Seismic Design and Performance Evaluation of Residential Buildings via the TBEC 2018, TEC 2007 and EC 8

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ABSTRACT

Every year, thousands of people were lost their lives in buildings that were collapsed due to the earthquake. However, the buildings should at least not collapse during the earthquake and ensure the safety of life. Therefore, countries are published earthquake codes with rules and instructions to design buildings earthquake-resistant. However, although these earthquake codes seem to be sufficient, they need to be built up in parallel with the developments in science and engineering. In this context, at the end of 2018, Turkey published a new earthquake code. In this new earthquake code, many sections of the previous earthquake code have updated. Also, many new rules have published. Therefore, in this thesis to examine the impact of these developments on building performance, it is aimed to compare the new Turkish Building Earthquake Code 2018 (TBEC 2018), the previous Turkish Earthquake Code 2007 (TEC 2007) and Eurocode 8 (EC 8) in terms of the performance of buildings. Firstly, the seismic design principles and seismic analysis steps of the earthquake codes were compared in the context of general information. Then, in the selection of the residential buildings, the types of irregularities mentioned in TBEC 2018 were taken into consideration. Accordingly, different types of plans were designed under six main headings. These are regular building and A1, A2, A3, B1 and B2 type structural irregular buildings. Afterwards, the design has been expanded with three different storey numbers (5, 10 & 20-Storey) to examine the behaviour of these buildings at different storey numbers. Furthermore, major changes observed on the previous Turkey Earthquake Zones Map with the publication of the New Turkey Earthquake Hazard Map. Therefore, to examine the effect of the location-based design, two locations (Atasehir & Izmit) which were in the same earthquake zone in the previous Turkey Earthquake Zone Map

but which had different spectral values were selected in the new Turkey Earthquake Hazard Map. In the numerical application part of the study, a total of 108 residential buildings were designed and analysed by linear dynamic analysis method. Then, multi-mode pushover analysis was performed to determine the performance levels of residential buildings which were designed according to three earthquake codes. Finally, the analysis results were evaluated by TBEC 2018 criteria to determine the performance level of residential buildings. In this study, base shear forces, maximum horizontal displacements, construction costs, damage rates of columns and beams and performance level of the buildings were compared. According to the pushover analysis results of the buildings, the controlled damage performance level targeted by the earthquake codes was achieved at a rate of 95%. In the buildings designed according to the spectral data of Atasehir, analysis according to EC 8 was found to be the worst in terms of column damage rate. However, in buildings designed according to spectral data of Izmit, analysis according to TEC 2007 has the worst column damage rate. The most ineligible results in terms of construction cost were obtained from the analysis according to EC 8. In terms of building costs, minimal differences have been observed between TBEC 2018 and TEC 2007; The reason for this difference is that the concept of earthquake zone used in TEC 2007 was abandoned in TBEC 2018.

Keywords: TBEC 2018, TEC 2007, Eurocode 8, Mode Superposition Method, Multi-Mode Pushover Analysis, and Nonlinear Dynamic Analysis

ÖZ

Her yıl binlerce insan deprem nedeniyle yıkılan binalarda hayatını kaybetmektedir. Ancak, binalar en azından deprem sırasında yıkılmamalı ve can güvenliğini sağlamalıdır. Bu nedenle, ülkeler depreme dayanıklı binaları tasarlayabilmek adına kurallar ve talimatlar içeren deprem yönetmelikleri yayımlanmaktadır. Bununla birlikte, bu deprem yönetmelikleri yeterli görünse de bilim ve mühendislikteki gelişmelere paralel olarak yenilenmeleri gerekir. Bu bağlamda, 2018 sonunda, Türkiye yeni bir deprem yönetmeliği yayınladı. Bu yeni deprem kodunda, önceki deprem kodunun birçok bölümü güncellenmiştir. Ayrıca, birçok yeni kural da yayınlanmıştır. Bu nedenle, bu gelişmelerin bina performansına etkisini incelemek amacıyla yapılan tez çalışmasında, yeni Türkiye Bina Deprem Yönetmeliği 2018 (TBDY 2018), bir önceki Türkiye Deprem Yönetmeliği 2007 (DBYBHY 2007) ve Eurocode 8 (EC 8)'in bina performansı açısından karşılaştırılması amaçlanmıştır. Çalışmada, ilk olarak genel bilgi bağlamında yönetmeliklerin sismik tasarım esasları ve hesap adımlarının karşılaştırması yapılmıştır. Daha sonra, konut binalarının seçiminde TBDY 2018 yönetmeliğinin düzensizlik kriterlerine bağlı kalınmıştır. Buna göre binalar, düzenli binalar ve A1, A2, A3, B1 ve B2 tipi düzensiz binalar olarak toplamda 6 farklı ana başlık altında sınıflandırılmıştır. Daha sonra, bu binaların farklı kat sayılarındaki davranışlarını da incelemek adına tasarım üç farklı kat sayısıyla (5, 10 ve 20 Kat) genişletildi. Ayrıca, önceki Türkiye Deprem Bölgeleri Haritasında, Yeni Türkiye Deprem Tehlikesi Haritasının yayınlanmasıyla birlikte büyük değişiklikler olduğu gözlemlenmiştir. Bu nedenle, lokasyon bazlı tasarımın etkisini inceleyebilmek adına, önceki Türkiye Deprem Bölgesi Haritasında aynı deprem bölgesinde bulunan ancak yeni Türkiye Deprem Tehlikesi Haritasında farklı spektral değerleri olan iki lokasyon

(Ataşehir ve İzmit) seçildi. Çalışmanın sayısal uygulama bölümünde ise, toplam 108 adet konut binası tasarlandı ve doğrusal dinamik analiz yöntemi ile analiz edildi. Daha sonra, üç deprem kanununa göre tasarlanmış konut yapılarının performans seviyelerini belirlemek için çok modlu itme analizi uygulandı. Son olarak, analiz sonuçları, konut yapılarının performans seviyesini belirlemek için TBDY 2018 kriterleri ile değerlendirildi. Çalışmada binaların, taban kesme kuvvetleri, en büyük yatay yer değiştirmeleri, yapım maliyetleri, kolon ve kirişlerin hasar oranları ve performans seviyeleri karşılaştırılmıştır. Binaların performans sonuçlarına göre yönetmeliklerin hedeflediği performans seviyesi %95 oranında elde edilmiştir Ataşehir'in spektral verilerine göre tasarlanan binalarda, EC 8'e göre yapılan analizlerin kolon hasarı oranı bakımından en kötü olduğu tespit edildi. Bununla birlikte, İzmit'in spektral verilerine göre tasarlanmış binalarda, DBYBHY 2007'ye göre yapılan analizler en kötü kolon hasar oranına sahiptir. Yapı maliyeti açısından en elverişsiz sonuçlar EC 8'e göre yapılan analizlerden elde edilmiştir. Diğer yönden, TBDY 2018 ile DBYBHY 2007 arasında yapı maliyetleri açısından kısmi farklılıklar gözlenmiştir; bu farklılığın sebebi olarak DBYBHY 2007'de kullanılan deprem bölgesi kavramının TBDY 2018'de terk edilmiş olmasıdır.

Anahtar Kelimeler: TBDY 2018, DBYBHY 2007, Eurocode 8, Mod Süperpoziyon Yöntemi, Çok Modlu İtme Analizi, ve Doğrusal Olmayan Dinamik Analiz

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$(\Delta_i)_{max}$	Maximum storey drift of i,th storey of the building.
$(\Delta_i)_{min}$	Minimum storey drift of i,th storey of the building.
$(\Delta_i)_{ort}$	Average storey drift of i,th storey of the building.
Δ_i	Storey drift of i,th storey of the building.
A	Gross floor area.
$A(T)$	Spectral acceleration coefficient.
A_0	Effective ground acceleration coefficient.
A_b	Total area of openings.
A_e	Effective shear area.
A_{Ed}	Design value of return period of specific earthquake motion.
a_g	Design ground acceleration on type A ground.
A_g	Section areas of structural elements at any storey.
a_{gR}	Reference peak ground acceleration on type A ground.
A_k	Infill wall areas.
a_{vg}	Design ground acceleration in the vertical direction.
A_w	Effective of web area of column cross sections.
a_y, a_x	Length of re-enter corners in x, y direction.
c_u	Undrained shear strength of soil.
E	Earthquake Load
E_d	Load Combinations.
E_n, E_y	Earthquake in direction to *n*.

e_{ox}	Distance between the centre of stiffness and the centre of mass, measured along the *x* direction, which is normal to the direction of analysis considered.
g	Gravity coefficient.
G	Dead load.
h_i	Height of i,th storey of building [m].
h_w	Height of wall or cross-sectional depth of beam.
I	Building importance factor.
L_{max}	Larger dimension in plan of the building.
L_{min}	Smaller dimension in plan of the building.
l_s	Radius of gyration of the floor mass in plan (square root of the ratio of (a) the polar moment of inertia of the floor mass in plan with respect to the centre of mass of the floor to (b) the floor mass).
Lx, Ly	Length of the building at x, y direction.
N	Number of stories in the structure.
N_{SPT}	Standard penetration test blow-count
q	Behaviour factor.
Q	Live load.
R	Wind Load
r_x	Square root of the ratio of the torsional stiffness to the lateral stiffness in the *y* direction (“torsional radius”).
S	Soil factor.
S	Soil Pressure Load
S(T)	Spectrum coefficient.
$S_{ae}(T)$	Elastic spectral acceleration.

$S_d(T)$	Design spectrum (for elastic analysis).
$S_{De}(T)$	Elastic displacement response spectrum.
$S_e(T)$	Elastic response spectrum.
$S_{ve}(T)$	Elastic vertical ground acceleration response spectrum.
T	Vibration period of a linear single degree of freedom system.
T_A, T_B	Spectrum characteristic periods
T_B	Lower limit of the period of the constant spectral acceleration branch.
T_C	Upper limit of the period of the constant spectral acceleration branch.
T_D	Value defining the beginning of the constant displacement response range of the spectrum.
$v_{s\,30}$	Average value of propagation velocity of S waves in the upper 30 m of the soil.
β	Lower bound factor for the horizontal design spectrum.
γ_I	Importance factor.
ε_{sy}	Design value of steel strain at yield.
η	Damping correction factor with a reference value of η=1 for 5% viscous damping.
η_{bi}	Torsionally irregularity factor defined at i,th storey of the building.
η_{ki}	Stiffness irregularity factor defined at i,th storey of the building.
λ	Slenderness.
ξ	Viscous damping ratio of the structure, expressed as a percentage.

LIST OF ABBREVIATIONS

AD	Advanced Damage
BKS	Building Usage Class
BYS	Building Height Class
C	Collapse
CD	Controlled Damage
CP	Collapse Prevention
CU	Continuous Usage
CQC	Complete Quadratic Combination
CR	Collapsing Region
DBD	Displacement Based Design
DCH	High Ductility Building
DCM	Medium Ductility Building
DD	Earthquake Ground Motion Level
DTS	Earthquake Design Class
EC 1	Eurocode 1
EC 2	Eurocode 2
EC 8	Eurocode 8
LD	Limited Damage
MD	Marked Damage
SBD	Strength Based Design
SRSS	Square Root of Sum of Squares
TBEC 2018	Turkish Building Earthquake Code 2018
TEC 2007	Turkish Earthquake Code 2007

TS-498	Design Loads for Building
TS-500	Requirements for Design and Construction of Reinforced Concrete Buildings

Chapter 1

INTRODUCTION

1.1 General

In Turkey, which is under the risk of earthquakes for a large part, according to research data of the Turkey Earthquake Research Department in 2018, 58,202 citizens lost their lives in the last fifty-eight years, 122,096 people were injured, and approximately 411,465 buildings were severely damaged or collapsed. Alongside with these facts, the importance of earthquake-resistant building design and evaluation of existing buildings have been proved again. Therefore, countries are publishing earthquake codes that contain rules and instructions to ensure that structures are designed to be earthquake-resistant and thus safe for people. However, countries should update earthquake codes as a result of developing technology and new researches.

In parallel with this information, a new earthquake code was published in Turkey at the end of 2018. Thus, as a result of the publication of the new regulation, many new rules on earthquake resistant structure design have been published. However, as a result of the design methods and unpredictable behaviour of buildings, there is still insufficient information about the performance of the existing buildings during an earthquake. As a result, it is aimed to reveal the differences of the codes by comparing the performances of the residential buildings designed according to the both Turkish Earthquake codes. Also, the scope of the study was extended by the inclusion of EC

8, the regulation applied by European countries. Thus, a more global perspective on the changes introduced by the new regulation can be obtained.

1.2 Literature Review

Earthquake-resistant building design and the performance of existing buildings are of great importance in earthquake codes. For this reason, many studies about this subject have been made in the literature. The results of several studies are listed below.

Meral (2009) compared TEC 1998 with TEC 1975 in his thesis. In the study, the differences in the analysis results of the 2, 4 and 7 storey structures examined in detail. According to the results of the study, it was observed that there was a significant improvement in the structures designed according to TEC 1998 compared to the structures designed according to TEC 1975.

Korkmaz et al. (2010), investigated the seismic behaviour of reinforced concrete 10-storey frame structures containing structural irregularities. According to the results obtained from the study, lateral displacement capacity of buildings increased in models without in-fill walls. However, soft storey irregularity occurred in those buildings. Thus, a significant decrease was observed in the seismic performance of buildings with soft storey irregularities.

Aydemir (2011) compared TEC 2007 with EC 8 in his thesis. In this study, the design rules and provisions of both earthquake codes were examined. According to the study, the two sample structures were analysed by using Sta4CAD software. The results obtained were evaluated in terms of cost. According to the results, the EC 8 remains on the more economic side comparing to the TEC 2007.

Safkan (2012) made a comparison of TEC 2007 with EC 8 applied in Cyprus island in his study. In this study, the analysis of a reinforced concrete structure for two different regions was made according to two earthquake codes and the differences were evaluated. According to the results, the high reduction factor of TEC 2007 also leads to lower base shear values. Furthermore, for the very soft soil types, EC 8 gives much higher base shear compared to TEC 2007.

Gök (2013), in her thesis, made a comparison of A3 type of irregular multi-storey reinforced concrete structure, by performing design and earthquake analyses according to TEC 2007, EC 8 and ACI 318 codes. In this study, seismic analysis was carried out by using the equivalent static analysis method in the three earthquake codes of the 10-storey structure using SAP2000 program. In this study, structural periods, base shear forces, relative displacements, maximum displacements, and second-order effects were calculated according to earthquake codes. Finally, the differences between earthquake codes were examined.

Tunç and Tanfener (2016) in their study summarized the similarities and differences between TEC 2007 and TBEC 2016 (draft). In this study, they examined the design differences arising from the regulations applied on a 10-storey reinforced concrete office building. The results showed that the structural periods and storey drift significantly increased in the analysis according to TBEC 2016. As a result of this increase, base shear forces decreased according to the TBEC 2016. However, despite of this decrease, due to the effect of the overstrength factor, the internal forces of the structural elements increased too much.

Başaran (2018), in his study, the equivalent static analysis method according to TEC 2007 and TBEC 2018, were evaluated. 5-storey and 10-storey sample reinforced concrete frame models were used in the analysis. In the study, the results obtained considering soil classes were compared and the variation of earthquake loads were investigated. For both frame models, it was noticeable that the equivalent earthquake loads calculated according to TBEC 2018 decreased compared to TEC 2007.

Elçi and Göker (2018) in their study, Turkish Earthquake Codes (TBEC 2018 and TEC 2007) were compared in terms of the seismic performance of reinforced concrete columns. In the theoretical and experimental study, they have been examined four column samples. Moment-curvature curves of the specimens and lateral force-displacement were obtained from the test results. The results obtained from the experimental study were observed to be generally compatible. Accordingly, TBEC 2018 gives conservative deformation limits comparing to TEC 2007.

1.3 Aim and Scope

Every year, thousands of people were lost their lives in buildings that were collapsed due to the earthquake. However, the buildings should at least not collapse during the earthquake and ensure the safety of life. Therefore, countries are published earthquake codes with rules and instructions to design buildings earthquake-resistant. However, although these earthquake codes seem to be sufficient, they need to be built up in parallel with the developments in science and engineering. In this context, at the end of 2018, Turkey published a new earthquake code. In this new earthquake code, many sections of the previous earthquake code have updated. Also, many new rules have published. Therefore, in this thesis to examine the impact of these developments on building performance, it is aimed to compare the new Turkish Building Earthquake

Code 2018, the previous Turkish Earthquake Code 2007 and Eurocode 8 in terms of the performance of buildings.

In this thesis, it is aimed to evaluate the performance of residential buildings. The design of the plans of these residential buildings is within the boundaries of the TBEC 2018 title of irregular structural systems. Accordingly, in total, different types of plans were designed under six main headings. These are regular building and A1, A2, A3, B1 and B2 type irregular buildings. Furthermore, the design has been expanded with three different storey numbers to examine the behaviour of these regular and irregular buildings at different storey numbers. Finally, to examine the effect of the location-based design introduced in TBEC 2018, two locations which were in the same earthquake zone in the previous Turkey Earthquake Zone Map but which had different spectral values were selected in the new Turkey Earthquake Hazard Map.

In the first phase of the numerical application, multi-storey reinforced concrete frame systems were analysed and designed separately for three earthquake codes. As the method of account, mode superposition method was used for linear dynamic analysis. According to the result of the linear analyses, changes in such as base shear forces and irregularity factors were examined. Then, in the performance evaluation phase, the performance levels of those buildings compared according to TBEC 2018 criteria. In order to determine the performance levels of these buildings, a multi-mode pushover analysis method was applied. Besides, the analyses performed within the scope of the study were made by using Sta4CAD V14.1 software program.

1.4 Thesis Outline

This study consists of six chapters and is organized according to the following outline,

- In the first chapter, the aim, method, and scope of the thesis were explained, and the previous studies on the subject were summarized.
- In the second chapter, the technical instructions of TBEC 2018, TEC 2007 and EC 8 regulations used in earthquake resistant building design are briefly examined, and the differences and similarities between them were summarized.
- In the third chapter, nonlinear evaluation procedure according to TBEC 2018 is explained.
- In the fourth chapter, the method applied in numerical application and the plans of the sample models are given.
- In the fifth chapter, the results obtained from the non-linear analysis method are examined and compared.
- In the sixth chapter, conclusions of the thesis and recommendations for future studies are given.

Chapter 2

COMPARISON OF EARTHQUAKE DESIGN CODES

2.1 Introduction

Resistance to earthquakes, strength, stiffness, and ductility should be present in the structural system as a whole, in the elements and in the junction areas to ensure that the loads created during the earthquake are safely transferred to the foundation ground (Özyer, 2016).

Details of the concepts mentioned in the previous paragraph are respectively; Strength is provided by cross-sectional dimensioning and detailing that can carry design loads. Stiffness is achieved by limiting the displacements. The concept of ductility is the ability to displace and deformation without losing strength (Özyer, 2016).

Considering the above conditions, two types of analysis methods are proposed which are linear static analysis and linear dynamic analysis are used in the earthquake design of new buildings. Static analysis method, is the most preferred method for earthquake analysis since it is a simple method. However, the simplicity of this method is limited by the type of building. In cases where the equivalent static analysis method cannot be applied, dynamic analysis methods are used. Dynamic analysis methods are Modal Response Spectrum, also known as Modal Superposition Method and Time Domain Analysis (Sandıkçı, 2014; Asfuroğlu, 2018).

In this chapter, linear analysis methods of the codes and design procedures are examined and design rules are explained in a simple way.

2.2 Specific Measures in Design

2.2.1 Turkish Building Earthquake Code 2018

According to TBEC 2018, some rules have been defined for earthquake resistant design of structures. The structural system of the building should be of sufficient simplicity. Vertical and horizontal irregularities should be avoided in the structural system, and as much as possible symmetrical structure design procedure must be followed (Tunc & Tanfener, 2016).

Sufficient rigidity must be provided to limit the loss of strength, in whole or in part, of the structural system elements under earthquake impact. It is expected that there will be an acceptable similarity between all system elements in terms of stiffness and strength so that structural systems can show sufficient strength and sufficient rigidity under earthquake impact. It is also expected that the slab elements which take part in the transfer of stresses and loads occurring under the influence of an earthquake between structural elements will show sufficient in-plane rigidity (TBEC, 2018).

2.2.2 Turkish Earthquake Code 2007

Design and construction of irregular buildings should be avoided. The structural system should be arranged symmetrically in the plan as far as possible. A significant portion of the earthquake load transferred to the building should be consumed by the ductile behaviour of the structural system. Ductile design principles must be applied (Aydemir, 2011).

The building structural system resisting earthquake loads and also each structural element of the system should be provided with sufficient stiffness, stability, and strength to ensure that the earthquake loads are transferred continuously and safely down to the foundation. It is essential that floor systems possess sufficient stiffness and strength to ensure the safe transfer of lateral seismic loads between the elements of the structural system. Otherwise, appropriate transfer elements should be rearranged on floors (TEC, 2007).

2.2.3 Eurocode 8

According to EC8, the structure should have simple and regular forms both in elevation and plan. The earthquake performance of the structure depends on the critical regions of the structure or the behaviour of the elements. Specially at these critical regions, premature formation of unstable structural mechanisms should be avoided. For this purpose, capacity design procedure, which is used to obtain the hierarchy of resistance of the various structural components and the failure modes necessary for ensuring appropriate plastic mechanism and for avoiding brittle failure, should be referred is where necessary. Consideration should be given to the connection details of these elements in the regions where the structural elements are expected to exhibit non-linear behaviour (Kacar, 2011).

The analysis should be based on an appropriate structural model, which also takes into account the effect of non-structural elements such as soil deformation and the presence of adjacent structures. The rigidity of the foundations must be suitable for the uniform transmission of the loads from the superstructure to the ground as much as possible (Karasu, 2015).

2.3 Soil Types and Parameters

2.3.1 Turkish Building Earthquake Code 2018

According to parameters of shear wave velocity, standard penetration resistance and undrained shear strength, the soils are divided into six different classes in TBEC 2018. Parameters related to soil classes and explanations are given in table below.

Table 2.1: Soil Class and Soil Type according to TBEC 2018

Soil Class	**Soil Type**	**Top 30 meters on average**		
		Shear Wave Velocity (V_S)30 [m/s]	**Standard Penetration Resistance (N60)30 [blows/30cm]**	**Undrained Shear Strength (C_U)30 [kPa]**
ZA	Tough, hard rocks	>1500	-	-
ZB	Low weathered, medium solid rocks	760-1500	-	-
ZC	Very dense sand, gravel and very stiff clay or very cracked weak rocks	360-760	> 50	> 250
ZD	Dense-medium dense sand, gravel or very stiff clay	180-360	15-50	70-250
ZE	Loose sand, gravel or soft –stiff clay or Providing conditions for PI> 20 and w> 40% soft clay thicker than 3 meters in total profiles. (CU)<25kPa	180	< 15	< 70
ZF	Ground requiring site-specific research and evaluation: 1) Soils that have the risk of collapse and potential collapse under the influence of earthquake (liquefaction soils, highly sensitive clays, poor cemented floors etc.), 2) Total thickness of more than 3 meters of peat and / or high content of organic clays, 3) High plasticity (PI> 50) clays with a total thickness of more than 8 meters, 4) Very thick (> 35 m) soft or medium stiff clays.			

2.3.2 Turkish Earthquake Code 2007

It is obligatory to perform soil investigations on the required field and laboratory tests, to arrange the relevant reports which are included in the project documents in the following 2 conditions (TEC, 2007).

- All buildings with a total height of more than 60 meters in the first and second seismic zones.

- The buildings where the Building Importance Factor is I = 1.5 and I = 1.4 independent of the building height in all earthquake zones.

Table 2.2: Soil Groups according to TEC 2007

Soil Group	Description of Soil Group	Standard Penetration (N/30)	Relative Density (%)	Unconfined Compressive Strength (kPa)	Drift Wave Velocity (m/s)
A	1.Massive volcanic rocks, unweathered sound Metamorphic rocks, stiff cemented sedimentary rocks	-	-	>1000	>1000
	2.Very dense sand, gravel	>50	85–100	-	>700
	3. Hard clay, silty lay	>32	-	>400	>700
B	1. Soft volcanic rocks such as tuff and agglomerate, weathered cemented sedimentary rocks with planes of discontinuity	-	-	500–1000	700–1000
	2. Dense sand, gravel	30–50	65–85	-	400–700
	3. Very stiff clay, silty clay	16–32	-	200–400	300–700
C	1. Highly weathered soft metamorphic rocks and cemented sedimentary rocks with planes of discontinuity	-	-	<500	400–700
	2. Medium dense sand and gravel	10–30	35–65	-	200–400
	3. Stiff clay and silty clay	8–16	-	100–200	200–300
D	1. Soft, deep alluvial layers with high ground water level	-	-	-	<200
	2. Loose sand	<10	< 35	-	<200
	3. Soft clay and silty clay	<8	-	<100	<200

Table 2.3: Local Site Classes according to TEC 2007

Local Site Class	Soil Group according to Table 2.2 and Topmost Soil Layer Thickness (h_1)
Z1	Group (A) soils Group (B) soils with $h_1 \leq 15$ m
Z2	Group (B) soils with $h_1 > 15$ m Group (C) soil with $h_1 \leq 15$ m
Z3	Group (C) soil with 15 m < $h_1 \leq 50$ m Group (D) soils with $h_1 \leq 10$ m
Z4	Group (C) soil with $h_1 > 50$ m Group (D) soils with $h_1 > 10$ m

2.3.3 Eurocode 8

In EC 8, the soil parameters are similar to TEC 2007 and are classified according to the shear wave velocity, standard penetration test, and free pressure resistance.

However, seven different soil classes have been defined in EC 8. Based on the project conditions and the purpose of the building, soil investigations are required. However, soil investigation can be neglected in areas where there is no earthquake risk. Soil types are given in Table 2-4, depending on the parameters obtained from the soil investigation.

Table 2.4: Soil Types according to EC 8

Soil type	**Description of stratigraphic Parameters**	**Parameters**		
		$(V_S)_{30}$ [m/s]	**N_{SPT} (blows/30cm)**	**$(C_U)_{30}$ [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 meters in thickness, characterized 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 meters.	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 vs 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	-	10–20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1			

For sites with soil conditions matching either one of the two special soil types S1 or S2, special studies for the definition of the seismic action are required. For these soils and especially for S2, unexpected behaviour may occur on the soil under the seismic action (Kacar, 2011).

2.4 Building Importance Factor and Building Usage Class

2.4.1 Turkish Building Earthquake Code 2018

In TBEC 2018, buildings are classified according to Building Usage Class (BKS) and Building Importance Factor (I) are defined according to these classes. Building usage classes are defined according to the importance and risk of the building during and after the earthquake, and three building usage classes are given as BKS = 1, BKS = 2 and BKS = 3. Explanations on building usage classes and building importance factor are given in table below (Tunc & Tanfener, 2016).

Table 2.5: Building Usage Class and Building Importance Factor according to TBEC 2018.

BKS	Purpose of Occupancy of Building	I
BKS=1	**Buildings required to be utilized after the earthquake, intensively and long-term occupied buildings and buildings preserving valuable goods and buildings containing hazardous materials** Buildings required to be utilized immediately after the earthquake (PTT and other telecommunication facilities, dispensaries, health wards, firefighting buildings and facilities, first aid and emergency planning stations, hospitals, power generation and distribution facilities, county and municipality administration buildings, transportation stations and terminals, governorate) b) Schools, dormitories and hostels, military barracks, other educational buildings and facilities, prisons, etc. c) Museums d) Buildings containing or storing toxic, flammable and explosive materials, etc.	1.5
BKS=2	**Intensively but short-term occupied buildings** Cinema, sport facilities, concert halls and theatre, etc.	1.2
BKS=3	**Other buildings** Buildings other than defined in BKS=1 and BKS=2 buildings. (Residential and office buildings, building-like industrial structures, hotels, etc.)	1

2.4.1.1 Earthquake Design Class

The earthquake design classes (DTS) in TBEC 2018 are defined according to the building usage class and the short period design spectral acceleration coefficient at DD-2 earthquake ground motion level (Asfuroğlu, 2018). The earthquake that, probability of exceedance in 50 years is %10, and the repetition period is 475 years. The parameters for earthquake design classes are given in Table 2-6.

Table 2.6: Earthquake Design Class according to TBEC 2018.

S_{DS} values in accordance with DD-2	**Building Usage Class**	
	BKS = 1	**BKS =2,3**
$0.75 \leq S_{DS}$	DTS = 1a	DTS = 1
$0.5 \leq S_{DS} < 0.75$	DTS = 2a	DTS = 2
$0.33 \leq S_{DS}$ 0.5	DTS = 3a	DTS = 3
$0.33 < S_{DS}$	DTS = 4a	DTS = 4

2.4.1.2 Building Height Class

Building height classes are defined according to the height ranges given in TBEC 2018 according to earthquake design classes. The structural system is selected according to the defined building height classes (Tunc & Tanfener, 2016).

Table 2.7: Building Height Class according to TBEC 2018

Building Height Class	**DTS = 1, 1a, 2, 2a**	**DTS = 3, 3a**	**DT 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	$H_N \leq 7$	$H_N \leq 10.5$	

2.4.2 Turkish Earthquake Code 2007

The building importance factor which plays an important role in the seismic analysis varies according to the type and purpose of the building to be constructed. The coefficient increases according to public safety and the environmental impact of the building during and after the earthquake. According to TEC 2007, coefficients are defined under four categories (Gök, 2013; Karasu, 2015).

Table 2.8: Building importance factor (I) according to TEC 2007

Purpose of Occupancy or Type of Building	**Importance Factor (I)**
1. Buildings required to be utilized after the earthquake and buildings containing hazardous materials a) Buildings required to be utilized immediately after the earthquake (PTT and other telecommunication facilities, dispensaries, health wards, firefighting buildings and facilities, first aid and emergency planning stations, hospitals, power generation and distribution facilities, county and municipality administration buildings transportation stations and terminals, governorate) b) Explosive and flammable materials, buildings containing or storing toxic, etc.	1.5
2. Intensively and long-term occupied buildings and buildings preserving valuable goods a) Military barracks, dormitories and hostels, other educational buildings and facilities, military barracks, schools, prisons, etc. b) Museums	1.4
Intensively but short-term occupied buildings Theatre and concert halls, sport facilities, cinema etc.	1.2
Other buildings Buildings other than above defined buildings. (hotels, building-like industrial structures, Residential and office buildings, etc.)	1.0

2.4.3 Eurocode 8

The buildings are divided into four classes of importance depending on the importance of public safety, the social and economic consequences of demolition and the consequences of major effects of buildings for human life. These importance classes are defined by different importance factors (γ_I) (Eurocode 8, 2004).

Table 2.9: Importance classes and factors for buildings according to EC 8

Importance class	**Buildings**	**Importance factor (γ_I)**
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. power plants, hospitals, fire stations etc.	1.4
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. cultural institutions, schools, assembly halls etc.	1.2
II	Ordinary buildings, not belonging in the other categories.	1.0
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8

2.5 Elastic Earthquake Loads

2.5.1 Turkish Building Earthquake Code 2018

In TBEC 2018, four different Earthquake Ground Motion Levels (DD) are proposed and design earthquake acceleration is selected according to this earthquake ground motion levels. The four earthquake ground motion levels, defined as DD-1, DD-2, DD-3 and DD-4, are classified by the percentage of probabilities of exceedance over 50 years and the annual repetition period corresponding to it (El Haj Ahmad, 2018). The parameters related to earthquake ground motion levels are given in the table below.

Table 2.10. Earthquake Ground Motion Levels according to TBEC 2018

DD	Probabilities of Exceedance in 50 years	Annual repetition period	Frequency and magnitude of earthquake
DD-1	%2	2475 years	Very rare / largest earthquake
DD-2	%10	475 years	Rare / standard design earthquake
DD-3	%50	72 years	Often
DD-4	%68	43 years	Very often / service earthquake

Seismic data for four different earthquake ground motion levels is available in the Turkey Earthquake Hazard Map, and data can be accessed from the website (https://tdth.afad.gov.tr/). The figure of the new earthquake hazard map is given in Appendix 1.

According to TBEC 2018, the map spectral acceleration coefficient for the short period of 0.2 seconds and the map spectral acceleration coefficient for 1 second period are determined with the data obtained from the map. The map spectral acceleration coefficients are multiplied by local soil effect coefficients. Finally, the design spectral acceleration coefficients are calculated (El Haj Ahmad, 2018).

$$S_{DS} = S_S . F_S \tag{2.1}$$

$$S_{D1} = S_1 . F_1 \quad (2.2)$$

Where,

S_{DS} the design spectral response acceleration coefficient at short periods

S_{D1} the design spectral response acceleration coefficient at 1-s period.

Ss the map spectral acceleration coefficient at short periods.

S_1 the map spectral acceleration coefficient at 1-s period.

Table 2-11 and Table 2-12 show the values of soil effect coefficients (F_S, F_1), depending on the S_S and S_1 values. Intermediate values of S_S and S_1 are obtained by interpolation.

Table 2.11: Soil effect coefficient, Fs, according to TBEC 2018

Soil Type	**Mapped Spectral Acceleration at Short-Periods F_S**					
	$S_s \leq 0.25$	**$S_s = 0.5$**	**$S_s = 0.75$**	**$S_s = 1.0$**	**$S_s = 1.25$**	**$S_s \geq 1.5$**
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	Soil requiring site-specific research and evaluation					

Table 2.12: Soil effect coefficient, F1, according to TBEC 2018

Soil Type	**Mapped Spectral Acceleration at One-Second Period F_1**					
	$S_1 \leq 0.1$	**$S_1 = 0.2$**	**$S_1 = 0.3$**	**$S_1 = 0.4$**	**$S_1 = 0.5$**	**$S_1 \geq 0.6$**
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	1.5	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
ZF	Soil requiring site-specific research and evaluation					

In TBEC 2018 both horizontal and vertical earthquake elastic response spectrum is defined.

2.5.1.1 Horizontal Elastic Design Spectrum

The following definitions are the horizontal elastic design acceleration spectrum defined for the 5% damping ratio (Başaran, 2018).

$$S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right) S_{DS} \quad ; \quad 0 \le T \le T_A \tag{2.3}$$

$$S_{ae}(T) = S_{DS} \quad ; \quad T_A \le T \le T_B \tag{2.4}$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \quad ; \quad T_B \le T \le T_L \tag{2.5}$$

$$S_{ae}(T) = \frac{S_{D1} T_L}{T^2} \quad ; \quad T_L \le T \tag{2.6}$$

Horizontal design spectrum corner periods T_A and T_B are defined depending on S_{DS} and S_{D1} (Koçer, Nakipoğlu, Öztürk, Al-Hagri, & Arslan, 2018).

$$T_A = 0.2\frac{S_{D1}}{S_{DS}} \tag{2.7}$$

$$T_B = \frac{S_{D1}}{S_{DS}} \tag{2.8}$$

The transition period to the fixed displacement zone T_L = 6s will be taken.

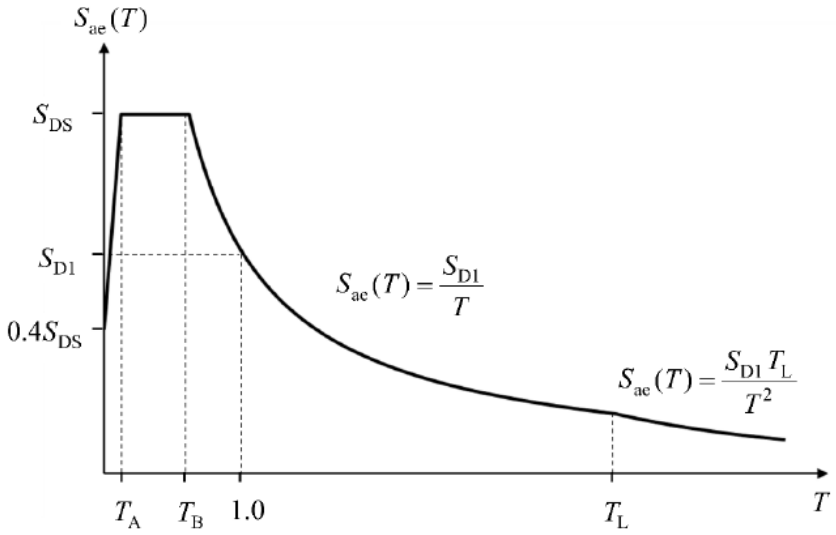


Figure 2.1: Horizontal Design Spektrum according to TBEC 2018

2.5.1.2 Vertical Elastic Design Spectrum

The following definitions are the vertical elastic design acceleration spectrum defined for the 5% damping ratio (Başaran, 2018; TBEC, 2018).

$$S_{aeD}(T) = \left(0.32 + 0.48\frac{T}{T_{AD}}\right) S_{DS} \quad ; 0 \le T \le T_{AD} \tag{2.9}$$

$$S_{aeD}(T) = 0.8S_{DS} \quad ; \quad T_{AD} \le T \le T_{BD} \tag{2.10}$$

$$S_{aeD}(T) = 0.8S_{DS}\frac{T_{BD}}{T} \quad ; \quad T_{BD} \le T \le T_{LD} \tag{2.11}$$

Corner Periods of vertical elastic design spectrum;

$$T_{AD} = \frac{T_A}{3} \quad , \quad T_{BD} = \frac{T_B}{3}, \quad , \quad T_{LD} = \frac{T_L}{2} \tag{2.12}$$

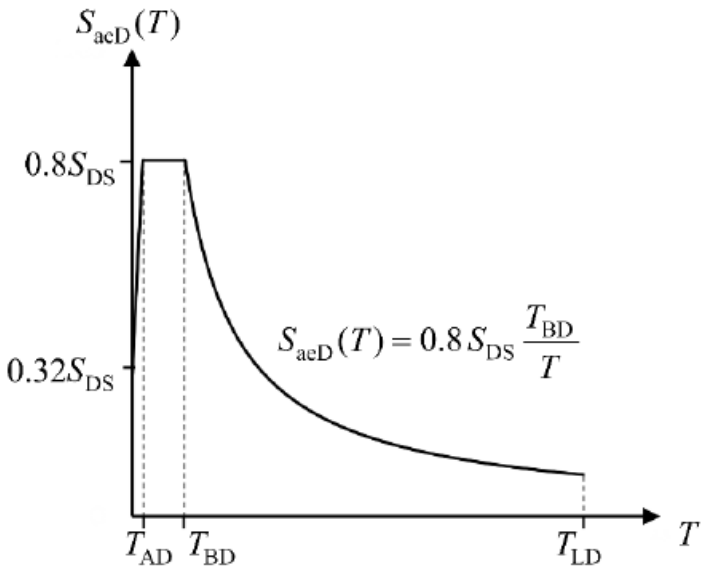


Figure 2.2: Vertical Design Spektrum according to TBEC 2018

2.5.2 Turkish Earthquake Code 2007

Earthquake loads shall be applied only in horizontal plane, unless otherwise specified in the TEC 2007. The earthquake loads shall be applied separately in X and Y directions perpendicular to each other. The design earthquake based on the code corresponds to a severe earthquake for buildings with a building importance factor of 1. The probability of exceeding this design earthquake within a period of 50 years is 10% (Aydemir, 2011).

The main coefficients for determining the earthquake loads on buildings are the Spectral Acceleration Coefficient and Earthquake Load Reduction factor (El Haj Ahmad, 2018). The spectral acceleration coefficient, A (T), which will be crucial for determination of earthquake loads, is given in equation 2.13. Elastic Spectral Acceleration, S_{ae} (T) which is the starting phase of Elastic Acceleration Spectrum defined for 5% damped rate is derived by multiplying Spectral Acceleration Coefficient with gravity, g (Kacar, 2011).

$$A(T) = A_O . I . S(T) \tag{2.13}$$

$$S_{ae}(T) = A(T) . g \tag{2.14}$$

In this expression, A_O is defined as the effective ground acceleration coefficient. The effective ground acceleration coefficient is defined in the following table according to different seismic zones. The map containing seismic zones is given in Annex 2.

Table 2.13: Effective ground acceleration coefficient according to TEC 2007

Seismic Zone	Ao
4	0.1
3	0.2
2	0.3
1	0.4

The spectrum coefficient, S (T) in the above Eq. (2.15), will be calculated by the following statements depending on the local soil conditions and the building natural period T (Gök, 2013; Koçer, Nakipoğlu, Öztürk, Al-Hagri, & Arslan, 2018).

$$S(T) = 1 + 1.5\frac{T}{T_A} \quad ; \quad (0 \le T \le T_A) \tag{2.15}$$

$$S(T) = 2.5 \quad ; \quad (T_A < T \le T_B) \tag{2.16}$$

$$S(T) = 2.5\left(\frac{T_B}{T}\right)^{0.8} \quad ; \quad (T_B < T) \tag{2.17}$$

The spectrum characteristic periods in the above given equations, T_A and T_B, are given in the table below depending on the local site classes according to the 2.3.2.

Table 2.14: Spectrum characteristic periods according to TEC 2007

Local Site Class	T_A	T_B
Z4	0.2	0.9
Z3	0.15	0.6
Z2	0.15	0.4
Z1	0.1	0.3

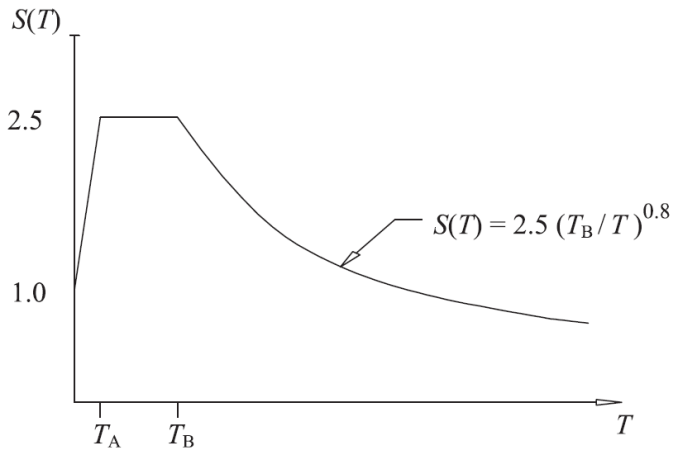


Figure 2.3: Elastic design spectrum according to TEC 2007

2.5.3 Eurocode 8

In the EC 8, as in TEC 2007, countries are divided into various earthquake zones and earthquake damage in each earthquake zone is considered to be constant. The damage is defined according to the effective maximum ground acceleration parameter (a_g) which is defined as design ground acceleration. The design ground acceleration is determined by the committee of each country by selecting an earthquake with a repetition period of 475 years per earthquake zone. For this purpose, the structure importance factor, (γ_I) = 1.0 is selected (Eurocode 8, 2004; Aydemir, 2011; Kacar, 2011).

The seismic action at any point is represented by the elastic acceleration response spectrum. This spectrum is also called the elastic response spectrum. Unlike TEC 2007, the elastic reaction spectrum of the earthquake in both horizontal and vertical directions is defined in EC 8 (El Haj Ahmad, 2018).

2.5.3.1 Horizontal Elastic Response Spectrum

The horizontal elastic response spectrum, $S_e(T)$ is defined by the following equations for the horizontal component of the seismic action (Eurocode 8, 2004; Kacar, 2011).

$$S_e(T) = a_g S\left[1 + \frac{T}{T_B}(\eta\, 2.5 - 1)\right] \qquad 0 \le T \le T_B \tag{2.18}$$

$$S_e(T) = 2.5\, a_g S\, \eta \qquad T_B \le T \le T_C \tag{2.19}$$

$$S_e(T) = 2.5\, a_g S\, \eta \left(\frac{T_C}{T}\right) \qquad T_C \le T \le T_D \tag{2.20}$$

$$S_e(T) = 2.5\, a_g S\, \eta \left(\frac{T_C T_D}{T^2}\right) \qquad T_D \le T \le 4s \tag{2.21}$$

The TB, TC, TD and S are the ground coefficients which determine the shape of the elastic response spectrum depending on the ground type. The values to be used for each type of ground and spectrum type in a country can be obtained from National Annex (Aydemir, 2011).

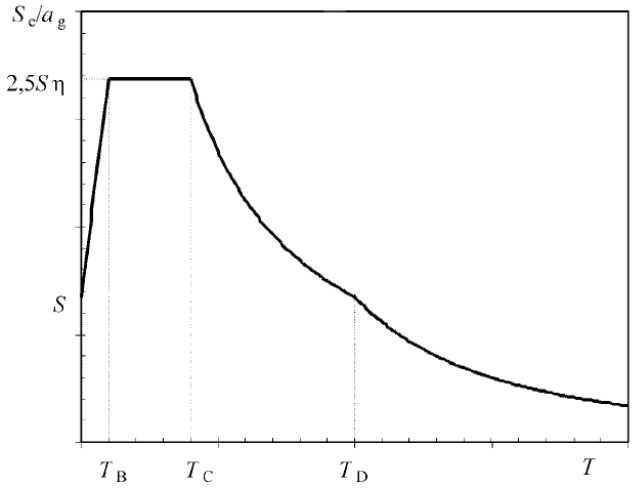


Figure 2.4: Elastic acceleration spectrum form according to EC 8.

Table 2.15: Type 1 Elastic response spectrum parameters according to EC 8

Ground Type	S	T_B	T_C	T_D
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.2	0.6	2.0
D	1.35	0.2	0.8	2.0
E	1.4	0.15	0.5	2.0

Table 2.16: Type 2 Elastic response spectrum parameters according to EC 8

Ground Type	S	T_B	T_C	T_D
A	1.0	0.05	0.25	1.2
B	1.35	0.05	0.25	1.2
C	1.5	0.1	0.25	1.2
D	1.8	0.1	0.3	1.2
E	1.6	0.05	0.25	1.2

Two different spectral shapes are recommended by EC 8 as Type 1 and Type 2. It is recommended to select the Type 1 spectrum if the earthquake surface wave magnitudes defined for a zone which are greater than 5.5 (El Haj Ahmad, 2018).

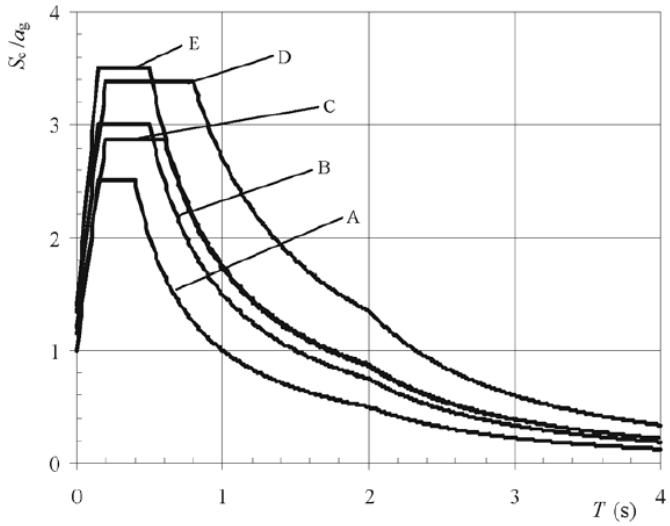


Figure 2.5: Type 1 Elastic Response Spectrum for Ground Type A to E. (%5 Damping)

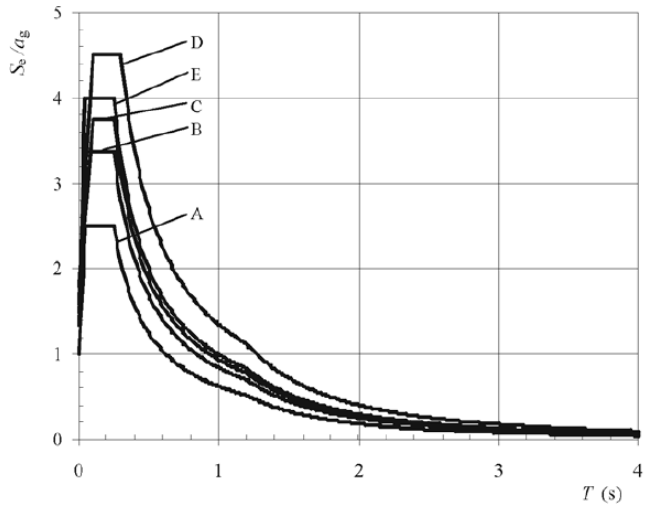


Figure 2.6: Type 2 elastic response spectrum for ground type A to E. (%5 Damping)

2.5.3.2 Vertical Elastic Response Spectrum

The vertical elastic response spectrum, $S_{ve}(T)$ is defined by the following equations for the vertical component of the seismic action (Eurocode 8, 2004).

$$S_{ve}(T) = a_{vg}\left[1 + \frac{T}{T_B}(\eta\, 3.0 - 1)\right] \quad 0 \le T \le T_B \tag{2.22}$$

$$S_{ve}(T) = 3.0\, a_{vg}\, \eta \qquad T_B \le T \le T_C \tag{2.23}$$

$$S_{ve}(T) = 3.0\, a_{vg}\, \eta \left(\frac{T_C}{T}\right) \qquad T_C \le T \le T_D \tag{2.24}$$

$$S_{ve}(T) = 3.0\, a_{vg}\, \eta \left(\frac{T_C T_D}{T^2}\right) \qquad T_D \le T \le 4s \tag{2.25}$$

Table 2.17: Vertical Elastic Response Spectrum Parameters according to EC 8

Spectrum	a_{vg}/a_g	T_B	T_C	T_D
Type 1	0.9	0.05	0.15	1.0
Type 2	0.45	0.05	0.15	1.0

2.6 Structural System Behaviour Factor and Earthquake Load Reduction Factor

2.6.1 Turkish Building Earthquake Code 2018

Structural system behaviour factor, R represents the energy absorption capacity during the non-elastic behaviour of the structure. In accordance with the TBEC 2018, elastic earthquake loads are reduced by the Structural System Behaviour Factors R which is dependent on the building's natural vibration period (T) (Asfuroğlu, 2018).

Table 2.18: Structural System Behaviour Factors according to TBEC 2018

Building Structural System	**Structural System Behaviour Factors R**	**Overstrength Factor D**	**Allowable Building Height Class BYS**
A. CAST-IN-SITE REINFORCED CONCRETE BUILDINGS			
A1. High Ductility Level Systems			
A11- Buildings in which seismic loads are fully resisted by reinforced concrete moment-resisting frames of high ductility level	8	3	BYS ≥ 3
A12- Buildings in which seismic loads are fully resisted by coupled structural walls of high ductility level	7	2.5	BYS ≥ 2
A13- Building in which seismic loads are fully resisted by solid structural walls of high ductility level	6	2.5	BYS ≥ 2
A14- Building in which seismic loads are jointly resisted by moment-resisting frames of high ductility level together with coupled structural walls of high ductility level	8	2.5	BYS ≥ 2
A15- Building in which seismic loads are jointly resisted by moment-resisting frames of high ductility level together with solid structural walls of high ductility level	7	2.5	BYS ≥ 2

The earthquake load reduction process is completed by dividing the resulting elastic earthquake load by the earthquake load reduction factor. Earthquake load reduction factor, Ra(T), is determined by the expression below (El Haj Ahmad, 2018).

$$R_a(T) = \frac{R}{I} \quad ; \quad T > T_B \tag{2.26}$$

$$R_a(T) = D + \left(\frac{R}{I} - D\right)\frac{T}{T_B} \quad T \leq T_B \tag{2.27}$$

Overstrength factor (D) for the elements which are not expected to exhibit ductile behaviour, the reduced internal forces obtained from the reduced earthquake loads with the structural system behaviour factor are increased by this coefficient. Thus, it is ensured that the brittle elements remain within the elastic limits under any circumstances. Briefly, according to the definition, it is used to express that the yield strength is higher than the design strength (Asfuroğlu, 2018).

2.6.2 Turkish Earthquake Code 2007

In order to take into account, the nonlinear behaviour of the structural system in the earthquake, the elastic seismic loads to be determined according to the spectral acceleration coefficient will be divided into the $R_a(T)$ earthquake load reduction factor. $R_a(T)$ is determined according to the following equation depending on the structural behaviour factor R and the natural vibration period T (TEC, 2007; Gök, 2013).

$$R_a(T) = 1.5 + (R - 1.5)\frac{T}{T_A} \quad ; \quad 0 \leq T \leq T_A \tag{2.28}$$

$$R_a(T) = R \quad ; \quad T_A < T \tag{2.29}$$

Table 2.19: Structural System Behaviour Factor according to TEC 2007

BUILDING STRUCTURAL SYSTEM	Systems of Nominal Ductility Level	Systems of High Ductility Level
1. CAST-IN-SITE REINFORCED CONCRETE BUILDINGS		
1.1 Buildings in which seismic loads are fully resisted by frames	4	8
1.2 Buildings in which seismic loads are fully resisted by coupled structural walls	4	7
1.3 Buildings in which seismic loads are fully resisted by solid structural walls	4	6
1.4 Buildings in which seismic loads are jointly resisted by frames and solid and / or coupled structural walls	4	7

2.6.3 Eurocode 8

The reduction of the earthquake load in the EC 8 is made directly by using the q behaviour coefficient. The values of the behaviour factor (q) are calculated by the following equation for different material and structural systems according to various ductility levels (Eurocode 8, 2004).

$$Q = q_o \,.\, k_w \geq 1.5 \qquad (2.30)$$

In the above equation, q_o indicates the basic value of the behaviour factor, dependent on the type of the structural system and on the regularity in elevation, k_w, is the factor reflecting the prevailing failure mode in structural systems with shear walls (The recommended value for k_w is 1.0) (Eurocode 8, 2004).

Table 2.20: Basic value of the behaviour factor, q_o, for systems regular in elevation

STRUCTURAL TYPE	**DCM**	**DCH**
Frame system, dual system, coupled wall system	$3.0(a_u/a_1)$	$4.5(a_u/a_1)$
Uncoupled wall system	3.0	$4.0(a_u/a_1)$
Torsionally flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

A) Frame equivalent dual system or Frames

- One-Storey Building: $(a_u/a_1) = 1.1$
- Multi-storey, one-bay frames: $(a_u/a_1) = 1.2$
- Multi-storey, multi-bay frames or frame-equivalent dual structures: $(a_u/a_1) = 1.3$

B) Wall- or wall-equivalent dual systems.

- Wall systems with only two uncoupled walls per horizontal direction: $(a_u/a_1) = 1.0$
- Other uncoupled wall systems: $(a_u/a_1) = 1.1$
- Coupled wall systems or wall-equivalent dual: $(a_u/a_1) = 1.2$

2.6.3.1 Earthquake Load Reduction Factor

The horizontal elasticity design spectrum, which is reduced by the building behaviour factor, is defined by the following relations.

$$S_d(T) = a_g . S . \left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5}{q} - \frac{2}{3}\right)\right] \quad (2.31)$$

$$S_d(T) = a_g . S . \frac{2.5}{q} \quad (2.32)$$

$$S_d(T) = a_g . S . \frac{2.5}{q} . \frac{T_C}{T} \geq \beta . a_g \quad (2.33)$$

$$S_d(T) = a_g . S . \frac{2.5}{q} . \frac{T_C T_D}{T^2} \geq \beta . a_g \quad (2.34)$$

In the above equations, $S_d(T)$, indicates design spectrum, q, indicates behaviour factor, β, represent lower bound factor (The recommended value for β is 0.20 according to EC 8) The value of the lower bound factor β can be found in National Annex (Kacar, 2011).

The elastic design spectrum described above is not sufficient for the design of structures having insulated or energy distribution systems. Specific studies and spectrum must be defined for these cases. As a result, the determination of the structural behaviour factor used in elastic earthquake load reduction is given in more general terms in EC 8 than in TEC 2007 (El Haj Ahmad, 2018).

2.7 Structural Irregularities

2.7.1 Turkish Building Earthquake Code 2018

It is known that the behaviour of buildings with irregularities is more complicated during the earthquake movements. Therefore, determining the behaviour of buildings with irregularities is important. According to TBEC 2018, structural irregularities are stated as the conditions that should be avoided due to the negativities in the structure

behaviour. The cases that cause irregularity are classified under two main headings as the conditions causing irregularity in the plan and vertical direction (Demirci, 2016; Suci, 2016).

2.7.1.1 A- Irregularities in Plan

2.7.1.1.1 A1- Torsional Irregularity

Torsional irregularity is generally due to the fact that the plan geometry or the rigidity distribution in the plan is not symmetrical in multi-storey buildings. According to TBEC 2018 the case where Torsional Irregularity Factor η_{bi}, which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum relative storey drift at any storey to the average relative storey drift at the same storey in the same direction, is greater than 1.2 (TBEC, 2018).

The torsional irregularity factor η_{bi} is calculated by the following equation.

$$\eta_{bi} = \frac{(\Delta i)_{max}}{(\Delta i)_{avr}} > 1.2 \tag{2.35}$$

$$(\Delta i)_{max} = (d_i)_{max} - (d_{i-1})_{min} \tag{2.36}$$

$$(\Delta i)_{min} = (d_i)_{min} - (d_{i-1})_{min} \tag{2.37}$$

$$(\Delta i)_{avr} = \frac{1}{2}\left[(d_i)_{max} - (d_i)_{min}\right] \tag{2.38}$$

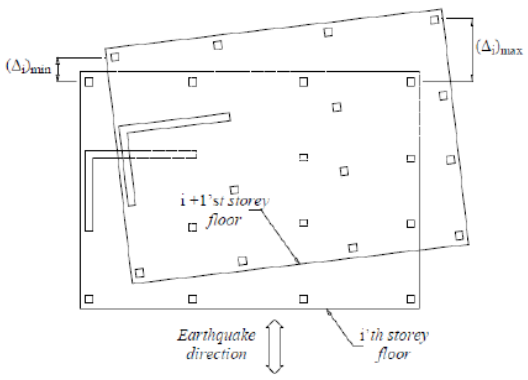


Figure 2.7: Torsional Irregularity according to TBEC 2018

The relative storey drifts will be calculated by considering the effects of ± %5 additional eccentricities. In TBEC 2018 torsional irregularity occurs when the torsional irregularity coefficient is between 1.2 and 2 values and sanction is applied to the building. In this case, ± 5% of the additional eccentricity applied on each floor is multiplied by the D_i coefficient for both earthquake directions and the new value is obtained.

$$D_i = (\frac{\eta_{bi}}{1.2})^2 \quad (2.39)$$

If the coefficient ηbi exceeds the upper limit of 2, dynamic analysis methods should be selected (Sandıkçı, 2014).

Demir A., and Dönmez D. studies, investigated the factors affecting the torsion irregularity of multi-storey buildings and factors effective in the maximum values of torsional irregularity coefficients.

- Plan geometry of the structure,
- Location of shear walls in the plan,
- Number of floors.

2.7.1.1.2 A2- Floor Discontinuities

According to TBEC 2018, it is accepted that the stiffness irregularities occurred in slabs, Slabs cannot show rigid diaphragm behaviour if the following conditions were found in the slabs in any floor.

- When the total space of the openings area, including stairs and elevator spaces, is more than 1/3 of the gross area of the floor.
- If there are local floor openings which prevent and difficult the transfer of earthquake loads safely to the vertical structural system components.

- In case of abrupt decreases in the strength and stiffness of the floor. The visual definitions related to floor discontinuity are given below.

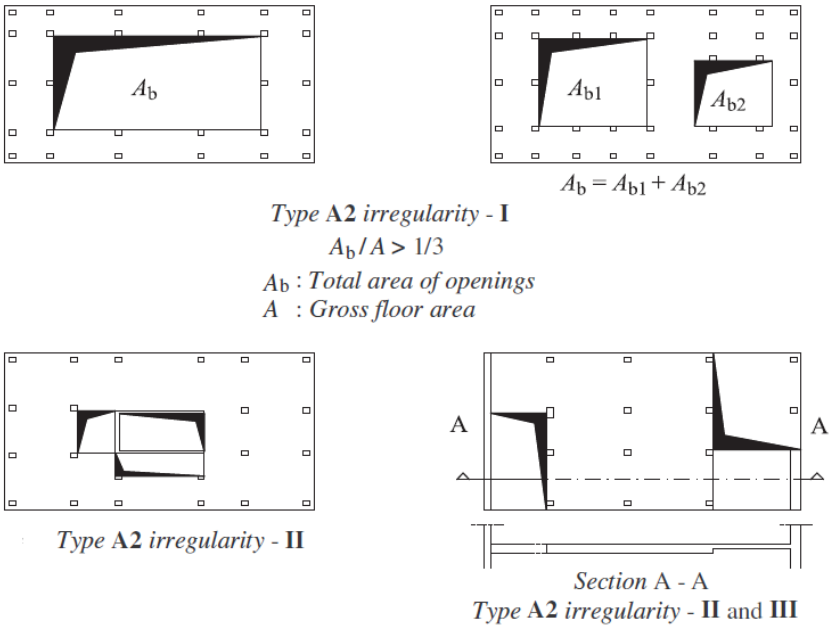
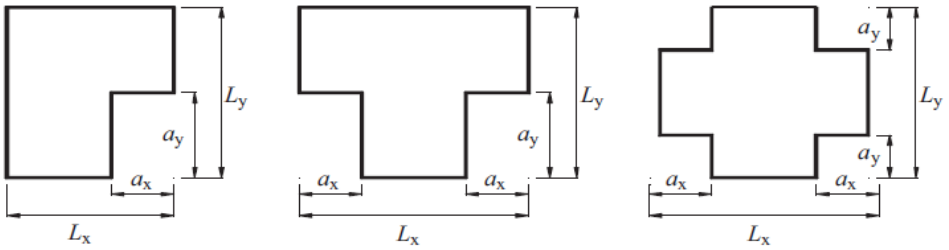


Figure 2.8: Floor Discontinuities according to TBEC 2018

2.7.1.1.3 A3- Projections in Plan

In the case of large projections in the buildings, there may occur stress accumulations in these sections of the building and the structures can be damaged by these sections (El Haj Ahmad, 2018). Therefore, the plan of the structure should be prepared with more uniform geometric shapes. If the plan of the structure is not symmetrical, the structure should be divided into symmetrical parts with dilatation joints (Sandıkçı, 2014).

In TBEC 2018 the cases where dimensions of projections in both of the two perpendicular directions in plan exceed the total plan dimensions of that storey of the building in the respective directions by more than 20%. The visual definitions related to projections in plan are given below (TBEC, 2018).



Type **A3** *irregularity:*
$a_x > 0.2\ L_x$ *and at the same time* $a_y > 0.2\ L_y$

Figure 2.9: Projections in Plan according to TBEC 2018

2.7.1.2 B- Irregularities in Elevation

2.7.1.2.1 B1- Interstorey Strength Irregularity (Weak Storey)

In case of significant changes in the strength between the storeys, low strength floor can cause damage. In TBEC 2018, it is considered that the irregularity exists in the case where the effective shear area is less than 0.80. The strength irregularity factor ηci, which is defined as the ratio of the effective shear area of any storey to the effective shear area of the storey immediately above. The coefficient of Interstorey Strength Irregularity(η_{ci}) is calculated by the following equation (TBEC, 2018).

$$\eta_{ci} = \frac{(\Sigma A_e)_i}{(\Sigma A_e)_{i+1}} < 0.8 \tag{2.40}$$

Furthermore, the effective shear area for any storey is obtained by the following equation.

$$(\Sigma A_e) = (\Sigma A_w) + (\Sigma A_g) + 0.15(\Sigma A_k) \tag{2.41}$$

In this case, the coefficient in the range 0.60 < (η_{ci}) min < 0.80, structural behaviour factor will be multiplied by 1.25 (η_{ci}) min and applied to the entire building in both earthquake directions. However, there will never be η_{ci} <0.60. Otherwise, the strength and stiffness of the weak storey shall be increased and the seismic analysis will be repeated (TBEC, 2018).

2.7.1.2.2 B2- Interstorey Stiffness Irregularity (Soft Storey)

The case where in each of the two orthogonal earthquake directions, Stiffness Irregularity Factor η_{ki}, which is defined as the ratio of the average relative storey drift at any i'th storey to the average relative storey drift at the storey immediately above or below, is greater than 2.0. The coefficient of stiffness irregularity is obtained by the following equations (Birol, 2010).

$$\eta_{ki} = [(\Delta_i)/h_i]_{avr} / [(\Delta_{i+1})/h_{i+1}]_{avr} > 2.0 \quad (2.42)$$

$$\eta_{ki} = [(\Delta_i)/h_i]_{avr} / [(\Delta_{i-1})/h_{i-1}]_{avr} > 2.0 \quad (2.43)$$

The calculation of the relative storey drifts will be calculated by taking into account the effects of ± 5% additional eccentricity (TBEC, 2018).

2.7.1.2.3 B3- Discontinuity of vertical structural elements

The cases in TBEC 2018 where vertical structural elements (columns or shear walls) are removed at some stories and supported by gusseted columns underneath or beams, or the shear wall of upper stories are supported by beams underneath or columns. In the arrangement of the structural system, there are conditions that should not be done in the vertical direction or which must be followed. In TBEC 2018, the limitations of the structural system elements in the vertical direction are stated below as to be applied in all earthquake zones (TBEC, 2018).

a) Columns should not be allowed to be placed on the cantilever beams or on top of or at the tip of gussets provided in the columns underneath.

b) In the case where a column rests on a beam which is supported at both ends, all internal force components induced by the combined effect of vertical loads and seismic loads shall be increased by 50 % at all sections of the beam and at all sections of the other beams and columns adjoining to the beam in the earthquake direction considered.

c) The shear wall on the upper floors should never be allowed to be placed on the columns below.

d) The shear walls should never be allowed to be placed on the beam span at any storey of the building.

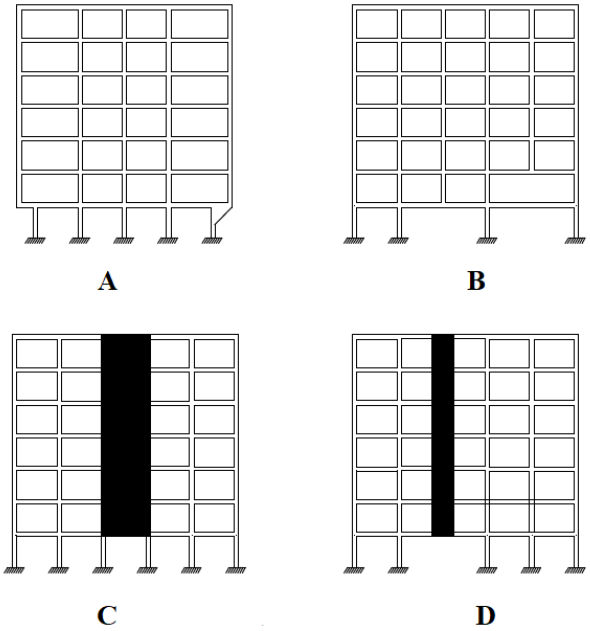


Figure 2.10: Discontinuity of vertical structural elements according to TBEC 2018.

2.7.2 Turkish Earthquake Code 2007

The irregularities defined in TEC 2007 are exactly the same as the irregularities defined in TBEC 2018. These irregularities were previously described under TBEC 2018 Structural irregularities part.

2.7.3 Eurocode 8

In terms of seismic design, structures are divided into 2 according to their regular or irregular condition. This distinction concerns the following aspects of seismic design:

- The structural model may be a simplified planar model or spatial model.
- The analysis method may be simplified by response spectrum analysis or modal.

- Definition of reduced structural behaviour factor ‘q’ for buildings with vertical irregularity.

According to the results obtained from structural irregularity in analysis and design, regularity characteristics of the building, plan and elevation are given in the table below (Aydemir, 2011).

Table 2.21: Structural Irregularity and Seismic Analysis Options of the Building according to EC 8.

Regularity		**Allowed Simplification**		**Behaviour Factor**
Plan	**Elevation**	**Model**	**Linear-Elastic Analysis**	**(For Linear Analysis)**
Regular	Regular	Planar	Lateral Force	Reference Value
Regular	Non-regular	Planar	Modal	Decreased Value
Non-regular	Regular	Spatial	Lateral Force	Reference Value
Non-regular	Non-regular	Spatial	Modal	Decreased Value

As defined in TEC 2007, the EC 8 is defined under two main headings as irregularities in plan and vertical direction.

2.7.3.1 Irregularity in Plan

- For each of the X and Y directions in the structure, the mass and stiffness should be as symmetrical as possible.
- The plan configuration shall be compact, each floor shall be delimited by a polygonal convex line. If in plan set-backs (re-entrant corners or edge recesses) exist, regularity in the plan may still be considered as being satisfied, provided that these setbacks do not affect the floor in-plan stiffness. The total size of the recesses in the earthquake direction considered in the plan should not exceed 5% of the external dimension of the plan (Eurocode 8, 2004).
- The planar stiffness of the slabs must be sufficiently large compared to the lateral stiffness of the vertical structural members. Thus, the deformation of the pavements has a small effect on the distribution of forces on the vertical

structural members. In this respect, plan forms L, C, H, I, and X should be carefully examined. In this case, the stiffness of the lateral parts must be close to the centre in order to achieve the rigid diaphragm condition (Kacar, 2011; Karasu, 2015).

- The ratio of the long size of the building in the plan to the short dimension should not exceed 4, (The slenderness of the building in plan, $\lambda = \frac{L_{max}}{L_{min}}$).
- At each level and for each direction of analysis x and y, the structural eccentricity e_{ox} and the torsional radius r_x shall be in accordance with the two conditions below, which are expressed for the direction of analysis y. (Eurocode 8, 2004)

$$e_{ox} \leq 0.3\, r_x \tag{2.44}$$

$$r_x \geq l_s \tag{2.45}$$

- Where, e_{ox}, indicates the distance between the centre of mass and centre of stiffness, $r_{x,}$ indicates the torsion radius of the floor and l_s, indicates the radius of gyration of the floor mass in plan (Aydemir, 2011).

2.7.3.2 Regularity in Elevation

In order for a structure to be classified regularly in the vertical section, it must meet the following conditions.

- The elements of the building carrying all the horizontal loads in the building must continue from the top floor of the building to the foundation continuously, without interruption.
- The bending stiffness and mass of the building should remain constant on each new floor from the foundation to the top of the building or a gradual reduction should be provided without sudden changes.

- In framed buildings, the actual strength of the floor should not change disproportionately between adjacent floors.
- When setbacks are present, the following additional conditions apply:

  a) In the case of gradual withdrawal by protecting the symmetry, the total setbacks shall not exceed 20% of the plan size of a lower floor.

  b) For a single setback that is less than 15% of the total height of the main structural system, the withdrawal ratio must not be greater than 50% of the previous plan size.

  c) If non-symmetrical floor contraction will be applied; the sum of the setbacks at all storeys will be not greater than 30 % of the plan dimension at the ground floor. The setbacks between any two layers should not exceed 10% of the size of the lower floor (Aydemir, 2011) (Karasu, 2015).

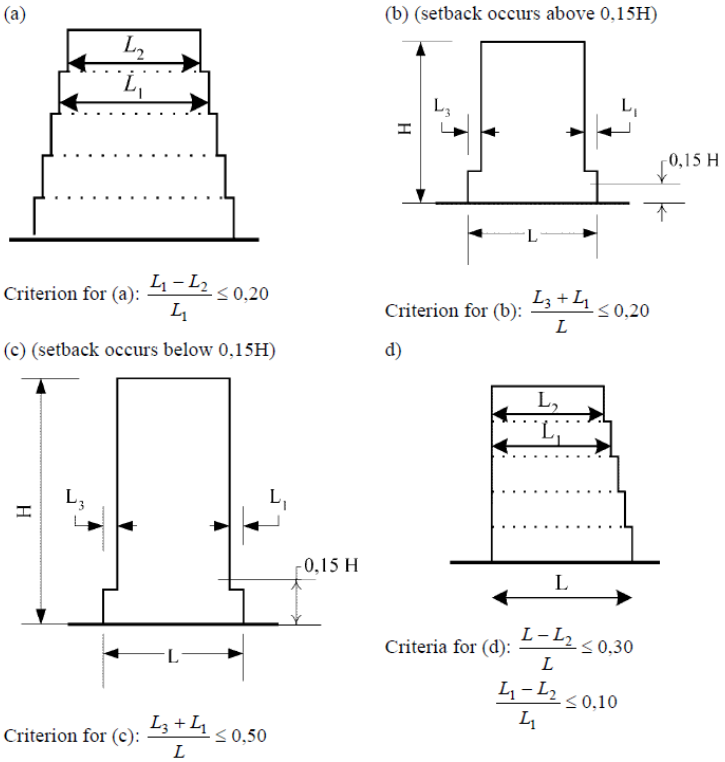


Figure 2.11: Criteria for regularity of buildings with setbacks according to EC 8

More general and less descriptive expressions of the irregularities defined in EC 8 than the irregularities defined in TBEC 2018 are given. The earthquake code expects the design engineers to take the initiative and evaluate them in practical applications.

2.8 Linear Analysis Methods

2.8.1 Turkish Building Earthquake Code 2018

The linear analysis methods to be used within the scope of Strength Based Design are Equivalent Static Analysis Method and Modal Analysis Methods. According to TBEC 2018, any of the modal analysis methods (mode superposition method, and analysis method in the time domain) can be used for the seismic analysis of all buildings. The buildings where the equivalent static analysis method can be applied are given in table below.

Table 2.22: Application limits of equivalent static analysis method according to TBEC 2018

Building Type	**Allowable Building Height Class**	
Buildings in which torsional irregularity coefficient satisfies the condition $\eta_{bi} \leq 2.0$ at every storey and at the same time without type B2 irregularity	BYS ≥ 4	BYS ≥ 5
All other buildings	BYS ≥ 5	BYS ≥ 6

2.8.1.1 Equivalent Static Analysis Method

The equivalent static analysis method, which is a static analysis method, is a simpler method compared to other dynamic analysis methods and it is preferred more than other methods in seismic analysis. The equivalent static analysis method will be applied separately for earthquakes acting on the buildings in the direction of earthquake (X) and (Y).

2.8.1.2 Modal Analysis Methods

Modal Analysis Methods based on the modal behaviour of the load bearing system under earthquake effect are divided into two groups. These are the Mode Superposition

Method based on the earthquake spectrum and the Analysis Method in the Time Domain.

2.8.1.2.1 Mode Superposition Method

The Reduced Design Acceleration Spectrum under the Horizontal Seismic Effect is calculated by the following equation.

$$S_{aR}(T) = \frac{S_{ae}(T)}{R_a(T)} \tag{2.46}$$

In this equation, $S_{ae}(T)$ shows the Horizontal Elastic Design Spektrum determined by Eq. (2.3) for DD-2 earthquake ground motion level and $R_a(T)$ shows the Seismic Load Reduction factor calculated by Eq. (2.22).

In a typical n'th vibration mode for the given earthquake direction, the *typical maximum modal behaviour magnitude*, $r_{n,max}$, corresponding to any behaviour magnitude is calculated by Equation (2.58).

$$r_{n,max} = \bar{r}_n \, S_{aR}(T_n) \tag{2.47}$$

a) Dynamic Degrees of Freedom to be considered;

In the application of this method, in buildings where the slabs work as a rigid diaphragm in the horizontal plane, three degrees of freedom are considered and the modal earthquake loads on each floor are calculated for these three degrees of freedom. However, in order to take into account, the additional eccentricity effect, earthquake loads are shifted by ± 5% of the floor dimension perpendicular to the earthquake direction and applied to the determined points. It may not work as a rigid diaphragm in the horizontal plane of the slabs where the floor discontinuity exists. In this case, the dynamic degree of freedom is not taken into account to ensure that the deformations of the slabs in their planes are taken into account.

b) Sufficient Number of Vibration Modes to be considered;

The base shear force calculated for each mode in the (X) and (Y) earthquake directions shall be determined according to the rule that the sum of the modal effective masses is not less than 95% of the total building mass. However, all modes with a contribution of more than 3% will be considered.

$$\sum_{n=1}^{YM} m_{txn} \geq 0.95 \tag{2.48}$$

c) Combination of Modal Contributions;

Rules to be applied for the statistical combination of non-simultaneous maximum contributions of response quantities calculated for each vibration mode, displacement and storey drift, internal force components, are specified below, provided that they are applied independently for each response quantity:

As the most general mode combination rule, the Complete Quadratic Combination (CQC) Rule is given in the following equation.

$$r_{max} = \sqrt{\sum_{m=1}^{YM}\sum_{m=1}^{YM} r_{m,max}\, \rho_{mn}\, r_{n,max}} \tag{2.49}$$

The cross-correlation coefficient in the above equation is calculated from the following equation if the modal damping ratios are assumed to be the same in all modes.

$$\rho_{mn} = \frac{\left(8\xi^2(1+\beta_{mn})B_{mn}^{\frac{3}{2}}\right)}{(1-\beta_{mn}^2)^2 + 4\xi^2\beta_{mn} + (1+\beta_{mn}^2)^2} \quad ; \quad \beta_{mn} = \frac{T_m}{T_n} \tag{2.50}$$

Here, β_{mn} shows the ratio of m'th and n'th natural vibration periods considered.

In the case of the β_{mn} <0.8 condition for all modes considered, the Square Root of Sum of Squares (SRSS) rule given in the following equation can be used instead of the CQC Rule.

$$r_{max} = \sqrt{\sum_{n=1}^{YM} (r_{n,max})^2} \quad (2.51)$$

2.8.1.2.2 Increasing the Reduced Internal Force and Displacement Effects According to the Equivalent Base Shear Force

In the case of $V_{tx} < \gamma_E + V_{tE}$ for any earthquake direction, all the reduced internal force and displacement magnitudes obtained by the modal analysis method are multiplied by the equivalent base shear magnification coefficient given below.

$$\beta_{tE} = \frac{\gamma E \, V_{tE}}{V_{tx}} \geq 1 \quad (2.52)$$

In the above equation, V_{tE} indicates the total equivalent static load (base shear force) calculated according to the equivalent static analysis method, and V_{tx} shows the total earthquake load in the X direction obtained by modal analysis methods. The multiplier γ_E is defined below.

In the building, if any of the irregularities A1, B2, and B3 defined in 2.7.1 are present, $\gamma_E = 0.9$ is taken. If there are no irregularities in the building, the γ_E value is assumed to be 0.8 (TBEC, 2018).

2.8.2 Turkish Earthquake Code 2007

According to this code, earthquake design is based on designing of new buildings corresponds to severe earthquake. In this earthquake code, the building importance factor (I) is accepted as 1, and the probability of exceedance within a period of 50 years is 10% (Gök, 2013; Karasu, 2015).

Methods to be used in seismic analysis of buildings and building types are divided into two as Equivalent Static Analysis Method and Modal analysis methods (Mode

Superposition Method, Analysis method in the time domain). Dynamic analysis methods can be used for the seismic analysis of all buildings.

2.8.2.1 Equivalent Static Analysis Method

In this method, the earthquake load is calculated as a single force for the whole structure. Total equivalent static load is expressed as the sum of the equivalent earthquake loads acting on the floors in a triangular shape along with the height of the structure.

All of the earthquake forces acting on the structure, and the shear forces occurring in the vertical structural elements at the lowest level of the structure are balanced in the horizontal direction. The sum of the shear forces of the vertical structural elements defined as the Base Shear Force forms a force pair with the total equivalent static load. This method is the easiest to apply compared to other methods. However, in order to apply the equivalent static analysis method, the building must meet the conditions given below (Kacar, 2011; Karasu, 2015).

Table 2.23: Applicability criteria for equivalent static analysis method according to TEC 2007

Seismic Zone	Building Type	Total Height Limit
1, 2	Buildings where the torsional irregularity factor at each floor provides the condition n_{bi} >2.	$H_N \leq 25m$
1, 2	Buildings where the coefficient of torsional irregularity at each floor provides the condition n_{bi} >2 and also there are no B2 type irregularities.	$H_N \leq 40m$
3, 4	All buildings.	$H_N \leq 40m$

2.8.2.2 Modal Analysis Methods

In this method, the structure behaviour (internal forces and displacements) is obtained by the statistical combination of a sufficient number of natural free vibration modes

with the maximum contribution after individual analysis. The analysis technique of the method is based on fully elastic behaviour (Özyer, 2016).

2.8.2.2.1 Mode Superposition Method

The ordinates of the reduced acceleration spectrum to be taken as a basis in the Mode Superposition Method, are obtained from the following equation taking into account any N'th vibration mode.

$$S_{aR}(T_n) = \frac{S_{ae}(T_n)}{R_a(T_n)} \tag{2.53}$$

a) Dynamic Degrees of Freedom to be considered

There is no change in the determination of the dynamic degrees of freedom to be considered which is similar to TBEC 2018.

b) Sufficient Number of Vibration Modes to be considered:

The base shear force calculated for each mode in the (X) and (Y) lateral earthquake directions shall be determined according to the criterion that the sum of the modal effective masses is not less than 90% of the total building mass (Özyer, 2016; El Haj Ahmad, 2018).

$$\sum_{n=1}^{Y} M_{xn} = \sum_{n=1}^{Y} \frac{L_{xn}^2}{M_n} \geq 0.9 \sum_{i=1}^{N} m_i \tag{2.54}$$

$$\sum_{n=1}^{Y} M_{yn} = \sum_{n=1}^{Y} \frac{L_{yn}^2}{M_n} \geq 0.9 \sum_{i=1}^{N} m_i \tag{2.55}$$

The calculations for L_{xn} and L_{yn} and M_n in the Eq. (2.54, 2.55) are given in the equation below for the buildings where floors behave as rigid diaphragms.

$$L_{xn} = \sum_{i=1}^{N} m_i \Phi_{xin} \quad ; \quad L_{yn} = \sum_{i=1}^{N} m_i \Phi_{yin} \tag{2.56}$$

$$M_n = \sum_{i=1}^{N} (m_i \Phi_{xin}^2) + (m_i \Phi_{yin}^2) + (m_{\Phi i} \Phi_{\Phi in}^2) \quad (2.57)$$

c) Combination of Modal Contributions

All rules related to the Combination of Modal Contributions are similar to the TBEC 2018. The application of the method is fully applicable to this earthquake code.

2.8.2.2.2 Increasing the Reduced Internal Force and Displacement Effects According to The Equivalent Base Shear Force

In the case of $V_{tB} < \beta V_t$ for any earthquake direction, all the reduced internal force and displacement magnitudes obtained by the modal analysis method are multiplied by the equivalent base shear magnification coefficient given below.

$$B_D = \frac{\beta V_t}{V_{tB}} B_B \quad (2.58)$$

In the building, if any of the irregularities A1, B2, and B3 defined in 2.7.1 are present, β = 0.90 is taken. If there are no irregularities in the building, the β value is assumed to be 0.80.

2.8.3 Eurocode 8

Depending on the structural properties of the structure, two types of linear elastic analysis method are described in this section which are Modal Response Spectrum Analysis and Lateral Force Method of Analysis.

2.8.3.1 Lateral Force Method of Analysis

This type of analysis method, in each direction, considered; it can be applied in buildings where the participation of vibration modes is not significantly higher than the primary vibration mode. In addition to this rule, the conditions of vertical regularity specified in the previous pages must be met and the primary vibration periods T_1 in both major directions must remain within the following limit (Asfuroğlu, 2018; El Haj Ahmad, 2018).

$$T_1 < 0.4\ T_c \quad ; \quad T_1 < 2s \tag{2.59}$$

T_c indicates, the upper period boundary of the region corresponding to constant acceleration in the elastic spectrum (Eurocode 8, 2004).

Modal analysis methods should be selected for the building seismic analysis which does not provide any of the conditions (El Haj Ahmad, 2018).

2.8.3.2 Modal Response Spectrum Analysis

The ordinates for the reduced acceleration spectrum, $S_d(T)$, to be taken as a basis in the modal response spectrum analysis are obtained by considering any n'th vibration mode (Aydemir, 2011).

2.8.3.2.1 Determining the Number of Modes to Take into Account

In determining the number of modes to be taken into account in the modal response spectrum analysis, the effective masses should not be less than 90% of the total building mass. Otherwise, it should be noted that the effective mass of each mode is greater than 5% of the total building mass. If these conditions are not satisfied, the number of modes to be considered in the accounts is calculated as stated in the following equation.

$$k \geq 3\sqrt{n} \tag{2.60}$$

$$T_k \leq 0.2s \tag{2.61}$$

In the above equations, k, indicates the number of modes taken into account, T_k, indicates the period of the vibration of mode k, and n, indicates the number of storeys above the foundation (El Haj Ahmad, 2018).

2.8.3.2.2 Combination of Modal Responses

In the combination of modal responses, the SRSS rule can be applied if the T_j/T_i ratio <0.90 condition is satisfied, with two different vibration modes T_j and T_i. The following equation calculates the earthquake effect.

$$E_E = \sqrt{\sum E_{Ei}^2} \tag{2.62}$$

In the above equation, E_{Ei} indicates the value of this seismic action effect due to the vibration mode *i*, and $E_{E,}$ indicates the seismic action effect under consideration.

In case the Tj / Ti ratio <0.90 condition is not satisfied, the CQC method is applied. In addition to these, the base shear force calculated for both directions of the earthquake shall not be less than 80% of the base shear force obtained as a result of the Lateral Force Method. If this condition is not satisfied, the base shear force calculated by the Modal Response Spectrum Analysis must be increased proportionally to satisfy the 80% requirement (El Haj Ahmad, 2018).

2.9 Summary of Comparison

In summary, although the results of the seismic analysis do not have significant changes, there are some distinctive differences between Turkish Earthquake Codes (2018 and 2007) and Eurocode 8. Firstly, regarding the general principles and rules examined in chapter 2, in a general aspect all three codes have the same goal; the protection of human lives, the limitation of damage to the structures in the event of occurrence of a reference earthquake.

There is no change in the statistical parameters based on standard design earthquake ground motion in the new TBEC 2018 compared to the TEC 2007, and as in the 2007 earthquake code, an earthquake movement with a % 10 probability of exceedance in

50 years and a repetition period of 475 years is defined. Eurocode 8, the standard design earthquake ground motion is similar to the other two earthquake codes, and for buildings with building importance coefficient $\gamma = 1$, the probability of exceeding within a period of 50 years is 10%.

In the TEC 2007, four soil groups for different soil types and four soil classes are defined depending on the floor layer height of these groups. In TEC 2007, soil spectrum characteristic periods are determined according to soil classes. Seven soil types are defined in EC 8 and spectrum characteristic periods are determined for the first five soil types which are considered to be robust. TBEC 2018 defines six soil classes belonging to the same definitions and determines the soil spectrum characteristic periods according to the first five types. Site-specific surveys and assessments are mandatory for the last soil class, which is the worst soil type to be valid in all earthquake codes, and a special earthquake ground motion spectrum is required depending to site-specific surveys. It is seen that TEC 2007 distances from realistic solutions because it determines the soil classes as simple and easier than other codes.

When the building importance coefficients of the codes examined, they are similar in general terms, but there are slight changes in the coefficients. The most striking point is that the importance coefficient for some buildings in EC 8 is taken as 0.8, as other codes do not have a building coefficient of less than 1.0. Moreover, according to TEC 2007, the building importance coefficient, which was 1.4 for buildings such as schools, dormitories, museums, penitentiaries, was increased to 1.5 in TBEC 2018. As a result of the increase in the coefficient, it is seen that the earthquake load that will affect such buildings and thus the building safety is increased.

TBEC 2018 includes new design criteria for the classification of structures not found in the previous TEC 2007. With more detailed classifications such as BKS, BYS, and DTS, it is possible to perform the designing stages in TBEC 2018 by considering different aspect of design compared to TEC 2007. These innovations enable the capacity design to be implemented more effectively.

In TEC 2007 and EC 8, the elastic earthquake load is defined according to the earthquake zones, while in TBEC 2018, is made according to the spectral information determined according to the coordinates of the location where each structure will be built. Thus, it shows that elastic earthquake loads are determined more accurately in TBEC 2018 compared to the other two earthquake codes. Furthermore, all three codes which are mentioned in this thesis are defined with elastic response spectra curves with the same %5 damping but with slightly different approach.

The reduction of elastic seismic loads is carried out according to the behaviour coefficient, which depends on the type of structural system of the structure. The determination of the load-bearing system types is made in EC 8 without going into too much detail. According to the definitions, EC 8 proposes lower structural system behaviour coefficients in almost all types of structures compared to other earthquake codes. As a result of the less structural system behaviour coefficients, designs according to EC 8 are safe but they are not economical. On the other hand, in TBEC 2018, closer and more comprehensive types of load-bearing systems and structural behaviour coefficients are defined compared to the other two codes. As a result of these comprehensive types of structural systems, the TBEC 2018 makes it more functional in terms of design and seismic analysis.

Although the guiding principles of conceptual design are reasonably the same, there are some differences between three codes in terms of its application. Both Turkish earthquake codes are exactly the same in terms of definitions of irregularity types and coefficients used in the determination of the irregular type of buildings. According to TBEC 2018 irregularities were divided into two different categories as irregularities in the plan and irregularities in the elevation. By defining a coefficient for each type of irregularity, the determination of the irregularities was made obligatory and, when it is necessary, it was compulsory to apply limitation. In EC 8, type of irregularities is given in more general terms than in other codes, and there is little detail on how to perform irregularity checks and what to do in case of irregularities. According to EC 8, classification of non-regular in elevation requires the use of modal analysis, and leads to a reduced q factor.

Lastly, the basis of seismic analysis, which is valid in the three earthquake codes is strength-based design. In this design approach, earthquake forces are reduced with a behaviour coefficient depending on the structural characteristics and analysis is made with linear analysis methods. The design of the building is completed by comparing the resulting demands and element capacities. However, all three codes seem to have slightly different seismic analysis procedures. All codes apply ±5 % additional eccentricity in each direction in order to account for uncertainties in the location of mass in the seismic motion.

Chapter 3

NON-LINEAR EVALUATION PROCEDURE ACCORDING TO TBEC 2018

3.1 Introduction

The purpose of the analysis under the influence of earthquake loads is to ensure the safety of people's lives and property. Therefore, preventing the collapse of the building or avoiding irreparable damaging in the residential building is the main reason for these analyses.

According to the existing earthquake codes, the structures are designed and projected to pass a design earthquake at least once in their lifetime. Linear analysis methods are far from giving a clear idea of the state of the structure after the earthquake. Therefore, nonlinear analysis methods which are more realistic solution method about earthquake behaviour and taking into account the elasto-plastic behaviour of the structure have begun to be preferred over linear analysis methods.

The aim of the pushover analysis is to evaluate the earthquake performance of the structural system, and determining the strength and deformation demand of the structure with inelastic static analysis and comparing this demand to the capacities of the expected earthquake performance levels. In the evaluation of the analysis, the specified performance values (Continuous Usage, Limited Damage, Controlled Damage, Collapse Prevention and Collapse Level) are taken as reference. The analysis

is continued until the performance value determined in the analysis stage is reached and thus the yield strength and failure conditions of all the elements or the whole structure and the change of the capacity curve of the whole structure are obtained.

Rules of analysis to be used in the assessment of performances in the building-type structures according to TBEC 2018 in seismic zones under the impact of earthquake forces are defined in this chapter.

3.2 Data Collection from Buildings

In order to determine the capacities of the structural system elements of existing buildings and to evaluate the earthquake resistance, information on the element size and details, structural system geometry and material properties are required. This information will be obtained from the projects and reports of the buildings.

3.2.1 Levels of Information

According to the scope of the data obtained from the examination of the buildings concerning the existing situation, information level for each building type, and consequently, the information level coefficients mentioned in TBEC 2018 are defined. The levels of information are classified as comprehensive and limited. The obtained information level is used in determining the structural element capacities.

Table 3.1: Information Level Coefficient for buildings according to TBEC 2018

Information Level	**Information Level Coefficient**
Limited	0.75
Comprehensive	1.0

3.2.1.1 Limited Information Level in Reinforced Concrete Buildings

The plan of the structural system of the building will be obtained by the fieldwork. In case the architectural projects are present, these can be used as aids to the works for preparation of measured drawings. The information obtained should include the location and material of all reinforced concrete elements and non-bearing walls on each floor, axis openings, heights and dimensions and should be sufficient for the creation of an analysis model for the building (TBEC, 2018).

3.2.1.2 Comprehensive Information Level in Reinforced Concrete

Reinforced concrete projects for the building are present. Compliance with the projects of the actual geometry is checked with the measurements performed in the building. If significant differences exist between projects and measurements, then the project is ignored. If there is no project for the reinforced concrete building, then the sketches of the building system will be obtained by the fieldwork (TBEC, 2018).

3.3 Confined and Unconfined Concrete Models

The following tensile-deformation correlations are described for confined and unconfined concrete in order to be used in performance evaluation with nonlinear methods when no other model is selected.

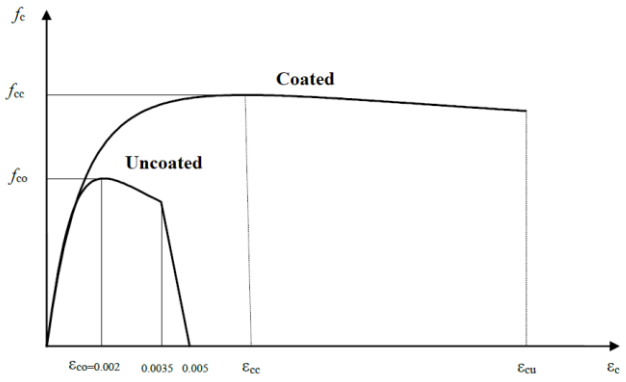


Figure 3.1: The compression - deformation correlations for Confined and Unconfined concrete (TBEC, 2018).

The concrete compressive stress in concrete f_c, is given with the following correlation as the function of compressive unit deformation ε_c.

$$f_c = \frac{f_{cc}\, x\, r}{r - 1 + x^r} \tag{3.1}$$

Here, f_{cc} indicates unconfined concrete strength, f_{co} indicates concrete pressure strength in non-confined concrete, x and r indicates the normalized concrete unit deformation relations.

The relation between unconfined concrete strength (f_{co}), and confined concrete strength (f_{cc}) in this correlation is given in below equation.

$$f_{cc} = \lambda_c f_{co} \quad ; \quad \lambda_c = 2.254\sqrt{1 + 7.94\frac{f_e}{f_{co}} - 2\frac{f_e}{f_{co}}} - 1.254 \tag{3.2}$$

The effective confining pressure (f_e) here can be taken as the average of the values given in below equation for two perpendicular directions in rectangular sections.

$$f_{ex} = k_e\, \rho_x\, f_{yw} \quad ; \quad f_{ey} = k_e\, \rho_y\, f_{yw} \tag{3.3}$$

Here, f_{ex} and f_{ey} refers to two perpendicular directions relations of effective confining pressure in rectangular sections.

In these correlations, ρ_y and ρ_x show the volumetric ratios of the transverse reinforcement in the relevant directions, f_{yw} show the yield stress of the transverse reinforcement, whereas k_e indicates confining performance factor as defined below.

$$k_e = \left(1 - \frac{\sum a_i^2}{6 b_o h_o}\right)\left(1 - \frac{s}{2b_o}\right)\left(1 - \frac{s}{2h_o}\right)\left(1 - \frac{A_s}{b_o h_o}\right)^{-1} \tag{3.4}$$

Here, A_s indicates area of longitudinal reinforcement, b_o and h_o indicates the section sizes remain among the axes of hoops that confines the core concrete, a_i indicates the distance between the axis of vertical reinforcements in the periphery of section, s

indicates the distance between the axes of hoops in vertical direction. Correlations concerning x and r variable of normalized concrete unit deformation in Eq. (3.1) are given below.

$$x = \frac{\varepsilon_c}{\varepsilon_{cc}} \quad ; \quad \varepsilon_{cc} = \varepsilon_{co}[1 + 5(\lambda_c - 1)] \quad ; \quad \varepsilon_{co} \cong 0{,}002 \tag{3.5}$$

$$r = \frac{E_c}{E_c - E_{sec}} \quad ; \quad E_c \cong 5000\sqrt{f_{co}} \ \ [\text{MPa}] \quad ; \quad E_{sec} = \frac{f_{cc}}{\varepsilon_{cc}} \tag{3.6}$$

Maximum compressive unit deformation in confined concrete $\mathcal{E}cu$ is given below.

$$\varepsilon_{cu} = \frac{0.004 + 1.4\,\rho_s\, f_{yw}\, \varepsilon_{su}}{f_{cc}} \tag{3.7}$$

Here, ρ_s indicates the total volumetric area of transverse reinforcement (in rectangular sections $\rho_s = \rho_x + \rho_y$), $\mathcal{E}su$ indicates the unit deformation due to strain under maximum tensile in transverse reinforcement steel.

3.4 Reinforcement Model

In order to use in the performance evaluation with non-linear methods, the following tensile-deformation correlations are defined for reinforcement steel.

$$f_s = E_s \varepsilon_s \quad ; \quad (\varepsilon_s \le \varepsilon_{sy}) \tag{3.8}$$

$$f_s = f_{sy} \quad ; \quad (\varepsilon_{sy} < \varepsilon_s \le \varepsilon_{sh}) \tag{3.9}$$

$$f_s = f_{su} - (f_{su} - f_{sy})\frac{(\varepsilon_{su} - \varepsilon_s)^2}{(\varepsilon_{su} - \varepsilon_{sh})^2} \quad ; \quad (\varepsilon_{sh} < \varepsilon_s \le \varepsilon_{su}) \tag{3.10}$$

Here, f_s indicates stress in reinforcing steel, ε_s indicates yield unit deformation of reinforcement steel in the beginning of strain hardening, f_{sy} indicates yield strength of reinforcing steel, f_{su} indicates the fracture strength of reinforcing steel.

The elasticity modulus of reinforcement steel is $E_s = 2x10^5\ MPa$. Further information about different reinforcement steel is given in the table below.

Table 3.2: Information about reinforcement steels according to TBEC 2018

Quality	f_{sy}(Mpa)	ε_{sy}	ε_{sh}	ε_{su}	f_{su} / f_{sy}
S220	220	0.0011	0.011	0.12	1.20
S420	420	0.0021	0.008	0.08	1.15 –1.35
B420C	420	0.0021	0.008	0.08	1.15 – 1.35
B500C	500	0.0025	0.008	0.08	1.15 – 1.35

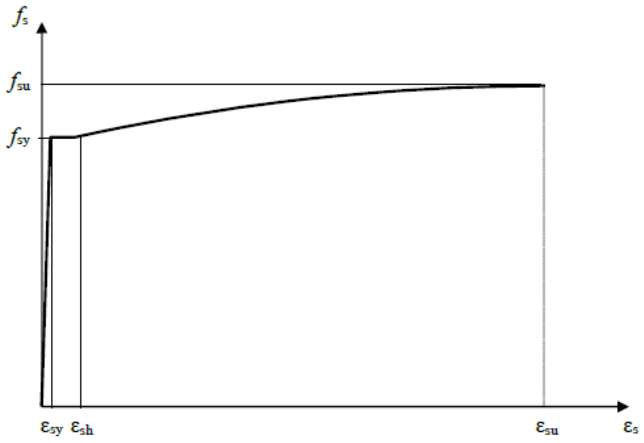


Figure 3.2: Stress-strain curve for reinforcing steel (TBEC, 2018).

3.5 Areas of Damage and Limits of Damage in Structural Elements

Three damage status and damage limits are defined for ductile elements on the cross section. These are Limited Damage (LD), Controlled Damage (CD), and Pre-Collapsing Damage (PC) states and their limit values. Limited Damage limit defines the beginning of the behaviour beyond elasticity, Controlled Damage defines the limit of the behaviour beyond elasticity that the section is capable of safely ensuring the strength, and Pre-Collapsing Damage defines the limit of the behaviour before collapsing. This classification is not valid for elements damaged in a brittle condition (TBEC, 2018).

3.5.1 Sectional Damaged Areas

Elements that the damages with critical sections do not reach LD are within the Limited Damage Region, those in-between LD and CD are within Marked Damage

Region, those in-between CD and PC are in Advanced Damage Region, and those going beyond PC are within Collapsing Region.

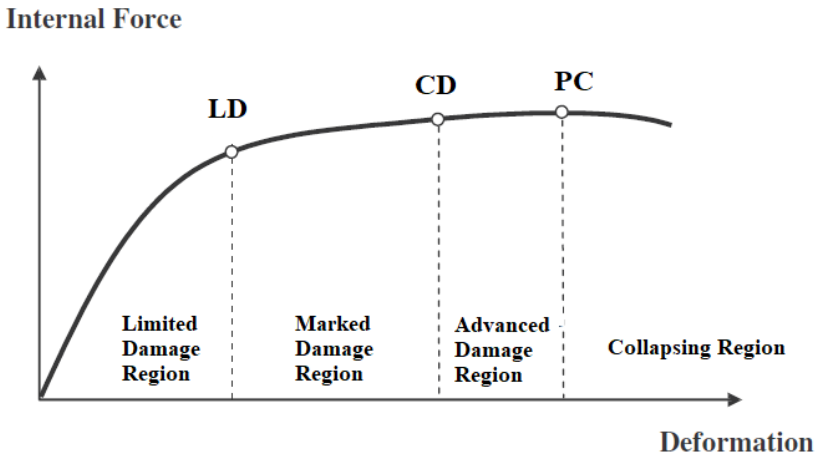


Figure 3.3: Sectional Damaged Areas (TBEC, 2018).

3.5.2 Section Unit Deformation Capacities of Reinforced Concrete Components

In order to be used in the performance evaluation for Collapse Prevention (CP) Performance Level, the total permissible limits in the concrete and reinforcement steel unit deformation of the new reinforced concrete building elements according to the plastic hinge behaviour model given in this section.

For Collapse Prevention upper bounds of the concrete unit pressure deformation: Rectangular columns, beams and shear wall.

$$\varepsilon_C^{(CP)} = 0.0035 + 0.04\sqrt{\omega_{we}} \leq 0.018 \tag{3.11}$$

The reinforcement steel unit deformation volitions:

$$\varepsilon_s^{(CP)} = 0.4\varepsilon_{su} \tag{3.12}$$

Here, ε_{su} shows the unit elongation which corresponds to tensile strength (Table 3.2).

The values to be used in the performance evaluation for the Controlled Damage (CD) Performance Level are defined based on the values defined for the level of performance of the Collapse Prevention.

For Section Controlled Damage (CD), per bounds of the concrete unit pressure deformation in the outmost fibre of hoop and the reinforcement steel unit deformation volitions.

$$\varepsilon_C^{(CD)} = 0.75\varepsilon_C^{(CP)} \quad ; \quad \varepsilon_S^{(CD)} = 0.75\varepsilon_S^{(CP)} \tag{3.13}$$

For Section Limited Damage Boundary (LD), upper bounds of the concrete unit pressure deformation in the outmost fibre of the section and the reinforcement steel unit deformation volitions:

$$\varepsilon_C^{(LD)} = 0.0025 \quad ; \quad \varepsilon_S^{(LD)} = 0.0075 \tag{3.14}$$

3.6 General Principles and Rules Related to Earthquake Damage

According to TBEC 2018, the purpose of the seismic damage analysis is to determine the earthquake performance of existing and reinforced buildings. For this purpose, the linear elastic or non-linear analysis methods defined in TBEC 2018 can be used. However, the performance evaluations of these methods based on different theoretical perceptions should not be expected to give the same results. The general principles and rules for nonlinear analysis method are described in this section.

- In the definition of the earthquake effect, the horizontal elastic design spectrum given for the determined earthquake ground motion levels will be used. Building Importance Factor will not be applied in the seismic analysis (I = 1.0).

- The seismic performance of buildings will be evaluated under the combined effects of vertical loads and earthquake effects on the building. The masses will be defined according to TBEC 2018.
- Seismic forces will be applied to both sides of the building in both directions, individually.
- The load-bearing system model of the building will be prepared with sufficient accuracy to calculate the internal force, deformations and translocations that will arise in the structural components due to the seismic effects and the collective effects of the vertical loads.
- For the buildings where the slabs act as rigid diaphragms on the horizontal axis, two horizontal translocation per floor and independence levels for the rotations around the horizontal axis will be considered. Independence levels of the floors will be defined for the centre of mass of each floor and additional eccentricity will not be applied.
- The ambiguities regarding the structural systems of the existing buildings will be reflected in the analysis methods by the information level coefficients defined in 3.2 in accordance with the scope of the information gathered regarding the building.
- Conditions for the definition of the interaction diagrams of the reinforced concrete sections under uniaxial or biaxial bending and axial force effects are given below:

    a) For concrete and reinforcing steel, the current strengths defined in the collection of information from buildings in the earthquake code are used.

b) The maximum unit deformation of the reinforcement steel is 0.01 and the maximum pressure unit deformation of the concrete is 0.0035.

c) Interaction diagrams can be modelled as multi-line or multi-axis diagrams by properly linearizing.

- In the definition of the component sizes of the reinforced concrete systems, confinement zones can be considered as infinitely rigid end zones.
- Active bending rigidities of the cracked section shall be used for the reinforced concrete components under the bending effect.
- Platform concrete and the reinforcements in the platform can be included in the analysis of positive and negative plastic momentums of the beams with reinforced concrete platforms.
- In the section capacity calculation in case of the reinforced concrete components with insufficient coupling or splicing length, yield tensile of the related reinforcement can be diminished by the amount of the shortage in the coupling and splicing length.

3.7 Seismic Analysis with Non-Linear Analysis Methods

3.7.1 Pushover Methods

As in all non-linear analysis methods, in the initial step of the calculation (step 0), the non-linear incremental static analysis is performed under non-earthquake loads. The internal forces and deformations obtained from this analysis will be considered as the initial values in the seismic analysis. Non-linear deformation of vertical loads in new buildings is not permitted.

As a result of the evaluation with pushover methods, plastic deformations which exhibit ductile behaviour, the internal forces corresponding to non-ductile (brittle) behaviour are compared with the allowable limit values for the selected performance level.

3.7.1.1 Single-Mode Pushover Method

In order to apply Single-Mode Pushover Methods, it is mandatory to provide both of the conditions given in below.

- The coefficient of torsional irregularity calculated on the basis of linear elastic behaviour without any additional eccentricity in any of the floors must provide $\eta bi < 1.4$ condition.
- Moreover, in accordance with the earthquake taken into consideration, the ratio of the effective shear force mass of the primary (dominant) vibration mode calculated taking the linear elastic behaviour as a basis point to the total mass of the building should be at least 0.70.

The aim of the Single-Mode Pushover Methods is implementing the non-linear pushover analysis under the effect of seismic loads that are gradually increased in a monotonic way up to the seismic volition threshold provided that it shall be proportional to the vibration mode type of the primary. In each step of the pushover analysis following the vertical load analysis, plastic deformation and internal force increments and cumulative values of these increments, the translocation and finally the maximum values corresponding to the seismic volition shall be calculated.

In the buildings where floor slabs are idealized as rigid diaphragms, two perpendicular horizontal drifts in the centre of mass of each floor and the rotation around the vertical

axis passing through the centre of mass shall be considered as the magnitudes of the primary (dominant) natural vibration mode shapes (TBEC, 2018).

3.7.1.2 Constant Single-Mode Pushover Method

During incremental pushover analysis, the distribution of the seismic load can be assumed to remain constant, independent of the plastic section formations in the load-bearing system. By means of the pushover analysis conducted in accordance with the constant load distribution, the pushover curves the coordinates of which are "top translocation – ground shear force" shall be obtained. With the help of the coordinate transformation applied to the pushover curve, the modal capacity diagram the coordinates of which are "modal translocation – modal acceleration" can be obtained.

In the final stage of the analysis, this diagram is based on the analysis of the modal displacement demand under the defined earthquake effect and the internal force and plastic deformation demands of the structural system (TBEC, 2018).

3.7.1.3 Variable Single-Mode Pushover Method

In the Variable Single-Mode Pushover Method, the earthquake load increases acting on the floors in the earthquake direction considered and the floor displacement increments that are compatible with them will be applied at each push step after out of seismic loads and the mode shapes will be calculated. Mode shapes are defined as proportional to the variable mode shape obtained from the renewed free vibration assessment by taking into consideration the previously formed plastic joints. In this method, the modal capacity diagram is obtained directly without drawing the pushover curve mentioned in the previous section (TBEC, 2018).

3.7.2 Multi-Mode Pushover Method

The Multi-Mode pushover method is equivalent to the multimodal application of the Single-Mode Pushover Method. The most significant disadvantage of conducting pushover analysis using the Single-Mode Pushover Method explained in previous section is the assumption proposing that the seismic behaviour of the load-bearing system is solely composed of the behaviour in the primary (dominant in the seismic direction) natural vibration mode. Due to this reason, the applicability of the method is limited to the few-floor buildings and the buildings that are symmetric or nearly symmetric to the seismic direction according to the plans. Although various pushover analysis methods that can be applied to the buildings that does not satisfy these conditions as they consider multiple vibration modes are proposed, the majority of these deal only with determining the global strength and deformation capacities of the load-bearing system. There are a limited number of methods that aim at deriving the volition values required to make performance evaluation under the effect of a certain earthquake (TBEC, 2018) (Aydınoğlu, 2003). By means of the Multi-Mode Pushover Methods, the contributions of individual modes to the formation of each plastic section can be considered in the pushover analysis, and the plastic rotations and internal force volitions can directly be derived without requiring any additional analysis (Chopra & Goel, 2002).

3.8 Determination of Nonlinear Spectral Displacement

Obtaining the modal displacement demand of the earthquake corresponds to the analysis of the maximum displacement of the modal single degree of freedom (SDOF) system represented by the modal capacity diagram under the given earthquake effect.

In a modal SDOF system, the maximum displacement is defined as nonlinear spectral displacement according to the following equation.

$$d_{1,max} = S_{di}(T_1) \tag{3.15}$$

Nonlinear spectral displacement, $S_{di}(T_1)$, in the first step of the pushover analysis, shall be obtained with the equation below depending on the linear elastic spectral displacement $S_{di}(T_1)$ which corresponds to T_1 beginning period regarding the first (dominant) mode calculated as based on linear elastic behaviour.

$$S_{di}(T_1) = C_R S_{de}(T_1) \tag{3.16}$$

Here, $S_{de}(T_1)$ represents the elastic design spectral displacement and C_R represents the spectral displacement ratio. C_R is defined in the following equation.

$$C_R = \frac{\mu(R_y, T_1)}{Ry} \tag{3.17}$$

Here, Ry, which shows the yield strength reduction factor, refers to a magnitude dependent on the yield strength directly obtained from the pushover analysis.

$$Ry = \frac{f_e}{f_y} = \frac{S_{ae}(T_1)}{a_{y1}} \tag{3.18}$$

In accordance with the Equal Displacement Rule, the ductility demand of the earthquake, $\mu(R_y, T_1)$, is taken equal to the yield strength reduction factor for structural systems with not much rigid.

$$\mu(R_y, T_1) = Ry \quad ; \quad T_1 > T_B \tag{3.19}$$

$\mu(R_y, T_1)$, is taken according to Eq. (3.19) for structural systems with high rigid.

$$\mu(R_y, T_1) = 1 + (Ry - 1)\frac{T_B}{T_1} \quad ; \quad T_1 \leq T_B \tag{3.20}$$

By utilizing the Eq. (3.18, 3.19), the spectral displacement ratio C_R, defined in Eq. (3.16) is expressed in the following equation.

$$C_R = 1 \quad ; \quad T_1 > T_B \tag{3.21}$$

$$C_R = \frac{1 + (R_y - 1)\frac{T_B}{T_1}}{R_y} \qquad ; \qquad T_1 \leq T_B \tag{3.22}$$

In Figure 3-4 and following Figure 3-5, modal capacity diagram that the coordinates are "modal displacement - pseudo acceleration response (d_1, a_1)" and belong to first (dominant) vibration mode and linear earthquake spectrum that the coordinates are "spectral displacement - spectral acceleration (S_{de}, S_{ae})" are drawn together.

The situation shown in Figure 3.4 corresponds to the application of Eq. (3.16) and Eq. (3.21). In this case, it is sufficient to show that the natural vibration period satisfies the condition $T_1 > T_B$ or meets the condition $\left(\omega_1^{(1)}\right)^2 \leq \omega_B^2$ in the first pushover step without performing any action on the modal capacity diagram.

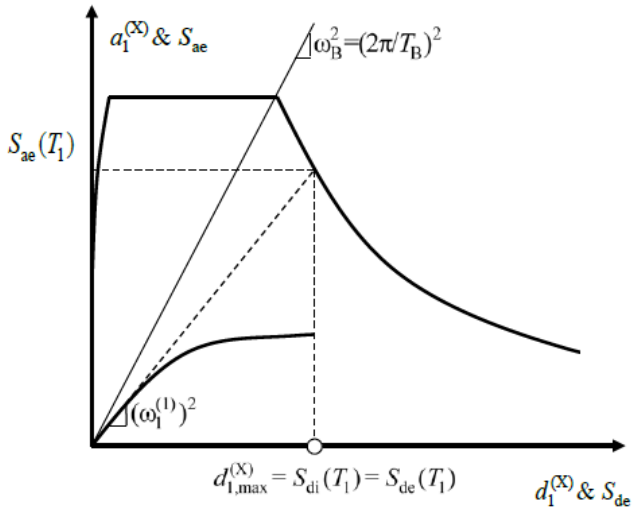


Figure 3.4: Modal Capacity Diagram 1 (TBEC, 2018).

On the other hand, the situation shown in Figure 3-5 corresponds to the application of Eq. (3.16) and Eq. (3.22). In this case, the spectral displacement ratio C_R is calculated using the successive approach. In the first step of the successive approach C_R = 1 is

assumed. Modal capacity diagram obtained as a result of pushover analysis, as shown in Figure 3-5 (a), is turned approximately into a bilinear diagram.

The conversion process is based on the equal areas rule under the diagrams. By using C_R in Eq. (3.22) coordinates of equivalent yield point is re-determined with equal areas rule by taking $S_{di}(T_1)$ calculated according to Eq. (3.16) as basis, as shown in Figure 3-5 (b) and accordingly a_{y1}, R_y and C_R are calculated again. When the results obtained from successive two steps reasonably close up then the successive approached is concluded.

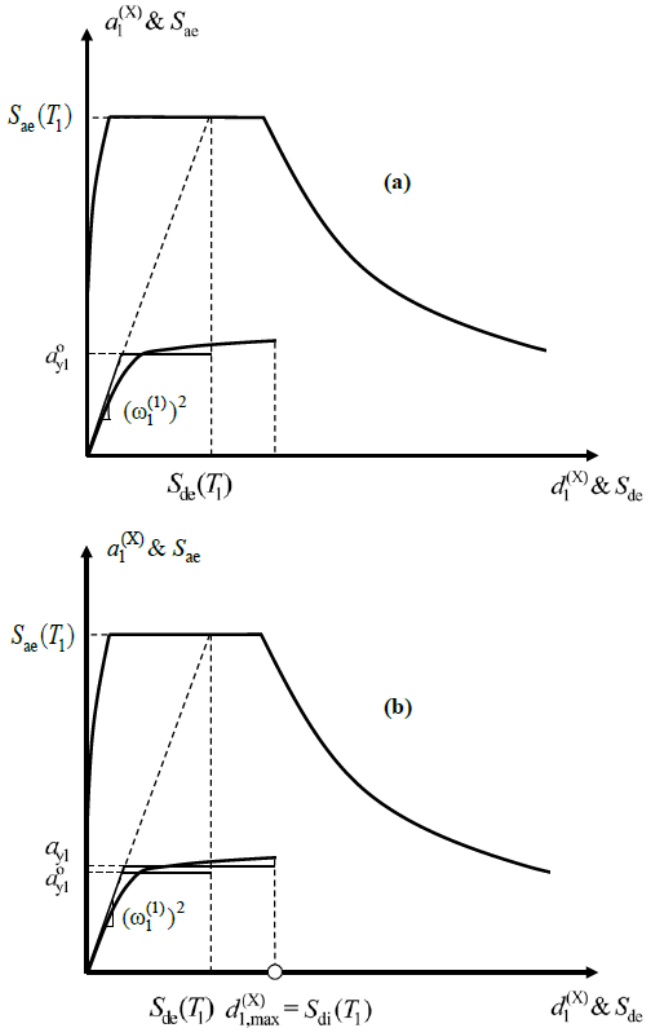


Figure 3.5: Modal Capacity Diagram 2 (TBEC, 2018).

3.9 Determining the Seismic Performance of the Building

The seismic performance of the existing buildings is related to the condition of the damages that are expected to come out under the effect of the earthquakes applied and is defined taking four different damage levels as a basis. The application of linear and nonlinear analysis methods and the determination of the performance of the members according to the section unit deformation capacities. The rules to be applied so as to determine the seismic performance of the buildings are given below.

3.9.1 Continuous Usage Performance Level in Existing Buildings

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

3.9.2 Limited Damage Performance Level in Existing Buildings

At each floor of reinforced concrete buildings, up to 20% of the beams may exceed to the Marked Damage Zone as a result of the analysis for each applied earthquake direction, but all other load-bearing components remain in the Limited Damage Zone. These buildings are considered to have a Limited Damage Performance Level, provided that the brittle damaged components, if any, are strengthened.

3.9.3 Controlled Damage Performance Level in Existing Buildings

The buildings that satisfy the conditions mentioned below can be agreed to be in Controlled Damage Performance Level provided that the brittle damaged components, if any, are strengthened:

- As the result of the analyses made for each earthquake direction applies on each floor, at most 35 % of the beams except for the secondary ones (that does not take place in the horizontal load-bearing system) and at most the proportion of the vertical components (columns, shear walls, reinforced partition walls) defined in paragraph (b) it may proceed to the Advanced Damage Zone.

- The total contribution of the vertical components in the Advanced Damage Zone to the shear force that is carried by the vertical components in each floor should not exceed 20 %. On the top floor, the ratio of the total shear forces of the vertical components in the Advanced Damage Zone to the total shear forces of all the vertical elements at that floor can be at most 40 %.
- All other load-bearing components are in Marked Damage Zone or Limited Damage Zone. However, the shear forces carried by the vertical components which exceeds the Marked Damage Bound both in upper and lower sections for any floor should not be more than 30 % of the shear force carried by all columns of the floor.

3.9.4 Collapse Prevention Performance Level in Existing Buildings

The buildings that meet the conditions given below are agreed to be in the Collapse Prevention Performance Level provided that the fact that all components that are brittle damaged are in the Collapse Zone.

- At the end of the analysis regarding all earthquakes applied on any floors, at most 20 % of the beams except for the secondary ones can enter the Collapse Zone.
- All other load-bearing components are in the Limited Damage Zone, Marked Damage Zone or in the Advanced Damage Zone. However, the shear forces carried by the vertical components which exceed the Limited Damage Bound both in lower and upper sections for any floor should not be more than 30 % of the shear force carried by all vertical components of the floor. The use of the building in the present situation is inconvenient in terms of life safety.

3.9.5 Collapse Level

If the building is not able to achieve the Collapse Prevention Performance Level, it is in the Collapse Level. Usage of the building under these circumstances poses threats to life safety.

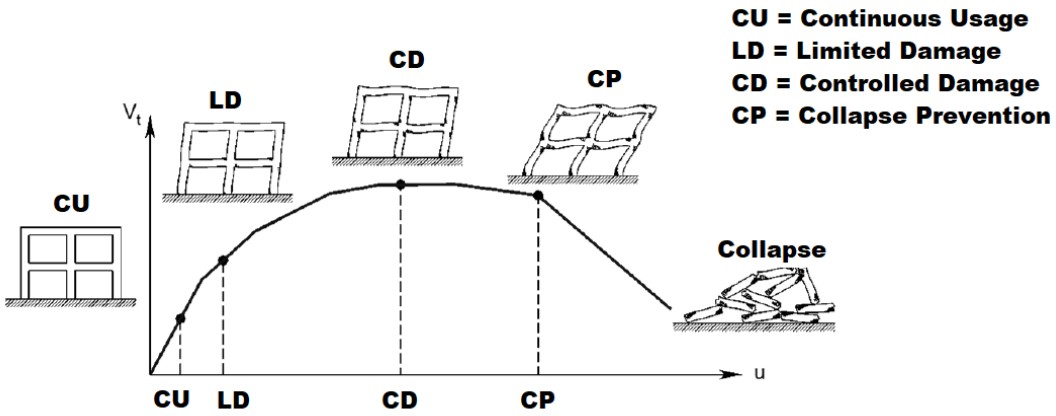


Figure 3.6: Seismic Performance Level of Buildings (Asfuroğlu, 2018).

3.10 Buildings Performance Targets

The following table describes the performance targets in accordance with the Earthquake Design Class, DTS =1, 1a, 2, 2a 3, 3a, 4, 4a defined for the 4 different Earthquake Ground Motion level defined on the perform in the buildings covered by the code.

Table 3.3: Performance Targets for New Building or Existing Buildings according to TBEC 2018(a, b, c)

a) New Reinforced Concrete and Precast Concrete and Steel Buildings (Expect High Buildings - BYS ≥ 2)

Earthquake Ground Motion levels	DTS = 1, 1a[(1)], 2, 2a[(1)], 3, 3a, 4, 4a		DTS = 1a[(2)], 2a[(2)]	
	Normal Performance Target	Evaluation / Design Approach	Advanced Performance Target	Evaluation / Design Approach
DD-3	-	-	LD	DBD
DD-2	CD	SBD	CD	SBD
DD-1	-	-	CD	DBD

b) New Buildings or Existing High Buildings (BYS = 1)

Earthquake Ground Motion levels	DTS = 1, 2, 3, 3a, 4, 4a		DTS = 1a, 2a	
	Normal Performance Target	Evaluation / Design Approach	Advanced Performance Target	Evaluation / Design Approach
DD-4	CU	SBD	-	-
DD-3	-	-	LD	DBD
DD-2	CD	SBD	CD	SBD
DD-1	CP	DBD	CD	DBD

c) Existing Reinforced Concrete, Pre-cast Reinforced Concrete and Steel Buildings (Except High Buildings - BYS ≥ 2)

Earthquake Ground Motion levels	DTS = 1, 1a[(1)], 2, 2a[(1)], 3, 3a, 4, 4a		DTS = 1a[(2)], 2a[(2)]	
	Normal Performance Target	Evaluation / Design Approach	Advanced Performance Target	Evaluation / Design Approach
DD-3	-	-	SD	DBD
DD-2	CD	DBD		
DD-1	-	-	CD	DBD

Chapter 4

METHODOLOGY

4.1 Introduction

In this chapter, design and analysis of residential buildings have been carried out by mentioned earthquake codes. In the analysis stage, the mode superposition method which is one of the linear dynamic analysis methods of the regulations was used. Then, in the evaluation of the performance of the buildings, the pushover analysis method of the TBEC 2018 was used.

In the comparative examination of the analyses; irregularity coefficients of Turkish earthquake codes, structural system behaviour factors and base shear forces of earthquake codes are presented in tables and graphs. Also, seismic design parameters of regulations and plans of buildings are given in this section.

4.2 General Information

The parameters used for the analyses during the seismic design phase is given in tables below for TBEC 2018, TEC 2007 and Eurocode 8, respectively. The coefficients and values varying according to the plan type are given in the related subheading.

Table 4.1: General Information used in TBEC 2018

TBEC 2018		
Earthquake ground motion level	DD-2	
Building type	Residential Building	
Structural system type	Buildings in which seismic loads are fully resisted by coupled structural walls of high ductility level	
Soil type	ZC	
Location	Atasehir	Izmit

Coordinates	40,99141 29,1311	40,7766 29,91559
The map spectral acceleration coefficient at short periods (Ss)	0.9032	1.5834
The map spectral acceleration coefficient at 1-s period (S_1)	0.2497	0.4313
The design spectral response acceleration coefficient at short periods (S_{DS})	1.084	1.9
the design spectral response acceleration coefficient at 1-s period (S_{D1})	0.375	0.647
Spectrum characteristic periods (TA-TB)	0.0692 - 0.3459	0.0681 – 0.3405
Building importance class (I)	1	
Earthquake design class (DTS)	1	
Live load participation factor (n)	0.3	
Modulus of subgrade reaction	Dense sand (7000 t/m^3)	
Soil stress ultimate strength factor	Dense sand (42.00 t/m^2)	
Seismic load eccentricity	0.05	
Damping correction Factor (η)	5 % damping	

Table 4.2: General Information used in TEC 2007

TEC 2007	
Seismic zone	1
Building type	Residential
Structural system type	Buildings in which seismic loads are fully resisted by coupled structural walls
Ductility Class	High
Local site class	Z2
Spectrum characteristic periods (TA-TB)	0.15 - 0.4
Building importance factor(I)	1
Modulus of subgrade reaction	Dense sand (7000 t/m^3)
Soil stress ultimate strength factor	Dense sand (42.00 t/m^2)
Live load participation factor (n)	0.3
Seismic load eccentricity	0.05
Damping correction Factor (η)	5 % damping

Table 4.3:General Information used in Eurocode 8

EC 8	
Seismic zone	1
Ground acceleration coefficient (Ao)	0.4
Building type	Residential
Structural system type	Frame system, dual system, coupled wall system
Ductility Class	DCH
Soil group	ZB
Spectrum characteristic periods (TB-TC)	0.15 - 0.5
Building Importance factor(γI)	1
Live Load Combination Constant (n)	0.3
Modulus of subgrade reaction	Dense sand (7000 t/m^3)
Soil stress ultimate strength factor	Dense sand (42.00 t/m^2)
Lover Bound Factor β	0.2
Damping Correction Factor (η)	1
Correction factor (λ)	0.85

4.3.5.5 Case B1 Type - Izmit 10-Storey (B1-I-10S)

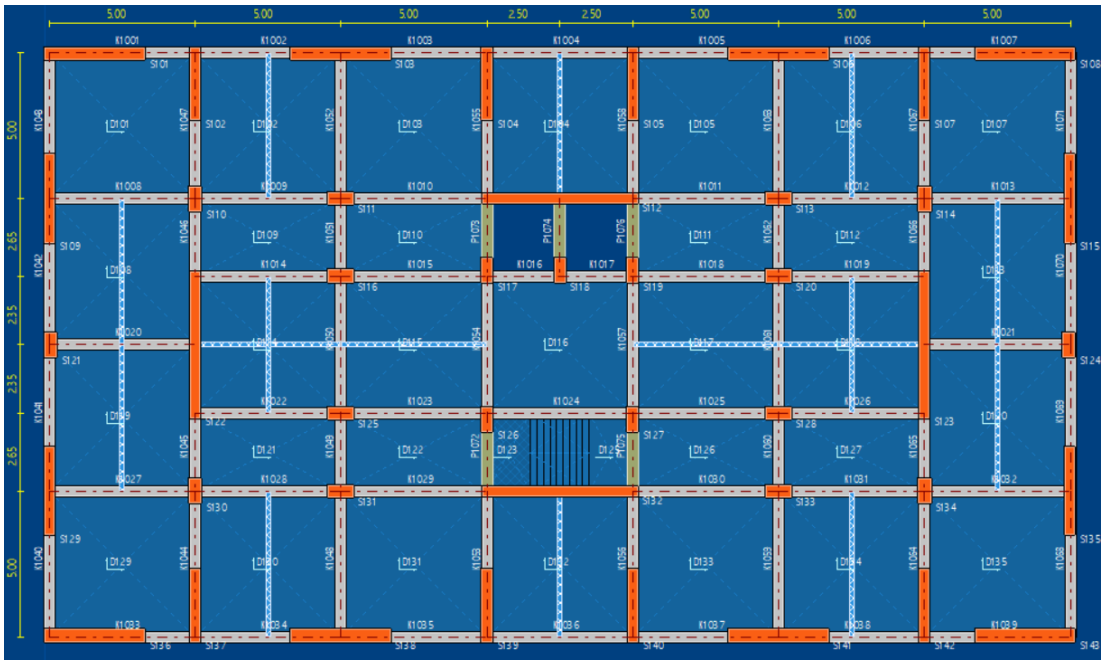


Figure 4.39: Plan of the Case B1-I-10S

4.3.5.6 Case B1 Type - Izmit 20-Storey (B1-I-20S)

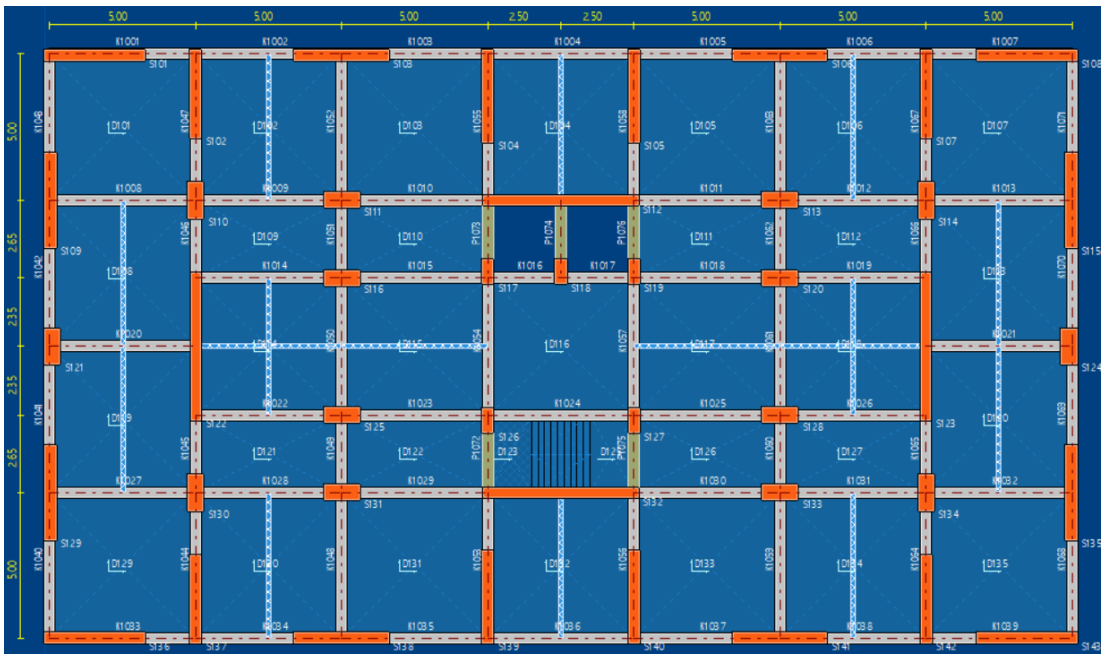


Figure 4.40: Plan of the Case B1-I-20S

Table 4.14: Irregularity Check List and Base Shear Forces for B1 - Irregular Buildings (Atasehir)

Case	R	ηbi	ηki	ηci	Explanation	Base Shear Force	
						Fx(t)	Fx(t)
B1-A-5S							
TBEC 2018	5.60	1.19	1.07	**0.67**	Irregular B.	503	538
TEC 2007	6.36	1.19	1.13	**0.67**	Irregular B.	575	594
EC 8	4.32				Irregular B.	834	867
B1-A-10S							
TBEC 2018	5.60	1.17	1.08	**0.69**	Irregular B.	612	678
TEC 2007	6.06	1.16	1.12	**0.69**	Irregular B.	847	888
EC 8	4.32				Irregular B.	1301	1374
B1-A-20S							
TBEC 2018	5.60	1.19	1.09	**0.77**	Irregular B.	750	750
TEC 2007	6.75	1.19	1.08	**0.77**	Irregular B.	907	1001
EC 8	4.32				Irregular B.	1398	1531

Table 4.15: Irregularity Check List and Base Shear Forces for B1 - Irregular Buildings (Izmit)

Case	R	ηbi	ηki	ηci	Explanation	Base Shear Force	
						Fx(t)	Fx(t)
B1-I-5S							
TBEC 2018	5.60	1.19	1.07	**0.67**	Irregular B.	888	953
TEC 2007	6.32	1.19	1.13	**0.67**	Irregular B.	878	903
EC 8	4.32				Irregular B.	833	860
B1-I-10S							
TBEC 2018	5.60	1.19	1.07	**0.73**	Irregular B.	1116	1267
TEC 2007	6.35	1.19	1.13	**0.73**	Irregular B.	844	923
EC 8	4.32				Irregular B.	1382	1537
B1-I-20S							
TBEC 2018	5.60	1.19	1.09	**0.77**	Irregular B.	1319	1319
TEC 2007	6.78	1.19	1.11	**0.77**	Irregular B.	908	1004
EC 8	4.32				Irregular B.	1403	1542

4.3.6 B2 Type: Interstorey Stiffness Irregularity (Soft Storey)

In the structure including the B2 type irregularity, the plan was chosen to be fully symmetrical. The gross floor area of the buildings is approximately 576 m^2. In this category, the ground floor height of buildings is 4.8m and the normal floor heights are determined as 3m, and the slab thickness is 15 cm for all buildings. At the end of this category, irregularity coefficients of buildings are listed in the irregularity table.

4.3.6.1 Case B2 Type - Atasehir 5-Storey (B2-A-5S)

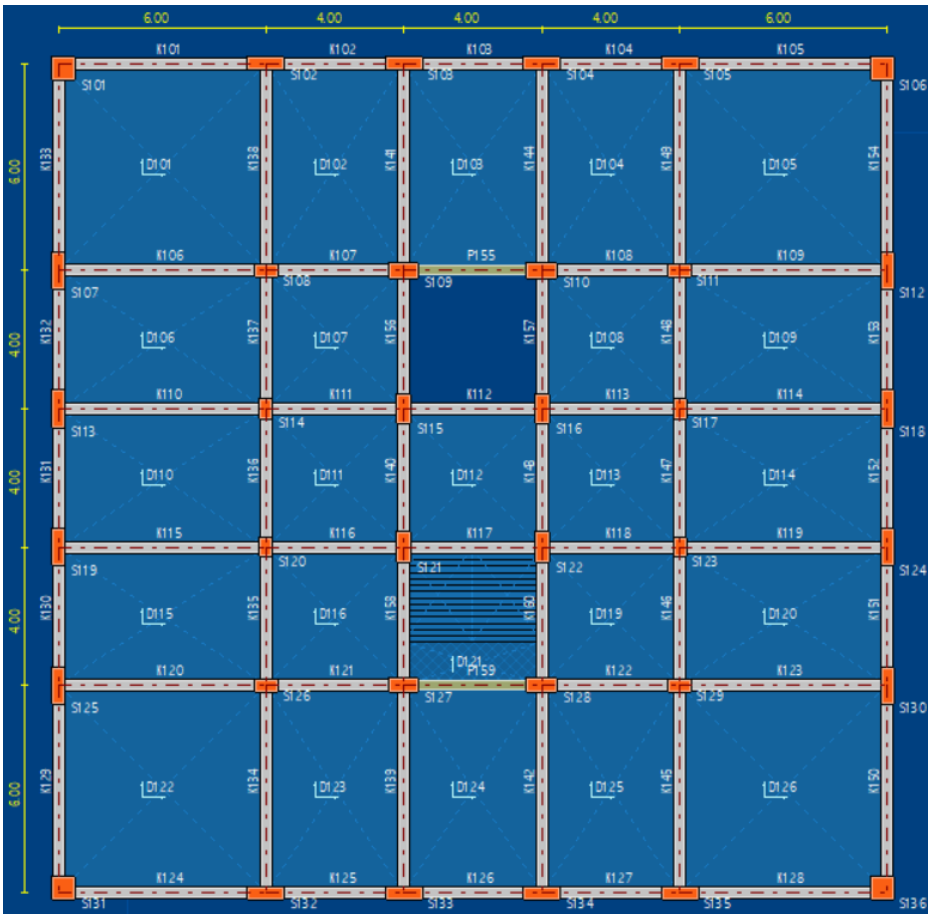


Figure 4.41: Plan of the Case B2-A-5S

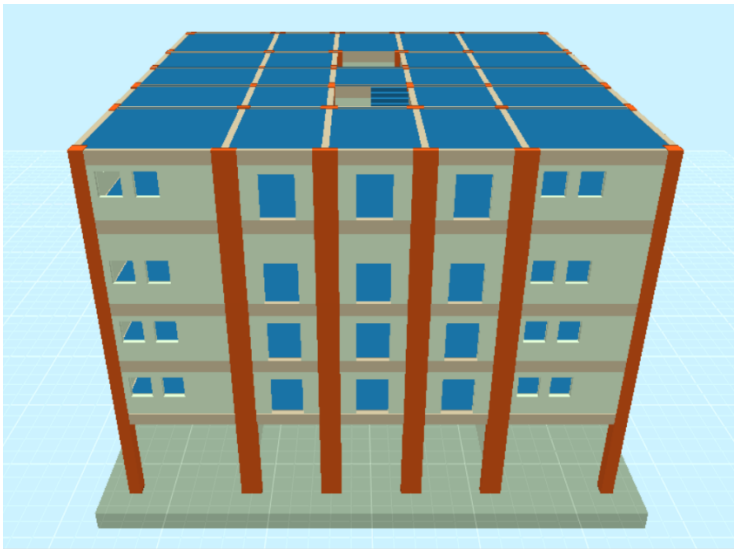


Figure 4.42: 3D Shape of the Case B2-A-5S

4.3.6.2 Case B2 Type - Atasehir 10-Storey (B2-A-10S)

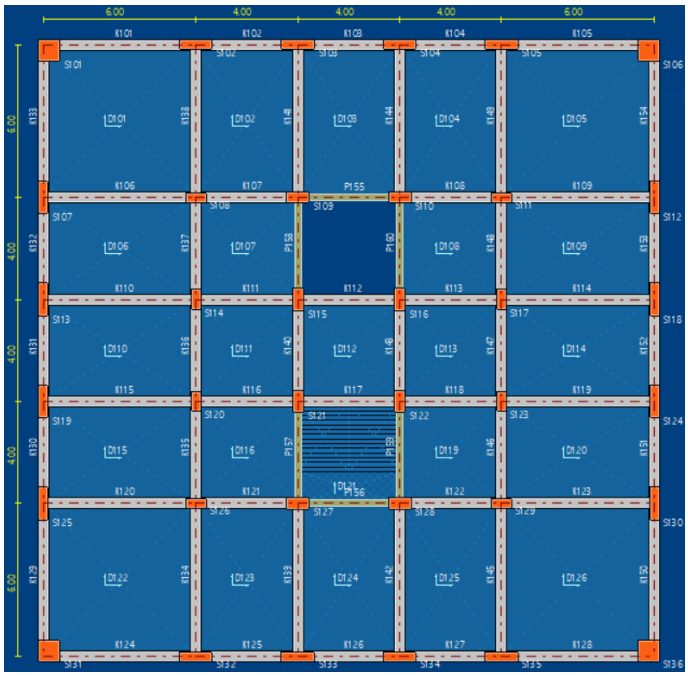


Figure 4.43: Plan of the Case B2-A-10S

4.3.6.3 Case B2 Type - Atasehir 15-Storey (B2-A-15S)

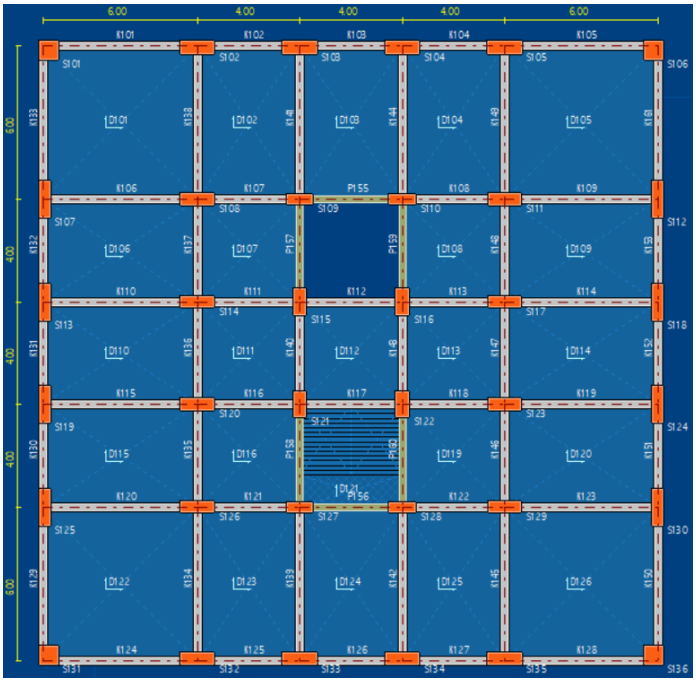


Figure 4.44: Plan of the Case B2-A-15S

4.3.6.4 Case B2 Type - Izmit 5-Storey (B2-I-5S)

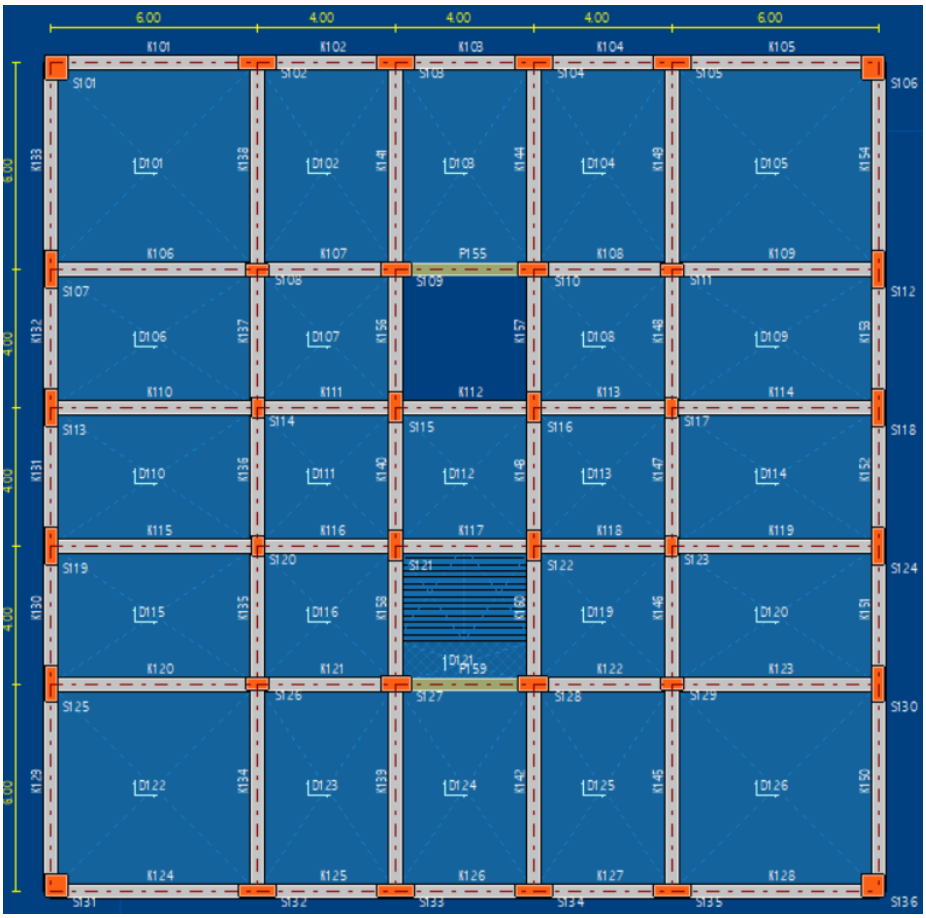


Figure 4.45: Plan of the Case B2-I-5S

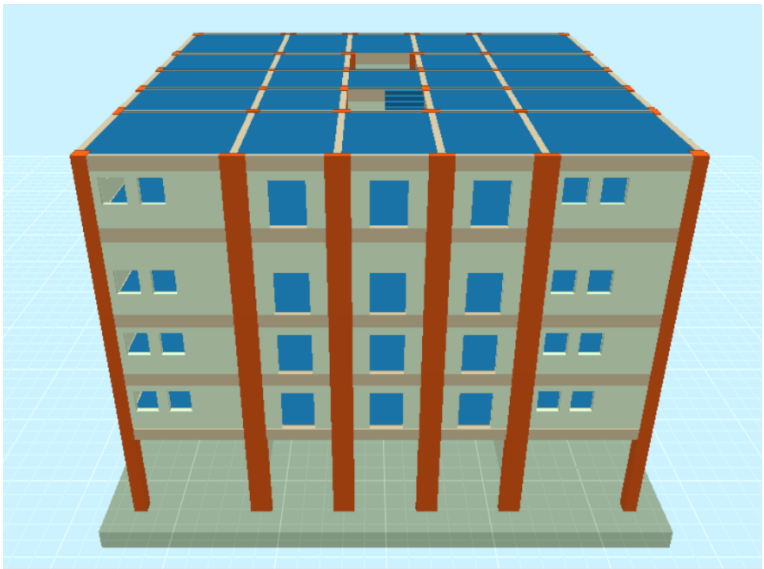


Figure 4.46: 3D Shape of the Case B2-I-5S

4.3.6.5 Case B2 Type - Izmit 10-Storey (B2-I-10S)

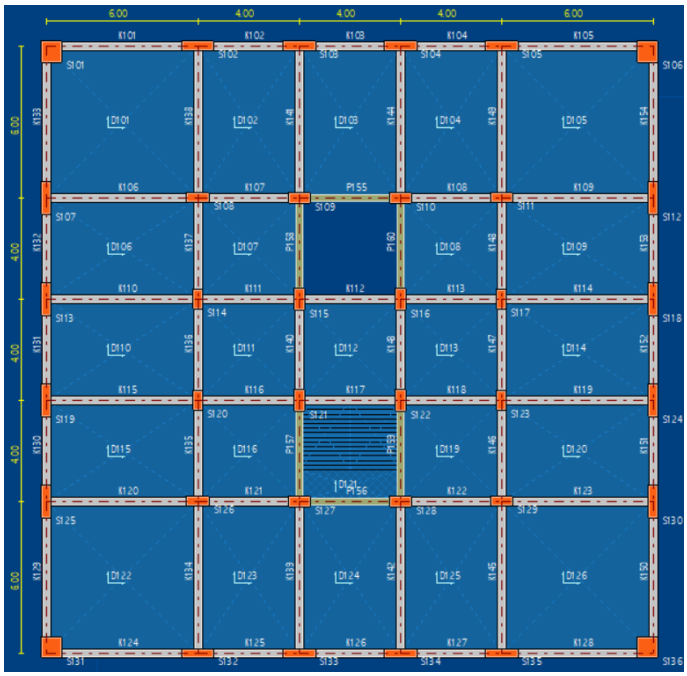


Figure 4.47: Plan of the Case B2-I-10S

4.3.6.6 Case B2 Type - Izmit 15-Storey (B2-I-15S)

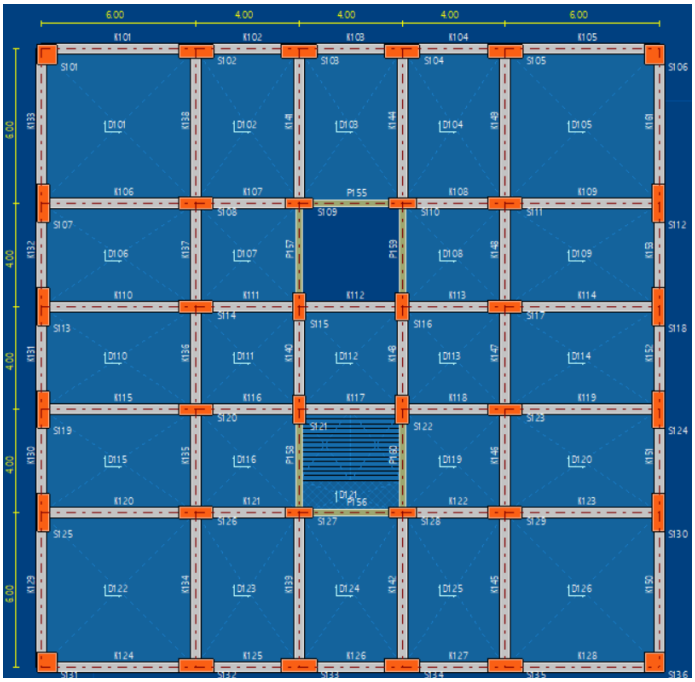


Figure 4.48: Plan of the Case B2-I-15S

Table 4.16: Irregularity Check List and Base Shear Forces for B2 - Irregular Buildings (Atasehir)

Case	R	ηbi	ηki	β	ηci	Explanation	Base Shear Force.	
							Fx(t)	Fx(t)
B2-A-5S								
TBEC 2018	7.00	1.18	**2.01**	**0.9**	0.95	Irregular B.	273	194
TEC 2007	7.00	1.16	**2.50**	**0.9**	0.95	Irregular B.	402	312
EC 8	4.32			**0.9**		Irregular B.	709	582
B2-A-10S								
TBEC 2018	7.00	1.19	**2.34**	**0.9**	0.95	Irregular B.	315	352
TEC 2007	6.84	1.19	**2.98**	**0.9**	0.95	Irregular B.	536	585
EC 8	4.32			**0.9**		Irregular B.	933	1041
B2-A-15S								
TBEC 2018	7.00	1.16	**2.40**	**0.9**	0.81	Irregular B.	431	431
TEC 2007	7.00	1.15	**2.87**	**0.9**	0.81	Irregular B.	728	736
EC 8	4.32			**0.9**		Irregular B.	1247	1264

Table 4.17: Irregularity Check List and Base Shear Forces for B2 - Irregular Buildings (Izmit)

Case	R	ηbi	ηki	β	ηci	Explanation	Base Shear Force	
							Fx(t)	Fx(t)
B2-I-5S								
TBEC 2018	7.00	1.18	**2.01**	**0.9**	0.95	Irregular B.	472	335
TEC 2007	7.00	1.16	**2.50**	**0.9**	0.95	Irregular B.	402	312
EC 8	4.32			**0.9**		Irregular B.	709	582
B2-I-10S								
TBEC 2018	7.00	1.19	**2.26**	**0.9**	0.96	Irregular B.	549	611
TEC 2007	6.84	1.19	**2.92**	**0.9**	0.96	Irregular B.	540	588
EC 8	4.32			**0.9**		Irregular B.	941	1047
B2-I-15S								
TBEC 2018	7.00	1.16	**2.39**	**0.9**	0.81	Irregular B.	757	757
TEC 2007	7.00	1.15	**2.87**	**0.9**	0.81	Irregular B.	728	736
EC 8	4.32			**0.9**		Irregular B.	1247	1264

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In this part of the thesis, firstly non-linear analysis results are discussed in detail, then construction costs of buildings are compared in tables.

As a result of the nonlinear pushover analysis applied to buildings, maximum displacements with base shear forces were obtained under the effect of step by step increasing forces. As a result of converting the data into graphical form, it has become possible to make comparisons between earthquake codes. Apart from the pushover curves of earthquake codes, beam damage ratios, column damage ratios at the performance level of the building are also compared in tables.

As a result of linear analysis applied to buildings, the amount of welded steel mesh for slabs, the amount of steel reinforcement and the concrete amount were determined. Then calculated values were multiplied by the current unit price of the materials to get the cost of buildings. Finally, the building costs of each earthquake code were compared via tables.

5.2 Results of Pushover Analysis

In this part of the study, the pushover curves obtained from the results of the non-linear analysis of buildings were given.

5.2.1 Regular Type Buildings

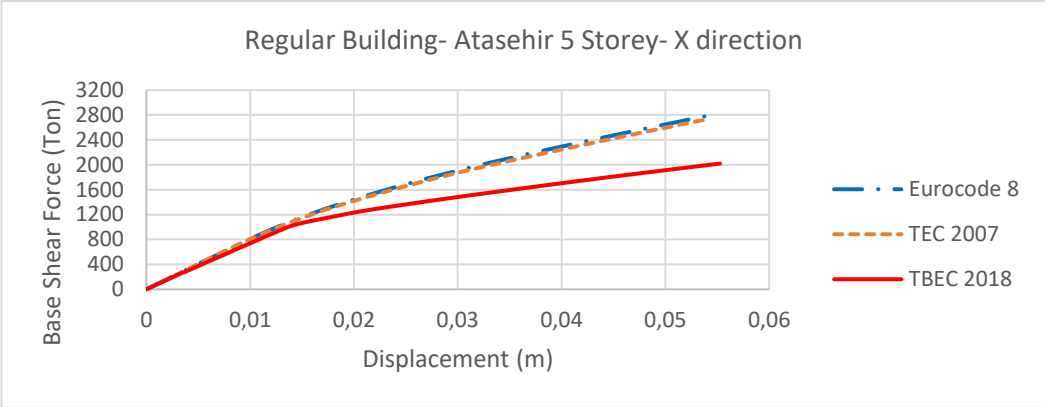


Figure 5.1: Pushover analysis curves of the R-A-5S building (X direction)

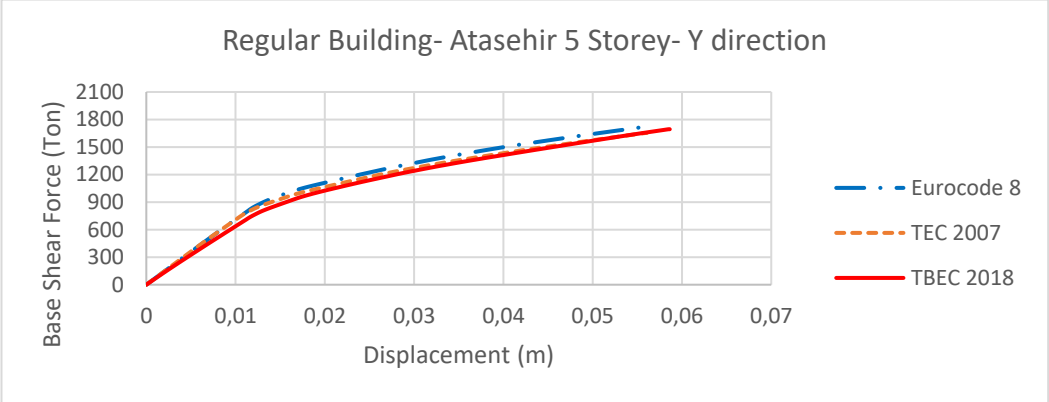


Figure 5.2: Pushover analysis curves of the R-A-5S building (Y direction)

The pushover curve shows that (Fig.5-1), there were partially differences in the pushover analysis results of the 5-Storey building in Atasehir. Base shear forces in the X direction of buildings are 2778t, 2715t and 2017t for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, there were slight differences between the pushover curves of the buildings in the Y direction (Fig.5-2).

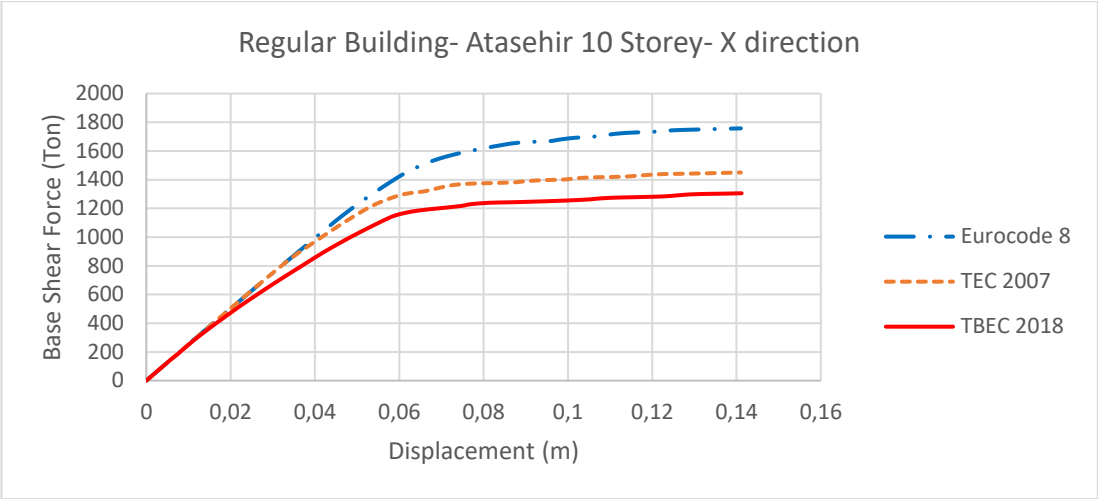


Figure 5.3: Pushover analysis curves of the R-A-10S building (X direction)

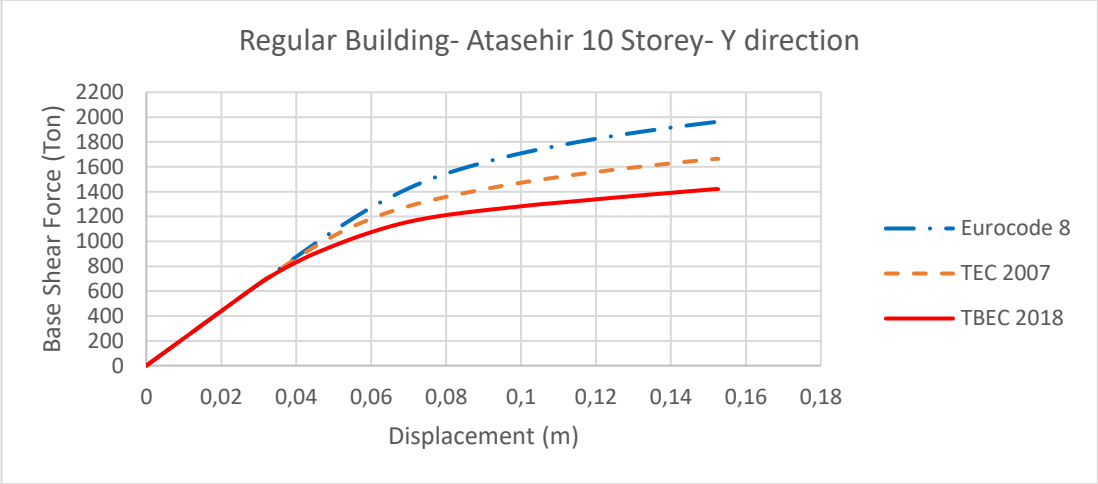


Figure 5.4: Pushover analysis curves of the R-A-10S building (Y direction)

The pushover curves show that (Fig.5-3 & Fig.5-4) there was a significant difference between the pushover analysis results of the 10-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1757t, 1449t and 1305t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

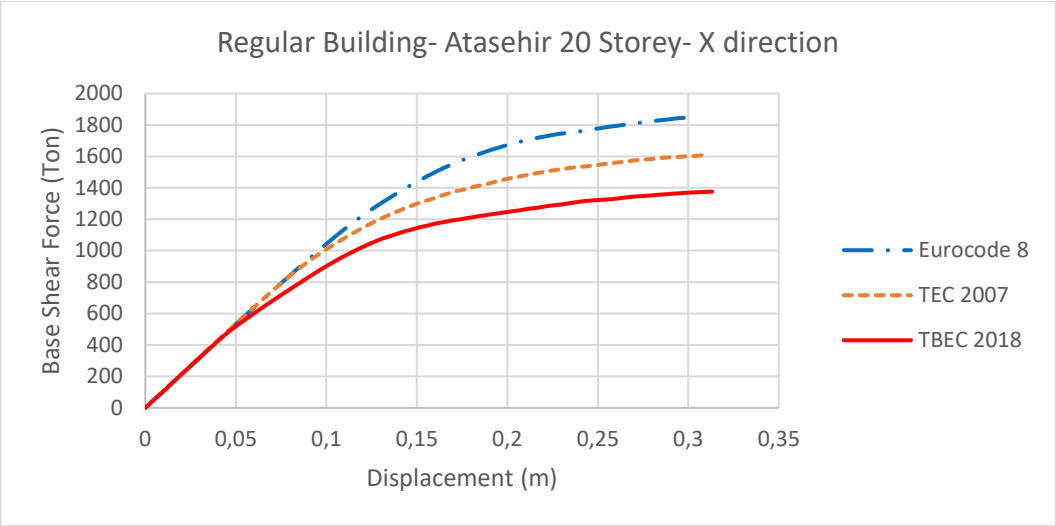


Figure 5.5: Pushover analysis curves of the R-A-20S building (X direction)

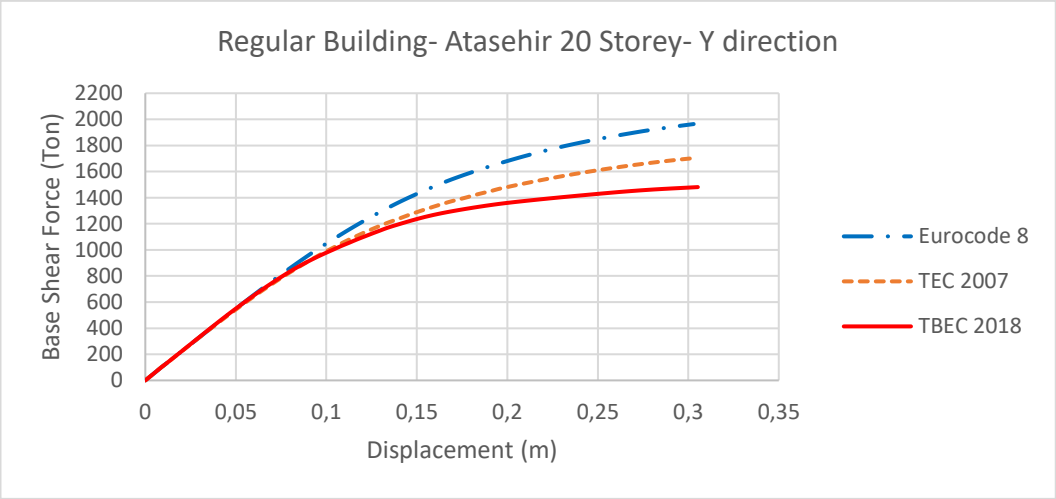


Figure 5.6: Pushover analysis curves of the R-A-20S building (Y direction)

The pushover curves show that (Fig.5-5 & Fig.5-6) there was a significant difference between the pushover analysis results of the 20-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1963t, 1702t and 1480t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

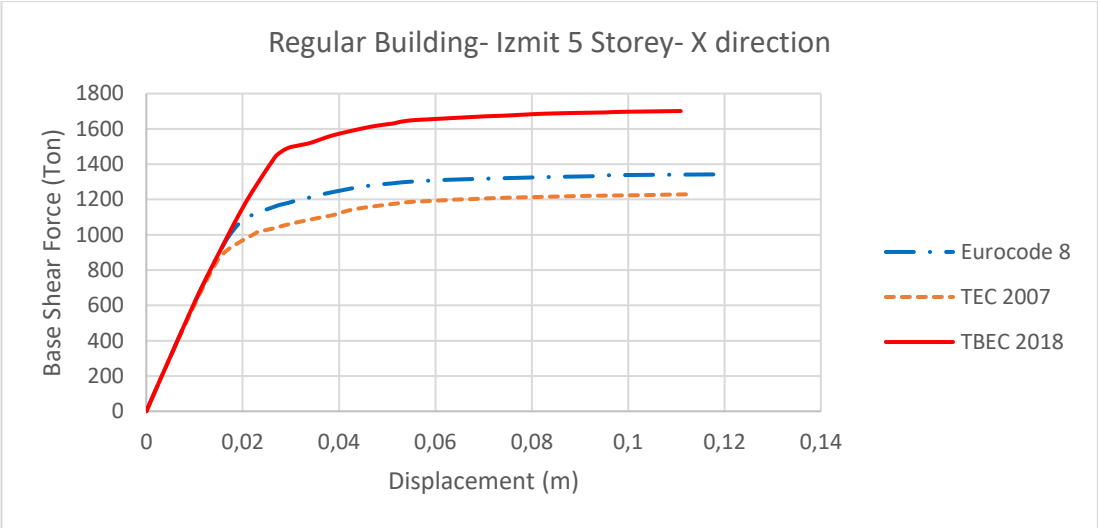


Figure 5.7: Pushover analysis curves of the R-I-5S building (X direction)

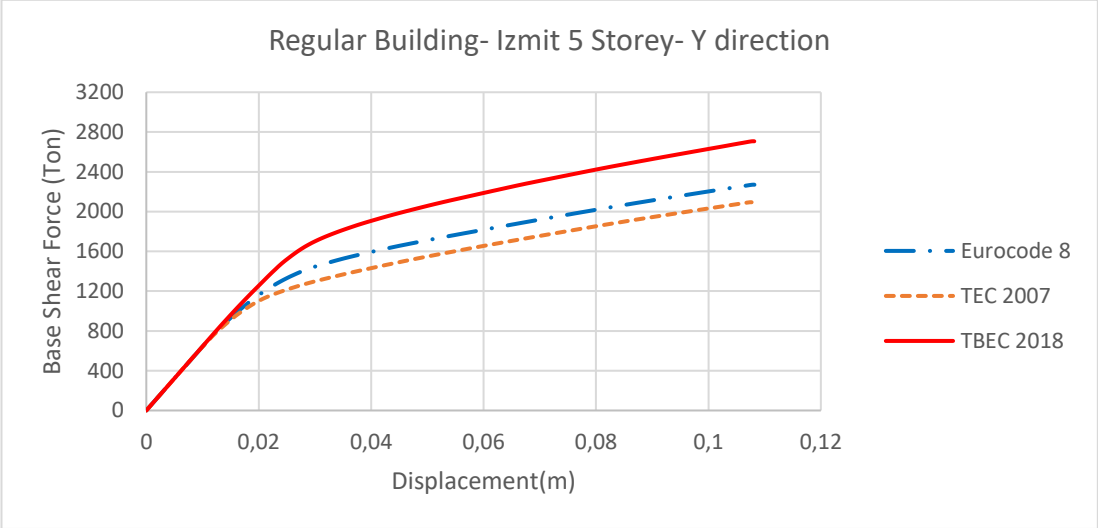


Figure 5.8: Pushover analysis curves of the R-I-5S building (Y direction)

The pushover curves show that (Fig.5-7 & Fig.5-8) there was a significant difference between the pushover analysis results of the 5-Storey building in Izmit. Base shear forces in the X direction of buildings are 1342t, 1229t and 1701t for EC 8, TEC 2007 and TBEC 2018, respectively. The pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

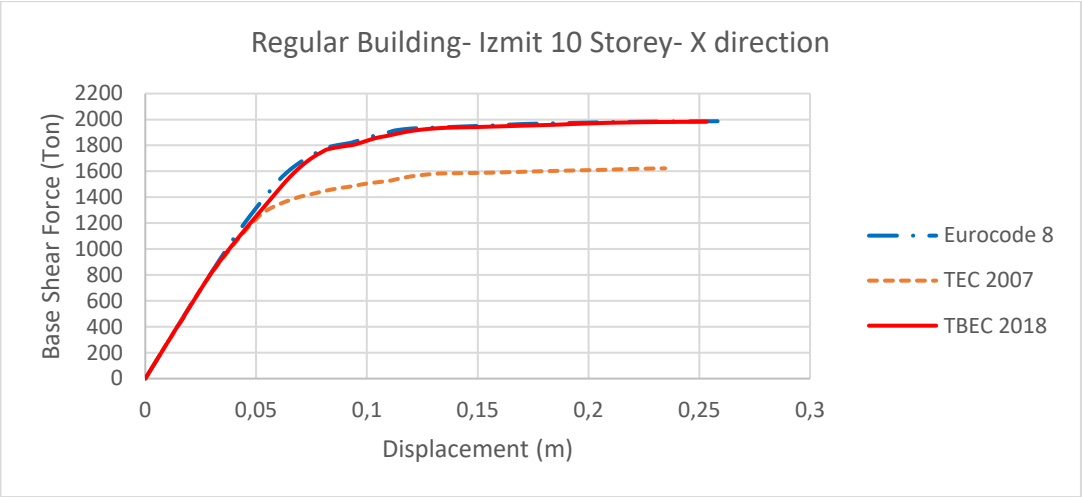


Figure 5.9: Pushover analysis curves of the R-I-10S building (X direction)

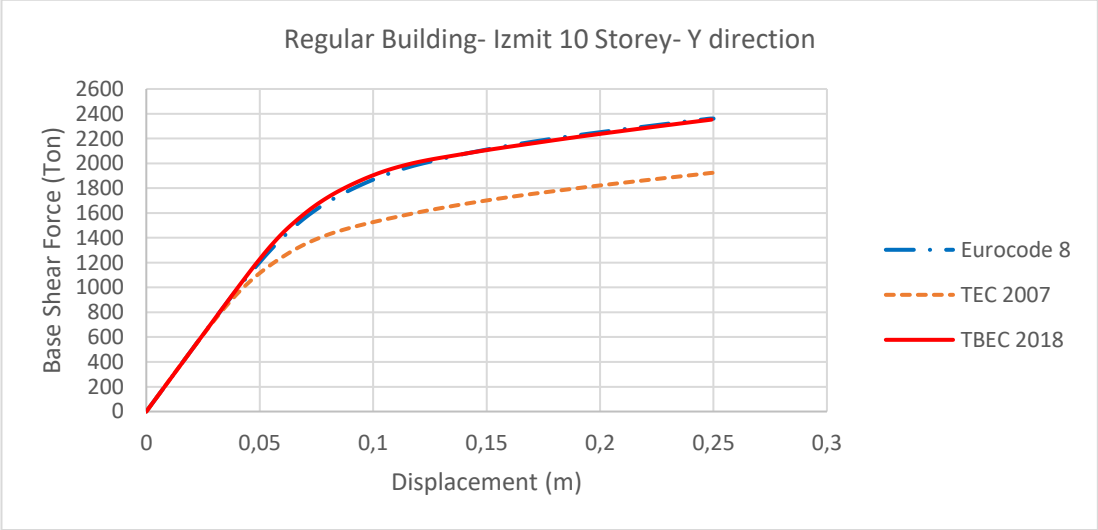


Figure 5.10: Pushover analysis curves of the R-I-10S building (Y direction)

The pushover curves show that (Fig.5-9 & Fig.5-10) there were partially differences between the pushover analysis results of the 10-Storey building in Izmit. TEC 2007 shows lower values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1986t, 1662t and 1982t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

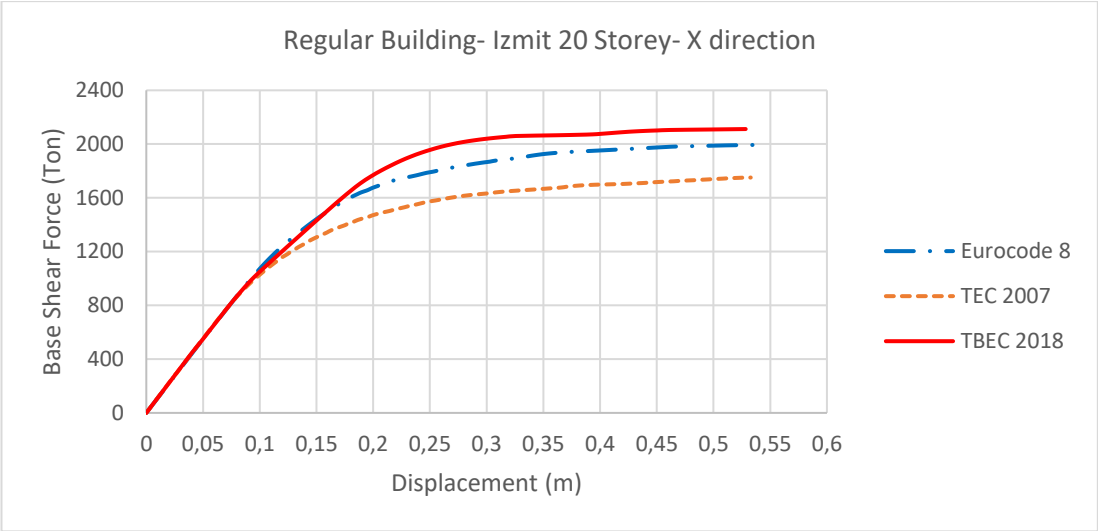


Figure 5.11: Pushover analysis curves of the R-I-20S building (X direction)

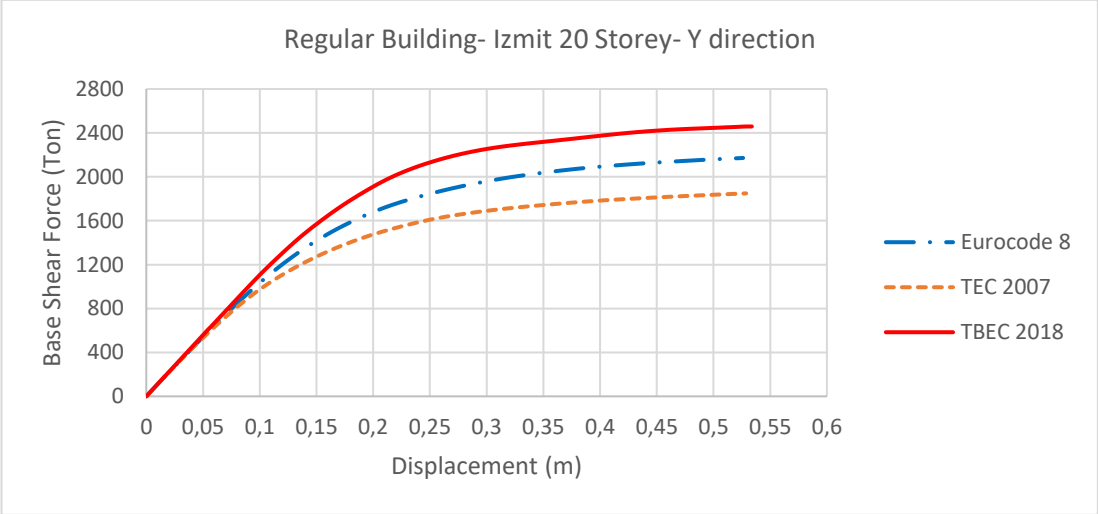


Figure 5.12: Pushover analysis curves of the R-I-20S building (Y direction)

The pushover curves show that (Fig.5-11 & Fig.5-12) there was a significant difference between the pushover analysis results of the 10-Storey building in Izmit. Base shear forces in the X direction of buildings are 1993t, 1750t and 2111t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-12, the difference between TBEC 2018 and EC 8 has increased, although the X and Y directions of the pushover analysis curves show similarity.

Table 5.1: Performance levels and base shear forces of regular type buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
Regular Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	439.3	0.005	LD	471.4	0.005	LD	252.6	0.003	LD
			2778.8	**0.053**	**CD**	**2715.3**	**0.053**	**CD**	**2017.6**	**0.055**	**CD**
		Y	344.1	0.004	LD	276.6	0.003	LD	44.4	0.0006	LD
			1724.9	**0.056**	**CD**	**1652.9**	**0.055**	**CD**	**1693.8**	**0.058**	**CD**
	10 Storey	X	535.9	0.021	LD	270.2	0.010	LD	142.4	0.005	LD
			1757.5	**0.141**	**CD**	**1449.9**	**0.141**	**CD**	**1305.3**	**0.141**	**CD**
		Y	276.8	0.012	LD	104.9	0.004	LD	438.7	0.019	LD
			1960.8	**0.152**	**CD**	**1663.4**	**0.151**	**CD**	**1420.4**	**0.151**	**CD**
	20 Storey	X	421.4	0.039	LD	408.6	0.038	LD	76.4	0.007	LD
			1860.2	**0.310**	**CD**	**1608.8**	**0.309**	**CD**	**1375.4**	**0.312**	**CD**
		Y	52.4	0.004	LD	52.4	0.004	LD	52.3	0.004	LD
			1963.8	**0.302**	**CD**	**1702.9**	**0.303**	**CD**	**1480.8**	**0.305**	**CD**
Izmit	5 Storey	X	252.4	0.004	LD	82.4	0.001	LD	188.8	0.003	LD
			1342.5	**0.120**	**CD**	**1229.0**	**0.112**	**CD**	**1701.0**	**0.110**	**CD**
		Y	411.5	0.006	LD	222.3	0.003	LD	656.2	0.010	LD
			2270.0	**0.107**	**CD**	**2093.7**	**0.107**	**CD**	**2706.6**	**0.107**	**CD**
	10 Storey	X	545.0	0.019	LD	255.3	0.009	LD	369.4	0.013	LD
			1986.7	**0.260**	**CD**	**1622.9**	**0.234**	**CD**	**1982.9**	**0.253**	**CD**
		Y	588.5	0.023	LD	322.3	0.012	LD	750.5	0.030	LD
			2361.1	**0.248**	**CD**	**1923.6**	**0.249**	**CD**	**2353.1**	**0.249**	**CD**
	20 Storey	X	401.6	0.036	LD	288.1	0.025	LD	427.0	0.038	LD
			1993.4	**0.535**	**CD**	**1750.9**	**0.529**	**CD**	**2111.7**	**0.528**	**CD**
		Y	84.07	0.007	LD	84.0	0.0074	LD	577.9	0.051	LD
			2171.4	**0.526**	**CD**	**1849.0**	**0.528**	**CD**	**2458.1**	**0.528**	**CD**

Table 5.2: Damage ratios at the performance level of R-A-5S building

Case Regular Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage	4.4			4.4			4.4		
		Columns Damage Percentage		0.6			0.6			1.3	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.3: Damage ratios at the performance level of R-A-10S building

Case Regular Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage	4.5			11.4			9.1		
		Columns Damage Percentage	1.3	1.2			1.2			-	
		Plastic Column Vc ratio	2.5			1.2			-		
		Performance Level	CD			CD			CD		

Table 5.4: Damage ratios at the performance level of R-A-20S building

Case Regular Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	20 Storey	Beam Damage Percentage	15.6			20.0			20.0		
		Columns Damage Percentage	3.3	12.6		2.9	10.6		7.9	4.4	
		Plastic Column Vc ratio	10.9			9.4			7.9		
		Performance Level	CD			CD			CD		

Table 5.5: Damage ratios at the performance level of R-I-5S building

Case Regular Type		Explanation Sectional Damaged Areas	Eurocode 8 MD	Eurocode 8 AD	Eurocode 8 CR	TEC 2007 MD	TEC 2007 AD	TEC 2007 CR	TBEC 2018 MD	TBEC 2018 AD	TBEC 2018 CR
Izmit	5 Storey	Beam Damage Percentage	13.6			13.6			22.7		
		Columns Damage Percentage	3.5	10.3		17.1	15.6		19.0	12.1	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.6: Damage ratios at the performance level of R-I-10S building

Case Regular Type		Explanation Sectional Damaged Areas	Eurocode 8 MD	Eurocode 8 AD	Eurocode 8 CR	TEC 2007 MD	TEC 2007 AD	TEC 2007 CR	TBEC 2018 MD	TBEC 2018 AD	TBEC 2018 CR
Izmit	10 Storey	Beam Damage Percentage	36.0			45.5			45.5		
		Columns Damage Percentage		19.6			3.5		11.1	12.8	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.7: Damage ratios at the performance level of R-I-20S building

Case Regular Type		Explanation Sectional Damaged Areas	Eurocode 8 MD	Eurocode 8 AD	Eurocode 8 CR	TEC 2007 MD	TEC 2007 AD	TEC 2007 CR	TBEC 2018 MD	TBEC 2018 AD	TBEC 2018 CR
Izmit	20 Storey	Beam Damage Percentage	40.9			40.9			54.5		
		Columns Damage Percentage	11.9	14.1		12.4	10.2		6.8	6.0	
		Plastic Column Vc ratio	7.1			8.8			6.1		
		Performance Level	CD			CD			CD		

The performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in residential buildings. In order to reveal the difference between the codes, the damage ratio comparison of the performance points of the regular type buildings is detailed below.

- Table 5-2 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-1, since TBEC 2018 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 0.6, 0.6 and 1.2 for EC 8 TEC 2007 and TBEC 2018, respectively. However, in the case of beam damage ratio, the performance ratio for all earthquake codes is observed as 4.4.
- Table 5-3 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-1, since TBEC 2018 has the lowest shear force in a 10-storey building, the column damage was not observed. Damage ratios at the performance level of buildings are the same and 1.2 for EC 8 and TEC 2007. However, TEC 2007 showed the worst performance in the case of beam damage ratio.
- Table 5-4 indicates the damage ratios at the performance level of 20-storey building at Atasehir. According to table 5-1, although TBEC 2018 has the lowest base shear force in a 20-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 12.6, 10.6 and 4.4 for EC 8 TEC 2007 and TBEC 2018, respectively. However, TEC 2007 and TBEC 2018 showed the worst performances in the case of beam damage ratio.

- Table 5-5 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to table 5-1, since TEC 2007 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 10.3, 15.6 and 12.1 for EC 8, TEC 2007 and TBEC 2018, respectively. However, TBEC 2018 showed the worst performance in the case of beam damage ratio.
- Table 5-6 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to table 5-1, although TEC 2007 has the lowest base shear force in a 10-storey building, it has a much lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 19.6, 3.5 and 12.8 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 36.0, 45.5 and 45.5 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-7 indicates the damage ratios at the performance level of 20-storey building at Izmit. According to table 5-1, since TBEC 2018 has the highest base shear force in a 20-storey building, it has a much lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 14.1, 10.2 and 6.0 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance levels are 40.9, 40.9 and 54.9 for EC 8, TEC 2007 and TBEC 2018, respectively.

According to tables, in the buildings where TBEC 2018 was used, as a result of the different spectral values of Izmit and Atasehir, significant differences were observed between the base shear forces.

5.2.2 A1 Type: Torsional Irregularity

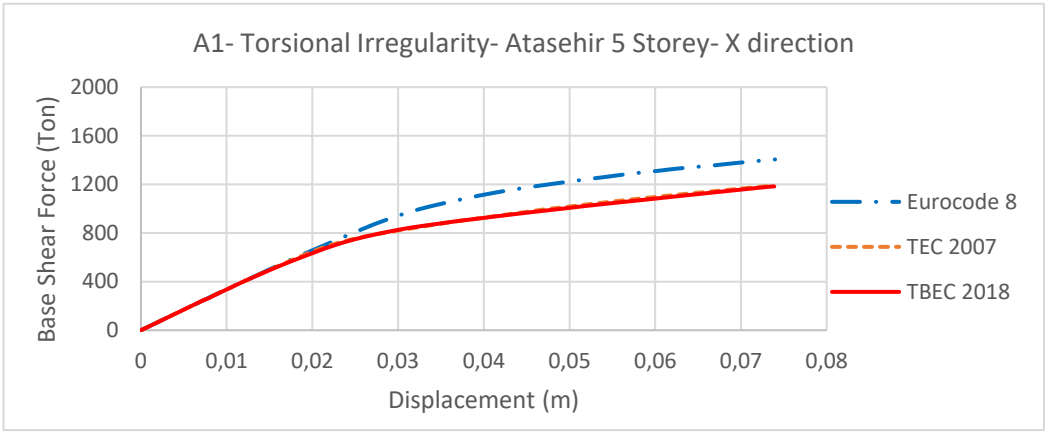


Figure 5.13: Pushover analysis curves of the A1-A-5S building (X Direction)

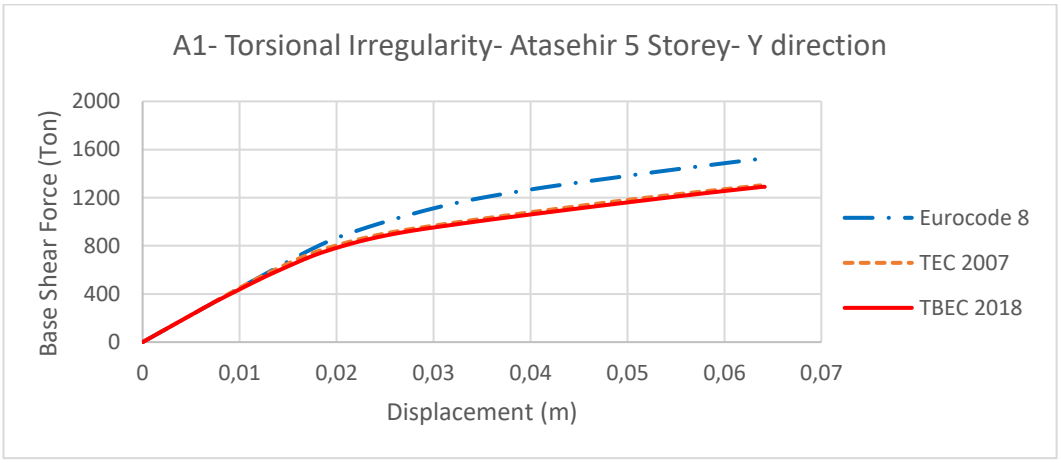


Figure 5.14: Pushover analysis curves of the A1-A-5S building (Y Direction)

The pushover curves show that (Fig.5-13 & Fig.5-14) there were partially differences between the pushover analysis results of the 5-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1405t, 1185t and 1183t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

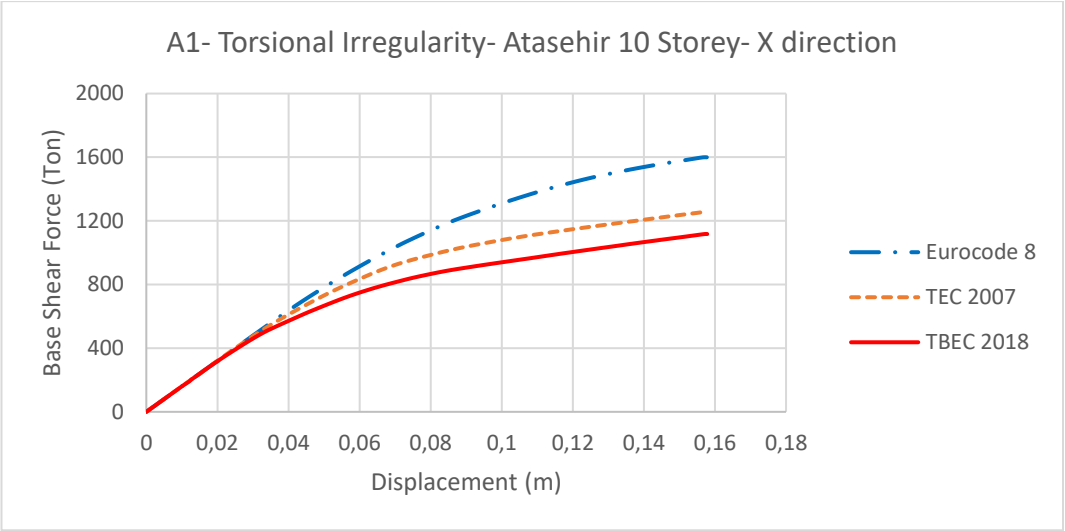


Figure 5.15: Pushover analysis curves of the A1-A-10S building (X Direction)

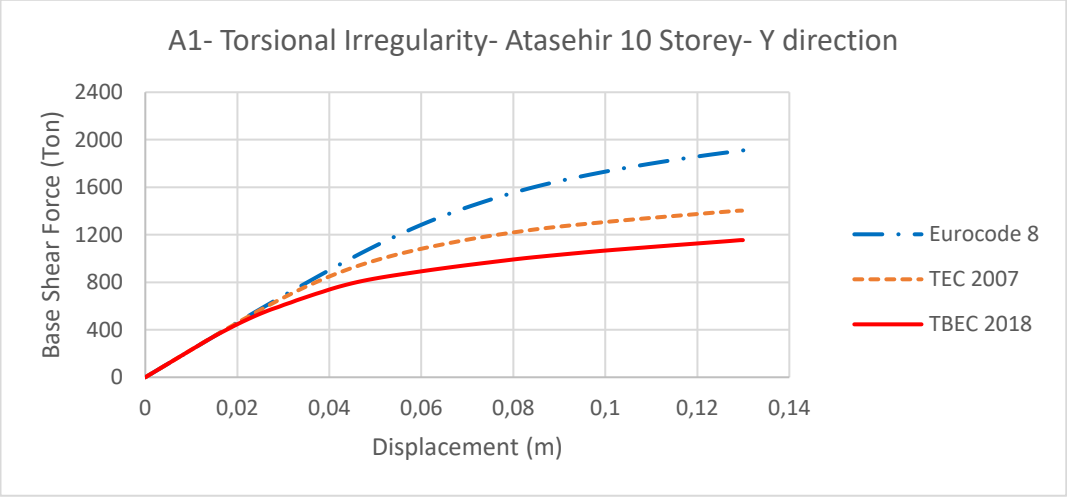


Figure 5.16: Pushover analysis curves of the A1-A-10S building (Y Direction)

The pushover curves show that (Fig.5-15 & Fig.5-16) there was a significant difference between the pushover analysis results of the 10-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1599t, 1253t and 1117t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the x direction.

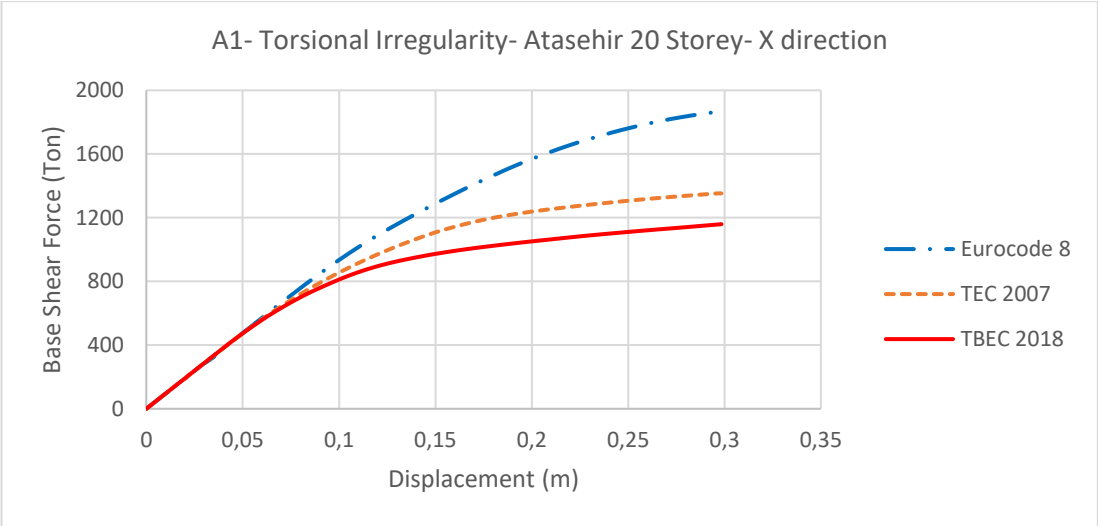


Figure 5.17: Pushover analysis curves of the A1-A-20S building (X Direction)

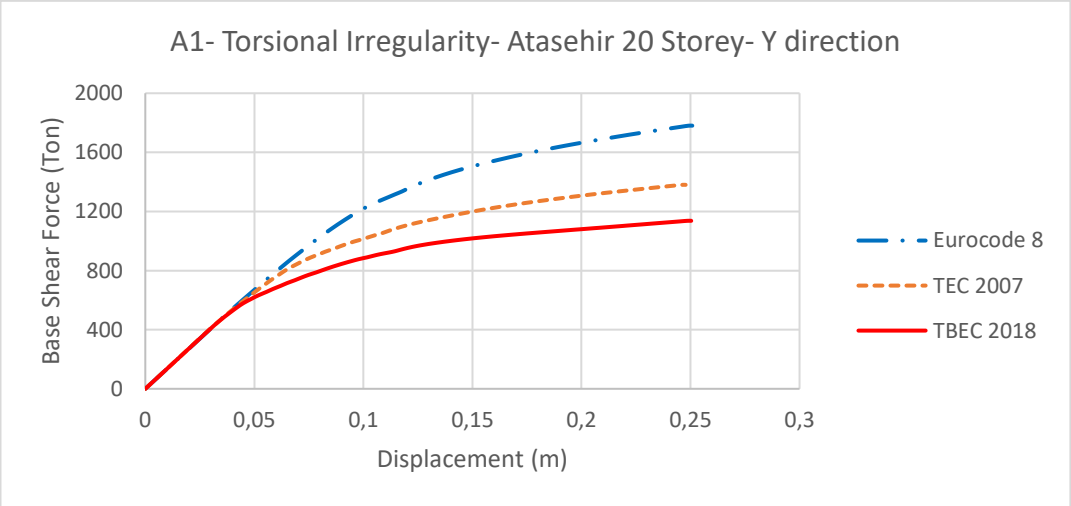


Figure 5.18: Pushover analysis curves of the A1-A-20S building (Y Direction)

The pushover curves show that (Fig.5-17 & Fig.5-18) there was a significant difference between the pushover analysis results of the 20-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1866t, 1352t and 1159t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

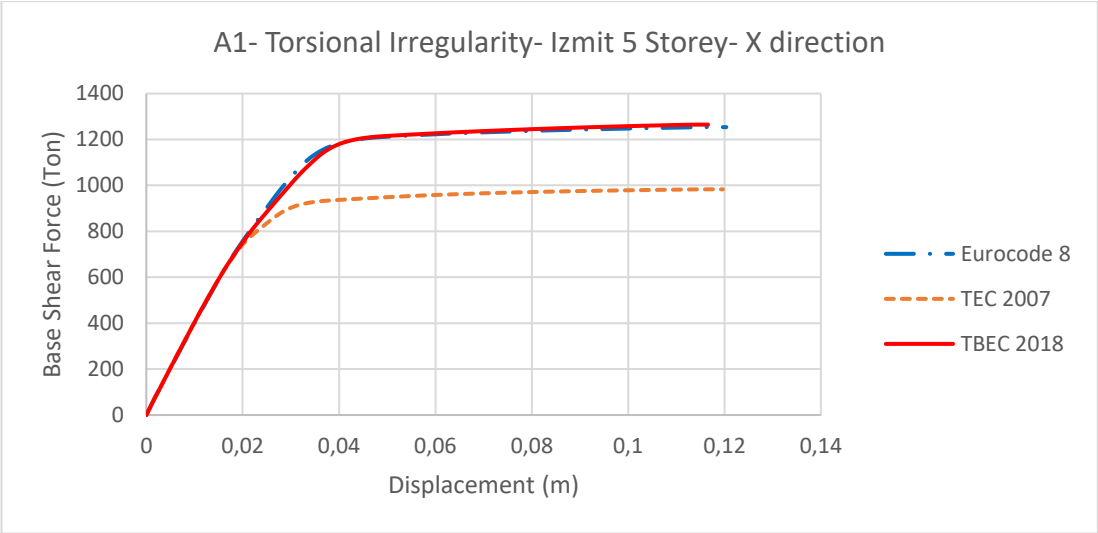


Figure 5.19: Pushover analysis curves of the A1-I-5S building (X Direction)

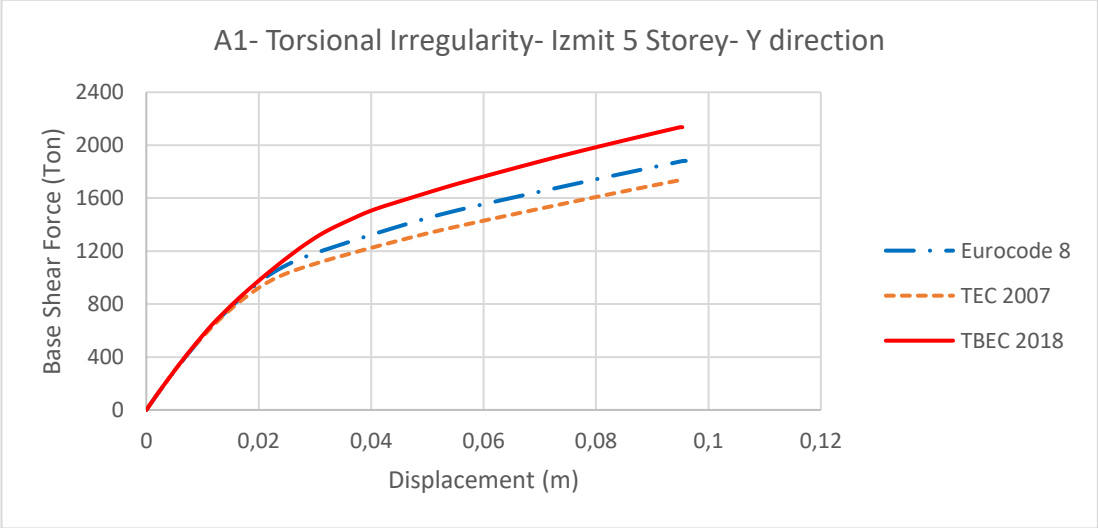


Figure 5.20: Pushover analysis curves of the A1-I-5S building (Y Direction)

The pushover curves show that (Fig.5-19 & Fig.5-20) there were partially differences between the pushover analysis results of the 5-Storey building in Izmit. TEC 2007 shows lower values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1253t, 982t and 1264t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig.5-20, the difference between the pushover curves of TBEC 2018 and EC 8 has increased.

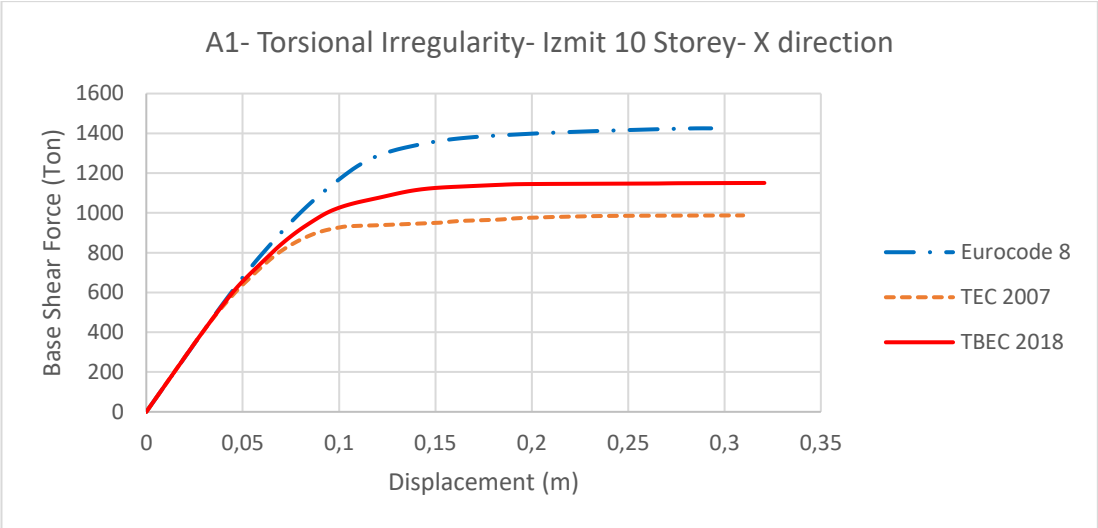


Figure 5.21: Pushover analysis curves of the A1-I-10S building (X Direction)

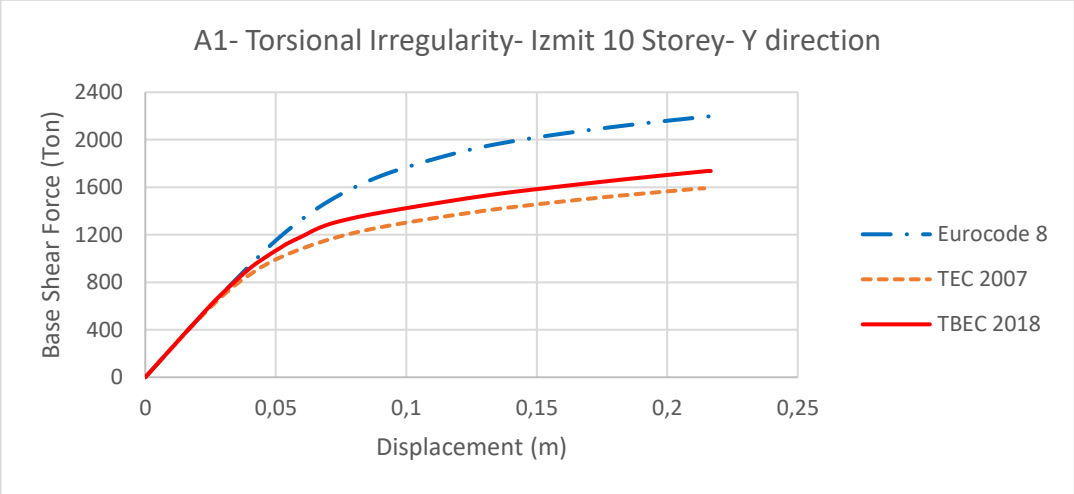


Figure 5.22: Pushover analysis curves of the A1-I-10S building (Y Direction)

The pushover curves show that (Fig.5-21 & Fig.5-22) there was a significant difference between the pushover analysis results of the 10-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1425t, 987t and 1150t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-22, the difference between TBEC 2018 and TEC 2007 has increased, although the X and Y directions of the pushover analysis curves show similarity.

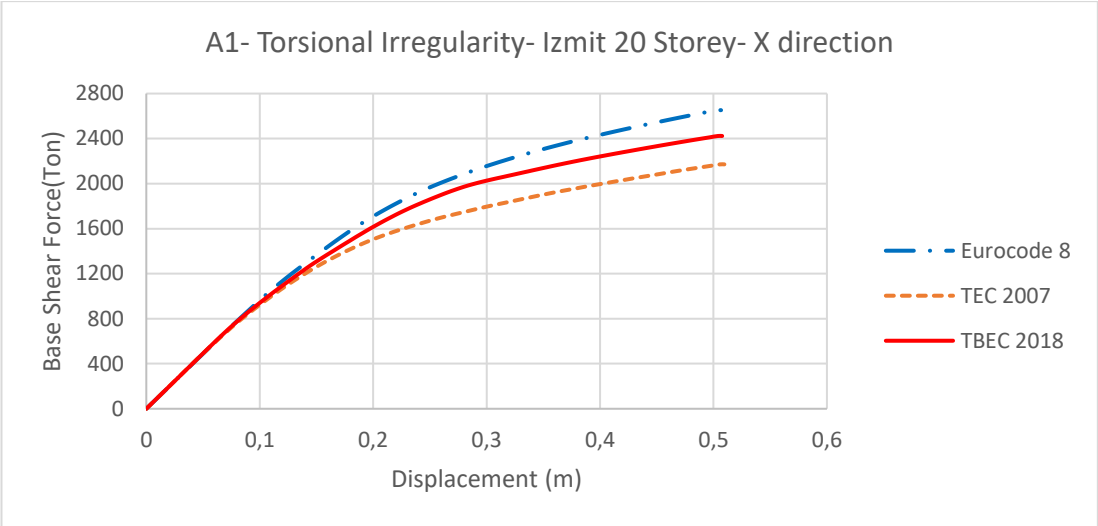


Figure 5.23: Pushover analysis curves of the A1-I-20S building (X Direction)

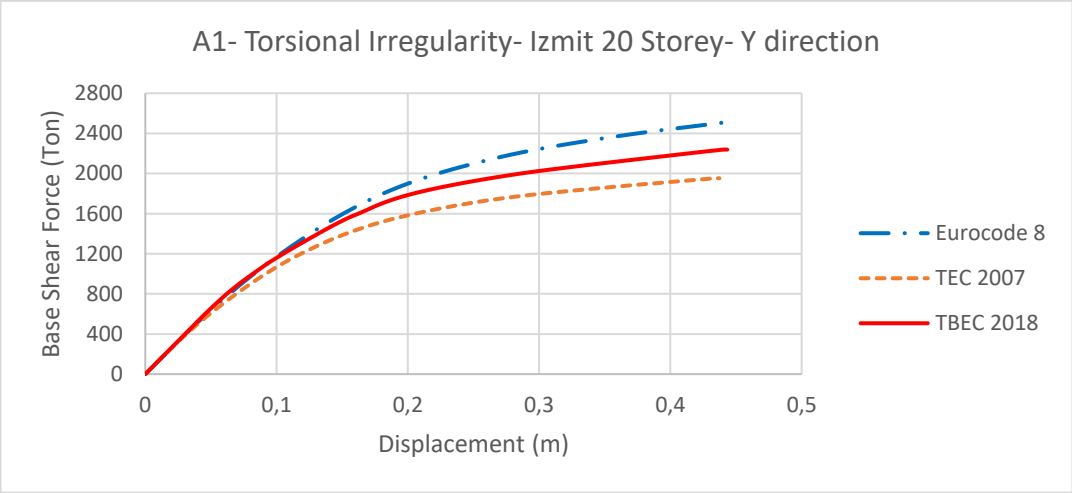


Figure 5.24: Pushover analysis curves of the A1-I-20S building (X Direction)

The pushover curves show that (Fig.5-23 & Fig.5-24) there was a significant difference between the pushover analysis results of the 20-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 2652t, 2171t and 2423t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

Table 5.8: Performance levels and shear forces of A1 Type irregular buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
A1 Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	364.8	0.010	LD	326.8	0.009	LD	240.0	0.007	LD
			1405.0	**0.073**	**CD**	**1185.9**	**0.073**	**CD**	**1183.0**	**0.073**	**CD**
		Y	435.3	0.009	LD	352.5	0.007	LD	250.2	0.005	LD
			1526.4	**0.064**	**CD**	**1302.0**	**0.063**	**CD**	**1289.6**	**0.063**	**CD**
	10 Storey	X	287.6	0.017	LD	209.2	0.013	LD	155.3	0.009	LD
			1599.3	**0.156**	**CD**	**1253.9**	**0.156**	**CD**	**1117.3**	**0.157**	**CD**
		Y	375.5	0.016	LD	273.5	0.011	LD	228.1	0.009	LD
			1912.6	**0.130**	**CD**	**1402.9**	**0.129**	**CD**	**1154.5**	**0.129**	**CD**
	20 Storey	X	264.7	0.027	LD	142.5	0.014	LD	347.3	0.036	LD
			1866.6	**0.297**	**CD**	**1352.4**	**0.295**	**CD**	**1159.2**	**0.298**	**CD**
		Y	388.6	0.028	LD	216.8	0.015	LD	187.1	0.013	LD
			1780.3	**0.249**	**CD**	**1380.1**	**0.245**	**CD**	**1136.7**	**0.248**	**CD**
Izmit	5 Storey	X	33.1	0.0007	LD	23.6	0.0005	LD	27.1	0.0006	LD
			1253.8	**0.115**	**CD**	**982.8**	**0.115**	**CD**	**1264.6**	**0.113**	**CD**
		Y	70.0	0.001	LD	66.9	0.001	LD	67.1	0.001	LD
			1881.1	**0.095**	**CD**	**1737.5**	**0.095**	**CD**	**2135.5**	**0.094**	**CD**
	10 Storey	X	328.5	0.023	LD	275.8	0.019	LD	279.8	0.020	LD
			1425.1	**0.284**	**CD**	**987.4**	**0.309**	**CD**	**1150.6**	**0.320**	**CD**
		Y	317.0	0.013	LD	149.1	0.006	LD	326.9	0.013	LD
			2197.7	**0.216**	**CD**	**1590.3**	**0.213**	**CD**	**1736.3**	**0.215**	**CD**
	20 Storey	X	565.9	0.057	LD	390.4	0.039	LD	450.8	0.045	LD
			2652.3	**0.502**	**CD**	**2171.1**	**0.505**	**CD**	**2423.1**	**0.503**	**CD**
		Y	120.9	0.009	LD	86.8	0.006	LD	435.7	0.033	LD
			2508.5	**0.441**	**CD**	**1952.4**	**0.433**	**CD**	**2238.1**	**0.440**	**CD**

Table 5.9: Damage ratios at the performance level of A1-A-5S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage				3.1			6.3		
		Columns Damage Percentage		12.3			5.6			6.6	
		Plastic Column Vc ratio	0.1			-			-		
		Performance Level	CD			CD			CD		

Table 5.10: Damage ratios at the performance level of A1-A-10S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage				3.1			15.6		
		Columns Damage Percentage	0.4	9.2			8.4		9.2	8.5	
		Plastic Column Vc ratio	0.7			-			-		
		Performance Level	CD			CD			CD		

Table 5.11: Damage ratios at the performance level of A1-A-20S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	20 Storey	Beam Damage Percentage	3.1			25			12.5		
		Columns Damage Percentage	4.3	10.4		2.4	5.5		2.2	3.4	
		Plastic Column Vc ratio	14.5			5.5			3.4		
		Performance Level	CD			CD			CD		

Table 5.12: Damage ratios at the performance level of A1-I-5S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	5 Storey	Beam Damage Percentage	62.5			40.6			25.0		
		Columns Damage Percentage	24.9	5.8		16.4	7.3		2.6	4.5	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.13: Damage ratios at the performance level of A1-I-10S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	10 Storey	Beam Damage Percentage	25.0			18.8			31.3		
		Columns Damage Percentage	13.9	7.7		2.2			4.6		
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.14: Damage ratios at the performance level of A1-I-20S building

Case A1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	20 Storey	Beam Damage Percentage	17.9			32.1			21.4		
		Columns Damage Percentage	1.9	6.5		4.8	7.9		2.3	5.2	
		Plastic Column Vc ratio	5.9			7.9			7.5		
		Performance Level	CD			CD			CD		

The performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in

residential buildings. In order to reveal the difference between the codes, the damage ratio comparison of the performance points of the A1 type irregular buildings is detailed below.

- Table 5-9 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-8, although EC 8 has the highest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 12.3, 5.6 and 6.6 for EC 8, TEC 2007 and TBEC 2018, respectively. However, according to Table 5-9, no beam damage was observed in EC 8.
- Table 5-10 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-8, although EC 8 has the highest shear force in a 10-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 9.2, 8.4 and 8.5 for EC 8, TEC 2007 and TBEC 2018 respectively. On the other hand, TBEC 2018 showed the worst performance in the case of beam damage ratio as 15,6.
- Table 5-11 indicates the damage ratios at the performance level of 20-storey building at Atasehir. According to table 5-8, although EC 8 has the highest base shear force in a 20-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 10.4, 5.5 and 3.4 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, TEC 2007 and TBEC 2018 showed the worst performances in the case of beam damage ratio.

- Table 5-12 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to table 5-8, since TEC 2007 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 5.8, 7.3 and 4.5 for EC 8, TEC 2007 and TBEC 2018, respectively. However, EC 8 showed the worst performance in the case of beam damage ratio as 62,2.
- Table 5-13 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to table 5-8, although TEC 2007 has the lowest base shear force in a 10-storey building, it has a much lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 7.7(Advanced Damage), 2.2(Marked Damage) and 4.6(Marked Damage) for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 25, 18,8 and 31,3 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-14 indicates the damage ratios at the performance level of 20-storey building at Izmit. According to table 5-8, since TEC 2007 has the lowest base shear force in a 20-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 6.5, 7.9 and 5.2 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance levels are 17.9, 32.1 and 21.4 for EC 8, TEC 2007 and TBEC 2018, respectively.

According to tables, in the buildings where TBEC 2018 was used, as a result of the different spectral values of Izmit and Atasehir, significant differences were observed between the base shear forces.

5.2.3 A2 Type: Floor Discontinuities

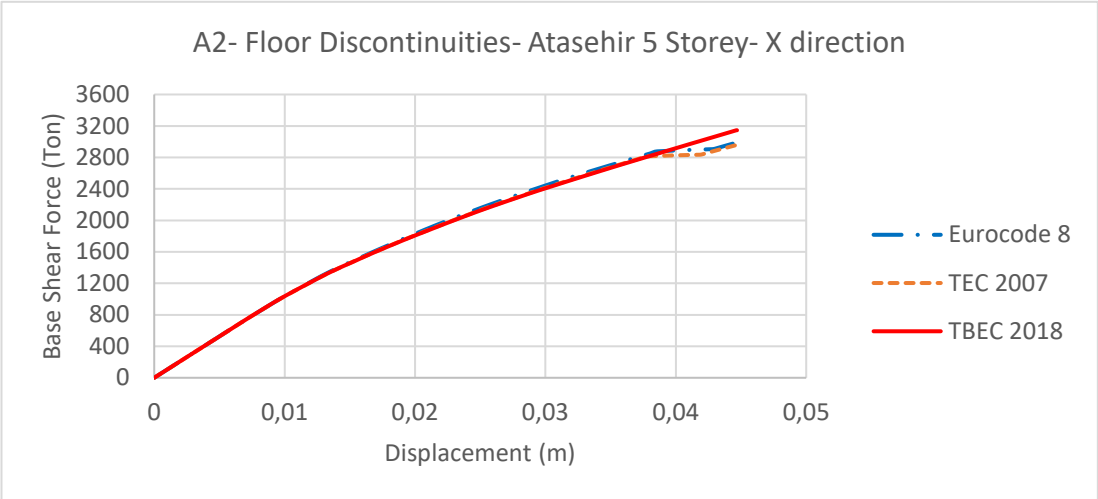


Figure 5.25: Pushover analysis curves of the A2-A-5S building (X Direction)

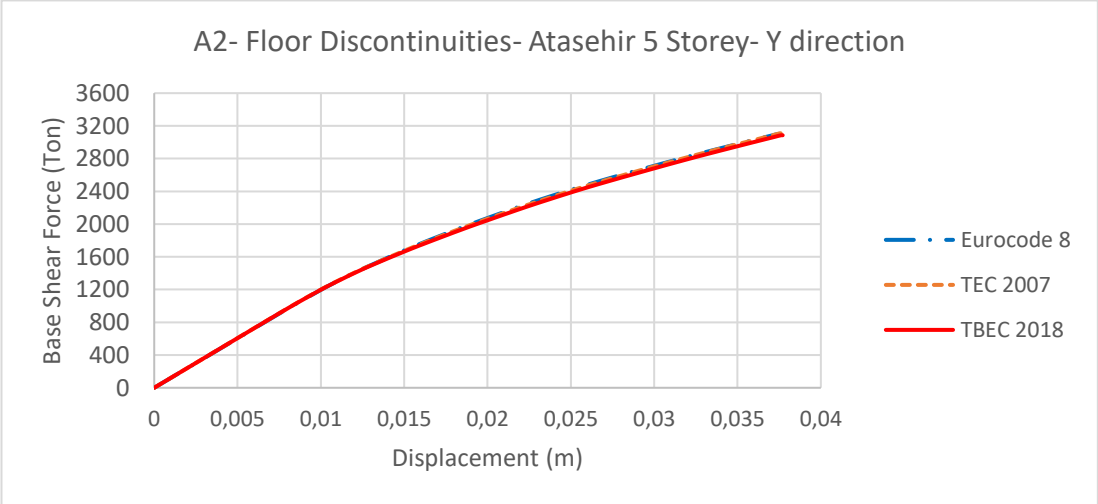


Figure 5.26: Pushover analysis curves of the A2-A-5S building (Y Direction)

The pushover curve shows that (Fig. 5-25) there were partially differences between the pushover analysis results of the 5-Storey building in Atasehir. Base shear forces in the X-direction of buildings are 3006t, 2954t and 3144t for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Fig. 5-26 the Y direction pushover curves of the buildings were almost similar.

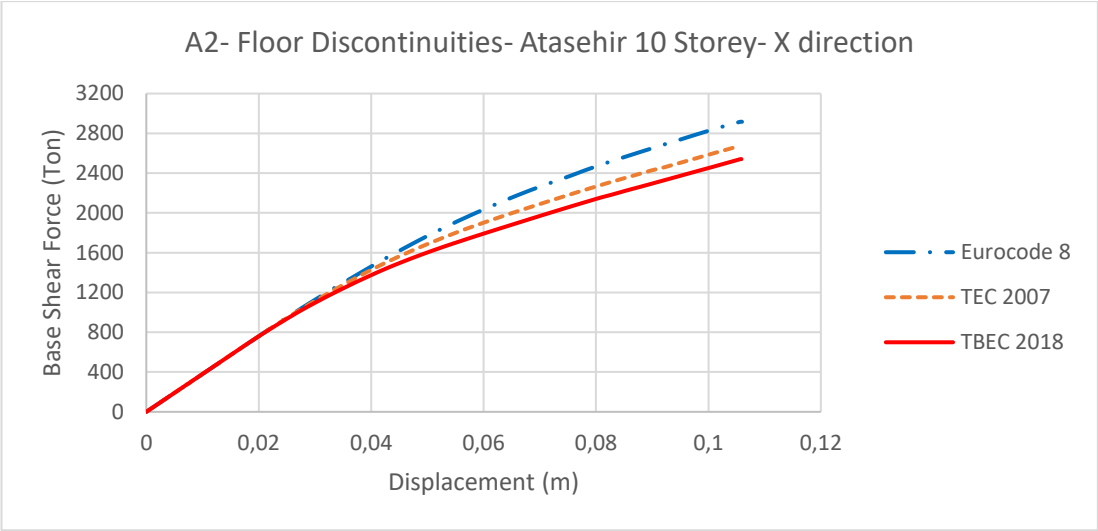


Figure 5.27: Pushover analysis curves of the A2-A-10S building (X Direction)

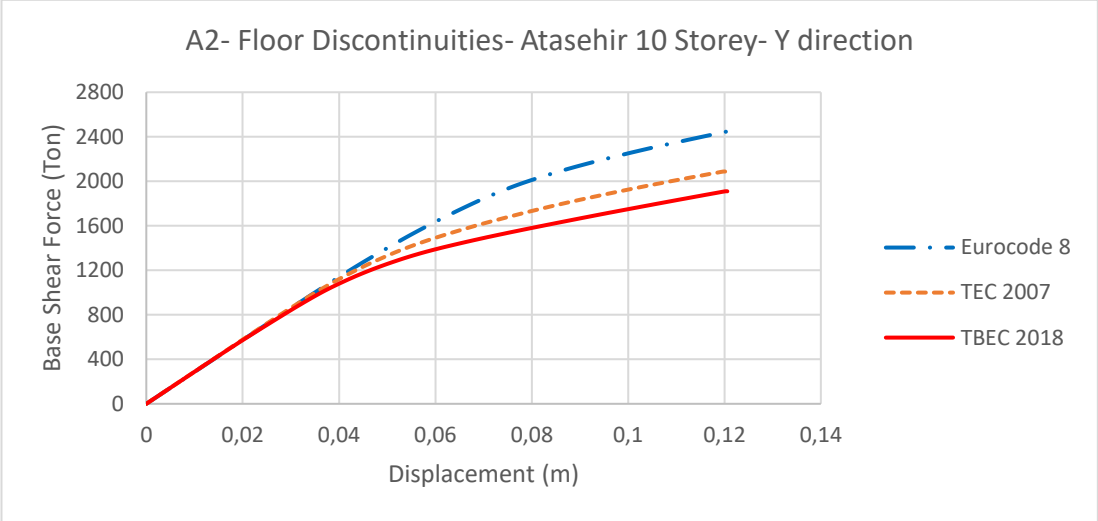


Figure 5.28: Pushover analysis curves of the A2-A-10S building (Y Direction)

The pushover curves show that (Fig.5-27 & Fig.5-28) there were partially differences between the pushover analysis results of the 10-Storey building in Atasehir. Base shear forces in the X-direction of buildings are 2476t, 2193t and 1991t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-28, the difference between TEC 2007 and EC 8 has increased, although the X and Y directions of the pushover analysis curves show similarity.

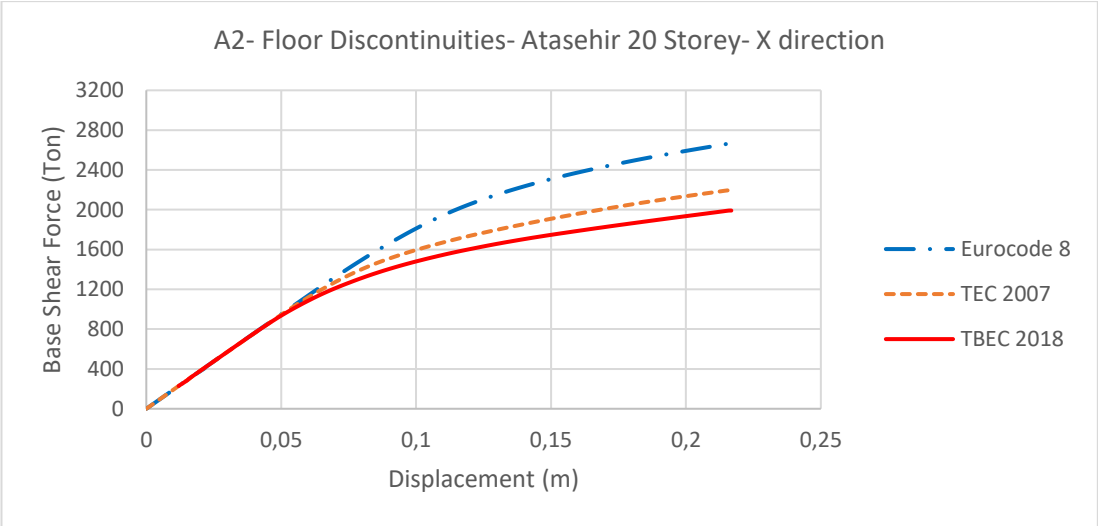


Figure 5.29: Pushover analysis curves of the A2-A20S building (X Direction)

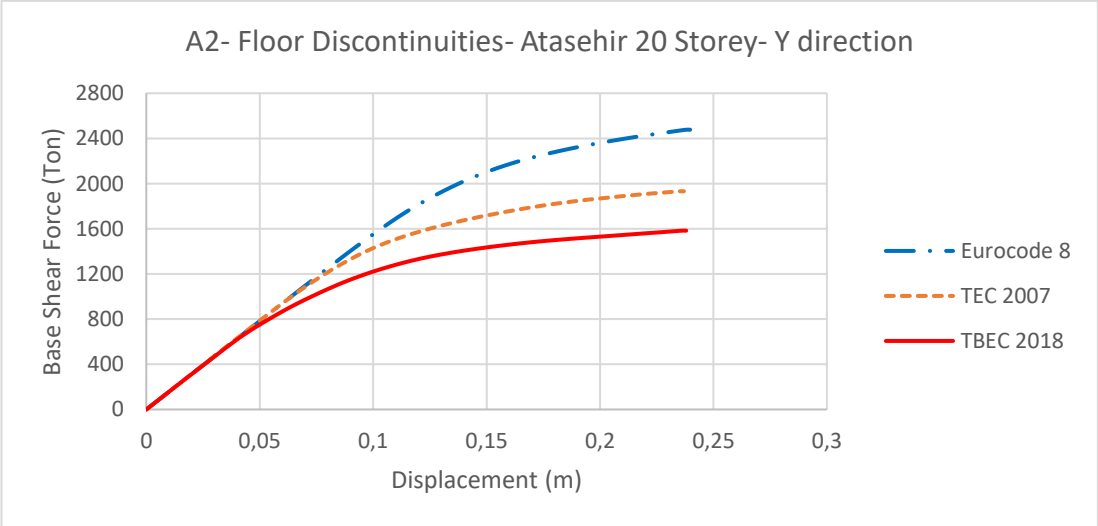


Figure 5.30: Pushover analysis curves of the A2-A-20S building (Y Direction)

The pushover curves show that (Fig.5-29 & Fig.5-30) there was a significant difference between the pushover analysis results of the 20-Storey building in Atasehir. Base shear forces in the X-direction of buildings are 2916t, 2671t and 2540t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-30, the difference between TEC 2007 and TBEC 2018 has increased, although the X and Y directions of the pushover analysis curves show similarity.

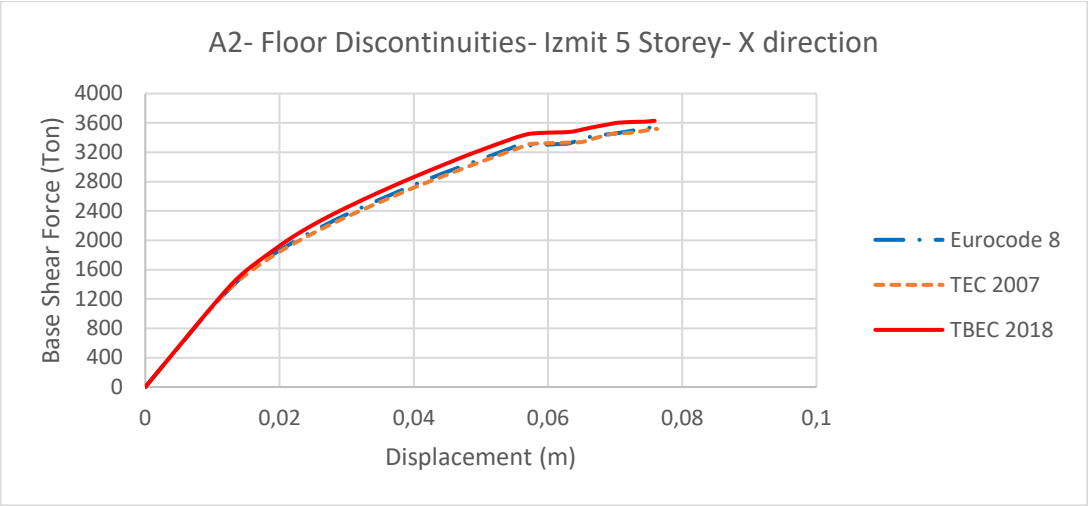


Figure 5.31: Pushover analysis curves of the A2-I-5S building (X Direction)

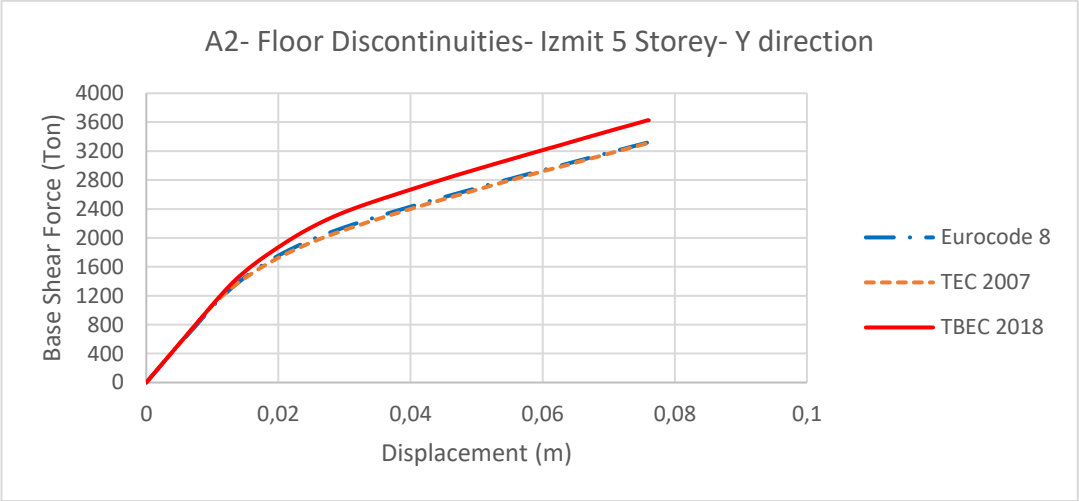


Figure 5.32: Pushover analysis curves of the A2-I-5S building (Y Direction)

The pushover curves show that (Fig.5-31 & Fig.5-32) there were partially differences between the pushover analysis results of the 5-Storey building in Izmit. TBEC 2018 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 3542t, 3517t and 3628t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

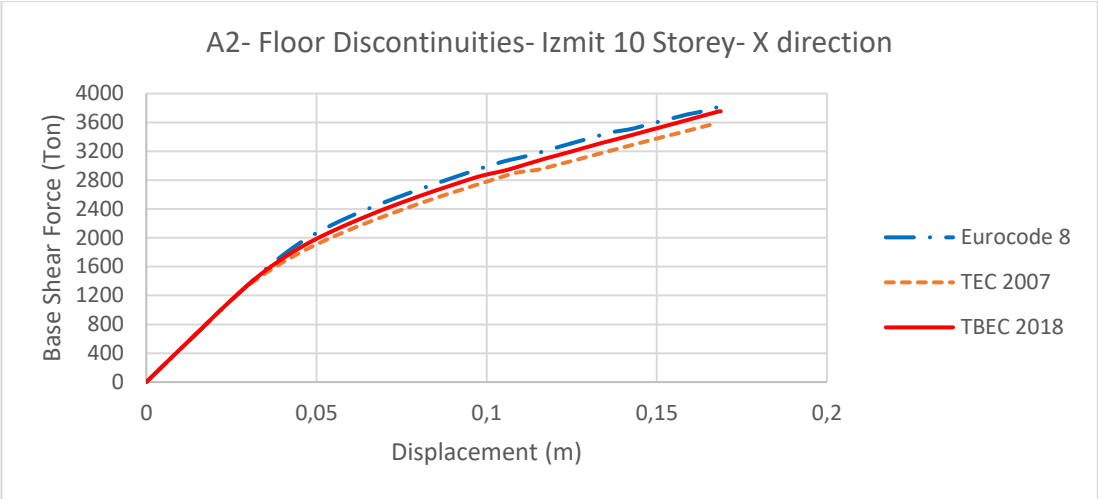


Figure 5.33: Pushover analysis curves of the A2-I-10S building (X Direction)

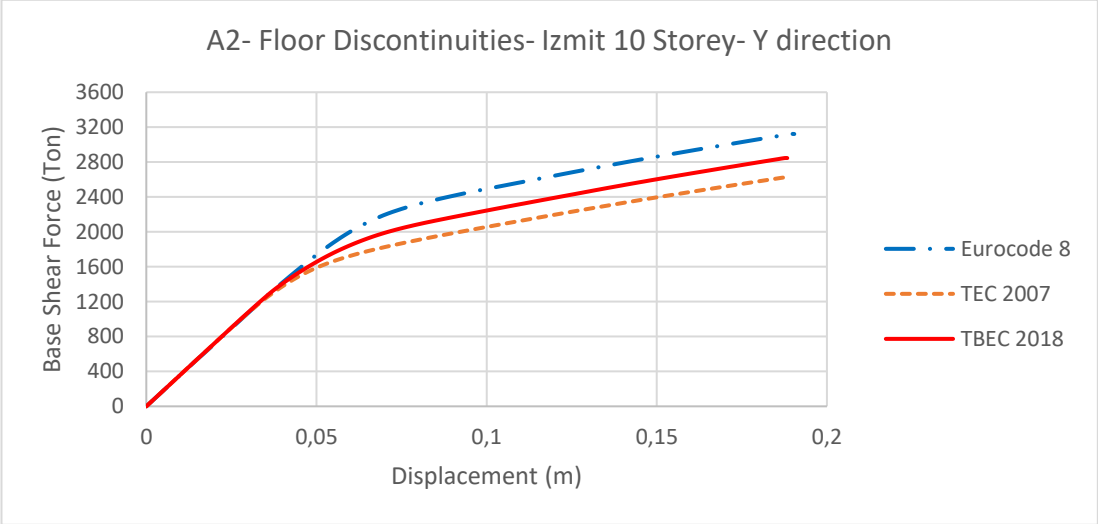


Figure 5.34: Pushover analysis curves of the A2-I-10S building (Y Direction)

The pushover curves show that (Fig.5-33 & Fig.5-34) there were partially differences between the pushover analysis results of the 10-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 3804t, 3582t and 3753t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-34, the difference between TBEC 2018 and EC 8 has increased, although the X and Y directions of the pushover analysis curves show similarity.

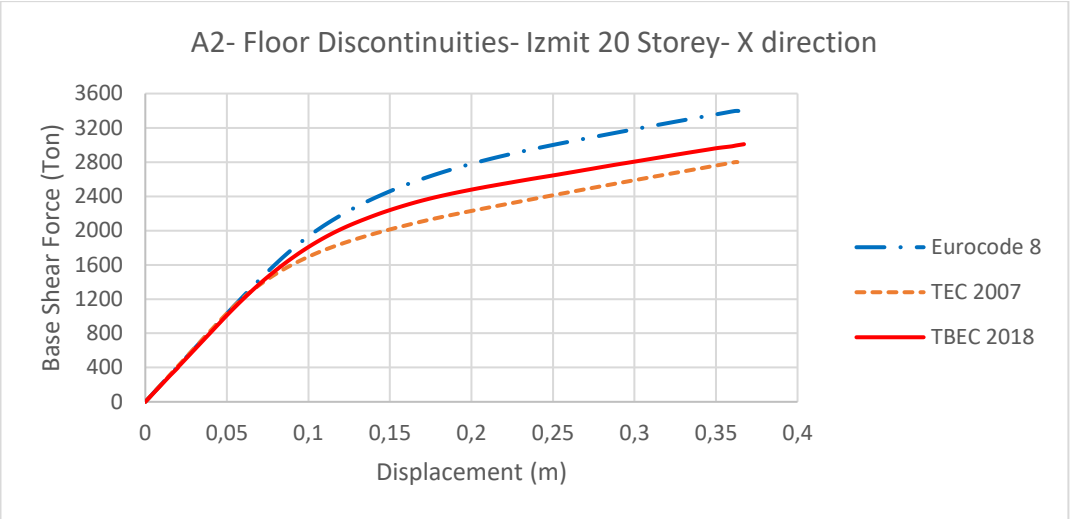


Figure 5.35: Pushover analysis curves of the A2-I-20S building (X Direction)

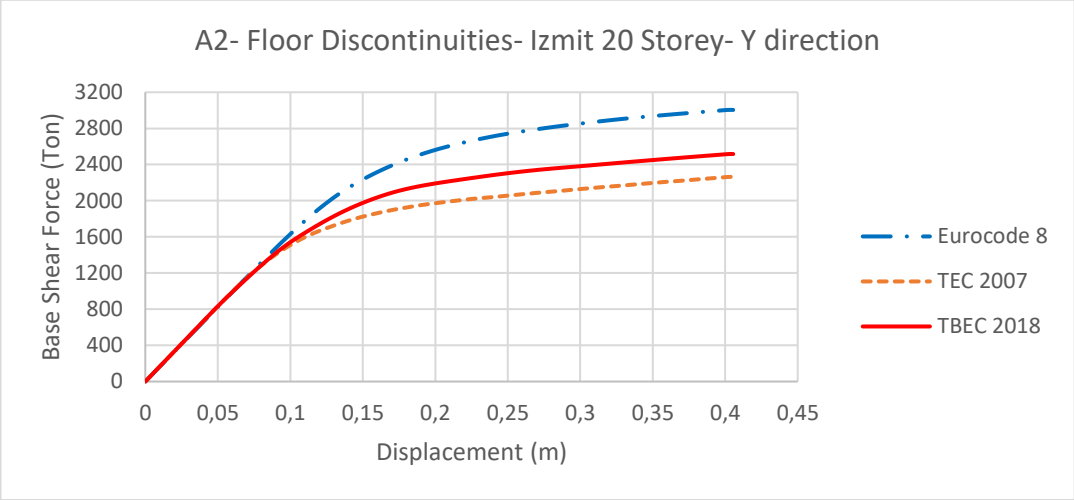


Figure 5.36: Pushover analysis curves of the A2-I-20S building (Y Direction)

The pushover curves show that (Fig.5-35 & Fig.5-36) there were a significant difference between the pushover analysis results of the 20-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 3396t, 2799t and 3008t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

Table 5.15: Performance levels and shear forces of A2 Type irregular buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
A2 Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	674.0	0.006	LD	689.2	0.006	LD	677.6	0.006	LD
			3006.9	**0.045**	**CD**	**2954.5**	**0.044**	**CD**	**3144.9**	**0.044**	**CD**
		Y	804.5	0.006	LD	846.0	0.006	LD	802.3	0.006	LD
			3102	**0.037**	**CD**	**3108.2**	**0.037**	**CD**	**3085.1**	**0.037**	**CD**
	10 Storey	X	709.7	0.018	LD	642.5	0.016	LD	593.97	0.015	LD
			2916.0	**0.105**	**CD**	**2671.1**	**0.105**	**CD**	**2540.6**	**0.105**	**CD**
		Y	554.7	0.019	LD	477.4	0.016	LD	232.02	0.008	LD
			2449.1	**0.120**	**CD**	**2087.2**	**0.119**	**CD**	**1909.6**	**0.120**	**CD**
	20 Storey	X	329.5	0.017	LD	2476.7	0.237	LD	228.3	0.011	LD
			2665.7	**0.216**	**CD**	**2193.7**	**0.215**	**CD**	**1991.4**	**0.215**	**CD**
		Y	692.0	0.044	LD	486.8	0.030	LD	216.4	0.013	LD
			2476.7	**0.237**	**CD**	**1932.2**	**0.235**	**CD**	**1583.3**	**0.236**	**CD**
Izmit	5 Storey	X	575.3	0.005	LD	845.6	0.007	LD	614.0	0.005	LD
			3542.5	**0.075**	**CD**	**3517.5**	**0.075**	**CD**	**3628.4**	**0.075**	**CD**
		Y	662.4	0.006	LD	861.4	0.008	LD	612.4	0.005	LD
			3336.6	**0.076**	**CD**	**3317.2**	**0.076**	**CD**	**3625.0**	**0.075**	**CD**
	10 Storey	X	402.1	0.008	LD	409.3	0.008	LD	460.4	0.010	LD
			3804.7	**0.167**	**CD**	**3582.2**	**0.167**	**CD**	**3753.4**	**0.168**	**CD**
		Y	1026.4	0.028	LD	647.4	0.017	LD	467.8	0.012	LD
			3121.0	**0.189**	**CD**	**2620.8**	**0.186**	**CD**	**2845.3**	**0.187**	**CD**
	20 Storey	X	340.9	0.016	LD	192.3	0.009	LD	298.2	0.014	LD
			3396.7	**0.361**	**CD**	**2799.6**	**0.361**	**CD**	**3008.6**	**0.367**	**CD**
		Y	485.4	0.029	LD	351.1	0.021	LD	634.8	0.038	LD
			3004.2	**0.401**	**CD**	**2263.4**	**0.402**	**CD**	**2516.5**	**0.402**	**CD**

Table 5.16: Damage ratios at the performance level of A2-A-5S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage									
		Columns Damage Percentage		2.1			2.1		0.8	0.9	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.17: Damage ratios at the performance level of A2-A-10S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage									
		Columns Damage Percentage	0.2	1.4			1.5			1.5	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.18: Damage ratios at the performance level of A2-A-20S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	20 Storey	Beam Damage Percentage									
		Columns Damage Percentage	0.7	2.0		0.7	2.6			3.2	
		Plastic Column Vc ratio	1.8			1.3			1.1		
		Performance Level	CD			CD			CD		

Table 5.19: Damage ratios at the performance level of A2-I-5S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	5 Storey	Beam Damage Percentage									
		Columns Damage Percentage	1.5	1.1		1.0	1.1		0.8	1.1	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.20: Damage ratios at the performance level of A2-I-10S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	10 Storey	Beam Damage Percentage	10.9			10.9			15.6		
		Columns Damage Percentage		16.3		28.8	18.0		0.4	17.8	
		Plastic Column Vc ratio	1.3			7.6			10.0		
		Performance Level	CD			CD			CD		

Table 5.21: Damage ratios at the performance level of A2-I-20S building

Case A2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	20 Storey	Beam Damage Percentage	31.3			39.1			39.1		
		Columns Damage Percentage	11.6	11.5		0.5	13.8		1.7	2.6	
		Plastic Column Vc ratio	11.1			10.1			9.2		
		Performance Level	CD			CD			CD		

The performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in residential buildings. In order to reveal the difference between the codes, the damage ratio comparison of the performance points of the A2 type irregular buildings is detailed below.

- Table 5-16 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-15, although almost all base shear forces are close to each other, TBEC 2018 has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 2.1, 2.1 and 0.9 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-16, no beam damage was observed in any code.
- Table 5-17 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-15, although EC 8 has the highest shear force in a 10-storey building, the column damage ratios are very close to each other between earthquake codes. Damage ratios at the performance level of buildings are 1.4, 1.5 and 1.5 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-17, no beam damage was observed in any code.
- Table 5-18 indicates the damage ratios at the performance level of 20-storey building at Atasehir. According to table 5-15, since EC 8 has the highest base shear force in a 20-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 2.0, 2.6 and 3.2 for EC 8, TEC 2007 and TBEC 2018,

respectively. On the other hand, according to Table 5-17, no beam damage was observed in any code.

- Table 5-19 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to Table 5-15, in a 10-storey building, since all base shear forces were close to each other, there was not much difference was observed in the column damage ratios. Damage ratios at the performance level of buildings are 1.5, 1.0 and 0.8 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-17, no beam damage was observed in any code.
- Table 5-20 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to Table 5-15, since TEC 2007 has the lowest base shear force in a 10-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 16.3, 18.0 and 17.8 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 10.9, 10.9 and 15.6 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-21 indicates the damage ratios at the performance level of 20-storey building at Izmit. According to Table 5-15, since TEC 2007 has the lowest base shear force in a 20-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 11.5, 13.8 and 2.6 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance levels are 31.3, 39.1 and 39.1 for EC 8, TEC 2007 and TBEC 2018, respectively.

According to tables, in the buildings where TBEC 2018 was used, as a result of the different spectral values of Izmit and Atasehir, significant differences were observed between the base shear forces.

5.2.4 A3 Type: Projections in Plan

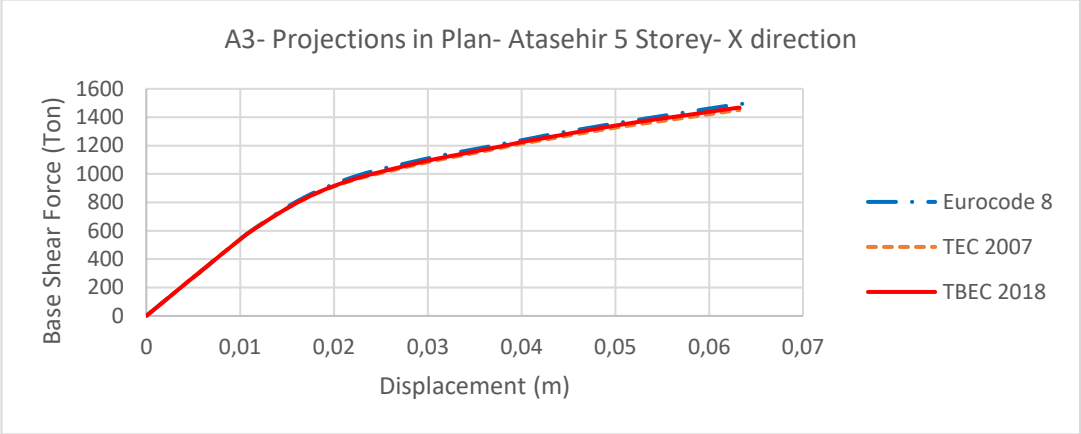


Figure 5.37: Pushover analysis curves of the A3-A-5S building (X Direction)

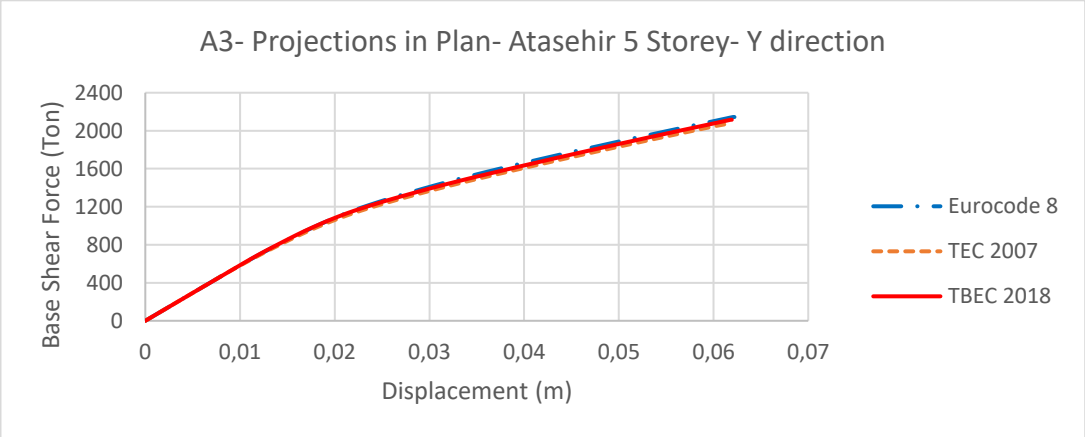


Figure 5.38: Pushover analysis curves of the A3-A-5S building (Y Direction)

The pushover curves show that (Fig.5-37 & Fig.5-38) the results of pushover analysis of 5-Storey building in Atasehir were almost similar. Base shear forces in the X-direction of buildings are 1493t, 1449t and 1466t for EC 8, TEC 2007 and TBEC 2018,

respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

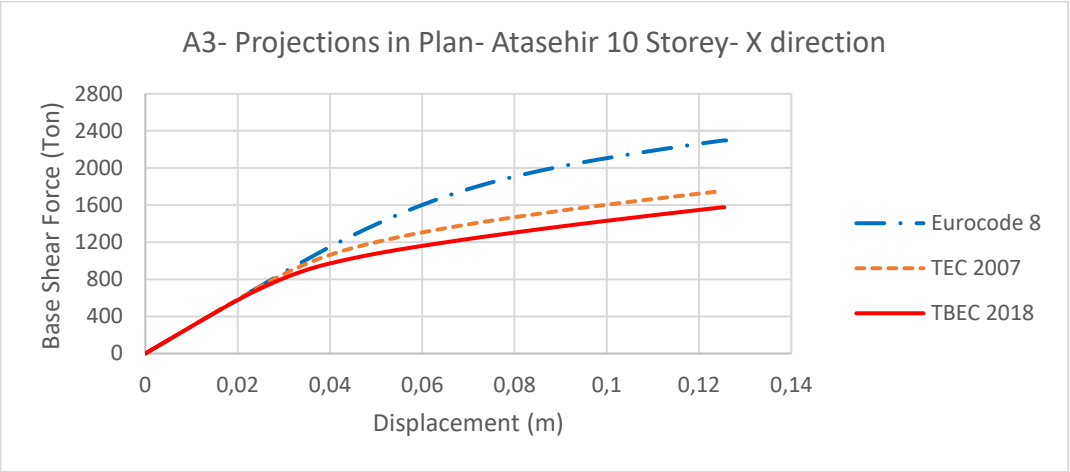


Figure 5.39: Pushover analysis curves of the A3-A-10S building (X Direction)

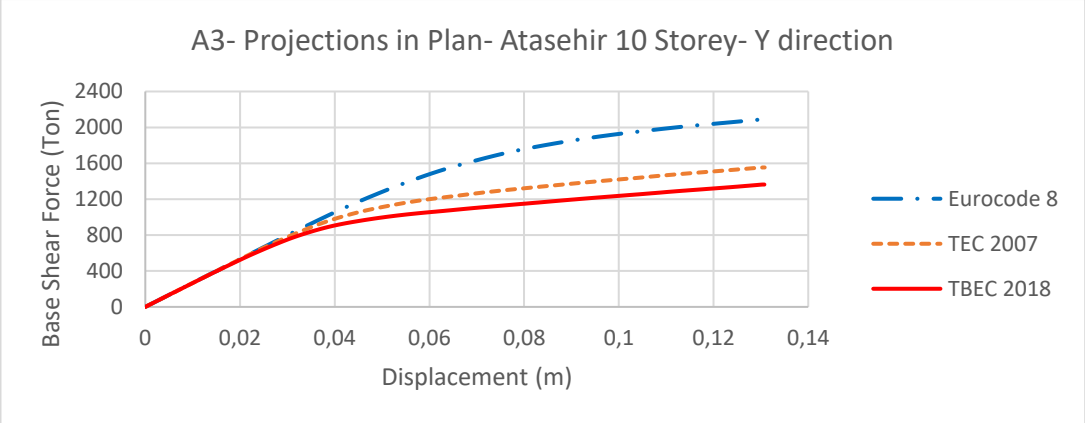


Figure 5.40: Pushover analysis curves of the A3-A-10S building (Y Direction)

The pushover curves show that (Fig.5-39 & Fig.5-40) there was a significant difference between the pushover analysis results of the 10-Storey building in Atasehir. Base shear forces in the X-direction of buildings are 2296t, 1748t and 1576t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-40, the difference between TEC 2007 and TBEC 2018 has increased, although the X and Y directions of the pushover analysis curves show similarity.

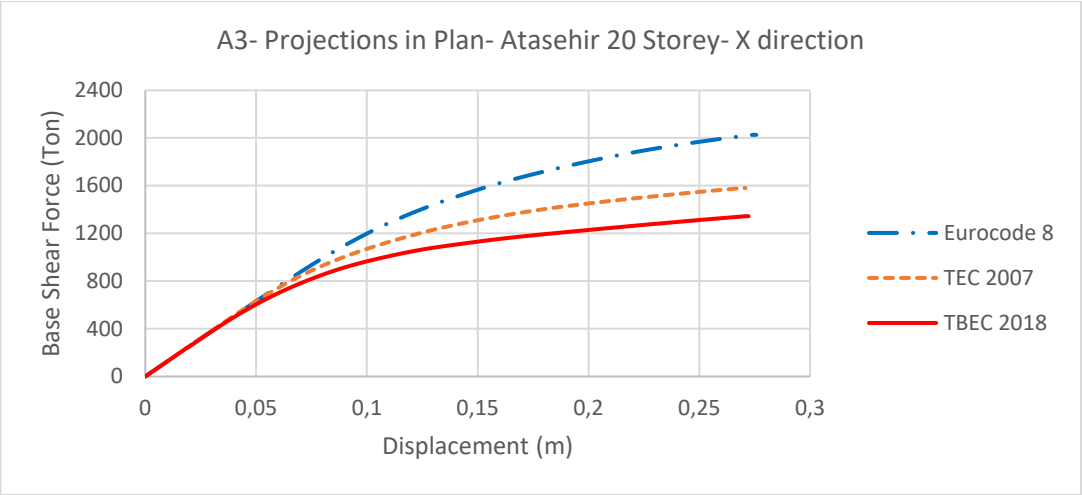


Figure 5.41: Pushover analysis curves of the A3-A-20S building (X Direction)

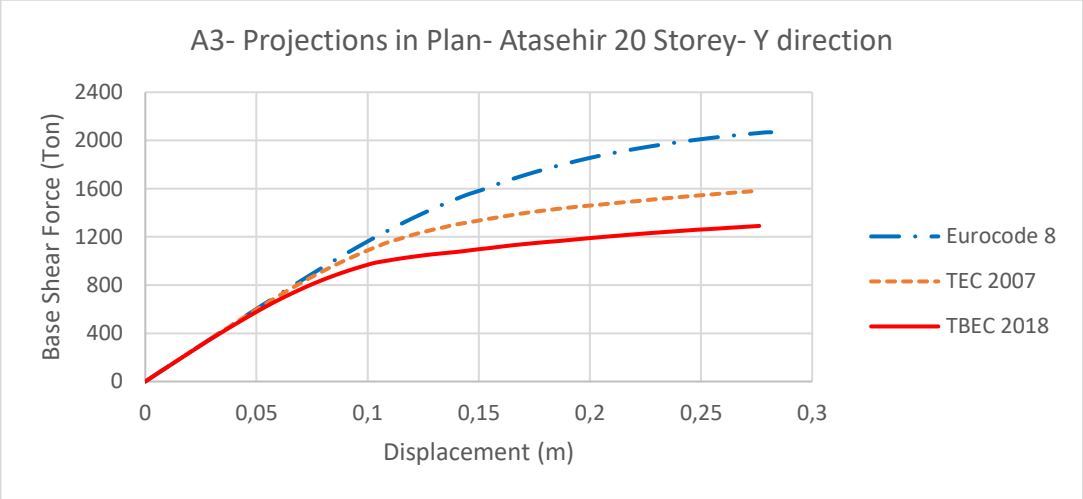


Figure 5.42: Pushover analysis curves of the A3-A-20S building (Y Direction)

The pushover curves show that (Fig.5-41 & Fig.5-42) there was a significant difference between the pushover analysis results of the 20-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 2026t, 1580t and 1344t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

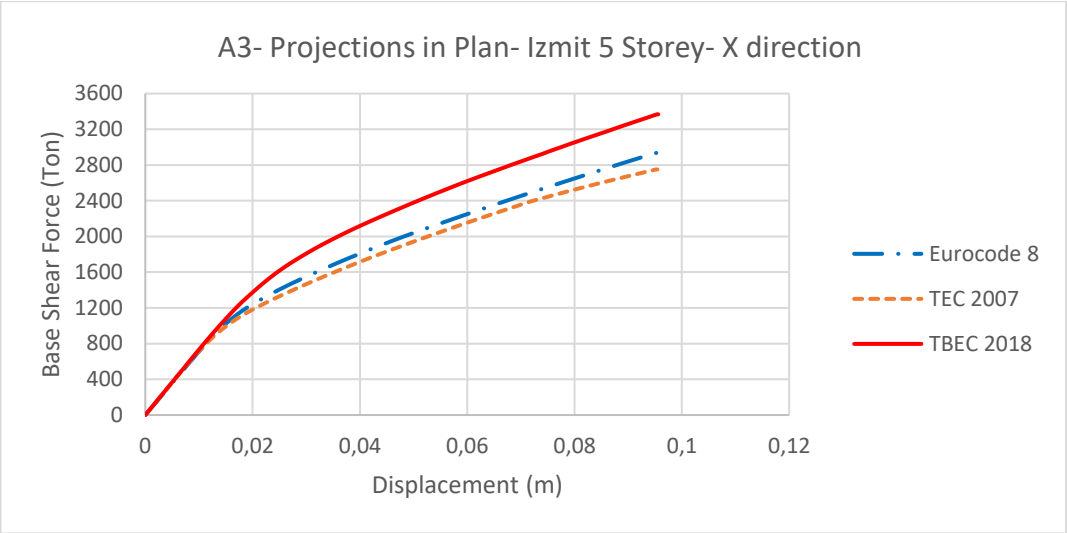


Figure 5.43: Pushover analysis curves of the A3-I-5S building (X Direction)

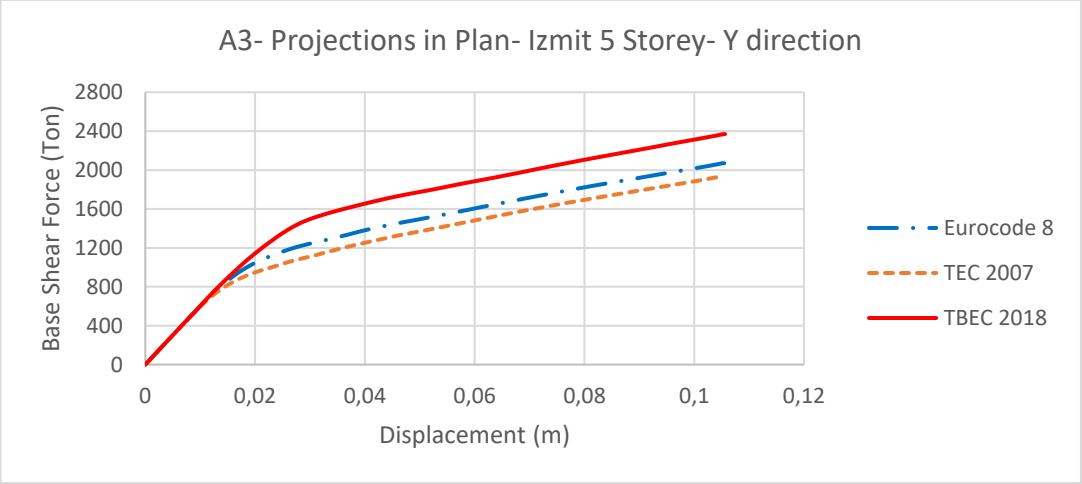


Figure 5.44: Pushover analysis curves of the A3-I-5S building (Y Direction)

The pushover curves show that (Fig.5-43 & Fig.5-44) there was partially differences between the pushover analysis results of the 5-Storey building in Izmit. TBEC 2018 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 2938t, 2749t and 3366t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

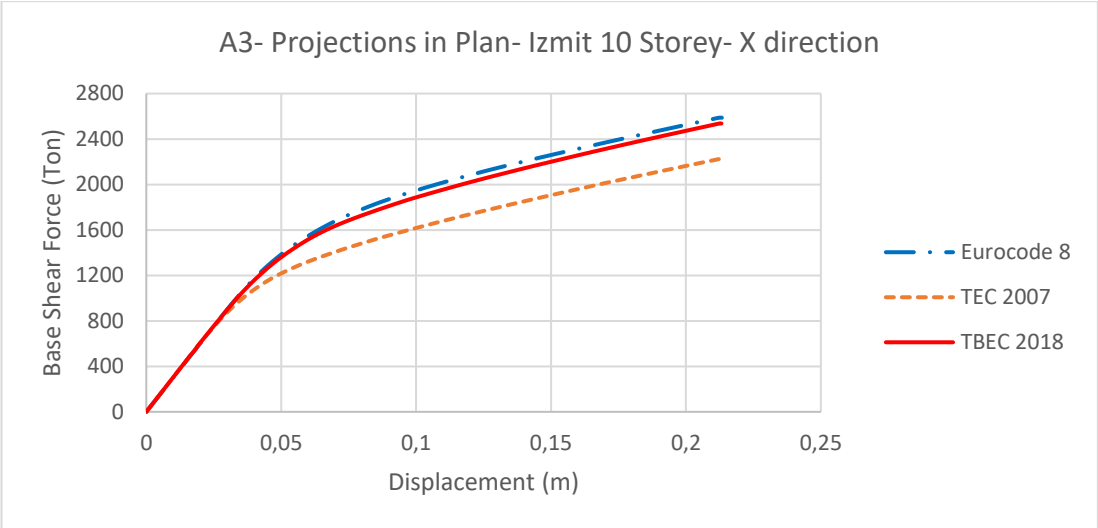


Figure 5.45: Pushover analysis curves of the A3-I-10S building (X Direction)

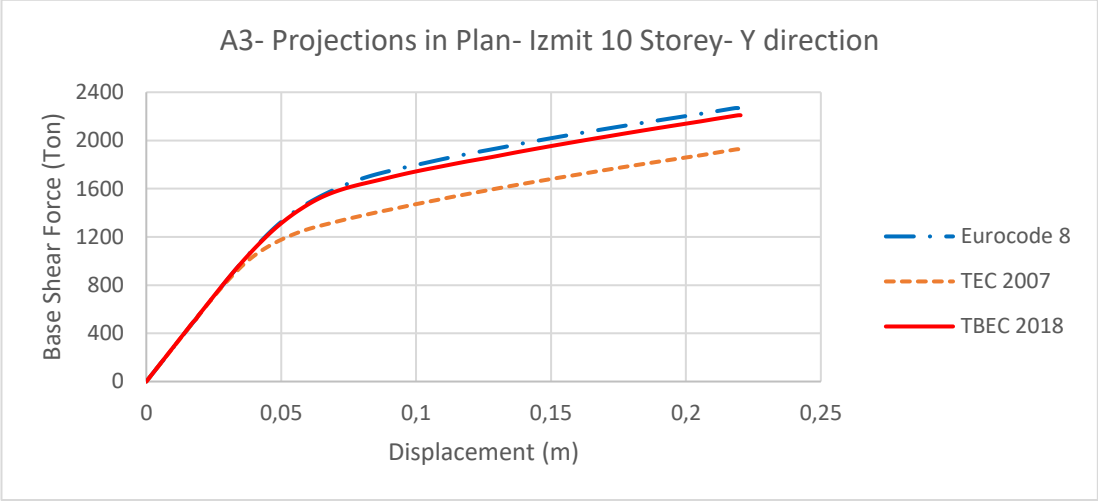


Figure 5.46: Pushover analysis curves of the A3-I-10S building (Y Direction)

The pushover curves show that (Fig.5-45 & Fig.5-46) there was partially differences between the pushover analysis results of the 10-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 2587t, 2224t and 2563t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

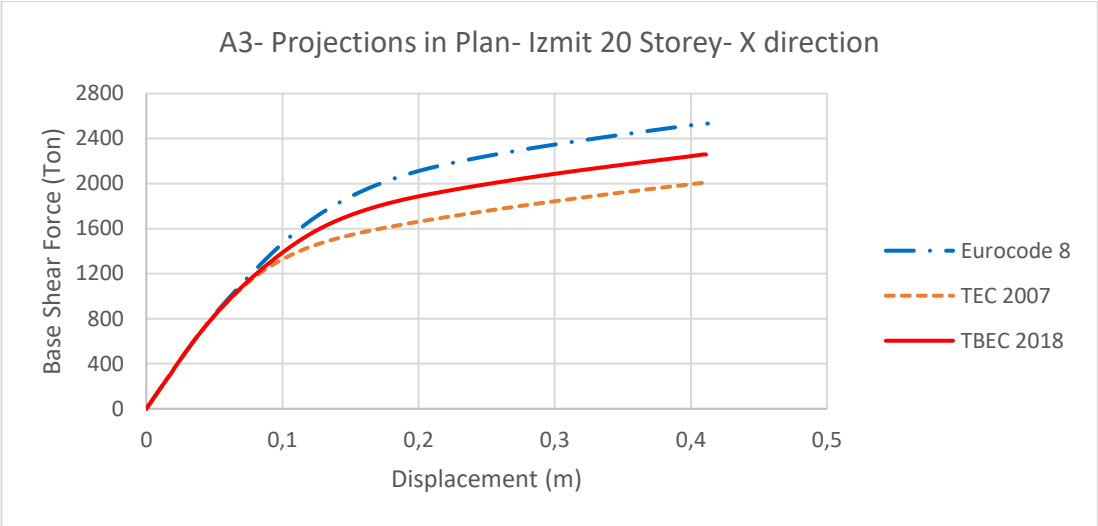


Figure 5.47: Pushover analysis curves of the A3-I-20S building (X Direction)

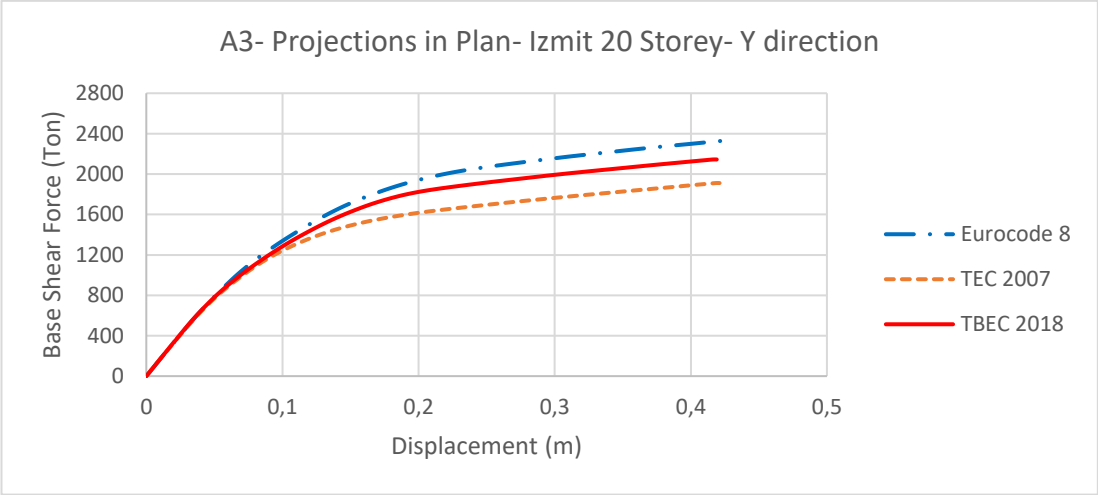


Figure 5.48: Pushover analysis curves of the A3-I-20S building (Y Direction)

The pushover curves show that (Fig.5-47 & Fig.5-48) there was a significant difference between the pushover analysis results of the 20-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 2532t, 2005t and 2258t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

Table 5.22: Performance levels and shear forces of A3 Type irregular buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
A3 Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	293.8	0.005	LD	315.9	0.005	LD	246.8	0.004	LD
			1493.5	**0.063**	**CD**	**1449.5**	**0.062**	**CD**	**1466.5**	**0.063**	**CD**
		Y	209.4	0.003	LD	211.2	0.003	LD	347.4	0.005	LD
			2143.9	**0.062**	**CD**	**2073.4**	**0.061**	**CD**	**2115.2**	**0.061**	**CD**
	10 Storey	X	705.3	0.024	LD	478.9	0.016	LD	369.3	0.012	LD
			2296.9	**0.125**	**CD**	**1748.7**	**0.124**	**CD**	**1576.6**	**0.125**	**CD**
		Y	328.7	0.012	LD	27.7	0.001	LD	122.6	0.004	LD
			2088.8	**0.130**	**CD**	**1553.1**	**0.130**	**CD**	**1362.8**	**0.130**	**CD**
	20 Storey	X	428.2	0.033	LD	291.6	0.022	LD	226.3	0.017	LD
			2026.2	**0.273**	**CD**	**1580.5**	**0.269**	**CD**	**1344.3**	**0.271**	**CP**
		Y	106.4	0.008	LD	48.2	0.003	LD	48.2	0.003	LD
			2067.4	**0.279**	**CD**	**1581.8**	**0.275**	**CD**	**1290.6**	**0.276**	**CP**
Izmit	5 Storey	X	467.1	0.006	LD	290.1	0.003	LD	560.2	0.007	LD
			2938.5	**0.095**	**CD**	**2749.9**	**0.095**	**CP**	**3366.9**	**0.095**	**CD**
		Y	184.9	0.003	LD	44.7	0.0007	LD	438.5	0.007	LD
			2069.8	**0.105**	**CD**	**1936.5**	**0.1051**	**CP**	**2369.5**	**0.105**	**CD**
	10 Storey	X	518.2	0.017	LD	321.1	0.010	LD	485.3	0.015	LD
			2587.3	**0.212**	**CD**	**2224.1**	**0.212**	**CD**	**2536.3**	**0.212**	**CD**
		Y	90.8	0.003	LD	44.2	0.001	LD	413.9	0.014	LD
			2268.4	**0.218**	**CD**	**1926.8**	**0.218**	**CD**	**2208.9**	**0.219**	**CD**
	20 Storey	X	377.3	0.021	LD	227.2	0.012	LD	234.9	0.013	LD
			2532.9	**0.409**	**CD**	**2005.7**	**0.407**	**CD**	**2258.7**	**0.408**	**CD**
		Y	178.6	0.010	LD	151.2	0.009	LD	260.4	0.015	LD
			2327.3	**0.421**	**CD**	**1910.9**	**0.418**	**CD**	**2144.2**	**0.416**	**CD**

Table 5.23: Damage ratios at the performance level of A3-A-5S building

Case A3 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage	4.9			4.9			4.8		
		Columns Damage Percentage	1.2	2.3		1.2	2.4		0.8	2.7	
		Plastic Column Vc ratio	0.2			0.2			0.3		
		Performance Level	CD			CD			CD		

Table 5.24: Damage ratios at the performance level of A3-A-10S building

Case A3 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage	2.4			7.0			7.0		
		Columns Damage Percentage	6.3	12.7		2.4	6.0		7.0	7.5	
		Plastic Column Vc ratio	8.3			4.5			5.1		
		Performance Level	CD			CD			CD		

Table 5.25: Damage ratios at the performance level of A3-A-20S building

Case A3 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	20 Storey	Beam Damage Percentage	9.8			9.3			7.3		
		Columns Damage Percentage	4.4	14.8		14.3	18.5		2.1	20.3	
		Plastic Column Vc ratio	11.9			10.3			11.1		
		Performance Level	CD			CD			CP		

Table 5.26: Damage ratios at the performance level of A3-I-5S building

Case A3 Type		Sectional Damaged Areas	Eurocode 8			TEC 2007			TBEC 2018		
			MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	5 Storey	Beam Damage Percentage	7.0						14.0		
		Columns Damage Percentage	17.8	19.0		0.8	22.7		10.1	14.2	
		Plastic Column Vc ratio	3.9			21.8			8.8		
		Performance Level	CD			CP			CD		

Table 5.27: Damage ratios at the performance level of A3-I-10S building

Case A3 Type		Sectional Damaged Areas	Eurocode 8			TEC 2007			TBEC 2018		
			MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	10 Storey	Beam Damage Percentage	23.3			20.9			23.3		
		Columns Damage Percentage	8.4	18.0		11.9	16.9		13.0	18.2	
		Plastic Column Vc ratio	15.6			15.9			14.1		
		Performance Level	CD			CD			CD		

Table 5.28: Damage ratios at the performance level of A3-I-20S building

Case A3 Type		Sectional Damaged Areas	Eurocode 8			TEC 2007			TBEC 2018		
			MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	20 Storey	Beam Damage Percentage	25.6			30.2			30.2		
		Columns Damage Percentage	4.6	15.9		4.0	16.0		2.4	15.9	
		Plastic Column Vc ratio	11.1			10.6			12.0		
		Performance Level	CD			CD			CD		

As a result of the pushover analysis of the 5-storey building in Izmit according to TEC 2007 and 20-storey building in Atasehir according to TBEC 2018, the performance level of the buildings is Collapse prevention. For the rest of the buildings the performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in residential buildings. In order to reveal the difference between the codes, the damage ratio comparison of the performance points of the A3 type irregular buildings is detailed below.

- Table 5-23 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-22, in a 5-storey building, since all base shear forces were close to each other, there was not much difference was observed in the column damage ratios. Damage ratios at the performance level of buildings are 2.3, 2.4 and 2.7 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-24 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-22, although EC 8 has the highest shear force in a 10-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 12.7, 6.0 and 7.5 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 2.4, 7.0 and 7.0 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-25 indicates the damage ratios at the performance level of 20-storey building at Atasehir. According to table 5-22, since TBEC 2018 has the lowest base shear force in a 20-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level

of buildings are 14.8, 18.5 and 20.3 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, EC 8 showed the worst performance in the case of beam damage ratio as 9.8.

- Table 5-26 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to table 5-22, since TEC 2007 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 19.0, 22.7 and 14.2 for EC 8, TEC 2007 and TBEC 2018, respectively. However, TBEC 2018 showed the worst performance in the case of beam damage ratio as 14,0.
- Table 5-27 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to table 5-22, although TEC 2007 has the lowest base shear force in a 10-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 18.0, 16.9 and 18.2 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 23.3, 20.9 and 23.3 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-28 indicates the damage ratios at the performance level of 20-storey building at Izmit. According to table 5-22, although TEC 2007 has the lowest base shear force in a 20-storey building, there was not much difference between the codes in terms of the column damage ratios. Damage ratios at the performance level of buildings are 15.9, 16.0 and 15.9 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance levels are 25.6, 30.2 and 30.2 for EC 8, TEC 2007 and TBEC 2018, respectively.

According to tables, in the buildings where TBEC 2018 was used, as a result of the different spectral values of Izmit and Atasehir, significant differences were observed between the base shear forces.

5.2.5 B1 Type: Interstorey Strength Irregularity

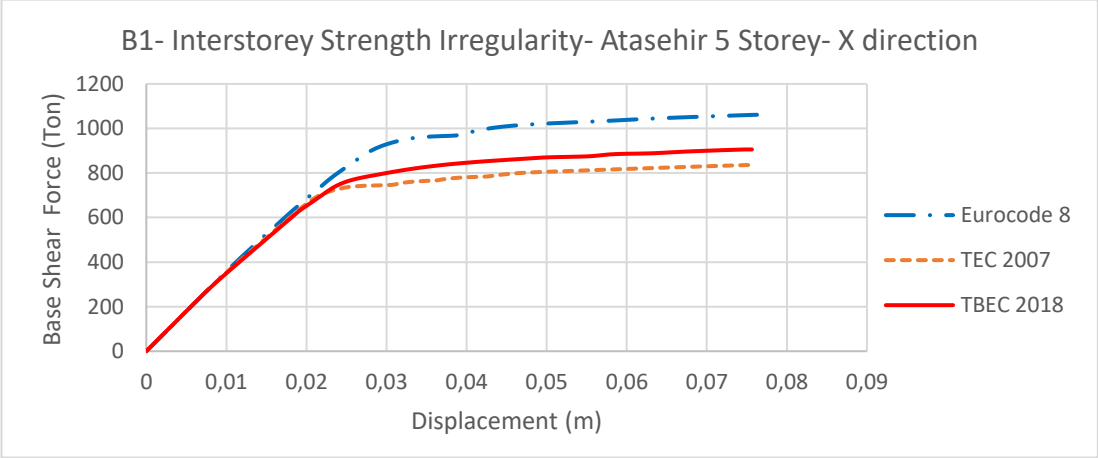
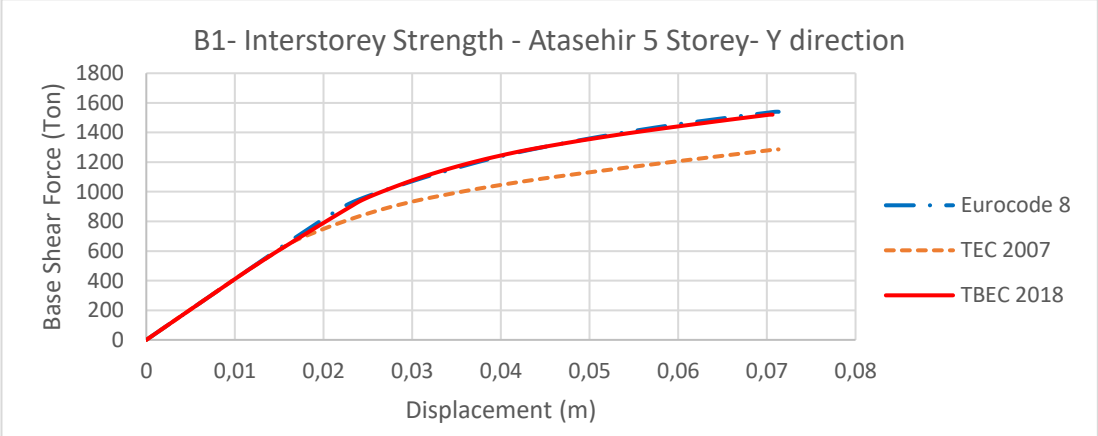


Figure 5.49: Pushover analysis curves of the B1-A-5S building (X Direction)



-Figure 5.50: Pushover analysis curves of the B1-A-5S building (Y Direction)

The pushover curves show that (Fig.5-49 & Fig.5-50) there was partially differences between the pushover analysis results of the 5-Storey building in Atasehir. Base shear forces in the X-direction of buildings are 1061t, 835t and 905t for EC 8, TEC 2007 and TBEC 2018, respectively.

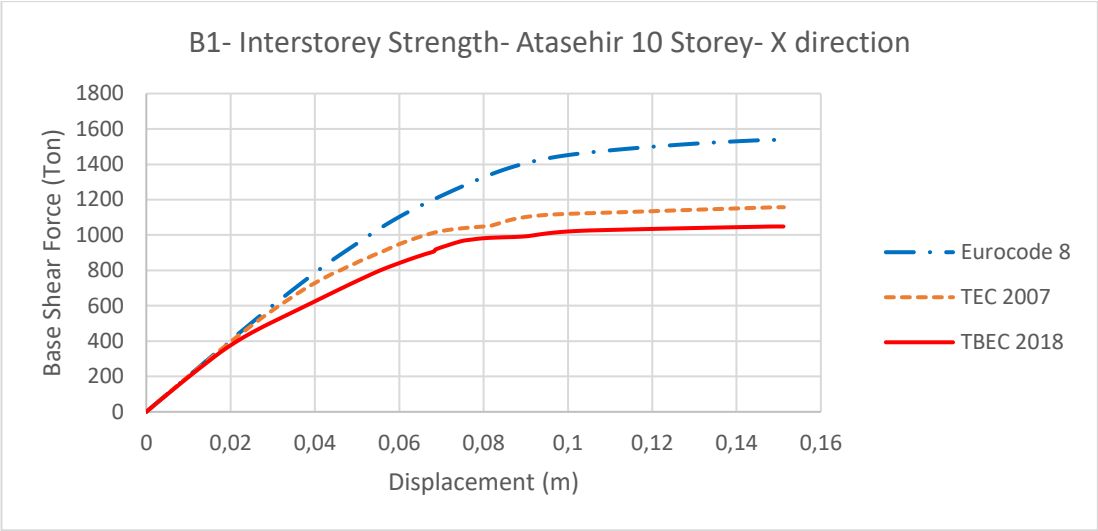


Figure 5.51: Pushover analysis curves of the B1-A-10S building (X Direction)

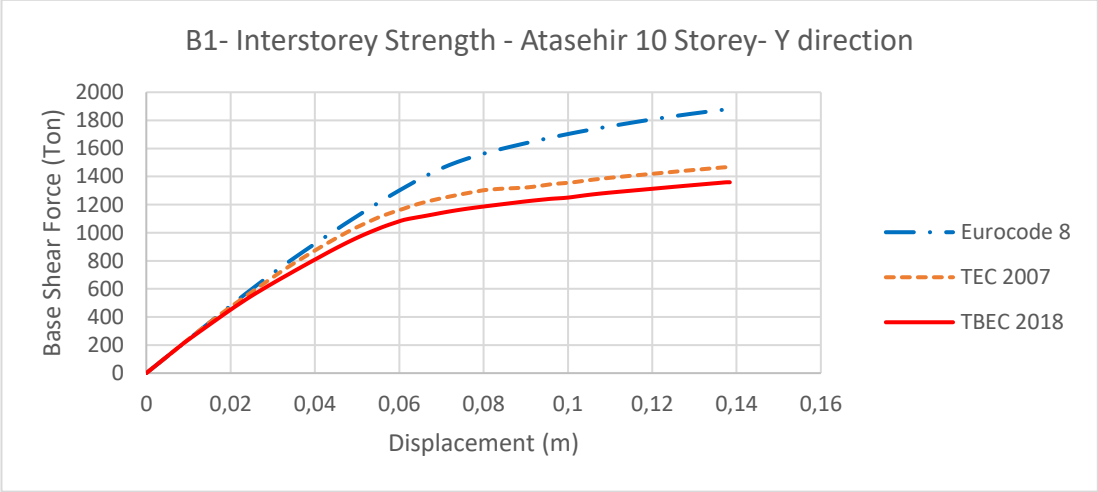


Figure 5.52: Pushover analysis curves of the B1-A-10S building (Y Direction)

The pushover curves show that (Fig.5-51 & Fig.5-52) there was a significant difference between the pushover analysis results of the 10-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1537t, 1157t and 1048t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

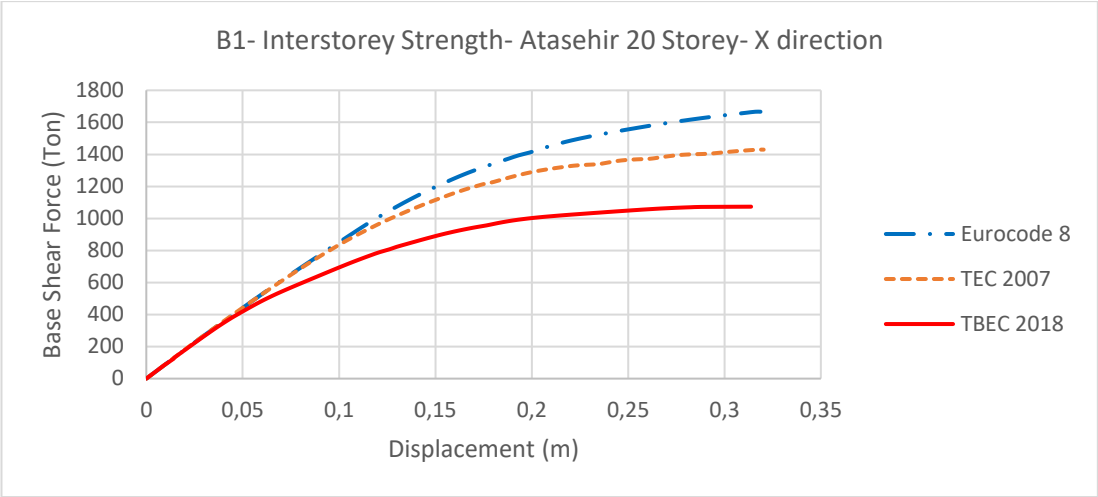


Figure 5.53: Pushover analysis curves of the B1-A-20S building (X Direction)

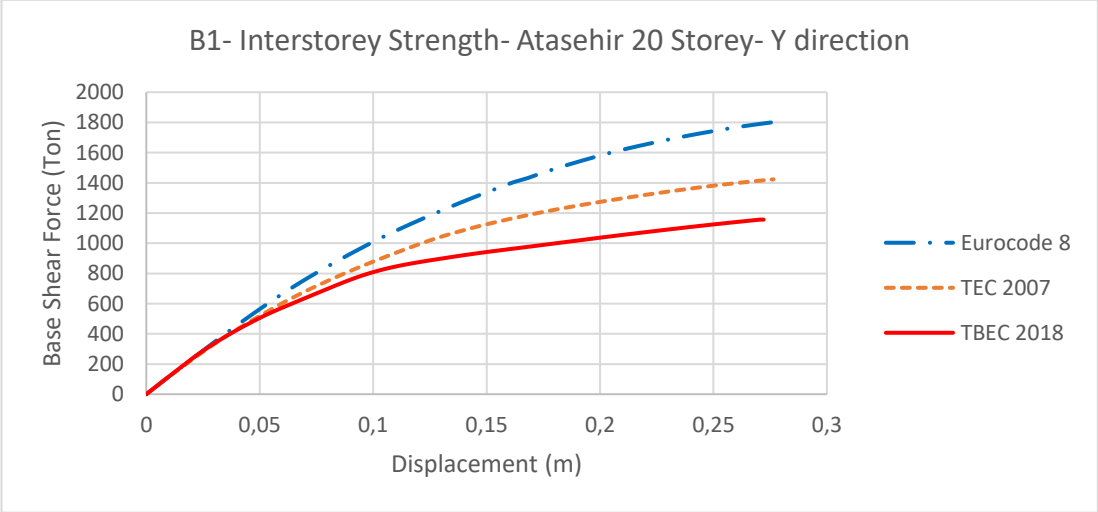


Figure 5.54: Pushover analysis curves of the B1-A-20S building (Y Direction)

The pushover curves show that (Fig.5-53 & Fig.5-54) there was a significant difference between the pushover analysis results of the 20-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1666t, 1429t and 1073t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

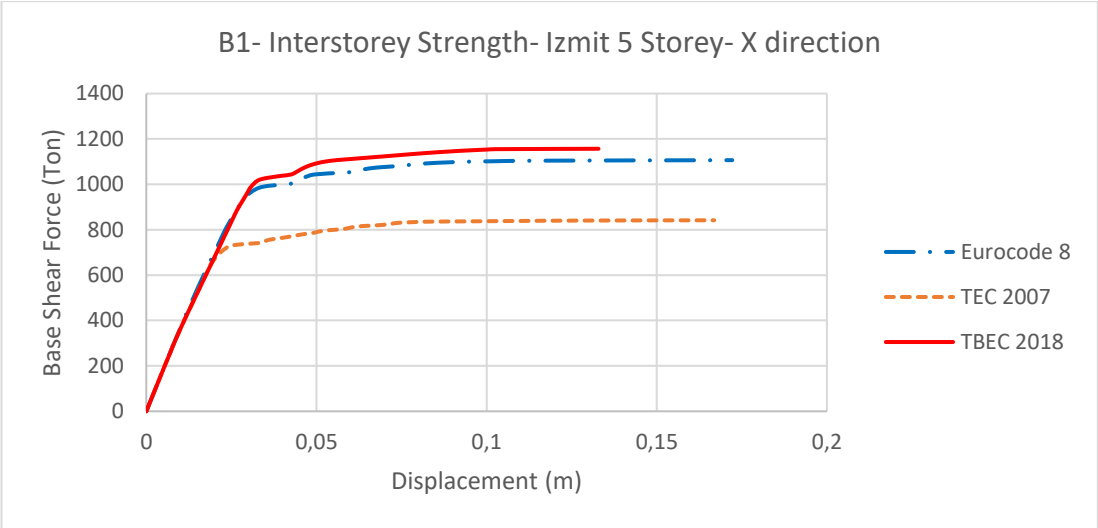


Figure 5.55: Pushover analysis curves of the B1-I-5S building (X Direction)

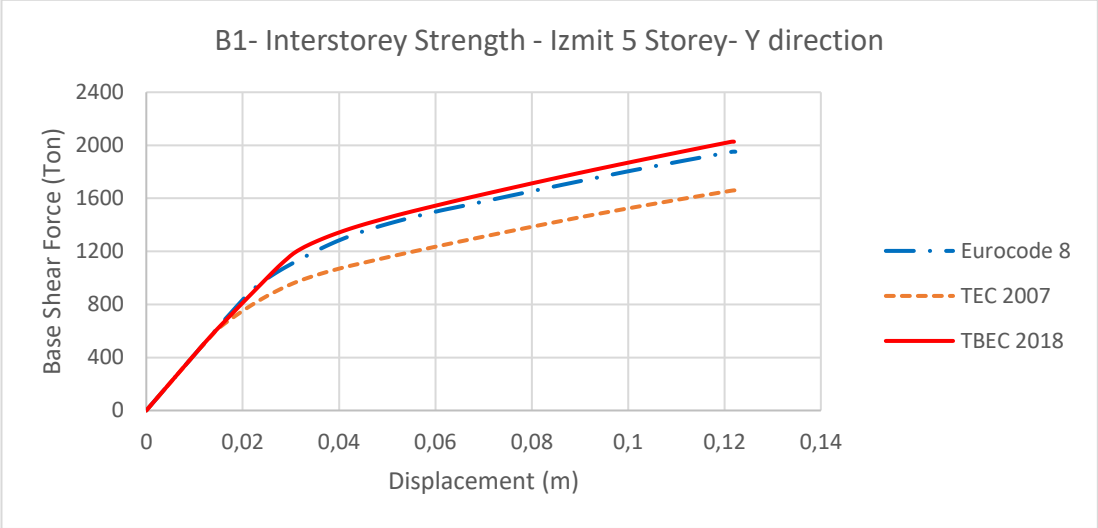


Figure 5.56: Pushover analysis curves of the B1-I-5S building (Y Direction)

The pushover curves show that (Fig.5-55 & Fig.5-56) there was a significant difference between the pushover analysis results of the 5-Storey building in Izmit. TBEC 2018 shows higher values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1106t, 841t and 1156t for EC 8, TEC 2007 and TBEC 2018, respectively. According to Fig. 5-56, the difference between TEC 2007 and TBEC 2018 has decreased.

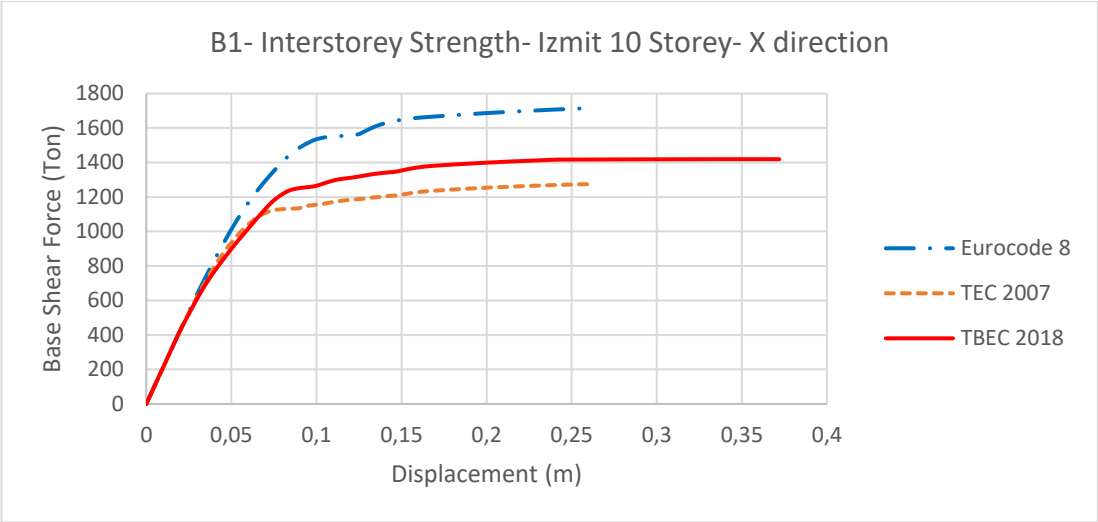


Figure 5.57: Pushover analysis curves of the B1-I-10S building (X Direction)

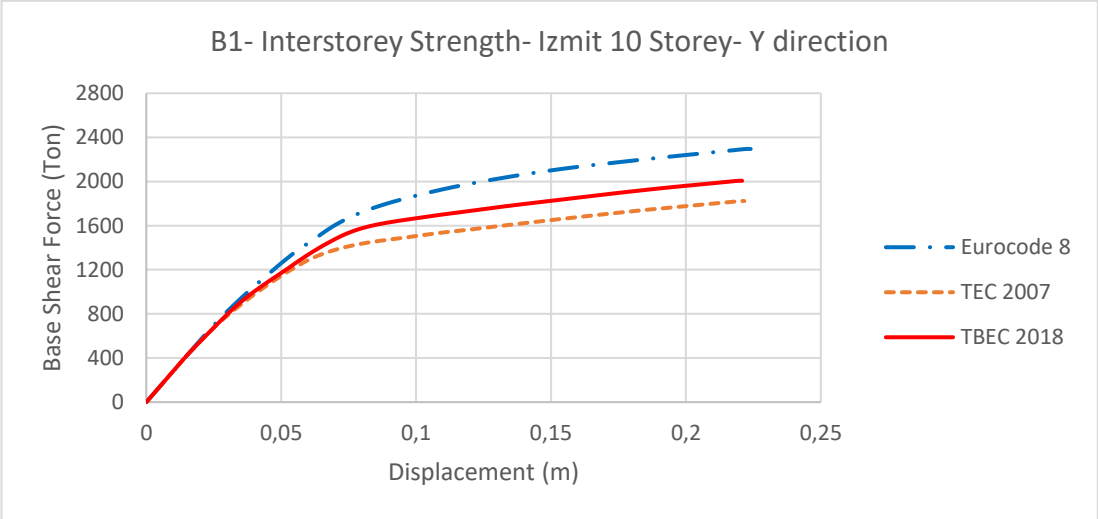


Figure 5.58: Pushover analysis curves of the B1-I-10S building (Y Direction)

The pushover curves show that (Fig.5-57 & Fig.5-58) there was a significant difference between the pushover analysis results of the 10-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. On the other hand, TBEC 2018 has much displacement capacity than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1713t, 1274t and 1419t for EC 8, TEC 2007 and TBEC 2018, respectively.

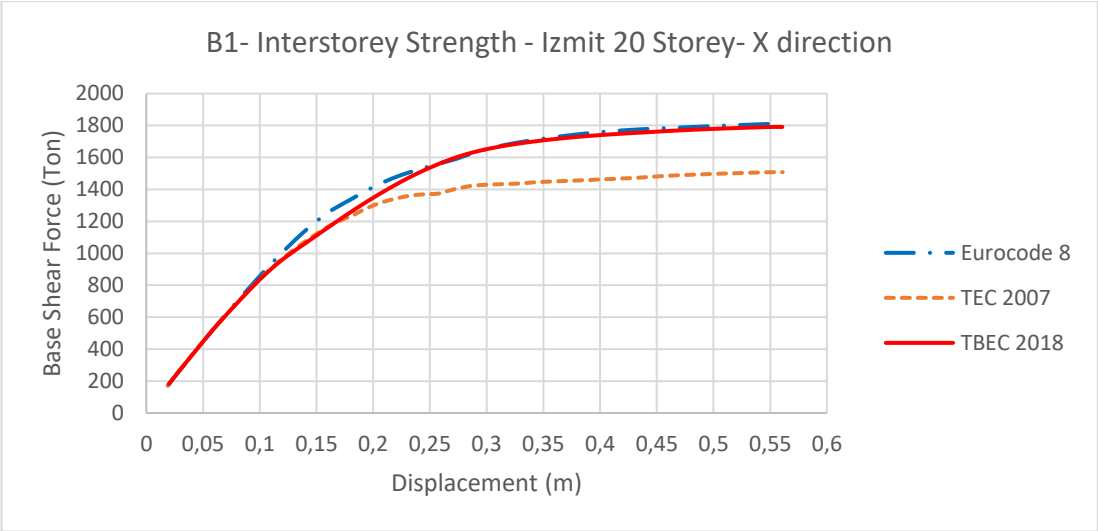


Figure 5.59: Pushover analysis curves of the B1-I-20S building (X Direction)

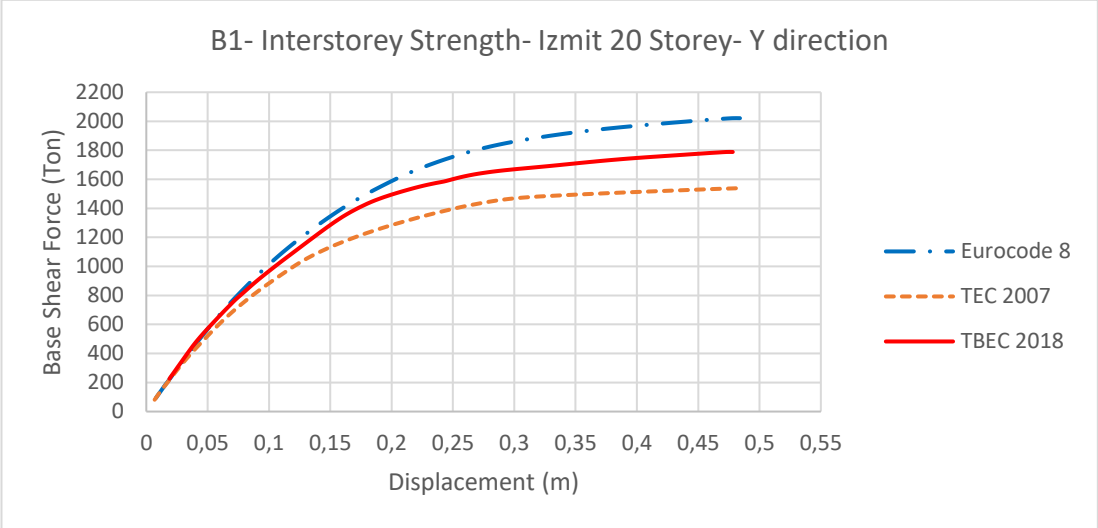


Figure 5.60: Pushover analysis curves of the B1-I-20S building (Y Direction)

According to pushover curves (Fig.5-59) partially differences were observed between the pushover analysis results of the 20-Storey building in Izmit. TEC 2007 shows lower values than the other two earthquake codes. Base shear forces in the X-direction of buildings are 1881t, 1507t and 1791t for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Fig. 5-60, the difference between the pushover curves of EC 8 and TBEC 2018 has increased.

Table 5.29: Performance levels and shear forces of B1 Type irregular buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
B1 Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	305.6	0.008	LD	164.8	0.004	CU	93.5	0.002	LD
			1061.4	**0.076**	**CD**	**835.8**	**0.075**	**CU**	**905.6**	**0.074**	**CD**
		Y	615.8	0.014	LD	371.3	0.009	CU	338.6	0.008	LD
			1539.7	**0.070**	**CD**	**1285.7**	**0.071**	**CU**	**1520.3**	**0.070**	**CD**
	10 Storey	X	323.2	0.015	LD	189.6	0.009	LD	36.9	0.001	LD
			1537.7	**0.147**	**CD**	**1157.1**	**0.149**	**CD**	**1048.1**	**0.148**	**CD**
		Y	373.9	0.015	LD	207.2	0.008	LD	128.5	0.005	LD
			1873.7	**0.136**	**CD**	**1465.4**	**0.137**	**CD**	**1358.8**	**0.137**	**CD**
	20 Storey	X	213.0	0.023	LD	213.7	0.023	LD	79.4	0.008	LD
			1666.2	**0.315**	**CD**	**1429.5**	**0.317**	**CD**	**1073.5**	**0.313**	**CD**
		Y	53.9	0.004	LD	46.4	0.003	LD	101.5	0.008	LD
			1807.9	**0.279**	**CD**	**1423.0**	**0.276**	**CD**	**1156.0**	**0.270**	**CD**
Izmit	5 Storey	X	278.3	0.007	LD	184.2	0.004	LD	204.4	0.005	LD
			1106.5	**0.172**	**CD**	**841.7**	**0.166**	**CD**	**1156.8**	**0.132**	**CD**
		Y	545.8	0.012	LD	389.6	0.009	LD	384.1	0.009	LD
			1951.2	**0.121**	**CD**	**1659.6**	**0.121**	**CD**	**2027.1**	**0.121**	**CD**
	10 Storey	X	297.9	0.013	LD	254.6	0.011	LD	170.1	0.007	LD
			1713.3	**0.255**	**CD**	**1274.0**	**0.255**	**CD**	**1419.3**	**0.331**	**CD**
		Y	452.7	0.016	LD	287.9	0.010	LD	301.4	0.010	LD
			2294.7	**0.222**	**CD**	**1822.8**	**0.220**	**CD**	**2006.4**	**0.219**	**CD**
	20 Storey	X	180.6	0.019	LD	215.05	0.023	LD	181.6	0.019	LD
			1811.1	**0.554**	**CD**	**1507.8**	**0.550**	**CD**	**1791.0**	**0.550**	**CD**
		Y	94.4	0.007	LD	81.5	0.006	LD	226.1	0.018	LD
			2021.1	**0.477**	**CD**	**1538.7**	**0.483**	**CD**	**1788.3**	**0.473**	**CD**

Table 5.30: Damage ratios at the performance level of B1-A-5S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage				7.7			5.1		
		Columns Damage Percentage		2.0						4.0	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CU			CD		

Table 5.31: Damage ratios at the performance level of B1-A-10S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage									
		Columns Damage Percentage	0.6	1.1			1.9		0.8	1.4	
		Plastic Column Vc ratio	1.4			1.9			1.4		
		Performance Level	CD			CD			CD		

Table 5.32: Damage ratios at the performance level of B1-A-20S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	20 Storey	Beam Damage Percentage	12.5			15.6			6.3		
		Columns Damage Percentage		6.3		1.0	7.4		0.3	4.7	
		Plastic Column Vc ratio	6.3			7.4			4.7		
		Performance Level	CD			CD			CD		

Table 5.33: Damage ratios at the performance level of B1-I-5S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	5 Storey	Beam Damage Percentage	23.5			14.7			20.5		
		Columns Damage Percentage	70.1	9.2		70.3	18.7		7.5		
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.34: Damage ratios at the performance level of B1-I-10S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	10 Storey	Beam Damage Percentage	48.7			23.1			38.5		
		Columns Damage Percentage	1.8	0.4		9.6			24.5	13.5	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CD			CD		

Table 5.35: Damage ratios at the performance level of B1-I-20S building

Case B1 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	20 Storey	Beam Damage Percentage	31.3			31.3			43.8		
		Columns Damage Percentage	5.1	14.0		6.1	15.9		3.7	6.2	
		Plastic Column Vc ratio	7.4			5.5			6.2		
		Performance Level	CD			CD			CD		

As a result of the pushover analysis of Atasehir 5-storey building according to TEC 2007, no damage was observed in the columns of the building. The performance of the building is the level of Continuous Usage. For the rest of the buildings, the performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in residential buildings. In order to reveal the difference between the codes, the damage ratio comparison of the performance points of the B1 type irregular buildings is detailed below.

- Table 5-30 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-29, although TEC 2007 has the lowest base shear force in a 5-storey building, no column damage was observed. Damage ratios at the performance level of buildings are 2.0 and 4.0 for EC 8, and TBEC 2018, respectively. However, TEC 2007 showed the worst performance in the case of beam damage ratio as 7.7.
- Table 5-31 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-29, although TBEC 2018 has the lowest base shear force in a 10-storey building, there was not much difference between the codes in terms of the column damage ratios. Damage ratios at the performance level of buildings are 1.1, 1.9 and 1.4 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-32 indicates the damage ratios at the performance level of 20-storey building at Atasehir. According to table 5-29, since TBEC 2018 has the lowest base shear force in a 20-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 14.8, 18.5 and 20.3 for EC 8, TEC 2007 and TBEC 2018,

respectively. On the other hand, EC 8 showed the worst performance in the case of beam damage ratio as 9.8.

- Table 5-33 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to table 5-29, since TEC 2007 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 9.2, 18.7 and 7.5 for EC 8, TEC 2007 and TBEC 2018, respectively. However, EC 8 showed the worst performance in the case of beam damage ratio as 23.5.
- Table 5-34 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to table 5-29, although TEC 2007 has the lowest base shear force in a 10-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 0.4(Advanced Damage), 9.6(Marked Damage) and 13.5(Advanced Damage) for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 48.7, 23.1 and 38.5 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-35 indicates the damage ratios at the performance level of 20-storey building at Izmit. According to table 5-29, since TEC 2007 has the lowest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 14.0, 15.9 and 6.2 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance levels are 31.3, 31.3 and 43.8 for EC 8, TEC 2007 and TBEC 2018, respectively.

5.2.6 B2 Type: Interstorey Stiffness Irregularity

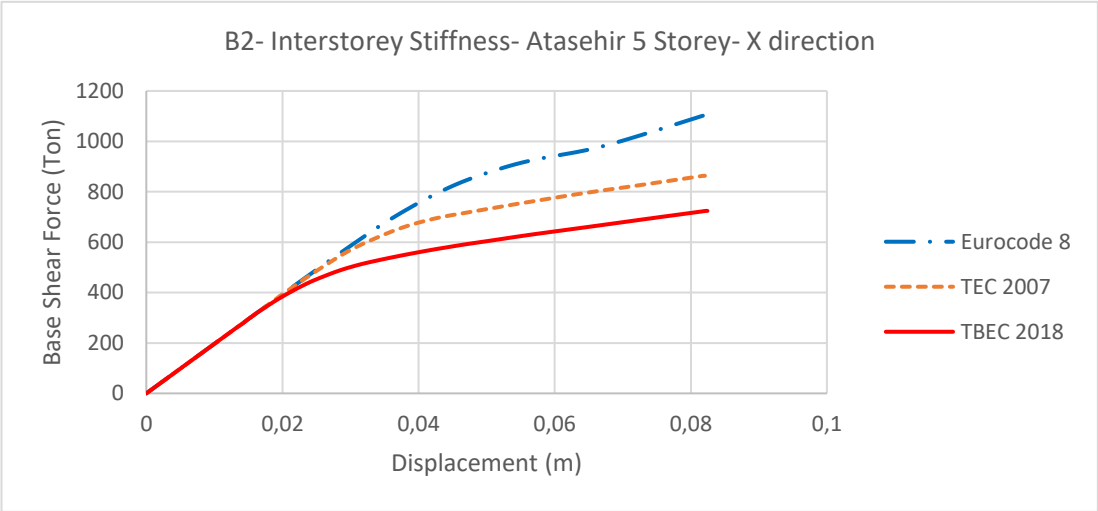


Figure 5.61: Pushover analysis curves of the B2-A-5S building (X Direction)

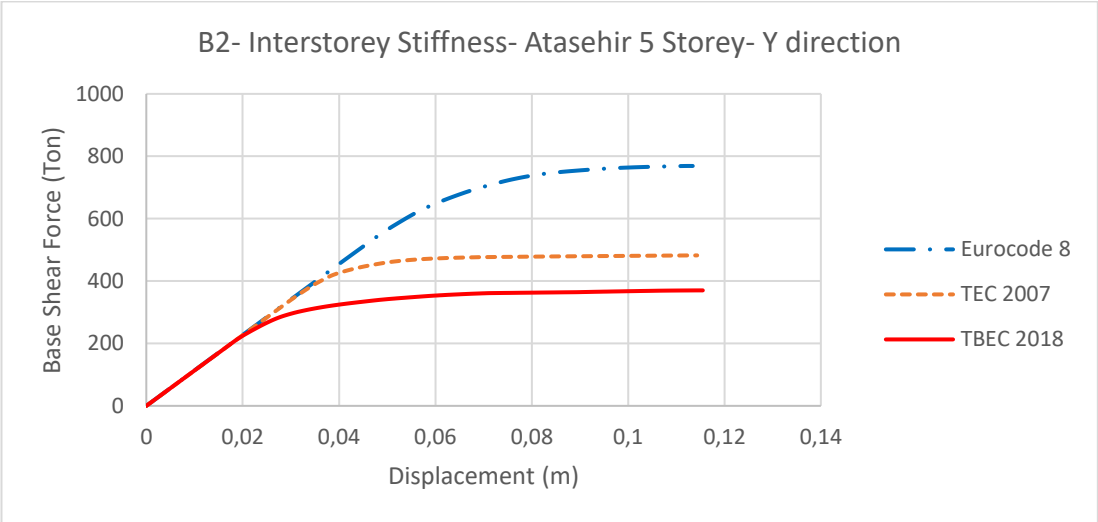


Figure 5.62: Pushover analysis curves of the B2-A-5S building (Y Direction)

The pushover curves show that (Fig.5-61 & Fig.5-62) there was a significant difference between the pushover analysis results of the 5-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1102t, 863t and 724t for EC 8, TEC 2007 and TBEC 2018, respectively.

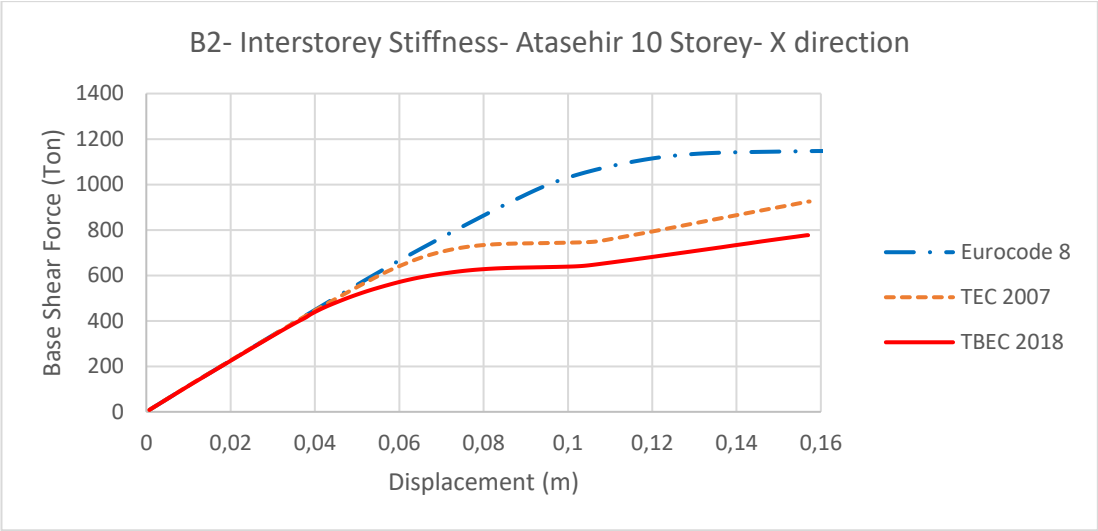


Figure 5.63: Pushover analysis curves of the B2-A-10S building (X Direction)

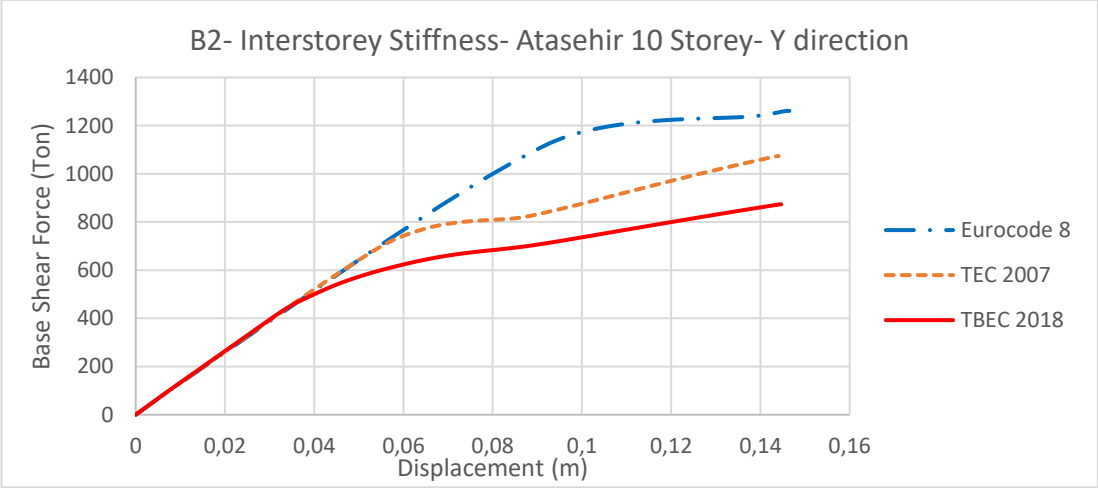


Figure 5.64: Pushover analysis curves of the B2-A-10S building (Y Direction)

The pushover curves show that (Fig.5-63 & Fig.5-64) there was a significant difference between the pushover analysis results of the 10-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1147t, 924t and 776t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

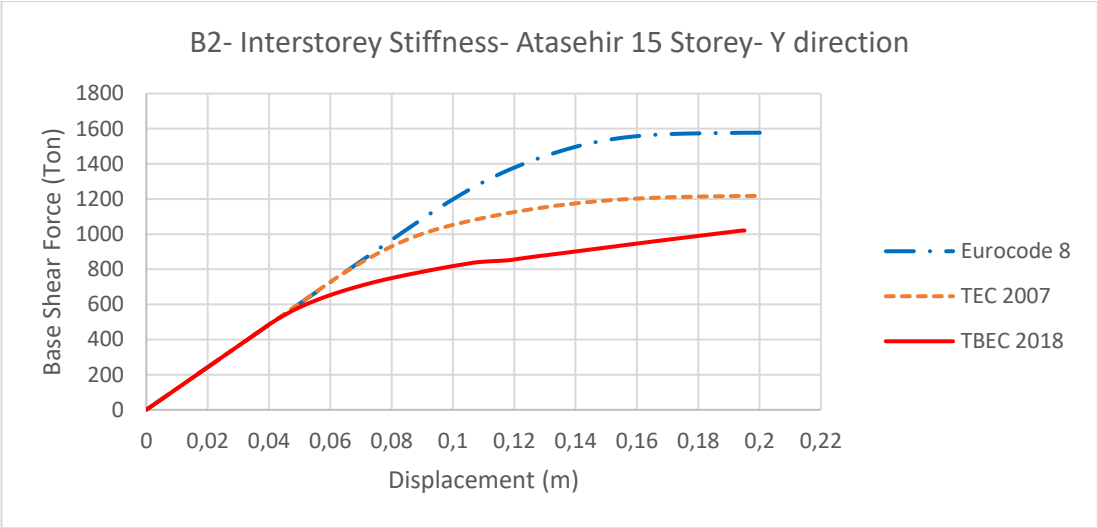


Figure 5.65: Pushover analysis curves of the B2-A-15S building (X Direction)

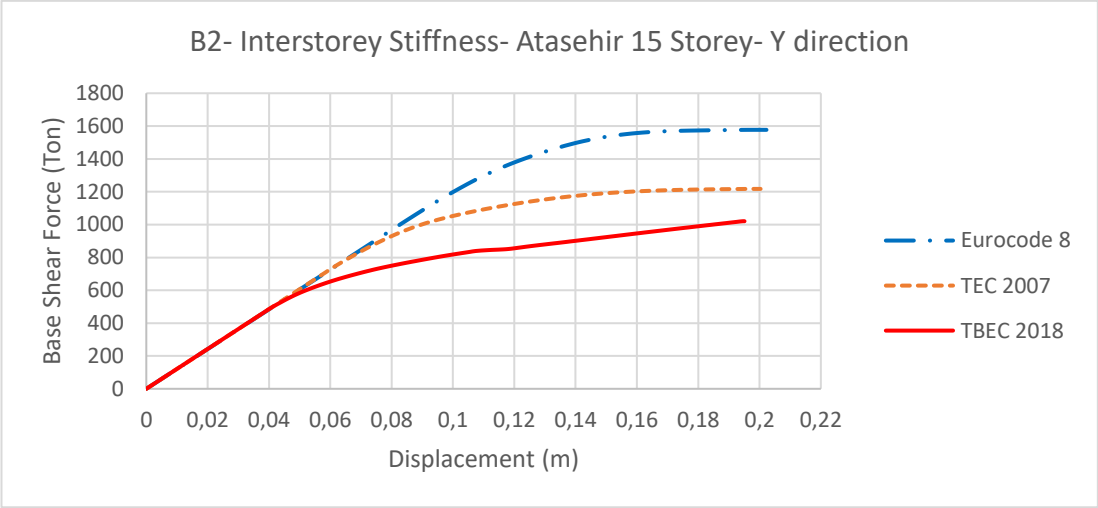


Figure 5.66: Pushover analysis curves of the B2-A-15S building (Y Direction)

The pushover curves show that (Fig.5-65 & Fig.5-66) there was a significant difference between the pushover analysis results of the 15-Storey building in Atasehir. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1585t, 1151t and 964t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

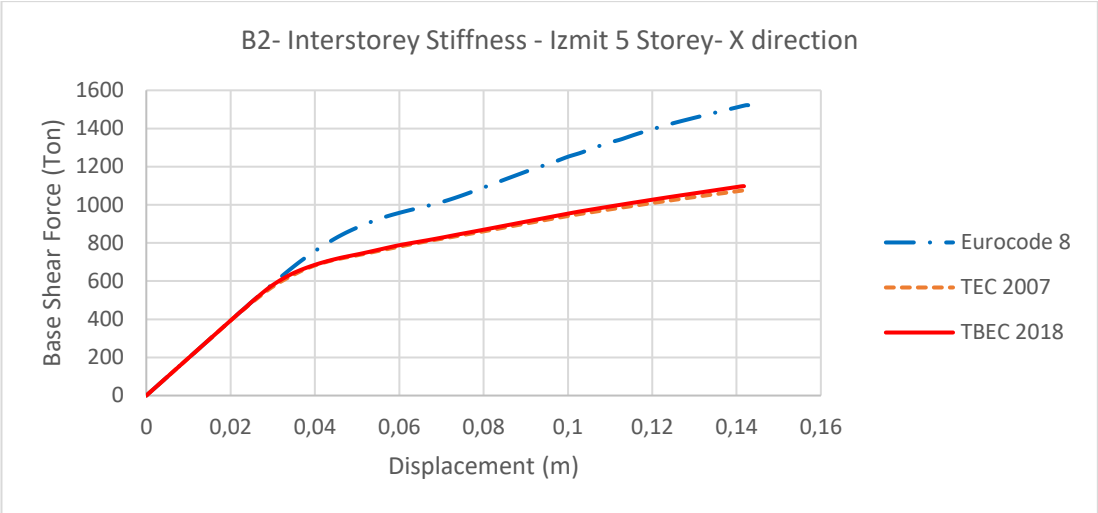


Figure 5.67: Pushover analysis curves of the B2-I-5S building (X Direction)

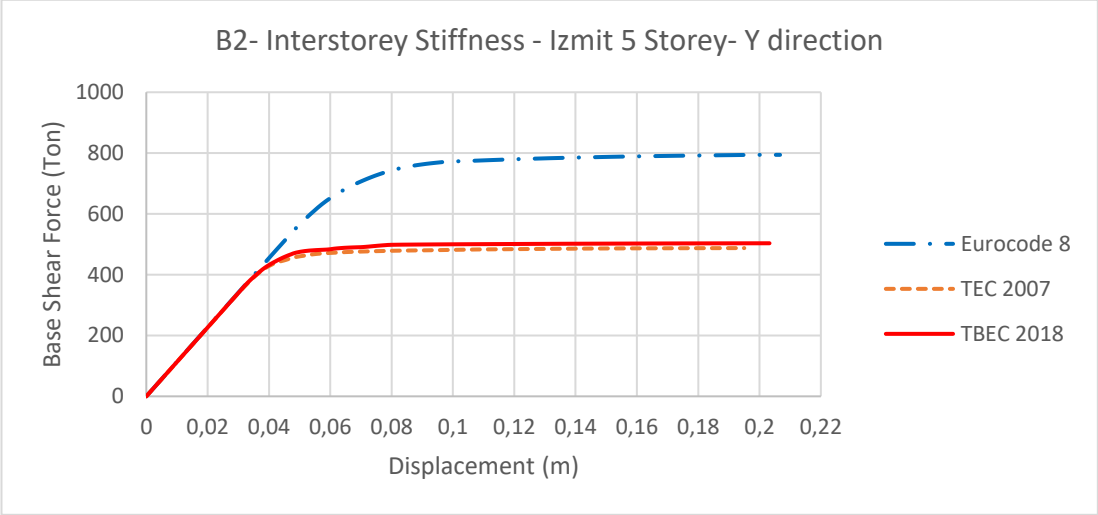


Figure 5.68: Pushover analysis curves of the B2-I-5S building (Y Direction)

According to pushover curves (Fig.5-67 & Fig.5-68) partially differences were observed between the pushover analysis results of the 5-Storey building in Izmit. EC8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1521t, 1075t and 1097t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

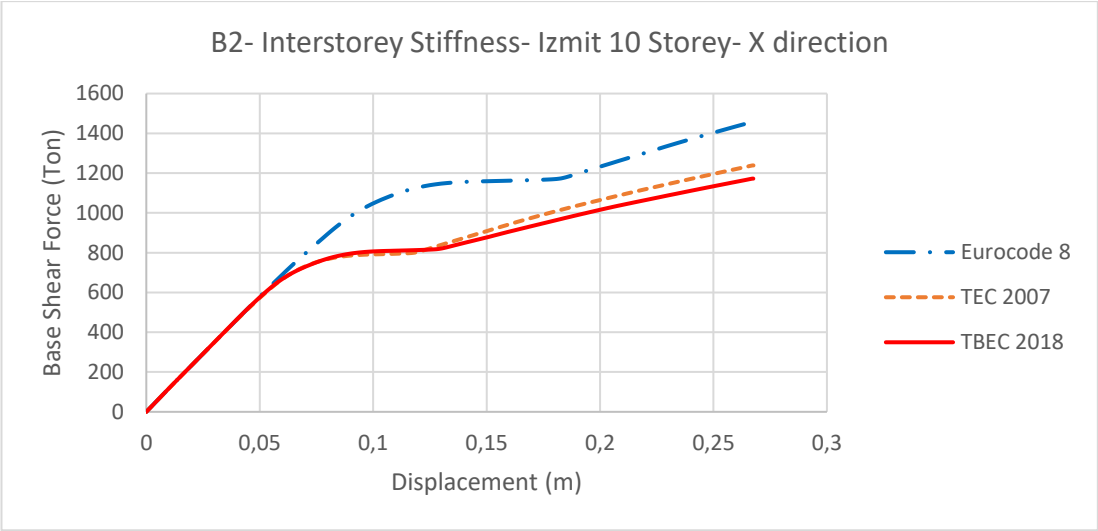


Figure 5.69: Pushover analysis curves of the B2-I-10S building (X Direction)

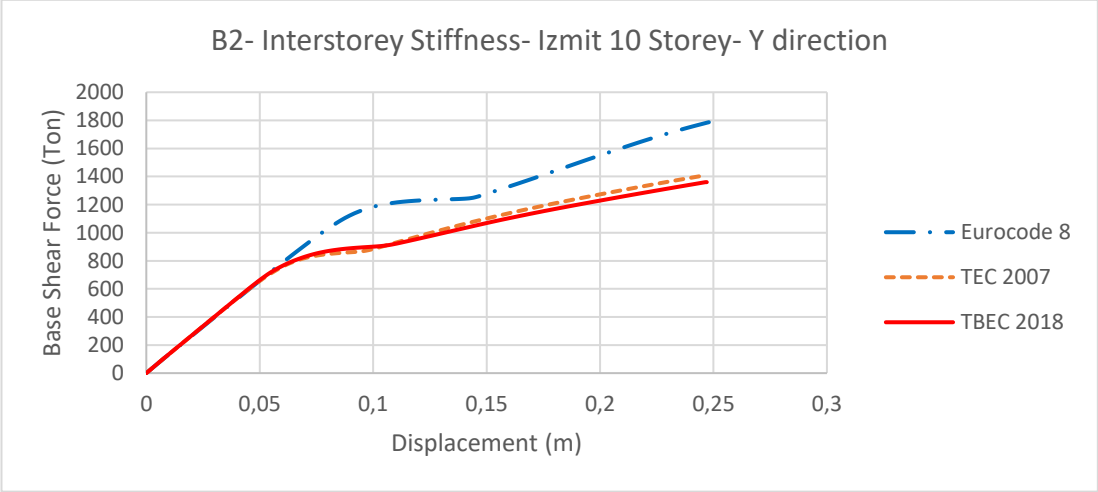


Figure 5.70: Pushover analysis curves of the B2-I-10S building (Y Direction)

According to pushover curves (Fig.5-69 & Fig.5-70) partially differences were observed between the pushover analysis results of the 10-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 1462t, 1238t and 1172t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

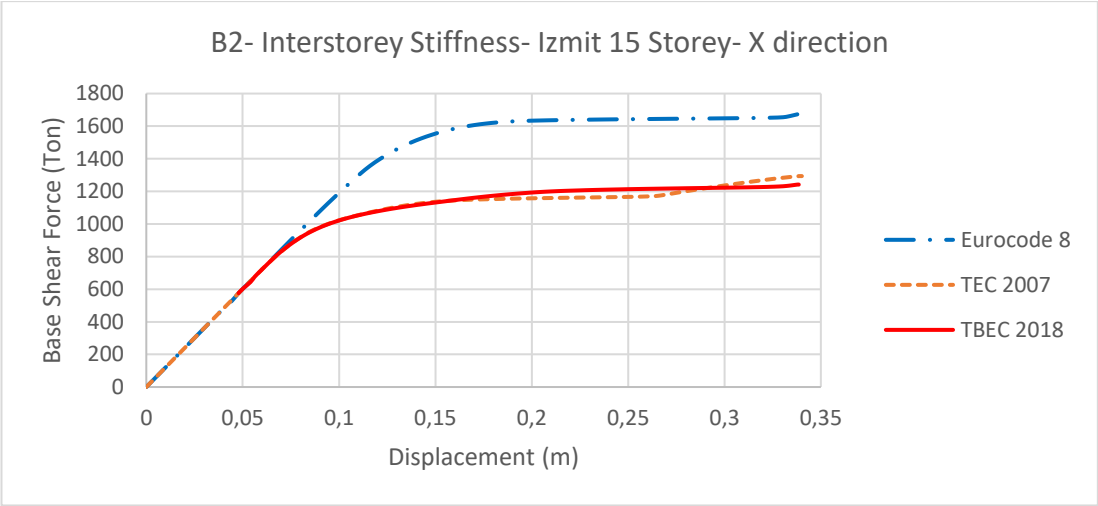


Figure 5.71: Pushover analysis curves of the B2-I-15S building (X Direction)

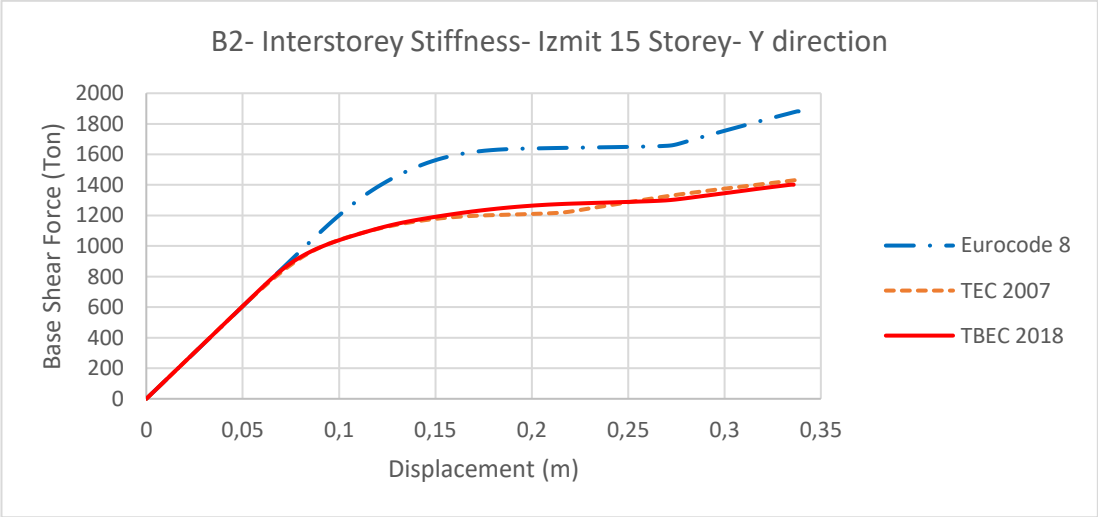


Figure 5.72: Pushover analysis curves of the B2-I-15S building (Y Direction)

According to pushover curves (Fig.5-71 & Fig.5-72) partially differences were observed between the pushover analysis results of the 15-Storey building in Izmit. EC 8 shows higher values than the other two earthquake codes. Base shear forces in the X direction of buildings are 859t, 650t and 575t for EC 8, TEC 2007 and TBEC 2018, respectively. In addition, the pushover analysis curves of the Y direction were observed to be almost similar to the pushover analysis conditions of the X direction.

Table 5.36: Performance Levels and shear forces of B2 Type irregular buildings

Case			Eurocode 8			TEC 2007			TBEC 2018		
B2 Type		Direction	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level	Shear Force V(t) (Ton)	Displacement (m)	Performance Level
Atasehir	5 Storey	X	363.8	0.018	LD	375.2	0.019	CU	290.6	0.014	CU
			1102.1	**0.081**	**CD**	**863.2**	**0.081**	**CU**	**724.0**	**0.082**	**CU**
		Y	428.4	0.037	LD	273.7	0.024	CU	197.4	0.017	CU
			768.9	**0.111**	**CD**	**482.2**	**0.114**	**CU**	**370.0**	**0.113**	**CU**
	10 Storey	X	466.1	0.041	LD	173.3	0.015	LD	226.9	0.020	LD
			1147.2	**0.159**	**CD**	**924.9**	**0.157**	**CD**	**776.8**	**0.156**	**CD**
		Y	490.3	0.038	LD	461.01	0.035	LD	370.1	0.028	LD
			1260.9	**0.145**	**CD**	**1073.5**	**0.143**	**CD**	**873.1**	**0.144**	**CD**
	15 Storey	X	869.4	0.072	LD	655.0	0.055	LD	391.7	0.032	LD
			1585.9	**0.196**	**CD**	**1151.7**	**0.196**	**CD**	**964.7**	**0.197**	**CD**
		Y	875.8	0.072	LD	445.8	0.036	LD	381.6	0.031	LD
			1577.1	**0.195**	**CD**	**1217.2**	**0.196**	**CD**	**1020.5**	**0.194**	**CD**
Izmit	5 Storey	X	406.1	0.020	LD	374.5	0.019	LD	415.5	0.021	LD
			1521.8	**0.142**	**CP**	**1075.5**	**0.141**	**CD**	**1097.3**	**0.141**	**CD**
		Y	439.5	0.038	LD	273.0	0.024	LD	331.5	0.029	LD
			794.0	**0.198**	**CP**	**487.4**	**0.195**	**CD**	**503.3**	**0.203**	**CD**
	10 Storey	X	541.4	0.046	LD	192.5	0.016	LD	410.7	0.035	LD
			1462.0	**0.268**	**CD**	**1238.5**	**0.267**	**CD**	**1172.2**	**0.267**	**CD**
		Y	657.7	0.049	LD	422.0	0.031	LD	356.8	0.026	LD
			1789.7	**0.248**	**CD**	**1406.9**	**0.245**	**CD**	**1359.5**	**0.246**	**CD**
	15 Storey	X	859.8	0.071	LD	650.5	0.054	LD	575.8	0.047	LD
			1678.4	**0.339**	**CD**	**1293.6**	**0.338**	**CD**	**1241.6**	**0.337**	**CD**
		Y	867.3	0.071	LD	445.5	0.036	LD	606.7	0.050	LD
			1881.1	**0.337**	**CD**	**1431.3**	**0.336**	**CD**	**1401.4**	**0.334**	**CD**

Table 5.37: Damage ratios at the performance level of B2-A-5S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	5 Storey	Beam Damage Percentage				20.0			13.3		
		Columns Damage Percentage	3.0	4.0							
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CD			CU			CU		

Table 5.38: Damage ratios at the performance level of B2-A-10S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	10 Storey	Beam Damage Percentage									
		Columns Damage Percentage	0.4	7.0			8.0		0.2	4.0	
		Plastic Column Vc ratio	2.4			2.0			-		
		Performance Level	CD			CD			CD		

Table 5.39: Damage ratios at the performance level of B2-A-15S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Atasehir	15 Storey	Beam Damage Percentage									
		Columns Damage Percentage		1.8			1.5			2.8	
		Plastic Column Vc ratio	1.9			1.5			2.8		
		Performance Level	CD			CD			CD		

Table 5.40: Damage ratios at the performance level of B2-I-5S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	5 Storey	Beam Damage Percentage	50.0			30.0			50.0		
		Columns Damage Percentage	8.6	47.5		36.3	1.9		21.8	17.0	
		Plastic Column Vc ratio	-			-			-		
		Performance Level	CP			CD			CD		

Table 5.41: Damage ratios at the performance level of B2-I-10S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	10 Storey	Beam Damage Percentage									
		Columns Damage Percentage		8.0		0.6	12.0		0.6	8.2	
		Plastic Column Vc ratio	3.7			2.6			2.6		
		Performance Level	CD			CD			CD		

Table 5.42: Damage ratios at the performance level of B2-I-15S building

Case B2 Type		Explanation	Eurocode 8			TEC 2007			TBEC 2018		
		Sectional Damaged Areas	MD	AD	CR	MD	AD	CR	MD	AD	CR
Izmit	15 Storey	Beam Damage Percentage									
		Columns Damage Percentage		1.6			3.6			2.2	
		Plastic Column Vc ratio	1.6			1.4			2.0		
		Performance Level	CD			CD			CD		

As a result of the pushover analysis of Atasehir 5-storey building according to TEC 2007 and TBEC 2018, no damage was observed in the columns of the building. The performances of the building are the level of Continuous Usage. In addition to this, as a result of the pushover analysis of the 5-storey building in Izmit according to EC 8, the performance level of the building is Collapse Prevention. For the rest of the buildings, the performance level results obtained for three earthquake codes are the Controlled Damage performance level, as expected, in line with the design earthquake target in residential buildings.

- Table 5-37 indicates the damage ratios at the performance level of 5-storey building at Atasehir. According to table 5-36, although EC 8 has the highest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. The column damage ratio at the performance level of building was 4.0 for EC 8, whereas the other two earthquake codes did not have column damage. However, EC 8, showed no damage in terms of beam damage.
- Table 5-38 indicates the damage ratios at the performance level of 10-storey building at Atasehir. According to table 5-36, although TBEC 2018 has the lowest base shear force in a 10-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 7.0, 8.0 and 4.0 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-38, no beam damage was observed in any code.
- Table 5-39 indicates the damage ratios at the performance level of 15-storey building at Atasehir. According to table 5-36, since TBEC 2018 has the lowest base shear force in a 20-storey building, it has a higher column damage ratio

than the other two earthquake codes. Damage ratios at the performance level of buildings are 1.8, 1.5 and 2.8 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-39, no beam damage was observed in any code.

- Table 5-40 indicates the damage ratios at the performance level of 5-storey building at Izmit. According to table 5-36, since EC 8 has the highest base shear force in a 5-storey building, it has a higher column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 47.5, 1.9 and 17.0 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, beam damage ratios at the performance level are 50.0, 30.0 and 50.0 for EC 8, TEC 2007 and TBEC 2018, respectively.
- Table 5-41 indicates the damage ratios at the performance level of 10-storey building at Izmit. According to table 5-36, since EC 8 has the highest base shear force in a 10-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 8.0, 12.0 and 8.2 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-41, no beam damage was observed in any code.
- Table 5-42 indicates the damage ratios at the performance level of 15-storey building at Izmit. According to table 5-36, since EC 8 has the highest base shear force in a 5-storey building, it has a lower column damage ratio than the other two earthquake codes. Damage ratios at the performance level of buildings are 1.6, 3.6 and 2.2 for EC 8, TEC 2007 and TBEC 2018, respectively. On the other hand, according to Table 5-42, no beam damage was observed in any code.

5.3 Building Costs

In this part of the study, the construction costs obtained from the results of the linear analysis of buildings were given.

5.3.1 Regular Type Buildings

Table 5.43: Cost of Regular Type Building - Atasehir 5-Storey

R-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	39.1	39.1	39	₺3.940,00
Reinforcement 8-12mm (Ton)	50.5	50.8	53	₺3.400,00
Reinforcement 14-50mm (Ton)	28.9	27.3	24.6	₺3.400,00
Concrete m^3	1345	1345	1360	₺340,00
Average Rebar Ratio	88.124 kg/m^3	87.176 kg/m^3	85.747 kg/m^3	
	23.427 kg/m^2	23.175 kg/m^2	23.057 kg/m^2	
Total	**₺881.314,00**	**₺876.894,00**	**₺879.900,00**	

Table 5.44: Cost of Regular Type Building - Atasehir 10-Storey

R-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	85.7	85.6	85.6	₺3.940,00
Reinforcement 8-12mm (Ton)	108.5	106.7	110.8	₺3.400,00
Reinforcement 14-50mm (Ton)	111.2	93.2	78.4	₺3.400,00
Concrete m^3	3115.2	3115.2	3115.2	₺340,00
Average Rebar Ratio	98.07 kg/m^3	91.654 kg/m^3	88.22 kg/m^3	
	30.196 kg/m^2	28.22 kg/m^2	27.163 kg/m^2	
Total	**₺2.143.806,00**	**₺2.076.092,00**	**₺2.039.712,00**	

Table 5.45: Cost of Regular Type Building - Atasehir 20-Storey

R-A-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	171.4	171.2	171.2	₺3.940,00
Reinforcement 8-12mm (Ton)	259.9	270.5	288.6	₺3.400,00
Reinforcement 14-50mm (Ton)	297.2	265	230.6	₺3.400,00
Concrete m^3	6810.7	6810.7	6810.7	₺340,00
Average Rebar Ratio	106.972 kg/m^3	103.767 kg/m^3	101.371 kg/m^3	
	36.005 kg/m^2	34.926 kg/m^2	34.12 kg/m^2	
Total	**₺4.885.094,00**	**₺4.810.866,00**	**₺4.755.446,00**	

Table 5.46: Cost of Regular Type Building – Izmit 5-Storey

R-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	42.8	42.8	42.8	₺3.940,00
Reinforcement 8-12mm (Ton)	52.4	51.8	56.8	₺3.400,00
Reinforcement 14-50mm (Ton)	43.8	41.2	51.5	₺3.400,00
Concrete m³	1545.5	1545.5	1545.5	₺340,00
Average Rebar Ratio	89.93 kg/m³	87.883 kg/m³	97.79 kg/m³	
	27.475 kg/m²	26.849 kg/m²	29.876 kg/m²	
Total	**₺1.021.182,00**	**₺1.010.302,00**	**₺1.062.322,00**	

Table 5.47: Cost of Regular Type Building – Izmit 10-Storey

R-I-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	85.7	85.6	85.6	₺3.940,00
Reinforcement 8-12mm (Ton)	120.6	117	121.6	₺3.400,00
Reinforcement 14-50mm (Ton)	129	107	123.9	₺3.400,00
Concrete m³	3266.6	3266.6	3266.6	₺340,00
Average Rebar Ratio	102.647 kg/m³	91.654 kg/m³	101.346 kg/m³	
	33.142 kg/m²	28.22 kg/m²	32.722 kg/m²	
Total	**₺2.296.942,00**	**₺2.209.508,00**	**₺2.282.608,00**	

Table 5.48: Cost of Regular Type Building – Izmit 20-Storey

R-I-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	171.4	171.2	171.2	₺3.940,00
Reinforcement 8-12mm (Ton)	264.1	274.2	297.7	₺3.400,00
Reinforcement 14-50mm (Ton)	295.2	265.4	302.2	₺3.400,00
Concrete m³	6868.3	6868.3	6868.3	₺340,00
Average Rebar Ratio	106.401 kg/m³	103.482 kg/m³	112.271 kg/m³	
	36.115 kg/m²	35.125 kg/m²	38.108 kg/m²	
Total	**₺4.912.158,00**	**₺4.844.390,00**	**₺5.049.410,00**	

5.3.2 A1 Type: Torsional Irregularity

Table 5.49: Cost of A1 Type Building – Atasehir 5 Storey

A1-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	33.4	33.4	33.4	₺3.940,00
Reinforcement 8-12mm (Ton)	38.8	40	27	₺3.400,00
Reinforcement 14-50mm (Ton)	37.1	27.7	40.5	₺3.400,00
Concrete m³	1071.7	1071.7	1071.7	₺340,00
Average Rebar Ratio	102.022 kg/m³	94.373 kg/m³	94.087 kg/m³	
	29.494 kg/m²	27.283 kg/m²	27.201 kg/m²	
Total	**₺754.034,00**	**₺726.154,00**	**₺725.474,00**	

Table 5.50: Cost of A1 Type Building – Atasehir 10 Storey

A1-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	66.3	66.3	66.3	₺3.940,00
Reinforcement 8-12mm (Ton)	85.3	88.7	93.7	₺3.400,00
Reinforcement 14-50mm (Ton)	104.9	76	60.1	₺3.400,00
Concrete m³	2353	2353	2353	₺340,00
Average Rebar Ratio	109.031 kg/m³	98.237 kg/m³	93.569 kg/m³	
	34.604 kg/m²	31.178 kg/m²	29.697 kg/m²	
Total	**₺1.707.922,00**	**₺1.621.222,00**	**₺1.584.162,00**	

Table 5.51: Cost of A1 Type Building – Atasehir 20 Storey

A1-A-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	132	132	132	₺3.940,00
Reinforcement 8-12mm (Ton)	232.5	244.2	255.9	₺3.400,00
Reinforcement 14-50mm (Ton)	208.2	157.4	116.7	₺3.400,00
Concrete m³	5298	5298	5298	₺340,00
Average Rebar Ratio	108.078 kg/m³	100.706 kg/m³	95.226 kg/m³	
	38.618 kg/m²	35.983 kg/m²	34.025 kg/m²	
Total	**₺3.819.780,00**	**₺3.686.840,00**	**₺3.588.240,00**	

Table 5.52: Cost of A1 Type Building – Izmit 5 Storey

A1-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	33.2	33.2	33.2	₺3.940,00
Reinforcement 8-12mm (Ton)	44.8	47.2	47.8	₺3.400,00
Reinforcement 14-50mm (Ton)	33.6	28.1	36.5	₺3.400,00
Concrete m^3	1179	1179	1179	₺340,00
Average Rebar Ratio	94.553 kg/m^3	91.984 kg/m^3	99.568 kg/m^3	
	30.095 kg/m^2	29.277 kg/m^2	31.691 kg/m^2	
Total	**₺798.228,00**	**₺787.688,00**	**₺818.288,00**	

Table 5.53: Cost of A1 Type Building – Izmit 10 Storey

A1-I-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	66.4	66.4	66.4	₺3.940,00
Reinforcement 8-12mm (Ton)	88.3	90.4	95	₺3.400,00
Reinforcement 14-50mm (Ton)	106.8	76.7	82.6	₺3.400,00
Concrete m^3	2378	2378	2378	₺340,00
Average Rebar Ratio	109.925 kg/m^3	98.172 kg/m^3	102.583 kg/m^3	
	35.262 kg/m^2	31.492 kg/m^2	32.907 kg/m^2	
Total	**₺1.733.476,00**	**₺1.638.276,00**	**₺1.673.976,00**	

Table 5.54: Cost of A1 Type Building – Izmit 20 Storey

A1-I-20S	**Eurocode 8**	**TEC 2007**	**TBEC 2018**	**Unit Price**
Steel Mesh (Ton)	132.6	132.6	132.6	₺3.940,00
Reinforcement 8-12mm (Ton)	234.1	243.8	247.6	₺3.400,00
Reinforcement 14-50mm (Ton)	216.4	175.5	174.1	₺3.400,00
Concrete m^3	5395	5395	5395	₺340,00
Average Rebar Ratio	108.085 kg/m^3	102.298 kg/m^3	102.751 kg/m^3	
	39.327 kg/m^2	37.221 kg/m^2	37.386 kg/m^2	
Total	**₺3.888.444,00**	**₺3.782.364,00**	**₺3.790.524,00**	

5.3.3 A2 Type: Floor Discontinuities

Table 5.55: Cost of A2 Type Building – Atasehir 5 Storey

A2-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	27	27	27	₺3.940,00
Reinforcement 8-12mm (Ton)	53.4	53.1	55.7	₺3.400,00
Reinforcement 14-50mm (Ton)	43.5	40.9	39.8	₺3.400,00
Concrete m^3	1363.6	1363.6	1363.6	₺340,00
Average Rebar Ratio	90.901 kg/m^3	88.782 kg/m^3	89.888 kg/m^3	
	29.744 kg/m^2	29.05 kg/m^2	29.412 kg/m^2	
Total	**₺899.464,00**	**₺889.604,00**	**₺894.704,00**	

Table 5.56: Cost of A2 Type Building – Atasehir 20 Storey

A2-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	54.3	54.3	54.2	₺3.940,00
Reinforcement 8-12mm (Ton)	98.5	113.9	112.9	₺3.400,00
Reinforcement 14-50mm (Ton)	152.8	116.8	96.2	₺3.400,00
Concrete m^3	2718.2	2718.2	2718.2	₺340,00
Average Rebar Ratio	112.435 kg/m^3	104.835 kg/m^3	96.852 kg/m^3	
	36.667 kg/m^2	34.189 kg/m^2	31.585 kg/m^2	
Total	**₺1.992.550,00**	**₺1.922.510,00**	**₺1.848.676,00**	

Table 5.57: Cost of A2 Type Building – Atasehir 20 Storey

A2-A-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	107.2	107.1	108.7	₺3.940,00
Reinforcement 8-12mm (Ton)	276	308.1	329.4	₺3.400,00
Reinforcement 14-50mm (Ton)	358.8	291.9	251.2	₺3.400,00
Concrete m^3	6137.7	6137.7	6137.7	₺340,00
Average Rebar Ratio	120.897 kg/m^3	115.217 kg/m^3	112.298 kg/m^3	
	44.513 kg/m^2	42.422 kg/m^2	41.347 kg/m^2	
Total	**₺4.667.506,00**	**₺4.548.792,00**	**₺4.489.136,00**	

Table 5.58: Cost of A2 Type Building – Izmit 5 Storey

A2-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	27.7	26.8	27	₺3.940,00
Reinforcement 8-12mm (Ton)	65.5	66.7	69.5	₺3.400,00
Reinforcement 14-50mm (Ton)	53.7	52.9	56.3	₺3.400,00
Concrete m³	1436.1	1436.1	1436.1	₺340,00
Average Rebar Ratio	101.615 kg/m³	101.944 kg/m³	106.397 kg/m³	
	35.015 kg/m²	35.129 kg/m²	36.675 kg/m²	
Total	**₺1.002.692,00**	**₺1.000.506,00**	**₺1.022.374,00**	

Table 5.59: Cost of A2 Type Building – Izmit 10 Storey

A2-I-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	53.2	53.3	53.9	₺3.940,00
Reinforcement 8-12mm (Ton)	129.4	142.4	140	₺3.400,00
Reinforcement 14-50mm (Ton)	157	126.5	131.9	₺3.400,00
Concrete m³	2924.3	2924.3	2924.3	₺340,00
Average Rebar Ratio	116.192 kg/m³	110.186 kg/m³	111.444 kg/m³	
	40.765 kg/m²	38.658 kg/m²	39.099 kg/m²	
Total	**₺2.177.630,00**	**₺2.118.524,00**	**₺2.131.088,00**	

Table 5.60: Cost of A2 Type Building – Izmit 20 Storey

A2-I-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	107.6	107.4	108.9	₺3.940,00
Reinforcement 8-12mm (Ton)	287.1	330.3	337.3	₺3.400,00
Reinforcement 14-50mm (Ton)	406.9	331.8	341	₺3.400,00
Concrete m³	6512	6515	6512	₺340,00
Average Rebar Ratio	123.094 kg/m³	118.158 kg/m³	122.289 kg/m³	
	48.086 kg/m²	46.157 kg/m²	47.224 kg/m²	
Total	**₺4.997.624,00**	**₺4.889.396,00**	**₺4.949.366,00**	

5.3.4 A3 Type: Projections in Plan

Table 5.61: Cost of A3 Type Building – Atasehir 5 Storey

A3-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	34.9	34.9	35	₺3.940,00
Reinforcement 8-12mm (Ton)	44	45.5	45.5	₺3.400,00
Reinforcement 14-50mm (Ton)	35	32.5	32.7	₺3.400,00
Concrete m^3	1222	1222	1222	₺340,00
Average Rebar Ratio	93.172 kg/m^3	92.355 kg/m^3	92.573 kg/m^3	
	26.784 kg/m^2	26.549 kg/m^2	26.612 kg/m^2	
Total	**₺821.586,00**	**₺818.186,00**	**₺819.260,00**	

Table 5.62: Cost of A3 Type Building – Atasehir 10 Storey

A3-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	69.3	69.6	69.3	₺3.940,00
Reinforcement 8-12mm (Ton)	96.2	109.6	111.2	₺3.400,00
Reinforcement 14-50mm (Ton)	130.8	90.2	79.9	₺3.400,00
Concrete m^3	2668	2668	2668	₺340,00
Average Rebar Ratio	111.121 kg/m^3	100.957 kg/m^3	97.587 kg/m^3	
	34.856 kg/m^2	31.668 kg/m^2	30.611 kg/m^2	
Total	**₺1.951.962,00**	**₺1.860.664,00**	**₺1.829.902,00**	

Table 5.63: Cost of A3 Type Building – Atasehir 20 Storey

A3-A-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	138.5	138.5	139.5	₺3.940,00
Reinforcement 8-12mm (Ton)	227.4	247.7	272.7	₺3.400,00
Reinforcement 14-50mm (Ton)	314.3	266.7	222.6	₺3.400,00
Concrete m^3	5910	5910	5910	₺340,00
Average Rebar Ratio	115.102 kg/m^3	110.467 kg/m^3	107.408 kg/m^3	
	39.984 kg/m^2	38.374 kg/m^2	37.311 kg/m^2	
Total	**₺4.396.870,00**	**₺4.304.050,00**	**₺4.243.050,00**	

Table 5.64: Cost of A3 Type Building – Izmit 5 Storey

A3-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	34.9	34.9	34.9	₺3.940,00
Reinforcement 8-12mm (Ton)	47.5	49.6	34.1	₺3.400,00
Reinforcement 14-50mm (Ton)	41.8	39.6	64.4	₺3.400,00
Concrete m³	1296	1296	1296	₺340,00
Average Rebar Ratio	95.83 kg/m³	95.756 kg/m³	102.824 kg/m³	
	29.216 kg/m²	29.194 kg/m²	31.349 kg/m²	
Total	**₺881.766,00**	**₺881.426,00**	**₺913.046,00**	

Table 5.65: Cost of A3 Type Building – Izmit 10 Storey

A3-I-10S	**Eurocode 8**	**TEC 2007**	**TBEC 2018**	**Unit Price**
Steel Mesh (Ton)	69.5	69.5	69.3	₺3.940,00
Reinforcement 8-12mm (Ton)	101.6	114.4	77.2	₺3.400,00
Reinforcement 14-50mm (Ton)	121.9	100.1	148.5	₺3.400,00
Concrete m³	2751	2751	2751	₺340,00
Average Rebar Ratio	106.513 kg/m³	103.201 kg/m³	107.204 kg/m³	
	34.452 kg/m²	33.381 kg/m²	34.676 kg/m²	
Total	**₺1.969.070,00**	**₺1.938.470,00**	**₺1.975.762,00**	

Table 5.66: Cost of A3 Type Building – Izmit 20 Storey

A3-I-20S	**Eurocode 8**	**TEC 2007**	**TBEC 2018**	**Unit Price**
Steel Mesh (Ton)	140	140	139	₺3.940,00
Reinforcement 8-12mm (Ton)	308	319.4	335.7	₺3.400,00
Reinforcement 14-50mm (Ton)	312	262.9	271.4	₺3.400,00
Concrete m³	6401	6401	6401	₺340,00
Average Rebar Ratio	118.711 kg/m³	112.785 kg/m³	116.602 kg/m³	
	44.66 kg/m²	42.431 kg/m²	43.867 kg/m²	
Total	**₺4.835.940,00**	**₺4.707.760,00**	**₺4.788.140,00**	

5.3.5 B1 Type: Interstorey Strength Irregularity

Table 5.67: Cost of B1 Type Building – Atasehir 5 Storey

B1-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	29	29	29	₺3.940,00
Reinforcement 8-12mm (Ton)	40.7	39.7	40.5	₺3.400,00
Reinforcement 14-50mm (Ton)	35.7	27.9	31.1	₺3.400,00
Concrete m^3	1083.9	1083.9	1083.9	₺340,00
Average Rebar Ratio	97.237 kg/m^3	89.045 kg/m^3	92.829 kg/m^3	
	30.695 kg/m^2	28.109 kg/m^2	29.303 kg/m^2	
Total	**₺742.546,00**	**₺712.626,00**	**₺726.226,00**	

Table 5.68: Cost of B1 Type Building – Atasehir 10 Storey

B1-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	60.9	60.8	60.8	₺3.940,00
Reinforcement 8-12mm (Ton)	94.8	104.7	106.7	₺3.400,00
Reinforcement 14-50mm (Ton)	96.7	72	63.3	₺3.400,00
Concrete m^3	2485.7	2485.7	2485.7	₺340,00
Average Rebar Ratio	101.559 kg/m^3	95.574 kg/m^3	92.847 kg/m^3	
	36.76 kg/m^2	34.594 kg/m^2	33.606 kg/m^2	
Total	**₺1.736.184,00**	**₺1.685.470,00**	**₺1.662.690,00**	

Table 5.69: Cost of B1 Type Building – Atasehir 20 Storey

B1-A-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	122.5	122.3	122.3	₺3.940,00
Reinforcement 8-12mm (Ton)	226	247.5	251.1	₺3.400,00
Reinforcement 14-50mm (Ton)	242.8	210.2	167.2	₺3.400,00
Concrete m^3	5441.4	5441.4	5441.4	₺340,00
Average Rebar Ratio	108.67 kg/m^3	106.585 kg/m^3	99.343 kg/m^3	
	43.052 kg/m^2	42.226 kg/m^2	39.357 kg/m^2	
Total	**₺3.926.646,00**	**₺3.888.118,00**	**₺3.754.158,00**	

Table 5.70: Cost of B1 Type Building – Izmit 5 Storey

B1-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	28.9	28.9	28.9	₺3.940,00
Reinforcement 8-12mm (Ton)	41.4	43.1	45	₺3.400,00
Reinforcement 14-50mm (Ton)	35.6	37.4	37.8	₺3.400,00
Concrete m³	1097	1097	1097	₺340,00
Average Rebar Ratio	96.211 kg/m³	99.672 kg/m³	101.789 kg/m³	
	30.737 kg/m²	31.842 kg/m²	32.519 kg/m²	
Total	**₺748.646,00**	**₺760.546,00**	**₺768.366,00**	

Table 5.71: Cost of B1 Type Building – Izmit 10 Storey

B1-I-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	60.8	60.8	60.8	₺3.940,00
Reinforcement 8-12mm (Ton)	105.7	111.8	113.6	₺3.400,00
Reinforcement 14-50mm (Ton)	107.1	79.5	86.7	₺3.400,00
Concrete m³	2640.1	2640.1	2640.1	₺340,00
Average Rebar Ratio	103.669 kg/m³	95.48 kg/m³	98.907 kg/m³	
	39.854 kg/m²	36.706 kg/m²	38.024 kg/m²	
Total	**₺1.860.706,00**	**₺1.787.606,00**	**₺1.818.206,00**	

Table 5.72: Cost of B1 Type Building – Izmit 20 Storey

B1-I-20S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	122.5	122.3	122.3	₺3.940,00
Reinforcement 8-12mm (Ton)	230.9	249.9	252.6	₺3.400,00
Reinforcement 14-50mm (Ton)	240.8	208.9	220.8	₺3.400,00
Concrete m³	5480.7	5480.7	5480.7	₺340,00
Average Rebar Ratio	108.415 kg/m³	106.035 kg/m³	108.699 kg/m³	
	43.261 kg/m²	42.312 kg/m²	43.375 kg/m²	
Total	**₺3.949.868,00**	**₺3.905.220,00**	**₺3.954.860,00**	

5.3.6 B2 Type: Interstorey Stiffness Irregularity

Table 5.73: Cost of B2 Type Building – Atasehir 5 Storey

B2-A-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	19.2	19.2	19.2	₺3.940,00
Reinforcement 8-12mm (Ton)	29.3	32.3	33.9	₺3.400,00
Reinforcement 14-50mm (Ton)	42.7	30.8	26.9	₺3.400,00
Concrete m^3	799	799	799	₺340,00
Average Rebar Ratio	114.236 kg/m^3	103.167 kg/m^3	100.272 kg/m^3	
	32.6 kg/m^2	29.441 kg/m^2	28.615 kg/m^2	
Total	**₺592.108,00**	**₺561.848,00**	**₺554.028,00**	

Table 5.74: Cost of B2 Type Building – Atasehir 10 Storey

B2-A-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	38	38	38	₺3.940,00
Reinforcement 8-12mm (Ton)	61.5	65.5	75.2	₺3.400,00
Reinforcement 14-50mm (Ton)	97.4	69.8	50.2	₺3.400,00
Concrete m^3	1639	1639	1639	₺340,00
Average Rebar Ratio	120.073 kg/m^3	105.713 kg/m^3	99.658 kg/m^3	
	35.148 kg/m^2	30.945 kg/m^2	29.172 kg/m^2	
Total	**₺1.247.240,00**	**₺1.167.000,00**	**₺1.133.340,00**	

Table 5.75: Cost of B2 Type Building – Atasehir 15 Storey

B2-A-15S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	62	62	62	₺3.940,00
Reinforcement 8-12mm (Ton)	145.4	153.1	170.3	₺3.400,00
Reinforcement 14-50mm (Ton)	157.5	113.7	80.9	₺3.400,00
Concrete m^3	2764	2764	2764	₺340,00
Average Rebar Ratio	132.025 kg/m^3	118.974 kg/m^3	113.322 kg/m^3	
	43.452 kg/m^2	39.157 kg/m^2	37.297 kg/m^2	
Total	**₺2.213.900,00**	**₺2.091.160,00**	**₺2.038.120,00**	

Table 5.76: Cost of B2 Type Building – Izmit 5 Storey

B2-I-5S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	19.2	19.2	19.2	₺3.940,00
Reinforcement 8-12mm (Ton)	29.3	32.3	34.5	₺3.400,00
Reinforcement 14-50mm (Ton)	42.7	30.8	28.9	₺3.400,00
Concrete m³	799	799	799	₺340,00
Average Rebar Ratio	114.236 kg/m³	103.167 kg/m³	103.451 kg/m³	
	32.6 kg/m²	29.441 kg/m²	29.522 kg/m²	
Total	**₺592.108,00**	**₺561.848,00**	**₺562.868,00**	

Table 5.77: Cost of B2 Type Building – Izmit 10 Storey

B2-I-10S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	38	38	38	₺3.940,00
Reinforcement 8-12mm (Ton)	61.9	65.9	76.3	₺3.400,00
Reinforcement 14-50mm (Ton)	96.6	69.9	56.5	₺3.400,00
Concrete m³	1642	1642	1642	₺340,00
Average Rebar Ratio	119.632 kg/m³	105.757 kg/m³	103.967 kg/m³	
	35.091 kg/m²	31.021 kg/m²	30.496 kg/m²	
Total	**₺1.246.900,00**	**₺1.169.720,00**	**₺1.159.520,00**	

Table 5.78: Cost of B2 Type Building – Izmit 15 Storey

B2-I-15S	Eurocode 8	TEC 2007	TBEC 2018	Unit Price
Steel Mesh (Ton)	62	62	62	₺3.940,00
Reinforcement 8-12mm (Ton)	143.1	153.1	167.8	₺3.400,00
Reinforcement 14-50mm (Ton)	157.5	113.7	100.5	₺3.400,00
Concrete m³	2764	2764	2764	₺340,00
Average Rebar Ratio	131.168 kg/m³	118.974 kg/m³	119.495 kg/m³	
	43.17 kg/m²	39.157 kg/m²	39.328 kg/m²	
Total	**₺2.206.080,00**	**₺2.091.160,00**	**₺2.096.260,00**	

In the analyses using the data of Atasehir, earthquake codes were listed as TBEC 2018, TEC 2007 and EC 8 respectively from the best efficiency to the worst efficiency in point of economic view.

- In buildings where data of Atasehir are used, analyses performed according to EC 8 are on average 8-10% more costly than TBEC 2018.
- In buildings where data of Atasehir are used, analyses performed according to TEC 2007 are on average 4-5% more costly than TBEC 2018.

In the analyses using the data of Izmit, earthquake codes were listed as TEC 2007, TBEC 2018 and EC 8 respectively from the best efficiency to the worst efficiency in point of economic view.

- In buildings where data of Izmit are used, analyses performed according to EC 8 are on average 1-2% more costly than TBEC 2018.
- In buildings where data of Izmit are used, analyses performed according to TEC 2007 are on average 2-3% less costly than TBEC 2018.

Chapter 6

CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDIES

6.1 Conclusions

This thesis has been conducted to investigate the performance of residential buildings. As a result of the publication of the new regulation, many new rules and many updates on existing rules have attracted attention. Therefore, the factors affecting the building performance of both Turkish earthquake codes (TBEC 2018 and TEC 2007) were examined. In addition to the examination, EC 8, the regulation used by European countries, has been added to compare the innovations introduced by the new Turkish Earthquake Code 2018. In the numerical study part of this thesis, the residential buildings were designed and analysed by applying the mode superposition method of the earthquake codes. Then, the performance of the buildings was evaluated according to TBEC 2018 criteria. According to the results of the analysis and evaluation, the performance levels and damaged element ratios of the buildings, first natural vibration period of buildings, irregularity parameters, base shear forces and the cost of the buildings were determined. The results of the linear analysis are listed below.

- In terms of first natural vibration period of buildings, although the value obtained for TEC 2007 and EC 8 was almost the same, TBEC 2018 gave 30 to 40% higher first natural vibration period of buildings compared to the other two earthquake codes. In terms of first natural vibration period of buildings, no significant differences were observed between Atasehir and Izmit regions.

- The base shear forces for all buildings in which Atasehir values have been used were listed from the highest to the lowest as in EC 8, TEC 2007 and TBEC 2018 respectively. On the other hand, the base shear forces for 5-storey buildings in which Izmit values have been used were listed from the highest to the lowest as in TBEC 2018, EC 8 and TEC 2007 respectively. However, in the case of 10 and 20-storey buildings, EC 8 exhibited higher base shear forces compared to TBEC 2018 and TEC 2007.
- According to the analysis results of buildings, EC 8 has the highest base shear force. As a result of EC 8 analysis, the most important reason for the higher base shear forces compared to TBEC 2018 and TEC 2007 is the structural system behaviour factor. In high ductile structures, this coefficient is taken as 7 in Turkish regulations, while in EC 8 it is taken as 5.4 or less.
- In the analysis performed according to TBEC 2018, since the shear walls in the structural system carried more than 66% of the total earthquake load, the earthquake load reduction factor was reduced to 5.6 with the formula according to the relevant section of the earthquake codes. Likewise, in the analysis performed according to TEC 2007, since the shear walls in the structural system carried more than 75% of the total earthquake load, the earthquake load reduction coefficient was reduced by the formula. However, in the analysis performed according to EC 8, the decrease in structural system behaviour factor can be seen more clearly. According to EC 8, if the building is vertically irregular, the q_o coefficient is reduced by 20%, and if the plan is irregular, the α_u/α_1 value is set to 1 to reduce the structural system behaviour factor.
- Generally, due to the differences in the spectral acceleration values used for the two locations in the analyses, different evaluations were made. According

to TBEC 2018 and TEC 2007, designs in Ataşehir allow engineers to design at a lower cost than EC 8 during the analysis phase. However, it has been observed that the safety parameters in earthquake analysis in EC 8 are used more effectively compared to TBEC 2018 and TEC 2007. Also, in terms of building cost, the lowest values were obtained from the analyses performed according to TBEC 2018. Thus, TBEC 2018 remained on the most economic side.

- According to TEC 2007, designs in Izmit allow engineers to design at a lower cost than TBEC 2018 and EC 8 during the analysis phase. However, it has been observed that the safety parameters in earthquake analysis in TBEC 2018 and EC 8 are used more effectively compared to TEC 2007. Also, in terms of building cost, the lowest values were obtained from the analyses performed according to TEC 2007. Thus, TEC 2007 remained on the most economic side.

Two different evaluations were performed for the performance results obtained from pushover analysis results. Because according to the TBEC 2018, the spectral acceleration values used in the buildings designed for Ataşehir and Izmit regions are different.

- Within the scope of the thesis, non-linear performance analysis was performed for 108 residential buildings. As a result of the pushover analysis, 95% of the buildings evaluated according to TBEC 2018 criteria achieved the expected controlled damage performance level.
- A total of 18 performance analyses were compared for 54 residential buildings designed using the spectral acceleration values of Ataşehir. In 7 of these 18 performance comparisons, EC 8 showed the worst performance in terms of column damage. Following EC 8, TBEC 2018 in 6 comparisons and TEC 2007

in 5 comparisons showed the worst column damage performance. However, in the same comparisons, TEC 2007 showed the worst performance in terms of beam damage in 7 out of 18 comparisons. Following TEC 2007, TBEC 2018 in 3 comparisons and EC 8 in 1 comparison showed the worst beam damage performance. In addition, beam damage was not observed for all three earthquake codes in 7 of 18 performance comparisons using Ataşehir data.

- A total of 18 performance analyses were compared for 54 residential buildings designed using the spectral acceleration values of Izmit. In 10 of these 18 performance comparisons, TEC 2007 showed the worst performance in terms of column damage. Following TEC 2007, EC 8 in 5 comparisons and TBEC 2018 in 3 comparisons showed the worst column damage performance. However, in the same comparisons, TBEC 2018 showed the worst performance in terms of beam damage in 8 out of 18 comparisons. Following TBEC 2018, EC 8 in 4 comparisons and TEC 2007 in 3 comparison showed the worst beam damage performance. In addition, beam damage was not observed for all three earthquake codes in 3 of 18 performance comparisons using Izmit data.
- In the designs made according to TEC 2007 and EC 8, the same spectral acceleration values were used for both cities. However, the spectral acceleration values of the buildings designed according to 2018 are different. Therefore, the structural system elements of suitably designed buildings in the Izmit are larger than those of Atasehir. Therefore, even if the same spectral acceleration values are used, the damage rate of the buildings designed for the Izmit region is higher than the buildings designed for the Atasehir region. The reason for the increase in the damage rate is the effect of the increase in base

shear force due to the increase in internal forces as a result of larger element cross-sections.

6.2 Recommendations for Future Studies

Suggestions are listed below;

1. Similar studies can be conducted with more ground motion analysis to investigate the behaviour of more irregular structures. It is thought that different results can be obtained in the comparisons made under different conditions (building importance factor, soil class etc.).
2. Modelling the same structural systems with finite elements model for further advanced analysis will enable us to get closer to a more realistic conclusion.

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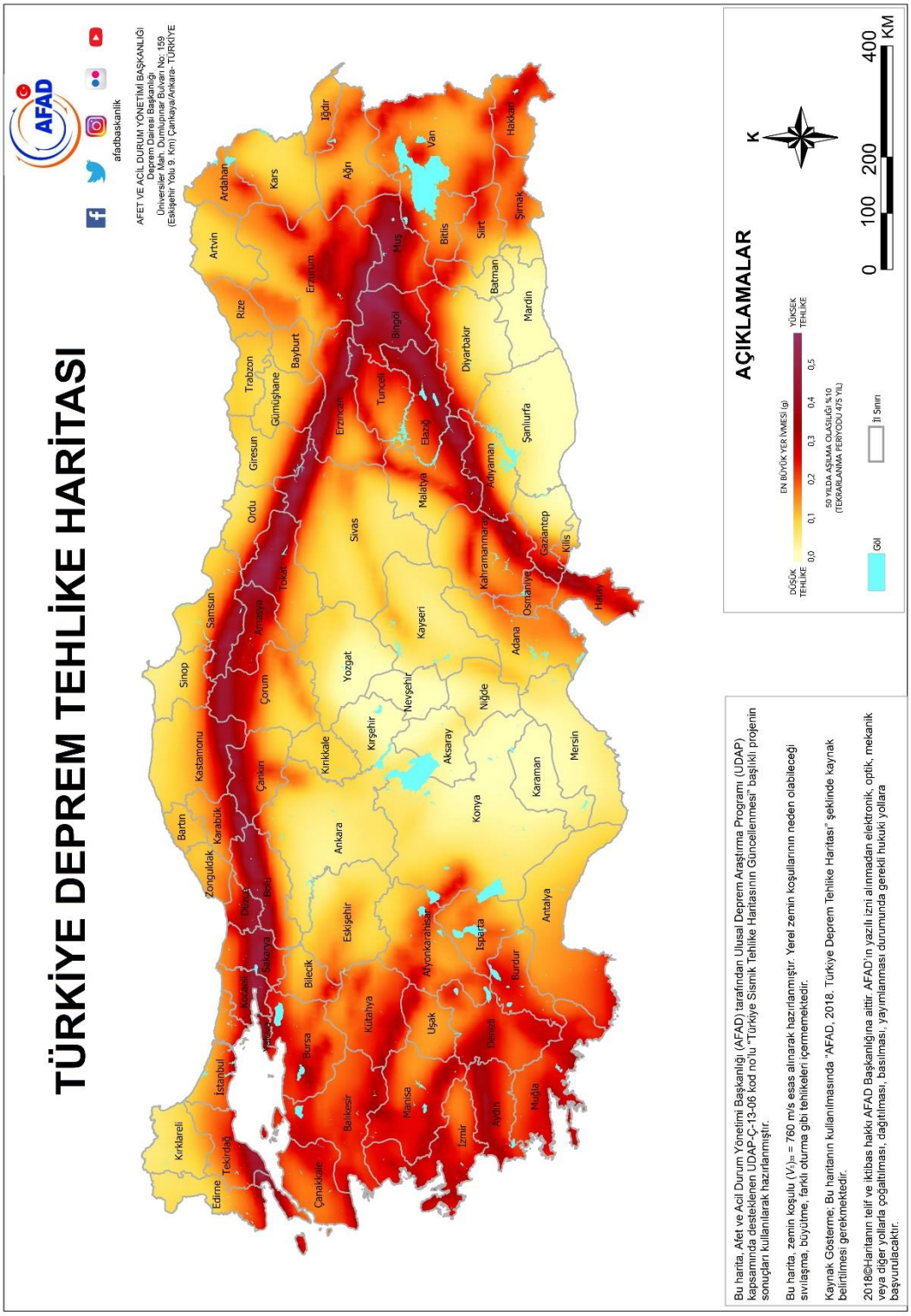
APPENDICES

Appendix A: New Interactive Turkish Earthquake Hazard Map



Appendix B: Turkish Earthquake Zones Map