ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

A STUDY OF WIND AND SEISMIC LOADS FOR CURTAIN WALL SYSTEM: CASE STUDIES IN ISTANBUL

M.Sc. THESIS

Rusul Saad Ali INIZI

Department of Architecture

Environmental Control and Construction Technologies Program

FEBRUARY 2021

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

A STUDY OF WIND AND SEISMIC LOADS FOR CURTAIN WALL SYSTEM: CASE STUDIES IN ISTANBUL

M.Sc. THESIS

Rusul Saad Ali INIZI
(502171528)

Department of Architecture

Environmental Control and Construction Technologies Program

Thesis Advisor: Asst. Prof. Dr. Cenk ÜSTÜNDAĞ

FEBRUARY 2021

ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

GİYDİRME CEPHE SİSTEMLERİ İÇİN RÜZGAR VE DEPREM YÜKÜ ÇALIŞMASI: İSTANBUL'DA VAKA ÇALIŞMALARI

YÜKSEK LİSANS TEZİ

Rusul Saad Ali INIZI
(502171528)

Mimarlık Anabilim Dalı

Çevre Kontrolü ve Yapı Teknolojisi Programı

Tez Danışmanı: Dr. Öğr. Üyesi Cenk ÜSTÜNDAĞ

ŞUBAT 2021

Rusul Saad Ai Inizi, a M.Sc. student of İTU Graduate School student ID 502171528, successfully defended the thesis entitled "A STUDY OF WIND LOAD AND SEISMIC LOAD FOR CURTAIN WALL SYSTEM: CASE STUDIES IN ISTANBUL", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Asst. Prof. Dr. Cenk ÜSTÜNDAĞ** .....
İstanbul Technical University

Jury Members : **Assoc. Prof. Dr. Fethiye Ecem EDİS** .....
Istanbul Technical University

Asst. Prof. Dr. Gökhan YAZICI .....
Istanbul Kultur University

Date of Submission : 22 January 2021
Date of Defense : 27 February 2021

FOREWORD

To my supervisor Dr Cenk Üstündağ, and I would like to thank Dr Ecem Edis for her kind approach and persistent guidance throughout the study. Without her help, we would not have been able to complete this research.
I would like to express my sincere thanks and appreciation;
M. Haldun Yılmaz who is one of the partners of FMT Facade Consultants,
N. Bahadır Buluk who is the Expert Façade Engineer in FDF Facade Consultancy and Engineering Services,
S. Çolak who is the Project Executive at Çuhadaröğlu,
for their help and support this study generously.
Finally, I would like to express my thanks and gratitude to my family for their continuous support and encouragement.

February 2021

Rusul Saad Ali INIZI
(Architect)

TABLE OF CONTENTS

Page

ABBREVIATIONS

AAMA : American Architectural Manufacturers Association
ASCE : The American Society of Civil Engineers
BS : British Standards
CFD : Computational Fluid Dynamics
CWCT : Centre for Window and Cladding Technology
DSF : Double Skin Facade
EN : European Standards
EPDM : Ethylene Propylene Diene Monomer
FEMA : The Federal Emergency Management Agency
ISO : International Organization for Standardization
IYBRY : Istanbul High-rise Building Wind Regulation
Low-E : Low Emissivity
SSG : Structural Silicone Glazing
TBDY : Turkey Building Earthquake Regulation
TS : Turkish Standard

LIST OF TABLES

Page

LIST OF FIGURES

Page

A STUDY OF WIND AND SEISMIC LOADS FOR CURTAIN WALL SYSTEM: CASE STUDIES IN ISTANBUL

SUMMARY

Curtain wall systems have become one of the most popular systems, depending on their advantages, not only in high-rise buildings but also in medium-rise residential commercial buildings and offices. In particular, each building's curtain wall's performance significantly impacts the building's overall performance, as the main criteria in the past required control of light, heat and water. However, due to technological development, high performance and control of earthquake and wind loads became one of the system's requirements to perform efficiently.

Past earthquakes in Turkey demonstrate the danger to human life due to the incorrect design of curtain wall systems, which increasingly used today. In addition, as the façades being the first component of the building exposed to the wind, it is necessary to know what winds and earthquakes generate on the system. Therefore, this study's main objective was to define and analyse seismic and wind load effects in different building heights on the curtain wall system's components and details. Besides, it aimed to know and analyse the methods used to calculate winds and earthquakes affecting the curtain wall system. This study consists of four stages.

Before studying winds and earthquakes, it was essential to analyse the curtain wall in general, in order to be able to analyse it precisely. Thus, in the historical period, parallel to the technological advances, the curtain wall witnessed numerous developments in materials and construction techniques. As a result, the curtain wall built with various construction methods, such as the stick, unitized, the combination of the two. The stick method usually used in medium-rise buildings. The unitized system commonly used in high-rise buildings when the curtain wall is evaluated in terms of cost, speed of completion, accuracy and construction techniques. The method of securing the glass to the curtain wall frame is different, as the structural silicon glazing one of the most preferred methods to use in high-rise buildings. In contrast, the pressure plate method and the point fixation system, are used on other buildings. The curtain wall can be either a double-skin facade used for controlling the ventilation and solar protection in addition, concerning the curtain wall components; for the frame, whose details and materials differ from one project to another, aluminium is considered one of the most preferred materials because of the benefits that aluminium provides in terms of design

flexibility, durability, environmentally friendly material as well as better tolerance. As for glass, there are several types and double glass generally used in Turkey beside to the anchor as well as a sealant. The performance requirements that's need to be fulfilled by the curtain wall is studied at this stage too.

After analysing the curtain wall, the effect of winds on the curtain wall is defined according to the literature reviews and standards in the second stage, In the beginning, the wind and prevalent winds of Turkey, in particular in Istanbul, the impact of winds on the building's façades explained. Furthermore, the winds on the curtain wall as a whole and its components explained in detail. The most common specifications used in designing the curtain wall are Turkish regulations IYBRY, the European standard and the American standard, then reviewing the differences and similarities between these specifications. Finally, the methods of analysis, experiments and wind measurement on the curtain wall reviewed.

In the third stage, to understand the impact of the earthquake on the curtain wall, earthquakes in Turkey, and the underlying causes of regular seismic events in Turkey which accompanied by an investigation of the earthquake's effect of on the building façades and the instability and collapse of certain parts of the facade is considered. The effect of earthquakes on the curtain wall components was studied and then the specifications used during the seismic design of the curtain wall are presented from the Turkish regulation for 2018. The European and American standard was used to deal with earthquakes and the resulting damages and then these specifications' similarities and differences were compared. Finally, at this stage, seismic analysis and testing methods were studied to find out the mechanical behaviour of the curtain wall elements.

In the fourth stage, the case buildings in Istanbul are considered by interviews with the curtain wall companies and the facade consulting companies, a questionnaire about projects prepared and projects details from these companies are gained , then analysing all the projects façade to study how the impact of earthquakes and winds calculated during the design phase, then making summary comparison between these project related to curtain wall system of the project in terms of details and methods of calculation used, the result was that most companies do not follow similar standards during the design phase of the curtain wall, due to the lack of a Turkish standard that is compatible with the prevailing conditions in Turkey, even the existing Turkish

regulations, are taken from the European standard, and this has led to each company following different standards.

GİYDİRME CEPHE SİSTEMLERİ İÇİN RÜZGAR YÜKÜ VE DEPREM YÜKÜ ÇALIŞMASI: İSTANBUL'DA VAKA ÇALIŞMALARI

ÖZET

Giydirme cephe sistemleri, avantajlarına bağlı olarak sadece yüksek binalarda değil, aynı zamanda orta yükseklikteki konut ve ticari (ofis) binalarda da uygulanan en popüler sistemlerden biri haline gelmiştir. Özellikle, her binanın giydirme cephe performansı geçmişte,ışık, ısı ve su kontrolünü gerektiren ana kriterlere göre tasarlanmış, bu nedenle binanın genel performansını önemli ölçüde etkilenmiştir. Ancak teknolojik gelişmeler nedeniyle, deprem ve rüzgarların yüksek etki ve kontrolü gereksinimi, sistemin önemli performans belirleme kriterlerinden biri haline gelmiştir.

Günümüzde giderek artan bir şekilde kullanılan giydirme cephe sistemlerinin yanlış tasarlanmasından dolayı geçmişte Türkiye'de yaşanan depremlerde insan hayatı için tehlike göstermiştir. Binaların giydirme cephe sistemleri üzerindeki rüzgar ve deprem etkilerinin detaylı olarak bilinmesi gerekmektedir. Bu nedenle, bu çalışmanın ana amacı, farklı bina yüksekliklerindeki sismik ve rüzgar yükü etkilerini, giydirme cephe sisteminin bileşenleri ve detayları üzerinde tanımlamak ve analiz etmektir. Ayrıca giydirme cephe sistemini etkileyen rüzgar ve depremlerin hesaplanmasında kullanılan yöntemlerin bilinmesi ve analiz edilmesi amaçlanmıştır. Bu hedefleri detaylı bir şekilde araştırmak için bu analiz dört aşamadan oluşmaktadır.

Rüzgarları ve depremleri incelemeden önce, genel olarak giydirme cephe sistemlerini analiz etmek gerekir. Tarihsel dönemlerdede teknolojik gelişmelere paralel olarak, giydirme cephe malzemeri ve yapım tekniklerinde çok sayıda gelişmeler olmuştur. Sonuç olarak, hızlı, kolay birleştirilebilen ikili kombinasyon olan, alüminyum ve cam gibi çeşitli inşaat yöntemleriyle inşa edilen giydirme cephe, dünya çapında birçok binada kullanılan en yaygın sistemlerden biri olarak kabul edilmiştir. Yüksek katlı binalarda ve orta yükseklikteki binalarda, giydirme cephe maliyet, tamamlanma hızı, doğruluk ve inşaat teknikleri açısından değerlendirildiğinde yaygın olarak kullanılan birleşik bir cephe sistemdir. Camı giydirme, cephe çerçevesine bağlama yöntemileri farklıdır, çünkü strüktürel silikonlu cephe, çok katlı binalarda kullanılmak üzere en çok tercih edilen yöntemlerden biridir.

Diğer binalarda ise baskı plakası yöntemi ve nokta tespit sistemi kullanılmaktadır. Giydirme cephe yöntemi, havalandırma ve güneş korumasını kontrol etmek için kullanılan çift cidarlı cephedir. Tek cidarlı cephe sistemleri bu avantajları sağlayamamıştır. Entegre cephe sistemi, doğal havalandırma gerektiğinde yüksek binalarda kullanılan her iki tip için de avantajlar sağlar. Giydirme cephe bileşenlerine ek olarak; detayları ve malzemeleri bir projeden diğerine farklılık gösteren çerçeve, alüminyumun tasarım esnekliği, dayanıklılığı, çevre dostu malzeme olarak sağladığı faydalar nedeniyle en çok tercih edilen malzemelerden biri olarak kabul edilmektedir.Daha iyi tolerans sağlamasının yanı sıra, Türkiye'de genellikle ankrajın yanında kullanılan çeşitli tiplerde elemanlar ve çift camlar ile giydirme yöntemleri incelenmiş ve bu aşamada giydirme cephenin gerçekleştirmesi için gereken performans gereksinimleri incelenmiştir.

Rüzgarların giydirme cephe üzerindeki etkisi analiz edildikten sonra, ikinci aşamada literatür incelemeleri ve standartlar tanımlanmıştır.Türkiye başta olmak üzere İstanbul'da etkili rüzgar ve hakim rüzgarların binanın cephelerindeki etkisi anlatılmıştır. Ayrıca, bir bütün olarak giydirme cephedeleri etkileyen rüzgarlar ve bileşenleri ayrıntılı olarak anlatılmış, giydirme cephe tasarımında kullanılan en yaygın şartnameler olan Amerikan standartlarına ek olarak Türkiye mevzuatı IYBRY ve Avrupa standarlarının farklılıkları ve benzerlikleri gözden geçirilmiştir. Bu şartnamelerin incelenmesi sonucunda giydirme cephe analiz, deney ve rüzgar ölçüm yöntemleri anlatılmıştır.

Üçüncü aşamada, depremlerin Türkiye'deki binalarda uygulanan giydirme cephe sistemleri üzerindeki etkisi incelenmiş ve depremlerin bina cepheleri üzerindeki etkisinin incelenmesi ile birlikte Türkiye'deki sismik olayların sebep olduğu olumsuzluklar anlatılmıştır. Depremlerin giydirme cephe bileşenleri üzerindeki etkisi doğrulanmış ve ardından 2018 Türkiye yönetmeliğinde giydirme cephe tasarımında kullanılacak şartnameler hazırlanmıştır. Depremler ve ortaya çıkan hasarlarla başa çıkmak için kullanılan Avrupa ve Amerikan standardı FMA ve sonra bu şartnameler arasındaki benzerlikler ve farklılıklar karşılaştırılmış ve son olarak bu aşamada giydrime cephe sistemi elemanlarının mekanik davranışını bulmak için sismik analiz ve test yöntemleri incelenmiştir.

İstanbul'daki durum çalışmaları olan dördüncü aşamada, giydirme cephe firmaları ve cephe danışmanlık firmalarının yaptıkları projelerle ile ilgili görüşmeler ve

incelemeler yapılmıştır ve bu firmaların yaptıkları giydirme cephe proje ve uygulamalarında kullandıkları hesap yöntemi, deprem ve rüzgar etkilerinin nasıl hesaplandığı, incelenmiştir. Projelerin tasarım ve uygulama aşamasında hangi analizlerin yapıldığı ve detayların nasıl belirlendiği araştırılmıştır.Sonuç olarak, çoğu şirketin, Türkiye'deki mevcut koşullarla, hatta mevcut Türk mevzuatıyla bile uyumlu bir Türk standardı olmaması nedeniyle giydirme cephenin tasarım aşamasında standart hesap yöntemi kullanmadığı görülmüştür. Genellikle tasarımlar Avrupa ve Amerika standartlarına göre yapılmakta ve bu da her firmanın farklı uygulamalar yapmasına yol açmaktadır.

1. INTRODUCTION

1.1 Problem Statement

The anticipated performance features of curtain wall systems have increased with technological advancement and advances in design techniques. In multi-storey buildings, especially high-rise buildings, building facades made of aluminium and glass have become more prevalent and used. That is due to the curtain wall system's multiple benefits, such as lightness, ease of installation, design flexibility, adaptation to various structural movements, and the interface aesthetic, providing a comfortable internal atmosphere for occupants. Therefore, the importance of choosing the curtain wall components materials to be used, the choice of connection types and specifics of the anchor, as well as the type of glass is increased.

Curtain wall systems (stick and unitized systems) are the most commonly used form of façade in Turkey for multi-story buildings (Yalaz, 2018). Since Turkey, and in particular, Istanbul is one of the high seismic areas in addition to variable and high wind speeds at its certain regions, there were some design and application problems related to the structural performance where the variable and frequent wind loads, earthquake loads and climatic conditions are the most critical factors that affect the structural performance of the system. Therefore, the configuration of an earthquake and windproof system may also significantly reduce the damage caused by the curtain walls.

Seismic loads and wind loads that will affect the building was highlighted in the study, particularly in the design phase, following international and local standards contribute greatly to obtaining satisfactory results, which will be researched and dealt with during this study.

1.2 Aim of the Study and Objectives

Modern implementations of façade systems in the construction industry recognize that the curtain wall system has become a global favourite for system designers and façade engineers, in particular in high-rise and medium-rise buildings, and not just at the level of Turkey, because of its many advantages in the field of construction and implementation. Therefore, the façade systems must satisfy and achieve the comfort

of the occupants. Since the curtain wall is the main envelope of the building, one of its primary functions is to resist the changing and recurring impact of winds and its ability to adapt to the structural movements resulting from earthquakes. Therefore, this investigation aims to define and analyse the effects of seismic and wind loads in different building heights on the components and details of the curtain wall system.

The study's main objective is to analyse criteria and methods for calculating wind and seismic loads on Turkey's curtain wall system. The last objective of this study is to determine and compare the difference with the details of the curtain wall in terms of height, wind and earthquake loads, which means whether the details of the curtain wall differ (glass - frames - anchor and the glazing system) if the building height differs or the curtain wall system differs. In other words, to investigate if the wind and earthquake loads differ or are fixed in all projects by analysing the curtain wall details for projects carried out at various heights in Istanbul. And one of the research questions is: Does wind and earthquake load calculation differ depending on the location of the building?

1.3 Procedure and Methodology of the Study

The first stage of this study was carried out through reviews of previous literary studies from articles, researches, reports and other publications related to this topic. Besides, to obtain sufficient information about the curtain wall and its components, manufacturers' web pages, details, technical drawings and related images are collected during the study, after that reviewed the different curtain wall classifications according to the construction method, glazing method and skin configuration method

For the second stage of this study, to analyse the effect of wind load on the curtain wall system, the wind is considered in general, and wind conditions in Turkey were reviewed and studied. Then the wind performance in the curtain wall components was studied and analysed using previous studies and research, books and articles related to this topic. Then, local and international standards and regulations used to calculate the impact of wind loads were analysed and compared. The methods used to analyse and test wind effects on the components of the curtain wall are also presented.

In the third stage, following the study to evaluate the performance of the curtain wall in terms of wind loads, earthquakes are considered in general, and the performance of

the façades in terms of seismic loads and the performance of the components of the curtain wall in particular to obtain a more accurate assessment were studied. The international and local standards and regulations used by the companies were then reviewed and examined in addition to reviewing the methods of analysis and tests used to evaluate the performance of the curtain wall in terms of earthquake loads.

The fourth stage of this study is the stage in which the details of the curtain wall projects obtained from the facade consulting companies and the curtain wall companies were studied and analysed. These projects have been used to obtain information on details. In addition, a detailed list of questions regarding the curtain wall, its components, wind and earthquake loads, which were raised regarding these projects were answered by these companies in order to study and evaluate how these companies deal in the design phase with wind and earthquake loads. Finally, the last stage consists of the overall evaluation and the conclusions of this study.

The approaches used in this research were literature review, questionnaire, and interviews. Literary analysis is used to analyse curtain wall structures. The analysing of curtain wall systems and wind loads has benefited from literature research and regulation and codes. Curtain wall and earthquakes are examined utilizing literature research beside the regulations. On the other hand, the case studies of curtain wall projects was done by obtaining samples of the curtain wall system projects executed in Istanbul from different companies and for different building projects, in terms of the curtain wall system used as well as the building height. In addition, questions were posed to the responsible persons who were interviewed to assess the effect of the seismic load and winds on the curtain wall system as given in Appendix A.

2. CURTAIN WALL SYSTEMS

In this section, curtain wall is defined and the historical development is presented according to literature reviews. The curtain wall system's main classification is presented to make it easier on the decision-maker when choosing the curtain wall system according to their designs. After that, the curtain wall's main components are introduced. Lastly, the performance criteria of the system are explained.

2.1 Definition and Historical Development of Curtain Wall Systems

The curtain wall term drives from the wall that are thin and hang on the structural frame like a curtain. Most curtain wall panels do not hang from the frame which generates tension, but supported from below at every floor level (Allen, 2004). In most literature, the curtain wall is defined as the external building envelope, a separation between the inside and the outside environment. It is a non-load-bearing wall, which means that it supports no vertical structural loads aside from its weight. The environmental forces acting on the curtain wall are transferred to the building structure (Vigener, 2016). Standards define the curtain wall (BS EN 13830) as follows:

"*Curtain walling designed as a self-supporting construction which transmits dead-loads, imposed loads, environmental load (wind, snow) and seismic load to the main building structure."*

In the late 19th century, the greenhouse structures designed to provide much daylight to the plants contributed to the advent of metal structures in architecture. In 1892 elevators were invented, also the high price of land in Chicago led to the prosperity of tall buildings construction. In addition to the method of frame construction with large spaces without obstruction, pre-manufacturing enabled fast construction as well, this in turn, led to the development of a new type of building, instead of the mega buildings with the external bearing walls. The first building in this kind was the Reliance building by Burnham and Root (Figure 2.1). This building represents the transition to the modern age where the load-bearing building structure was separated from the facade structure, which marks the beginning of the curtain wall system's emergence.

Figure 2.1: Reliance building, Burnham and Root, 1895, (Craven, 2019).

Several references stated that the first introduction of the curtain wall, forgetting previous attempts, was in 1951 in Crystal Palace design by Joseph Paxton, the whole building consisted of iron and glasses inserted in between (Begeç and Savaşır, 2004).

The buildings designed to have an envelope that was a lightweight non-loadbearing curtain wall frame instead of a large loadbearing wall at the start of the twentieth century. However, aluminium has merged through landmark projects of pioneer architects, such as Walter Gropius, Mies van der Rohe, Peter Behrens. The glass properties such as transparency, translucency and reflection has been among the architects focused beside the architectures went towards the manipulation of light, shadow, view and reflection (Patterson,2008). Increasing the glass durability and strength led to the widely use of curtain wall, especially for high-rise buildings (Dogan, 2013). A curtain wall that was first applied on a high-rise building was in Lever house in New York, constructed in 1952. The formal image of those curtain walls still repeated today by the use of modern profile construction.

Begeç & Savaşır (2004**)** stated that post-world war 2 period had a significant effect on the aluminium curtain wall system process. There had been a dramatically demand of a new construction system that led to the curtain wall system's development that consists of modular components (Begeç & Savaşır, 2004). Metal and glass curtain wall began to appear on commercial and institutional buildings. The post-war world's booming economies led to an increase in the number of high-rise buildings due to the

low-cost cladding strategies by increasing the land leasable in a given footprint. The industrial revolution has led to the development of materials and technology that's the case using stainless steel and aluminium as preferable construction materials (Doğan, 2013). The window technology had been affected by the earliest curtain wall design process as well. The system developers have optimized the aluminium sections and integrated components regarding building envelope performance requirements and market demand. Understanding the initial frame section of the curtain wall helped in the design development process (Yeomans, 2001).

In 1970's, there has been a massive demand for energy-saving and sustainable solution in architectural design because of the energy crisis happen at that time (Begeç and Savaşır, 2004). For this reason, in the building's envelope this precaution had to be considered, so there were multiple attempts to reduce energy consumption by using multiple layers of glass to increase thermal insulation as well as other developments in the glass industry, which led to the emergence of highly reflective glazed buildings all over the world where the sun's rays are reflected by the outer skin of the building to avoid overheating in the interior spaces (Klein, 2013).

In the nineties, there was an increase in the awareness to conserve energy and preserve the environment. To achieve this purpose in the curtain wall, double skin façade was started to be used to reduce consumption of energy as well as protection from sunlight and wind in high-rise buildings and also providing natural ventilation by helping the protective windows in the internal part of the facade. The use of double skin facades is usually very little due to the high cost, besides the curtain wall system became more than a barrier between inside and outside and a light façade system, but became an as intelligent system that fulfils the indoor comfort quality requirements.

2.2 Classification of The Curtain Wall System According to Construction Method

Curtain wall can be classified by their fabrication and installation methods into three categories: stick system, unitized system and mullion and unit system.

2.2.1 Stick curtain wall system

This system consists of vertical (Mullions) and horizontal (Transom) members that make up the frame, and the opening between the frame members are filled with glass or infill panels as shown in Figure 2.2. The frame members prefabricated and painted

in the factory, then installed and connected in the construction site, then the glass and infill, panels attached. This system referred to as “stick built” due to the grid-based construction (Pattroson, 2008).

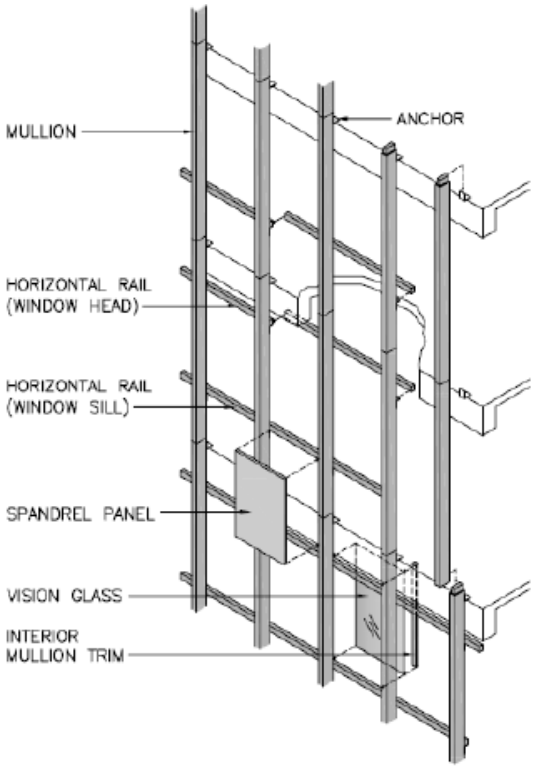


Figure 2.1: Stick curtain wall system (Sanders, 2006).

In its installation process, firstly anchorage members are installed at the floor slab and in specific areas, then the vertical members are attached to them, then the horizontal members are connected. To control the wind, seismic and thermal movement, and deflection on the system, the anchorage members should be arranged to allow the movement of vertical and horizontal members. Lastly, the glass and infill panels are installed between the grid system (Sezer, 2003).

The advantages of stick curtain wall system are that most of the stick system are standard, thus it offers low material cost, and it gives the low shipping cost. Beside, this system offers the flexibility to on site adjustment. The main disadvantage is derived from the method of on-site assembly and this may cause slow work and increase the cost of labour in addition to problems related to the quality of the performance. This system cannot be used in constructing high-rise building’s façade or large areas, but is used mostly in the facades of low- and medium-rise buildings**.**

2.2.2 Unitized curtain wall system

The units are manufactured and assembled at the factory, then shipped to the construction site for installation. Usually, the units can be one story high by a modular width (Boswell, 2013).

In the installation of unitized curtain wall system according to (BCI (Architectural Glazing and Building Enclosures Company))**,** firstly the anchor's points are identified following the grid line made by the architect. The cast in a concrete channel inserted into the place due to the grid line, and the curtain wall brackets placed over the channels. Moreover, T screws or anchor screws are inserted into the holder, and then securely fastened with anchor bolts. In Turkey, this method does not apply because it takes time and needs accurate work so they apply the brackets directly on a slab without inserting the channel. Then the unite is installed, and because its heavyweight, each pane is attached to a crane or davit located on a higher floor, the crane lifts the panels into place, workers will guide into the assigned plan, as shown in Figure 2.3. Then the panel hung from the brackets are installed on the building and adjusted following the next panels, then bolted into place and joints are sealed with silicone, gaskets and caulking (Ascher, 2013). Figure 2.4 shows a unitized curtain wall system.

Figure 2.2: Installation of the unitized curtain wall system, (HALFEN A CRH Company, 2018).

Advantage of unitized curtain wall is speed of completion because most of the work is done in the factory. This system is used to construct high rise building's facades because the unit's fabrication is done in factories under controlled condition, so quality efficiency is higher, the number of workers is less, therefore the cost is less. Design capability to accommodate in-plane movements due to sways and seismic events

(CMHC, 2004). The disadvantages of this system are that the units are more sophisticated to handle and raise on site. Also, protection during transportation and before installation should be more expensive. Because modules are based on an interlocking mullion, it can be difficult to leave openings in the interface for purposes of access unless the number of units can slide or be sideways or if special joints are provided details in the access panel. Replacement of the damaged unit can also be a problem (Boswell,2013).

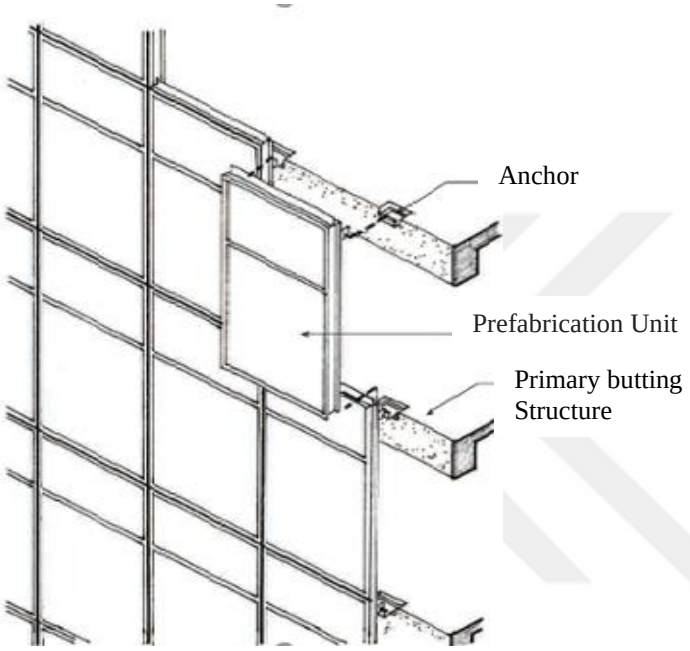


Figure 2.3: Unitized curtain wall, (Chew. M.Y.L, 1999).

2.2.3 Mullion and unit curtain wall system

This system is a combination of stick and unitized types. This system was usually used when the design of mullion is a deep member, but it is rarely use today. In is installation firstly, the mullion members with one story height or more installed, then preassembled frame units are installed between them (Figure 2.5). The frame section may be either full floor height or divided into vision panel and spandrel units (Auer, 2014).

Advantages of this system is the same as the unitized system. With the addition of opening, temporary access can be provide more easily. Its disadvantages are the requirement of more labour on site, beside the additional connection linked to mullion members.

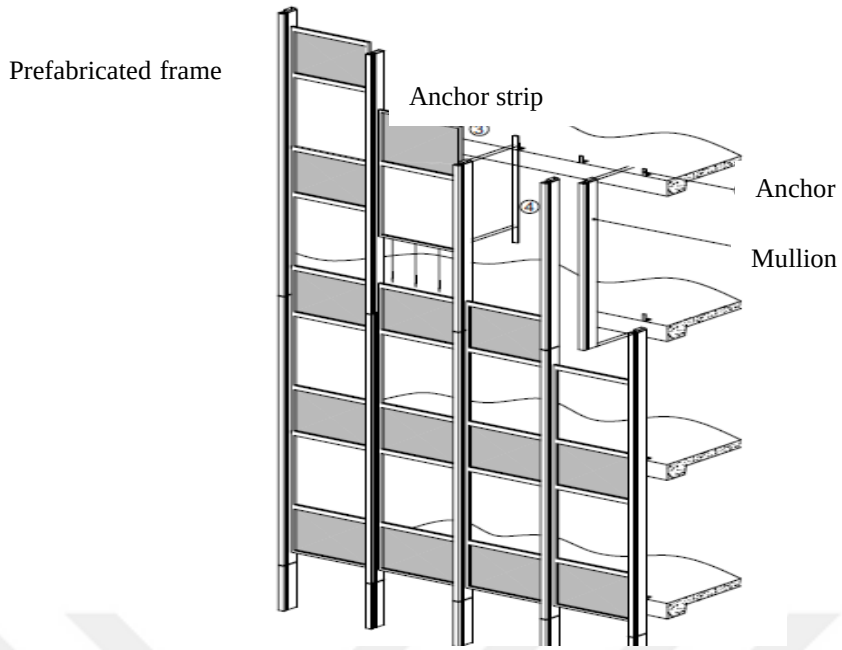


Figure 2.4: Unit and mullion curtain wall (CMHC, 2004).

2.3 Classification of The Curtain Wall According to Glazing Method

Curtain wall can be classified into three categories related to the glazing method: Structural silicone glazing system, pressure plate system and point-fixing system.

2.3.1 Structural silicone glazing system (SSG)

Structural silicone glazing system is a glass bonding method to the aluminium frame utilizing a high-performance and strong silicone sealant (Figure 2.6). The bond between glass, frame and silicone provide structural resistance to lateral load. This is one of the curtain wall types used primarily for high rise buildings. One of the advantages of this system is, when used to bonding glass to frame without any necessity of mechanical retention such as beads, clips, or bolt fixing, it provides provisions for the entire system (Garg, 2007). Besides wind loading out off the plane, another available option with the SSG is the design of the glass panel as a diaphragm to resist the forces in the plane. The small, continuous bead of structural sealant provides great shear and tension values that move the shear forces edge directly inside the plane, and this feature of SSG is especially useful in designing corner conditions in curtain walls (ASCE, 2013).

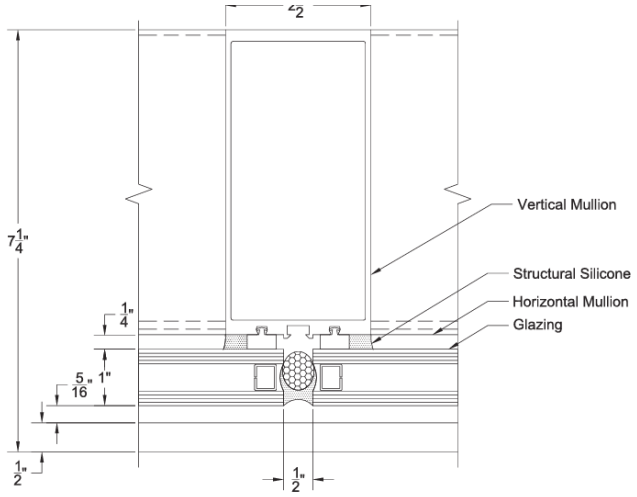


Figure 2.5: Structural silicone glazing system, (ASCE,2013).

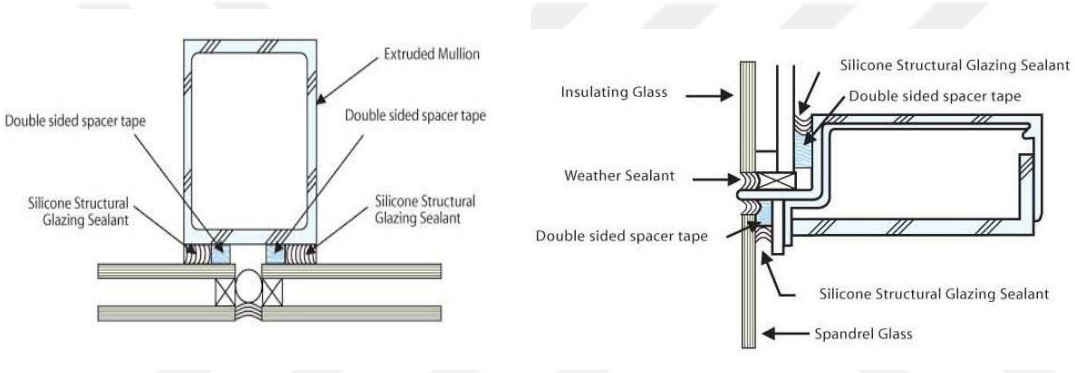


Figure 2.6: Structural silicone glazing types, 2 sided, 4 sided, (URL-2, 2009).

According to glass and metal curtain wall best practice guide (CMHC, 2015), there are two types of SSG, 2-sided which means two edges of infill adhere to the framing with structural silicone sealant and two edges are usually mechanically fixed using Pressure plates (Figure 2.7). While 4-sided means the four edges of infill adhere to the framing with structural silicone sealant, the infill materials' dead load supported by metal fin and setting block.

2.3.2 Pressure plate system

The pressure plate system is the most famous architectural system and widely used. The frame building technology is the method to construct this system. According to the glass and metal curtain wall best practice guide (CMHC, 2015), it depends on the use of pressure plate, stating that "Pressure plates must provide adequate compression to the glazing gaskets through the proper tightening of pressure plate screws. At least

three weep slots should provide to drain the glazing cavity". The initial version consists of mullions, transoms, glass parts with pressure plate and cover caps. In modern architecture, there are three types of this system: standard type, two-sided type (Figure 2.8) and four-sided type (Dogan, 2013).

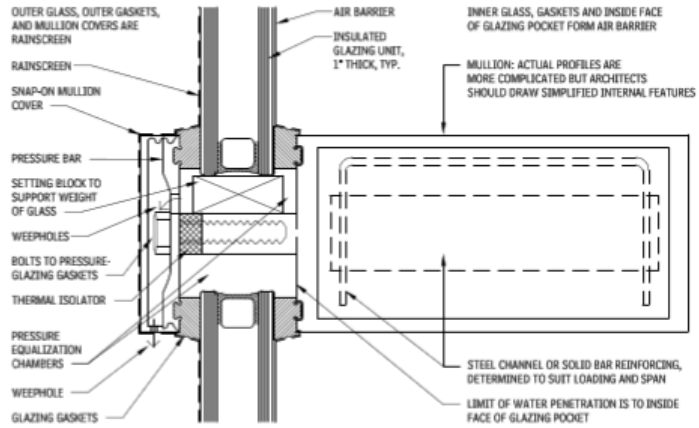


Figure 2.7: Two-Sided pressure plate system, (Hedges, 2017).

The standard type consists of both horizontal and vertical cover cap; the cover cap gives the linearity impression to the façade, the cover cap installed above the pressure plate for hiding the pressure plate and the fasteners, and more functionally important, it acts as a barrier to the drainage holes in the horizontal pressure plate. The two-sided type is also called mixed type, and in this type the cover cap is used in one direction either horizontally or vertically and silicon used in the opposite direction (Dogan, 2013).

Lastly, in the four-sided system silicone is applied in the vertical and horizontal direction, the same way as the structural silicone glazing system gives the impression of a flat face view. This diversity gives the designer the ability to create various façade designs with aesthetic appearances (Winxie, 2007).

2.3.3 Point fixing system

This system is used to provide the largest possible transparent area by taking advantage of the transparency of the glass with minimum structural elements. Many types of structural systems can be used to collect the point support location such as spider fitting (Figure 2.9), cables network and tension structure, and the support points are designed to absorb all the static and dynamics loads then distribute them to the supporting

structure. It requires strict structural analysis and field coordination due to the effect of the bearing on the structure. Due to the flexibility of the wall, the deflection may seen under excessive lateral loading conditions, Therefore, the types and thickness of glass also the location of the point play a very important role in the structural performance of the façade (Bertan,2016). Insulated tempered and laminated safety glass are preferred due to safety reasons since this type of glass remains intact in the event of breaking.

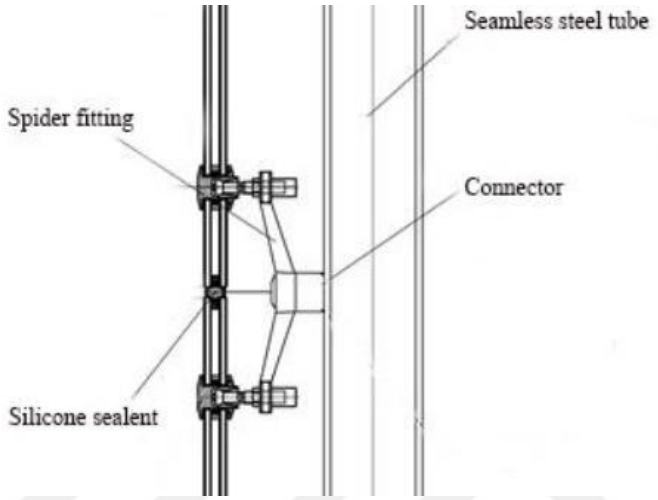


Figure 2.8: Typical spider curtain wall system,(BERTAN,2016).

2.4 Classification of The Curtain Wall According to Skin Configuration

Curtain wall can classify into three categories related to the skin configuration design method: Single skin façade system double skin façade system and integrated façade system.

2.4.1 Single skin façade

Single skin façade consists of one layer referred from the name; it can build in both construction methods as a stick and unitized system. The glass supporting system classified into a structural silicone glazing system, pressure wall system, and pointed support system. Kloft & Eisele (2002) stated that single skin facade removes the following performance features only to a limited degree compatibility with the double skin façade: summer night cooling, intruder protection when inner windows are open, reducing wind gusts and pressure fluctuations when interior windows are open, ensuring 100% outdoor shading performed regardless of wind strength.

2.4.2 Double skin façade (DSF)

The DSF concept was introduced in the early 20th century, but until the 1990s little progress has made. This system is usually used in Europe and other countries. There are several definitions of double skin façade. However, the most comprehensive definition was given by Oesterle, E., Lieb, R., Lutz, M., Heusler, W., (2001) as; "a double skin façade consists of a multi-layered façade envelope, which has an external and internal layer that contains a buffer space used for controlled ventilation and solar protection". The ventilation of DSF can be mechanical, natural or hybrid (i.e. both mechanical and natural). The ventilation mode selection in the cavity of the DSF depends on the climate of the building area.

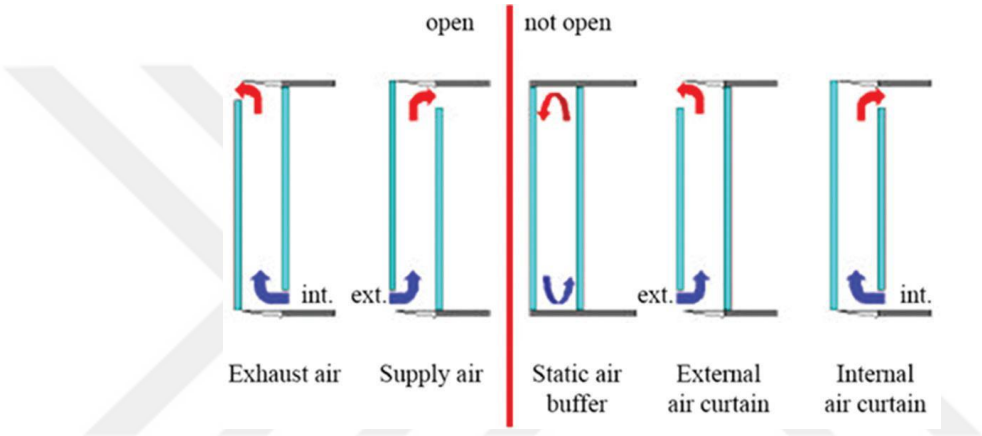


Figure 2.9: Types of DSF according to air flow in the cavity, (Haase et al.,2009).

In a cold and temperate climate, it is naturally ventilated, while in a hot climate are mechanically ventilated, but in general, the dependence is on natural ventilation in winter and mechanical ventilation in summer. As a function of the concept applied between 200 mm and more than 2m, the cavity width may be varied according to the climatic condition of the building (Chan, 2009). The choice of glazing type, width and division of the air cavity and the ventilation mode is affected by the building orientation, design requirements and the climate (Aksamija, 2013).

The primary benefits attributed to the double skin façade are its ability to provide solar energy and daylight to the interior of the building, concerning reducing energy use. DSF is credited with being able to mitigate the impact of climatic and environmental conditions prevailing on the inside of the building, allowing to reduce the HVAC system components size, extent and building heating, air-conditioning and ventilation systems operation (Ahmed.M. M. S., 2016). The disadvantage of this system regarding many literature reviews is that it is highly costly when compared to other curtain wall types.

There are many classifications for the double skin façade. However, it can be classified according to how the air cavity is partitioned (i.e. box window, corridor, shaft box and multi-story) as shown in Figure 2.11, the airflow path in the cavity (i.e. exhaust air, supplier air, static air buffer, external air curtain and internal air curtain) Figure 2.10, and ventilation mode (i.e. mechanical, natural and hybrid) (Aksamija and Perkins+Will, 2013).

Double skin façade types according to air cavity partitions can be explained as follows (Oesterle et al., 2001; E. Lee et al. 2002; Aksamija et al.,2013):

- Box window type: There are vertical, and horizontal partitions that divide the façade into smaller windows. These façades are used in two cases; when there is a special requirement for sound insulation, and when there is a high noise level. An openable window can be included in this system to provide natural ventilation.
- Shaft box type: They are boxes connected vertically across the floors to form the shaft. This type of façade requires few opening in the outer skin for better sound insulation and the possibility of a thermal uplift shaft.
- Corridor type: It is a separate horizontal passage for each floor, which contains a pure air intake and exhaust for each floor, which allows maximum natural ventilation, and this horizontal division is used for security, ventilation, sound insulation or fire prevention purposes. Air exchange in this faced cavity is done either vertically at the floor level or vertically at the building corners.
- Multi-Story type: The cavity area between the interior and the exterior is fully open without horizontal or vertical barriers, usually for one façade or around all of the building. The air inlet is at the top, and its exit is from the bottom. In the rooms behind the facade, it is necessary to use mechanical ventilation. These facades are used in places with a high noise level.

In the case of a double façade, the sunshade can be used, which are usually placed between the two façades. Likewise, it is possible to use louvres, and in this case in the closed state, it works as an airtight facade and in the open state, it allows increased ventilation inside the cavity (BBRI, 2004).

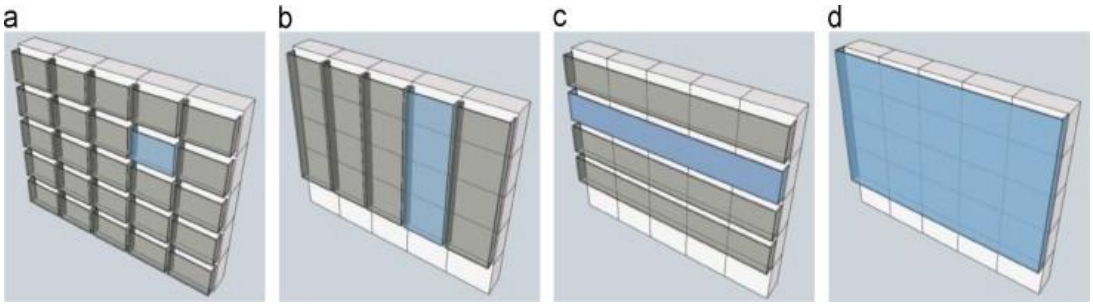


Figure 2.10: Double skin facade types in term of cavity partitions, (Barbosa, 2014). a) Box window type, b) Shaft box type, c) Corridor type, d) Multi-Story type.

Regarding the glazing types of the double-skin façade, the inner skin is made of double or triple thermal insulated glass, while the external skin usually made from a single tempered layer of laminated glass (Poirazis, 2004).

Double skin façade is consider as a sustainable strategy for high-rise building, not as a comprehensive solution but as a component of an integrated building design system because this system reduces energy consumption by using the passive design concept and energy efficiency strategies. The potential greenhouse effect in the buffer can be used to produce and exchange heat. Natural ventilation for high-rise conditions reduces air conditioning loads (Harrison K., 2003).

2.5 Curtain Wall System Components

The curtain wall system is a complex system consisting of several interconnected parts; some to perform the function of protecting the building from external conditions and some transferring the loads to which it exposed to the building's structure. Therefore, it can be said that the curtain wall system consists of structural components that include the frame and anchors, infill components usually glass for transparency, and opaque parts consisting of stone or different materials, and sealant as shown in Figure 2.12.

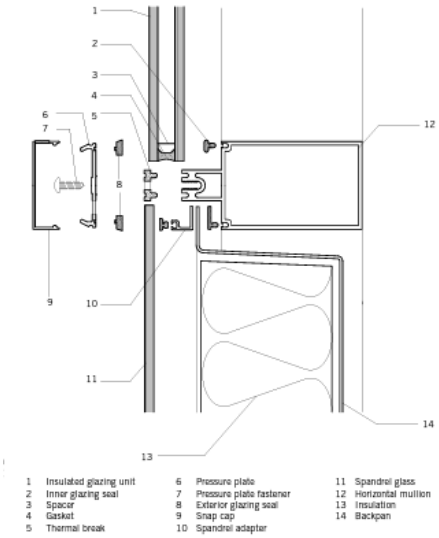


Figure 2.11: Basic component of the curtain wall system (Aksamija, 2013).

2.5.1. Framing system

It is the main part of the curtain wall, since the loads are transferred directly from the glass to the frame, they must be strong enough to carry these loads to the building's structure. The frames are consisted from a vertical and a horizontal part usually made from aluminium or steel. The selection of the material type depends on the aesthetics choices, module spacing, load and grid considerations. Conventional curtain walls integrated aluminium framing with the glazed opening. The framing members contain not just the load-carrying mullion and transom but also the pressure plate, snap cap and stiffening components as shown in Figure 2.13. The aluminium framing can be found in many depths for vertical and horizontal elements. One of the critical architectural advantages of using aluminium framing is that multiple profiles can be easily streamed to develop specially shaped framing files or distinct configurations, the depth of the system is mainly determined by the requirements for wind load (ASCE,2013).

By the facade technology development, members of the aluminium curtain wall system can be produced lighter to reduce the weight of the curtain wall system. Moreover, the uses of the smaller aluminium section will reduce the load of curtain wall on the building beside it can be more economically solution. Aluminium has many advantages when used as a curtain wall framing material, but it has the obvious drawback that it is three times more deformed than steel. Usually, deflection is the ruling criteria in curtain wall design. So the building set a deflection limit for

perpendicular (wind-induced) and in-plane (dead load-induced) due to limit the deflection of glass to ensure that it does not come out of its pocket in mullion as well as to ensure that it is not broken under massive deflection.

In the case of steel framing, a steel frame can be implemented as individual elements, such as the "sticks" of the frame as shown in Figure 2.14, or as an assembly as trusses. Horizontal and vertical supports are used. Horizontal supports can be used to support the stone panels by developing module units, and vertical trusses, such as bow truss or tubular pipe truss, can be used to support glazing. Other types of steel are steel cable which are used in cable net system. This system is used to provide much transparency with minimal framing, but the deflection allowed is significantly greater than it is for traditional framed systems (ASCE,2013).

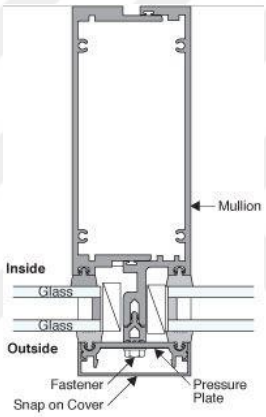


Figure 2.12: Typical detail of Aluminium curtain wall plan, (URL-3).

With steel framing larger spans can be achieved without the need for additional supports or intermediate connection like aluminium. Besides, the steel framing can hold or withstand larger glass size than aluminium curtain wall system. Finally regarding the durability, steel profiles can resist denting, scratching, and for aesthetical issues and more durability, a snap cap of stainless steel can be included (Naqash M. T., 2016). It is more efficient to use steel as a framing material with an extruded aluminium glass transformer or to use steel as a hidden reinforcement within an aluminium profile (CMHC, 2013). The vertical mullion connected to the horizontal transoms through extruded channels called connecter. Some connecters can transmit moments to the vertical, while some others only transfer shear forces.

Framing is not limited to horizontal and vertical elements only, but other parts play an important role such as pressure plate, snap cap or cover cap and fastener. The pressure plate’s principal function is to fix the glass from the outside and can be replaced by

other glazing methods (e.g. structural silicone glazing). It is made from the same material as the frame. Vertically, pressure plates are typically installed in segments along the mullion. Horizontally, the pressure plates of the bars between the pressure plates are proportional to the presence of an expansion gap in each end. The pressure plates are pre-pressed to accept the pressure plate screws. The centre of the holes varies with uses between 150 and 200 mm (6 to 8 inches) in the middle, and the vent/drain holes are punctured in the horizontal bar pressure plates. Manufacturers use a variety of sizes and shapes to open. The size and shape of the vent/drain hole should depend on the specific project design details (CMHC,2013).

Snap cap or cover cap is used in the case pressure plate is used. The main function is not just as cover to pressure plate, but as a barrier to the drainage openings in the horizontal pressure plate. A snap can be made from the same material of the frame system or stainless steel or copper. There are different shapes and size of it depend on the architectural design intents. Caution should take to snap cap joints that should accommodate vertical elements' thermal movement to use the metal splices.

Fasteners such as screw and bolts are used to assemble curtain wall framing, fixing pressure plate, and fixing the curtain wall to the building structure through the anchors. Fasteners made in different shapes and sizes made from either stainless steel in case it is used outside or for fixing the pressure plate, or carbon steel should be used only for wall fasteners and frame assembly, if they are located on the inner side of the air barrier. All carbon steel fixings shall be coated or polymer-coated to protect against corrosion (CMHC,2013).

Figure 2.13: Steel curtain wall framing system (URL-3).

2.5.2 Infill component

Glass is an essential architectural component of the curtain wall system due to its three main properties; transparency, translucency and reflectance. As its primary function, it helps to penetrate light into the interior in addition to providing transparency to the occupant inside the building. So that it helps to see the outside, that is, it works to communicate between the inside and outside, in addition to the idea of energy efficiency, safety and acoustics that have become an essential role in choosing the type of glass. There are other requirements such as heat and solar control, noise and fire protection, which affects the total performance of the curtain wall system. There are many types of glass according to the particular requirements of the building and the types used in the curtain wall system need to be of high efficiency, strength and durability because they are exposed to external conditions as the influencing factors such as wind load, earthquakes. The main types of glass used in curtain wall system are insulating glass, safety glass (laminated, toughened), coated glass (low emissivity, solar control) and opacified glass (Dogan,2013).

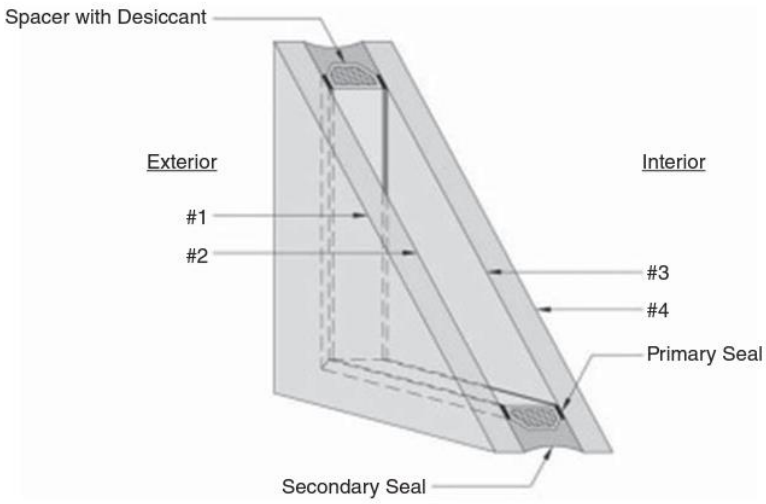


Figure 2.14: Insulating glass units (ASCE,2013).

2.5.2.1 Insulating glass

It is composed of two or more glass layers separated by a gap to create a hermetically sealed air space (Figure 2.15). This gap filled either with air or gas such as argon or krypton. The gap is between 12 mm to 20 mm wide depending on the size of the glass and type of gas infill. The gap edge is enclosed by edge sealant to prevent the water vapour penetration. The most common glass types used in an insulating glass are annealed and heat strengthened glass. The primary function of insulated glass is to

reduce heat loss by preventing the heat transfer between inside and outside besides to reduce exterior noise and this depends on the combination of glass used. Glass types are chosen to provide some visual effects and performance characteristics. Spacers and seals are mainly chosen based on performance characteristics (CMHC,2013). The thickness of the insulating glass is determined according to wind load consideration.

2.5.2.2 Safety glass

Safety glass can be classified into two types as laminated and tempered glass as explained in the following paragraphs.

Laminated glass consists of two or more prime glass layers combined by plastic interlayer (commonly polyvinyl butyral PVB) as shown in Figure 2.16. The interlayer thickness varies from 0.04 mm to 0.23 mm (ASCE,2013). The reason of using the plastic interlayer is that it adds a significant improvement to the glass behaviour in breakage if one or both of the layers of glass expose to an effect, glass fragments stick to the PVB to reduce the risk of injuries. The plastic inner layer contributes to preventing UV transmission too, and is available in various colours to provide specific aesthetic effects. There are different shapes and size of it depend on the architectural design intents. Caution should take to snap cap joints that should accommodate vertical elements' thermal movement to use the metal splices.

- Besides the safety properties of laminated glass, it had a significant contribution to sound reduction. It could be used individually or as part of an insulation glass.

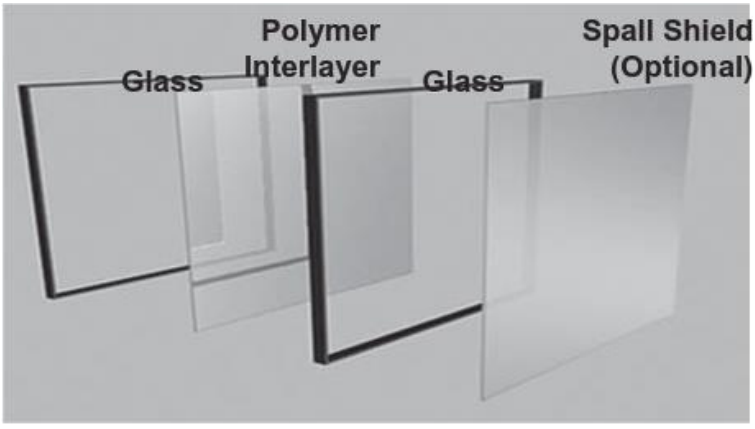


Figure 2.15: Laminated glass, (ASCE,2013).

- **Tempered glass or Toughened glass** is made by heating the glass under high temperature, then quickly cooling it in a controlled processing process to increase its strength, and thus its strength becomes four to five times more than an ordinary glass. In case it is subjected to breakage, it becomes small harmless fragments; thus, it reduces the risk of injuries. Besides, it offers excellent thermal strength and resistance to sudden changes in temperatures (Grag, 2007).

2.5.2.3 Coated glass

The increasing demand for energy efficiency in the curtain wall system has led to a significant development in the glass industry due to the increased use of glass in architecture, which led to the emergence of coated glass, which consists mainly of two types as follows:

Low emissivity glass (energy saving glass) is used because it reflects mostly the sun's rays and leads to heat control and energy conservation in building envelopes, as well as it has little reflection and greater permeability of sunlight. It is designed to prevent heat escaping from inside to outside or on the contrary by the help of coating (Figure 2.17). It consists of two types. The first type is used in the cold climates, which is through coating the glass's internal surfaces, provides heat retention indoors, gaining maximum heat and providing sunlight, which reduces the cost of heat for the building (Patterson, 2008). The second type is used in hot climates through the coating of the glass's outer surfaces, which led to limit the heat gain from the sun that keeps the internal environment cooler in summer and hotter in winter, which reduces the heating and cooling expenses for the building (Tortu, 2006).

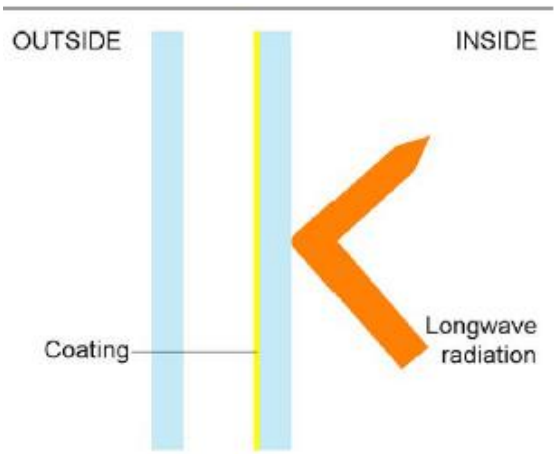


Figure 2.16: Coated low emissivity glass (Matusiak at el,2012).

- **Solar Control glass** is widely used for high-rise buildings because the reflectiveness became a symbol for high-rise building facades. This type of glass is coated to have high solar reflective properties and comes in several metal colours, such as gold, bronze, and others. The coating can be applied on inside surfaces when there is more emphasized on the colour and the glass's outer surfaces when emphasising the glass's reflectiveness (Figure 2.18). The metal oxide coating which is achieved without affecting the glass's transparency can help reduce the heat gain and glare from the exterior. Besides, it allows for the visible light transmission to the interior and reduce the cooling load of the building (Grag, 2007).

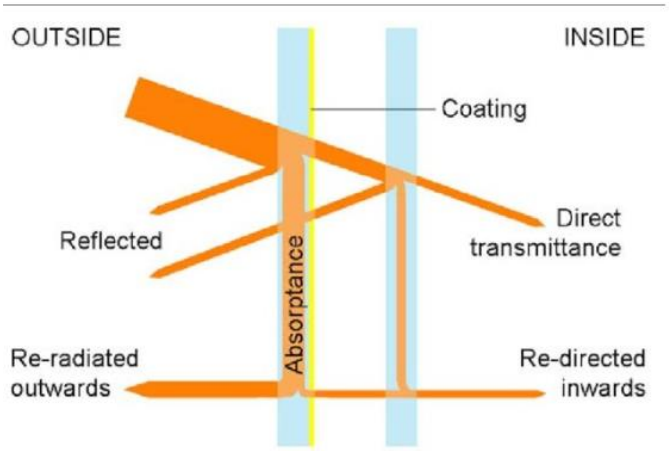


Figure 2.18: Coated solar control glass (Matusiak at el, 2012).

2.5.2.4 Opacified glass (spandrel glass)

Structural elements such as columns and beams can be hidden by this type of glass designed to be opaque. They are commonly located between vision glass on each floor

of the building to hide the end of the slabs as shown in Figure 2.19, to achieve the designer's aim of the finished project. It must be heat-treated according to the level of heat stress required. In addition, to make this glass opaque, the manufactures add silicone-based paint or ceramic frits to the interior surface of the glass, and it can be found in different colours. Grün Consulting (2020) stated that the spandrel panel generally achieved R-value between 0.5 and 0.8m^2K / W. This value depends on the panel's geometrical shape, which indicates the spandrel panel often has less than one-fifth of the required thermal resistance.

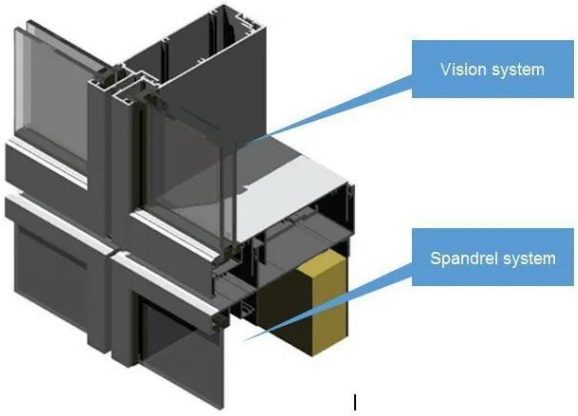


Figure 2.19: Spandrel glass system, (Grün Consulting, 2020).

2.5.3 Anchors

The anchors are used to connect the curtain wall frame system to the main structure of the building. Anchors can be divided into two groups: gravity and lateral load anchors (fixed) and lateral load anchors (slotted). Every anchor consists of two parts: an embedded component that is cast in or drilled at the top of the edge of the floor slab edge; and a mounting lug assembly that fixes the embed and the framing (CMHC,2013) (Figure 2.20 and Figure 2.21). The attachment mode depends on the wind load at the specified location. Beside, the wind load can be different at the different parts of the building that leads to anchor design which can be different in the same project.

There are anchors of different shapes and sizes, but the most effective one to resist the additional load is channel anchors. Usually, the installation is done by casting into a concrete member of the building structure. However, in Turkey, most of the contractors welded it or bolt it to the slab instead of the cast into the concrete because it took much time or the difficulties, although this method was considered the most

effective against the earthquake load. The traditional approach to connect the curtain wall to the building floor slabs is by using mechanical or chemical post-installed anchors or steel plates with stud welded anchors. This method changed nowadays by using the mechanical friction bolts, and it has many advantages such as no time consuming, efficient, adjustable installation (Halfen,2014). According to the MBY engineering (2019), the maximum load on each anchor should not increase by 20 kN(KiloNewton), and the thickness of the bracket depending on the load (6-15 mm). Dogan (2013) stated that for high-rise buildings "there should be almost no deviation of the anchor points in the curtain wall. Otherwise, flaws in application details turn out to be a big problem when the height of the interface becomes longer."

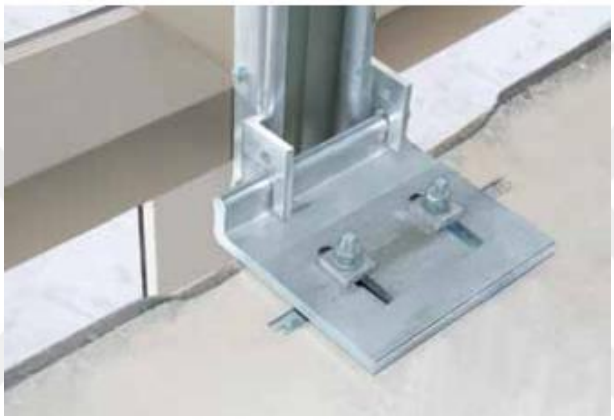


Figure 2.17: Curtain wall connections to the top of the floor slabs, (HALFEN,2014).

Figure 2.21: Curtain wall connections to the edge of the floor slabs, (HALFEN,2014).

2.5.4. Sealant

Sealant is one of the most essential component of the curtain wall system, where it is used to prevent the penetration of water and air through the system. One of the most essential characteristics of the sealant is that it must resist changes, that is, the ability to accommodate cyclic movement; i.e. resulting movement due to heat, humidity, the

sound, wind. The seals classified into three ranges: low range, medium range and high range (CMHC,2013). Cost and longevity fall into the same category as the low cost implies low movement ability and vice versa. Figure 2.22 shows a different types of sealant. The use, material and/or characteristics of these three sealant ranges are as follows ((CMHC,2013):

- **Low Range Sealant**: The use of it is very little in the modern curtain wall system due to its lack of adaptation to movement and used in places with limited access, i.e. the internal parts of the system. The basis for these seals are oil and resin, and these seals are generally mineral fillers.
- **Medium Range Sealant**: Its use is limited in the curtain wall system; used in non-moving joints such as back pan perimeter seals and joinery seals. Also, in places not exposed to ultraviolet radiation. One of the properties of this sealant is that it absorbs movement resulting from creep and deformation instead of elastic tension and pressure.
- **High Range Sealant**: It is one of the most usable types in the modern curtain wall system. It includes two types; silicone and polyurethane.
    - Silicone seals are a highly adjustable product and adapt to the movement caused by elastic tension and compression by 70%, provides high adhesion with all curtain wall components, and has excellent UV resistance beside being resistant to ozone. One of the disadvantages of silicone is that it tends to collect dust and some of its release oil. Silicone seals can be used exposed or in moving joints.
    - In contrast, the polyurethane seals have the same characterized as silicon. However, its ability to adapt to movement is less than 50%, which makes most of the contractors use silicone sealants for all joints (CHMC,2013).

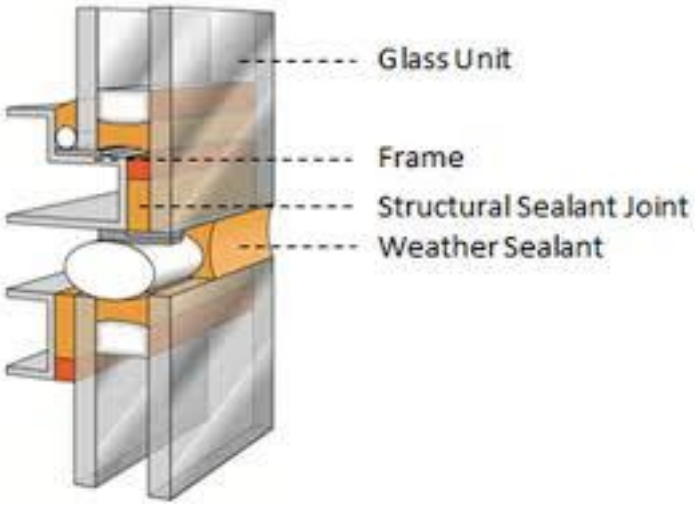


Figure 2.18: Types of curtain wall sealant,(URL-4).

2.6 Curtain Wall Performance Criteria

Since the curtain wall is the barrier between the interior and the exterior, it is highly and directly exposed to environmental conditions such as heat, humidity, light, fire, wind, and earthquake movement. Accordingly, buildings' façades must adapt to the changes that occur over time and provide protection and safety for the occupant. Generally, tall building facades exposed to stronger environmental factors than low-rise building facades, such as wind load, which are higher on the upper floors, and the corners of the building than the lower floors, meaning the higher the height, the stronger the wind. In addition, regarding the rains that substantially impact the façade, the curtain wall system must prevent water's influence through specific treatments that are implemented, and other factors such as noise and light have to be considered. The curtain wall system must deal with these. Accordingly, the curtain wall is subject to test and performance standards as shown in Table 2.1 used to evaluate the curtain wall's performance in relation to requirements. Therefore, it will be explained in the following subsections the performance criteria needed for the curtain wall system in five groups: structural integrity, water, moisture and air control, control of daylight and heat, control of sound transmission and fire control.

Table 2.1: Test and performance standards regarding curtain wall.

	Standard number	Year	Standard name
Test Standards	BS EN 12179	2000	curtain walling- resistance to wind load
	TS EN 13051	2019	curtain walling-water tightness - site test
	TS EN 12155	2000	curtain walling- water tightness-laboratory test under static pressure
	BS EN 13050	2011	Curtain Walling. Water tightness. Laboratory test under the dynamic condition of air pressure and water spray
	TS EN 12153	2000	Curtain walling. Air permeability. Test method
	TS EN 1364-3	2014	Fire resistance tests for non-loadbearing elements. Curtain walling. Full configuration (complete assembly)
	AAMA 501.4	2009	Recommended static test method for evaluation curtain wall and storefront system subjected to seismic and wind Induced interstory drift
	AAMA 501.5	2007	Test method for thermal cycling of exterior walls
	AAMA 501.6	2018	Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from Window Wall, Curtain Wall and Storefront Systems
Performance Standards	TS EN 13830	2015	Curtain walling. Product standard
	TS EN 13116	2001	Curtain walling. Resistance to wind load.
	TS EN 12154	2004	Curtain walling. Water tightness. Performance requirements and classification
	TS EN 12152	2002	Curtain walling. Air permeability. Performance requirements and classification
	TS EN 1991-1-4	2004	Euro code 1. Actions on structures. General actions. Wind actions
	ASTM C1392 - 20		Standard Guide for Evaluating Failure of Structural Sealant Glazing
	EN 14019	2016	Curtain Walling - Impact resistance - Performance requirements
	EN ISO 11600	2003	Building construction - Jointing products - Classification and requirements for sealants

2.6.1 Structural integrity

Since its structural integrity is related to saving a life, it has become the main thing associated with the curtain wall design. the stiffness and strength is one of the basic principles in designing the curtain wall. In addition to providing the necessary movement, it is also an essential part of structural integrity. The curtain wall's structural design is affected by primary loads, which means that it must take into consideration in every design, which are the dead load and winds, and secondary loads meaning that it may be present or not. It is seismic, impact, guard, window washing, blast, bunshades, temperature, snow (CMHC,2013).

Wind load plays an important role in the curtain wall design; the wind load varies depending on the height, which is an essential factor in high-rise buildings, the geographical location and the geometric form. The windproof façade includes the calculation of wind pressure and the distribution of wind since it plays role in choosing the form of glass and its thickness, as well as the thickness of the frame, which is determined by the maximum permissible deflection measured by the length of the frame L/200 (Atalay, 2006). Besides, a rigorous control process following legal sources (code sources), a correct design that considers the limitations of production and assembly are necessary. A good design resisting to wind can be achieved in three dimensions by defining the components' behaviour under load and the distribution of loads and how to resist it. Therefore, it is necessary to understand and know the gradual transfer of loads between the components of the curtain wall (ASCE,2013).

According to BS EN 13830 (2015), curtain wall systems must resist wind load without loss of pressure, permanent deformation, or loss of specific performance characteristics between the internal and external environment. Wind tests can be applied to curtain walls following BS EN 12179 (2000) standard. According to this standard, the maximum frontal deflection (d) in the framing members shall not exceed the following limits;

$$d < L / 200, \text{ if } L < 3000 \text{ mm}$$

$$d < 5 \text{ mm} + L / 300, \text{ if } 3000 \text{ mm} < L < 7500 \text{ mm} \qquad \textbf{(2.1)}$$

$$\text{When } d < L / 250, L > 7500 \text{ mm}$$

L is the length of the curtain wall framing members.

It is calculated according to equation (2.1) and expected to remain below the specified values (BS EN 13830, 2015). It is essential to pay attention to the selection and design of other components of the curtain wall system, such as glass and spandrel panels, since it is crucial to design a security system in determining the design of loads and taking into account the calculations (Yalaz, E.T., Unlu.t.A, Celik. O, 2018).

The other significant factor affecting on the curtain wall's structural design is earthquake. Especially in seismic zones, it leads to two types of impact on the curtain wall system, the first of which is the movement that occurs in the curtain wall system itself, due to its mass. Secondly, the action in the building structure that leads to

damage to the curtain wall system, including deformation of the frame, as well as the breaking of glass, especially on the edges, because of the fragility and inflexibility of the glass. So to avoid these problems occurring, it is necessary to take into consideration allowing horizontal and vertical movement in the frame by attaching the frame to anchors like channel anchors to allow movement and to prevent the breakage of the glass. Arnold C. (2016) stated that it is essential to maintain the adequate clearances and to insert small rubber block spacers between the glass and the frame for allowing the movement that occurs during the earthquake. According to Dogan (2013), the stick system is more flexible than the unitized curtain wall during the earthquake. During the earthquake, the movement transfer from one part to another provides the flexibility to stick system more than the unitized system. More explanation about seismic load will be given in Chapter 4.

Another environmental factor affecting the curtain wall system is the heat resulting from the solar effect. The change in temperature leads to noticeable changes in the system, the most important of which is movement, especially the snap cap movement, which leads to bending or separating the covers. It can be avoidable by leaving clearance between the caps.

As mentioned earlier, there are several types of movement occurring inside the curtain wall system, such as caused by winds, earthquakes and creeping, and movement caused by wind and heat load. Figure 2.23 and Figure 2.24 show the expansion size detail in the unitized and stick curtain wall respectively. These movements do not lead to system failure only but result in sound, fatigue failure and weather seal failure (CMHC,2013).

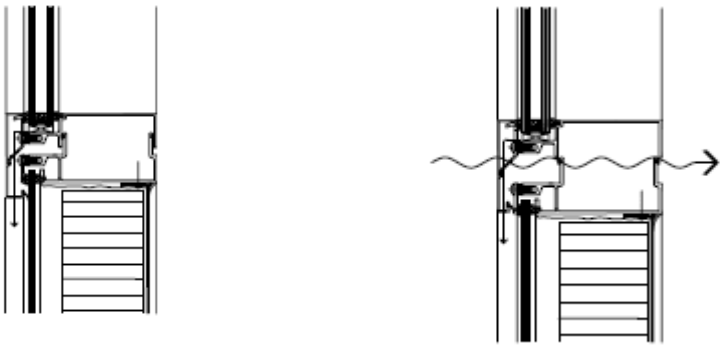


Figure 2.19: Details of the unitized system expansion and the effect of incorrectly resizing this joint, (CMHC,2013).

Figure 2.20: Details of the stick system expansion and the effect of incorrectly resizing this joint, (CMHC,2013).

2.6.2 Water, moisture and air control

Two of the essential factors that need to be considered in designing and constructing the curtain wall system are water leakage and excessive air infiltration. Preventing these largely depend on providing the proper movement and proper design of the joints. Management of excessive air leakage can easily provided when compared to water leakage. BS EN 13830 (2015) mentioned that water-tightness in the curtain wall system is the ability of curtain walls to prevent rainwater from entering the building that could affect hygiene and internal health, and water should not enter inside the curtain wall and drain outside. Uncontrolled rainwater penetration, which carried by strong winds, leads to falling in all directions and aggregation in the curtain wall joints, which are the weakest points in the system.

There are two methods for preventing leakage through the curtain wall. The first method known by the name “internal drainage”, is by supplying the wall with flashing and collecting devices and ample drainage outlets on the outside of the wall, which contribute to collecting and draining water from the curtain wall to the outside. The second method known as “pressure equalization” is generally based on the rain screen principle. It requires a ventilated exterior wall surface supported by drained air space to maintain the pressure with the wall's sealed inner face against the passage of air (Figure 2.25). For these two methods to work convincingly and adequately required a clear understanding of the action of wind-driven rain, careful detailing, proper installation (Winxie, 2007).

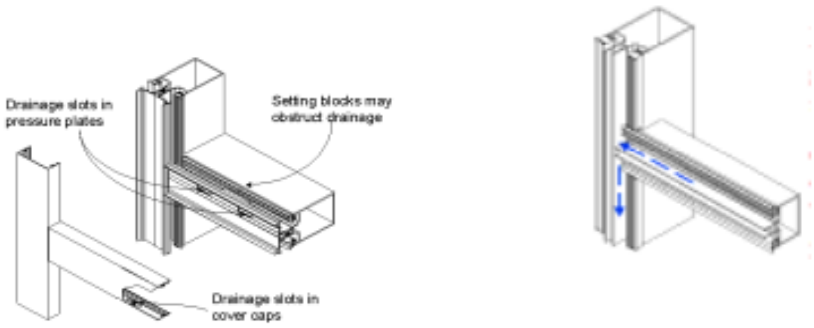


Figure 2.21: Pressure equalization frame (CWCT,2008).

According to CWCT (2008), gaskets and seals are one of the critical components that controlled the penetrating of water and air. There are two kinds of gaskets: static gaskets used to close joints between fixed elements, and dynamic gaskets used around opening joints such as windows, doors, and access openings. There are two applications of sealant in curtain wall design: weather seal silicone used at joints to provide water and air tightness, while structural silicone is used to keep the glass or support without the need for any other components, so it used to provide a smooth exterior, considered as one of the materials that prevent the influence of water and air.

In Turkey, standards mentioned in Table 2.2 are used in factories to evaluate the curtain wall's performance concerning water leakage and air infiltration.

Table 2.2: Curtain wall air permeability and water tightness test and performance standards.

	Standard No	Year	Name
Test Standard	TS EN 12153	2000	Curtain walling. Air permeability. Test method
	TS EN 12155	2000	Curtain walling. Water tightness. Laboratory test under static pressure
	AAMA 501.1	2017	Water Penetration of Windows, Curtain Walls and Doors Using Dynamic Pressure
	EN 13050	2011	Curtain Walling. Water tightness. Laboratory test under the dynamic condition of air pressure and water spray
Performance Standard	TS EN 12152	2002	Curtain walling. Air permeability. Performance requirements and classification
	BS EN 12154	2000	Curtain walling – water tightness - performance requirements and classification

Moisture is a significant factor in assessing curtain wall performance even though glass and metal do not allow penetration of moisture, as well as, provide a highly efficient

barrier against water vapour but their ability to maintain heat is very little which leads to the possibility of moisture occurring on the interior surfaces of the wall. So understanding the occurrence of condensation; the reason behind its occurrences and possible place of occurrence are important in avoiding the problem. The use of a high-efficiency vapour barrier placed next to the sealant and gaskets is a solution within this scope. The spandrel wall is more susceptible to moisture than metal and glass, so attention must be paid to the internal details about moisture control (Sanders, M.R, 2006). EN 13830 (2015) mentioned that for a non-transparent infill panel, a vapour barrier should be chosen following the specified hygro-thermal conditions of the building. The type of vapour control layer shall be declared. Accordingly, the details in the wall in case of condensation should be detailed, collected and drained from the wall, resulting in the absence of moisture.

2.6.3 Control of sound transmission

One of the curtain wall's critical performance requirements is a reduction of the noise coming from the outside. The curtain walls' performance in densely built urban areas is reasonable compared to the other materials. However, in areas with high noise such as airports, the performance of the curtain wall need to follow several steps to achieve an acceptable performance; such as environmental noise assessment, determining of the minimum acceptable transmission loss (TL) or sound transmission class (STC), choosing the type of glass and spandrel, window frame design and installation. To evaluate the TL and STC level, determined by an acoustic consultant as well as the required minimum values submitted to the curtain wall designer, with the total value of TL or STC, the designer will consider the vision and extension areas separately (CMHC,2013). Therefore, determining the STC value in the glass depends on glass thickness, the air space's thickness and the separator type beside damping between layers. Winxie (2007) stated that the weak links in most walls are glazed areas and openings, where a high degree for sound insulation is required leakage through the curtain wall should be minimized, and double glazing, well-sealed and separated, is for performing a high degree of sound insulation. While the opaque spandrel parts of the curtain wall, consisting of several similar materials because of the curtain wall's unique features (metal panels, aluminium tubes) do not make the standard handbook values applicable. Therefore, its sound performance tested by mock-up assemblies.

The design of the acoustic performance of the curtain wall is subject to several standards. Furthermore, the aural performance tests should be according to these standards shown in Table 2.3.

Table 2.3: The acoustic performance tests standards.

Standard no	Year	Standard name
TS EN ISO 10140	2016	Acoustics. Laboratory measurement of sound insulation of building elements. Application rules for specific products
BS EN ISO 16283-3	2016	Acoustics. Field measurement of sound insulation in buildings and of building elements. Façade sound insulation
TS EN ISO 10140-2	2011	Acoustics - Laboratory measurement of sound insulation of building elements - Part 2: Measurement of airborne sound insulation
EN ISO 717-1	2013	Acoustics. Rating of sound insulation in buildings and of building elements

2.6.4 Control of fire

Control of fire considered as one of the most critical performance criteria for a curtain wall especially for high-rise buildings. Therefore, the curtain wall should resist fire and smoke transfer from one floor to another at the slab edge.

The reaction of the materials against fire varies and depending on the classification of the material as combustible and non-combustible, and combustible materials are classified as non-flammable or normally flammable materials. The curtain walls generally consist of non-combustible materials such as aluminium, glass, stone and secondary explosive components such as sealants and gaskets permitted in the non-combustible construction. Therefore, it is required to meet the required standards in Turkey, and the materials for high-rise building facades must construct from non-combustible material. In contrast, the low rise building façade materials must be at least non-flammable.

For the curtain wall to stop the spread of fires and flames, usually, fire stop and smoke seal is used Figure 2.26. In case of fire occur, the safety of both of these elements depends on the curtain wall and the back pan remaining in place (CMHC,2013).

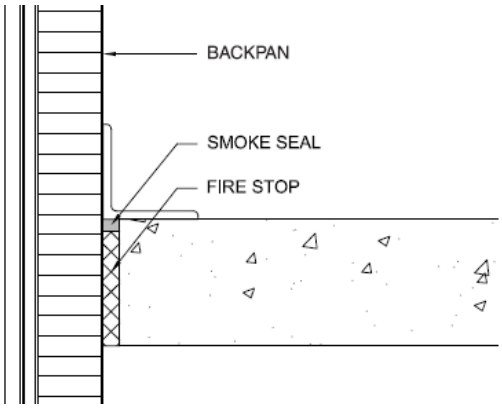


Figure 2.26: Fire stop between the floor slab and glass curtainwall, (CMHC,2013).

For evaluating the fire-resisting performance of the curtain wall system, curtain wall factories should use the standard mentioned in Table 2.4 for testing and performance.

Table 2.4: Curtain wall fire resistance performance tests standards.

Standard no	Year	Standard name
EN 1364-3	2014	Fire resistance tests for non-loadbearing elements - Part 3: Curtain walling - Full configuration (complete assembly)
EN 1364-4	2014	Fire resistance tests for non-loadbearing elements - Part 4: Curtain walling – Part configuration
EN 13238	2010	Reaction to fire tests for building products - Conditioning procedures and general rules for the selection of substrates
EN 13501-1	2018	Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests
EN 13501-2	2016	Tracked Changes. Fire classification of construction products and building elements. Classification using data from fire resistance tests, excluding ventilation services

2.6.5 Control of daylight and heat

Heat and light are two of the essential factors affecting the curtain wall's performance, as they contribute to the comfort and health of the occupants. The amount of light and heat entering into the interior spaces must be controlled to prevent solar gaining when necessary. Therefore, one method to retain heat and light is to include shading devices in the curtain wall design and depend on the sun seasonal altitude and orientation. It can be fixed or moveable (motorized). Selected shading devices can be either in horizontal direction that is considered to be the better solution in the southern façades, or vertical for to be used on the west and east façade to block the sunlight from lower

angles. Moveable sun shading devices considered more effective than fixed ones due to the better adjustability for the daily and seasonal changing in the sun and the sky. Therefore, attention should be taken in designing shading devices according to EN 13363-1, EN 13363-2/ They demonstrate the calculation of solar transmittance and light by shading elements. In summer, sunlight should be provided in a way that will not lead to increase the heat on interior spaces. In contrast, in winter, sun shade device should give as much as possible of sun lighting; and this passage will reduce energy consumption in the building.

Another method to control heat and light is the use of high-performance coating on the glass surfaces as explained before. To increase the thermal performance of the curtain wall it is also preferred to use double or triple glazing. Generally, in Turkey double glazing used, beside the use of gas such as argon and krypton between the glass layers instead of the dry air due to efficiency in reducing heat and sound transmission to interior spaces.

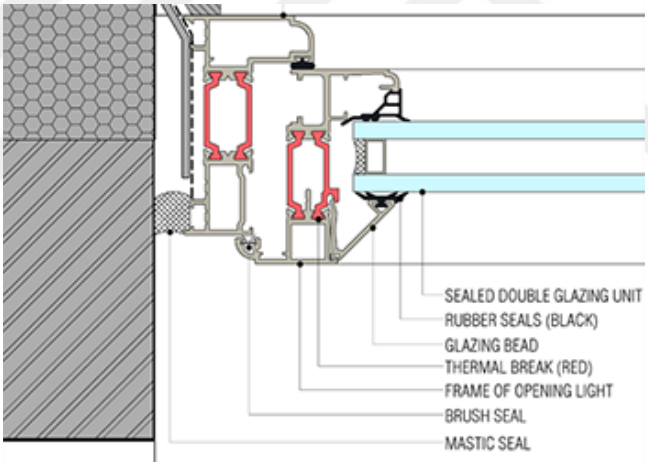


Figure 2.27: Red parts indicates thermal break between the framing of the curtain wall, (URL-5).

To control heat transferring through the framing element, the use of the thermal break to prevent conductive thermal energy loss, besides insulation should be at the interior faces of the frames and the insulation must be continuous so that there is no vacuum to allow heat to pass. The heat control of the spandrel area is also essential; it consists of many materials. One of these essential materials is moisture control to prevent condensation between the thermal insulation and the back pan.

2.7 Discussion

This chapter provided an overview of curtain wall, how to classify it through the method of construction, design and glazing, in addition to a review of the components of the curtain wall that need to be known for evaluating the performance of the curtain wall during the design stage and the following stages, where its performance considered through experiments and simulation programs. After that, the type of curtain wall will be determined on the project chosen, but the problem is that the conditions that applied to the curtain wall during experiments and simulation programs are approximate to reality Sometimes the curtain wall fails to perform under realistic conditions. The effect of winds on the curtain wall system will explain in the next chapter.

3. THE EFFECT OF WIND LOAD ON CURTAIN WALL SYSTEM

Usually, the curtain wall system is the first part of the building effect by the wind load. Intuitively, the curtain wall designer understands that wind impacts on the system are likely to affect the system's structural performance; however, the method of determining good quality specifications is not apparent. This method involves an aerodynamic study of the manipulation structure thorough review and adherence to defied source code, careful selection of material composition and geometry, fabrication and assembly limitations, among other considerations (ASCE, 2013).

For this reason, the process required precise tracing of a wind load from its initial contact with the surface of the outer curtain wall panel to its perimeter supports, its frame elements and ultimately the primary structure of the building. In this chapter, the wind will check in Turkey and internationally, particularly in Istanbul, and how the wind load affects the high and mid-rise building facades for more precisely describe how wind load impacts the components of the curtain wall, as well as the standard and regulations used by the Turkish curtain wall companies stacks during the design process to determine the effect of the wind load, other approaches, such as simulation programs and wind tunnel tests which produce more precise outcomes in specific cases.

3.1 Wind

The wind is the transferor movement of air masses from one region to another horizontally in the air, based on the difference in atmospheric pressure values from one region to another, such that winds often pass quickly from regions of high air pressure to areas of low air pressure. There are powerful winds with gustiness in the atmosphere at lower levels, which form primarily due to their contact with surface characteristics. The average wind speed, for more or less ten minutes, appears to rise with height while the gustiness decreases, such as the direction of the wind must be taken into account when assessing wind pressure. If the wind pushes against the surface of the building, it is called the "windward," which works positively. Negative wind pressure (leeward) produced when winds blow away from the surface concerned. The building will be subject to negative pressures or positive pressure depending on the average direction of airflow in an environment.

Wind load: is the primarily horizontal load arising from the wind blowing on the building's facade, which must be effectively and securely transferred from the facade to the structure of the building, which, in turn, is transferred to the foundations of the building to prevent structural failure. Typically wind load depend on the wind velocity, shape and surface of the building. It is essential to distinguish between the global wind load on the load-bearing structure often referred to as the structural wind. The local wind load on the facade is often referred to as the panel load, the local turbulence load on the panel can exceed 500 kg / m^2. In comparison, the global structural load is only 150 kg / m^2, both types of wind load are so important for the structure of the facade, the structural load deforms the building and forms the basis for the design of the principal deformation joints for the facade's structure. In sizing the facade structure, consideration should be given to peak panel loads and local distortion profiles (Kloft & Eisele, 2002).

Wind Speed (Wind Velocity): is an air that travels from high to low pressure, typically due to fluctuations in temperature over the ground at the height of 10 m above ground level. The velocity unit and the proposed unit according to the world meteorological organization, the wind velocity report shall be metres/second (m/s). The wind shall measure by reference to the true north (not the magnetic north) and shall indicate where the wind blows.

Vertex Shedding: is a phenomenon, when the wind blows through a structural member, the vertex fall alternately from side to side and where the alternating low-pressure regions generated on the wind side of the structure resulting in an oscillatory force acting at correct angles to the wind direction (F.Fu,2018) Figure 3.1. The frequency of vortex elimination should be determined by the strouhal number (St) depends on the cross-section of the building or object through which the flow flows and also depends on the velocity of the flow or the number of reynolds. Equation (3.1) shows how to work out the St number.

$$S_t = \frac{Df_v}{U} \qquad \textbf{(3.1)}$$

Here: S is the St number, D is the width of the building or object over which the flow passes, f_v is the frequency of the vortex shedding, and U is the flow speed.

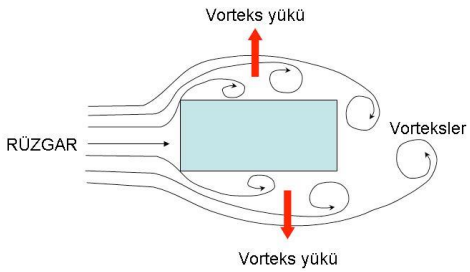


Figure 3.1: Vortex shedding around the buildings, (İYBRY, 2009).

3.1.1 Wind drift design

In specific codes of wind loading and construction, the limits of wind deflection or relative deflection between the adjacent floors of the buildings, in some instances, these restrictions are not mandatory but considered to be guidelines. The main causes for the installation of a small wind turbine are to minimize damage to the exterior of the building, partitions and internal finishes and to reduce P-Delta or secondary loading effects.

3.1.2 Wind load in Turkey

The influence of wind on the design curtain wall was one of the goals of this study. Therefore, knowing the wind speed in Turkey, especially in Istanbul is necessary. According to the midwives that conducted with several companies, there is no clear wind map for Turkey or Istanbul to calculate the wind speed; therefore, the speed adopted basic wind speed. The baseline wind speed is the wind speed that corresponds to the probability of exceeding the 10-minute average wind speeds measured in any direction at 10m above ground, at least once in 50 years in an open field (such as at airports). İYBRY: According to 2009, as a result of the analysis of the wind speed measurement data continuously made at 1-minute intervals at Istanbul Atatürk Airport, the basic wind speed V for Istanbul and its vicinity as b = 25 m / s. In addition to the wind loads, as the wind loads on the primary loading system of the building, the exterior cladding and other wind-exposed structural and non-structural components must not be less than 0.5 kN/square metre. Figure (3.2) shows the Turkish wind map

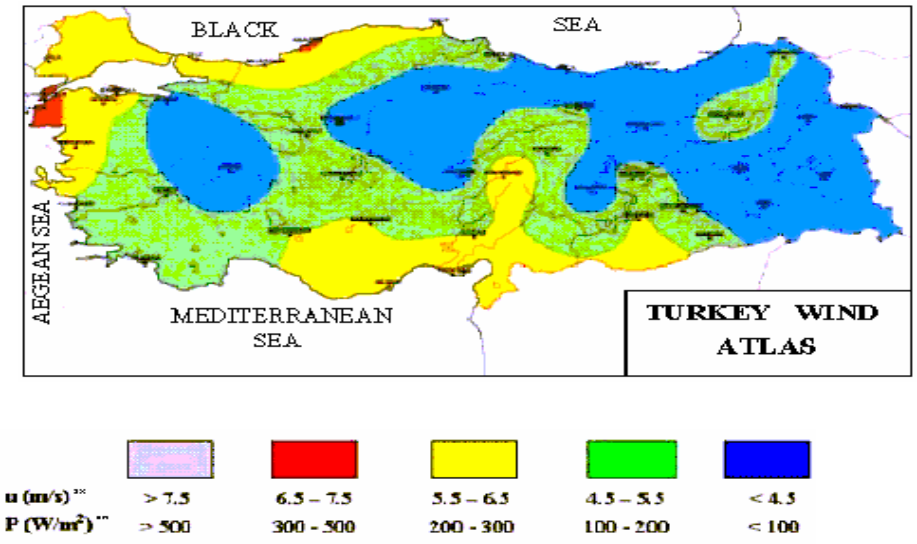


Figure 3.2: Wind map of turkey, (WES, 2003).

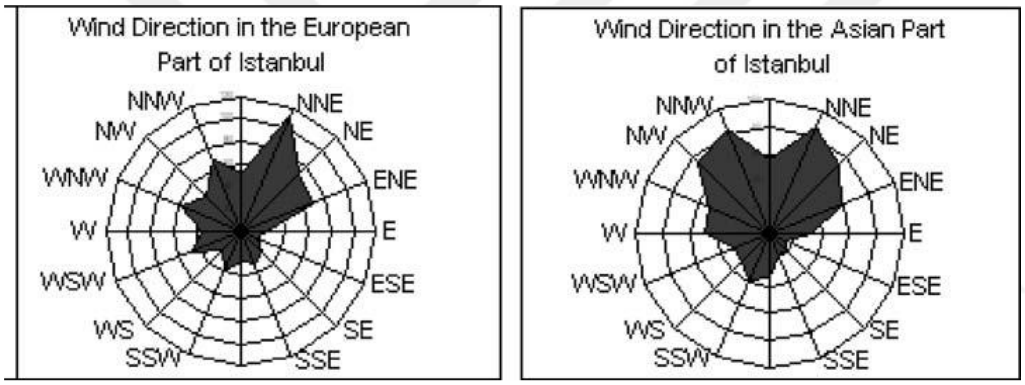


Figure 3.3: Wind direction in Asian and European parts of Istanbul, (U. A. Sahin et al., 2011).

By observing the map, the wind speed in Istanbul varies between 5.5-6.5 m/s while in some areas of the Asian part, the wind speed ranges between 6.5-7.5m/s. Due to the wind velocity differential between regions. Istanbul's municipality decided basic wind speed a 25 m/s .one of the most important criteria while designing a curtain wall system, especially for high rise building in Istanbul is the wind, the dynamic effect of wind loading becomes more crucial at height. The direction of the winds also a significant factor in the design of the building's facades. Figure 3.3 demonstrates the direction of the winds in Istanbul, the prevailing wind direction in the European part is NNE while the Asian part of Istanbul is between the northeast and northwest.

3.1.3 Wind load performance high and mid-rise building's envelope

One of the essential criteria in buildings design, especially tall buildings, is wind loads due to the more significant the height, the greater the wind speed, which means the loads will be higher on the upper floors than on the lower floors Figure 3.4. Since the first component of the building will expose to the wind load is the façade; therefore, it is necessary to know the displacement that the wind will cause to the façade, due to the dynamic nature of the wind and the remarkable progress in building techniques, so it is possible to accurately work out the effects of wind pressures on the building façades as the wind working along the building's facade induces horizontal loading and is transmitted to the slabs. The slabs are affected as diaphragms and laterally the shear load transportation to the vertical components. The compression flange of the steel girder below and the other elements acts as a single fixed unit. According to its in-plan rigidity, diaphragms exposed to shear forces in the case of concrete. The horizontal loads are transferred from the slab to the beams via welded studs. (Taranath, 2012). Given how slabs are related to the façade, the stress distribution in the slabs differs. Since the slabs directly connected to the facade, a distributed load produced. Point loads generated where the facade linked to the columns. Moreover, one of the critical factors that must be considered when designing the facades of high and medium buildings is the deformation that occurs as a result of wind load. Therefore, Special attention should be paid to the deformation behaviour or the relative deformation of the load-bearing structure in the transition areas between the building structure (slab) and façade, that is, at the façade junction, the technique is either to reduce the deformation or to identify simple deformation and rotation paths through the expected joint length that is consistent with both the load. As already mentioned, the wind load is either local, which affects and is related to the ability and performance of the building structure. As for the global wind load considered a reference in designing the joints of the façade. Most of the international and local codes determine the level of permissible deflection if the wind load peak is considered, the façade load, which determines the loads' design. The absorption of deflection or deformation at the facade level must check. (Kloft, K., Eisele, J., 2002).

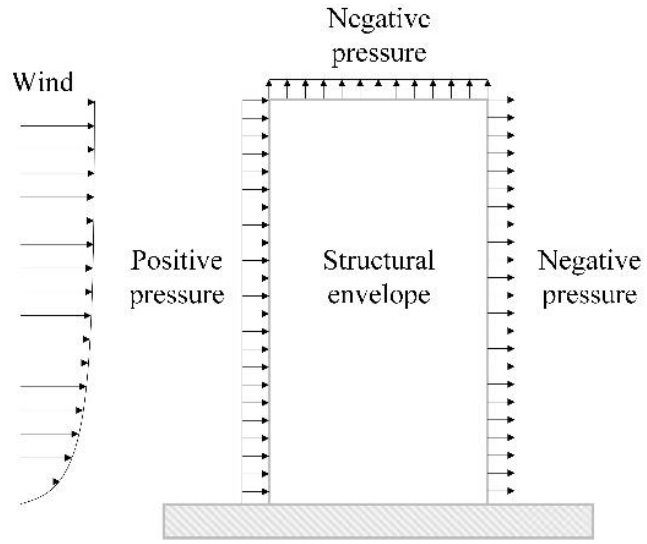


Figure 3.4: Effects of positive and negative pressure on the exterior wall of the building. (Choi, I., Kim, J. and Kim H., 2015).

3.1.3.1 Wind load performance of curtain wall components

To design a successful wind curtain wall system requires the ability to produce a three-dimensional model for testing in laboratories, to ensure its ability to withstand and transmit wind loads, as well as simulation theories using computer programs that significantly contribute to an approximate estimate of the wind load to which the wall components are exposed. One of these programs that are currently in great use is the Computational Fluid Dynamics (CFD) software, which will discuss later. If the building height exceeds 200 meters and becomes more complex, this requires tunnel wind experiments. In addition to global, local codes and standards, all these methods require an understanding of the design components and how the load transfer graded through the curtain wall components. The curtain wall system and its connection assemblies and its anchorage fix to the primary structure of the building, i.e. the horizontal elements through connection points these are where the curtain wall engineer concentrates the effort; therefore, the design of these connections is essential in the case of the transmission of wind loads Figure 3.5. A wide area of vitreous or other panel surfaces that resists wind pressure is the first feature carried in the curtain wall. Then these panels shift their load to stiffeners or supports for perimeters. The perimeter supports the dump load of linear continuous framing members, either directly or indirectly. These framing members are often arranged in beam-column mullions in an orthogonal grid pattern spanning from floor to floor and transferring accumulated loads to the primary building structure. In between the vertical mullions,

the horizontal framing elements will serve as secondary elements holding portions of wind and dead loads to the primary wall elements. These last supports built as embedded anchors to steel and concrete components with direct welding or bolting.

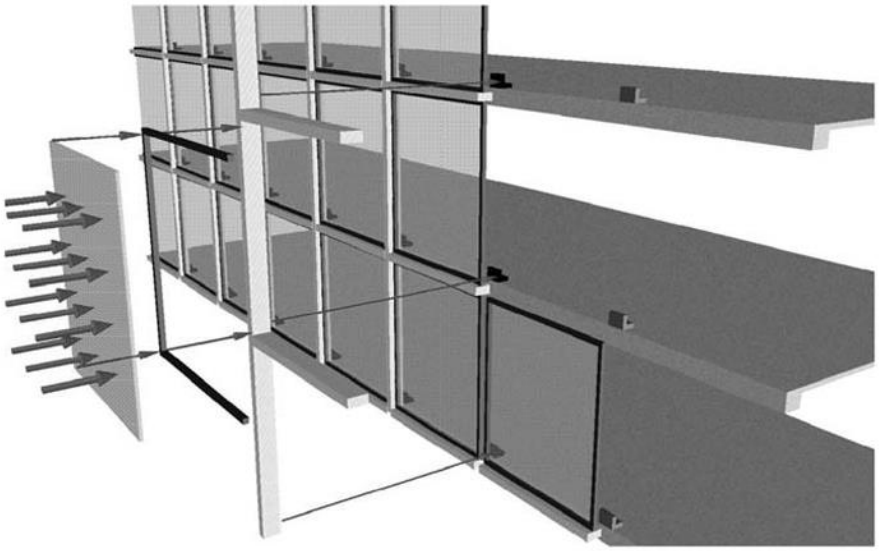


Figure 3.5: Wind flow through Curtain wall component to the buildings primary structure. (Clift & Bonnheim, 2013).

Suppose there are openings in the wall during the wind event. In that case, consideration must take, i.e. during the calculations, because alternative loading paths may occur and internal pressures may develop that may or may not work in advance with external pressures.

– **Frame**

The essential criteria for the design of the curtain wall concerning the wind are the wind load, which can cause the wind to displace the curtain wall structure, the glass and the frame and this happens as a result of the adaptation or tolerance of the permissible wind force and if the structure is unable to withstand the wind force, that causes the lack of allowable displacement.

According to the European standards BS EN 13830-2015 that most Turkish and European company's fellow, the largest permissible forward displacement of the curtain wall's frame should not exceed the permissible limits.

- $d \leq L/200$, if $L \leq 3000$ mm;
- $d \leq 5$ mm $+ L/300$, if 3000 mm $< L < 7500$ mm;
- $d \leq L/250$, if $L \geq 7500$ mm.

When measured between the points of support or anchorage to the building's structure (L)d: is the deflection; besides, the permissible deflection limits of the infill (IGU, stone, etc.) shall take into account.

- **Glass**

The pressure caused by the wind is one of the most critical factors affecting the determination of the thickness and selection of glass in the facades of high and mid-rise buildings and the higher the height, the greater the wind load and this means that the thickness of the glass may vary. However, before choosing the type of glass, the maximum wind load is determined and after that the appropriate type and thickness of the glass chosen. The same type and thickness are used throughout the building, meaning there is no difference between the upper and lower floors. Suppose the glass is not able to cope with the loads. In that case, fractures appear on the glass, or the curtain wall's components separated due to the failure to use the types of glass suitable for different environmental conditions, especially the high wind load when designing glass panels stiffness considered as objective. For determining the glass panels' deflection, many parameters should involve such the occupant comfort, interaction with adjacent materials, potential for cumulative movement, or loss of bite (Clift & Bonnheim, 2013).

Depending upon the type of glass, and the duration of load, the design value of the glass resistance depends on the characteristic value of the bending strength of glass material and the partial factors, the load duration. In addition to that, the load distribution on the glass panels is to be carried out unanimously over the whole area of the glass panels, the rules followed throughout the design process.

- **Anchors**

Through the anchor system design, one of the most important criteria is to transfer the wind load to the main structure of the building beside they allow movement. This also allows the floors to move independently of the glazing system. The curtain wall anchors and brackets should design and dimensioned to withstand high horizontal and vertical loads. Therefore, the design should withstand the forces resulting from winds and earthquakes and bear the weight of the curtain wall. In the design phase, the weight

of the curtain wall determine. Then by some calculation software s maximum weight and load on the anchors will be determined then compare the results with the maximum loads allowable by the standards. The calculation could divide into two parts of calculating loads on connection points and checking the anchor channel's ability and concrete component to take these loads (Hashemi, 2018).

Many types of anchor systems exist, but the preferred type is the anchor channels, as we mentioned earlier. One of the advantages of the anchor channels is the ease and security of movement caused by winds, so it does not cause the wall glass to break down or deflect.

3.1.4 Specification used in the design of buildings curtain wall system

A necessary first step in understanding this subject is analysing and comparing local and international standards and their approach to wind design for non-structural components such as the curtain wall. Therefore, the purpose of observing and recognizing these requirements these standards is for the building equipped with the curtain wall system to resist the occurrence of wind and transfer it to the main structure of the building quickly and safely without causing damage or deformation of the curtain wall system. In this regards with Turkish regulation, the Eurocode - 1, will be reviewed alongside U.S requirements.

3.1.4.1 IYBRY 2009-Istanbul high rise buildings wind load code

In this legislation, minimum wind loads set to use in the design of systems subject to wind loads, such as the main structural systems of the building and external elements and non-structural systems. For calculating the wind speed affecting the building Equation 3.2

$$V(z, t) = V_m(z) + w(z, t) \qquad (3.2)$$

V (z, t) shows the total wind speed defined depending on the height z measured from the ground surface and time (t). The average wind speed Vm (z) called the static component of the wind and corresponded to the average wind speeds acting on the building over a selected time interval. W (z, t) is the dynamic wind speed expressing the velocity changes (turbulence) around the average value. The average wind speed at any zone and height can be calculated according to Equation 3.3

$$V_m(z) = C_e(z)\, C_t\, V_b \qquad (3.3)$$

V_b shows the basic wind speed, C_e (z) the surface roughness coefficient, a coefficient is describing the effects of surface roughness in wind direction on mean wind speed and change of velocity with altitude. Varying with the height can be defined in equation 3.4, the Ct is the topography coefficient.

$$z > z_{min} \text{ for } C_e(z) = k_r \ln(z/z_o) ; k_r = 0.23(z_o)^{0.07}$$
$$z \leq z_{min} \text{ for } C_e(z) = C_e(z_{min}) \quad (3.4)$$

In this equation, Z_o is the surface roughness length(m), Z_{min} is the minimum height (m) at which the coefficient of surface roughness is constant, the Z_0 and Z_{min} differs depending on the land type which included in this regulation five types of lands and shown in Table 3.1

Table 3.1: Surface roughness lengths (z_o) and minimum heights (z_{min}).

Land type no	Land Type	zo (m)	zmin (m)
0	Coastlines open to the sea	0.003	1
I	Lake surroundings or flat and wide areas without unevenness	0.01	1
II	Plain, meadow-type areas with sparse trees and structures (roughness intervals more than 20 times the average height of roughness)	0.05	2
III	Villages, suburbs, wooded areas (rough gaps less than 20 times the average roughness height)	0.3	5
IV	City centres and similar areas covered with buildings with an average height of at least 15% and 15m and above	1.0	10

While the C_t coefficient for all regions in Istanbul can take from Equation 3.5

$$C_t = 1.0 + 0.001 \# \quad (3.5)$$

Where # is the height of the location of the building above sea level in m. In case that the building is in the city centre and surrounded by buildings of lower height, then the average wind speed is calculated according to Equation 3.6. However, in the absence of information about the neighbouring buildings' height, it is assumed that their height is h_o= 15. The winds of a tall building are calculated by shifting the wind profile and the loads affecting the building under normal conditions until it reaches H_Y in the vertical direction Figure 3.6.

$$\begin{gathered} x < 2h_o \text{ if } h_y = \min[0.8h_y, 0.6h] \\ 2h_o < x < 6h_o \text{ if } h_y = \min[1.2h_0 - 0.2, 0.6h] \\ x \geq 6h_o \text{ if } h_y = 0 \end{gathered} \quad (3.6)$$

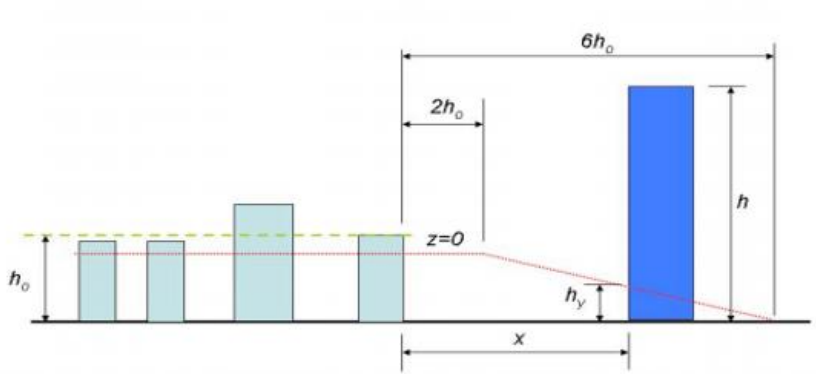


Figure 3.6: The effect of surrounding structures on the average wind speed profile, (İYBRY, 2009).

There are two forms of wind dynamic and static, as described before. Wind turbulence is called dynamic wind speed. Wind turbulence modelled as a random process generally distributed with a mean value of zero and the standard turbulence variance Q_w in Equation 3.7. in case it affects buildings, the average maximum turbulent wind speed, W_{max}, is taken as 3.5 times the standard deviation which means Wmax =3.5 Q_w

$$\mathbf{Q_w = k_r v_b} \qquad \mathbf{(3.7)}$$

Calculates turbulence intensity I_w (z) varies with height in Equation 3.8, which determines the relative amplitude of turbulence concerning average wind speed.

$$\mathbf{Z > Z_{min}\ \ for\ \ I_w(z) = {Q_w}/{V_m}\,(z) = {1}/{C_t}\,In(\frac{z}{z_o}} \qquad \mathbf{(3.8)}$$
$$\mathbf{Z \le Z_{min}\ \ \ for\ \ I_w(Z) = I_w(Z_{min})}$$

The second parameter that defines the disturbance magnitude is the disturbance length. The turbulence length L (z) is the average turbulence wavelength of the wind waves and can approximately determine from Equations 3.9.

$$\mathbf{z \ge z_{\,m}\ in\ for\ \ L(z) = 300\ (z/200)^{\,\&}\ ;\ \&= 0.67 + 0.05ln(z_o)}$$
$$\mathbf{z < z_{\,min}\ for\ \ L(z) = L(z_{\,min})} \qquad \mathbf{(3.9)}$$

Maximum wind speed: One of the important factors that are taken into consideration when calculating wind loads is the maximum wind speed |V(z,t)|max it can calculate from the Equation 3.10**.**

$$\mathbf{|V(z,t)|_{max} = V_m(z)} + W_{max} \qquad \mathbf{(3.10)}$$

Maximum wind pressure: In the Turkish High-Rise Building Wind Regulation Part, four explains how to calculate the maximum wind pressure effects on a point.

Therefore, Maximum wind pressure qp (z) per unit area at z height in the plane perpendicular to the wind is calculated by Equation 3.11.

$$qp\ (z) = 1/2\ \rho |V(z+t)|^2_{max} \qquad (3.11)$$

Where |V (z, t) | max is the maximum wind speed acting at z height, ρ is the air density (ρ = 1.25 N / m^3). In case that W_{max} = V (z), the following relation can write for the maximum wind pressure:

$$qp\ (z) \sim 1/2\ \rho\ V^2_m(z) + \rho\ V_m(z).\ \varpi_{max} \qquad (3.12)$$

$$qp\ (z) \sim 1/2\ \rho\ V^2_m(z)[1+7\ I\ \varpi(Z)],\ qp\ (z) \sim Cq(z)\ q_p$$

The basic wind pressure qb and the impact coefficient Cq (z) varying with height. For the five land types given in Table 3.1, the variation of Cq (z) with height is given in Figure 3.7, assuming the Ct topography coefficient is 1.0.

Wind load: To calculate the maximum wind load in this regulation, given in part 4.2, the maximum wind load Q (z) acting on a surface at height z in the plane perpendicular to the wind can calculate as shown in equation 3.13:

$$Q\ (z) = q_p(z) C_P A \qquad (3.13)$$

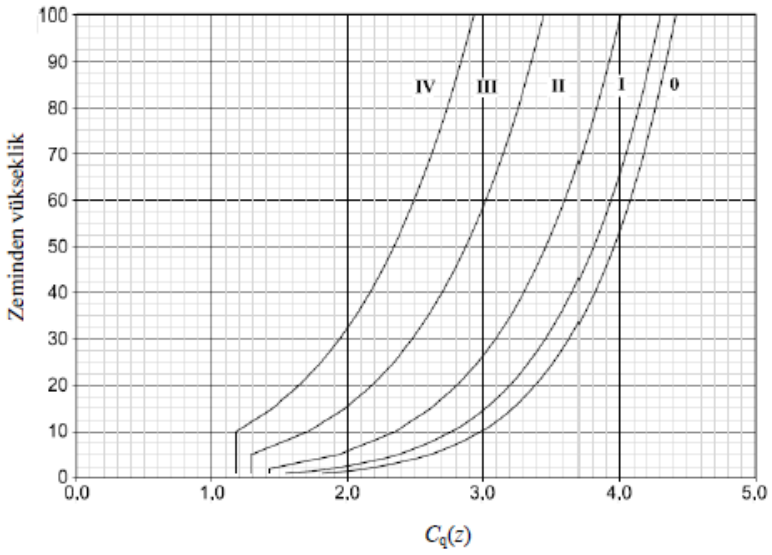


Figure 3.7: The impact coefficient Cq (z) for the five land type.

Suppose it is for a surface and different kind of plan shapes like rectangle and circular and if the shape is not rectangular or circle, the wind tunnel test should determine the wind load on it. For non-structural elements such as curtain wall, the Cp coefficient equal one used in the calculation of wind loads. The largest displacement of wind on the building calculated by applying the wind as a static load. In dynamic properties, is calculated by performing a precise dynamic analysis using random vibration theory.

Part 9 of these laws, explained when to conduct a wind tunnel experiment and what type of building to conduct these experiments.

3.1.4.2 Eurocode 1

This standard guides determining natural wind procedures for a building's structural design, which includes the entire structure and associated elements such as the curtain wall, parts, and fixings. This standard applies to buildings of up to 200 m in height. To perform calculations and know the effect of winds on the curtain wall and the building's structural structure, it is necessary to know the wind velocity that consists of a medium component and a volatile component. To determine the average wind velocity from the base wind velocity that depends on the climate, altitude change, terrain, roughness, and planning g, and to determine the peak pressure velocity, the oscillating component of the wind represented by the intensity of the turbulence.

The basic wind velocity Vb defined as a wind direction function and the time of year at 10 m above ground level of category II shall calculate from Equation 3.14.

$$\boldsymbol{V_b = C_{dir} \times C_{season} \times V_{b,0}} \qquad \textbf{(3.14)}$$

Where V_b is the basic wind velocity, $V_{b,0}$ the fundamental value of the basic wind velocity, C_{dir} the directional factor, so the value for various wind directions may be found in the National Annex. The recommended value is 1,0., C_{season} the season factor. The value may give in the National Annex. The recommended value is 1,0.

For calculating the basic velocity pressure from Equation 3.15:

$$\boldsymbol{q_b = 0.5\, \rho_{air} \times V_b^2} \qquad \textbf{(3.15)}$$

Where q_b is the design wind pressure in Pa, ρ_{air} the density of air (1.25 kg/cu), V_b^2 basic wind velocity in m/s. The peak velocity pressure $q_p(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined according to Equation 3.16

$$\boldsymbol{q_b(z) = 0.5[1 + 7\, I_v(z)] \times \rho_{air} \times V_m(z)^2} \qquad \textbf{(3.16)}$$

Where $V_m(z)$ is the mean wind velocity**,** m/s,

$$\boldsymbol{V_m(z) = C_r(z)\, C_o(z)\, V_b} \qquad \textbf{(3.17)}$$

Cr(z) is that the orography factor and Co(z) is that the roughness factor, which accounts for the variability of the mean wind velocity at the positioning of the structure

due to: the peak above ground level and therefore the ground roughness of the terrain upwind of the structure within the wind direction considered for calculating the roughness factor from the Equation 3.187.

$$C_r(z) = k_r \, In\left(z/z_o\right) : \; Z_{min} \leq Z \leq Z_{max}$$
$$C_r(z) = C_r(Z_{min}): \; Z \leq \; Z_{min} \qquad \textbf{(3.18)}$$

Where Z_0 is the roughness length m and K_r is the terrain factor, depending on the roughness length $Z_{0\ calculated}$ using Equation 3.19:

$$K_r = 0.19\left(Z_0/Z_{0.II}\right)^{0.07} \qquad \textbf{(3.19)}$$

Where $Z_{0,II}$ = 0,05 m, Z_{min} is the minimum height, Z_{max} is taking 200 m. Z_0, Z_{min} depends on terrain class. Recommended values are given in Table 3.2 based on five representative terrain classes.

Table 3.2: Terrain categories and terrain parameters, table 4.1 of EN 1991-4-1**.**

Terrain category	z0 m	zmin m
0 Sea or coastal area exposed to the open sea	0,003	1
I Lakes or flat and horizontal area with negligible vegetation and without obstacles	0.01	1
II Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0.05	2
III Area with a regular cover of vegetation or buildings or with isolated obstacles with separations of a maximum of 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0.3	5
IV Area in which at least 15 % of the surface covered with buildings and their average height exceeds 15 m	1.0	10

External Wind Pressure is the wind pressure acting on the external surfaces, should be obtained from Equation 3.20:

$$W_e = q_p(Z_e)C_{pe} \qquad \textbf{(3.20)}$$

where $q_p(z_e)$ is the peak velocity pressure, Z_e is the reference height for the external pressure, C_{pe} is the pressure coefficient for the external pressure. The external pressure coefficients C_{pe} for buildings and parts of buildings depend on the size of the loaded area A, which is the area of the structure, that produces the wind action in the section to calculate $C_{pe,\ one}$ value for the small elements with an area1m^2 and Cpe,10 for the large element with an area 10 m^2 and the intermediate situation 1< A< 10 logarithmic interpolations suggested

$$C_{pe} = C_{pe,1} - (C_{pe,1} - C_{pe,10}).\log_{10}(A) \qquad (3.21)$$

Internal wind pressure W_i can develop and will act simultaneously with external wind pressure. The formula for calculating W_i:

$$W_i = q_p(z)C_{pi} \qquad (3.22)$$

Where Wi: the internal wind pressure, $q_p(z)$peak pressure, C_{pi} the internal pressure coefficient. Following section 7.2.9 of EN 1991-1-4, the internal and external pressures should be considered simultaneous. The worst combination of external and internal pressures should consider each combination of potential openings and other leaking direction. Cpi's internal pressure coefficient depends on the scale and distribution of the openings in the building envelope.

3.1.4.3 ASCE 7-10

The prevailing wind loads information and requirements (Minimum load design for buildings and other structures) provided in Chapter 26. In contrast, in Chapter 30, details are provided on how the wind load on the components and cladding calculated. Components and claddings defined in Chapter C26 of ASCE 7-10: "Components receive wind loads directly or from cladding and transfer the load to the MWFRS".

MWFRS: A set of structural elements intended to provide support and stability to the overall structure, generally receiving wind load from more than one surface.

There are two formulas for determining the wind pressure in chapter 26 on closed building and for open building; for closed building and partially enclosed buildings Equation 3.23 should be followed:

$$P = q\,.GC_p - q_i(GC_{pi}) \qquad (3.23)$$

Where G is the gust effect factor, Cp is the external pressure coefficient, GC_{pi} is the internal pressure coefficient, q is the velocity pressure, given by the formula:

$$q = 0.00256\,k_z\,k_{zt}\,k_d\,v^2 \qquad (3.24)$$

Where $q=q_h$ is for leeward walls, sidewalls, and roofs, evaluated at roof mean height, $q=q_z$ for windward walls, evaluated at height, $q_i=q_h$ for negative internal pressure(-GCpi), q_z for positive internal pressure evaluation (+GCpi) of partially enclosed buildings but can take q_h as for conservative value. K_z is the velocity pressure coefficient, k_{zt} topographic factor, k_d wind directionality factor, and V is the basic wind

speed in mph. for solving the wind design pressure, the Directional Procedure in chapter 30 should use. The first thing to do for calculating the wind design pressure is the risk category classification, which depends on the building's use and occupancy. Which given in Table 3.3,

Table 3.3: Risk category of buildings and other structures (ASCE/SEI 7-10, 2013).

Use or Occupancy of Buildings and Structures	Risk category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life.	III

To determine the basic wind speed (V), the ASCE 7-10 provides a wind map where the corresponding basic wind speed. After this exposure category should be determining in ASCE, Section 26.7 shows the details produce. The structure's exposure from the upwind 45 ° sector shall be determined based on the wind direction chosen. The exposure to take should be exposed to the highest wind load from that direction. The definition of each exposure classification detailed in Sections 26.7.2 and 26.7.3 of ASCE 7-10.

Minimum design wind pressures: For cladding and component shall not be less than a net pressure of 16 1b/ft2 (0.77 kn/m2) acting in either direction normal to the surface.

Wind Directionality Factor K_d: the wind direction factor provides in Table 26.6-1 of ASCE 7-10, as shown below in Table 3.4.

Table 3.4: Wind directional factor based on structure type.

Structure type	Wind direction factor, K_d
Buildings	
Main Wind Force Resisting system	0.85
Components and cladding	0.85
Arched roofs	0.85
Chimneys, tanks and similar structure	
Square	0.90
Hexagonal	0.95
Round	0.95
Solid freestanding walls and solid freestanding, attached signs	0.85 0.85
Open signs and lattice framework	0.85
Trussed towers	
Triangular, square, rectangular	0.85
Other cross-section	0.95

Topographic Factor, Kzt The topographic factor explained in ASCE Section 26.8 if the building located in a flat area Kzt will be 1.0; otherwise, the factor can calculate from Figure 3.8.

Velocity pressure coefficient, K_z: Table 27.3-1 of ASCE 7-10 can use to measure the velocity pressure coefficient k_z. The height of the wind pressure and the category of exposure depend on this parameter. The values of α and zg based on the following formula and can found in Table 26.9.1 of ASCE 7-10:

$$\textbf{for 15ft} < \mathbf{z} < \mathbf{z_g}: \mathbf{K_z} = \mathbf{2.01}\left(\mathbf{z}/\mathbf{z_g}\right)^{\mathbf{2}/\boldsymbol{\alpha}} \qquad \textbf{(3.25)}$$

$$\boldsymbol{for\ z < 15\ ft}: \boldsymbol{K_z} = \mathbf{2.01}\left(\mathbf{15}/\boldsymbol{z_g}\right)^{\mathbf{2}/\boldsymbol{\alpha}}$$

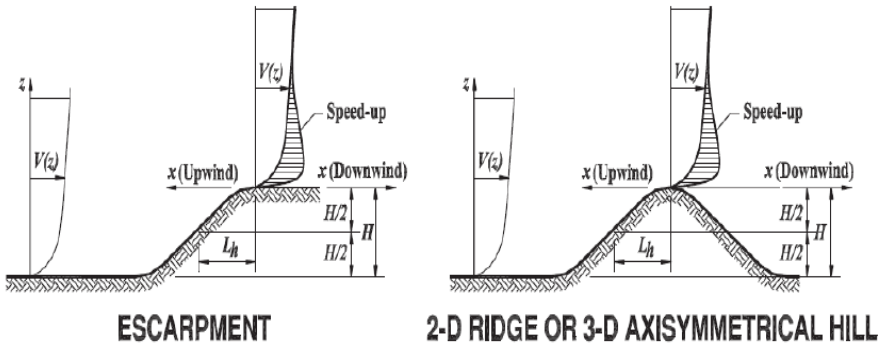


Figure 3.8: Parameters required for topographical factor calculation, (ASCE/SEI 7-10, 2013).

The velocity pressure coefficients at the mean roof height K_h, and each floor level, K_{zi}, are the values that would need to solve for the design wind pressures. As shown in Table 3.5.

Velocity pressure: From Equation 3.23, velocity pressure can calculate at each elevation being consider.

Gust effect factor: as determined by section 26.9. the gust effect factor for a typical rigid building can take as 0.85.

Table 3.5:The velocity pressure coefficient for different floor height.

Height above ground level, z		Exposure		
ft.	(m)	B	C	D
0-15	(0-4.6	0.70	0.85	1.03
20	(6.1)	0.70	0.90	1.08
25	(7.6)	0.70	0.94	1.12
30	(9.1)	0.70	0.98	1.16
40	(12.2)	0.76	1.04	1.22
50	(15.2)	0.81	1.09	1.27
60	(18)	0.85	1.13	1.31
70	(21.3)	0.89	1.17	1.34
80	(24.4)	0.93	1.21	1.38
90	(27.4)	0.96	1.24	1.40
100	(30.5)	0.99	1.26	1.43
120	(36.6)	1.04	1.31	1.48
140	(42.7)	1.09	1.36	1.52
160	(48.8)	1.13	1.39	1.55
180	(54.9)	1.17	1.43	1.58
200	(61.0)	1.20	1.46	1.61
250	(76.2)	1.28	1.53	1.68
300	(91.4)	1.35	1.59	1.73
350	(106.7)	1.41	1.64	1.78
400	(121.9)	1.47	1.69	1.82
450	(137.2)	1.52	1.73	1.86
500	(152.4)	1.56	1.77	1.89

Internal pressure coefficient (GCpi): The internal pressure coefficient shall base on Table 26.11-1 of ASCE7-10. Table 3.6 shows that the internal pressure coefficient depends on the building type as open or partially or enclosed building.

Table 3.6: Internal pressure coefficient ($GC_{pi)}$, (ASCE/SEI 7-10, 2013).

Enclosure classification	(GC_{pi})
Open buildings	0.00
Partially enclosed buildings	+0.55
	-0.55
Enclosed buildings	+0.18
	-0.18

External pressure coefficient (GCp): For determining the external pressure coefficient shall be using the details given in Figure 27.4-1 to Figure 27.4-3 of ASCE 7-10 for the enclosed and partly enclosed buildings. For a partly enclosed structure with a gable roof, see Diagram 27.4-1. Moreover, for walls, see figure 30.4-1 of ASCE 7-10.

Design wind pressure for cladding and components: In chapter 30 of ASCE 7-10, design pressure for components and cladding shall compute using Equation 3.26

$$\boldsymbol{P = q_h\left[(GC_p) - (GC_{pi})\right]} \qquad \textbf{(3.26)}$$

In this equation, q_h is the velocity pressure evaluated at mean roof height, (GC_p) is the

internal pressure coefficient and (GC_{pi}) is the external pressure coefficient.

3.1.4.4 Comparison of specifications

The development of standardized international codes and guidelines emphasizes the need to recognize better the essential gaps between the key international standards for wind loading.

- The average wind velocity (V_0) and wind-induced response times differ between the codes/standards and within the codes/standards themselves.
- The basic wind speed as defined in ASCE the gust speed in 3 seconds, while in Eurocode and IYBRY standards it is described as the average wind speed in 10 minutes. The reference height (h_{ref}) for which gust loading/effect factor is determined, and other parameters, is different between codes/standards.
- The wind velocity profile in EU and IYBRY described using the logarithmic law while in ASCE the power law has been used.
- The basic wind speed in the EU can simply be 1.0 while in IYBRY the value was 25 m/s whereas in ASCE there is a wind map for determining the basic wind speed.
- The term gust effect factor (G) in ASCE has an additional multiplicative factor of 0.925 added to change the prediction to the standard's previous versions. While in IYBRY know as a tail factor and the EU as a structural factor (*CsCd*).
- The peak factor determines the fluctuating response peak defined as the ratio between the maximum and standard deviation. ASCE uses a constant value between 3 and 4 while in EU use *gR*.
- In terms of wind design, external and internal pressures are of great concern. In this analysis, all codes/standards considered include external coefficients of pressure as the windward and leeward directions. Internal pressure in ASCE provides a table 26.1-1with values for a different kind of building, Eu provides an equation for calculating while IYBRY, external pressure for non -structural elements value should be one while the internal pressure coefficient can calculate by using two-equation, If the open surface area is at least twice the amount of the open surface area of other surfaces: Cpi =0.75CpeIf the surface

open areas are at least three times the total of the surface open areas on the other surfaces: Cpi = 0.90Cpe= 0.90Cpe

- Across-wind and torsional loads, ASCE, EU and IBYRY utilize a partial loading approach to account for a cross-wind and torsional loads, although ASCE provides an alternative method in the Commentary (C26.9)
- Acceleration responses, across-wind and torsional accelerations not included in every standard.
- There are several potential variations of the total peak response associated with wind, crosswind and torsional wind loads. In reality, some codes/standards provide a combination rule, e.g., ASCE7 (Figure 27.4-8).

3.1.5 Wind load experimental and analysis methods (Wind resistance test, CFD and wind tunnel)

There are many methods of an accurate analysis of the effect of wind loading, followed by companies producing curtain wall and facade consulting firms and others to identify and evaluate how wind affects the curtain wall system. The test was done on the curtain wall, or the wind tunnel experiments, CFD-simulation software. After the project design completed, which method will be most suitable depending on the project shape, the type of wall, the degree of complexity, project height.

3.1.5.1 Wind resistance tests

Wind resistance testing is essentially an examination of the efficiency of the fixed parts of the system that can open under the wind load that are negatively and positively affected. The test carried out according to BS EN 12179-2000 Curtain walling. Resistance to wind load. Test method. Sensors positioned at three points measure the amount of displacement on the vertical stand on the centre axis before the test begins. As shown in Figure 3.9, The displacement should not exceed 1/200 or according to the following equations:

- $d \leq L/200$, if $L \leq 3000$ mm;
- $d \leq 5$ mm $+ L/300$, if 3000 mm $< L < 7500$ mm;
- $d \leq L/250$, if $L \geq 7500$ mm.

From a distance between the structural supports of the facade. Nevertheless, at least 95% of the deflection formed in the façade system must be restored within an hour

after the load removed. Any deformation must be temporary. (BS EN 13116, 2004). In the beginning, the test applied in negative and positive directions. Three effects applied to the system in less than one second and no more than 3 seconds. This effect 50% of the design load. Through the test, effects applied 25%,50%,75% and 100% from the design load on the façade in 15-second intervals of more or less 5 seconds the same process is repeated consecutively in the negative direction. façade frontal displacement measured by sensors installed at the beginning of the test, in case of damage to the face is detected during the test or after it should be recorded. (BS EN 12179, 2000).

Figure 3.9: Placement of measurement sensors on stick curtain wall system. (Yalaz E. , 2018).

Within this test's scope, the system performance evaluated under a safety load directly affecting the interface system samples 150% of the design load for 15 seconds. At this stage, the front deflection measurement of the façade not taken, in case the glass broken during the test, the glass unit changed, and the cause of the refraction must be known, and the test continues.

3.1.5.2 CFD simulation program

Computational fluid dynamics (CFD) Can be a useful method for building façades to evaluate the mean wind pressure coefficients. It is a popular method for modelling wind flow in and around buildings. It enables 2D and 3D wind flow simulations to created and wind speed, temperature and pressure data to be displayed promptly. Simultaneously, the visualization process uses basic representations of colour patterns, streamlines, and surfaces. For a precise or extensive CFD simulation, it is essential to create several parameters and lots of time to measure process conditions which are not

possible at the start of the design process to generate a 3D visualization of realistic wind defect patterns and turbulences (Castro. R, 2015).

This method used for low and medium-rise buildings with uncomplicated shapes. The higher the building height, the results may be inaccurate, so the wind tunnel experiment is performed. This simulation used to determine the wind load on the building's different facades and determine which points in the façade are exposed to the maximum load and performed after the design completed. As shown in Figure 3.10, where a mid-rise building has stimulated, it shows the wind effect and distribution at the building façade.

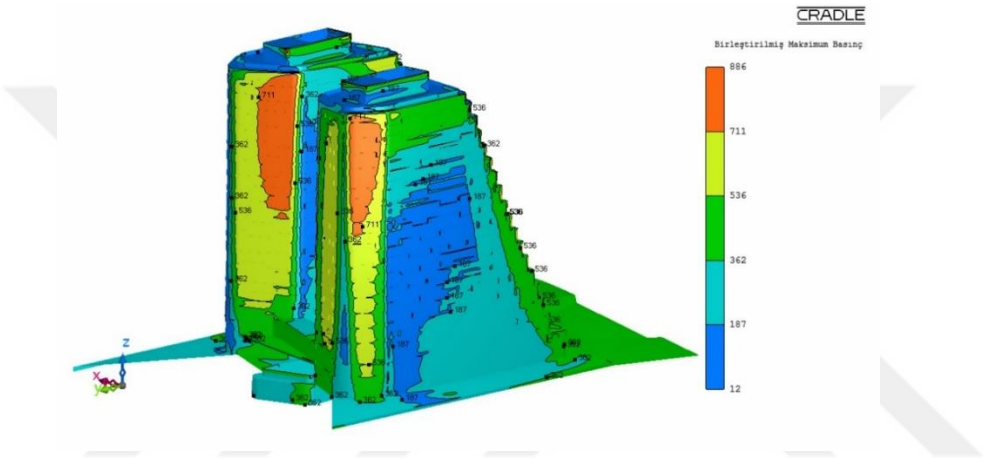


Figure 3.10: CFD for mid-rise building located in Bakirkoy, (FMT, 2020).

3.1.5.3 Wind tunnel

According to (ASCE/SEI49-12, 2012) defined the wind tunnel " Wind tunnel tests use to predict the wind loads and responses of a structure, structural components, and cladding to a variety of wind conditions".

The engineering and designer of buildings and facades must accurately follow the wind loads to achieve high design efficiency to avoid facades and glass's excessive design. If the buildings are of a standard shape, the wind loads can be estimated by following local and international standards and simulation programs. If the buildings are more complex and taller, the standards are not able to provide accurate calculations. The wind force for the design is expensive and comparing these loads with the seismic loads in general. Therefore, the standards determine which buildings the wind tunnel experiment should be conducted on, where the Turkish regulation for tall buildings in Istanbul (IYBRY) is determined when the height of the building exceeds 200 m and other types of buildings in addition to the presence of certain conditions when

conducting wind tunnel test. Therefore, the wind tunnel test provides more accurate results and an understanding of wind loads and contributes significantly to reducing the maximum pressures.

A wind tunnel test carried out before any structural analysis of the façade is carried out, and the size of the façade components is determined. Therefore, it is preferable to perform this test after testing the façade type. After receiving the test results (wind pressures imposed on the façade parts), the maximum wind pressures and suction on each type of façade are transferred to the technical design to inform the design of the façade and its parts.

This test carried out with cooperation between the designing, construction and consultant team. It performed after choosing the geometric shape of the building. A model made for the building, the consulting company determines the most appropriate model, and usually ranges between 1: 200 to 1:500 depending on the height of the building with the adjacent areas around the building, usually for tall buildings, it is 1200 feet around the building or 1600 feet is the most common. This is because the nearby winds have a great effect on the resulting wind load and greatly reduce wind loads (Denoon, 2018) . Wind (close to the wind in the project area) directed toward the model through a tunnel. The model should place in simulated conditions that are close to realism as shown in Figure 3.11. Therefore, all factors affecting wind pressure calculated. The wind speed is adjusted, taking into account the building's location, direction, time of year, hazards, terrain. The test must conduct to a reasonable standard. This can be done for several guides ranging from the descriptive ASCE Manual of Practice No. 67 on Wind Tunnel Study of Buildings and Structures to the more prescriptive ASCE/SEI Standard 49-12, Wind Tunnel testing of buildings and other structures. There are standards including how to perform this test and how to collect information and calculations from this test. First checking should be done to compare the loads, local pressures with code values also local negative (or suction) pressures, that are larger than code values are not unusual in limited areas of the building and the peak positive pressures in case that is larger than the codes it is a sign that must check for accuracy.

Figure 3.11: Wind tunnel experiments model, (Denoon, 2018).

After obtaining the results from the test, they compared them with the results of the standards. Usually, the values given in the standards are much less than the results of the wind test. According to the studies that were combined the CFD and the wind tunnel, it concluded that CFD could use with wind tunnel test to give accurate results of the effect of wind load on building facades.

3.1.6 Conclusion of the chapter

As noted in this chapter, the winds in general and the prevailing winds in Turkey, especially Istanbul, have been explained, as the prevailing winds in the European part are NNE, and the north-east and north-west winds are prevalent in the Asian part. Besides mentioning, usable standards and regulation in Turkey and internationally when calculating the wind loads on the building and curtain wall. The Turkish regulation based on buildings height does not exceed 200 m, the basic wind speed calculated to be 25 m/s in addition to the methods used to measure the wind speed using average wind speed and dynamic wind speed, maximum wind speed, the maximum wind pressure through an air density of 1,25 n/m2, the wind load using an impact factor, as mentioned in this regulation that the maximum displacement caused by the wind can be calculated by considering the wind a static load on the building. The European standard developed a method for calculating the internal and external pressure. After the load calculation stage during the design stage is resorting to a simulation program (CFD), in addition to the wind tunnel test that conducted, in which simulated conditions applied to realistic conditions, which leads to obtaining more accurate results than the results of standards The values given in the standards are

much lower than the wind test results. According to the studies that combined the CFD and the wind tunnel, it concluded that CFD could use the wind tunnel test to give accurate results of the effect of the wind load on the building facades., in the case of neglecting the conduct of wind purification experiment and simulation programs together Failures such as the glass being cracked and broken, as well as the frame is twisting due to wind loads.

4. THE EFFECT OF EARTHQUAKE ON CURTAIN WALL SYSTEM

4.1 General

The curtain wall is a recent subsystem within the existing construction structure of buildings. Therefore, there is no estimation of earthquake damage in the curtain wall system in literature, although the curtain wall system is non-structural, it must transfer the inertia to the main structure of the building in addition to its ability to absorb the drift that occurs between the floors of the building (Huanga, Chenb, W.Lub, & Mosalamc, 2017).

A seismic occurrence will cause a high rate of acceleration in the basement of the building. This acceleration can be converted into various reactions through the building structure and non-structural components such as the curtain wall system, where they have a particular response process that is calculated by understanding the specific time of the building; utilizing these parameters, it is possible to determine how the building structure reacts to excitations such as earthquakes and wind since the earthquake involves a vibration or acceleration in the basement, which is definitely horizontal but may also be vertical to a lesser degree. A particular kind of tension would have to be taken into consideration based on the perceived technology system. For applying dynamic acceleration, first of all, it should be necessary to carry out an exhaustive study and measurements of the behaviour of the building structure; secondly, a historical time reaction of the building itself to the seismic activity should be obtained and finally, the application of time function acceleration to the facade unit should be considered. However, even supposing all of these analyses and studies on the building behaviour were to carry out, therefore, based on the particular seismic context, the consequence of applying this acceleration to the façade system will again be that the stress caused by the different elements, like the stress value of the fastening system, is significantly lower than the value of the wind load at high height (Galli, 2011).

The curtain wall system's acceleration demand relates to the seismic design force in existing code specifications and related criteria. For this reason, in this chapter, the earthquake in turkey, the effect of earthquakes on the high and mid-rise building’s façade is going to be explained therefore the seismic load effects on curtain wall components, as well as the earthquakes standards and regulations that curtain wall

follows through the design stage beside a general review of seismic experimental and analysis methods.

4.2 Earthquake

It is the movement that occurs on earth surfaces as a result of the release of energy in the inner layer, which consists of seven tectonic plates, which shifts concerning each other, the shaking of tectonic plates produce high tension in the lithosphere (the uppermost layer of the earth) produce the seismic waves, The intensity of earthquakes varies from a weak movement that human cannot feel it too so strong that cause a tsunami which produces unimaginable damages to everything built and everyone living there.

- **Acceleration and inertial force**

The seismic body and surface waves create idle forces inside the building. Inertial forces are created inside an object when an external force tries to make it move if it is at rest or change its rate or direction of movement if it is moving. (C. Arnold, 2006)

According to (Webster, 2020)

"force opposite in direction to an accelerating force acting on a body and equal to the product of the accelerating force and the mass of the body."

That has led us to Newton's Second Law of Motion equation 4.1, inertial force equal to mass multiplied by the acceleration.

$$F = M\,a \qquad (4.1)$$

F: inertial force, M: the mass, a: acceleration, this law appears why light building in case of earthquake tends to perform better than heavy ones because of the forces on the building is less.

The acceleration, or the rate of velocity shift of the waves that set the building in motion, defines the percentage of the building mass or weight that must handle as a horizontal force (Arnold C., 2016).

- **The natural period of buildings**

Its tendency can waver back and forth at its standard time when earthquake motion starts a building vibrating. Time in seconds is the time taken to complete one cycle of a seismic wave (or fractions of a second). Frequency is the opposite – the number of

cycles in a second, measured in "Hertz." One Hertz per second is one loop. Although other construction design elements may also make a minor contribution to the reduction in mitigation measures, the natural duration is an essential factor for seismic design. The building would be "resonating," and its vibration rises or "amplifies" several times whether the ground motion and the building's standard duration coincide. Usually, amplified ground motion passes through the building structure; the standard amplification is 2 or 3. The acceleration at the upper floors will be 2 - 3 times while on roofs approximately 4 - 5 times at the ground floor. As mentioned previously, each building has its fundamental period; the period depends on the building's height. This means the taller get, the more period takes.

As a result, horizontal forces create seismic waves, influence the building and cause internal forces that deform the primary structure. Therefore, since tall buildings are subject to several types of vibrations shown in Figure 4.1, the subsequent vibrations' patterns are more important than the natural period. In contrast, in medium and low-rise buildings, the most significant is the natural period.

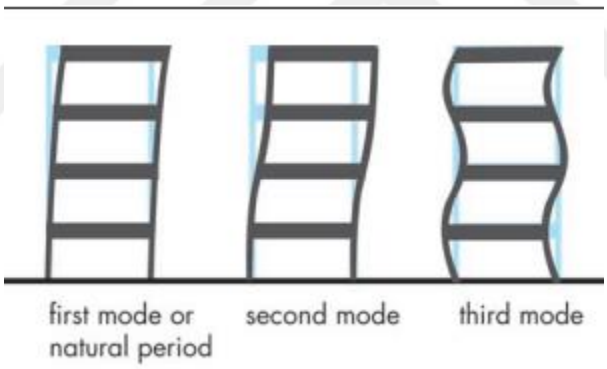


Figure 4.1: Vibration modes of the natural period, (Arnold C., 2016).

4.2.1 Earthquakes in Turkey

Turkey is a highly seismic region, with a complicated tectonic regime. Turkey ranks tenth of the world's 50 seismically active countries in terms of its seismicity, using Gumbel's intense theory for this reason. The factor used is the magnitude of the earthquake, which within 85 years is most probable to be the strongest. This magnitude is 7.7 for Turkey, which is the same as for Colombia, Honduras, Panama and Iran (Bayrak, Ozturk, G.Ch.Koravos, G.A.Leventakis, & Tsapanos, 2008). The Aegean Arc, West Anatolian Graben Complex (WAGC), North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone (EAFZ), North East Anatolian Fault Zone (NEAFZ), Bitlis

Thrust Zone (BTZ) and the Caucasus are the most critical tectonic areas in Turkey Figure 4.2. The motion between Africa and Eurasia does not take up one plate's boundary but driven by the Aegean and Turkish plates' flow. According to its unusual seismic activity, exceptionally well-defined surface expression and significance for the eastern Mediterranean region's tectonics, NAFZ(North Anatolian Fault Zone) is one of the best known strike-slip faults in the world (Bayrak, Ozturk, G.Ch.Koravos, G.A.Leventakis, & Tsapanos, 2008).

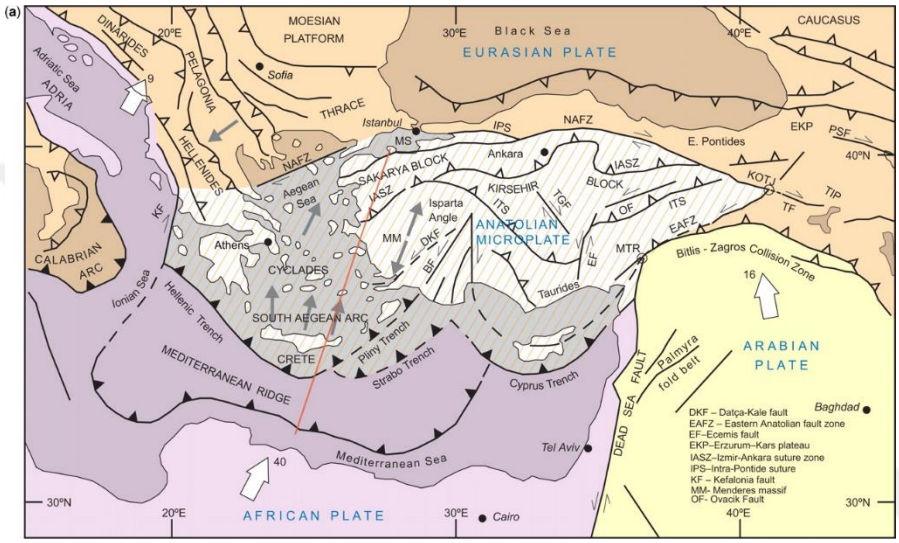


Figure 4.2: The tectonic map of Turkey, (Dilek, Y., Altunkaynak, Ş., 2009).

Cities that lie along two major faults lines are at significant risk of earthquakes, as it noticed that some areas of Istanbul located on the north and the east Anatolian fault which are the boundaries of the Anatolian plate Figure 4.3, This is what led to the large earthquakes in Istanbul in 1998, which called Izmit earthquakes (also known as the Kocaeli or Golcuk earthquake) happen at 17 of August in northwestern turkey, measured 7.4 on Richter scale lasted for 45 seconds, killing around 17,000 people and left more than 250,000 people homeless. The nearby city of İzmit was severely damaged (Maraza, 2004). Following this event, Turkey released various earthquake regulation and standards which will be addressed later, especially about mid and tall buildings and the curtain wall system.

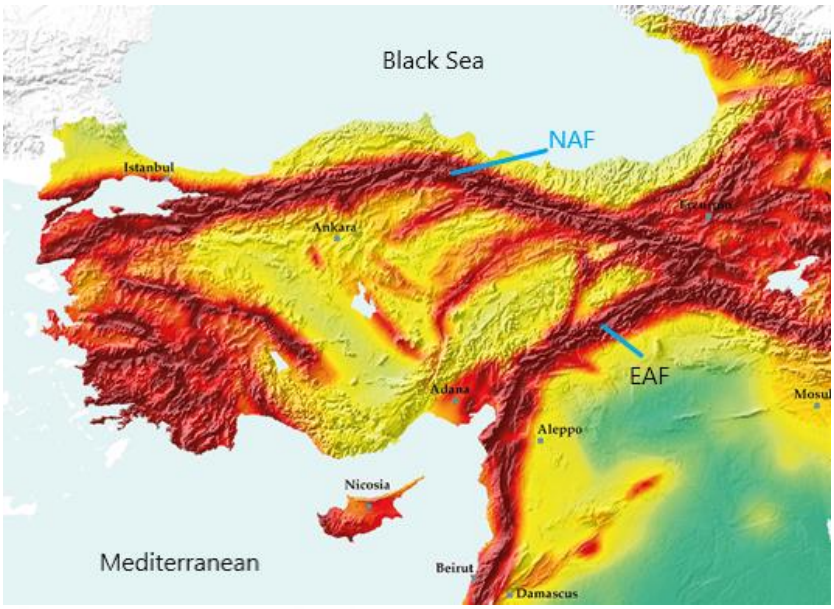


Figure 4.3: Earthquake zoning map of Turkey, (Rademacher, H.; Hellweg, P, 2020).

4.2.2 Seismic performance of buildings envelope

Even if a building is structurally appropriate, seismic activity should closely consider non-structural elements connected to the primary structure such as curtain walls and other buildings envelope. The earthquake will cause instability in the structural system to very high displacement and stress values. Non-structural elements must accompany such displacements without breaking apart or being a detriment to human life. Furthermore, good design should continue service after the earthquake. (Buluk, N.B, 2015).

According to the buildings code required from the curtain wall system accommodate the relative displacement caused by earthquakes, such as shear drift beside the water, air vapour-proof through its service life.

When looked at building envelopes' performance during previous earthquakes, noticed that the heavy cladding system's performance is good. In contrast, the possibility of glass breaking, falling and separating the heavy concrete facade panels represented a threat to human lives. In contrast, the metal or glass curtain wall's performance was reasonable compared to other systems' performance because of glass's inherent strength, the flexibility of metal frames, the flexibility of glass retaining materials, and the glass panels' small size.

4.2.2.1 Seismic performance of curtain wall components

Generally, different designs of curtain wall systems respond differently to building story drifts caused by earthquakes, with the widespread use of different glass curtain wall systems, there is an urgent need to understand these systems' best behaviour in light of earthquake impacts and how it designed for safety and serviceability concerns.

As already mentioned, the curtain wall is a non-structural framework connected to the building structure by a brackets system that stabilizes it, enabling the necessary adjustment both of the construction and the building's natural motions. An earthquake's impact produces a high degree of acceleration in the building structure even if this earthquake is usual or not unusual. As a result of this acceleration, which occurs on the ground floor of the building and moves horizontally to the upper floors, the building tends to stay in place due to internal forces. This reaction creates a deformation in the structure as well as in the curtain wall system. Therefore, the curtain wall must have the ability to transmit the internal forces to the buildings structure, flexibility sufficient to cope with the story drift of the main building. To understand the structural system, relevant international regulatory specifications and the Turkish regulation (Specification for buildings to be built in seismic areas), verify structural elements, specified after the assessment and measurement of base acceleration, under the action of static forces.

Concerning non-structural systems, the worst load condition must be assessed for each component separately, such as displacement, acceleration or forces, depending on their classification, anchorage system, and location within the building. For calculating the earthquake effects on curtain wall system initially, the building structure's behaviour calculated and analysed, then the temporal history of the building itself obtained; finally, the facade applied to the time function acceleration. As are these analysing and estimates for the buildings' behaviour, the earthquakes' stress on the parts of the curtain wall is entirely different. For example, the stress stabilization mechanism is considerably less than the stress value exerted on wind loads at high altitude levels. The glass frame structures and the wind load stabilization system also meet the seismic load, particularly in tall buildings.

4.2.2.1 Frame

The curtain wall design essential criteria are the relative displacement that occurs between two adjacent stories, this displacement leads to deformation in the building structure thus permeant deformation in the curtain wall frame system, this occurs as a result for the system to cope with this displacement beside breaking and falling of glass in case that the system cannot make tolerant with the earthquakes movements.

Figure 4.4 show the mullions can deform in such a stick-built construction method to handle construction narrative drifts. The glass frame in this state assumes the general shape of a parallelogram and contributes to the translation and the glass pan's rotation to change the deformed glass structure. Therefore, glass to frame Clearance plays a crucial role in the potential harm of glass. Figure 4.5 shows the required clearance between glass and frame, the clearance between the frame and the glass, the larger it is, the less likely it to break the glass and the greater the drift that can be absorbed. In the unitized system, the vertical stack joints sometimes horizontal stack joints between the units, allowing in-plane sliding with each other, which leads to accommodate the building story drifts without excessive deformation of the frame. The result is that it is unlikely that the units will rotate or deform to accommodate the story drifts and thus the contact between the glass and the frame decreases. The likelihood of glass damage reduced.

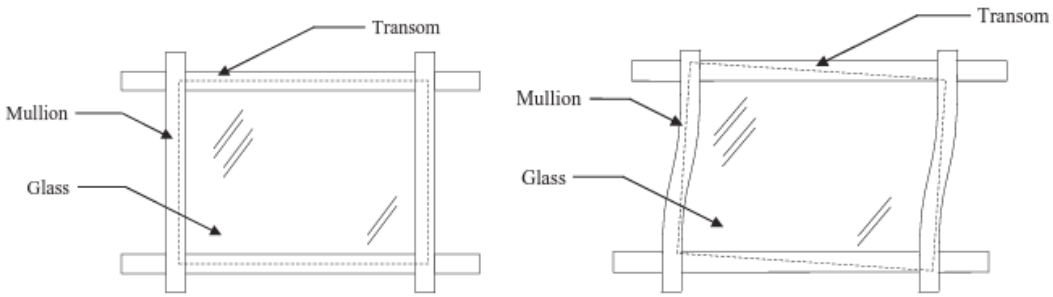


Figure 4.4: The deformation of mullions in stick curtain wall System, (ASCE, 2013).

4.2.2.2 Glass

Glass is one of the most influencing elements on human life during earthquakes due to its fragile nature, as the glass can only move to tolerant with the displacement that occurs between floors during earthquakes. However, it cannot change its shape or deform such as aluminium or curtain wall frame; in this case, the glass may crack or fall out the glass sheet from the frame.

It has observed through previous earthquakes that glass can destroy during medium to powerful earthquakes. It has also observed that glass damage in buildings with a flexible structure is three to four times more than buildings with a rigid structure, and the damage has occurred to the structural components.

According to ASTM 2004, the glass treated with heat increased the glass strength. Whereas the heated strengthen glass two times stronger than the annealed glass. At the same time, the fully tempered glass is four times stronger.

The use of laminated glass is one of the best options in seismic regions due to a polyvinyl butyral layer, which prevents the glass fragments from falling if the glass shattered or any glass sheets broken.

The use of insulating glass, which is relatively heavy glass, as making one of its layers of laminated glass will increase its strength, besides using sealants and spacer between the two layers of glass, leads to making up a stiffer and rougher with enormous in-plane strength. The larger the glass, the more force and out of plane deflection exposed, the thicker the glass, the greater in-plane resistance.

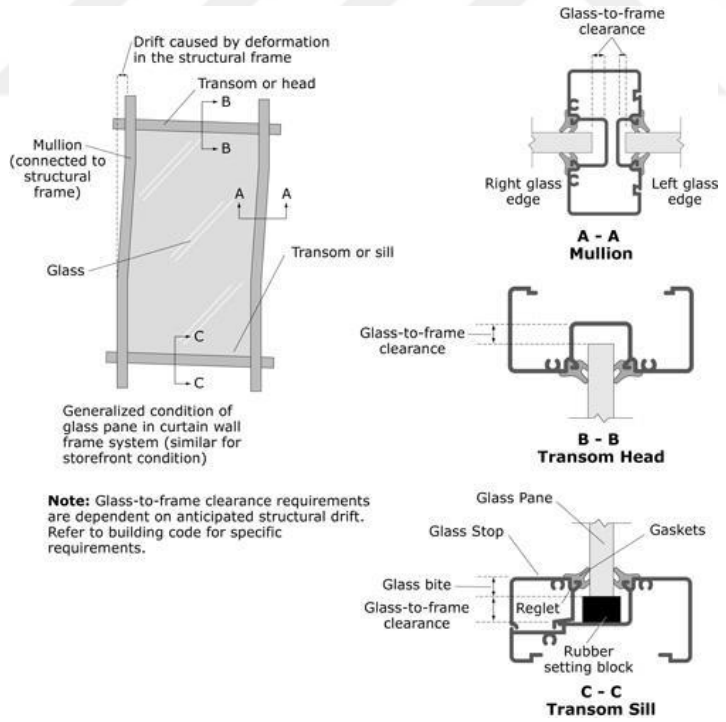


Figure 4.5: Required clearance between the frame and glass,(URL-5).

- **SSG (structural silicone glazing)**

The use of SSG instead of dry glazing in the curtain wall system reduces the possibility of glass damage because the edge of the glass not fixed inside the pockets of the glass frame and thus will not directly touch the glass edge or the corners during the racking movement that occurs due to earthquakes, as well as if the gap between the edges of the glass adjacent filled with a watertight seal is wide enough Figure 4.5, so the possibility of glass damage significantly reduced.

The use of SSG in the stick system will impose the silicone to shear forces and deformation resulting from the racking movement, which lead to that the glassing part will absorb these deformations, while in the unitized curtain wall system, the combination between the SSG and the unitized frame will lead to a high seismic efficiency curtain wall system.

- **Brackets and anchors**

The main factor for designing the anchor system in seismic regions is providing necessary rotation without any permanent damage for the curtain wall profiles in case of story drifts. Therefore, it is preferable to use channel anchors for the safety of application beside the channel anchors able to transfer the shear and tension forces in all directions, as this type of anchors directly connecting to the building structure and fixed during the pouring of the concrete slab that's enable it to transfer the loads immediate from anchors to the concrete and not like the previous type mentioned in chapter two. The use of channel anchors preferring for high-rise buildings and buildings in seismic and winds loads areas. In Europe, Anchor Channels governing by the European Assessment Paper (EAD) 330008-02-06014 and are constructed according to requirements EN 1992-4, in the United States of America by the International Code Council's (ICC-ES') Evaluation Service (AC232 - Acceptation Requirements for anchor channels in Concrete 5).

4.2.3 Specification used in the design of buildings curtain wall system

The consideration and comparison of several local rules and their approach to the seismic design of non-structural elements, such as a curtain wall system, is an essential initial step for evaluating and understanding this subject. These standards' main aim is: any building's behaviour provides a curtain wall system or non-structural façade

through earthquake and displacement to meet these displacement and earthquake loads without any collapse or life safety hazard.

Therefore, the criteria contained and articulated by those regulations must be met by a designer who has to deal with a curtain wall, or more widely a non-structural component. Moreover, the importance of considering and comparing approaches to the same problem from a remarkably different perspective, such as those from countries and regions of the world with profoundly different traditions, building technologies and understand exactly how is an additional value. Along with the US standards, the European standard will review with Turkish standards and regulation.

4.2.3.1 TBDY 2018 -Turkish building earthquake regulation

The new Turkish building earthquakes regulation published on the 18 of March 2018, there are two methods of analysis which are linear and nonlinear method. Concerning the curtain wall, the seismic force that affects the curtain wall system's elements not indicated. However, the earthquake force to be applied to all non-structural architectural elements defined in section 6 of the regulation under headings (DESIGN PRINCIPLES OF NON-STRUCTURAL BUILDING ELEMENTS UNDER EARTHQUAKE). A seismic force is required to apply to the components of the curtain wall system. In addition to this seismic force, movement control restrictions were imposed during the earthquake to control the movement or displacement of the curtain wall framework's elements. Furthermore, this regulation contains a provision that provides requirements for the testing of earthquake systems. Displacement restrictions added, in addition to this seismic force to control movement or displacement of the curtain wall system elements during the earthquake, which used for measuring the connections of these elements to the building system elements. Therefore, it evaluated the limits of the regulation's description due to the curtain wall structure classification as non-structural components. The recommended earthquake load F_{ie} acting horizontally on the centre of gravity of the element or equipment and acting on the element or equipment given following Equation (4.2).

$$\boldsymbol{F_{ie} = \frac{m_{ie} A_{ie} B_e}{R_e}} \qquad \textbf{(4.2)}$$

Where m_e is the working mass of the element or equipment, A_{ie}, DD-2 is the greatest total acceleration affecting the area where the element or equipment on the i'th floor is connected to the floor under earthquake ground motion, B_e the magnification

coefficient applied to the element or equipment, R_e is the behaviour coefficient defined for the element or equipment, I show the building importance coefficient showed in Table 4.2. B_e and R_e coefficients are given in Table 4.1 for non-structural architectural elements

The seismic loads calculated at half the equivalent seismic load for no vertical elements as calculated in the above formula.

Table 4.1: Element amplification and behaviour coefficients, (TBDY, 2018).

Architectural Element	B_e	R_e
Non-structural masonry interior walls and partitions	1.0	1.5
Other non-structural interior walls and partitions	1.0	2.5
Console elements that do not have lateral support or whose lateral support is below the center of gravity (parapets, cantilever inner walls, chimneys, etc.)	2.5	2.5
Console elements with lateral support above the center of gravity (parapets, cantilever outer walls, chimneys, etc.).	1.0	2.5
External walls and their connections	1.0	2.5
Facade cladding panels	1.0	1.5
Roof floors independent of the building system	2.5	3.5
Suspended ceilings	1.0	2.5
Storage cabinets and laboratory equipment	1.0	2.5
Access floors	1.0	1.5
Billboards	2.5	2.5
Other rigid architectural elements	1.0	2.5
Other flexible architectural elements	2.5	2.5

Besides, in the regulation, three different analysis methods are defined in Equation (4.1), using the highest A value obtained from those analyses, for the maximum accelerating value (A_{ie}) affecting the element or equipment. These approaches:

– The total acceleration value measured for building element or equipment on any floor in the related direction can, in response to linear earthquake analysis to carry out on the building carrier system in the design stage 1-A specified in the regulation as A_{ie} will calculate with A_{ie} Equation 4.3

$$A_{ie} = \left(R/I\right)\left(\frac{2\pi}{T_p}\right)^2 u_i \qquad \textbf{(4.3)}$$

Here, Tp is the dominant natural vibration period of the building in the direction of the earthquake considered. R is the carrier system behaviour coefficient defined in Table 4.1. u_i is the horizontal displacement

Based on the nonlinear earthquake analysis to be performed over the time period defined in the regulation in the design stage for Standard Class 1 – B B buildings or the design stage 3 for special class buildings, the time in the relevant direction is stated at the position of the item or equipment on any floor The value that is the greatest average of measured total acceleration of seven groups of an earthquake in the induction zone, can be defined as A_{ie}.

- In cases where rigidity and masses of the element or its connections must be considered, the spectrum acceleration corresponding to the element Te's natural vibration duration which, using the time field acceleration function as described in the earlier procedure, calculated as a corresponding order of the flooring spectrum. The magnification factor for an element in the above table can take like 1. if measured using this formula. The time of natural vibration shall be determined using the formula in the following Equation (4.4).

$$T_e = 2\pi\sqrt{\frac{m_e}{k_e}} \qquad \textbf{(4.4)}$$

The earthquake load calculated in Equation (4.2) shall not take less than Equation's value (4.5).

$$F_{ie} \geq 0.3 m_e I S_{DS}\, g \qquad \textbf{(4.5)}$$

Equivalent earthquake load shall be applied separately in two vertical earthquake directions, together with the dead load of the element or equipment, service loads and the vertical equivalent earthquake load (± 0.3me ISDSg).

- Displacement limitations

In addition to the earthquake force associated with the non-structural architectural function, a restriction relating to relative displacement exists in Section 6.3 of the regulation. This relative value (e) cannot exceed the value in Equation (4.6) below.

$$\delta_e^{(x)} \leq \left(h_x - h_y\right)\frac{\delta_{i\,max}^{(x)}}{h_i} \qquad \textbf{(4.6)}$$

Here, hx, hy and respectively indicate the height of the upper and lower connection points of the non-structural element from the respective floor.

($\frac{\delta_{i\,max}^{(x)}}{h_i}$) The statement shows the maximum allowable relative floor drift rate, depending on which of the methods suggested in the used regulation. For example, in the design with nonlinear analysis for the life safety performance target, each vertical bearing element's relative story drift ratio at each floor in each direction will not exceed 0.025.

To demonstrate that external elements suspended in floor-height glass or thin-wall panel structures can move without a break or collapse, static and dynamic tests are available in the regulatory title "Non-Structural Facade Elements and Connections."

Table 4.2: Building use classes and building importance factors (TBDY, 2018).

Building Usage Class	Purpose of Use of the Building	Building Importance Factor (I)
BKS= 1	Buildings that need to be used after an earthquake, buildings where people are long and concentrated, buildings where valuable goods are stored and buildings containing dangerous substances: a) Buildings that should be used immediately after an earthquake (Hospitals, dispensaries, health centers, fire brigade buildings and facilities, PTT and other communication facilities, transportation stations and terminals, energy production and distribution facilities, province, district governorship and municipal administration buildings, first aid and disaster planning stations) b) Schools, other educational buildings and facilities, dormitories and dormitories, military barracks, prisons, etc. c) Museums d) Toxic, explosive, flammable, etc. buildings where substances with properties are located or stored	1.5
BKS= 2	Buildings where people are short-term and concentrated Shopping centers, sports facilities, cinema, theater, concert halls, places of worship, etc.	1.2
BKS= 3	Other buildings Other buildings (residences, workplaces, hotels, building-type industrial buildings, etc.) that are not included in the definitions given for BKS = 1 and BKS = 2.	1.0

Static testing will conduct in the AAMA standard 501.4-00 and dynamic tests following the conditions defined in the AAMA 501.6-01 standard as mentioned below.

According to the regulation, the seismic analysis shall replicate with the structural system's increased rigidity in cases where a requirement described above is not satisfied at any building floor. However, even if the condition is complied with, operability under successful story drifts of non-structural fragile elements (façade elements) is checked by calculation.

Chapter 13 of this regulation is devoted to covering the particular rules applied to High-Rise buildings under the effects of earthquakes. According to this regulation,

buildings whose height exceeds 70 meters classified as high-rise. Based on the height of the building, the buildings referred to in (a), (b), (c) below in Table 4.3 are specified as high-rise buildings and listed as BYS (Building Height cases) = 1.

(a) Buildings with height HN> 70 m for DTS (Earthquake Design Classes) = 1, 1a, 2, 2a;

(b) buildings with height HN> 91m for DTS = 3, 3a;

(c) Buildings with height HN> 105 m for DTS = 4, 4a.

According to this regulation, the high builder's design must carry out in three stages, and each stage has special laws to calculate the impact of earthquakes. Design Phase I: Preliminary Design Sizing Under DD-2 Earthquake Ground Motion, Design Phase II: Evaluation - Improvement for DD-4 or DD-3 Earthquake Ground Motion for Continuous Use or Limited Damage Performance Target. Design Phase III: Evaluation - Improvement - Final Design for Prevention of Migration under DD-1 Earthquake Ground Motion or Controlled Damage Performance Target.

Table 4.3: Building height classes defined according to building height classes and earthquake design classes.

Building height class	Height ranges defined according to building height classes and earthquake design classes		
	DTS= 1,1a, 2, 2a	DTS= 3,3a	DTS= 4, 4a
BYS= 1	$H_N > 70$	$H_N > 91$	$H_N > 105$
BYS= 2	$56 < H_N \leq 70$	$70 < H_N \leq 91$	$91 < H_N \leq 105$
BYS= 3	$42 < H_N \leq 56$	$56 < H_N \leq 70$	$56 < H_N \leq 91$
BYS= 4	$28 < H_N \leq 42$	$42 < H_N \leq 56$	
BYS = 5	$17.5 < H_N \leq 28$	$28 < H_N \leq 42$	
BYS= 6	$10.5 < H_N \leq 17.5$	$17.5 < H_N \leq 28$	
BYS= 7	$7 < H_N \leq 10.5$	$10.5 < H_N \leq 17.5$	
BYS= 8	$H_N \leq 7$	$H_N \leq 10.5$	

4.2.3.2 Eurocode 8

Euro code is the standard used in Europe beside most of the Turkish companies used these standards.

In compliance with BS EN 1998-1:2004, non-structural elements shall check alongside their connections and attachments or anchorages. The local transmission of non-structural elements shall take into account by fixating the system and its effect on its structural behaviour.

The seismic force acting on the curtain wall defined as the horizontal force F_a applied to non-structural elements due to seismic activity. Chapter 4.3.5 suggest the seismic force, as shown in Equation 4.7:

$$F_a = (S_a * W_a * Y_a)/q_a \qquad (4.7)$$

where: F_a the horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavourable direction; W_a the weight of the element S_a the seismic coefficient applicable to non-structural elements; Y_a is the importance factor of the element, q_a is the behaviour factor of the element;

The seismic coefficient S_a may calculate using the following expression:

$$S_a = \alpha . S(3(1+z/H) / (1+T_a/T_1)_2\text{-}0,5)] \qquad (4.8)$$

Where,α is the ratio of the design ground acceleration on type A ground, ag, to the acceleration of gravity g; S is the soil factor, a is the fundamental vibration period of the non-structural element; T1 is the fundamental vibration period of the building in the relevant direction; z is the height of the non-structural element above the level of application of the seismic action (foundation or top of a rigid basement), and H is the building height measured from the foundation or the top of a rigid basement.

The value of the seismic coefficient Sa may not take less than αS.

For the following non-structural elements, Ya's importance factor shall not be less than 1,5: anchorage elements of machinery and equipment required for life safety systems. Tanks and vessels containing toxic or explosive substances considered to be hazardous to the general public's safety. In all other cases, the importance factor Y_a of non-structural elements may assume to be Y_a= 1,0. Upper limit values of the behaviour factor qa for non-structural elements are given in the Table 4.4.

Table 4.4: Values of behaviour factor q_a for non-structural elements.

Type of non-structural element	qa
Cantilevering parapets or ornamentations	1.0
Signs and billboards	
Chimneys, masts and tanks on legs acting as unbraced cantilevers along with more than one half of their total height	
Exterior and interior walls	2.0
Partitions and facades	
Chimneys, masts and tanks on legs acting as unbraced cantilevers along less than one half of their total height, or braced or guyed to the structure at or above their centre of mass	
Anchorage elements for permeant cabinets and book stacks supported by the floor	
Anchorage elements for false (suspended) ceilings and light fixtures	

In Eurocode 8, the damage limitation in terms of story drift has given in Equation 4.9:

$$\mathbf{d_r.v \leq \alpha.h} \qquad \mathbf{(4.9)}$$

v: is the reduction factor which takes into account the lower return period of the seismic activity associated with the damage limitation requirement (The recommended values of v are 0,4 for importance classes III and IV and v = 0,5 for importance classes I and II according to EN 1998-1). h: the story height, α: is a factor that considers the type of the non-structural elements and their arrangements into the structure.

Euro Code 8 provides an example of the evaluation of story drift. Related information and the control table are as follows:

Building importance class: II, Corresponding reduction factor: 0.5(EN 1998-1/4.4.3.2(2), α: 0.005 (for a building having non-structural elements of brittle materials attached to the structure).

The equation = $d_r.v/h \leq \alpha$

The most severe story drift not exceeded in any storey. Additionally, the European code specifies that the damage limitations of non-structural elements shall be satisfied: $d_r.\ V \leq 0.01h$ for steel buildings Table 4.5

Table 4.5: Control of storey drifts in both direction.

Level	d_r (m) in CM		h	v	V* d_r /h		α		
	Dir. X	Dir. Y	(m)		Dir. X	Dir. Y	(a)	(b)	(c)
Roof	0.019	0.016	3	0.5	0.0031	0.0027			
5	0.021	0.017	3	0.5	0.0034	0.0028			
4	0.022	0.017	3	0.5	0.0036	0.0028	0.005	0.0075	0.01
3	0.022	0.016	3	0.5	0.0036	0.0026			
2	0.020	0.013	3	0.5	0.0033	0.0022			
1	0.020	0.010	4	0.5	0.0025	0.0013			

4.2.3.3 FEMA

One of FEMA's priorities and the NEHRP Department of Homeland Security is to promote the design and development activities that deal with the risk of earthquakes and reduce the risk of damage and injury.

The rules set out criteria for the design and construction of an earthquake-resistant structure. The herein specified level of earthquake motion can lead to structural and non-structural damage. For the calculation and verification of architectural

components, Chapter 6 provides for a large section. In particular, the subject of non-structural elements such as exterior wall panels also discussed.

- Seismic load to be used in the design

The Specification indicates in Equation (4.10) the force of seismically horizontal design suggested in Section 6.2.6.

$$\mathbf{Fp=((0,4.a_p.SDS.\ W_p).\ (1+2z/h)\ .l_p/R_p\ )} \qquad \mathbf{(4.10)}$$

Where: F_p: The seismic design force applied to a particular non-structural component, a_p: The component amplification factor selected, S_{DS}: The short period spectral acceleration parameter, W_p: Operating weight of a non-structural component: The height above the base of the point of attachment of the component, but z shall not take less than 0 and the value of z/h need not exceed 1.0, h: The average roof height of structure above the base, l_p: The component importance factor, R_p: The component response modification factor Table 4.6.

In the regulation, for exceptional cases, it is suggested to reduce the seismic force given above by the ratio given below. According to this; If the natural vibration period of the non-structural architectural element is Tp> Tflx (1 + .25 * z / h) * (SD1 / SDS), it can reduce by multiplying the F_p value by the value (tflx / T_p). In addition to this exceptional situation, another limitation has imposed for its value. F_p this limitation given in Equation (4.11).

$$\mathbf{(0.3*SDS*I_p*F_p)<}\ F_p\ \mathbf{<(1.6*SDS*I_p*W_p)} \qquad \mathbf{(4.11)}$$

The force F_p shall independently apply in each of two orthogonal horizontal directions in combination with service loads. Besides, the non-structural component shall design for a concurrent vertical force ± 0.2SDS Wp.

Wind loads at the non-structural exterior walls and the building code exceed Fp. Those loads shall regulate the strength design, but the specifications and restrictions stated in this section are applicable.

According to the regulation, in combination with other loads (dead loads, live loads, wind loads, etc.) the horizontal seizure force in Equation (4.9) should be applied in both orthogonal directions to the centre of gravity relevant element. Furthermore, in addition to the horizontal seismic force, the regulation proposed a vertical seismic force, which stated that a vertical force should consider at the same time in its design.

Table 4.6: Coefficients for architectural components, ((FEMA450, 2003).

Architectural Component or Element	a_p	R_p
Interior non-structural walls and partitions		
Plain masonry walls	1.0	1.5
All other walls and partitions	1.0	1.5
Cantilever Elements, unbraced or braced (to structural frame) below their centres of mass		
Parapets and cantilevered interior non-structural walls	2.5	2.5
Chimneys and stacks where laterally supported by structures	2.5	2.5
Cantilever elements braced (to structural frame) above their centres of mass		
Parapets		
Chimneys and stacks	1.0	2.5
Exterior non-structural walls	1.0	2.5
	1.0	2.5
Exterior non-structural wall elements and connections		
Wall element	1.0	
Body of wall-panel connections	1.0	
Fasteners of the connecting system	1.25	
Veneer		
High deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
Penthouses (except were framed by an extension of the building frame)	2.5	3.5
Ceilings	1.0	2.5
All		
Access floors		
Special access floors	1.0	2.5
All other	1.0	1.5
Appendages and ornamentation	2.5	2.5
Signs and billboards	2.5	2.5
Other rigid components		
High deformability elements and attachments	1.0	3.5
Limited deformability elements and attachments	1.0	2.5
Low deformability elements and attachments	1.0	1.5
Other flexible components		
High deformability elements and attachments	2.5	3.5
Limited deformability elements and attachments	2.5	2.5
Low deformability elements and attachments	2.5	1.5

- Limitation of Displacements

In Section 6.2.7 of the FEMA standard, certain limitations have been added for the relative displacement of these elements and connections in addition to the seismic sensitivity required for elements and connections of the curtain wall systems. The relative displacement formula given in this Specification for the non-structural architectural element is the same as in IYBDY 2007. Therefore, in Equation (4.12), the relative displacement formula is given.

$$\mathbf{D_p = \delta_{xA} - \delta_{yA}} \qquad \mathbf{(4.12)}$$

where: Dp: Relative seismic displacement that the component must design, δXA: Deflection at level x (first one of two adjacent stories) of structure A,δYA: Deflection at level y (the second one of two adjacent stories) of structure A, Dp not required to take greater than:

$$\mathbf{D_p = (X\text{-}Y)\ \Delta_{\alpha A}/h_{sx}} \qquad \mathbf{(4.13)}$$

where: X: Height above the base of the upper support attachment (at level x), Y: Height above the base of lower support attachment (at level y), ΔαA: Allowable story drift for structure A,hsx: Story height used in the definition of the allowable drift in the regulation

According to the regulation, the curtain wall connection and elements should allow relative movement between floors, and this movement should not be less than DP or 13mm. Besides, holes should design to allow these movements and the bolts should slip in these holes during movement. Fasteners must have a specific ductile capacity.

Glass in glazed curtain walls, glazed storefronts and glazed partitions shall meet the relative displacement requirement as follows:

Δ fallout ≥ 1.25 I D p or 0.5 in. (13mm), whichever is greater.

Dp, the relative seismic displacement that the glazed curtain walls, glazed storefronts or glazed partitions components must design.

Δfallout is the drift causing glass fallout from the curtain wall, shall be determined following AAMA 501.6, or by engineering analysis.

Exception: Glass with sufficient clearances from its frame such that physical contact between the glass and frame will not occur at the design drift as follows:

D clear ≥ 1.25 Dp

$$D_{clear} = 2C1\ (1 + h_p C2 / b_p C1) \qquad (4.14)$$

where:C1: The clearance (gap) between vertical glass edges and the frame

C2: The clearance (gap) between horizontal glass edges and the frame, hp: The rectangular glass height, bp: The width of the rectangular glass.

- Allowable story drift: According to FEMA 450 provision Figure 4.7, the design story drift, Δ should not exceed the allowable story drift, Δ a, as obtained from Table 4.7 for any story. For structures with significant torsional deflections, the maximum drift shall include torsional effects. All portions of the structure shall design and act as an integral unit in resisting seismic forces unless separated structurally by a distance sufficient to avoid damaging contact under total deflection.

4.2.3.4 Comparison of specifications

Consideration of the national standards and codes described could be useful to present a comparison between these standards. Each global and national standard that previously presented provides and requires an exact calculation method through multiple and different factors. After that, the horizontal seismic force applied to the centre of mass of the non-structural element can obtain.

- The American regulations specifically considered the drift between stories.
- FEMA requires that junctions and plate joints allow for relative movement between stories of no less than the Dp story drift and is the only one to indicate and specify additional references for conducting experimental performance model tests. One such reference called the fall, as the offset can cause the glass panel to fall off the curtain wall. Instead, it is evident that Euro code eight does not recognize this parameter and does not require precise checking on the inter-storey drift value (Table 4.7).
- The significant difference is that FEMA regulations, TBDY take into account the vertical and horizontal seismic force applied to non-structural elements and those specific equations provide.
- A short section for non-structural elements included in the Turkish standard. The Equation of the horizontal seismic force to use for the mass centre of the element requires a general restriction of historical drift which essentially

increases the height of the story by 1/50 (if these limitations not satisfied after the seismic analysis, the stiffness of the structural system shall be modified, according to the regulation) Besides the differences displacement has been taken into account for façade system beside In these specifications, correlations and limitations for the relative floor translation are proposed.

Table 4.7: Allowable story drift, Δ a, (FEMA450, 2003).

Structure	Seismic Use Group		
	I	II	III
Structures, other than those using masonry seismic-force-resisting systems, four stories or less with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts	$0.025h_{sxc}$	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures [d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear walls structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
Special masonry moment frames	$0.013h_{sx}$	$0.013h_{sx}$	$0.010h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a] h_{sx} is the story height below Level x.
[b] for Seismic design categories D, E and F, the allowable story drift shall comply with the requirements as they are defined in Sec.4.5.3 of FEMA 450-1.
[c] There shall be no drift limit for single-story structures with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.
[d] Structures in which the basic structural system consists of masonry shear walls designed as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible

- Only TBDY and EUROCODE Specifications have taken into account the curtain walls system element's natural vibration period when suggesting seismic force to affect the facade system.
- Finally, it can be concluding from these standards that two criteria applied to the seismic examination of curtain wall systems: horizontal and vertical forces generated by seismic action (these loads generated, in many cases, less than the wind load, specifically for high rise buildings) and inter-story drift, which is more critical for the analysis of the behaviour of the curtain wall system.

4.2.4 Analysis methods - seismic experimental and analysis methods (mockup and finite elements)

After designing the curtain wall specifically for each project, it is necessary to ensure the appropriate design by knowing the behaviour of this element made of different components with different mechanical behaviour under the influence of earthquakes. Therefore, the façade systems must design to prevent damage caused by earthquake movement and not separate any facade components during and after the earthquake. There are two critical issues to develop a good curtain wall system against earthquake-induced motions. The first is that the systems have the highest motion tolerance possible, bearing in mind that severe loads can be affected. The other is to design the details that will provide the correct movement mechanism. For this reason, it is imperative to determine the most appropriate parameters and tolerances for movement through discussion with engineers from the design stage (Charleson, 2007). Issues such as type of façade, type of glass used, and glass delivery method effectively understand systems' behaviour under the influence of earthquakes (ASCE, Curtain Wall Systems A Primer, 2013). In facade systems, corner points are the parts that are most sensitive to horizontal movements. In these sections, encounter situations such as severe damage or falling glass.

To verify the appropriate design, advanced tools such as finite element modelling analysis conducted for some large projects, may be used to evaluate the design parameters, or through experimental methods (mock-up) and these tests conducted according to AAMA 501.4, and AAMA 501.6 are used for evaluating the behaviour of a storefront system subjected to the inter-storey drift and for determining the seismic drift causing glass fallout from a wall system.

4.2.4.1 Mock Up test method

According to AAMA 501.4 and AAMA501.6, these tests should evaluate the curtain wall and storefront system's performance. A brief explanation will give of how these tests work.

- **AAMA 501.4:2018**

The test protocol was designed to assess the behaviour of curtain walls and storefront wall system under specified horizontal displacements in the wall's plane. In this test method, dynamic, torsional or vertical movement excluded. The test specimen subjected to (which the width of the specimen must not be less than two units and its

height is equal to the height of the building floor or the height of the unit and it must include a complete horizontal joint that accommodates the vertical expansion in addition to that the facade specimen must contain the same material, type of glass, details, construction techniques and anchors with real dimensions) to a horizontal displacement in both directions with a capacity of 0.01 times greater than the adjacent story elevations for three-cycle Figure 4.6 and each cycle defined as a complete displacement. Then visual problems such as disengagement, frames deformation, seal failure, permanent deformation are recorded. If the glass broke, the cause must investigate, and in of the cause is not known, the glass shall replace and the experiment repeated. This seismic testing phase preceded by a complete first series of system serviceability tests for air and water leakage control. After its completion, followed by another complete additional series of air and water leakage tests. (Galli, 2011). There is no time limit between cycles and no information on calculating the different amplitudes of motion performed in the earthquake.

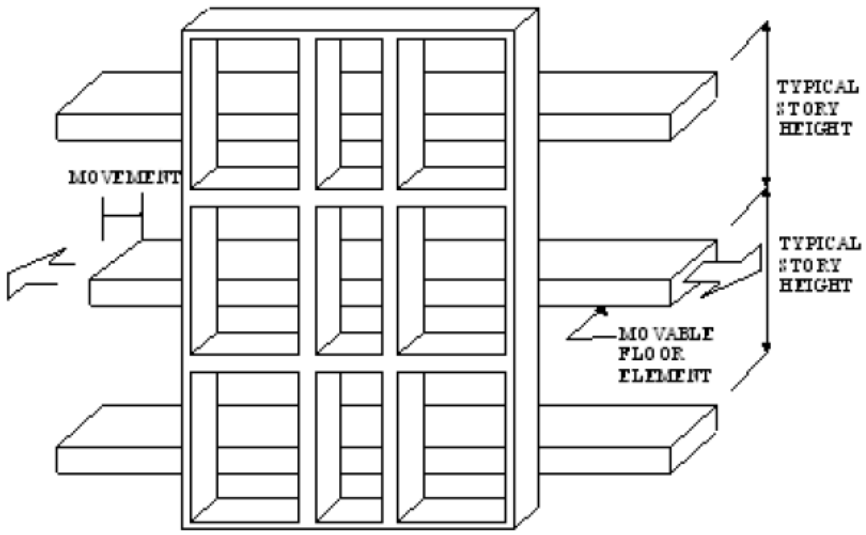


Figure 4.6: Configuration of a typical test sample, (AAMA501.4, 2018).

- **AAMA501.6: 2018**

The objective of this test is to describe" a dynamic racking crescendo test for determining Δ fallout", defined as the "in-plane dynamic drift causing glass fallout from a glazed curtain wall panel, a glazed storefront panel or a glazed partition panel". This test performed if the clearance between glass and frame is insufficient, as was previously mentioned, the design subjected to this test. Figure 4.7 showed a dynamic

racking test facility for curtain wall mockup. The sample must contain a critical glass panel with a high potential for fallout. The connection used to attach the glass into the test sample should be identical to the support conditions installed on the building. The test consists of a concatenated series of "ramp up" intervals and "constant amplitude" intervals. Ramp up, and constant amplitude intervals shall consist of four sinusoidal cycles each. At each step, the displacement is increased by the constant increment of 0.25 in. (6.4 mm) Each step is shown consists of eight cycles, four during the ramp-up and four during the constant amplitude intervals as shown in Figure 4.8.

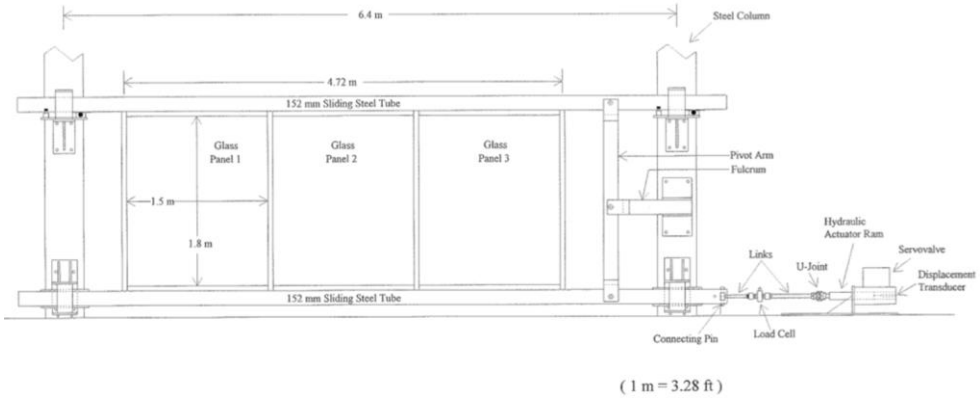


Figure 4.7: Dynamic racking test facility for curtain wall mockup, (AAMA501.6, 2018).

The protocol states that the crescendo test should continue until one of the following conditions is reached: (1) A piece of glass drops at least 1.0 in 2 (645 mm2) into the area; (2) The drift index (defined as the drift above the glass panel divided by the height of the glass panel) over the height of the glass panel is at least 0.1 (i.e. 10%); Or (3) reach a maximum racking displacement of 6.0 in. (152.4 mm). This determines when the test should stop. Under condition (1), the drift at which the glass falls referred to as $\Delta_{\text{fallout.}}$

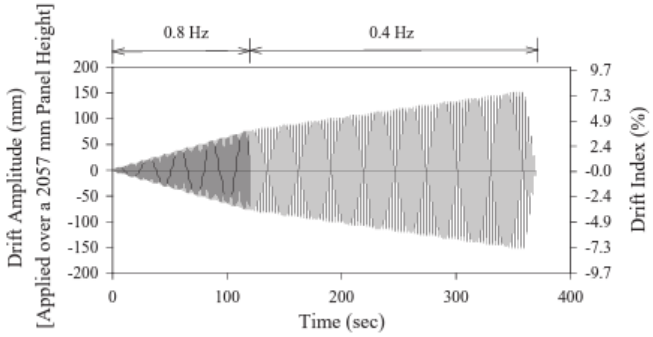


Figure 4.8: Drift time-history for a dynamic racking crescent test, (AAMA501.6, 2018).

4.2.4.2 Finite element analysis method

The finite element model (the network and other data required to describe the problem) is a computational model used to simulate a physical system's behaviour. In designing such a situation, the finite element analyst needs to consider the Geometric representation of a physical structure (network), the material analysis used (constituent equations), loads and constraints imposed externally (boundary requirements), analysis sufficient to solve the problem (select a solution) (Galli, 2011).

The finite element method must implement by deconstructing the studied real physical element into several more superficial elements. This method also used to predict the deflection behaviour of the glass panels of the curtain wall system. In this program, surface stress is drawn to understand nonlinear behaviour when glass and frame subjected to significant distortion. The finite element method is the best and most versatile solution in terms of flexibility. The program takes place in several stages

The first stage, which is modelling the unit as shown in Figure 4.9, can be implemented faster and simpler by implementing an appropriate and accurate description of the relationships between the different elements and correct representation of the registration plans and higher accuracy of real phenomena. The last step is to apply the loads to the unit appropriately this characteristic behaviour, during the modelling phase, it is necessary to leave the suitable degree of freedom: the unit's rotation in its plane.

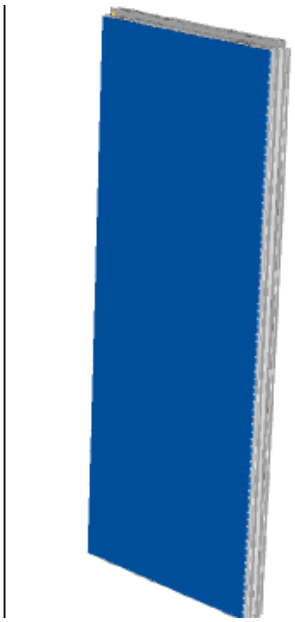


Figure 4.9: Modelling of curtain wall unite in FEM,(Galli, 2011).

It is possible to analyse the seismic behaviour of the glass panels and the frame by applying a horizontal displacement on the interface in two directions, the positive direction which leads to the occurrence of rotational behaviour and distortion of the unit and the negative direction, which leads to the occurrence of the complete deformation in the unit and is considered the most dangerous stage of the analysis. Figure 4.10, show the results of applying horizontal force on the frame and the glass of the curtain wall system.

Straus7 software provides different ways to analyse and derive numerical results from the model under analysis while evaluating findings after resolution. Firstly, Straus7 provides many details, such as displaces and force, on any particular element of the pattern, a point, a column, a plate or even a brick element, and both parts, this element and The element's pressure value may differently specify. The Straus7 software provides different methods for measuring this value for each model's element, for example, the von Mises method, critical stresses, or secondary stress methods. For each element of the model. A particular method of calculation is chosen based on the material properties of the product considered. Therefore, the von Mises method used to measure the stress on the unit structure elements, and in reverse, due to the stern and fragile nature of the glass material, the simple tension line stress level "11" is sought for the glass plate (Galli, 2011).

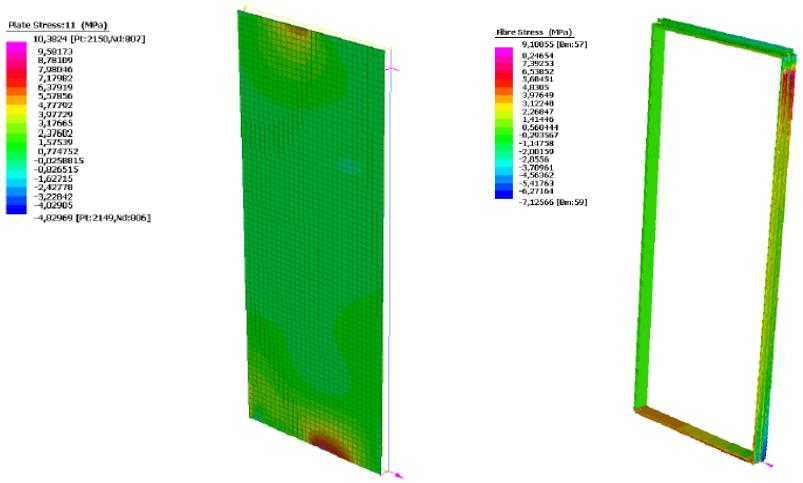


Figure 4.10: The result of applying horizontal displacement in the negative direction on the curtain wall frame,(Galli, 2011).

5. ANALYSIS OF THE CASE STUDIES FROM ISTANBUL

In this chapter, analysis of the four cases from medium to high-rise buildings and located in different regions of Istanbul. These cases were analysed through detailed sections of the curtain wall and information gathered on how curtain wall companies and facade consulting firm's companies dealt with the curtain wall during the design phase. The case studies' names are not mentioned concerning privacy concerns.

5.1 Methodology

The information Table 5.1 related to the four projects was obtained with the help of the curtain wall companies and the facade consultancy companies, through conducting various interviews for an hour during August and September of 2020 with people specializing in the curtain wall from the design and static department of Cuhadaroglu Company, as well as with the facade specialist and the partner The founder of FDF façade Consulting and the General Manager of FMT facade Consulting, the interviews included questions about the curtain wall in general and how wind and earthquake loads are calculated for projects, and then questions related to the four buildings that will be reviewed in this chapter such as curtain wall type used and the reason behind choosing this type of curtain wall, material type and the glass used in this projects, the reason for choosing this type, and what methods are used to calculate wind and earthquake loads, and simulation programs that were used to measure the impact of wind and earthquake loads, and other questions that are found in Appendix A.

5.2 Case Building 1

The building located in Istanbul, district of Bakırköy, the project has a golden LEED certificate, comprising 17 floors. It consists of two buildings, established between 2015 and 2019. It is a multi-purpose building (residential, commercial and partly a hotel) and has a height of 65 m and classified as medium buildings. In this project, the structural systems used are reinforced concrete. Figure 5.1 show the projects facades.

Table 5.1: Case building general information.

Case buildings	Construction years	Building location	Floor number	Buildings structural system	Building type	Curtain wall system type	Glass types	The number of layers of glass
Case Building 1	2015-2019	Bakirköy	17	Reinforced Concrete	Mix use residential, commercial and partly a hotel	Stick Curtain Wall System	Solar low E	Double glass unit (6 mm T + 16 AS + 55.2 cl. Lam) 28mm
Case Building 2	2017	5.Levent	20	Reinforced Concrete	Office building	Stick Curtain Wall System	Insulated glass	Double glass unit (8 / 16 / 6+0,76+6 mm Tempered Glass) 37mm
Case Building 3	2015	Maltepe	30	Reinforced Concrete	Mix used building	Unitized curtain wall system	Insulated glass	Double glass unit (6+1,52+6 / 16 / 8 mm Tempered Glass) 37 mm
Case building 4	2018	Maslak	49	Reinforced Concrete	Residence and hotel	Unitized curtain wall system	Solar low E	Double glass unit (6 mm T + 16 AS + 55.2 cl. Laminated) 28 mm

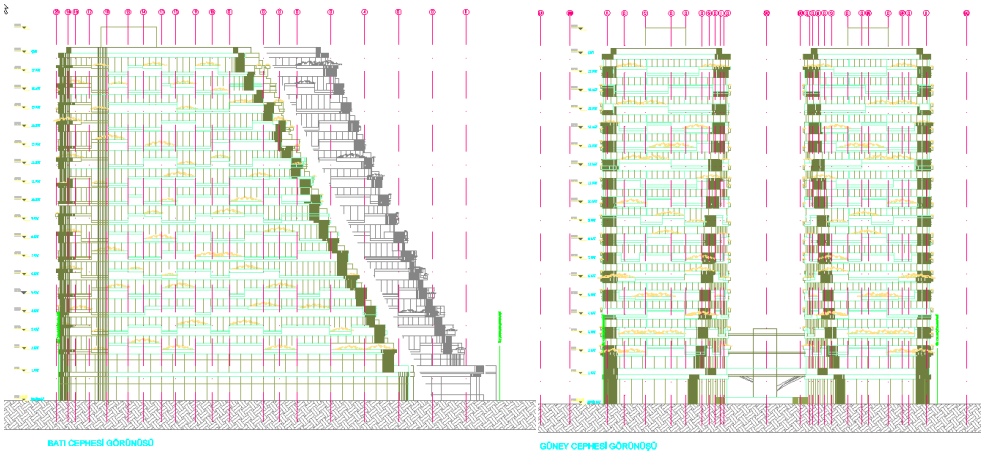


Figure 5.1: Case Building 1 - West and south elevation of the project.

5.2.1 Case building 1 - general configuration and characteristics of the curtain wall system

Initially, the architects planned the project to be aluminium windows. However, the facade consulting company proposed to use the curtain wall system on three elevations according to the wind and earthquakes calculation requirements, the curtain wall system proposed for use in the project was the stick system and the unit system. However, due to building shape and the cost reductions, a stick curtain wall system has implemented the curtain wall's details shown in Figure 5.2.

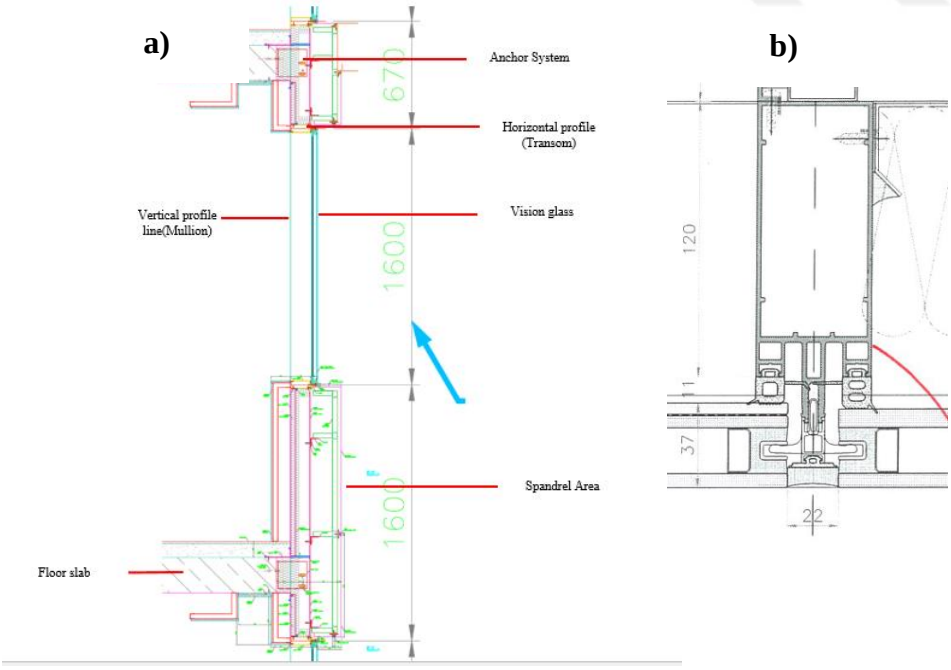


Figure 5.2: Case Building 1 – a**)** Vertical section in stick curtain wall system, vision and spandrel Areas, b) Frame detail on the plan view.

The main floor height was 320 cm, the vision area of the curtain wall system:160 cm while the spandrel area: 67 cm as shown in Figure 5.2- a, as for the frame of the curtain wall, according to the calculation and the final structure report, the frame measurements were determined:120mm*50mm as shown in Figure 5.2 -b.

The thermal performance and u-value requirements for the curtain wall system, the profile system max 2,6, glazing units it is 1,4 and overall 1,8 (all W/m^{2}K), and it is a warm-edge spacer and for the spandrel area 0,35 W/m^{2}K, they are fulfilled in this project.

The spandrel area has been well designed, as the stone wool used as a sound and thermal insulating material and is a substance that prevents the spread of fire. Figure 5.3 showed the accurate details of the spandrels area.

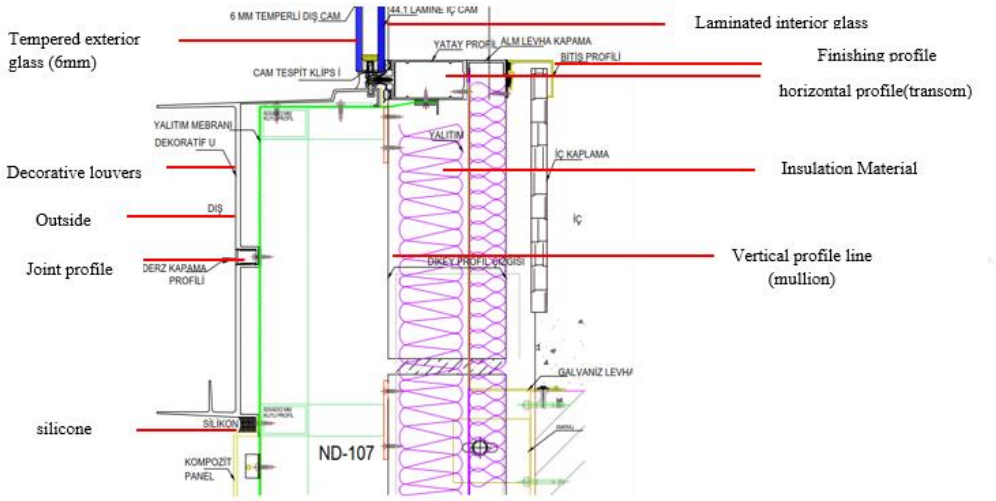


Figure 5.3: Case building 1- Spandrel areas and decorative louvres details.

The glass used in this project is solar Low-E glass, composed of two layers (double glass), including a vacuum of argon gas. 6mm of tempered glass,16m argon gas (the gap), the inner layer of glass contains laminated insulating glass. This glass resisted the summer temperature and other reasons that the company found necessary, including glass statics. The glass-coated 50/33, means daylight transmission is 50% which means that only 50 % from sunlight allowed to enter the inner spaces. While 33 means that %33 of the solar energy can pass through the glass. For LEED, thermal insulation, human safety, solar protection SHGC (Solar Heat Gain Coefficient) values, architectural Intent, acoustics, availability and cost. The thermal transmittance (u-value) of the curtain wall system 1.8 W/m^{2}K.The maximum deflection of the glass

caused by wind loads calculated according to a TS EN 13830 standard. The method used to attach the glass to the frame is Structural silicone glazing, as shown in Figure 5.4. In SSG curtain walls, silicone sealants serve as a weather seal and a structural bonding feature, removing the need for external retainers and covers.

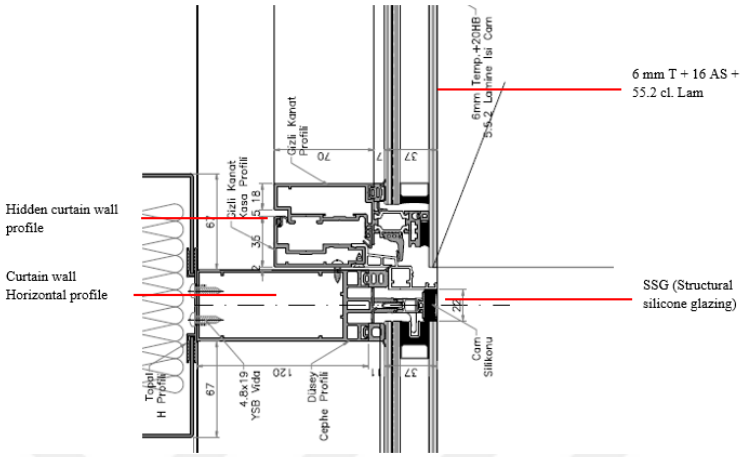


Figure 5.4: Case building 1- Curtain wall frame and glass bonded through SSG system on section view.

5.2.1 Anchors and brackets used in the system

The type of anchor used to attach the curtain wall components to the floor slab for the whole project facades is the fixed anchor system of steel and bolts fixed the brackets, the anchor was fastening on the edge of the floor slab as shown in Figure 5.5.

The dimensions, shape of anchors and brackets used for this project provided in Figure 5.6. It was calculated following Eurocode 3 as shown in Figure 5.7, for all the anchors and brackets to hold and transfer the loads from the curtain wall to the building structure.

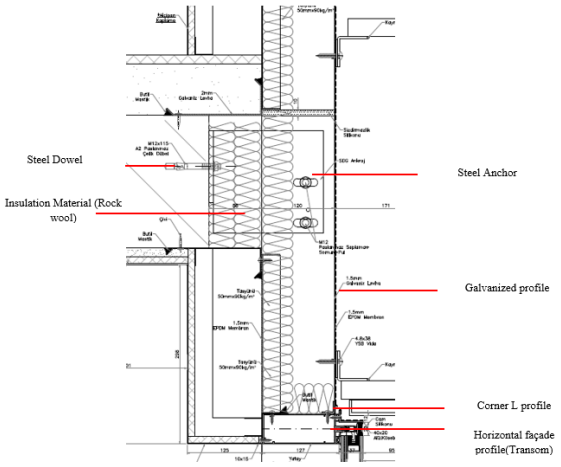


Figure 5.5: Case building 1 - Anchor system connected to the floor slab on section view.

Since the maximum permissible weight or load to carry by the brackets and the anchor is, according to Eurocode 3, 3600kg/cm^3, whereas the obliterate weight of 3273 kg/cm^2 is less than the maximum permissible weight or load, the anchor is capable of carrying the weight and loads acting onto with high performance.

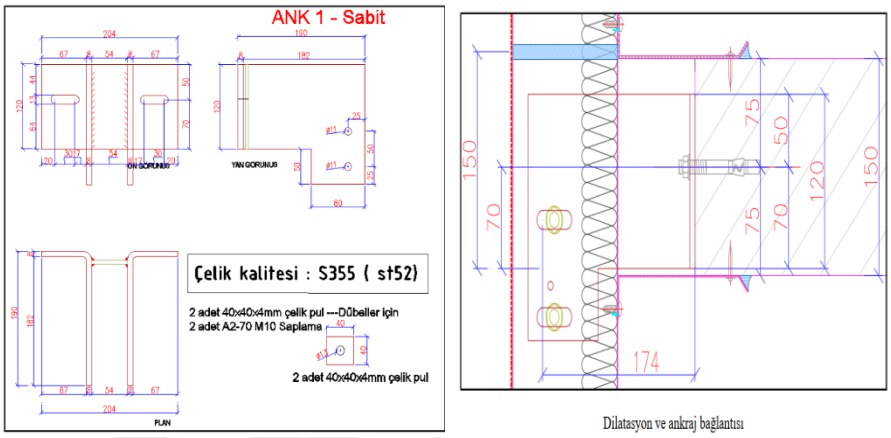
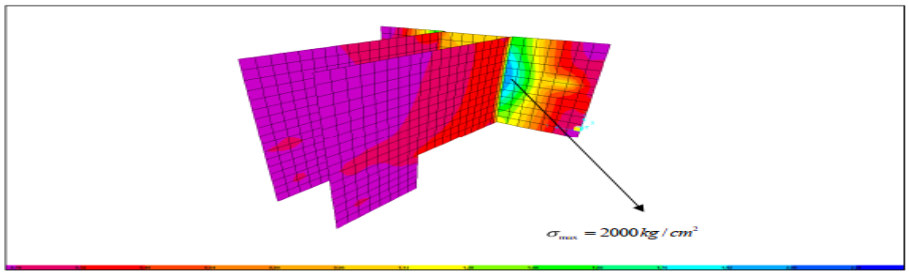


Figure 5.6: Case building 1 - Dimensions and shape of the anchors and brackets.

As for wind loads and how it calculated in this project, the process was carried out according to the European standard (Eurocode 1) and a CFD simulation program was utilized. The leading wind force above ground level at 10 meters is 25m/s. In contrast, the wind load considered during the design prosses was 150kg/m^2, one of the basic requirements when calculating wind loads is related to deflection;



Ankrajın gerilme diyagramı (Kombinasyon DLLWND1)

Gerilme Analizi

$\sigma_{max} = 2000\,kg/cm^2$ (*Von misses gerilmesi*)
$\sigma_{akma} = 3600kg/cm^2$ (*St52 çelik için*)
$\gamma_{M1} = 1.1$ (*Eurocode – 3*)
$\sigma_{izinverilen} = \frac{\sigma_{akma}}{\gamma_{M1}}$
$\sigma_{izinverilen} = \frac{3600}{1.1} = 3273kg/cm^2$ (*St52 çelik için*)
$\sigma_{izinverilen} > \sigma_{max} \rightarrow$ *OK*

Figure 5.7: Case building 1 - Calculation of the loads on anchors and brackets.

The maximum allowable deflection following Eurocode 1(d≤5mm + 3200/300 =15.6 cm) is 15.6 cm while the expected deflection for the curtain wall system 14.9 cm which is less than the maximum allowable deflection of 15.6 cm as shown in Figure 5.9, This makes the performance of the curtain wall adaptable to higher wind loads and is not subject to any damage.

In addition to deflection, an important requirement when calculating wind loads is stress. For this project, the stress calculated, as shown in Figure 5.9. As the maximum stress to withstand by the system is 985 kg/ cm^2.

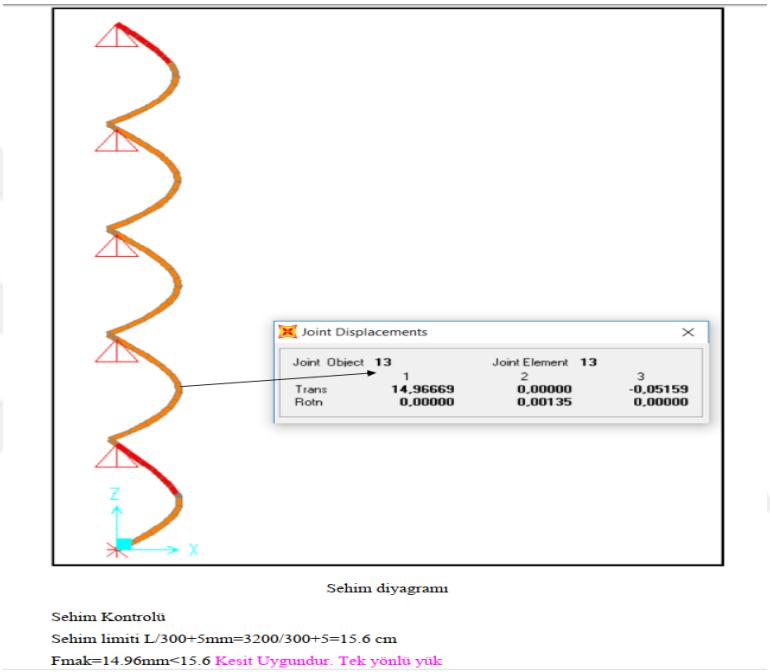


Figure 5.8: Case building 1 - Curtain wall deflection calculation.

While calculating the wind loads of the curtain wall components, which are usually greater than the earthquake loads, the building will be able to withstand the earthquake loads greatly.

Nevertheless, wind load calculations are still required in every project, as seismic load calculations were made for this project in accordance to "Deprem Bölgelerinde Yapılacak Binalar Hakkında Yönetmelik" -2007 because the building was constructed before 2018 as shown in Figure 5.10. The expected earthquake forces are 63 km/m^2, while the calculated load combinations Wrz is 132kg/m^2, more significant than the expected earthquake forces. Therefore, the system can handle seismic loads efficiently.

2.3 Deprem Yükleri

Kaplama taşıyıcı sistem tasarımı, meydana gelebilecek bir depremde kaplama elemanlarına etki edecek olan deprem yüklerinin güvenle taşıyıcı sistem elemanları tarafındankarşılanmasını esas almıştır. Mimari unsurlarda meydana gelecek deprem yükleri Deprem Yönetmeliği Denklem 2.21'de verilmiştir. Cephedüzlemine dik Doğrultuda rüzgar yükleri deprem yüklerine gore baskın çıkmaktadır. Cephe düzlemine paralel doğrultudaki hareketler bu rapor kapsamı dışındadır.

$$f_e = 0.5 A_0 I w_e (1 + 2\frac{H_i}{H_n})$$ (DBYBHY 2007, denklem 2.21)

En olumsuz kat en üstte meydana gelmektedir.

F_e=0.5*0.4*1.5*(70kg/m²)*3= 63 kg/m²

Wrz=21-100m arası 132 kg/m²>Fe

Rüzgar yükleri sistemde daha etkindir.

Figure 5.9: Case building 1 - Seismic load calculation.

Tek yönlü yük

DLLPTS Mak mom (35.458 kg.cm/1.5=23.639kg.cm)

$\sigma_{akma} = 2000 kg/cm^2$ (EN AW 6063 T66)

$\sigma_{izin\ verilen} = \frac{\sigma_{akma}}{\gamma_{M1}}$

$\gamma_{M1} = 1.1$ (Eurocode – 9)

$\sigma_{izin\ verilen} = \frac{2000}{1.1} = 1818 kg/cm^2$

$\sigma_{max} = 1.5 \times \frac{M_{max}}{W}$

$M_{max} = 35.458 kg.cm$

$W_x = 24 cm^3$

$\sigma_{max} = \frac{35.458}{24} = 1477 kg/cm^2$

$\sigma_{izinverilen} > \sigma_{max}$ → OK

Table 6.1 - Partial safety factors for ultimate limit states

resistance of cross-sections whatever the class is:	γ_{M1}
resistance of members to instability assessed by member checks:	
resistance of cross-sections in tension to fracture:	γ_{M2}
resistance of joints:	See Section 8

NOTE 1 Partial factors γ_{M1} may be defined in the National Annex. The following numerical values are recommended:

$\gamma_{M0} = 1.10$

$\gamma_{M2} = 1.25$

NOTE 2 For other recommended numerical values see EN 1999 Part 1-2 to Part 1-5. For structures not covered by EN 1999 Part 1-2 to Part 1-5 the National Annex may give information.

Akma Dayanımı 200 Mpa, hesap Dayanımı =0.6*2000=1200kg/cm2

Mmak= **23.639kg.cm Tek yönlü yük**

Maks. Gerilme =Mmak/Wx

Maks. Gerilme =23.639 / 24=985kg/cm2

Figure 5.10: Case building 1 - Maximum stress calculation for the curtain wall system.

5.3 Case Building 2

The building located in Istanbul, district of 5. Levent, comprising 20 floors, was built in 2017. Therefore, is an office building with a height of 90 m and is listed as a high-rise building. For this project, reinforced concrete and structural steel are the selected structural systems.

5.3.1 Case building 2 - general configuration and characteristics of the curtain wall system

The stick curtain wall system has chosen to be implemented at the whole façade. Figure 5.12 shows the stick curtain wall system for this project. The dimensions for

the aluminium frame (H: 200mm and W: 50mm as shown in Figure 5.13), these dimensions used according to the structural design calculations of the project, the floor height: 370 cm. The vision area in which the transparent glass used is 250 cm, and the spandrel area was 120 cm, in some parts of the project, the spandrel area was treated with spandrel glass, while in the other parts the composite sheet was used. Figure 5.14 shows the spandrel area specifics formed by the spandrel glass in detail.

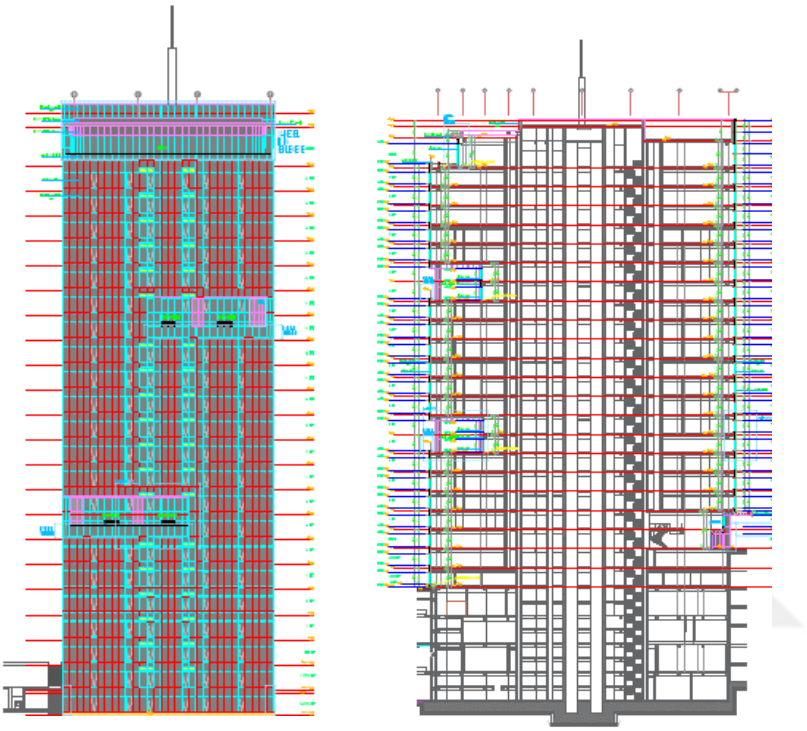


Figure 5.11: Case building 2 - Front elevation and section.

The stone wool thickness in front of the floor slab 5mm+5mm+ 100mm and galvanized sheet used behind the composite sheet and spandrel glass for thermal insulation and the fire resistance spread, which is one of the most necessary treatments in the gap between the curtain wall system and the building floor slab. The gap thickness from the floor slab to the curtain wall glass is 250 mm.

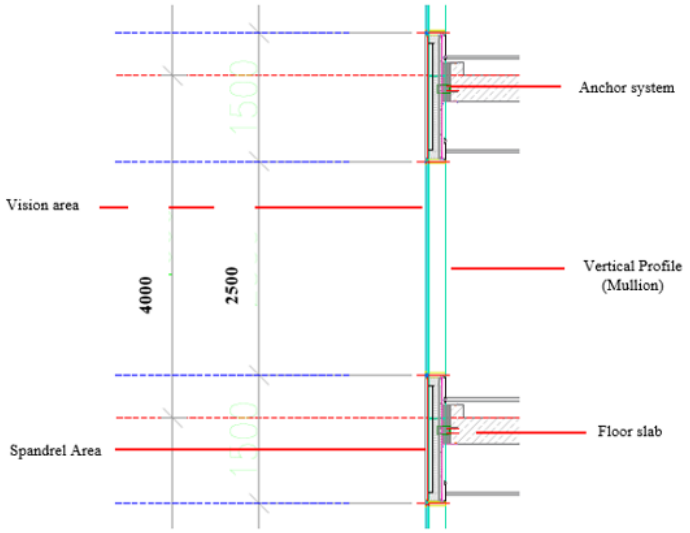


Figure 5.12: Case building 2 - Vertical section of stick curtain wall system.

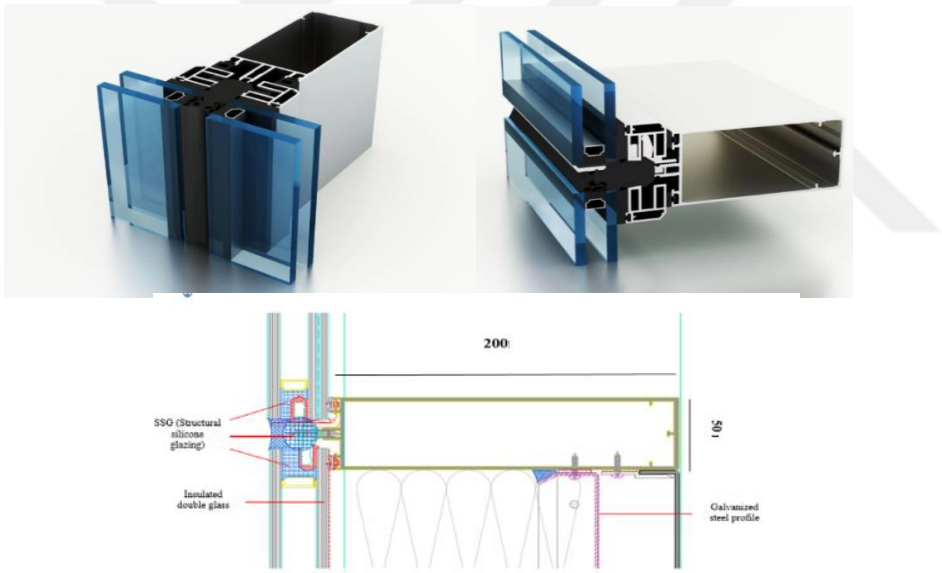


Figure 5.13: Case building 2 - Transom and mullion of stick curtain wall system detail.

To avoid sunlight projecting directly on the facade beside the aesthetic purposes, the louvres used in this project.

Also, the thermal transmittance (u-value) of the curtain wall system is 1.78 W/m^{2}K while that of glass is 1.4 W/m^{2}K.

The used glass in this project is the insulating glass, which consists of two layers and has a vacuum of argon gas with a thickness of 16 mm, while the outer layer is of tempered glass, with a thickness of 8 mm. In comparison, the inner layer made of two layers of laminated glass with a thickness of 6 mm, 0.76 mm, 6 mm. The glass coating 50/33 means that only 50% of sunlight transmitting to inner spaces. While 33 means that %33 of the solar energy can pass through the glass. Practically while selecting the glass type technical consulting requirements have been applied besides the other factors affecting the performance efficiency of the glass used in the curtain-wall systems, is the light transmittance is: 50 %, the U-value (Thermal) is:1.4 W/m^2K, the acoustic is: 40 dB (-2, -6) db. And the energy efficiency is:75% and the reflections is:0.35-0.40.

The glazing method used to connect the frame to the glass is structural silicone glazing as shown in Figure 5.14.

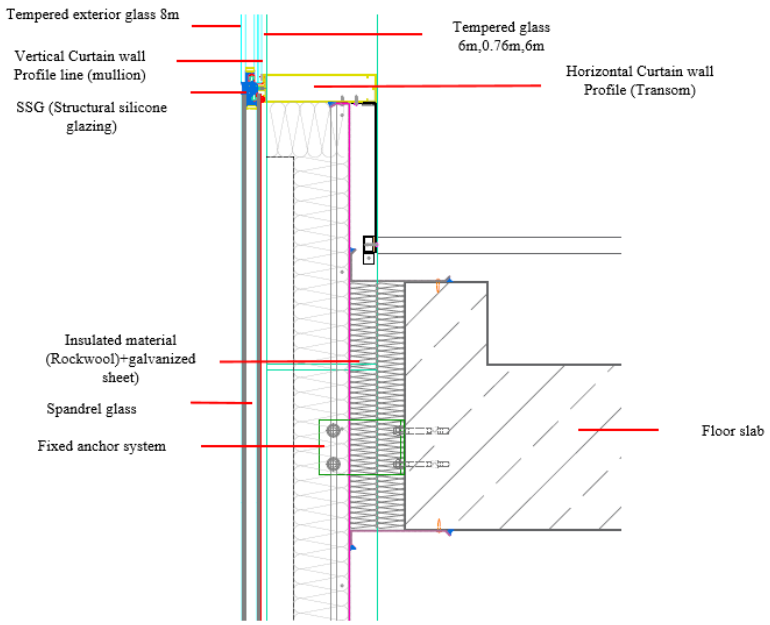


Figure 5.14: Case study 2 - Spandrel area with spandrel glass details.

5.3.2 Anchor and brackets used in the system

The type of anchor used to attach the curtain wall components to the floor slab is the fixed anchor system of steel in L and U shape, and the brackets fixed by bolts, the anchor was fixed on the front surface of the concrete slab as shown in the Figure 5.15.

Anchor and bracket systems designed to allow the movement in all directions that the wind load caused and the lateral movement that the seismic load caused.

The wind load imposed on the curtain wall calculated according to Eurocode 1 and the Turkish regulation IYBRY and the simulation program, Therefore, the wind tunnel experiment for more accurate results since it is a high-rise building. The wind forces took into account during the calculations was 160 kg / m^2.

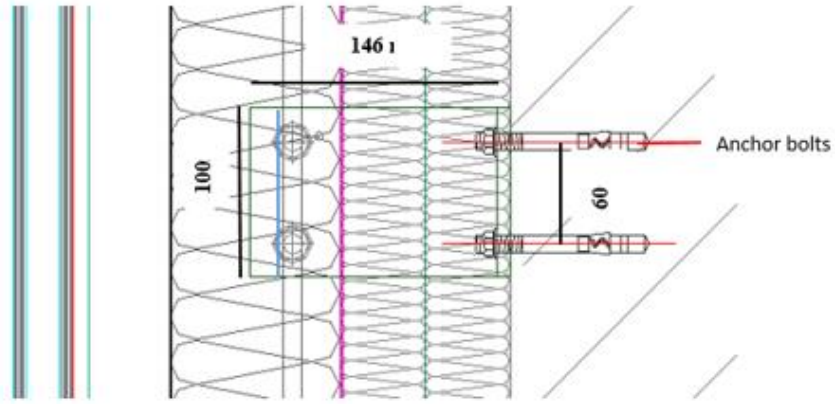


Figure 5.15: Case Building 2 - Anchor system, L type.

The maximum permissible deflection limit of the curtain wall according to the Euro code 1 and Turkish regulation, according to the equation D ≤ 5mm+ 3700/300 = 17.3 mm, while the maximum deflection that can occur as a result of the wind load is 14 mm, which is less than the permissible deflection limit and means that the curtain wall can withstand wind loads more.

The seismic loads calculated according to the old Turkish regulation 2007, since the building built before 2018. Therefore, how to calculate the earthquake forces, was done based on the equation

$$\mathbf{Fa = 0{,}6 \,.\, W} \qquad (\mathbf{5.1})$$

Fa: is the horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavourable direction, W: Weight of the element.

Moreover, during the design stage, the curtain wall components movement has calculated based on the combination of loads in the standards. The resulting movement resisted by the space left between the curtain wall elements and the structural building system. As in the calculations, the maximum movement permitted in the curtain wall

is 10 mm, which results from the calculation of the maximum displacement between floors.

5.4 Case Building 3

The building has 30 floors and a height of 132 meters. It is listed as a high-rise building constructed in 2015. It is located in Istanbul, in the Maltepe district, and is a multi-purpose building that includes residences and offices. The reinforced concrete is the building structural system used. Figure 5.16 shows two different building sections.

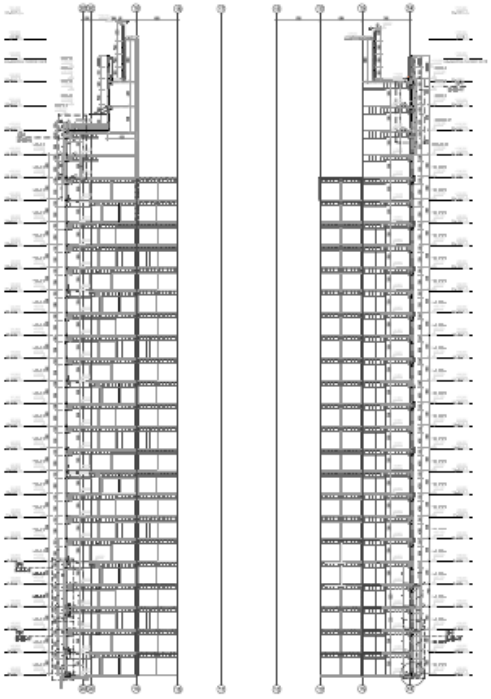


Figure 5.16: Case building 3 - Sections.

5.4.1 Case building 3 - general configuration and characteristics of the curtain wall system

The unitized curtain wall system used to cover all facades of the building. Due to the computations of wind and earthquake charges, dead loads and acoustic specifications listed in the first chapter, where aluminium frame sizes reached 147mm *30 mm and 175 mm*100mm, various descriptions of this system have used as indicated in Figures 5.17.

The floor's height in this building is 3500mm, where the vision area occupies 2350 mm while the spandrel area is 1150 mm.

In first detail, given in Figure 5.17 shows a continuous spandrel area, the second detail showing the presence of certain protruding parts (Composite box), the aim behind using it for giving shape for the façade which runs along the façade by linking the components of the curtain wall differently from the first detail, as well as the different frame measurements, Figure 5.18 shows the difference between the frame dimensions used in both descriptions.

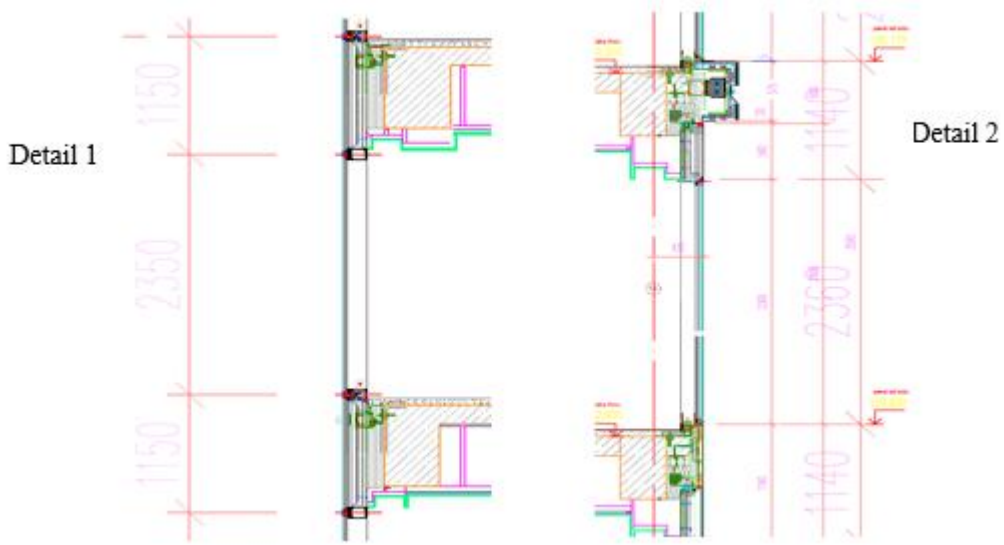
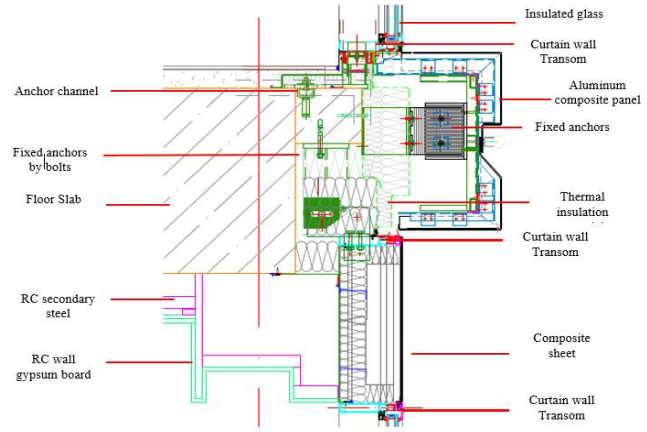


Figure 5.17: Case building 3 - Unitized curtain wall system section.

The exterior cladding varies also in these spandrel area details, where a composite sheet is used in Detail 2, while spandrel glass is used in Detail 1. these claddings, stone wool thermal insulation is used also for resistance to fire propagation.

Besides, the thermal transmittance (u-value) of the curtain wall system is 1.86 W/m^2K while for glass is 1.4 W/m^2K. In certain parts of the project, louvres, including aesthetics, were used to reduce the sun's rays' effect in the inner spaces. Figure 5.19 demonstrates the method of connecting the louvres to the horizontal curtain wall profile.

Detail a



Detail b

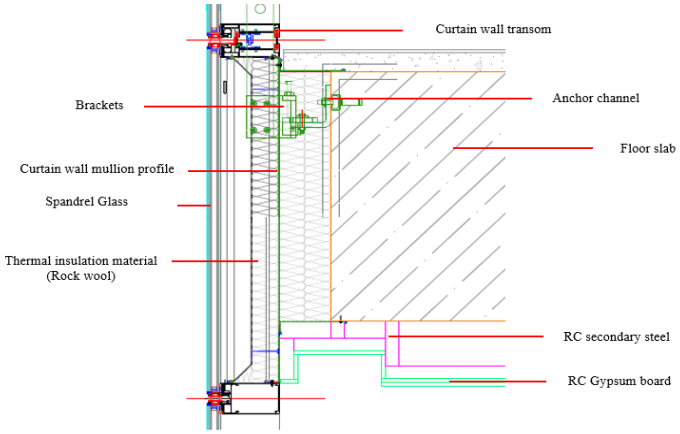


Figure 5.18: Case building 3 - Spandrel areas details, detail A) illustrator for detail 2, detail B) illustrator for detail 1.

This detail reminds how the stick system used rather than a unitized system and how a pressure plate connects the louvres to the curtain wall components.

The insulating glass used on all facades of the project, with a thickness of 38 mm. It consists of two layers of tempered glass, including a gap of argon gas.

The laminated glass used in the outer layer consists of two layers with a thickness of 6 mm, including a layer of plastic with a thickness of 1.52 mm, while the inner layer is 8 mm thick, the gap is 16 mm thick, the glass is coated with 50/33 specifications, means that only 50% of sunlight transmitting to inner spaces. While 33 means that %33 of the solar energy can pass through the glass. In addition to the other specifications of this type of glass, the light transmittance is 50 % while the U value (Thermal)for the glass: 1,4 W/m^{2}K, the acoustic is: 40 dB (-2, -6) dB and the energy efficiency is:75% and the reflections is:0,35-0,40.

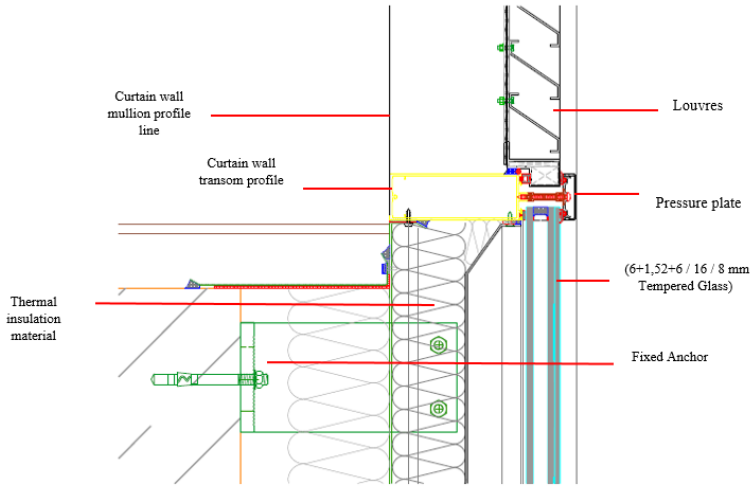


Figure 5.19: Case building 3 - Louvres detail section view.

As for the maximum deflection of the glass, it was 17.5 mm, because it is calculated based on the worst combination of loads placed on it.

Since the same form of glass is chosen in normal condition on all facades of the project, but the maximum deflection occurs at the corners of the building due to loads of the prevailing winds, as to how the glass relates to the components of the building.

Figure 5.20 show the curtain wall file does not require silicone or pressed plate, it consists of specific details.

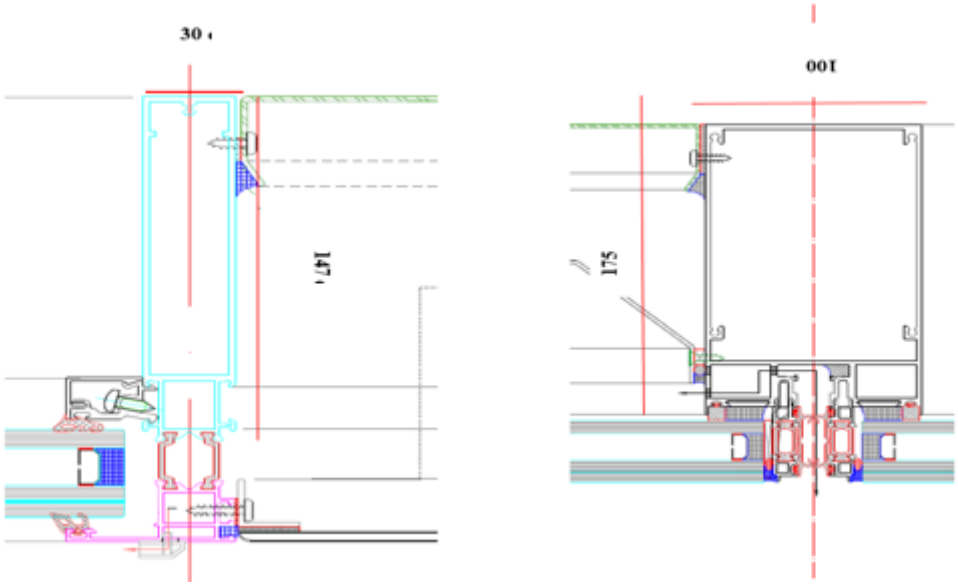


Figure 5.20: Case building 3 - Curtain wall frame details.

5.4.2 Anchors and brackets used in the system

In this project, components of the curtain wall connected to the floor slab with two types of steel anchor: fixed anchor and channel anchor, to achieve the necessary motion during earthquakes and winds and not damage the components of the curtain wall as shown in Figure 5.18. According to the building calculations performed during the design stage, the anchor system has different aspects and dimensions.

The fixed anchoring system was attached to the floor slab through bolts on the front surface of the concrete, but this system, as shown in Figure 5.20, was left a certain gap to ensure a certain movement because in the case it was fixed, the curtain wall would be harmed, while the channel anchor system was installed on the upper surface of the concrete and this system of anchors is preferred in seismic areas.

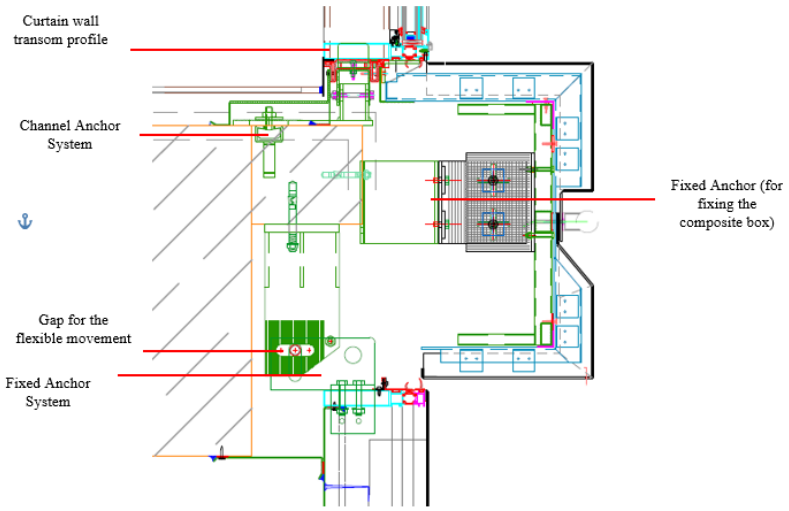


Figure 5.21: Case building 3 - Anchor system types.

The wind loads took into account during the calculations was 200 kg/m^2, while it was 260 kg/m^2 at the highest at the corners. The anchor must therefore be able to bear these loads efficiently as the project is a high-rise project. Wind tunnel experiment needed for more exact and efficient results.

Calculating the maximum permissible deflection limit of the curtain wall according to Eurocode 1 and the regulation IYBRY, according to equation D ≤ 5mm+ 3700/300 =16.6mm. The while the maximum deflection that can occur as a result of the wind load is 12 mm, which is less than the permissible deflection limit and means that the curtain wall can withstand wind loads more.

5.5 Case Building 4

The project located in Istanbul, Maslak, the project was established in 2018 and comprised 49 floors, approximately 189 m height a mixed-use building consisting of a residential and a hotel. Essentially the structural system of the building is reinforced concrete.

5.5.1 Case building 4 - general configuration and characteristics of the curtain wall system

The aluminium unitized Curtain wall system has chosen for this project; the reason behind choosing this system is the short installation period on the site and better quality assurance thanks to the factory's manufacturing process. Figure 5.22 show a section in the unitized curtain wall system for this project. It achieved a simple way to replace the glass unit from the outside with this custom uniform device. The outside and inside components used at joints can also quickly replaced when aged.

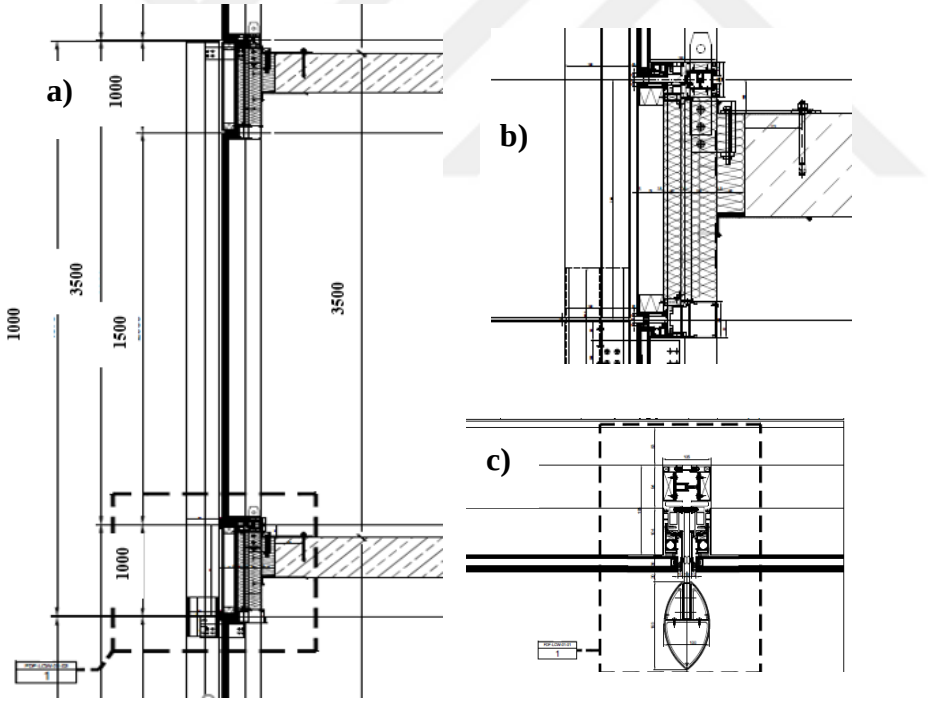


Figure 5.22: Case building 4 - a) Section at unitized Curtain wall system
b) Floor slab section shows the anchor system the spandrel area detail
c) Unitized system plan detail shows the frame, glass and the profile used for attaching curtain wall components.

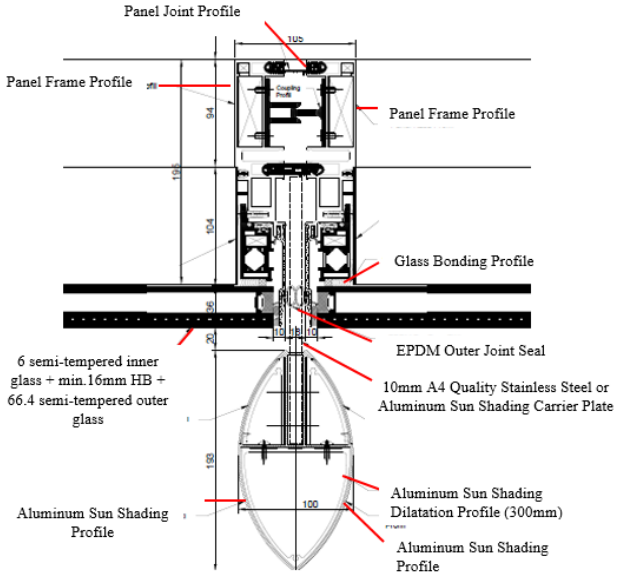


Figure 5.23: Case building 4 - Illustration of the unitized curtain wall system frame plan detail.

According to the structural calculations, the curtain wall frame system has determined 195*105 mm. Figure 5.23 shows the frame dimensions and frame details.

The floor heights 3500mm in this project. The vision area 1500mm while the spandrel area:1000mm.

Aluminium sheets used to cover the spandrel area, to prevent the spread of fires and resist them. A fire-resistant structural board integrated with 2mm galvanized sheets and fire mastics at the edge of the ceiling have to contact the curtain wall, as shown in Figure 5.24.

The space between the curtain wall and the floor slab surface was closed by 1 mm of APDM members al galvanized pressure sheet used for weather sealing. There is no use of louvres or separate sunshade devices, but as shown in detail given in Figure 5.24, aluminium sun shading profiles used to block direct sunlight.

As for the thermal transmittance (U-value) for the curtain wall system, the profile system more than 1.7 W/m^{2}K, while for the glass units: 1.1 W/m^{2}K.

The solar low E- coated double glass units used on the project's facade, with a total thickness of 28 mm. It consists of two layers of tempered glass, including a gap of argon gas.

The laminated glass used for the outer layer consist of two layers with a total thickness of 12 mm, including a layer of plastic (PVB) with a thickness of 1.52 mm the inner layer thickness 6 mm of fully tempered glass, the gap is 16 mm thick. The glass is coated with 50/32, Solar Low-E coating carries out solar protection 32 means that %32 of solar energy can pass through the glass.

As for the requirements that the company found important when choosing this type of glass: the structural, security and internal comfort of the occupants in addition to the physical standards of the building.

In addition to the other specifications of this type of glass, its light transmittance: is 50 % while the U value (Thermal) for the glass: is 1,1 W/m^{2}K. The reflection to outside: is 23% and reflection to inside: is 22 %.

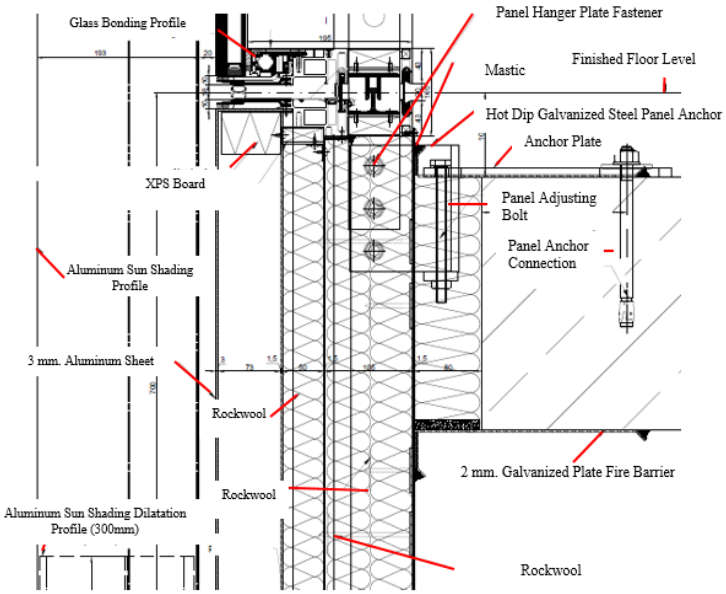


Figure 5.24: The floor slab section shows the anchor system the spandrel area detail.

The maximum deflection for the maximum sized glass is 7.3 mm because it is calculated based on the combination of loads placed on it, the wind loads to consider in the calculations was:

Pressure: 3.0 kN / m^2

Suction: -3.00 kN / m^2

Figure 5.20 show the method used to bond the glass units to the curtain wall profile was an auxiliary profile.

5.5.2 Anchor and brackets used in the system

The anchor, which connects the curtain wall's components to the floor slab, is the fixed anchor with different dimensions shown in Figure 5.25. the anchor system made of hot-dip galvanized steel, designed to allow the movements in both vertical and horizontal directions by more than 25 mm. It installed on the top of the floor slab.

As mentioned previously, in the analysis performed for the deformation in the curtain wall system and the anchors, the applied stress is analysed, as shown in Figures 5.26 and 5.27.

The maximum stress occurring in the anchor profile is approximately 3050 kg/cm^2 (stress concentrations are negligible) less than 3500(floor height) divided by 1.1 equal to 3180 kg / cm^2, while the maximum deflection in the anchor profile is: 0.29mm.

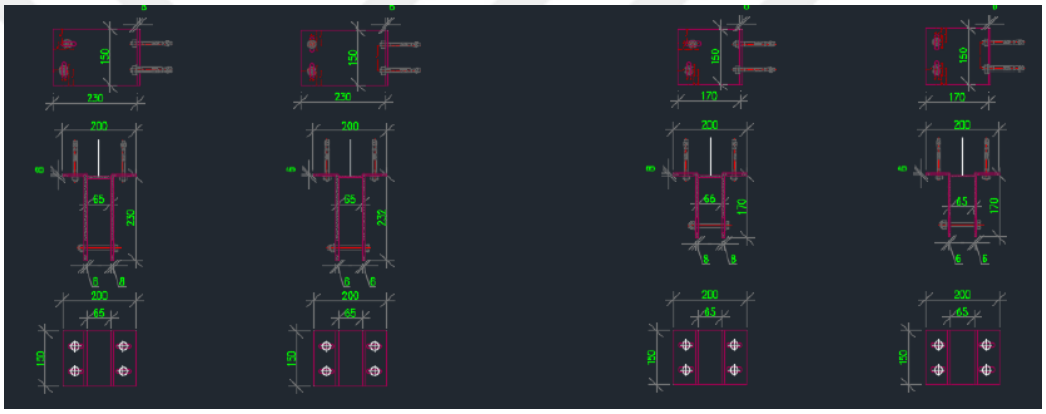


Figure 5.25: Case building 4 - Fixed anchor dimensions.

As for wind, as indicated in the Turkish Regulation for the year 2018, the wind speed approved during the calculations is 25 m / s, the wind load that was adopted is ±3kPa. In addition to the stress calculations applied on the curtain wall, the maximum deflection estimated to occur in the curtain wall components due to wind load is 16 mm.

Maximum deflection value: 16mm less than deflection limit value according to Eurocode1 facade product standard which is floor heights divided by 300 m plus 5mm, 350 divided by 300 plus 0.5 equal 16.6 mm as shown in Figure 5.28.

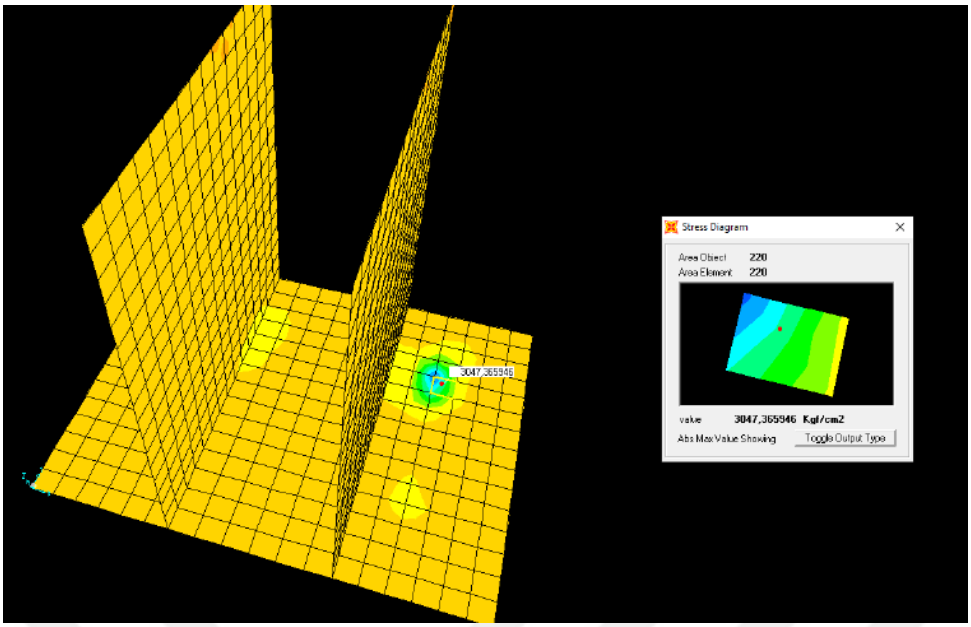


Figure 5.26: Case building 4 - Maximum stress on the anchor system.

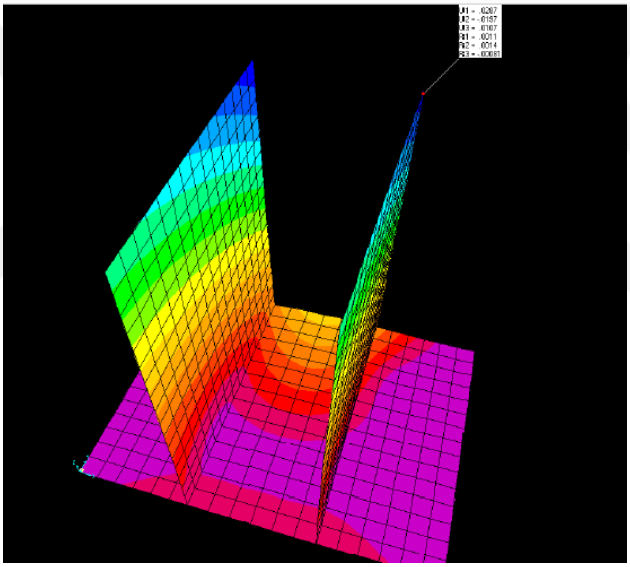


Figure 5.27: Case building 4 - Deflection in the anchor system.

Table 5.2: Stress analysis for the curtain wall profiles.

$\sigma_{max} = M_{max}/W + N/A$	(84450/70) +(90x7/10) 1206+63 1270 kg/cm^2
profile ≥	σ_{max} = 1270kg / cm^2 <1600 / 1.1 = 1450 kg / cm^2 limit stress value (EN AW, field (6060 T66): 200Mpa) ≥ SUITABLE!!

As for earthquakes, the new Turkish regulation of 2018 has adopted, and the equation has calculated the seismic load:

$$F_e = 0.5\ A_0 I\ w_e\ [1+2\ \frac{Hi}{HN}\ ] \qquad (5.2)$$

A_0: effective ground acceleration coefficient

I: building an importance factor

w_e: the weight of the equipment (façade unit)

Hi: height of the story measured from the top foundation level

H_N: total height of the building measured from the top foundation level

As for quantifying earthquakes during the design phase, the horizontal moment of inertia of the suggested profiles and the anchor profiles are proved under the maximum estimated seismic load. for predicting the movement in the curtain wall components during earthquakes the maximum displacement between the floors calculated. Thus, the maximum displacement or deformation that could occur in the curtain wall was approximately 5 mm.

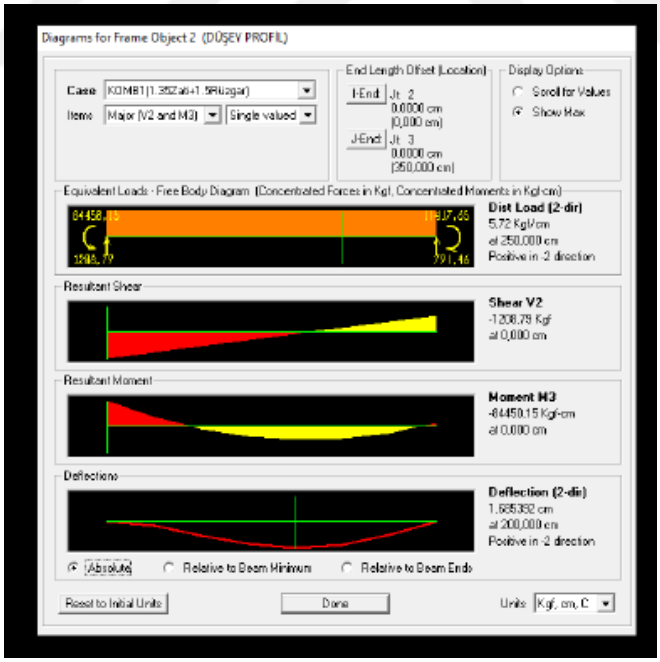


Figure 5.28: Case building 4 - Deflection analysis according to Eurocode.

5.6 Case Buildings Comparisons

According to what was observed in the four cases studied in this Chapter, two types of curtain walls were used: Stick and unitized systems while the other types of curtain wall were not used.

The buildings varied from medium to high Table 5.3 as their height varied from 60 m to 189 m. Buildings over 70 m high classified as high-rise buildings, according to the Turkish earthquake regulation in 2018. Buildings were in various Istanbul regions. That was one of the study purposes of selecting buildings of different heights and in various Istanbul, regions to know how to handle the velocity and load of winds and earthquakes in different geographical locations.

Table 5.3: Case buildings curtain wall profiles comparison

Case buildings	Building heights	Curtain wall type	Profile size	Standard used in the calculation
Case building 1	65m	Stick curtain wall	120*50mm	EN13830
Case building 2	90m	Stick curtain wall	200*50mm	TS EN 13830
Case building 3	132m	Unitized curtain wall	147*30mm-175*100mm	TS EN 13830
Case building 4	189m	Unitized curtain wall	195*105mm	TS EN 13830

The curtain wall frame dimensions differed concerning both the type of curtain wall used and the structural calculations made in connection with wind, earthquakes and dead load during the design stage.

As for the glass used, the company's structural and being free from danger requirements and internal comfort and physical construction standards differed between the projects. Table 5.4 seen the glass characteristics used in the four case buildings. In general, the double-tempered glass used because it is four to five times stronger than a single glass and in addition to its thermal strength and its resistance to the sudden temperature change, it does not hurt when broken.

Table 5.4: Glass characteristics used in case buildings.

	Case building 1	Case building 2	Case building 3	Case building 4
Building height	65 m	90 m	132 m	189 m
Glass type	Solar Low-E	Insulated Glass	Insulated Glass	Solar Low-E
Glass thickness	28 mm	37 mm	37 mm	28 mm
Coating type				
Daylight transmittance/ G-value	50/33	50/27	50/33	50/32
Layers number	Double glass (6 mm T + 16 AS + 55.2 cl. Lam.)	8 / 16 / 6 lam.+0,76+6 mm Tempered Glass	6+1,52+6 / 16 / 8 mm (laminated) Tempered Glass	6mm T+16 mm HB+ 55.2 tempered laminated
Light transmittance	49%	50%	50%	50%
Glass's U- value	1.4 W/m^2K	1.4 W/m^2K	1.4 W/m^2K	1.1W/m^2K
Curtain wall U-value		1,86W/m^2K	1,86 W/m^2K	1.7-1.8 W/m^2K
Reflections	24%	0.35-0.40	0.35-0.40	23 % from outside 22 %from inside
curtain wall glazing type (securing method)	SSG Structural Glazing	SSG Structural Glazing	Special pressure plate with the system	Special design for the pressure plate

Table 5.5: Anchor System used in case buildings.

	Case building1	Case building 2	Case building 3	Case Building 4
Anchor type	Steel Fixed anchor (L shape)	Steel Fixed anchor (L and U shape)	Steel fixed and channel anchor	Steel fixed anchor
Fixation method	Mechanical	Mechanical	Mechanical	Mechanical
Location of the anchor on the floor slab	Front	Front	Front	Top

As shown in Table5.5 channel anchor used for one project, while this type of anchor is better than the fixed type, does not want companies to use it, because both it and its high cost are the methods of installation before placing the concrete.

Table 5.6: Wind loads for the case buildings.

	Case building 1	Case building 2	Case building 3	Case building 4
Basic wind load	25 m/s			25m/s ± 3 kPa
Wind load during the design process	150 kg/m^2	160 kg/m^2	200 kg/m^2	198.8 kg/m^2
Standard and regulation used for calculation the wind load	Eurocode 1	Eurocode 1+ IYBRY	Eurocode 1+ IYBRY	Eurocode 1
The equation used for calculating the deflection of the curtain wall	D ≤ 5mm+ L/300 if 3000mm <L<7500mm			(5.3)
Expected deflection	14.9 mm	14 mm	12 mm	16 mm
Limit deflection according to standard	15.6mm	17.3mm	16.6mm	16.6mm

As seen in Table 5.6 that they complied with standards in the first and fourth cases, whereas in the third and fourth cases, the standards were not complied with because a new method of calculation adopted. The adopted equation used to calculate the maximum stress.

$$\sigma_{max} = M_{max}/W + N/A \text{ profile} \qquad (5.4)$$

where M_{max} : The maximum moment, W: The moment of strength, N: The Axial force and A: The Section Area in cm. As for calculate the seismic load Table 5.7 that the complied with standards in all the case buildings.

Table 5.7: Seismic loads for the case buildings.

	Case building 1	Case building 2	Case building 3	Case building 4
Earthquake standards and regulation	DBYBHY-2007	DBYBHY-2007	DBYBHY-2007	TBDY-2018
The equation used for calculating	$F_e = 0.5\ A_{0I}\ w_e [1+2\frac{Hi}{HN}]$(5.2)	Fa = 0,6 . W (5.1)	Fa = 0,6 . W (5.1)	$F_e = 0.5\ A_{0I}\ w_e [1+2\frac{Hi}{HN}]$ (5.2)
Max. displacement occurs		10mm	12mm	5mm

6. CONCLUSIONS AND RECOMMENDATIONS

The research aimed to examine and analyse curtain walls components' behaviour in high and medium-sized buildings in Turkey, especially in Istanbul, under the influence of earthquakes and winds, in addition to checking whether wind and earthquake loads and forces in the design phase fulfil the standards. In this thesis, four case buildings with different heights in different regions of Istanbul are studied. Generally, the obtained results showed that both types of curtain wall system are preferred to be used in high and medium-height buildings, i.e. aluminium stick and aluminium unitized systems.

As the details of the curtain wall's components, the frame made of aluminium, but the details, size and shape differ, in addition to the glass. Structural calculations differ, but the anchor design is capable of movement in the X and Y directions, this does not reflect the reality of earthquake movement, as seismic movement is not only in the vertical and horizontal directions, there is also ground vibration.

As far as wind loads are concerned, the companies have asked questions regarding these projects and obtained answers; all these undertakings fellow the requirements explained in the third chapter such as the Euro Code, besides IYBRY. Regarding the seismic loads, what achieved is that these companies follow the standards described in advance in Chapter Four. However, since the buildings were constructed at different times, some followed the old version of the Turkish regulation, DBYBHY 2007. The buildings designed after 2018 followed the new regulation TBDY 2018. However, concerning earthquakes, the companies made it clear that the essential load highlighted when designing the curtain wall or façade in general for tall or medium-rise buildings is the wind load since this load is directly and massively attached to the building façade. Besides, this load is variable and frequent in different ways, as for the seismic load, it is equivalent to 10-15% of the wind load. Therefore, if the curtain wall is designed correctly in terms of wind loads, the curtain wall is highly qualified and adapted to deal with earthquake loads. If the construction of high rise buildings facades not considered the wind load, damage to the curtain wall, including glass cracking, or framework deformation, and other damage caused. Thus wind and earthquake loads are determined throughout the design process to mitigate risk.

While studying the wind loads on the projects, it was noticed that the projects were not dealt with differently according to the geographical location of the project, when the basic wind speed adopted was 25 meters/s in line with Turkish regulation, as it was relied on European standards (Euro Code) and Turkish regulations, as it noticed that in some projects European standards have taken into consideration. However, in other projects that have not taken into account, this is due to the Turkish standards taken from European standards. The Turkish regulations must be more comprehensive to Turkey's conditions and amended in parallel with the current requirements. According to the interviews, the questions raised and the details obtained, wind loads' interest was more significant during the design stage. In contrast, the earthquake loads did not gain this importance, due to seismic forces effects on the structural system studied during the design stage and based on these calculations it is calculated on the curtain wall, in addition to the earthquake loads being less than the wind loads, therefore when wind loads calculated, the curtain wall able to deal with seismic forces efficiently.

This study was a preliminary study to analyse the impact of earthquakes and winds on the curtain wall components in Turkey and because of the information specified by the stakeholders. Therefore, this topic must be studied further to determine the problems exposed to the curtain wall due to the wind and earthquakes by obtaining a wider number of projects, details, and more information on the topic. Future researches can be done regarding the curtain walls resistance to blast loads. Indeed, the stakeholders need to be involved in academic studies to better resolve the issues as the stakeholder contribution during this study was less than expected insufficient.

REFERENCES

AAMA501.4. (2018). *Recommended Static Test Method for Evaluating Curtain Wall and Storefront Systems Subjected to Seismic and Wind Induced Interstory Drifts.* Schaumburg, IL, USA: AAMA.

AAMA501.6. (2018). *Recommended the seismic drift causing glass fallout from window wall, Curtainwall and storefront systems.* Schaumburg, IL, USA: AAMA.

Ahmed.M. M. S., A.-R. A. (2016, Jan). Double Skin Façade: The State of Art on Building Energy Efficiency. *Clean Energy Technologies, 4*(1).

Aksamija, A. P. (2013). *Sustainable Facades, Design Methods for High-Performance Building Envelope.* New Jersey, USA: John Wiley &Sons.

Allen, E. (2004). *Fundamentals of Building Construction.* New Jersey: John Willey and Sons.

Arnold C. (2016). *Seismic Safety of the Building Envelope*. Retrieved May 22, 2020, from https://www.wbdg.org/resources/seismic-safety-building-envelope.

ASCE. (2013). *Curtain Wall Systems a Primer.* Virginia: American Society of Civil Engineers.

ASCE/SEI 7-10. (2013). *Minimum Design Loads for Buildings and Other Structures.* American Society of Civil Engineers.

ASCE/SEI49-12. (2012). *Wind Tunnel Testing for Buildings and Other Structures.* American Society of Civil Engineers.

Ascher, K. (2013). *The heights, Anatomy of a skyscraper.* USA: Penguin Publishing Group.

Atalay, B. (2006). Analysis of aluminium curtain wall system selection during the preconstruction phase. (Master's thesis). Faculty of Architecture, ITU.

Auer, T. B. (2014). *Facades. Principle of Construction.* Berlin, Germany: Birkhäuser Verlag AG.

Barbosa S., K. I. (2014). Perspectives of double skin façades for naturally ventilated buildings: A review. *Renewable and Sustainable Energy Reviews, 40*, 1019-1029.

Bayrak, Y., Ozturk, S., G.Ch.Koravos, G.A.Leventakis, & Tsapanos, a. T. (2008). Seismicity assessment for the different regions in and around Turkey based on instrumental data: Gumbel first asymptotic distribution and Gutenberg-Richter cumulative frequency law. *Natural Hazards and Earth System Sciences*, 109–122.

BBRI. (2004). *Ventilated Double Facades.* Belgium, Department Of Building Physics, İndoor Climate & Building Service, Belgian Building Research Institute.

BCI (Architectural Glazing and Building Enclosures Company). Retrieved May 5, 2020, from www.bcindustries.com.

Begec, H. and Savasır, K. (2004). Analysis of the Ventilation Types of Intelligent Curtain Walls. *Proceedings of the First National Roof & Façade Symposium.* Faculty of Architecture, DEU, Izmir.

Bertan, S. (2016). Analysis of the aluminium curtain wall design and construction process current status in Turkey. (Master's thesis). Faculty of Architecture, ITU Graduate School of Science Engineering and Technology.

Boswell, K. (2013). *Exterior Building Enclosures: Design Process and Composition for Innovative Facades, for Innovative Facades.* Hoboken, New Jersey, USA: John Wiley& Sons.

BS EN 12179. (2000). *Curtain walling - Resistance to wind load - Test method*. BSI Standards Publication.

BS EN 13116. (2004). *Curtain walling. Resistance to wind load. Performance requirements.* BSI Standards Publication.

BS EN 13830. (2015). *Curtain walling. Product standard*. BSI Standards Publication.

BS EN 1991-1-4.(2005)**.** *Eurocode 1. Actions on structures. General actions. Wind actions.*BSI Standards Publication.

BS EN 14019. (2016). *Curtain Walling. Impact resistance. Performance requirements*. BSI Standards Publication.

Buluk, N.B. (2015, June 14). *Facade Construction in Seismic Regions, Development of a Façade Construction for Seismic Regions*. International Facade Design and Construction, Hochschule Ostwestfalen-Lippe – University of Applied Science.

Castro. R. (2015). Wind analysis in the early design stage: An empirical study of wind visualisation techniques for architects.

Chan, L. S. (2009). *Investigation of the energy performance of double skin façade in Hong Kongpp*. 1135–1142, *Energy Build*, *41*(11), 1135–1142.

Charleson, A. (2007). *Architectural Design for Earthquake A Guide to The Design of Non-Structural Elements*. https://www.nzsee.org.nz/db/PUBS/ADE2007.pdf.

Choi, I., Kim, J. and Kim H. (2015). *Composite Behaviour of Insulated Concrete Sandwich Wall Panels Subjected to Wind Pressure and Suction*. *Materials*, 1-19.

Chwe. M.Y.L. (1999). *Construction Technology for Tall Buildings.* Singapore: Singapore University Press, National University of Singapore.

Clift, C. D., & Bonnheim, N. (2013). *Design of Curtain walls for wind load*. ASCE, *Curtain Wall System a Primer* (s. 87-104). United States of America: American Society of Civil Engineers.

CMHC. (2013). *Glass and metal curtain walls best practice guide building technology.* Canada Mortgage and Housing Corporation. Retrieved April 27, 2020, from http://tboake.com/guides/curtain.pdf.

Craven, J. (2019, August 15). *THOUGHCO. What is the Chicago school:* Retrieved October 20, 2020, from https://www.thoughtco.com/chicago-school-skyscrapers-with-style-178372

Denoon, D. (2018, June). *Wind Tunnel Testing for Tall Buildings*. Retrieved October 9, 2020, from https://www.structuremag.org/?p=13256.

Dilek, Y., Altunkaynak, Ş. (2009, January 1). Geochemical and temporal evolution of Cenozoic magmatism in western Turkey: mantle response to a collision, slab break-off, and lithospheric tearing in an orogenic belt. *Geological Society, 311, 213-233*. doi:https://doi.org/10.1144/SP311.8

Dogan, B. N. (2013). *An investigation on the performance of an aluminium panel curtain wall system in relation to the facade tests*. (Master's thesis). Faculty of Architecture, Middle East Technical University, Ankara.

EN ISO 11600. (2003). *Building construction. Jointing products. Classification and requirements for sealants*. BSI Standards Publication.

FDF. (2020). Interview, Istanbul. Retrieved October 9, 2020, http://www.fdf.com.tr/.

Fu, F. (2018). *Design and Analysis of Tall and Complex Structures.* Butterworth-Heinemann.

FEMA 450. (2003). *Recommended provisions for seismic regulations for new buildings and other structures.* Washington.

FMT. (2020). Interview 2020, Istanbul. Retrieved October 9, 2020 www.fmtfacade.com

Galli, U. (2011). Seismic Behavior of Curtain Wall Facades, A Comparison Between Experimental Mock-Up Test and Finite Element Method Analysis. *Politecnico Di Milano*.

Garg, N. (2007). *Guidelines for Use of Glass in Buildings.* Delhi, India: New Age International Ltd.

Grün Consulting. (2020). *Building Code: An Important (Thermal) Bridge to Span*. Retrieved June 2020 from Grün Consulting company: https://grunconsulting.com/2016/10/12/building-code-an-important-thermal-bridge-to-span/.

Haase, M., Marques da Silva, and Amato, A. (2009). Simulation of ventilated facades in hot and humid climates. *Energy Build*, *41*(4), 361–373.

HALFEN A CRH Company. (2018). *HALFEN HCW curtain wall technical product information*. Retrieved May 15, 2020, from https://www.halfen.com/application/filebrowser/library/us/media/catalogues/fixingsystems/HCW_14-US.pdf.

Harrison K., C. D. (2003). *Understanding the Principles of the Double Façade System.* Terri Meyer Boake: Terri Meyer Boake, Associate Professor School of Architecture, University of Waterloo.

Hashemi, M. (2018). *Anchor Channels in Curtainwall*. Retrieved May 15, 2020, from https://www.linkedin.com/pulse/anchor-channels-curtain-wall-connections-masoud-hashemi.

Hedges, K. (2017). *Architectural Graphic Standards.* American Institute of Architects, John Wiley& Sons.

Huanga, B., Chenb, S., W.Lub, & Mosalamc, K. M. (2017).Seismic demand and experimental evaluation of the nonstructural building: Curtain wall: A review. *Soil Dynamics and Earthquake Engineering*, 16–33.

İYBRY. (2009). *ISTANBUL HIGH BUILDINGS WIND REGULATION ((İYBRY).* İstanbul: İSTANBUL METROPOLITAN MUNICIPALITY BUILDING DIRECTORATE.

Kılıç, A. (2012). *Wall Cladding and Facades Security.* Retrieved May 22, 2020, from http://www.yangin.org/dosyalar/cephe_yanginlari_ve_yonetmelik.pdf.

Klein, T. (2013). Integral facade construction: towards a new product architecture for curtain walls. (Doctoral dissertation). Architectural Engineering.

Kloft, E., & Eisele, j. (2002). *High-Rise Manual, Typology and Design, Construction and Technology.* Basel, Boston, Berlin: Birkhauser.

Maraza, V. I. (2004). *On the death toll of the 1999 Izmit (Turkey) major earthquake.* Bucharest, Romania: On-leave from Seismological Laboratory, National Institute (R&D) for Earth Physics.

Matusiak, B. (2012). *Colour shifts behind modern glazing, Trondheim.* the Norwegian University of Science and Technology (NTNU), Trondheim. Retrieved May 20, 2020, from https://www.researchgate.net/publication/263470151.

MBY Engineering,(2019). Interview. 20 December, Istanbul.

Naqash M. T., F. A. (2016). Aluminium Framing Members in Facades. *Key Engineering Materials,1662-9795, pp 327-332,* pp 327-332.

Oesterle, E., Lieb, R., Lutz, M., Heusler, W. (2001). *Double Skin Facades Integrated Planning.* New York, USA.: Prestel Verlag.

Patterson, M. (2008). Structural glass facades. A unique building technology. (Master Thesis), University of Southern California, San Francisco.

Poirazis, H. (2004). *Double Skin Facades: A Literature Review, A report of IEA SHC Task 34 ECBCS Annex 43.* Lund Institute of Technology, Lund University. http://www.ebd.lth.se/fileadmin/energi_byggnadsdesign/images/Publikationer/Bok-EBD-R3-G5_alt_2_Harris.pdf.

Rademacher, H.; Hellweg, P. (2020, Jan 26). *Quake in Turkey highlights the hazard in the East Bay*. Berkeley Seismology Lab: https://seismo.berkeley.edu/blog/2020/01/26/quake-in-turkey-highlights-the-hazard-in-the-east-bay.html.

Sanders, M.R. (2006). CurtainWalls: Not Just Another Pretty Facade. *Hofmann Architects Journal, 23*(1).

Sanders, R. (2006). Curtain Walls: Not Just Another Pretty Façade, Journal of Architectural Technology, *1 (23)*. http://www.hoffarch.com/assets/Vol-23-N1-Curtain-Walls.pdf.

Sezer, Ş. F. (2003). *Giydirme cephe kavramı. Mimarlık, 311 (2003).* mimarlik: http://www.mimarlikdergisi.com/index.cfm?sayfa=mimarlik&DergiSayi=8&RecID=206.

Taranath, B. (2012). *Structural Analysis and Design of Tall Buildings.* NW: CRC Press.

TBDY. (2018). *Türkiye Bina Deprem Yönetmeliği, Afet ve Acil Durum Yönetimi Başkanlığı.* Turkey: Resmî Gazete.

Tortu,Ş.Ş. (2006). *Examination of the relationship between the thermal performance and durability of aluminum curtain walls.* (Master's thesis). Faculty of Architecture, ITU Graduate School of Science Engineering And Technology, Istanbul.

TS EN 12152. (2002). *Curtain walling -Air permeability- Performance Requirements and Classification*, Turkish Standards Institution. Ankara.

TS EN 12153. (2000). *Curtain walling -Air permeability- Test method*, Turkish Standards Institution. Ankara.

TS EN 1215. (2000). *Curtain walling - Water tightness - Performance Requirements and Classification*, Turkish Standards Institution. Ankara.

TS EN 12154. (2004). Curtain walling - Water tightness - Performance requirements and classification, Turkish Standards Institution. Ankara.

TS EN 12155 *Curtain walling - Water tightness - Laboratory Test Under Static Pressure*, Turkish Standards Institution. Ankara.

TS EN 13050. (2011). *Curtain Walling - Watertightness - Laboratory test under the dynamic condition of air pressure and water spray.* Turkish Standards Institution. Ankara.

TS EN 13051-1. (2019). *Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests.* Turkish Standards Institution. Ankara.

TS EN 1364-3. (2007). *Fire resistance tests for non-loadbearing elements - Part 3: Curtain walling - Full configuration.*Turkish Standards Institution. Ankara.

U. A. Sahin et al. (2011). *A New Approach to Prediction of SO2 and PM10 Concentrations in Istanbul, Turkey: Cellular Neural Network (CNN)*. *Environmental Forensics*, 253-269.

(CWCT), C. f. (2008). *CWCT Curtain Wall Installation* Technology *Handbook, Unversity of Bath.* May 30, 2020.

Vigener, N. P. (2016). *Building envelope design guide: Curtain walls*. Retrieved June 5, 2020, from wbdg.org: https://www.wbdg.org/design/env_fenestration_cw.php.

WES. (2003). *Wind Energy Estimation System.* Ankara: T.R. Ministry of Environment and Forest State Meteorology Administration.

Winxie, W. (2007). Analysis and design of curtain wall systems for high rise buildings. (Doctoral dissertation). Faculty of Engineering and Surveying, University of Southern Queensland.

Y. Bayrak et al. (2008). Seismicity assessment for the different regions in and around TurkeySeismicity assessment for the different regions in and around Turkey. *Natural Hazards and Earth System Sciences*, 109–122.

Yalaz, E. (2018). Lifetime performance evaluation of stick and panel curtain wall systems by full-scale testing. *Construction and Building Materials, 170*, pp 254–27.

Yalaz, E. (2018). lifetime performance of stick and unitized cladding facade system by the experimental procedure. (*Doctore thesis)*, Istanbul Technical University, Institute of Science, Istanbul.

Yeomans, D. (2001). The Origins of the Modern Curtain Wall. *APT Bulletin, 32 (1)*, 13-18.

URL-1 <https://www.thoughtco.com/chicago-school-skyscrapers-with-style-178372>, date retrieved May 5, 2020.

URL-2 <http://www.gmwebsite.com/Website/index.asp?preview=1&ContentID=ContentID-090807135320260>, date retrieved Dec 15, 2020.

URL-3 < https://www.commercialwindows.org/frames_curtainwall.php>, date retrieved May 20 , 2020.

URL-4 <https://vcn.vitroglazings.com/structural-glazing-sealants-for-advanced-fa%C3%A7ades >date retrieved April 25,2020.

URL-5 <https://www.fema.gov/ > date retrieved May 23,2020

Cuhadarolgu aluminium company <https://www.cuhadaroglu.com/ > date retrieved February 10, 2021.

APPENDIX A: Questionnaire Forms for Facade Consultant and Façade Companies

A. GENERAL QUESTIONS

1. Building Name (Optional):
2. Construction years:
3. Building location district:
4. Building Type (Office building, residence, commercial …etc.):
5. The number of floors:
6. Is it a high or mid-rise Building?
7. What is the material of the building's structural (i.e. steel or reinforced concrete)?

B. SPECIFIC QUESTIONS REGARDING THE CURTAIN WALL COMPONENTS

B.1 FRAME SYSTEM

1. What is the material of the chosen curtain wall? (aluminium, steel, wood, etc.)
2. What is the selected curtain wall system? (stick, unitized, simi unitized.) and what is the reason behind your curtain wall type?
3. What are the dimensions of the frame system? And why?
4. What are the spans between vertical and horizontal elements?
5. What is the fixation methodology of the louvres (sunshades if existed)?
6. How have spandrel areas been studied? In terms of thermal insulation and fire stopping?
7. What is the AWW permeability standards (airtightness, water tightness, wind permeability)
8. A vertical section in the spandrel area to determine the FFL with the horizontal transom?
9. What is the U-value of the selected curtain wall system? (thermal insulation of CW system)?

B.2 GLASS

1. Glass type:
2. Thicknesses of glass panels:
3. Coating type:
4. How many layers (single, double, triple)? If it is insulating glass, the thickness of the air gap between the panes?
5. What is curtain wall glazing type, structural clamps, structural sealant or pressure plate, cover cap anchors, and brackets?
6. Which requires your company found it necessary through the choosing of glass?
7. Heat gain coefficient, light Transmittance, u- value(thermal), acoustic, energy efficiency, reflections.
8. What is the treatment used at the glass for thermal and solar insulation?
9. In summer for resist, the high temperature did your company use a special kind of glass for this purpose and did you consider the sunlight?
10. What is the achieved U-value (thermal insulation) for glass and aluminium?
11. Deflection of the glass sheet based on the wind load in the facade's centre and the corner of the façade?

B.2 ANCHOR AND BRACKETS SYSTEM

1. What is the type of anchoring, either stick or unitized system? Material (Steel or aluminium)
2. What type of brackets has used?
3. Fixation methodology?
4. Movement accommodation by anchor slots in the brackets (vertically and horizontally)
5. where is the anchor located at the top of the slab or edge?

C. SPECIFIC QUESTIONS REGARDING THE WIND AND SEISMIC LOAD FOR THE CURTAIN WALL SYSTEM

C.1 WIND LOAD

1. Wind speed in the building Area?

2. Wind load considered during the design process?

3. How your company determined the wind load used in the calculations. For instance, according to regulations, or according to simulations, or according to wind tunnel test…?

4. What are the lateral movements you have taken into account? And how is it accommodating in your curtain wall system? (Wind load, seismic, thermal, live loads)

5. Concerning wind or some other reasons, if your company proposed different solutions at different heights or different orientations, e.g. different sized anchors at different heights due to increased wind load, wider expansion joints at certain orientations etc.?

6. What is the maximum deflection and stress in the curtain wall due to the wind load?

C.2 SEISMIC LOAD

1. What are the estimated earthquake loads?
2. How to consider the earthquake through the design stage, which criteria have followed?
3. What programs have used to evaluate the static calculation of the building façade (curtain wall and glass)?

4. Expected movement in the building structure and who was the façade have treated to resist?
5. What is the maximum story-drift?
6. What is the maximum deflation in the curtain wall that happens because of the seismic load?
7. How is the sealing and connection between the curtain wall and the building in all directions?

D. Sustainability

1. Are there sustainable specifications in selected curtain wall in LEED, BREAM, CRADLE TO CRADLE certificated?
2. What are the sustainability factors have achieved through the façade?

The questioners have four parts:

A. General questions
B. Specific questions regarding the curtain wall components
C. Specific questions regarding the Wind and seismic load on the curtain wall system
D. Sustainability

Name of interviewee:
…….
Name of company:
…….
Date of interview:
……

Name-Surname **:** Rusul Saad Ali Inizi

EDUCATION:

B.Sc. **:** 2014, Baghdad University, College of Engineering, Architecture department.