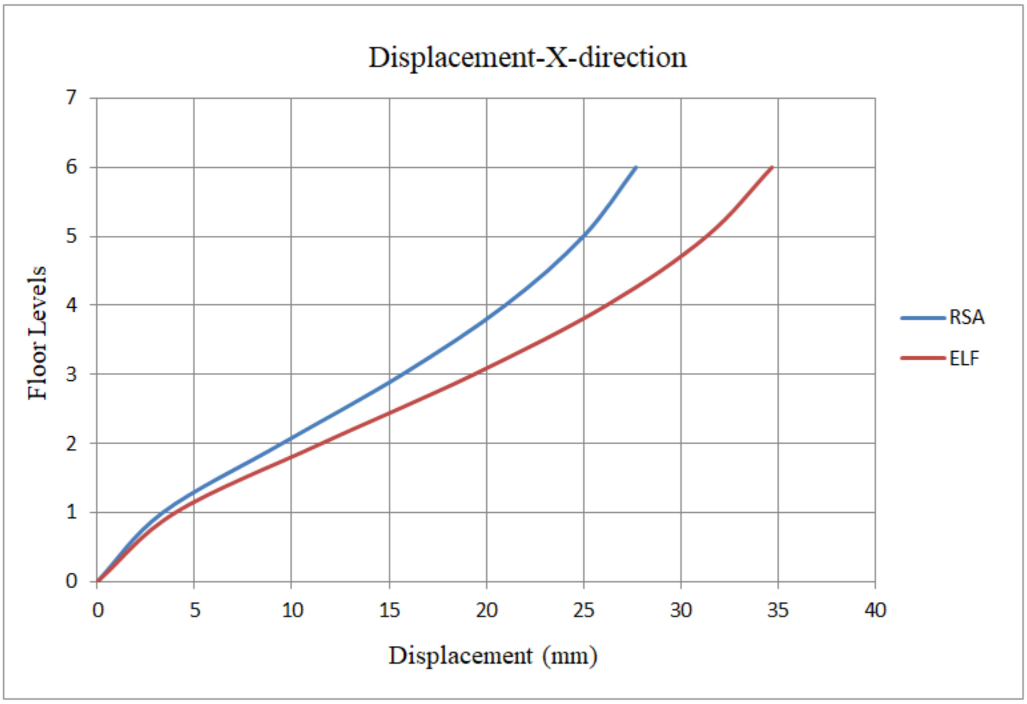


Figure 4.11: Displacement EC8-2004

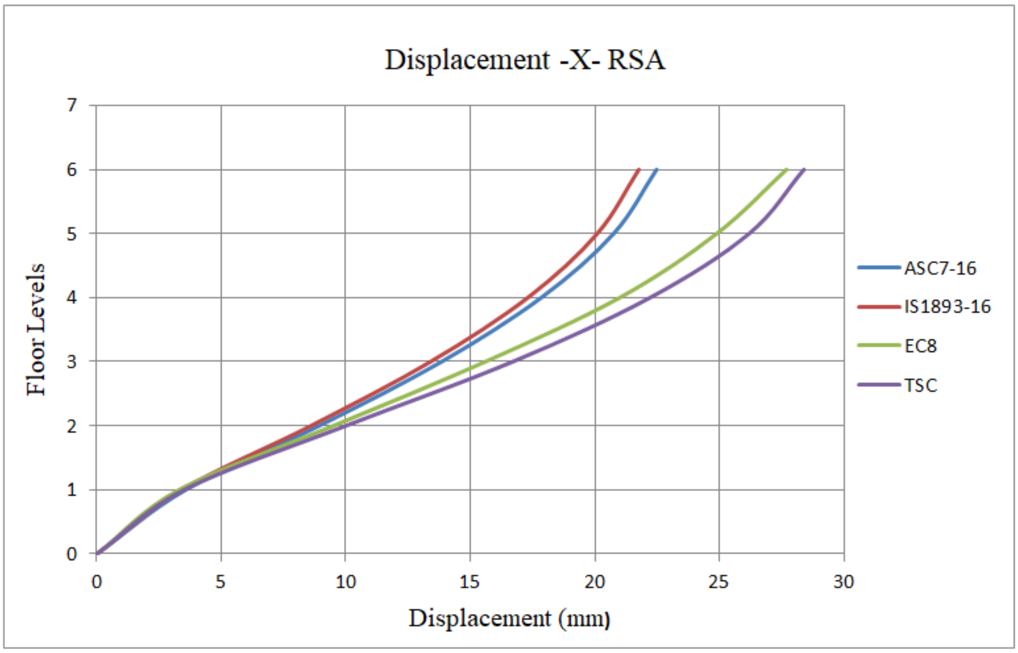


Figure 4.12: Displacement RSA

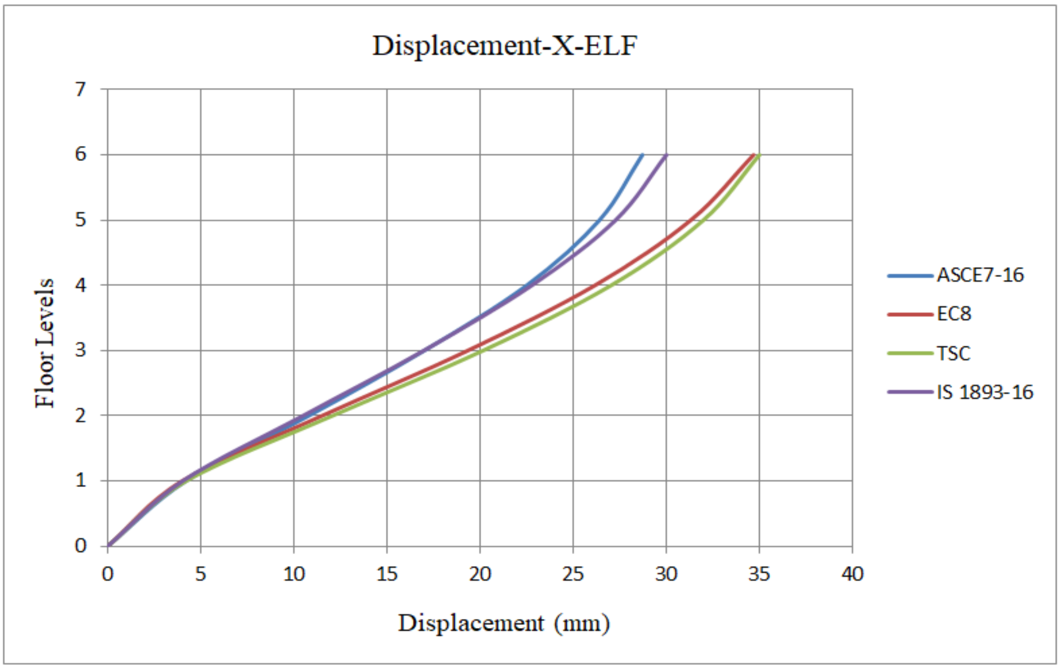


Figure 4.13: Displacement ELF

4.6 Results and Discussion

It has been examined that Turkish code obtained the highest base shear in this study both static linear and dynamic linear analysis. The base shear found Eurocode 8 is nearby to the Turkish code. The lowest base shear observed in IS 1893 code. The main difference among codes is that some codes not consider a minimum base shear such as Eurocode 8 and Indian code. Additional, there is imperative distinction in the design base shear for seismic codes. The distinction may cause the design spectra, modification factors, effective stiffness member values, load combination, and most prominently, the period of structure.

Most codes describes to scale the dynamic base shear to the static base shear and limited the required percentage despite codes are different, but American code (ASCE7-16) described that percentage required for dynamic base shear should not be less than 85% for static linear base shear. Moreover, it has been observed that all the codes achieved the required percentage. Also, observed that the design base shear Turkish code according to the static linear analysis is 18% for the weight of the building, and rest codes, ASCE7-16 for 16%, Indian code 15%, and Eurocode 8 is 17%.

Codes recognized the drift is an essential control parameter. However, the processes that drifts and permissible drift limit is computed by seismic codes is different. According to ASCE7-16 consider a deflection amplification factor that has been used to compute the inelastic deformations and this factor depends on the structure type. ASCE7-16 code limits the story drift according to building usage and permits up to 2.5%. The drift result obtained according to ASCE7-16 depicts that is under limit

Eurocode 8 not consider deflection amplification factor to amplify the elastic displacement but use a behavior factor. The type of non-structural elements regarding to the allowable drift and the structural type, Eurocode defines three non-structural types, brittle, and ductile.

The results has been obtained by this code shows that some story exceeded the allowable limits of structure having non-structural brittle material. Indian code not considers reduction factor to amplified elastic displacement and limits story drift 4% depends on ductility level. Turkish code use modification factor to amplify the elastic displacement and allowable drift depends on both infill rigid connected frame 0.008k, and flexible frames 0.016k. K should be 1 for concrete, and 0.5 for steel. In this study has been addressed that dirty obtained Turkish code is under limit.

There is destination among seismic codes according to effective modal mass, it has been observed that codes ASCE7-16 and Eurocode 8 allows that sum of effective modal mass should be at least 90% while, Turkish code defines that should be at least 95%. In this study, has been found that sum of effective modal mass for longitudinal X and transverse Y direction greater than 98%.

CHAPTER 5

CONCLUSION

In general, protecting human life under infrequent events is the first requirement is associated with the purpose that codes established, through preclusion of the global and local collapse of the building. Later the event, the structure should be kept its integrity and maybe existent considerable damages including enduring drifts, it can be economically irredeemable, during evacuation structure must able to sustain human life.

Earthquake codes were established to reduce the destruction, and economic losses caused by earthquakes and provide guidelines to the designer, which can able to design the structure with a minimum requirement that the structure can resist the earthquake loads.

With the lack of building codes, the design will become appropriate. However, to compare codes is very crucial when the building codes are developed. During earthquake design, it must define seismic loads to foresee the coming earthquakes for a particular site.

The forces that earthquake induces with a short period, it is imperative that the structure able to withstand without collapse. Even an earthquake has the least magnitude, which causes minor damage to the structure and needs the least cost of maintenance cost must structures able to resist. The most useful and standard procedure is linear analysis, which codes used for the new buildings.

- The main reason of this study is to compare the building codes include Turkish, Eurocode, and American code, to discover the difference triggered the earthquakes. Seismic codes were comparing design spectra. In this study, the design spectra recommended Turkish, Eurocode, and American codes considered.

- To make a conceivable comparison among seismic codes, the analyses have been used elastic response spectrum considered behavior and reduction factors to account the inelastic deformation caused by strong earthquakes. SAP 2000 program have been performed the analysis using the modal response spectrum and static equivalent lateral force. The periods obtained from Turkish code and American code using ELF are higher than the period obtained for modal analysis.

- Seismic codes are slightly different from the computation for interstorey drift but Eurocode is more detailed and criteria than other codes. Codes use a modification or behavior factor to account for the inelastic deformation caused by strong earthquakes. ASCE considers the deflection amplification factor to multiply the elastic design displacement to account for the maximum drift for the inelastic portion. In addition, the reduction factor that Eurocode defines to account for the lower return period for seismic actions depends on the functionality of the building. Codes use an important factor to compute the interstory as well.

- The maximum base shear obtained both for static and dynamic linear analysis for the Turkish code. The percentage among the highest base shear (Turkish code) and lowest base shear (Indian code) found 35.6%. The base shear obtained by dynamic linear analysis is scaling to check that is less or more than the base shear obtained by static linear analysis that seismic codes required and found the allowable ratio for each seismic code.
- Most codes define that sum of the modal effective mass should not be less than 90% of the total mass of the building. The cumulative sum of the effective modal mass result obtained from seismic codes using the modal response spectrum is more than 98%.

REFERENCES

[1] Rizwan, Akram. (2018). Analysis of Strong Ground Motion Records of Kocaeli Region for the Assessment of Site Fundamental Frequency. *Conference paper 2018*

[2] Murat, Bikce., Tahir, Burak. Celik. (2016). Analysis of Newly Constructed RC Buildings Designed according to the 2007 Turkish Seismic Code during the October 23, 2011, Van earthquake. *Engineering Failure Analysis 64 (2016) 67–84*

[3] M, B. Waris, H. Saeed, K. S. Al-Jabri, and I, El-Hussain. (2017) Comparison of Oman seismic code for buildings with international counterparts. *16th World Conference on Earthquake, 16WCEE 2017*

[4]Tariq, M. Nahhas. (2018). A Comparison of Saudi Building Code with 1997 UBC for Provisions of Modal Response Spectrum Analysis using a Real Building *Open Journal of Earthquake Research, 2017, 6, 98-116*

[5] Corina, Schott., and Jochen, Schwarz. (2004). Reliability of Eurocode Spectra and the Problems of their Application to Central European Earthquake Regions *13th World Conference on Earthquake Engineering Vancouver, B.C., Canada*

[6] Asena, Soyluk., and Zeynep, Yesim. Harmankaya. (2000) History of Development in Turkish Seismic Design Codes. *International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol: 12 No: 01*

[7] Turkish Earthquake Code (2007). Specification for Structures to be built in Disaster Areas Ministry of Public Works and Settlement, Government of Republic of Turkey.

[8] Resatoglu, R., & Atiyah, R. S. (2016). Evaluation of Reinforced Concrete Buildings in Northern Cyprus using TEC2007 and EC8 in Respect of Cost Estimation, S*cientific Research and Essays, 11(19), 194–201.*

[9] Kumar, V. R. (2017). Comparative Study on Regular & Irregular Structures using Equivalent Static and Response Spectrum Methods, *International Journal of Civil Engineering and Technology (IJCIET), 8(1), 615–622.*

[10] Landingin, J., Rodrigues, H., Varum H., Arede, A., & Costa, A. (2012). Comparative Analysis of RC Irregular Buildings Designed According to Different Seismic Design Codes. *15th International Conference on Experimental Mechanics (ICEM15) Faculty of Engineering, University of Porto*

[11] Zasiah, T., Johinul, I. J., & Tameem, S. (2016). Earthquake Response Analysis of a Multistoried RC Building under Equivalent Static and Dynamic Loading as Per Bangladesh National Building Code 2006. *Malaysian Journal of Civil Engineering*, *28*(1), 108–123.

[12] Bagheri, B., Firoozabad, E.S., and Yahyaei, M. (2012). Comparative Study of the Static and Dynamic Analysis of Multi-Story Irregular Building. *Word Academic of Science Engineering and Technology*

[13] A, S. Patil., and P, D. Kumbhar. (2013). Time History Analysis of multistoried RC buildings for different seismic intensities, *International journal of structural and civil engineering research*

[14] Gizem, Mestav. Sarica. (2014). Comparison of mean site-specific response spectra in Turkey with the design Spectra of AASHTO, *MSc thesis*

[15] Khaled, Ahmed. Abdel-Raheem. (2010). Evaluation of the Building Structural Response under Seismic Action According to Egyptian Code, *MSc thesis*

[16] Amer, Hassan1., Shilpa, Pal. (2018). Effect of Soil Condition on Seismic Response of Isolated Base Buildings, *International Journal of Advanced Structural Engineering (2018) 10:249–261*

[17] M, D. Trifunac. (2008). 75th Anniversary of the response spectrum method - A historical review. *Soil Dynamics and Earthquake Engineering, 2008 28: pp. 675.*

[18] M, D. Trifunac., and M, I. Todorovska. (2008). Origin of the Response Spectrum Method. *The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China*

[19] P, Moradi. Pour., Karisiddappa, M. S. Jaafar., and J, Noorzaei. (2014). Comparative Study between Codes of Spectrum for a Single Degree of Freedom (SDOF) System in Two Different Hazardous Regions.

[20] M,D. Trifunac., and M,I. Todorovska. (2001). Evolution of Accelerographs, Data Processing, Strong Motion Arrays, and Amplitude and Spatial Resolution in Recording Strong Earthquake Motion. *Soil Dynamics and Earthquake Engineering 21 (2001)*

[21] Mihailo, D. Trifunac. (2008). Historical Review Early History of the Response Spectrum Method. *Soil Dynamics and Earthquake Engineering 28 (2008) 676–685)*

[22] M, D. Trifunac. (2006). Brief history of the Computation of Earthquake Response Spectra. *Soil Dynamics and Earthquake Engineering 26 (2006) 501–508*

[23] Paulo, Marcelo., Vieira, Ribeiro., Lineu, Jose. Pedroso. (2017). Dynamic Response of Dam-Reservoir Systems. *Lat. Am. j. solids struct. vol.14 no.4 Rio de Janeiro Mar. 2017*

[24] Izuru, Okawa., Emeritus, Yuji. Ishiyama., Makoto, Watabe. Fundamentals Structural Dynamics (Book)

[25] Bilal, Ahmad. Najar., Imtiyaz, Akbar. Najar. (2016). Comparative Seismic Analysis of El Centro and Japan Earthquakes using Response Spectra Method

[26] Haluk, Sucuoglu., and Sinan, Akkar. Basic Earthquake Engineering from Seismology to Analysis and Design

[27] Bo, Li., Wei-Chau, Xie., and M, D. Pandey. (2016). Newmark Design Spectra Considering Earthquake Magnitudes and Site Categories. *Earthq Eng & Eng Vib (2016) 15: 519-535*

[28] Ajaya, Kumar. Gupta. Response Spectrum Method Seismic Analysis

[29] Sigmund, A. Freeman. (2007). Response Spectra as a useful Design and Analysis Tool for Practicing Structural Engineers. *ISET Journal of Earthquake Technology, Paper No. 475, Vol. 44, No. 1, March 2007, pp. 25–37*

[30] Claudiu, Sorin. Dragomir., Iolanda, Gabriela. Craifaleanu., Daniela, Dobre. (2018). Prospective Studies for the Implementation of a Remote Access Earthquake Damage Detection System for High-Rise Buildings in Romania

[31] Juan, Carlos. Vielma-Perez., María, Manuela., Mulder, Montes. De Oca. (2018). Influence of the use of Coupling Beams on the Seismic Response of Plan Irregular RC Framed Buildings.

[32] Amit, Shiuly. (2018). Global Attenuation Relationships for Estimating Peak Ground Acceleration. *Journal Geological Society of India Vol.92, July 2018, pp.54-58 74*

[33] Heng, Li., and Feng, Chen. (2017). Damping modification factors for acceleration response spectra. *Geodesy and Geodynamics 8 (2017)*

[34] Sinan, Akkara., Saed, Moghimib., Yalın, Arıcıc. (2018. A Study on Major Seismological and Fault-Site Parameters Affecting Near-Fault Directivity Ground-Motion Demands for Strike-Slip Faulting for their Possible Inclusion in Seismic Design Codes. *Soil Dynamics and Earthquake Engineering 104 (2018) 88–105*

[35] M, Davoodi., and M, Sadjadi. (2015). Assessment of Near-Field and Far-Field Strong Ground Motion Effects on Soil-Structure SDOF System. *International Journal of Civil Engineering, Vol. 13, Nos. 3&4B, Transaction B: Geotechnical Engineering, September & December 2015*

[36] Y, Fahjan., and Z, Ozdemir. (2008). Scaling of Earthquake Accelerograms for Non-linear Dynamic Analyses to Match the Earthquake Design Spectra. *The 14 world conference on earthquake engineering October 12-17, 2008, Beijing, china*

[37] Hiroki, Akehashi., Kotaro, Kojima., Kohei, Fujita., and Izuru, Takewaki. (2018). Critical Response of Nonlinear Base-Isolated Building Considering Soil-

Structure Interaction Under Double Impulse as a Substitute for Near-Fault Ground Motion. *Front. Built Environ., 17 July 2018*

[38] Abdelwahab, Mourad. Khellafi., Zamila, Harichane., Hamid, Afra., and Amina, Sadouki. (2013). Case study of Accelerometric Records Analysis of May 21st, 2003, Boumerdes (Algeria) Earthquake. *International Journal of Geotechnical Earthquake Engineering, 4(2), 34-52, July-December 2013*

[39] Mehdi, Ahmadizadeh. (2007) Evaluating the Effects of Ground Motion Parameters on Response Spectra of Iranian Earthquakes. *Asian journal of civil engineering (building and housing) vol. 8, no. 1 (2007) pages 25-48*

[40] F, Lopez-Caballero., C, Gelis., J, Regnier., L,F. Bonilla. (2012). Site Response Analysis Including Earthquake Input Ground Motion and Soil Dynamic Properties Variability.

https://www.iitk.ac.in/nicee/wcee/article/WCEE2012_4247.pdf

[41] Praveen, K. Malhotra. (2003). Strong Motion Records for Specific Site Analysis. *Earthquake Spectra, Volume 19, No. 3, pages 557–578, August 2003*

[42] Sokolov, V.Y. (2000). Site and Region-specific Response Spectra a Probabilistic Approach. *Soil Dynamics and Earthquake Engineering 20, 273-281*

[43] Bo, Li. (2013). Response Spectra for Seismic Analysis and Design. *Thesis*

Doctor of philosophy in civil engineering

[44**]** FEMA 454 Designing for Earthquakes December 2006.

[45] Md, S. Bari., T. Das. (2013) A Comparative Study on Seismic Analysis of Bangladesh National Building Code (BNBC) with Other Building Codes. *J. Inst. Eng. India Ser. A (August–October 2013) 94(3):131–137*

[46**]** Reza, Karami. Mohammadi., and M, Hesham. El Naggar. (2004) Modifications on Equivalent Lateral Force Method. *13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004 Paper No. 928*

[47] Turkish Earthquake Code (2018). Specification for Structures to be Built in Disaster Areas Ministry of Public Works and Settlement, Government of Republic of Turkey.

[48] Haluk, Sucuoglu. (2018). New improvements in the 2018 Turkish Seismic Code. *International Workshop on Advanced Materials and Innovative Systems in Structural Engineering Seismic Practices*

[49] Mohammad, Azim. Eirgash (2019) A Comparative Study of Seismic Performance of the Building Designed using Four Major Codes. *International Journal of Engineering Research & Technology (IJERT) Vol. 8 Issue 08, August-2019*

[50] Earthquake Behaviour of Buildings.
https://www.iitk.ac.in/nicee/IITK-GSDMA/EBB_001_30May2013.pdf

[51] Mesut. Oğurlu. (2019) Investigation of Seismic Behavior of Steel Structures Using Response Spectrum Analysis. *M.Sc. Thesis in Civil Engineering*

[52] ASCE/SEI 7-16. Minimum Design Loads and Associated Criteria for Buildings and Other Structures

[53] Khadar. Elmi., and Erdal, Coskun. (2020. Comparative of Study the Design Spectra Defined by Various Seismic Codes. International Journal of Engineering Research & Technology (IJERT) Vol. 9 Issue 03, March-2020

[54] Vijay, Namdev. Khose., Yogendra, Singh., and Dominik, Lang (2010). Limitations of Indian Seismic Design Codes for RC Buildings. Conference, 14th

Symposium on Earthquake Engineering: Indian Institute of Technology, Roorkee, December 17-19, 2010

[55] Prajwal, Giri., Anand, Dev. Bhatt., Dipendra, Gautam., Hemchandra, Chaulagain. (2018) Comparison between the Seismic Codes of Nepal, India, Japan, and EU. *Asian Journal of Civil Engineering*

[56] IS1893-2016 part 1, Criteria for Earthquake Resistance Design for Structures

[57] Dogangun, Adem., Livaoglu, R. (2006). Comparative Study of the Design Spectra Defined by Eurocode 8, UBC, IBC and Turkish Earthquake Code on R/C Sample Buildings Journal of Seismology, 3, 335–351s

[58] EN 1998-1: 2004 Eurocode 8, Design of Structures for Earthquake Resistance– Part 1: General Rules, Seismic Actions, and Rules for Buildings.

[59] Ishfaq, Bashir. (2019) Comparative Study of an RC Chimney as Per Different Codes. *Master of Science Thesis.*

[60] Modal analysis - Technical Knowledge Base - Computers and Structures, Inc.

[61] M, Soós., & L,G. Vigh. (2012) On the Eurocode 8 limited damage criteria for non-structural elements – Analysis and requirements

[62] Altin, Seranaj., Forcim, Softa., Agim, Seranaj., Fanjola, Koroveshi. (2016) Damage Limitation Requirements According Eurocode 8 for Flexible Reinforced Concrete Low-Rise Buildings. *3rd International Balkans Conference on Challenges of Civil Engineering, 3-BCCCE, 19-21 May 2016, Epoka University, Tirana, Albania*

[63] Idlir, Frangu., Huseyin, Bilgin. (2012). Evaluation of Seismic Analysis Procedures for Seismic Actions: A Comparative Study between Eurocode 8 and KTP-89. *International Students' Conference of Civil Engineering, ISCCE 2012, 10-11 May 2012, Epoka University, Tirana, Albania*

[64] B, Erkmen. (2015) Evaluation of seismic design provisions for a drift and inter-story drift relationship. *WIT Transactions on the Built Environment, Vol 152, © 2015 WIT Press*

[65] Ali, Al-Obaidi. (2019) Comparison between the American Code ASCE7-16 and the Australian Code AS1170.4 against the Seismic Design Effects. *M.Sc. Structural Engineering Thesis*

APPENDIX

Design Spectrum ASCE7-16

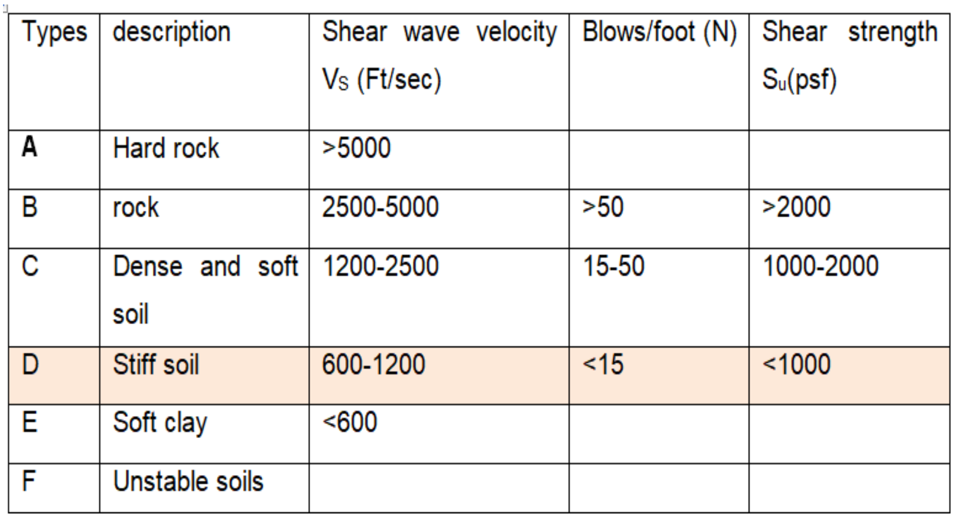
General procedure that can obtain the design ground motion according to the ASCE7-16

Step 1: Obtain the ground motion parameters of S_S and S_1 from the website as defined below these values

$S_S = 1.573$

$S_1 = 0.701$

Step 2: Define your site classification according to chapter 20



Types	description	Shear wave velocity V_S (Ft/sec)	Blows/foot (N)	Shear strength S_u(psf)
A	Hard rock	>5000		
B	rock	2500-5000	>50	>2000
C	Dense and soft soil	1200-2500	15-50	1000-2000
D	Stiff soil	600-1200	<15	<1000
E	Soft clay	<600		
F	Unstable soils			

Step 3 obtain the site class coefficient to modify the response spectrum

SITE CLASS	$S_S \leq = 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq =1.25$	$S_S \geq =1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.3
D	**1.6**	**1.4**	**1.2**	**1.1**	**1.0**	**1.0**
E	2.4	1.7	1.3			
F	A site response analysis must be performed					

Site Class	$S_S \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 = 0.5$	$S_1 \geq 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.4	1.5	1.4
D	**2.4**	**2.2**	**2.0**	**1.9**	**1.8**	**1.7**
E	4.2					
F	A site response analysis must be performed					

Step 4: Calculate the adjusted MCE spectral response parameters S_{MS} and S_{M1}

$$S_{MS} = F_a \, s_s$$

$$S_{MS} = 1.0 * 1.573 = 1.573$$

$$S_{M1} = F_v \, s_1$$

$$S_{M1} = 1.7 * 0.701 = 1.1917$$

Step 5: Calculate the spectral design parameters S_{DS} and S_{D1}

$$S_{DS} = \frac{2}{3} s_{Ms}$$

$$S_{DS} = \frac{2}{3} * 1.573 = 1.0487$$

$$S_{D1} = \frac{2}{3} s_{M1}$$

$$S_{D1} = \frac{2}{3} * 1.1917 = 0.7945$$

Steps 6: Compute the pertinent period parameters.

$$T_o = 0.2 \frac{S_{D1}}{S_{DS}}$$

$$T_o = 0.2 \frac{0.7945}{1.0487} = 0.1515 \text{ sec}$$

$$T_s = \frac{S_{D1}}{S_{DS}}$$

$$T_s = \frac{0.7945}{1.0487} = 0.757 \text{ sec}$$

Steps 7 compute the design response spectrum

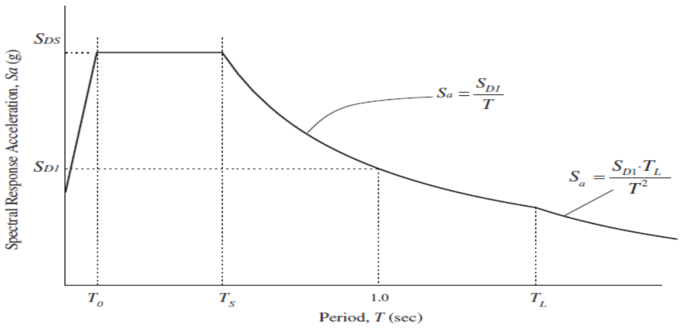


Figure A. 1: Response spectrum curve

Design Spectrum TSC-2018

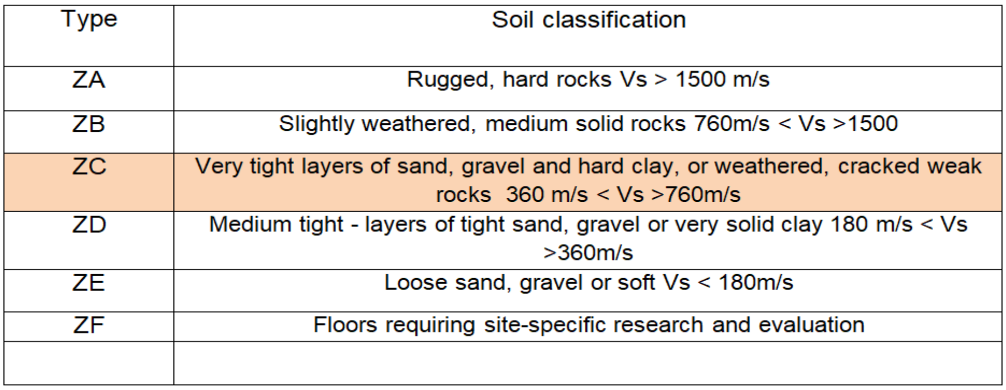
General procedure that can obtain the design ground motion according to the TSC-2018

Step 1: Obtain the ground motion parameters of S_S and S_1 from the website as defined below these values

$S_S = 1.573$

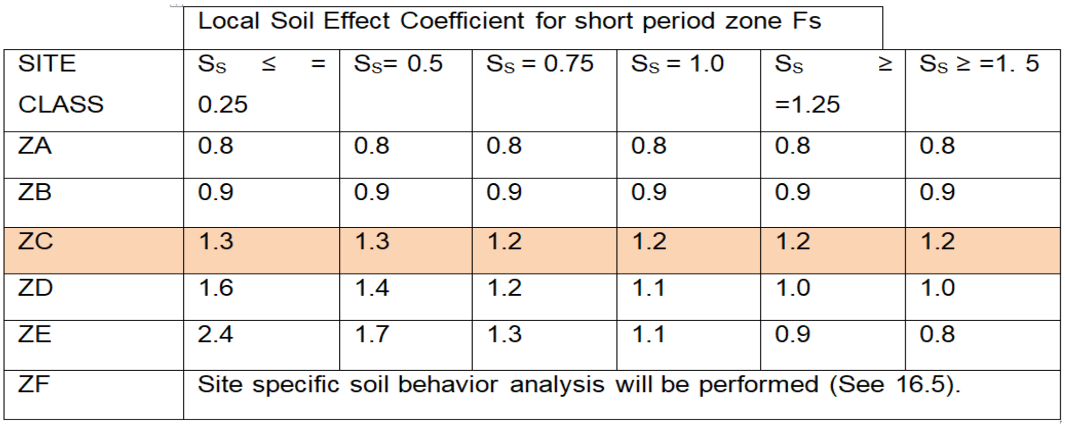
$S_1 = 0.701$

Step 2: Define your site classification, the site class has chosen soil class C for this example

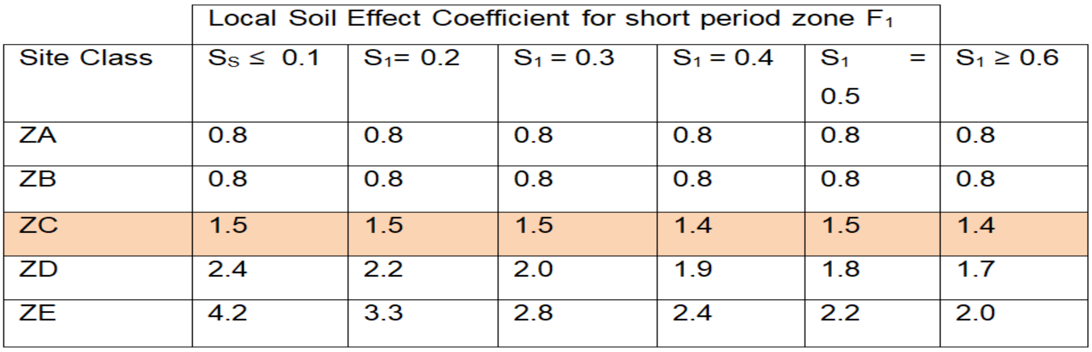


Type	Soil classification
ZA	Rugged, hard rocks Vs > 1500 m/s
ZB	Slightly weathered, medium solid rocks 760m/s < Vs >1500
ZC	Very tight layers of sand, gravel and hard clay, or weathered, cracked weak rocks 360 m/s < Vs >760m/s
ZD	Medium tight - layers of tight sand, gravel or very solid clay 180 m/s < Vs >360m/s
ZE	Loose sand, gravel or soft Vs < 180m/s
ZF	Floors requiring site-specific research and evaluation

Step 3 Obtain the local site coefficients F_S and F_1 to modify the response spectrum



	Local Soil Effect Coefficient for short period zone Fs					
SITE CLASS	S_S ≤ = 0.25	S_S= 0.5	S_S = 0.75	S_S = 1.0	S_S ≥ =1.25	S_S ≥ =1. 5
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.3	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.2	1.1	1.0	1.0
ZE	2.4	1.7	1.3	1.1	0.9	0.8
ZF	Site specific soil behavior analysis will be performed (See 16.5).					



	Local Soil Effect Coefficient for short period zone F_1					
Site Class	$S_S \leq$ 0.1	S_1= 0.2	S_1 = 0.3	S_1 = 0.4	S_1 = 0.5	$S_1 \geq$ 0.6
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.4	1.5	1.4
ZD	2.4	2.2	2.0	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2.0

Step 4: Calculate the spectral response parameters S_{DS} and S_{D1}

$$S_{DS} = F_s\, s_s$$

$$S_{DS} = 1.2 * 1.573 = \ 1.8876$$

$$S_{M1} = F_v\, s_1$$

$$S_{D1} = 1.4 * \ 0.701 = 0.981$$

Steps 5: Compute the pertinent period parameters.

$$T_A = 0.2\, \frac{S_{D1}}{S_{DS}}$$

$$T_A = 0.2\, \frac{0.981}{1.8876} = 0.104 \text{ sec}$$

$$T_B = \frac{S_{D1}}{S_{DS}}$$

$$T_B = \frac{0.981}{1.8876} = 0.52 \text{ sec}$$

Steps 6 compute the design response spectrum

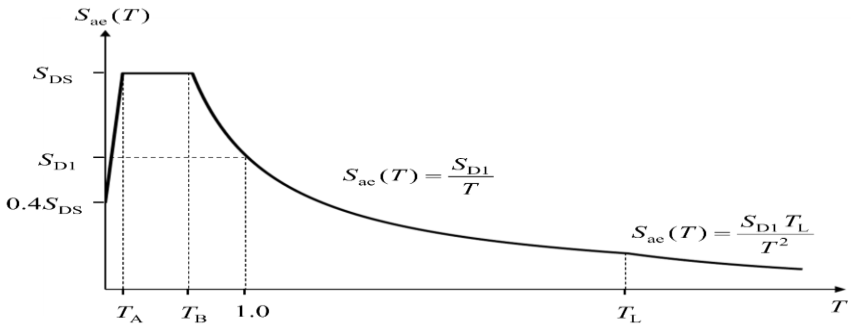


Figure A. 2: Response spectrum curve

EUROCODE

Input data analysis

Moment resistance frame Concrete structures

D.L= 15KN/m^2

L.L= 10KN/m^2

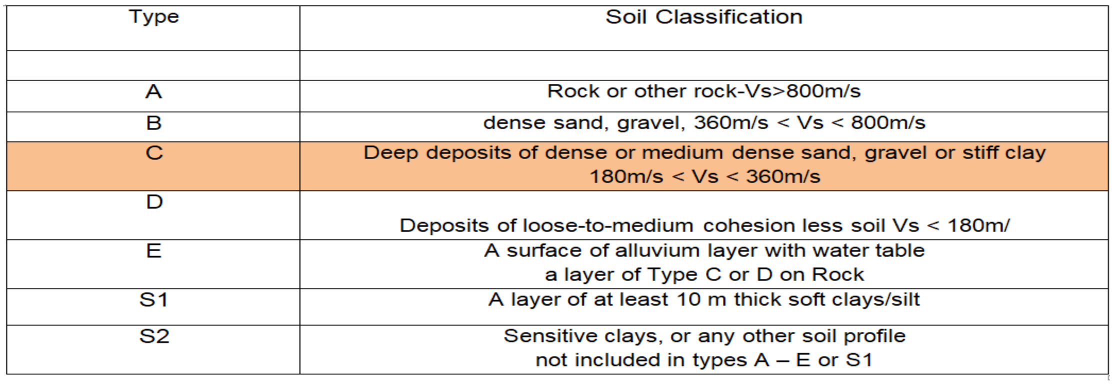
Beam length x-x direction = 5m

Beam length x-x direction = 5m

Type of building

School

Soil class: C

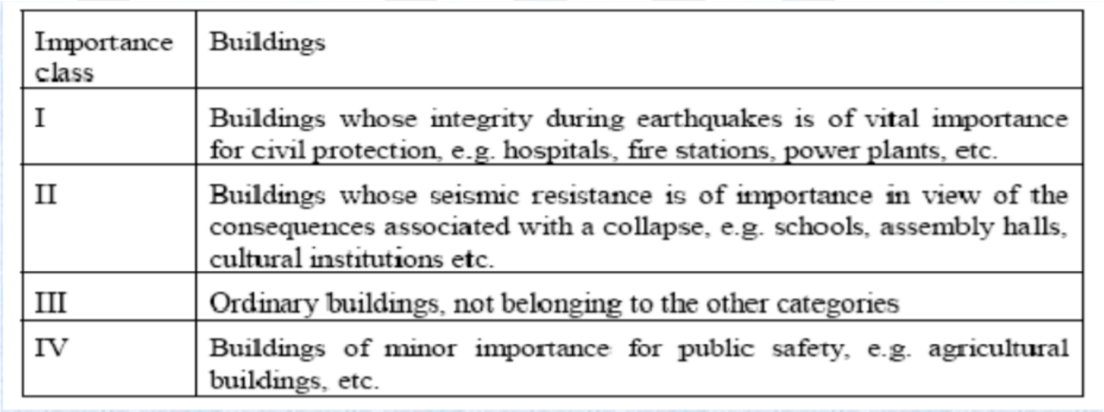


Type	Soil Classification
A	Rock or other rock-Vs>800m/s
B	dense sand, gravel, 360m/s < Vs < 800m/s
C	Deep deposits of dense or medium dense sand, gravel or stiff clay 180m/s < Vs < 360m/s
D	Deposits of loose-to-medium cohesion less soil Vs < 180m/
E	A surface of alluvium layer with water table a layer of Type C or D on Rock
S1	A layer of at least 10 m thick soft clays/silt
S2	Sensitive clays, or any other soil profile not included in types A – E or S1

Frame system in DCM design

Earthquake action calculation

Importance class $\gamma I = 1.2$



Importance class	Buildings
I	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.
II	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
III	Ordinary buildings, not belonging to the other categories
IV	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.

Seismic zone II of Greece $a_{gr} = 0.24$ $a_g = \gamma_I a_{gr} = 1.2 * 0.24g = 2.09 m/s^2$

Ground Type	S	$T_B(S)$	$T_C(S)$	$T_D(S)$
A	1.0	0.15	0.5	2.0
B	1.2	0.15	0.6	2.0
C	1.15	0.20	0.8	2.0
D	1.35	0.20	0.6	2.0
E	1.4	0.20	0.5	2.0

$S = 1.15$ $T_B = 0.20s$ $T_C = 0.6s$ $T_D = 2.0s$

Frame system in DCM

$\mathrm{q_o = 3a_u/a_1}$

Multi bay frame system

$\mathrm{a_u/a_1 \ = \ 1.3}$

Frame system $\mathrm{K_w = 1} \qquad \mathrm{q = q_o.k_w \ = (3*1.3)*1 = 3.9}$

Design spectrum

$$\mathrm{T = 0} \qquad \mathrm{S_d = (T) = a_g * S * \frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5}{q} - \frac{2}{3}\right) = 2.83 * 1.15\left(\frac{2}{3}\right) = 2.17 m/s^2}$$

$$\mathrm{T}_B = 0.20\mathrm{s} \qquad \mathrm{S_d = (0.2) = a_g * S * \frac{2.5}{q} = 2.83 * 1.15 \frac{2.5}{3.9} = 2.09 m/s^2}$$

$$\mathrm{T}_C = 0.60\mathrm{s} \qquad \mathrm{S_d = (0.60) = a_g * S * \frac{2.5}{q} = 2.83 * 1.15 \frac{2.5}{3.9} = 2.09 m/s^2}$$

$$\mathrm{T_C = 2.0s} \qquad \mathrm{S_d = (2.0) = a_g * S * \frac{T_C}{T} = 2.83 * 1.15\left(\frac{0.60}{2}\right) = 0.63 m/s^2}$$

$$\mathrm{T_D = 3.0s} \qquad \mathrm{S_d = (T) = a_g * S * \frac{2.5}{q}\left(\frac{T_{\mathit{C}}.T_{\mathit{D}}}{T^2}\right) = 2.83 * 1.15 \frac{2.5}{3.9}(0.013)}$$

$$\mathrm{= 0.28 m/s^2}$$