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Tuğçe ERARTSIN

23/12/2022

ANALYSIS OF INTERACTION BETWEEN CLADDING-CURTAIN WALLS AND STRUCTURAL SYSTEMS OF BUILDINGS

(M. Sc. Thesis)

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ABSTRACT

Today, curtain wall systems have been developed that are designed in accordance with a specific design decision, using different materials, which are not load-bearing, suspended on the main structural system of the building, limited to carrying itself only and acts as a shell separating the interior and exterior atmosphere of the building from each other. Since curtain walls are the elements suspended on the main structural system of the buildings and directly affect the structural system, the interaction between them is a configuration that directly affects the façade designs of the buildings. Since curtain walls systems start with the birth of high-rise buildings, it is not wrong to examine the structural systems of high-rise buildings for this reason, but it is an incomplete evaluation. This thesis presents some analyzes in order to explain the interaction between the façade cladding-curtain wall system and the main structural system, which is one of the factors affecting the design of the buildings in design phase. In the numerical analysis of high-rise buildings, height values and structural systems come to the fore rather than the interaction between the curtain wall and the main structural system. In order to evaluate and examine the façade-structural system interaction of buildings such as airports, shopping malls, culture and life complexes, which are called large-scale buildings, a 5-storey building was symbolized and analyzes were made. These analyzes consist of results that simulate the behavior of structures under certain loads by modeling them with SAP2000, one of today's digital design software. These numerical analyzes were evaluated by considering 4 symbolic buildings with the same structural system and different curtain wall geometries. This study constitutes a step to show that some decisions can be made at the building design stage without the need for advanced engineering calculations by examining the displacements and moments under wind load of buildings with curtain walls of different geometries. For future studies, these analyzes can be expanded to examine different façade cladding materials and their seismic behavior in addition to this purpose.

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ÖZET

Günümüzde cephe duvarlarının taşıyıcı olmadığı, binanın ana taşıyıcı sistemine asılarak giydirilen, taşıyıcılığı yalnızca kendini taşımakla sınırlı olan, binanın iç ve dış atmosferini birbirinden ayıran bir kabuk görevi gören, farklı materyaller kullanılarak estetik ve belirli bir tasarım kararı doğrultusunda tasarlanan sistemler geliştirilmiştir. Yapının yüksekliği, konumu, yapının kullanım amacı ve yapının strüktür sistemi yapılarda cephe oluşumunu etkileyen faktörlerdir. Giydirme cepheler binaların ana taşıyıcı sistemine asılan elemanlar olduğu ve ana taşıyıcı sistemi doğrudan etkilediği için aralarındaki etkileşim de binaların tasarımlarını doğrudan etkileyen bir konfigürasyondur. Giydirme cepheler yüksek binaların doğmasıyla başlayan elemanlar olduğu için, bu sebeple yüksek binaların taşıyıcı sistemleriyle incelemek yanlış değil ancak eksik bir değerlendirme olmaktadır. Bu tez yapılar tasarlanırken, tasarıma etki eden faktörlerden biri olan cephe kaplaması-giydirme cephe sistemi ve ana taşıyıcı sistem arasındaki etkileşimi açıklayabilmek için bazı analizler sunmaktadır. Yüksek binaların sayısal analizinde giydirme cephe-ana taşıyıcı sistem etkileşiminden çok yükseklik değerleri ve strüktürel sistemleri ön plana çıkmaktadır. Büyük ölçekli binalar olarak adlandırılan havaalanları, alışveriş merkezleri, kültür ve yaşam kompleksleri gibi binaların da cephe-taşıyıcı sistem etkileşimini değerlendirebilmek ve inceleyebilmek için 5 katlı bir bina sembolize edilerek analizler yapılmıştır. Bu analizler yapıların bazı yükler altındaki davranışlarını günümüzdeki dijital tasarım yazılımlarından biri olan SAP2000 ile modellenerek simüle edilen sonuçlardan oluşmaktadır. Bu sayısal analizler aynı ana taşıyıcı sisteme ve farklı giydirme cephe geometrilerine sahip olan 4 sembolik bina ele alınarak değerlendirilmiştir. Bu çalışma, farklı geometrideki giydirme cepheye sahip binaların rüzgâr yükü altındaki yer değiştirmeleri ve momentlerini inceleyerek, ileri mühendislik hesaplamalarına gerek kalmadan bina tasarım aşamasında bazı kararlar alınabileceğini göstermek için bir adım oluşturmaktadır. Gelecekteki çalışmalar için bu analizler genişletilerek farklı cephe kaplama malzemeleri ve sismik davranışları bu amaca ek olarak incelenebilir.

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SYMBOLS AND ABBREVIATION

In this study, the used symbols and abbreviations are explained below.

Symbols	Definition
cm	Centimeter
kgf/m^2	Kilogram-force/square meter
kN	Kilonewton
kNm	Kilonewton meter
kN/m^2	Kilonewton/square meter
m	Meter
mm	Millimeter
m^2	Square meter
Δ_X	Displacement in X direction
Δ_Y	Displacement in Y direction

Abbreviation	Definition
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
EC1	Eurocode1
UV	Ultraviolet
TS498	Calculation values of the loads to be taken in the dimensioning of the building elements – Design loads for buildings

1. INTRODUCTION

With the developing technology and increasing population after the industrial revolution, rapid developments have been made in the fields of architecture and engineering. People have started to have difficulties for shelter, which is one of their most basic needs. This problem has allowed the emergence of structures at unusual heights. The foundations of multi-storey buildings began to form in the city centers in this way, and they began to be built as the symbol and prestige of the city. Because every multi-storey structure of its period also represented the technology and power of the country and people in which it was located. For this reason, these structures are faced with more and more engineering problems every day. While trying to overcome these problems, the limits of the materials and systems used were forced and tried to be solved. Engineers and architects have tried to keep up with the constantly advancing and developing material and form technology while achieving these.

The problems that nature has brought forward in construction technology have been solved with engineered aesthetic steps. In particular, the horizontal loads that shape the façade and the structural system setup are met by the presence of the structural elements that shape the façade. Power lies in the most basic meaning of multi-storey buildings, which have different meanings in different locations. The buildings show what they want to tell with their shells. The first impression left by the buildings on silhouette and human perception is again these shells. These structures are fed by the technology of their age, the building materials used, the spatial setup of their time and the traditionality of their surroundings. If read in an architectural sense, these buildings express themselves with their structures. With today's technology conditions, the desire to go higher has always played a role in the development of structural systems of these buildings. As the role of the structural system grew and the buildings rose, it began to manifest itself and directly shape the façade design.

Today, façade systems have been developed that are not load-bearing, that are hung on the building structural system, that function as a shell by separating the building and the external environment, and that create aesthetics and visuality with different materials. Curtain wall systems are independent of the building structural system, only carrying their own weight and transferring the loads acting on them to the building structural system. From this point of view, it can be seen that building structural systems and curtain wall systems complement each other by developing together. While both systems show improvements in themselves, they both direct the design of the structures.

The interaction between the façade and the structural system has always been important, starting with the development of these systems, while the buildings are being designed and built. In order to prevent natural or artificial problems that may arise during or after the construction phase, it is necessary to make some analyzes during the design phase. This thesis addresses this issue by exploring the analysis of structures at the design stage so that such problems do not arise.

The study starts with the literature review of the basic typology of buildings, the construction techniques and background made with basic materials in the world, and comprehensive basic information about the building structural systems used in architecture. In order to examine the interaction between the façade cladding-the curtain wall and the structural system of the building, knowing the properties of the materials used in the façade and classification of façade systems, how these materials and the structural system of the buildings basically behave under environmental factors are investigated by researching in the literature. In the section that distinguishes this study from other studies, the study ends by making the necessary analyzes based on how the form of the buildings should be chosen while basically designing the buildings and the interaction of this building form with the main structural system of the building.

Background and problem definition

This study has been made so that architects can consider all the data that will shape the design while starting the design, not only for multi-storey buildings, but also for all structures designed curtains walls as façades such as airports, bus-train terminals. It is foreseen that the analyzes made in this study will be helpful in the design phase, without mastering the complex engineering calculations. In addition to the importance of building materials used aesthetically for façade design, it is emphasized that the analysis made in this study should be designed as a guideline in the architectural design phase, taking into account the interaction between the façade design and the building structural system.

The following study questions are the main focus of this study:

- Is there an interaction between the structural elements that shape the façades and the structural systems of the buildings? To what extent can this interaction be analyzed?

In order to answer these questions, the following sub-questions were also investigated:

- Considering the interaction between the façade components and the main structural system of the building, how can this interaction be integrated into the design at the architectural design stage?
- What and how do the buildings behave when the loads acting on the structures are basically analyzed without the need for complex engineering calculations? How do these behaviors affect the façade or the shell of the building?

Research hypothesis

Research hypothesis will be tested with sample examples which will be basically the same height structures designed in 4 different forms by using simulation research of the numerical analysis.

- Loads which are not considered and considered in design phase are important for the buildings.
- The behavior of claddings and curtain walls made of the same materials against the loads is related to the shape of the buildings.
- The main structural systems of the buildings are in direct interaction with the shapes of the curtain walls in the direction of external loads.
- Different forms of cladding and curtain walls of the buildings with the identical main structural system directly affect their behavior under lateral loads.

Research aim

The main objectives of this research are as follows:

- To examine and analyze the loads acting on the structures in the context of the shape-structural system of the structure.

- To make use of the analyzes made in shaping of the façade forms of the buildings during the architectural design phase.
- To ensure that not only civil engineers, but also architects are aware of the effects of loads acting on the structure in an uncomplicated order.

Significance of the study

This study is important in terms of enabling architects to make their own decisions about building calculations at the building design stage, with the help of the SAP2000 program, without relying on analyzes that require advanced engineering calculations, and to enable this. In this study, since the design conditions that require advanced engineering calculations are an obstacle for architects, it has been studied to see the potentials of doing this with simplified calculation methods. Since digital design has been of great importance in the architectural design, construction and assembly stages recently, it is vital to research and analyze that will contribute to this field.

Limits of the study

This study is based on the investigation of the façade that forms the architectural form and the structural system of the building. Since the effect of different forms in the same structural system under loads was examined in the study, different structural systems were not analyzed. Future studies need to investigate and analyze behaviors for examples in different structural systems and forms in addition to these analyses. This study has an interdisciplinary limitation as it relates the subject of curtain wall and structural system with simple engineering calculations.

Methodology

For this research, 4 buildings with different façade forms, the same structural system and the same height were selected to investigate the interaction between the façade cladding-curtain wall and the main structural system. In the analysis to be made to examine the interaction between the curtain wall and the structural system, the structural system of high-rise buildings will be more prominent with their feature of height, so in the analysis, 5-storey building samples have been analyzed. Height information is a very important data when examining the interaction of façade and structural system of high-rise buildings. The example of a 5-storey building has been taken into account by considering the buildings where the curtain wall is at the forefront, such as airport structures, culture and life complexes, train stations and shopping centers, which can be described as large buildings. Structures with different curtain wall geometries were modeled in SAP2000 software and the same magnitude of wind loads were applied to all of them to observe the behavior under load. The behavior of the curtain wall under the applied wind load is examined and the results and simulation images of all are listed. The analysis process of this study was done as digital modeling in computer environment. As a result of this research, the experiences at each stage were noted and evaluated.

2. INTERACTION BETWEEN CLADDING AND STRUCTURAL SYSTEMS

While determining the architectural form, architectural purposes such as spatial organization and flow control of the vitality that will continue there are taken into consideration. Architectural form is also related to the perception of space created by the building on people, its location and its symbolic meaning in the city. What matters to the structural form is primarily determined by the structural requirements to support gravity and lateral loads. Another important part of determining the structural form is to create a building envelope to protect against the outside. A carefully designed structural form can provide endless aesthetics for architectural form. Structural form can define the visuality of a building with its structural elements such as elegant columns that are exposed to the outside as well as ensuring the strength of the building. While the architectural form emerges as decorative, the structural form is seen as the transformation of creativity into mathematics and economy (Saliklis, Bauer, & Billington, 2008). With the developing technology, the ability of structural engineers to calculate the stresses and determine the forces in the structural elements also provides the formation of elegant structural forms.

2.1. Basic Typology of Structural Systems of Buildings in Architecture

The characters of cities in the world are shaped not only by their natural landscapes, but also by the buildings constructed. Not only investors, but also societies want buildings to have a modern appearance without compromising their service life. In order to meet these requirements, in addition to modern technology, material and form selections must be made accordingly. A building should be able to meet all kinds of needs of its inhabitants according to its purpose. Even if a building cannot provide functions and comfort, it will need some changes that will show this need over time. Form is a three-dimensional object or structure perceived by the observer, made possible by the effect of light and shadow. In this study, buildings as physical forms are gathered in four basic groups as regular buildings, buildings with unusual geometry, low-rise buildings and high-rise buildings.

2.1.1. Regular buildings

Structural form has an effect on strength and rigidity level of buildings. The shapes and size of the structural elements, the direction of their longitudinal axes according to the load applied on them, determine the types of internal forces developing in them and affect the magnitudes of these forces. The structural element and the structural form determine the type and magnitude of the internal force created under a certain load, as well as the nature of material to be selected for the elements. In this way, it has a significant impact on the level of structural efficiency (Macdonald, 2018: 37).

It is possible to call regular shaped structures as prismatic shaped structures. At the end of the 19th century, in the light of economic and social factors, multi storey buildings came into existence by getting rid of religious and cultural functions and by taking on functions such as housing and trade that foresee intensive use. The first buildings built in this period are examples of bulky masses influenced by the dominant architectural styles, which could not get rid of ornamentation, and where vertical and horizontal loads were met by thick stone walls. In these structures, as the height increases, the wall thickness also increases, which leads to a decrease in the usage areas on the ground (Tuğrul, 2014).

The 16-storey Monadnock Building, see in Figure 2.1, which was built in Chicago in 1891 and has a regular shape, is considered to be the most advanced point reached by the masonry wall system built in this period. This structure, which consists of masonry walls on the outside and iron frames on the inside, has 2.13 m thick walls on the ground. These walls not only occupy 15% of the gross area, but also prevent natural light and natural ventilation on the floor (Y. L. M. Chew, 2017: 1-2).

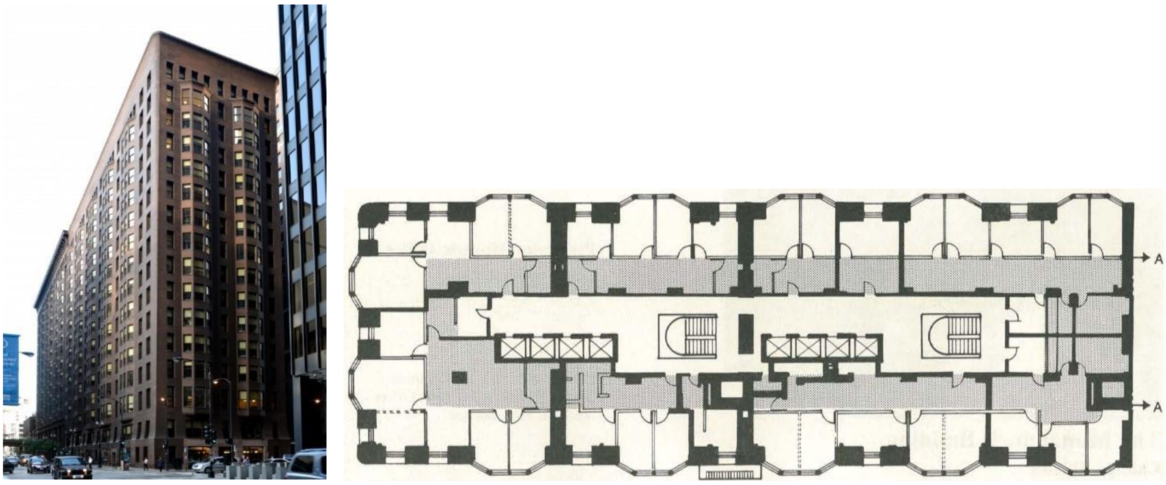


Figure 2.1. Monadnock Building (left) (URL-1), Monadnock building plan (right) (URL-2)

The first multi storey buildings, carried with iron frames and masonry walls, continued their morphologically prismatic form for a while with the discovery of steel frame and glass curtain wall over time. In the following period, depending on the wind factor, pyramidal shaped tall structures emerged with the logic of reducing the surface at the upper points where the wind was most affected. When the era of super-high buildings was entered, unusual geometrically shaped tall buildings began to be designed with aerodynamic concerns and the development of technology.

2.1.2. Unusual geometry of building structures

Today, architects tend to construct aesthetic, unusual geometrically shaped structures that push the boundaries of architecture, apart from the usual prismatic mass form in multi storey buildings, in line with both aesthetic concerns and aerodynamic requirements. In the past, this trend often got stuck in the structural system and could not go beyond being a conceptual project. Today, thanks to innovations in structural systems and developments in computer software, it is possible to design and produce all kinds of shapes. There are 3 basic steps to be followed in the creation of unusually shaped tall structures (Tuğrul, 2014):

- Design based on wind and seismic load,
- Selection of a suitable structural system for the form,
- It is the use of computer software to generate shapes and solve the equations required for the analysis of complex structural frames.

The load-bearing system, which must be applied in extraordinary ways, which is a current approach in high-rise buildings, is also different from the common systems. Thanks to structural systems such as mega column and mega core systems, sheared frame systems, tube systems, diagrid systems, it is possible to implement unusual geometrical shaped tall structures. As shown in Figure 2.2 the 35-storey 160-meter-high Capital Gate Building in Abu Dhabi and the 54-storey 190-meter-high Turning Torso in Malmö can be given as examples of today's unusual geometrically shaped tall buildings.

Figure 2.2. Capital Gate Building (left) (URL-3), Turning Torso Building (right) (URL-4)

2.1.3. Low-rise buildings

Low-rise buildings are defined as low structures with roofs less than 15 m high (Holmes, 2007: 195). These structures were used for all needs before tall buildings became popular. Hotels, schools, residences, business centers were built at certain heights, which we can call low-rise buildings, with the technology brought by the era. According to Emporis Data Standards, a low-rise building is a closed structure with an architectural height of less than 35 meters and regularly divided into habitable floors. It covers all closed regular multi-storey buildings that are below the height of a tall building and are not completely underground (URL-5). Most of the structural damage in windstorms around the world comes from these low-rise buildings, particularly family residences, which are often non-engineering and poorly maintained (Holmes, 2007: 195). As the height of the buildings increases, the structural system options decrease. The choice of structural system is also very important in low-rise buildings. Because at this point, cost plays a role in efficiency. Low-rise buildings can be residential houses, hotels, public institutions that are not in city centers. Since the range of structural systems is wide, the range of material selection is also very wide in low-rise structures.

2.1.4. High-rise buildings

The concept of high-rise building is constantly changing over time, renewing and developing itself. When the changing needs and living conditions are considered within the structure, it has started to function in different dimensions compared to the past. There is no single definition accepted worldwide for high-rise buildings. The definition of high-rise building may vary according to country, state, city, even professional disciplines (architect and civil, mechanical and electrical engineers, etc.) and regulations. Definitions can be based on the number of floors or the total height of the building (Tunca, 2019). High-rise buildings are defined in various ways by architecture and connected with architectural disciplines. Some of these definitions are:

- Emporis Data Standards calls buildings between 35-100 meters high or with a floor number of 12-39 as high-rise buildings (URL-6).
- Buildings with more than 20 floors are skyscrapers (Hasol, 1979).
- According to The Council on Tall Buildings and Urban Habitat (CTBUH), a building with 14 or more floors or 50 meters/165 feet high can be used as the criterion for the definition of "tall building". Tall buildings reaching significant heights are classified into two additional subgroups: Tall buildings 300 meters/984 feet or more are defined as “supertalls” and tall buildings 600 meters/1,968 feet or taller are defined as “megatalls” (URL-7).
- ASHRAE Technical Committee for Tall Buildings, TC 9.12, defined buildings higher than 91 meters/300 feet as tall buildings (Simmonds & Zhu, 2013).
- All buildings with a height of more than 22 m in Germany are classified as high-rise buildings and are divided into two subgroups. It is divided into buildings larger than 22 m but shorter than 60 m and buildings larger than 60 m (URL-8).
- In Russia, the definition of a tall buildings is which are at least 75 m (Generalov, Generalova, Kalinkina, & Zhdanova, 2018).

Since the concept of height is relative, there is no common and definite opinion about the height or number of floors a tall building should be. The growth due to the increasing population and increasing work intensity all over the world has been continuing since the beginning of urbanization. In proportion to these, it is a fact that has emerged and will emerge that the buildings rise more and more as time passes. At the same time, high-rise buildings built as prestige structures of cities have emerged as an option to eliminate the problem of housing. Although high-rise buildings are built as a necessity of urbanization today, they are also built as impressive structures (Öztan Fidan & Güven, 2019). Tall buildings are structures that have to relate to the city because otherwise they can cause great problems for the future of urban life. Since the technological conditions of the country in which they are located are used in high-rise buildings, they become a political symbol. Progress in construction technology has played a greater role in the development of tall buildings compared to other types of construction. The development in vertical circulation has allowed it to go to higher heights by giving itself to steel instead of iron (Günel & Ilgın, 2014: 8). With the discovery and development of the column-beam-frame system, high-rise buildings continue to increase and compete.

2.2. Materials And Construction Techniques in Building Design in Architecture

2.2.1. Masonry buildings

Using concrete blocks, bricks, stones or other stacked modular elements, the wall construction is completed and the walls and the structure itself are created. These walls are called masonry walls and the structure is called masonry structures (Yu, 2013: 5). It is one of the oldest and most durable construction methods. It is possible to come across these structures in the history of all cultures that have stone and brick production. These buildings, which are made of extremely durable materials and are robust, can be found in surviving examples from past times. Each component part of the structure is positioned overlapping one another. To withstand external loads, these structures use their own modular elements weight. Modular elements of masonry structures are structurally efficient in compression, however their resistance to perpendicular tension forces is weaker.

Loads acting on masonry structures include their own weight, floor loads, roof loads and loads due to other environmental effects. All these mentioned loads must be transferred to the floors and ground by of masonry elements. When defining the load bearing capacities of masonry buildings and their elements, it is necessary to consider the interaction of the masonry unit and the mortar. The behavior of the masonry walls against the load is made possible by the bond between the masonry unit and the mortar. The bond ensures that the horizontal forces and vertical forces between the masonry unit and the mortar are evenly distributed throughout the building. The situations that can be called failure in masonry structures are as follows: The deterioration of the masonry unit used in the building, the deterioration of the mortar and the deterioration of the bond between the mortar and the unit. While the strength of the masonry unit used in the building is determined by the type, geometry and size of the material, the strength of the mortar is determined by the joint thickness and type (Pfeifer, Achtziger, Ramcke, & Zilch, 2001: 92-132). Another issue that affects the strength of the structure is the production quality and workmanship standards.

2.2.2. Timber buildings

Wood is a sustainable material that is completely compatible with nature and is easy to recycle, has a very good strength compared to other building elements compared to its density, is compatible with other building materials and can be very long-lasting when used correctly (Çalışkan, Meriç, & Yüncüler, 2019). With the effect of the Industrial Revolution in the 19th century, the use of new products in the construction sector together with the technological developments, especially the widespread use of stone and brick masonry systems, the emergence and application of steel and reinforced concrete construction systems, the use of wood as a structural material in buildings decreased (Bilici, 2006). The methods of wood frame construction, which is rarely used today, has horizontal, vertical and diagonal supports in the plane of the wall. In past examples, the cross-sections of the elements are large because they are not derived from a structural analysis (Söffker & Deplazes, 2005: 97).

Wood is a material that is frequently used in construction practice as a building element. This is because of its many advantages. In particular, the reasons such as being a renewable material, easy access to its source, easy to carry and assembly to the area where the application will be made, being light and yet giving good strength values, being easy to maintain in all kinds of natural conditions, as well as being able to be produced in these weather conditions have made wood material attractive (Algın, Algın, & Ekmen, 2016).

Although it has sufficient strength, it is a very light material. As a result of the lightness of the material, the dead load of wooden buildings is reduced, and the dimensions of the foundation and other load-bearing elements are reduced. It is good in terms of thermal insulation and resistant to chemical effects and acids. It is resistant to water and humidity. When it is not protected, it absorbs water easily, swells as it absorbs, shrinks after the water dries and causes cracks to form. Its structure is not homogeneous, it is an anisotropic material. The material properties at all points and directions are not equal. Due to its fibrous structure, it has high compressive and tensile strength in the fiber direction and lower in other directions (Çalışkan et al., 2019).

2.2.3. Steel buildings

The use of structural steel first began in the 19th century in the construction of bridges, roofs, and simple one-story buildings. Since the beginning of the 20th century, when the upward trend in buildings arose, it began to be used as the skeleton of multi-storey high-rise buildings (Vayas, Ermopoulos, & Ioannidis, 2019: 295-297). It has started to become preferable as it shortens the construction period and offers structural advantages. Steel, with its strength and flexibility properties, has offered more advantages compared to traditional construction methods and has become a more suitable solution. Structures made of mostly steel, steel frames as skeletons, concrete slabs to resist vertical loads, and brick walls for lateral stability. Buildings, which more than half are made of steel, are more preferred in locations where seismicity is high, such as Japan. In addition to the seismicity as advantage of steel structures, their sensitivity to corrosion and fire is a disadvantage. Steel framed construction is the most efficient and cost-effective construction type for tall buildings. Due to its high strength compared to the lightness of steel, ease of production and assembly, and ease of logistics, it is a building material preferred all over the world for medium-rise and high-rise buildings, especially for supertall and megatall buildings. Steel structural systems are classified according to the number of floors of the building to be applied.

Steel resists better under tensile stresses and forces than concrete. Concrete needs to be reinforced with steel under tension. Steel columns and beams are lighter than concrete that performs the equivalent function. Compared to concrete, the behavior of steel structures is more predictable (Baker & Skidmore, 2013). The construction of precast light steel structures for residential purposes is increasing, due to the ease of manufacturing and the ease of processing of the steel frames to the site, reducing labor and production costs. Steel structures can generally be made more resistant to lateral loads by producing trussed frames or moment resistant frames. Steel structurally has a high resistance to tension. High strain occurs in steel structures where high stress is obtained (Ambrose & Vergun, 1997: 37). This can cause deformations and damage to non-structural elements of the structure. Therefore, deformation analysis is an important point in the design of steel structures, especially for moment resisting frames.

2.2.4. Reinforced concrete buildings

One of the general purposes in choosing a structural system is to minimize the amount of material. Many benefits make concrete a useful and widely material, including economy, functionality, shaping properties and resistance to long-term failures (Koç, Gültekin, Durmuş, & Dikmen, 2009). It can be constructed by cast-in-situ construction or with precast elements. In the early days when reinforced concrete started to be used, structural engineers realized that reinforced concrete was more advantageous than steel structures. The first noticeable advantages were lower cost of construction and resistance to fire. Tall concrete buildings have larger bearing elements and greater mass than tall steel buildings. This helps to minimize the perception of lateral displacements and sway and provide stability against wind and seismic loads (Rizk, 2010). Concrete structures have become more popular because the cost is lower than steel structures. Since the strength of reinforced concrete is less than that of steel, the cross-sections of structural elements such as columns and beams should be larger. This enlarges the area where the building sits. In order to eliminate this problem, high-strength concrete and precast/prestressed concrete are used as different design methods with the developing technology (Dasgupta, 2021: 76-77). Prestressed concrete elements are mostly used in bridges and prefabricated buildings. The type of cement used in reinforced concrete structures and the mixture of the aggregate are the most important factors affecting the fire resistance of these structures. Depending on the type of aggregate used, the strength of the concrete and therefore the strength of structure is increased, while the fire resistance may not be in the same proportion (Reynolds, Steedman, & Threlfall, 2007: 40-41). According to Ashraf (2017: 32-33) , in reinforced concrete buildings, there are two different systems to transmit lateral loads from external effects to the ground. Moment resistant frames and shear walls, or a combination of the two. Moment resisting frames consist of beams and columns that resist loads. Columns are designed for axial forces and bending, while beams are designed for bending and shear. In the shear wall system, beams and columns resist the gravity load, while shear walls are designed to resist lateral loads.

2.3. Classification of Bearing Systems Used in Building Design in Architecture

The load-bearing systems applied in the buildings vary depending on whether the material used is steel, reinforced concrete or composite, the number of floors of the building, architectural planning and purpose of use. According to the idea put forward in the 1960s, regardless of the material type of the structural system of the building; Frame systems are recommended for buildings up to 30 floors, tube systems with different effectiveness for buildings between 30-100 floors, and tube systems with completely cantilever behavior for buildings higher than 100 floors (Iyengar, 1972, as cited in Sev, 2001). As shown in Figure 2.3, in another classification method, steel and reinforced concrete systems are considered separately for tall buildings, considering their heights. However, the structural systems determined for heights for this classification should not be considered as a definitive rule. For example, the 102-storey Empire State Building was built with the rigid frame and curtain wall system recommended for structures with less than 40 floors (Khan, 1972, as cited in Sev & Ozgen, 2009).

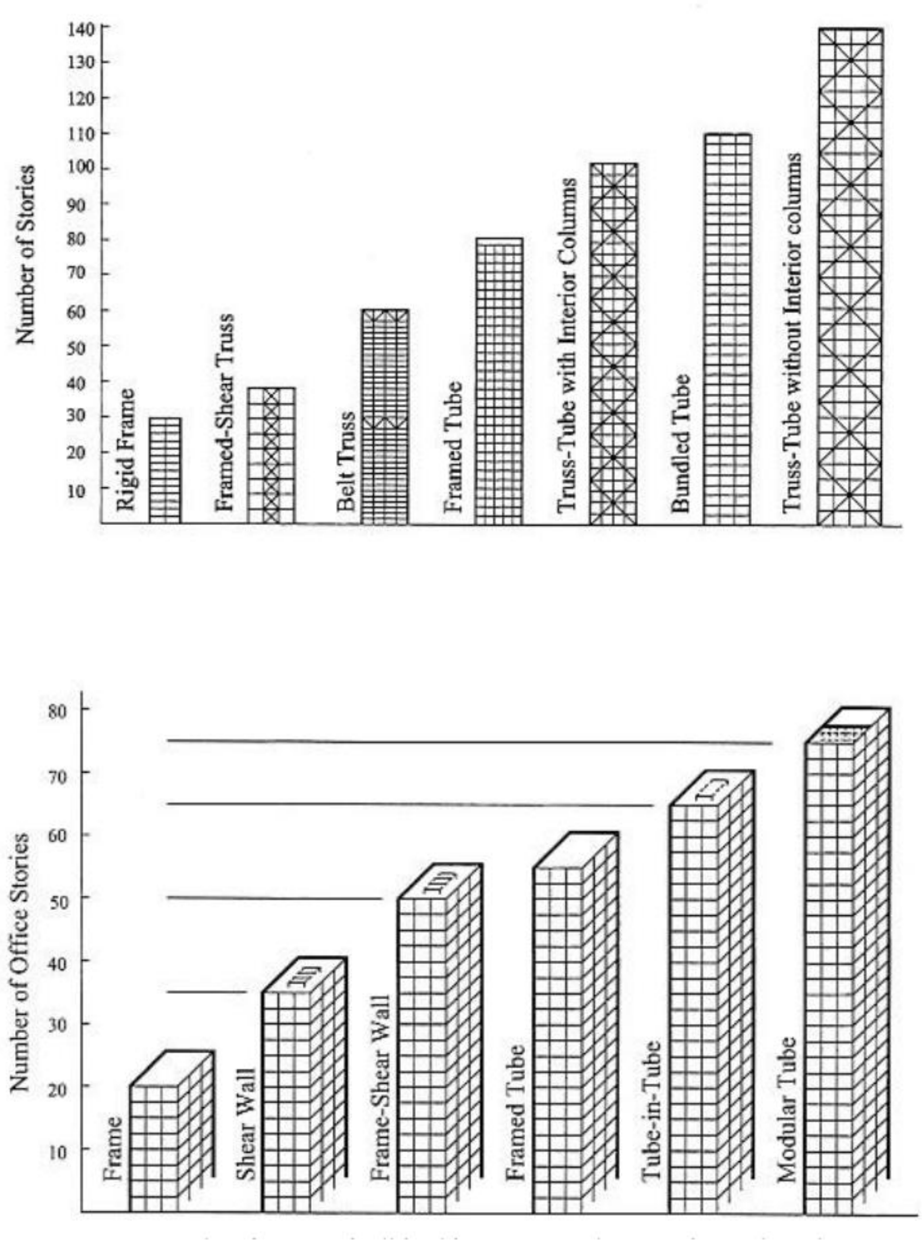


Figure 2.3. Classification of tall building structural systems by Fazlur Khan (above: steel; below: concrete) (Ali & Moon, 2007)

Ali and Moon (2007) brought a new approach to bearing classification by considering the distribution of the lateral loads of the structure on the building as seen in Figure 2.4. If the majority of the building's resistance to lateral loads is located inside the system, it is classified as interior structures. If the majority of the loads of the building are covered by the external system, it is classified as exterior structures. This classification includes both primary structural systems and auxiliary damping systems. In order to determine the best height in high-rise buildings, the classification of structural systems according to their resistance to lateral loads has been preserved as before. A few elements of the system may be internal or external; where it is the density that affects the classification. The main purpose of this classification was to bring the structure-based classification to the forefront by reducing the effectiveness of height.

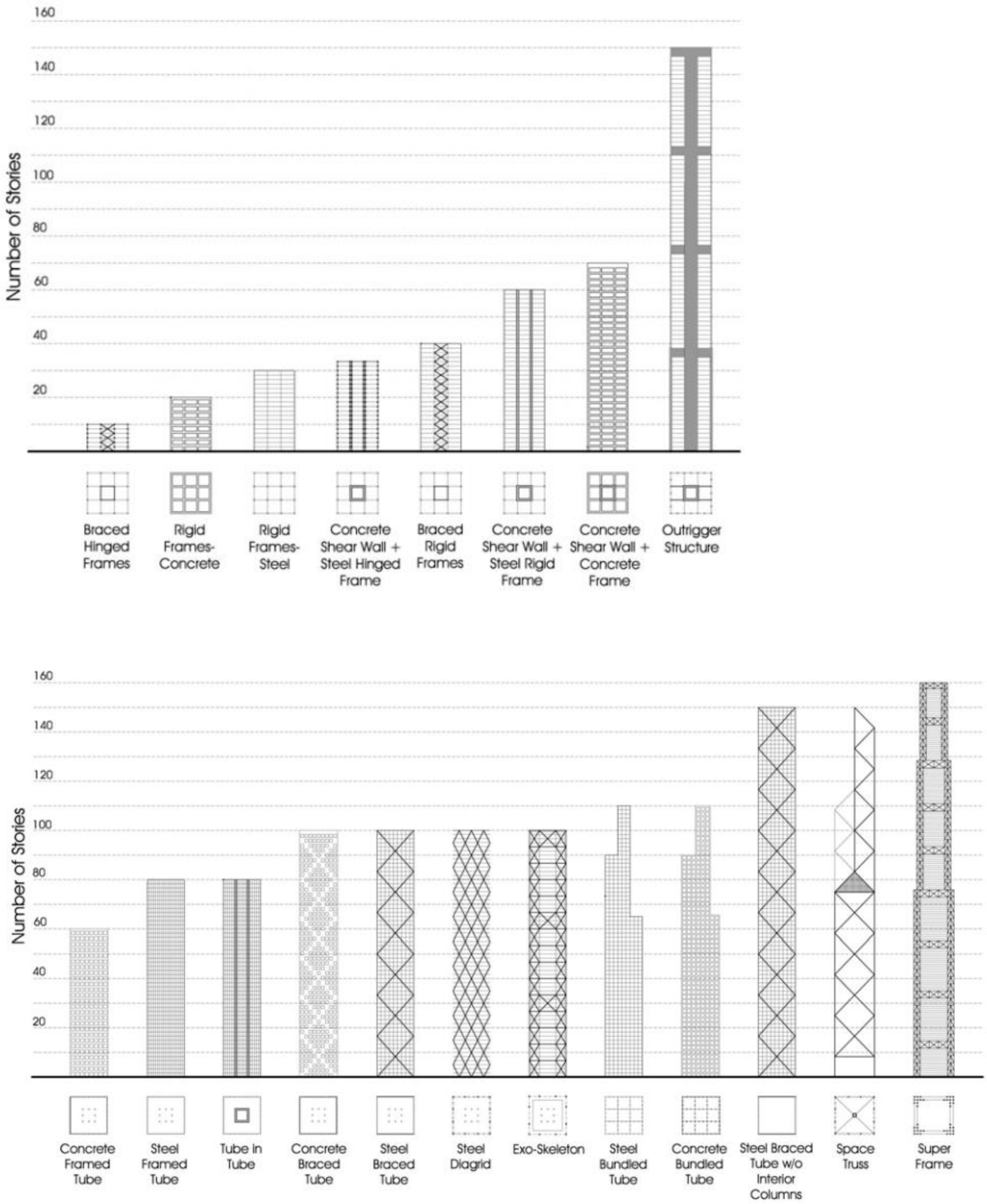


Figure 2.4. Interior Structures (above), Exterior Structures (below) (Ali & Moon, 2007)

In the design of the structural system, the share of horizontal loads in the dimensional calculation of the structural members should not go beyond what is necessary for transmitting the vertical loads. For this reason, resisting the earthquake and wind forces that increase with height should be provided not by increasing the cross-sectional dimensions of structural members, but by the efficiency of the structural system. Load bearing systems in multistorey buildings vary according to the type of material used, the height of the building, the number of floors and the function of the building. As the height of the building increases, the resistance of the building against swaying, that is, against lateral loads, should increase.

In the past engineering structures, columns and beams forming a rigid frame system were not sufficient to resist the lateral forces. In order to meet this situation, shear walls and rigid frames were used together. Other systems emerged as time passed and technology progressed, with improvements made through engineering. Types of load bearing systems used to transfer horizontal and vertical forces acting on tall buildings; It can be classified as frame system, shear wall system, frame and shear wall system, core system, tubular system, outrigger system and diagrid system. In this study, the classification is made by examining the lateral load resistant systems commonly used for high-rise buildings.

2.3.1. Rigid frame system

A rigid frame, also called a moment frame is designed to resist lateral loads from moment interaction between columns and beams. First, the rigid frame system is a structural system developed for multi-storey reinforced concrete and iron structures in the late 1800s. As time passed and structures began to increase in height and decrease in weight, it was assumed by the engineers that the lateral loads were generated by the frame itself (Taranath, 2016: 2-3). In addition to vertical forces in buildings, horizontal forces such as earthquakes and winds must be carried and transmitted to the foundations. For this reason, a structural system that carries vertical and horizontal loads together should be designed. In this context, frame systems formed by rigidly interconnecting columns and beams have emerged.

Frame systems in high-rise buildings commonly consist of vertical columns and horizontal beams formed with rigid connections (see Figure 2.5). The rigid frame is basically based on the principle of keeping the angles between the intersecting elements unchanged under the influence of vertical and lateral loads. For this reason, reinforced concrete is an optimum material for the rigid frame system and provides rigidity in its connections (Günel & Ilgın, 2014: 22). The strength of these structural systems, in which reinforced concrete and steel materials can be used, against horizontal loads depends on the rigidity of the connection points. Rigid frame is economical for steel structures up to 30 stories and for reinforced concrete structures up to 20 floors (Işık, 2008). The main advantage of the frame system is that it provides freedom in the arrangement of spaces such as windows and doors in planning. Frame systems are plane frames and space frames in terms of computational methods. Plane frame systems are structural systems consisting of columns and beams in the same vertical plane. Space frame systems are structural systems consisting of a large number of planar frames parallel to each other and joined by horizontal beams (Koç et al., 2009).

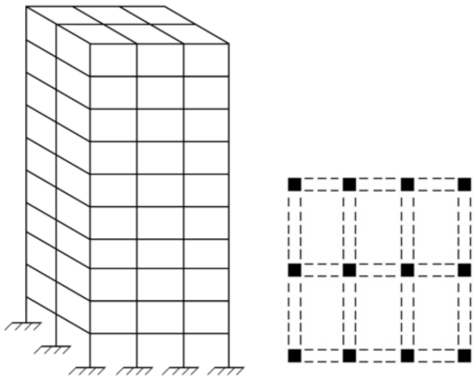


Figure 2.5. Rigid frame system

2.3.2. Shear wall system

In history, structural systems with load-bearing walls started as heavy and thick masonry walls. As the number of floors of the buildings increases, the increase in wall thickness has eliminated the usability of these systems. However, the development of contemporary building materials and construction methods has brought the shear wall systems back to the fore. Above 8-10 floors building height, frame systems are insufficient to carry horizontal loads. In this case, "shear walls" are formed by arranging the fixed partitions to be built in the building to resist vertical and horizontal loads (A. Güler, 2001).

Shear walls are vertical planar diaphragms that act as vertical cantilevers, providing the structure more rigidity against seismic and wind forces than frame systems (Harmankaya & Soyluk, 2010). It is possible to divide the shear wall system into two as open and closed. The open shear wall system is formed by single plane elements and their incompletely closed form. Closed shear wall system is formed by combining multiple plane elements to form a box. The arrangement created in this way is called the core (Köksoy, 2001) (see Figure 2.6).

Shear wall systems are commonly used to form service core and circulation cores in high office buildings. In contrast to office buildings, smaller cores are used in high-rise residential buildings, which require less service space, elevators and lobby. Because shear walls used in elevator and service core, they provide resistance to fire because of their certain thickness. However, the construction processes take much longer time than the steel elements, which makes the building construction process longer.

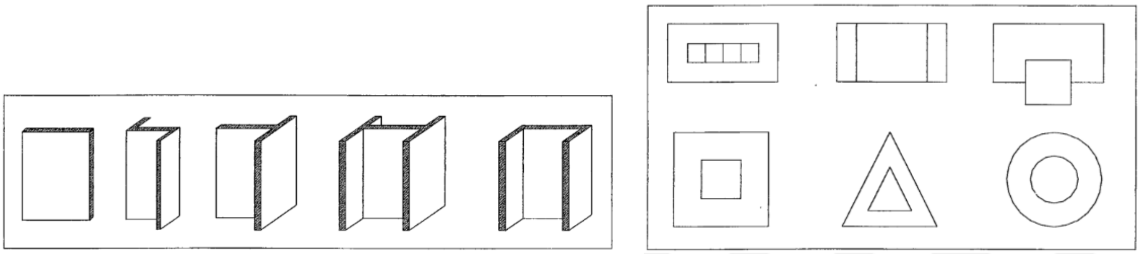


Figure 2.6. Open shear wall systems (left), Closed shear wall systems (right) (Köksoy, 2001)

Core systems consisting of reinforced concrete shear walls can be formed in 3 ways: steel hinged frames with reinforced concrete shear walls, rigid steel frames with reinforced concrete shear walls, and concrete frames with reinforced concrete shear walls (Tuğrul, 2014). Since the 1970s, steel plate shear walls have been used in the USA and Japan to create more resistance to seismic forces as seen examples in Figure 2.7. There are some advantages to using a steel shear wall instead of a reinforced concrete shear wall to resist lateral loads (Astaneh-Asl, 2001).

- The steel plate shear wall system has high initial stiffness and is therefore resistant to lateral displacements.
- Compared to reinforced concrete shear walls, it has a much more lightweight mass and this causes the foundation and columns to carry less load. Less weight of the structure also causes less seismic load.
- With the advantage of the steel construction material, the assembly and construction time is shorter than the reinforced concrete shear walls.
- Since steel plate shear walls are thinner in thickness, they allow the use of more net space in buildings.

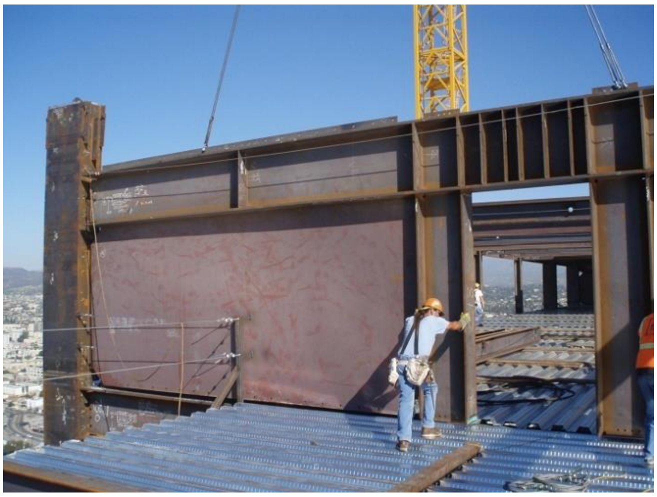


Figure 2.7. Steel plate shear wall examples left (URL-9), right (URL-10)

2.3.3. Frame and shear wall systems

Frame system or shear wall system alone may not always provide the desired height. Fazlur Khan observed that after these two systems were brought together in a single structure, they did not act independently of each other, but acted together as a single system against horizontal loads (Ali & Al-Kodmany, 2022) (see Figure 2.8). The distribution of lateral loads on the frame and shear walls in multi-storey buildings depends on the stiffness properties of the connections between them. The rigidity of the structure increases as a result of the linear sliding of the frame combined with the parabolic sliding of the shear wall under the effect of horizontal load. The sliding of the shear wall is prevented by the frame on the upper floors, and the sliding of the frame is prevented by the shear wall on the lower floors (Sev, 2001). Care should be taken at the design stage as a shear wall with voids can act as a frame.

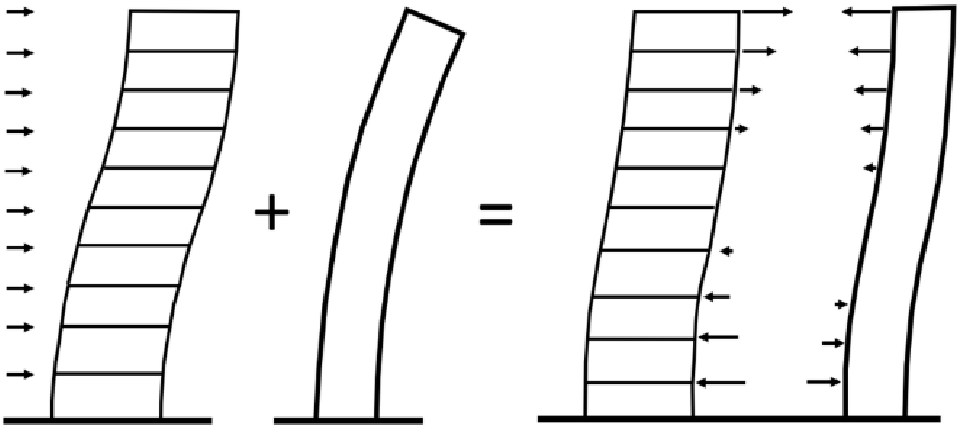


Figure 2.8. Shear wall-frame interaction system under lateral loads
(Sketch by K. Al-Kodmany, Ali & Al-Kodmany, 2022)

Since shear walls are prestressed due to the pressure forces caused by gravity loads, they increase the shearing capacity of the structural system against shear forces. Frames, on the other hand, undergo shear deformation under horizontal load, the displacement between floors depends only on the shear force at that floor. Therefore, the largest strain value is at the base. On the other hand, the biggest deformation is at the top as the shear walls are in bending effect and act like cantilever beams. Due to these incompatible deformation characteristics of these two systems, non-uniform interaction forces arise between these elements. While the core is pulled back in the upper part of the structure, it is faced by the shear wall in the lower part (Işık, 2008). Thus, shear walls help the frames by supporting most of the horizontal loads. Frames, on the other hand, reduce the horizontal effects by reducing the great rigidity effect of the shear walls and increasing the ductility ratio of the overall system.

If there are different materials used in structural systems consisting of Frame-Shear Wall combination, the necessity of connecting them to each other with rigid flooring elements in order to safely overcome the problems caused by their different rigidities offers limited design possibilities in the area where it is applied. If there is no material difference between the structural systems, if the building is higher than 30 floors, the diagonal elements used because of the need of connecting the frame and core to each other also cause restrictions on the façade (Harmankaya & Soyluk, 2010).

2.3.4. Core systems

Core systems are the most widely used system to ensure stability, especially in multi-storey buildings. In general terms, the core refers to a shaft containing the vertical circulation systems, energy distribution systems of a structure and is usually formed as reinforced concrete but can also be formed as a steel and steel-reinforced concrete combination. The dimensions of the core systems vary according to the purpose and area of use of the building.

As the advantage of core systems, elevators and stairs provide fire resistance as they are located in cores formed by rigidly joined shear walls. The cores can be triangular, square, circular or rectangular in shape. The behavior of core systems against lateral loads depends on the shape of the cores, their homogeneity, the level of stiffness, and the direction of the load. In core systems, slabs can be hung on the core, working like a cantilever (Köksoy, 2001). Composed of individual plane elements, load-bearing shear wall systems are well suited to buildings such as residences and hotels where functions and user requirements are specific and precise. However, today, large areas and free plan conditions are required in office and commercial buildings. Flexibility in these large spaces is provided by temporary or movable partition elements. In this case, it is difficult to install the necessary shear walls inside the building, but they are also necessary to resist the loads. For this reason, core or cores formed by combining shear walls are used especially in office buildings. Like shear walls, cores can be arranged inside or on the façade of the building (Koç et al., 2009). In core systems, since the structural system creates the core itself, there is no need for vertical restrictive columns, and thus the plan-façade design is liberalized.

In order to provide the necessary and sufficient resistance to horizontal loads, the gaps for doors, windows and mechanical system gaps in the core must be small, and it is useful to design cores by changing their position in the plan between floors (see Figure 2.9) (Özgen, 1989, as cited in Kırkan, 2005). The important features of the cores can be listed as follows (Özgen, 1989, as cited in Kırkan, 2005):

- Location of the cores: Inner (a), perimeter (b) or outer (c)
- Shape of the cores: Open (d), closed (e)
- Number of cores: Single (f), multiple (g)
- Arrangement of cores: Symmetrical (h), asymmetrical (i)
- Core-building geometry relationship: Similar form (j), different form (k)

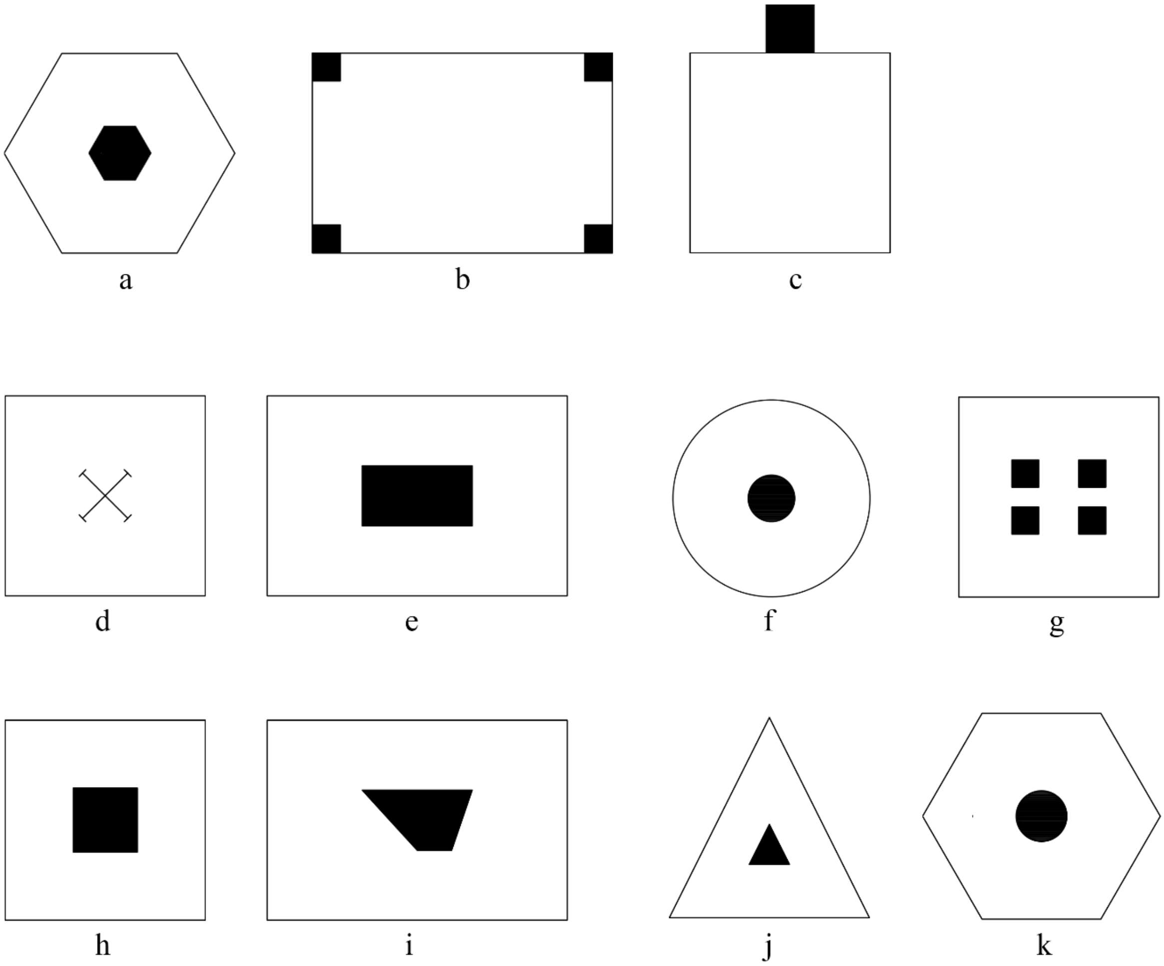


Figure 2.9. Classification of core systems

2.3.5. Tubular systems

The tube system is a structural system developed by Fazlur Rahman Khan in the early 1960s. It can be likened to a column rising from the floor as cantilever. It was first used in the 43-storey, 120 m high DeWitt-Chestnut Apartment Building in Chicago, in 1966. The tube system is basically the development of the rigid frame system. It can be thought of as a three-dimensional rigid frame capable of withstanding all lateral loads with the façade of the building. In tubular design, the stiffness of the structural system against lateral loads can be increased with the following solutions (Günel & Ilgın, 2014: 71-72):

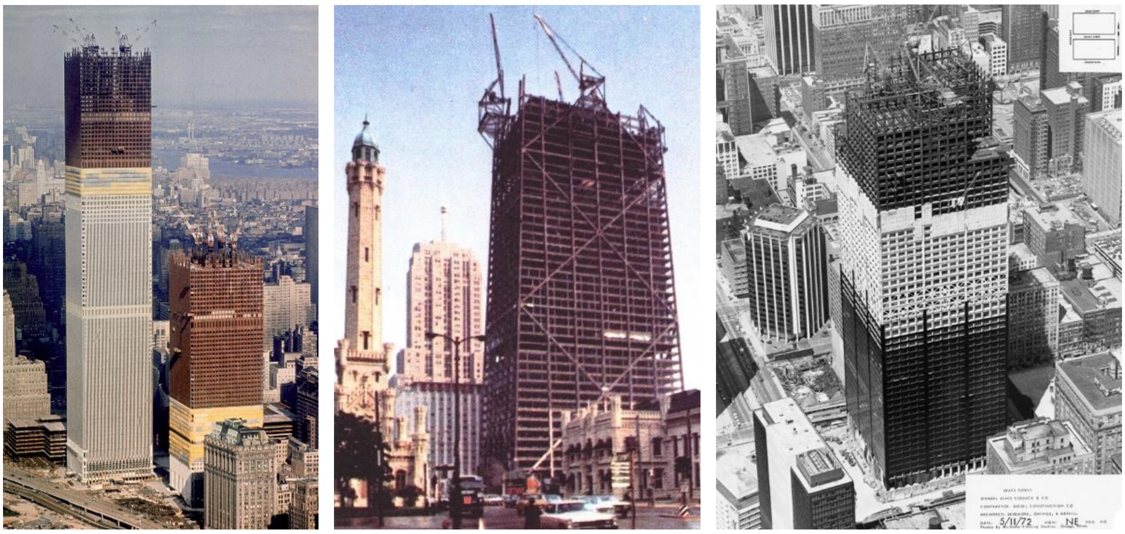
- Increasing the distribution of perimeter columns
- Increasing the depth of the perimeter beams to which the perimeter columns are attached
- Addition of shear trusses/braces or shear walls to the core
- Addition of an inner tube in place of the core (tube-in-tube)

- Addition of a truss (multi-storey braces) to the building exterior (trussed tube)
- Combination of more than one tube (bundled tube)

The tube is very rigid and resists horizontal loads similar to a cantilever beam. Tubular systems not only increase the structural efficiency compared to the framed systems, but also save 50% from the structural material. Thus, it allows the construction of lighter buildings. Structural designers show tubular systems as the most effective, most economical and safest structures among tall building structural systems (Harmankaya & Soyluk, 2010). While the outer tube is designed to resist all of the lateral loads, it is assumed that the inner structures resist the vertical loads. These systems can be used efficiently in buildings with 40 floors and above. There are four subcategories of this structural system (Taranath, 1998, as cited in Sev & Ozgen, 2009).

- Framed-tube systems
- Trussed (braced)-tube systems
- Tube-in-tube systems
- Bundled-tube systems

As seen in Figure 2.10, the framed tube system was used for the collapsed World Trade Center Twin Towers (1974) in New York, a braced tube (1969) for the John Hancock Building in Chicago, and a bundled tube system for the Willis Tower (formerly the Sears Tower) (Cruz, 2013: 270). A feature of all of these structures is that their façades are determined by the structure of the building itself. Although the emergence of all tubular façade elements is a structuralist expression from the outside, it can also be considered as a window arrangement from an architectural point of view. The wall-window systems between the column and span beams cause to reduce the coating costs.



a b c

Figure 2.10. World Trade Center Twin Towers (a) (URL-11), John Hancock Building (b) (URL-12), The Sears Tower (c) (URL-13)

<u>Framed-tube systems</u>

Moment resistant tubular frames consist of rectangular or square columns and rectangular beams. Column spacings can typically vary between a value slightly less than storey height and a storey height value. As the building height increases, the column and beam sections are designed as larger rectangles to meet the bending resistance, and with this, the need for closer column spacing arises. The framed tubular systems are designed to have equal bending stiffness of columns and beams (Sarkisian, 2016: 138).

<u>Trussed (braced)-tube systems</u>

Trussed-tube systems (also known as braces tube systems) are obtained by adding cross members along more than one storey height to the outer surface of the framed tube system. Thus, by increasing the structural rigidity and efficiency, the column spacings are wider compared to the frame tube system. Atabey (2019) states that, in steel buildings, more than one storey high steel diagonals or crosses are used on the building surface, while in reinforced concrete buildings, window openings are formed with reinforced concrete curtains crosswise to form a diagonal of several floors on the building surface.

Tube-in-tube systems

Horizontal loads are carried by both the inner core and the outer framed tube system. The inner system and the outer system are connected to each other by the diaphragm formed by the floor slab. The core system inside can be shear wall, braced (trussed) tube or framed tube system. In this way, the systems in which two different tube systems are used inside and outside are called tube-in-tube systems.

Bundled-tube systems

Bundle tube systems have a system structure in which framed tube and trussed tube systems are used together in order to provide much more column opening compared to trussed tube systems and to provide freedom to architectural design (Özcan, Duran, & Erol, 2019). These systems provide the opportunity to make original designs in floor plans and volumes, because the tube system has the feature of starting and ending at the desired floor and height.

2.3.6. Outrigger systems

In recent years, when creating horizontal and vertical structural models of multi storey buildings, structural systems with a shear wall system in the center of the building plan and columns in the perimeter are preferred. The interaction between the central core and the frame columns on the outer wall is provided by beams and floors. However, in order to strengthen the cooperation and interaction between these two load-bearing elements, rigid horizontal elements, usually made of trussed steel bars, are located between the wall and the columns in certain parts of the height of the building. The main function of these structural elements, called the outrigger system, is to strengthen the mutual interaction between the shear walls and columns and to increase the bending rigidity of the structure against horizontal loads. Outrigger system can be applied in one or more floors in the building (Calayır & Dedeoğlu, 2017). While the outrigger trusses are rigidly connected to the walls, they can be rigidly connected to the columns (moment transferring connection) or jointed (moment nontransferable connection). In outrigger systems, the distance between the perimeter columns is not as narrow as in framed systems. Outrigger trusses, which are connected to the core of the building from the surrounding columns as seen in perspective view in Figure 2.11 and are resistant to lateral loads, do not significantly manage the façade design as in other systems.

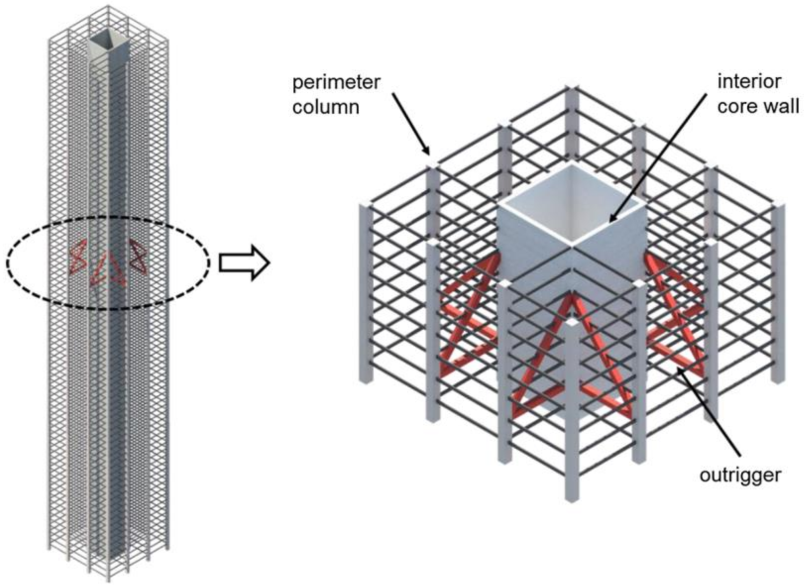


Figure 2.11. Perspective view of outrigger configuration (Kim, 2018)

Some super tall buildings, 632 m high Shanghai Tower in Shanghai (see Figure 2.12), 555 m high Lotte World Tower in Seoul, 508 m high Taipei 101 in Taipei, 484 m high International Commerce Center and 412 m Two International Finance Center both in Hong Kong, structured with an outrigger system. In all these buildings, outrigger systems are not directly expressed on the façades (Moon, 2018).

Figure 2.12. Shanghai Tower under construction (left) (URL-14), (right) (URL-15)

2.3.7. Diagrid systems

Diagrid systems can be thought of as an improved version of the braced tube system they are similar systems, but in diagrid systems, the entire perimeter is assembled angularly by removing the vertical columns (vertical mega-columns can be in corners for protect stability) and increasing their density (see Figure 2.13).

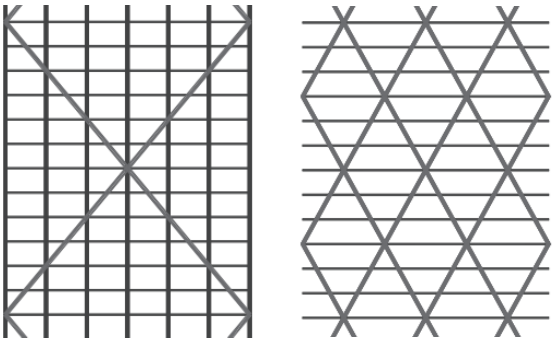


Figure 2.13. Braced tube (left), Diagrid (right) (Moon, Connor, & Fernandez, 2007)

In diagrid systems, in the perimeter structure where the columns are eliminated, much lighter diagonal elements on the outer braces create a truss appearance. The external system acts like a shell by resisting the loads that may come from the outside of the structure and allows the structure to behave like a solid tube. Besides structural capabilities, diagrid systems add an aesthetic to the structure in its own character. The scale, material, form, color, inclination, and structural details of the diagrid system should be examined and decided upon. Diagrid structures have the features of structuring in various shapes and designs. The form of expression of the building is created with the differing dimensions and angles of the diagrid unit as shown in Figure 2.14. Sculptural forms for structures can be created using smaller diagrid units (Ali & Al-Kodmany, 2022).

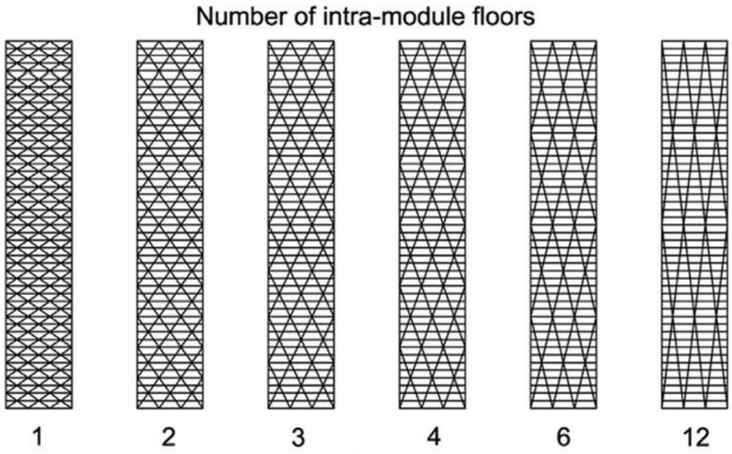
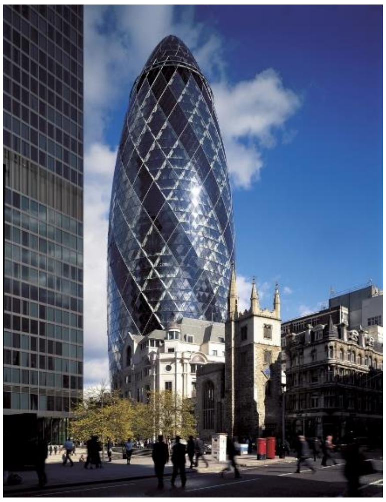


Figure 2.14. Different expressions of different angles of diagrid units
(Lacidogna, Scaramozzino, & Carpinteri, 2020)

An engineered outrigger building is very efficient at reducing the moment under the elements and drifting the structure. However, outrigger systems do not provide shear rigidity, so cores with high rigidity are needed. Diagrid systems provide shear rigidity and do not need cores, this can be covered by the perimeter diagrids (Moon et al., 2007). Since the basic shape forming the diagrid is triangle, it is possible to construct buildings in different shapes from rectangular prisms.

The IBM Building (Figure 2.15.a), which was completed in 1963 and whose architectural design was made by Curtis and Davis, located in Pittsburgh, USA, is the first example of a building constructed with a diagrid system. This structure did not attract the attention of architects and engineers when it was built. In the 1980s, Sir Norman Foster presented a skyscraper structure with a diagrid system in the Humana Headquarters competition. Although Foster did not win the first place in this competition, Swiss Re (30 St. Mary Ax) (Figure 2.15.b) in London and Hearst Tower (Figure 2.15.c) in New York, which he designed in the following years, made diagrid structures known and known all over the world (Moon et al., 2007).

a



b

c

Figure 2.15. The IBM Building (a) (URL-16), Swiss Re (b) (URL-17), Hearst Tower (c) (URL-18)

3. FAÇADE CLADDING SYSTEMS

Façade have come to English from the Vulgar Latin "facia", meaning “face.” It has entered the literature as written exactly as “façade”, which comes from French (URL-19). Claddings are the surface of the building in contact with the atmosphere and are the elements that absorb the first impact from the atmosphere. They are the shells that receive the direct impact from the atmosphere by filtering them into the building, and therefore this task will actually be covered by the cladding material. Cladding materials are generally selected and applied in accordance with the design and aesthetic appearance of the building. In this section, the most basic materials used in façade cladding, the general properties of these materials and the use of these properties will be introduced. In addition, the façades, which serve as shells, will be classified and explained in two different groups in terms of their own weight and the load of environmental factors on them, together with their role as a bridge between the building and the outside.

3.1. Façade Materials

3.1.1. Natural stone

Natural stones are the first building products used in housing and other structures from the very beginning of human history. It has been the most used product in the process until concrete and reinforced concrete structures developed and took their current form. Although natural stones were born that way, with the development of technology, they were not only used to create the main skeleton. After it started to be processed finely by using technology, natural stones started to be seen as façade cladding material. The most basic feature for natural stones to be used as a coating, which acts as a shell that will separate the building from the outside, is to filter some natural factors such as hot-cold air, humidity, sun and sound.

Natural stones have more sound and heat insulation than cladding materials, especially glass and metal. It also has lower maintenance costs and higher weather resistance compared to the same materials. However, since natural stones can be produced very thin with today's technology, in case of situations such as not being able to carry their own weight, they may need to be fixed with different engineering methods Lewis (1995: 20-22). This natural product, obtained directly from the earth's crust, can be divided into three main classes according to its origin and can be seen as examples in Figure 3.1.

- igneous stones (a)
- sedimentary stones (b)
- metamorphic stones (c)

a b c

Figure 3.1. Example of igneous stone (a) (URL-20), Example of sedimentary stone (b) (URL-21), Example of metamorphic stone (c) (URL-22)

These three main titles are divided into three types as granite stones, limestone and travertines, marble respectively. These types can be used in a wide variety of fields. For example, granite stones can be used from solid and heavy structures to the thinnest façade cladding (Herzog, Krippner, & Lang, 2004: 63).

3.1.2. Clay

Clay, which is the main product of baked materials used for more than 7000 years, is also the main component of all ceramic building materials. Ceramic materials, whose basic steps of production have not changed from past to present, can be called modern building materials. Clay basically has the capability to absorb, store and release moisture in the environment it is in, due to its component. Although this is a favorable feature for arid areas, it can cause adverse health conditions for humid climatic regions (Pfeifer et al., 2001: 9-11).

Fired clay units exist in a wide variety of forms, but their main ingredients are natural loams and clays. Around 14th century B.C., mud bricks made without firing and molded by hand began to harden as time passed and the mud inside dried. This hardness is not in the sense of getting stronger, it is a simple hardening, and it loses its strength as it absorbs moisture or water. For this reason, in the 5000 B.C. period, people learned to fire clays d at temperatures around 1000°C and this building material now forms the covering or wall unit that has survived to the present day (Söffker & Deplazes, 2005: 32-35). When designing a façade with facing bricks, components are put together with mortar on a single façade, unlike other façade materials. With this compactness and gap ratio, various requirements are met on the façade, and besides its load-bearing properties, movements arising from effects such as humidity and temperature differences are also provided (Herzog et al., 2004: 83-87).

3.1.3. Concrete

Zongjin (2011: 1) states the following;

> Concrete is a manmade building material that looks like stone. The word “concrete” is derived from the Latin concretus, meaning “to grow together.” Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together …. The simplest definition of concrete can be written as concrete = filler + binder.

While designing concrete façades, it can be considered by using precast concrete, which is prepared beforehand, as well as planned to be made on-site. For concrete, the most important factor in this position is the formwork. At this point, architects and other experts must decide precisely what is desired in the design, as the visible parts of the concrete surfaces create a copy of the formworks.

The absorption properties of the mold can affect the final appearance, as well as the frequency of use and cleaning of the formwork directly affects the pore formation in the concrete (Herzog et al., 2004: 103-107).

Precast concrete

From the past to the present, the use of precast concrete has generally aimed at artistic façade architecture. Although in some cases it fulfills the load-bearing function, the main purpose is mostly the architecture of the building. The main reason arising from the fabrication is that the concrete can be produced in the desired shape as shown in Figure 3.2.a (mold variety) and the desired properties can be given to the concrete (high strength, load carrying capacity, different color variety, high weathering resistance) (Bachmann & Steinle, 2011).

Reinforced concrete

Reinforced concrete is a composite material consisting of steel bars (see Figure 3.2.b). According to the load carried, steel resists tensile forces, while concrete supported by steel carries compressive forces. Understanding the behavior of concrete is the most important factor to use it in the design process and to bring it into reality.

Fiber reinforced concrete

People have sought ways to reinforced concrete not only today but also in the past, and fibers have been used as binding reinforcements in past ages as well. In the history, horsehair mortar and straw in adobe bricks were used. In the recent past, in the 1960s, fibers have started to be used such as steel, glass, synthetics, etc. in concrete as shown in Figure 3.2.c. Fibers are used to control cracks in concrete, thereby reducing water infiltration by reducing the permeability of the concrete (Wietek, 2021: 47-48).

a b c

Figure 3.2. Precast concrete (a) (URL-23), Reinforced cement concrete (b) (URL-24), Fiber reinforced concrete (c) (URL-25)

Zollo (1997) states,

> According to terminology adopted by the American Concrete Institute (ACI) Committee 544, Fiber Reinforced Concrete, there are four categories of FRC based on fiber material type. These are SFRC, for steel fiber FRC; GFRC, for glass fiber FRC; SNFRC, for synthetic fiber FRC including carbon fibers; and NFRC, for natural fiber FRC.

The most widely used steel fiber reinforced concrete differs according to the various surfaces and textures of the steel used. Steels with deformed steel surfaces that have rib or hook shapes, or rough surfaces are stronger in terms of adhesion strength than those with smooth surfaces. Steel fiber reinforced concrete increases the dead load of the composite due to the specific gravity of the steel itself. This creates a disadvantage for steel fiber. Glass fiber reinforced concrete is also a type of reinforced concrete that is widely used. Glass fibers have high tensile strength. Non-alkali-resistant glass fibers are less durable than alkali-resistant glass fibers because they can be attacked by alkaline solutions in cement-based composites. Glass fibers show low resistance to moisture. Carbon fibers structurally have higher strength and stiffness than glass fibers. This is an advantage for carbon fibers, but a disadvantage is their high cost. In addition to having high strength, carbon fibers have high resistance to moisture and chemicals, and are unresponsive to fatigue (Johnston, 2014: 124-135). Due to the geographical effect, natural fiber is available in most of the countries and because it is renewable, it is used as reinforcement for concrete at low cost. Although they have a lower strength in terms of strength and stiffness, composites made from natural fibers have been used a lot in the past and still continue to be used because of their low density and cost as well (Lilargem Rocha et al., 2022).

3.1.4. Timber

Timber has been used since ancient times in terms of its availability in nature and continues to be used. Looking at the architectural examples in the past, it has been used to form the structural system of roofs and floors in masonry buildings at home scale and to form the general frame of the building. As can be seen in traditional architecture, while wood is used as a structural system, it creates the visuality and bearing that will directly affect the aesthetics of exterior of the building. Since the material belongs to the original tree trunk, the use of its own structural system has become important. It is suitable for carrying bending type loads in the structure as it has the strength of tensile and compressive forces. The material has a low density and this is due to the strength of the cell walls that form it (Macdonald, 2018: 25-29). Since it is used as a vertical and horizontal element in wooden structures, the openings are relatively small since it has less load bearing compared to other materials (for example, steel). Examples of wood products are laminated wood, composite boards such as plywood.

Laminated woods are the product of large rectangular cross-section elements obtained by bonding smaller rectangular cross-section woods under pressure. The vein of each section is in the same direction. As an advantage, it allows the production of massive elements with large cross-sections. Since very long elements can be obtained by joining them end-to-end through finger joints, it is possible to achieve larger spans in structures and it is also possible to make curved elements (Brookes & Meijs, 2008: 174-185). Composite boards are formed by overlapping thin sheets cut from wood in different directions and gluing them under pressure. The directions of the outer floors are parallel to each other, so it is an odd number of sheets combined. Its strength varies with the quality of the wood used and the relationship between the thickness of the plies (Herzog et al., 2004: 128). Engineered wood such as glued laminated timber, which has been researched and developed, is significantly stronger and has a higher stiffness than other wood types (McMullin & Price, 2017: 23-29). It increases the sustainability of the wood as it is made using smaller pieces. Since the component parts are smaller and glued together, the defects are also naturally smaller and unobtrusive. There is no strong water resistance as the parts in the component are small and bonded to each other with adhesive. For the same reason, their resistance to fire is weak.

3.1.5. Metal

The first use of metal materials as façade cladding material was in the middle of the 19th century (see Figure 3.3). Today, stainless steel and aluminum are used as metal cladding. Metal façade claddings are generally used in curtain wall systems (Sev, 2001).

Aluminum

Pure aluminum is a weak material but can be strengthened by alloying. The most commonly used aluminum alloys used as building materials are the 6082 and 6063 series, which contain magnesium and silicon (de Sousa Camposinhos, 2014: 159). Since it has high strength and is resistant to corrosion, it began to be widely used in curtain walls towards the middle of the 20th century. Aluminum as a structural material has an important role with glass in the process of development of the curtain wall from the past. One of the first buildings with a curtain wall to be constructed using aluminum and glass during this period was the Equitable Savings & Loan Building in Portland, Oregon, in 1948, by Pietro Belluschi as shown in Figure 3.3 (Ashby, 1999). The fact that aluminum can be produced in desired shapes and can be produced in optional visuality such as color, texture, brightness is one of the reasons for preference today. Since aluminum is a good heat conductor, cladding components must be thermally isolated when used on façades.

Figure 3.3. Oriel Chambers, first metal (iron) framed glass curtain wall, in 1864 (Left) (URL-26), Pietro Belluschi's Equitable Savings & Loan Building in Portland, Oregon, in 1948 constructed with an aluminum curtain wall (Right) (URL-27)

<u>Stainless Steel</u>

The use of steel as a building material began in the 19th century with the search for inexpensive materials for larger-scale structures. It has equal strength and high strength in tensile and compression forces. The fact that its own weight is not much compared to its high load carrying capacity supports the use of steel in large spans and large structures. Having a delicate appearance not only increases the reason for preference, but also expands its usage areas. One of the problems that can be listed for steel is its poor performance against fire and the reason for this is that it loses its mechanical properties at low temperatures. Another problem is its chemical instability, which makes it inclined to corrosion (Macdonald, 2018: 30-34). These problems have been weakened somewhat by making the steel non-flammable and durable with paints applied to the steel, but they have not been fully resolved in any way. The steel is made resistant to corrosion, usually with zinc, which is coated on the steel (Çıkış, 2007). In places where the fire issue is important, the use of steel should be continued by taking this information into consideration.

3.1.6. Glass

It is quite easy to find and access the glass types produced for different purposes and special needs with its developing features, which is one of the most common and also one of the oldest building materials. Glass of façade cladding systems is generally used by inserting aluminum or steel frames into them. The glass, which is placed inside the metal frames beforehand, is then moved to its place and the glass is brought to the façade system or inside the metal frames fixed on the façade system. With the use of structural silicones, it is possible to make façade designs in which the façade frame is not perceived from the outside and the glasses are not placed inside the metal cases (Sev, 2001). Glass used as façade cladding is expected to have properties such as minimizing heat transfer, non-reflective and sound insulation. Absorption, reflection and radiation of solar energy can be reduced by applying some coatings to glass surfaces (Çıkış, 2007). Glass has a great impact on the interior and exterior environments of the building in which it is used. It realizes energy saving or consumption depending on how it is used. When used poorly, it provides excess energy loss and discomfort for the living things in the building, while when used well, it makes the circulation in it more comfortable.

According to Patterson, “Glass today is tinted, coated, fritted, laminated, insulated, layered, perforated, notched, wired, tempered, switched, and available in a vast array of these combined processes.” (2011: 43). On the other hand Herzog and others (2004: 184) examined glass in 4 main titles and emphasized that the most used glass type is float glass. The other 3 titles can be listed as sheet glass, antique glass and rolled glass. Float glass forms the basic material of glass types used in façades today. It has high quality and its surfaces are parallel to each other. Glasses can be curved in order to make them suitable for the design by methods called thermal bending and cold bending.

3.1.7. Plastic

Plastics are produced from materials whose final form is not found in nature. They are obtained from petroleum derivatives and are the products resulting from chemical reactions. In the 1930s, plastics began to be used for interior fittings and furniture, but in the late 1950s it began to be used on a building scale. It is not possible to describe the material properties with a single type, because the properties may vary by using different formulations during their chemical formation. It has also been possible to produce glass fiber reinforced plastic, for example, as with concrete. Plastics do not outlive the life of a structure in terms of material life. This information should be taken into account when designing plastics to be used as façade elements or roof elements. As material general properties, plastics are flammable materials and smoke emission can be very dangerous according to the molecules they contain as a result of chemical reaction. In addition to the fact that many toxic gases are released when burning, it will not provide convenience during a fire in this structure and may cause difficulties for living things. The flammability of the material can be reduced somewhat by using a flame retardant.

Although plastics have disadvantages in terms of flammability, they also have some advantages. Due to chemical reactions, the hardness resistance can be provided according to the desired properties of the material to be used. While it can be produced as transparent as glass, it also has a color scale that can be produced completely opaque to be pitch black. Plastics with low water absorption capacity also have high elasticity and low density. They do not create a load that will cause a serious problem during use in the building (Herzog et al., 2004: 210-212). Plastic construction material can be examined in two main classes. Thermoplastic plastics can be softened by reheating at any time after they are produced and regain their original properties when cooled. Thermoset plastics cannot be remelted after production. Thermoset plastics are more resistant to heat and chemically more stable than thermoplastics (Allen & Iano, 2019: 739-740).

3.2. Classification of Façade Systems

The façade, which is the shell of the building, has a structure designed with the architectural understanding of its time, blended with the harmony of the structure and material of the building. The façade is an indispensable element for the building and is considered together with the structure of the building. Sometimes façades that help the main structural system of the building are designed, sometimes façades that are designed visually and aesthetically rather than helping the main structural system of the building can be designed with a certain amount of load. For this reason, it should be taken into account that the façade load will also affect the building mass while designing the buildings. Factors affecting the formation of the façade can be classified as the height of the building, environmental conditions, the purpose of the project (hotel, restaurant, office or cultural center) and the character of the structural system (Harmankaya & Soyluk, 2010).

Lang (2012) stated that the following criteria can be used when considering the construction criteria in façade classification:

- Load transferring (structural or not)
- The structure of the outer wall in terms of shell arrangement (single shell or multiple layers)
- The structure of the outer wall in terms of the order of the layers
- Radiation transmission (transparent, translucent or opaque)

A structural façade wall can be designed as load bearing structure from the floors or roof and transfer it to the foundation. A façade can be designed as non-load-bearing building envelope which is curtain wall. As the façade walls have to withstand external factors such as earthquake and wind as well as their own weight, façade systems can be divided functionally into two groups (Sev, 2001).

3.2.1. Load bearing (structural) façade systems

Until the Industrial Revolution, walls made of massive stones, bricks and timber covered the façades of buildings. In addition to providing security, these walls also had functions such as protecting from weather effects and providing sound insulation (Sev, 2001). Its use in non-multi-story buildings was more functional because the walls had to get thicker as the building height increased. This is not preferred because it narrows the usage area and causes the construction process to take more time. Today, these walls continue to be used only in low-rise buildings. In today's tubular building systems (see the part 2.3.5.), façade walls are load bearing. Façade cladding is commonly made on this façade wall with materials such as natural stone and metal. In multi-storey high-rise buildings, curtain walls are widely used in order to reduce the dead load of the building and increase the construction speed (Kırkan, 2005).

3.2.2. Curtain wall systems

Different façade formations emerged with the use of materials such as steel and glass, which developed as a result of the Industrial Revolution and Industrialization, and these actually formed the basis of the curtain wall. It has been observed that these two materials have some disadvantages. Due to the inability of glass to show sufficient resistance to sun and heat and the inability of steel to transmit heat, the desired comfort could not be achieved and different solutions were sought (Öztan Fidan, 2019). This situation has led to the development of curtain wall. Curtain wall systems, which emerged in parallel with the developments in material and construction technology since the beginning of the 20th century, have become an indispensable building envelope for high-rise buildings in a short time due to their lightness, aesthetic appearance, ease of manufacture and assembly, and resistance to external climates. Along with the curtain wall systems; The understanding of using natural energy sources such as wind and sun in providing indoor comfort, which has been applied for centuries, is replaced by the understanding of using mechanical systems to provide heating, cooling and ventilation (Eşsiz, 2004).

Curtain wall systems are widely seen today due to the fact that metal profiles bring less load to the building structure, they are independent from the building structural system and act independently, fast assembly possibility and aesthetics. Curtain wall systems are outer covering systems that are suspended on the outer surface of the building, independent of the main structural system of the building, and consist of elements that do not carry loads but transmit the loads on them. According to Klein (2013: 35), curtain wall can be defined as a non-load-bearing building envelope. They are hung or snapped into the primary structure of the building. Basically, curtain walls are composed of metal vertical and horizontal bars (mullion and rails), a structural framework and infill elements. But such as wood and glass fiber reinforced plastics, other frame materials are possible. The definition of curtain wall also includes panel façades.

In structural analysis; Apart from the own weight of the façade, the pressure and absorbing forces of the wind on the façade, the height and form of the building gain importance. Necessary examinations should be made while designing the system and façade. Application of curtain wall systems in high and large surface buildings; it means expressing possible errors with great costs, sometimes with impossible solutions (Sezer, 2013). For this reason, experimental studies at the design stage are especially important and necessary.

Curtain walls are divided into two groups considering their weight: these are heavy curtain walls and light curtain walls.

Heavy curtain walls

Heavy curtain walls are walls with a weight of more than 100 kg/m² and generally composed of concrete-based precast panels. Apart from reinforced concrete materials, glass fiber reinforced concrete or plastic or metal materials are also used (Gür, 2001). The fact that concrete is a material with a high thermal conductivity coefficient necessitates the application of thermal insulation in heavy suspended curtain wall systems where concrete-based ready-made elements are used. In addition, due to their heavy weight, they bring more dead load to the building structural system. The application area is much less than the lightweight suspended curtain wall systems (Sezer, 2003). The Marmara Hotel in Istanbul is an applied example of this system as shown in Figure 3.4.

Figure 3.4. The Marmara Hotel (URL-28)

Light curtain walls

Light curtain walls are systems with a weight of less than 100 kg/m² (Gür, 2001). Lightweight suspended curtain wall system is a type of curtain wall formed by transparent or opaque panels, in which the façade elements are placed on a structural frame. The façade elements are carried by the load-bearing elements fixed to the beams and slab foreheads of the building with point connections (Sezer, 2005). Framed light panel façade system consists of frames that provide the structure of the façade element and opaque (infill panels) and transparent (glass) components. Panel surfaces can be completely transparent or completely opaque, and sometimes consist of opaque and transparent components. The framed light panel façade system differs from the framed light curtain wall system in terms of positioning it on the building structural system (Özcan & Naiboğlu, 2020). In this type of façade systems, since the façade elements are placed on the floor, the building does not completely cover the structural system components (Göçer, 1997) (see Figure 3.5).

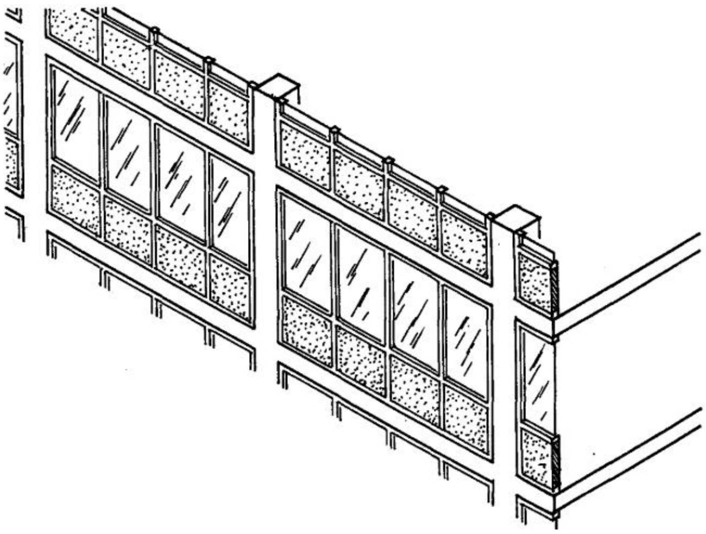
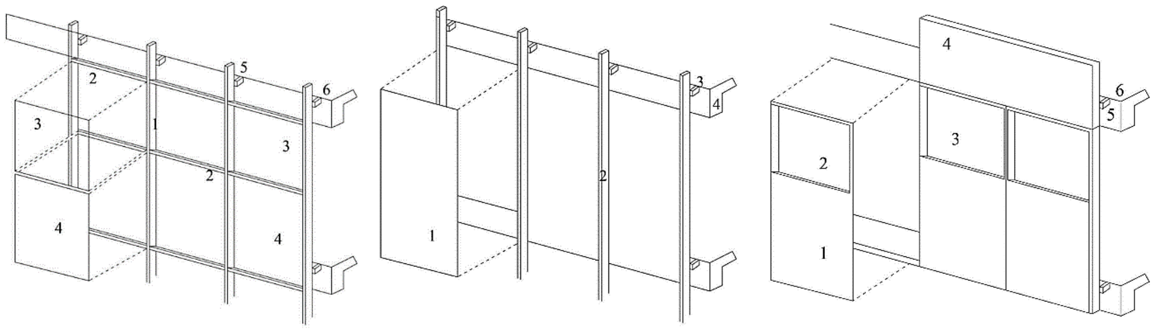


Figure 3.5. Framed light panel façade system (Göçer, 1997)

According to Tortu (2006) and Gür (2001), light curtain walls can be classified in three ways according to the load-bearing frame type as shown in Figure 3.6 as detail examples:

- Stick system, which is fixed with on-site mounted continuous carrier and horizontally connected profiles, on which transparent zone and parapet units are attached.

- Semi-panel system, fixed at floor height and with horizontal profiles, where transparent zone and parapet units are attached, and the system is separated by horizontal joints on floor basis.
- Panel system in which the transparent zone and parapet units are completely assembled in the workshop, with the vertical floor height of the façade system and the dimensions of the determined axis intervals, and the horizontal and vertical joints and panels are separated from each other during assembly.



a b c

Figure 3.6. Stick system façade detail (a), Semi-panel system façade detail (b), Panel system façade detail (c) (Ağdemir, 2017)

Light curtain walls are divided into two according to the number of shells as single skin curtain walls and double skin curtain walls. The main concern in classifying curtain walls according to their shell structure is energy conservation and sustainability.

A façade is the barrier between the exterior and interior of a building. In the "passive façades" heating or cooling is provided by natural means. "Active façades", on the other hand, use mechanical systems or electronic devices to influence the indoor climate (Poursani, n.d.).

- Single skin curtain wall is the most widely known and applied system, consisting of a single-shell cover separating the outside and the inside. It is formed by the transfer of dead and live loads of the cover layers to a single structural system. Although the curtain wall consists of a single shell, it seems economical in terms of the initial investment cost in terms of load-bearing system and surface area calculation, it may require additional measures to provide the comfort conditions of the building in the long run (Bıyıklı, 2015).
- Double skin curtain walls are the systems that the primary façade of the building is framed by a secondary glass façade. Exteriors are generally made of a single transparent glass

while interiors are mostly double glazed, mostly made of low-e or solar-controlled glass. These building shells are separated from each other by a space that called as air shaft, which can be between 20 cm and 2 m. This space is referred to by names such as air corridor and air duct in the literature. This air shaft can continue along the height of the building as well as along the floor height. Ventilation of the shaft between these two façades should be done very well in order to prevent overheating in the air duct, especially in summer when the sun's rays are too much (İnan & Başaran, 2015).

As shown in Figure 3.7, an example of a double-skinned façade is the Zurich Blue Building in Madrid, Spain. Its double-skinned façade emphasizes transparency, implementing a curtain wall solution on four façades with a three-dimensional pattern mixing glass and micro-perforated stainless-steel sheets to provide environmental and acoustic control.

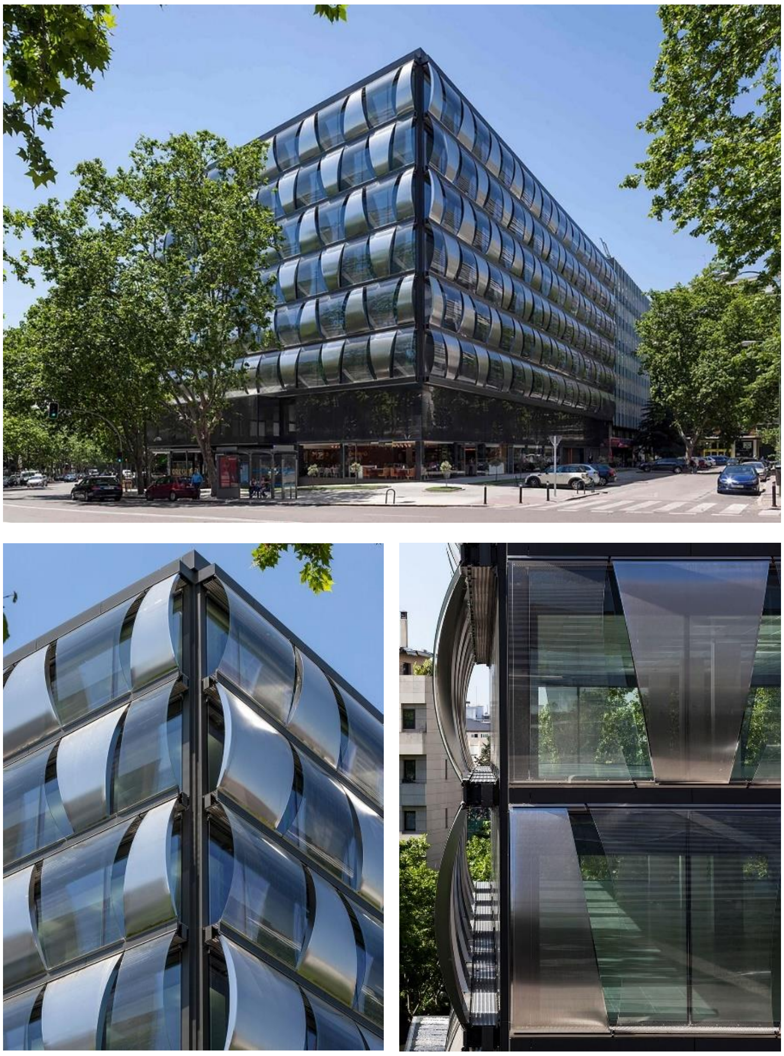


Figure 3.7. Blue Building in Madrid, Spain designed by Rafael de La-Hoz in 2017 (URL-29)

4. ENVIRONMENTAL FACTORS ON FAÇADE CLADDING AND STRUCTURAL FRAME

Materials generally undergo deformation over time due to some environmental effects. After the completion of the buildings, it is possible for the materials that make up the exterior to undergo some changes due to environmental factors and according to their atomic structure. The structural system of the building must be sufficiently secure against the loads acting on the building. The structural system should be rigid against horizontal displacements and adequately ductile against overturning and translation (Sev, 2001). Since the horizontal loads generated by earthquakes and winds are significantly higher than the vertical loads in buildings, resistance to horizontal loads is of great importance in the design of the structural system. The façade cladding cost of a building constitutes approximately 25% of its total cost (M. Chew, Tan, & Kang, 2005). At the design stage, it is necessary to successfully establish the appropriate cladding material for the building, the appropriate façade type and the interaction with the structural system.

Façade systems on the building surface were heavily influenced by environmental factors. For example, the heating effect of the sun causes expansion and contraction by increasing the temperature of the façade surface, and with the effect of UV rays, color changes in the façade components or deterioration in the sealing components occur. Damages such as rupture of the façade filling components or breakage of the structural components are observed due to the effect of the strong wind. In addition, the inability of the façade to adapt to the movements caused by the earthquake is among the causes of damage. Similarly, intense environmental dynamics (eg traffic) can cause structural movements. In cases where these movements are not met, fractures are observed in the façade system components (Yalaz, Tavil, & Çelik, 2016). Loads taken into account during the design phase can be considered as permanent and temporary. Gravitational loads are evaluated on a continuous basis, while wind, temperature, seismic and snow are considered temporary (Sarkisian, 2016).

4.1. Natural Factors

Natural factors alone or in combination can have a disruptive effect on the façade. These factors; wind, thermal, water, sun rays, harmful gases and seismicity.

4.1.1. Wind

One of the most important factors that should not be ignored during the design of buildings is the wind factor. The wind force is directly proportional to the elevation. When the height of the structure increases, the effect of the wind becomes greater as well. Another factor more important than the height of the building is the speed of the wind. Wind loads on the curtain wall are of primary importance in the design of the structural system. These forces determine the properties of the system, such as the thickness of the material used, the strength of the anchor details, the cross-sections of the structural elements. Wind loads are different from other loads that are valid in determining the structural system affecting the structure. Therefore, it should be well known and studied.

Wind loads are transmitted to the building structural system with the help of anchor elements. For this reason, connection elements must have adequate tensile strength, compression, stretching, ability to function under negative and positive loading and return to their original shape. The wind does not only have an effect on the building, but also negatively affects the air circulation between the streets if the buildings are in the wrongly constructed buildings. The effect of the wind is completely related to the height of the buildings and their construction forms. If the effect of a building on the wind is taken into account, it is seen that the wind speed increases in the upper parts of the windy surface of the building and the windy roof, turbulence occurs in the windproof part of the building, and the wind mixes into a smooth flow again (Erdoğan, 2007).

Apart from the wind loads on the structure, the wind is the most accessible natural factor that will benefit the concept of sustainability in terms of its energy. The rapid increase in high-rise buildings in recent years has created new areas for the use of wind turbines. As the height of the buildings increases, the interactions with the wind continue uninterrupted and the speed of the wind becomes higher at the higher points of the buildings. With the wind turbines used in these parts, the building is provided to produce some of its own electrical energy (Albayrak, 2014). During the façade and building design phase, it is necessary to design by taking these into consideration. In the application of wind turbines in tall buildings, parameters such as site plan layout, wind aerodynamics in the building form, local wind pattern, wind speed density, wind speed distribution frequencies and prevailing wind direction should be taken into account during the design phase (Hamidabad & Begeç, 2015).

Therefore, there are very different features for each structure. Bahrain World Trade Center, Pearl River Tower, Lighthouse Tower and Strata SE1 buildings can be given as examples for the use of wind turbines in tall buildings as shown in Figure 4.1.

Figure 4.1. Bahrain World Trade Center in Manama, Bahrain, (Left) (URL-30), Strata SE1 in London, England (Right) (URL-31)

4.1.2. Thermal

Heat is defined as the total energy released by the vibrations and kinetic energies of the atoms of a material. The volume of the material changes as a result of heating or cooling for any reason, this phenomenon is called thermal deformation (Erdoğan, 2007). The greater the applied heat, the greater the deformation. Apart from the building material used in buildings, thermal insulation materials are used to prevent heat loss or to control the heat exchange from outside. Façade cladding, which is described as the outer shell, is the building element that should act as a thermal barrier between the interior and exterior environment. This thermal conduction must be met by the materials and the design of the system. If the thermal conduction resistance of the system is low, this is compensated by adding insulation to the system. Air or water leakage from the system adversely affects the thermal efficiency (ASCE, 2000). In terms of thermal performance, leaking out weak points, called thermal bridges are joints, edge seals of glasses and panels, and around fasteners. Sweating and condensation reduce the value of water-retaining materials in façade elements, corrode metal composition elements, cause surface blooms on the building surface and swelling and shedding of the cladding material (Koçu & Dereli, 2008).

According to Oraklıbel (2014), criteria related to 'thermal performance' were determined as follows:

- Heat transfer should be low
- Must have heat storage feature
- There should be no thermal bridge
- Surface temperature must be compatible with indoor temperature
- The radial heat transfer should be low

In order to both provide user comfort and not cause economic losses, the interior environment of an existing building, the thermal properties of the façade materials and material components of that building should be analyzed very well. The exterior façade, which acts as a transition between the interior and exterior by itself, fulfills its thermal performance by acting as a thermal filter and adapting to the external environmental conditions sufficiently (Rostron, 1964). Design strategies to control heat flow often aim to use an insulation. Preventing a heat loss through air leakage and increasing the air gaps between the materials used means preventing thermal bridging (Aksamija, 2013). But "controlling" the heat transfer between the interior and exterior of the structure does not always mean preventing it. Trying to heat the inside of a building by means of external heat energy can be a fundamentally sustainable design principle.

4.1.3. Water

Among the environmental factors, water, which is in an important position in terms of its effect on the façade; solid, liquid and gaseous states have the potential to create serious problems. Water rots wood oxidizes metals and provides a habitat for mold and fungi. It causes swelling and expansion of some materials, transport of dirt and blooms. If the temperature drops below freezing, the water in these cracks freezes, expands and causes damage to the wall. In structures, rain can often run vertically upwards, and careful protection is needed on soffits, water escape holes, and exterior overhangs. It should be checked in wall detailing that snow or water is not allowed to freeze, which may damage the profiles, joints or joint materials (Oraklıbel, 2014). Water can penetrate the overall system of a structure in different ways. According to Yu (2013: 71):

1. Water needs an opening to enter the system.
2. A force is needed to push the water through the opening.

He made the following order for these forces:

- Gravity (can be eliminated by creating a slope against the most likely water flow patterns)
- Momentum (water traveling horizontally with the force of the wind can be prevented from entering a system by using a chamber or labyrinth)
- Surface tension (water adhering to materials gets into the system and this can be avoided by preventing a drop or bridging)
- Capillary action (drops of water are drawn in by a crack, pipe or cavity, causing more moisture in the system)
- Air flow

Façade elements must be in a structure that will not allow water, moisture and steam to pass through from the interior and exterior to its body. In addition, it should be in a structure that will allow events such as moisture that may occur in its structure for any reason to escape into the atmosphere. If the structure of the curtain wall materials is not suitable for these conditions, the building will transmit water and moisture to the interior, therefore deformations such as decay will occur both in the building and in the materials and goods used in the building. The water penetrating the building causes corrosion of the iron in the bearing parts of the building and decreases the bearing capacity. Moreover, the humid air that occurs inside will adversely affect human health. In order to avoid these problems, the material to be used should have suitable properties and the application phase should be made in accordance with the detailed solutions.

Most materials used in metal curtain walls are resistant to moisture and water. This greatly reduces the area through which water can pass but increases the importance of joints and gaskets. Although the storage capacity of the materials used is low due to water absorbency, typical curtain wall sections contain gaps that can potentially accumulate water. Water that can accumulate here can damage the seals and cause premature damage to the insulated glass units, especially. Three different strategies have been and are being used to control water penetration in curtain wall systems (CMHC, 2004).

- Exterior face seal,
- Internal drainage,
- Two-stage weather tightening or pressure equalized rainscreen: PER

4.1.4. Sun rays

The sun's rays are an energy that comes from the sun to the earth by passing through the atmosphere. Of these short-wave solar rays, 27% come directly to the earth, and 16% come to the earth as diffuse radiation through reflection from the atmosphere. Among the rays coming from the sun, there are rays that cannot be seen with the naked eye. These are ultraviolet and infrared rays (Dereli, Tosun, & Koçu, 2018)

- Ultraviolet Rays (UV Rays): Incoming particles with ultraviolet rays collide with the atoms of organic materials, disrupting the atomic structure, causing aging and color changes (Dereli et al., 2018).
- Infrared Rays: These rays heat the surface they hit, depending on its color, raise its temperature and cause it to expand. For example, bright surfaces reflect radiation, while dark surfaces absorb it (Dereli et al., 2018).

Bright and light-colored surfaces reflect most of the solar radiation, while dark-colored surfaces absorb the most. Due to the heat generated on the surface as a result of this absorption, the building elements expand (Eriç, 2002: 141). Solar radiation can cause deformations in the structure or its components, such as thermal stress, discoloration and breakage/cracking. However, today, by means of new technologies, the thermal energy of sunlight can be used for useful methods such as heating (H. Güler, Sezer, & Sedat, 2010).

As a result of the transmission and passing of the sun's rays from the building façade into the building, the development of heat inside the building and inside the façade material is called solar heat gain (ASCE, 2000). In summer, when the sun angle is large, heat gain is not desired, in winter when the sun angle is low, both light and heat are required, but glare due to low sun angle is not desired.

4.1.5. Harmful gases

Parallel to the development of technology, the increase in all kinds of production, the proliferation of motor vehicles, the necessity of using various fuels for heating; Increasingly, polluting gases such as carbon dioxide, carbon monoxide and sulfur dioxide of the atmosphere mixed into the air and polluted it. These polluting and harmful gases, which turn into acids with precipitation (gases such as SO_3, CO_2 in the air, especially in industrial areas, combine with rain fog and humidity of the air, cause the formation of sulfuric and carbonic acids such as H_2SO_4 and H_2CO_3), have a significant effect on building materials, plasters and paints. Considering that these effects will wear down the building and the protective materials in a shorter time, the maintenance works to be done for the purpose of protection should be done at more frequent intervals (Eriç, 2002: 152).

Oxygen gas has a corrosive effect on metals. In construction materials as well as in industry, this effect can be reduced by passivating the metal. It can be made by deoxygenating the materials or by adding enough of some compounds. The most widely used method for protecting metals from corrosion is by coating or covering the surface of metals. The harmful gases that may occur as a result of the chemical reaction of the materials during the fire also damage the inside and outside of the building. In order to prevent the building materials from the effects of harmful gases, it would be right to prevent fire (Turner, 2019). Materials may be under the influence of some acids and bases due to weather or any other external factor. Various chemical effects are pollution, flowering, melting and dissolution caused by acids and sulfates, which are generally found in air and water, on structures (Eriç, 2002: 157-174).

4.1.6. Seismicity

Movements occurring underground create seismic forces. Seismic forces shake the buildings and different degrees of damage and deformation occur when the elements of the building do not show sufficient resistance to these forces (Pao, 2002). Predicting and calculating this element is an important issue. The response of curtain wall systems under seismic force depends on the response of the building on which they are located. Therefore, it depends not only on the characteristics of this ground motion that moves the structure, but also on the dynamic properties of the structure (Villaverde, 1997). The failure of the horizontal and vertical elements of the structure (roof, shear walls, rigid frames, beams, columns) or any connection between them brings the possibility of complete collapse of the structure in the event of an earthquake. In some cases, these elements are allowed to act independently of each other. Making a secure connection between the structure and the non-structural element (façade cladding) can result in undesired force transmission. In this case, it may be necessary to use fasteners and details that allow relative independence of movement (Ambrose & Vergun, 1997: 20-22).

Curtain wall systems and cladding systems create a significant load on the building structural system due to their self-weight. They interact with the main structural system of the building due to the dynamic and reversible loads formed under the effects of wind and earthquake. However, this interaction is not unidirectional. In cases where the structure makes significant lateral or vertical displacements such as earthquakes, seismic forces or settlements, the building structural system also applies loads on the curtain wall. The connection points where this mutual interaction takes place between the structural system of the building and the structural system of the curtain wall are of critical importance in terms of both positioning and detailing (Saban & Özmen, 2022). The structural elements used in curtain walls can vary from structurally flexible to very flexible when their movements under load are taken into account. Force is calculated as mass times acceleration. Considering the weight of curtain walls, the weight of a curtain wall and its cladding is considered an advantage in resisting wind loads, but it is a disadvantage for seismic forces (M. R. Patterson, 2008). Curtain wall elements can be manufactured in a lighter weight with the developing technology, so the self-load of the building decreases and in parallel with this, the earthquake load value that will affect the building is also reduced (İrtem & Tığ, 2006).

4.2. Dead And Live Loads

The loads used for the design of a structure, which can be sustained or transient, are design loads. These loads include gravity, wind, seismic, temperature as well as other loads that take into account certain building components and systems. Dead load is permanent load due to gravity which includes the structure's own weight. Live load is any non-permanent load component which is load superimposed by the use and occupancy of the building, including those caused by wind, seismic effects, temperature effects, and non-permanent gravitational forces (Ambrose & Vergun, 1997: 219). Apart from the building and the building materials used in the building, dead and live loads are another topic to be considered in the design.

While dead loads on the structure are designed depending on walls, ceilings, floors and mechanical systems, live loads are defined as the purpose of use of the structure and the loads that vary within the structure (Sarkisian, 2016: 76). When calculating the design loads, the expected real compressive strength for the structure is tried to be taken into account. In some cases, the loads at the design stage may be deficient between 10-25% after the construction is completed, according to the actual in-situ compressive strength. For example, while 90% of the total load on an outer column inside the structure is dead load, 10% is likely to be live load (Sarkisian, 2016: 111).

5. NUMERICAL ANALYSIS

High-rise buildings are generally integrated with curtain walls and glass material, which is one of the most used materials in curtain walls. The structural behavior of high-rise buildings requires more detailed and different investigations. While examining the interaction between the curtain wall and structural systems of high-rise buildings, the height characteristics of tall buildings come to the fore. In this numerical analysis, since the focal point will not be height, analyzes were made by choosing a 5-storey building. In this chapter, the interaction between the curtain wall and the structural system is analyzed, not only in high-rise buildings, but also in structures such as congress and cultural centers, airports, shopping centers, bus and train terminals, which we can define as large buildings. The main purpose here is not to evaluate the structural system of the building alone, but to examine the interaction between the curtain wall and the main structural system.

The interaction between the façade cladding or curtain wall and structural systems of buildings can be examined in four main categories:

- Structural problems related to the details of the joining elements of the cladding-curtain wall to the building surface.
- Structural problems caused by the temperature difference or other stress changes of the cladding-curtain wall surface.
- Structural problems in cladding-curtain wall elements due to displacements that occur due to the geometric configuration of the building's main structural system due to earthquakes or other loads.
- The failures that occur in the main structural system of the building due to the geometric form determined by the cladding-curtain wall.

Some local damage may occur in the main structural system of the building, depending on the connection details of the cladding-curtain wall to the building surface and the properties of the joint elements. This type of structural damage is often seen in later cladding applications that were not in the original design of the building. Such claddings-curtain walls, which are applied without a careful project and calculation, can cause damage to secondary or tertiary structural elements such as consoles, parapets, balcony railings, nonbearing walls. Such damages do not affect the structural performance of the building much, but rather cause problems in architectural appearance and use.

The temperature difference or other stress changes on the cladding-curtain wall surface can create serious structural problems depending on the characteristics of the main structural system of the building. If the main structural system consists of a reinforced concrete frame consisting of columns, beams and shear walls, the cladding-curtain wall will not cause any damage to the structural system of the building. However, serious damage may occur to the structural system of the curtain wall itself. Expansion or contraction in the cladding-curtain wall can cause damage to the main structural system of the building in cases where the rigidity ratio of the structural elements forming the structural system and the cladding-curtain wall is low. For example, such damage can be observed in wooden or unreinforced masonry buildings. In some steel structures, depending on the characteristics of the steel structural system element (such as roof or slab), they can cause significant structural damage.

One of the most common damages is the damages on the cladding-curtain wall due to horizontal and vertical displacements in the main structural system of the building due to earthquake or any other reason. Even if there is no damage to the main structural system of the building that will endanger the safety of the building due to ground settlements, very small displacements can cause very significant structural damage to the cladding and the structural system supporting the cladding.

Depending on its architectural character, sometimes the curtain wall can determine the general geometric form of the building. In this case, the cladding that defines the exterior surfaces and the main structural system of the building must be designed together interactively. Especially against horizontal loads, the main structural system should be determined according to the quality and ratio of the contribution of the cladding-curtain wall to the structural system of the building.

A simplified calculation method to examine the interaction between the cladding-curtain wall and the structural system of the building

In order to keep the behavior of the buildings under control in case of a possible earthquake, the structural system must be designed according to the regulations that will affect the architectural requirements significantly and which are generally impossible to change. These structural design conditions/rules that require advanced engineering calculations are a major obstacle for architects. Simplified calculation methods can be used to solve this problem.

In order to examine the interaction between the claddings-curtain walls of the buildings and the main structural system, the following numerical models were prepared in two different stages:

In the first stage, four different numerical models were prepared to examine the effect of the geometric form of the cladding-curtain wall on the behavior of the main structural system of the building.

In order to examine the behavior of the main structural system in an easier and more understandable way, a simple five-story frame system consisting of two openings in one direction and one opening in the other direction was chosen as shown in Figure 5.1. The span between the columns is 10 m and the floor height is 4 m. Considering the stiffness ratio of the cladding-curtain wall and the main structural system, the dimensions of the columns and beams and the material type were determined. The structural elements of the frame bearing the cladding consist of steel pipe sections with a diameter of 100 mm, while the columns and beams are made of steel box sections of 300 mm x 300 mm. The connecting elements combining the cladding-curtain wall to the main structural system consist of steel pipes with a diameter of 200 mm. The shell elements that compose the cladding are defined as an abstract material close to the material properties of 20 mm thick glass. The main purpose of these analyzes is to examine the effect of the geometric form of the curtain wall on the structural behavior of the building's structural system. For this reason, the contribution of slabs to the structural behavior has been ignored in order to see the behavior of structural elements (columns and beams) more easily. Due to the elastic material property of steel, steel columns and beams are preferred to provide a more easily understandable interpretation of the structural behavior of the displacements obtained.

In order to examine the effect of the geometric form determined by the exterior of the building on the structural behavior of the regular main structural system, in addition to the regular exterior geometry R-shape (regular shape) shown in Figure 5.1, different digital models were respectively prepared shown in Figure 5.2, Figure 5.3 and Figure 5.4, as diamond D-shape, Crescent C-shape and sinuous S-shape.

As the second stage, the most appropriate load effect to analyze the effect of irregular geometric shapes of buildings on the structural performance of the main structural system is wind pressure. The tensile and compressive forces acting on complex geometric surfaces can be calculated exactly with complex aerodynamic and fluid mechanics equations. It is not feasible to determine an optimum structural system configuration with such complex calculations at the architectural design stage. For this reason, the load that is simple but fully suitable for the purpose of the analysis has been defined. With the "projected uniform loads" option, which the computer program used for shell elements, a realistic loading similar to the wind effect was made on the changing surface geometry of the building. Thus, it was possible to apply the same intensity of load for each different exterior geometry. According to global axis, the projected surface in the X-Z plane is 416 m^2, and the projected surface in the Y-Z plane is 256 m^2. As shown in Table 5.1, the total base shear of the columns in both directions are almost the same as a result of each analysis. This shows that the same wind load is applied for all four types of buildings.

In order to simulate the wind effect, by taking TS498 (Calculation values of the loads to be taken in the dimensioning of the building elements – Design loads for buildings) and EC1 (Eurocode 1: Actions on structures – Part 1-4: general actions – Wind actions) as an example, the possible wind pressure, it is taken into account as p=1,5 kN/m^2 (150 kgf/m^2). This simulated wind pressure was applied separately to the projected surfaces in the global X and global Y directions, as shown in Figure 5.5 through Figure 5.8, respectively. Wind load calculations were made with the SAP2000 software program.

The intensity of the effective wind pressure varies according to the shape of the building's surface. As can be seen in the figures showing the wind pressure distribution (Figure 5.5 through Figure 5.8), the maximum accepted wind pressure p=1,5 kN/m^2 is indicated in blue, and depending on the geometry of the surface, the wind pressure decreases according to the order in the color scale. This way of loading can help demonstrate, in a simple but realistic way, the influence of surface geometry on the building's structural system during architectural design. Thus, the interaction of surface geometry with the structure of the building is determined by a simplified calculation method during the architectural design phase, without the need for complex and continuous data exchange with the engineering design team.

The displacements and internal forces obtained by this simplified analysis method provide information to assist the architectural design regarding the dimensions and configuration of the main structural elements and curtain wall elements. From Figure 5.9 to Figure 5.12, respectively, the deformations of R-Shape, D-Shape, C-Shape and S-Shape building types obtained as a result of wind loads applied in global X and global Y directions are shown.

Interpretations of the analysis results

As a result of the parametric analyzes carried out, results were obtained that describe the interaction between the curtain walls and the main structural system of the buildings, which can be useful during the architectural design of such buildings.

In the direction of the global X and global Y axes, the wind load of the same intensity was applied to the curtain wall surfaces in four different types of geometric forms, which they have different surface areas due to the geometry of the building. Thus, it has been observed how the internal forces change due to the geometric form of the building in the columns that form the structural system of different geometric forms. The total base shears, summarized in Table 5.1, were calculated as 1248 kN at the same magnitude for all four models in the Y direction. On the other hand, although they have very different surface areas and geometries, the base shear forces in the X direction are calculated to be almost equal to each other.

Table 5.2 summarizes the shear forces obtained as a result of the wind loads applied in the X-direction and Y-direction on the supports of the columns. The positions of the columns defined as C1, C2, C3, C4, C5 and C6 are shown in Figure 5.1. In these parametric analyzes, in which a general structural behavior is investigated, the configuration of the main structural system is chosen as simple and symmetrical in order to interpret the results in an easy and understandable way according to the basic mechanics theories. In Table 5.2, it is seen that the shear forces of the R-Shaped model, which represents a regular geometric form, are distributed symmetrically. This is an expected result and can be easily verified with static equation of equilibrium. A similar distribution can be seen relatively in the D-Shaped model, which has a symmetrical geometric form. However, in the C-Shaped and S-Shaped models where the symmetry is broken, the shear forces in the columns are almost different in each. Considering that these are the results of experimental analysis, of course, the magnitude of the shear forces has no meaning in evaluating the structural behavior and performance of the structure. However, it is clearly seen how the main structural system, which has a symmetrical and regular shape, is exposed to different forces due to the curtain wall with different geometric shapes.

In Table 5.3, the moments obtained as a result of the wind loads applied in the X direction and Y direction on the supports of the columns are listed. The distribution of moments at the supports of the columns also shows similar characteristics to the distribution of shear forces. In the R-Shaped model, which defines the curtain wall in harmony with the shape of the structural system, the moment magnitudes are very close and symmetrical. In the C-Shaped and S-Shaped models where the symmetry is broken, the moment magnitudes show remarkable differences.

In addition to the distribution of shear forces and moments in the columns, which helps to explain the interaction between the curtain walls of the buildings and the structural system, the displacements that occur in the columns along all floors are also significant. From Figure 5.9 to Figure 5.12, the deformed shape of the R-Shaped, D-Shaped, C-Shaped and S-Shaped building types in the X and Y directions are shown. As seen in the figures, it is an expected and usual result that different deformations occur in the curtain wall structure depending on different geometric forms. The fact that the common structural system accepted for the curtain wall in parametric analyzes exhibits a different behavior in each model is not important in terms of defining the interaction of the curtain wall and the main structure of the building. It is clearly seen that different building types show unique behavior according to their geometric forms. However, as a result of the analysis of buildings representing four different geometries under equivalent loads, different displacements were obtained in the columns of the identical structural systems. In Figure 5.13 and Figure 5.14, the different displacements obtained for each building type at floor levels in a typical column (C1 column) as a result of the wind loads applied in the X and Y directions, respectively, are shown in a common chart. The horizontal axis of the chart shows the floor levels and the vertical axis shows the displacement in the columns in millimeters. As seen in these charts, the displacements of the R-Shaped model, which represents the regular curtain wall geometry, as indicated by the blue line, increased with respect to the floor levels, as an interesting finding, decreased in other building types. Contrary to the similar results obtained above in terms of base shear forces and moments, in the columns of the main structural system, it is seen that the complex geometry makes a positive contribution to the structural system of the buildings in terms of displacements.

Table 5.1. Total base shear of four building types due to wind load analysis

Building type	Total base shear in X direction (kN)	Total base shear in Y direction (kN)
R-Shaped	768	1248
D-Shaped	768	1248
C-Shaped	912	1248
S-Shaped	941	1248

Table 5.2. Maximum shear forces at the supports of columns in global X and global Y direction due to wind load analysis

Building Type		R-Shaped		D-Shaped		C-Shaped		S-Shaped	
Column	Loading Direction	Shear force (kN)		Shear force (kN)		Shear force (kN)		Shear force (kN)	
		Vx	Vy	Vx	Vy	Vx	Vy	Vx	Vy
C1	X	-120,31	4,19	-132,01	12,49	-155,65	17,65	-142,71	0,71
	Y	7,62	-227,04	32,93	-277,10	10,96	-243,86	20,82	-216,15
C2	X	-143,37	0,00	-199,77	0,09	-203,85	0,00	-190,11	11,64
	Y	0,00	-169,92	1,39	-67,53	0,01	-109,67	15,33	-153,15
C3	X	-120,31	-4,19	-131,99	-12,31	-155,66	-17,65	-161,09	-15,06
	Y	-7,62	-227,04	-30,01	-277,17	-10,96	-243,87	-13,48	-247,33
C4	X	-120,31	-4,19	-132,14	-12,47	-135,39	-2,28	-158,26	23,21
	Y	-7,62	-227,04	-32,52	-277,06	-23,15	-268,16	-25,38	-236,85
C5	X	-143,37	0,00	-119,88	0,08	-126,05	0,00	-142,71	0,71
	Y	0,00	-169,92	-0,95	-67,63	-0,01	-114,28	20,82	-216,15
C6	X	-120,31	4,19	-132,20	12,12	-135,39	2,28	-137,68	11,10
	Y	7,62	-227,04	29,17	-281,51	23,13	-268,17	8,64	-227,57

Table 5.3. Maximum moments at the supports of columns in global X and global Y direction due to wind load analysis

Building Type		R-Shaped		D-Shaped		C-Shaped		S-Shaped	
Column	Loading Direction	Moment (kN·m)		Moment (kN·m)		Moment (kN·m)		Moment (kN·m)	
		Mx	My	Mx	My	Mx	My	Mx	My
C1	X	-328,54	-5,47	-288,45	16,81	-361,54	-40,21	-330,30	-1,58
	Y	9,95	628,08	48,27	607,64	13,66	603,24	34,99	542,39
C2	X	-358,28	0,00	-271,60	-0,22	-426,54	0,00	-394,21	-18,25
	Y	0,00	512,35	2,93	177,41	0,00	317,22	28,99	417,81
C3	X	-328,54	0,00	-288,45	16,81	-361,56	40,21	-354,68	11,59
	Y	-9,96	628,08	-42,18	605,74	-13,63	603,25	-12,31	585,12
C4	X	-328,54	5,47	-288,78	17,10	-300,73	-13,51	-352,92	30,61
	Y	-9,95	628,08	-47,42	607,57	-35,34	637,17	-37,56	570,02
C5	X	-358,28	0,00	-271,88	-0,21	-287,71	0,00	-342,50	-22,41
	Y	0,00	512,35	-2,04	177,54	0,00	322,91	-9,64	434,87
C6	X	-328,54	-5,47	-288,84	-16,80	-300,73	13,51	-324,39	-23,46
	Y	9,95	628,08	41,44	611,55	35,31	637,18	9,45	559,58

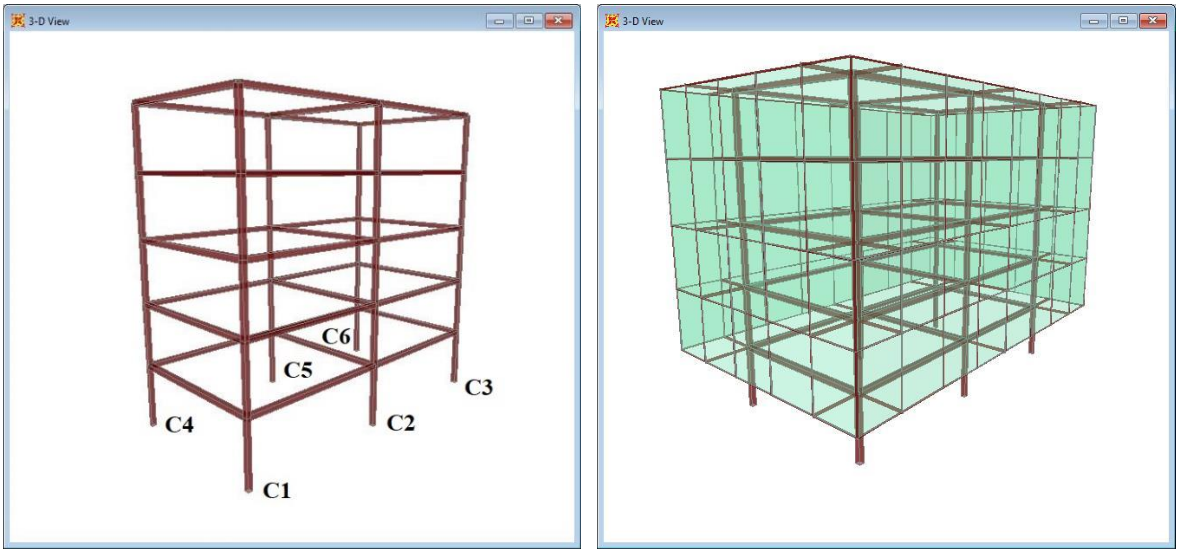


Figure 5.1. Configuration of main structural system of R-shape (Regular shape) with columns, beams, connection members, frames of glazing and curtain walls.

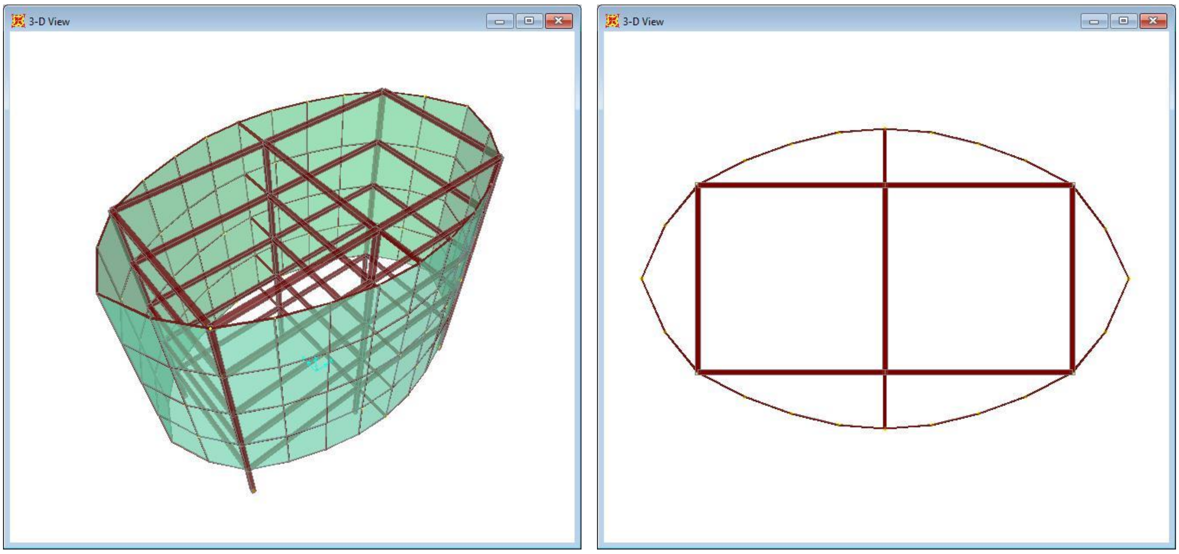


Figure 5.2. Numerical model of D-shaped (Diamond-Oval shape) curtain walled building

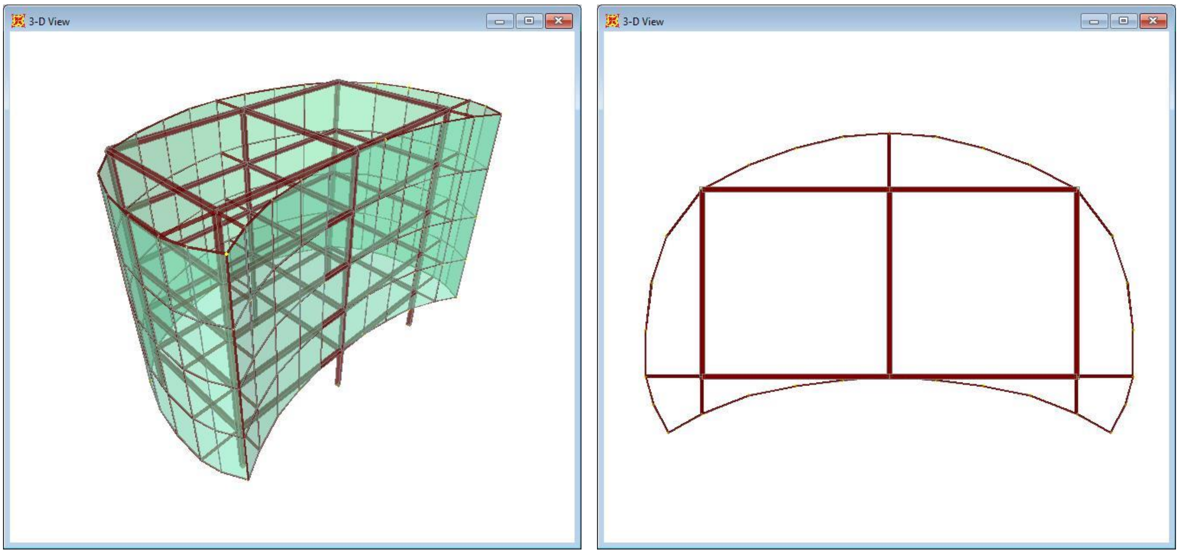


Figure 5.3. Numerical model of C-shaped (Crescent shape) curtain walled building

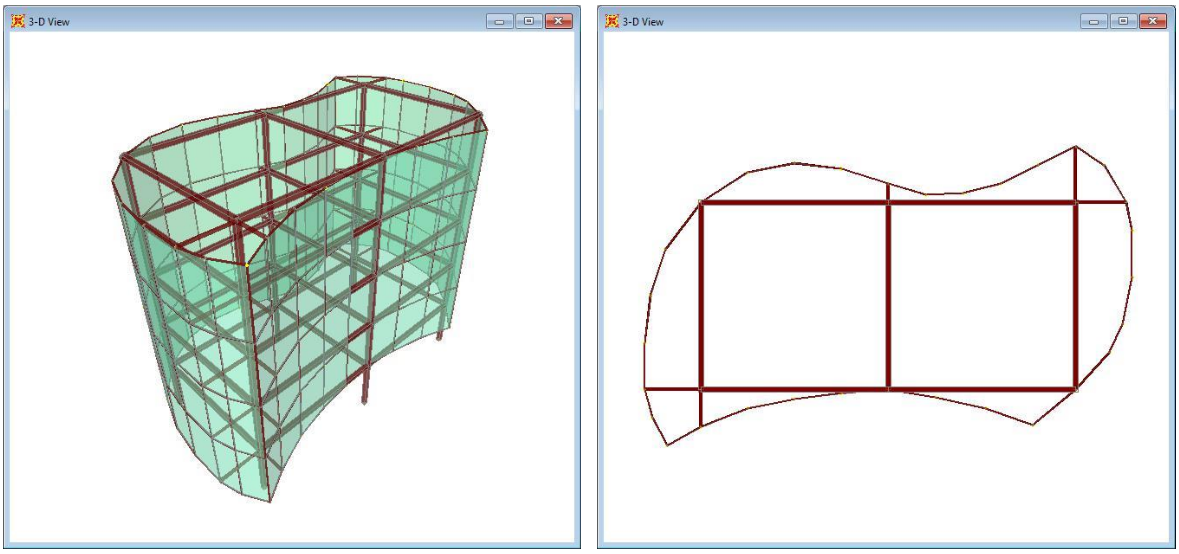


Figure 5.4. Numerical model of S-shaped (Sinuous shape) curtain walled building

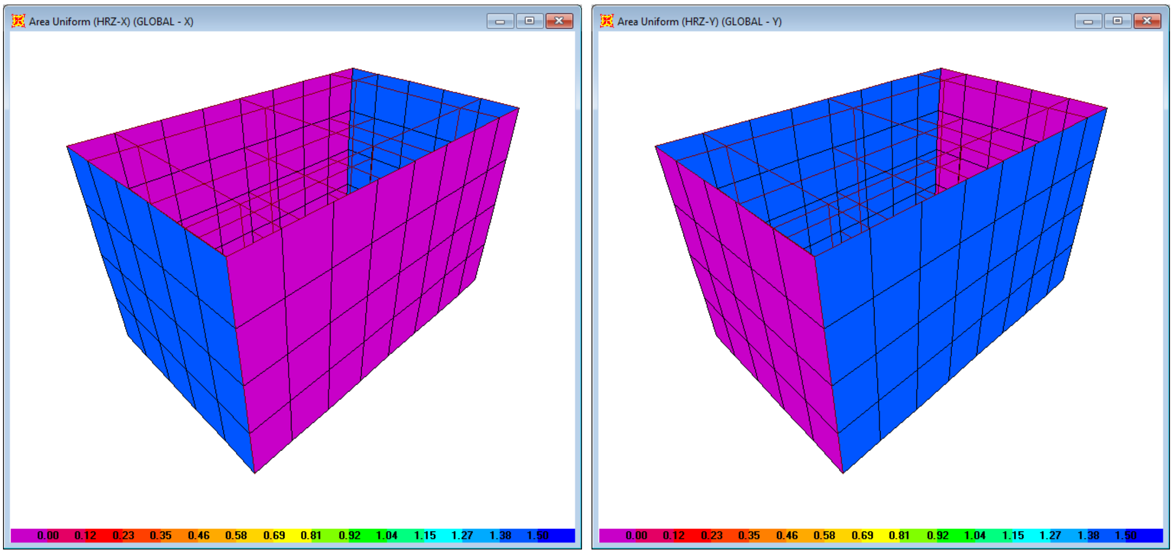


Figure 5.5. R-shaped (Regular shape) building: Projected wind loads in global X and global Y directions respectively.

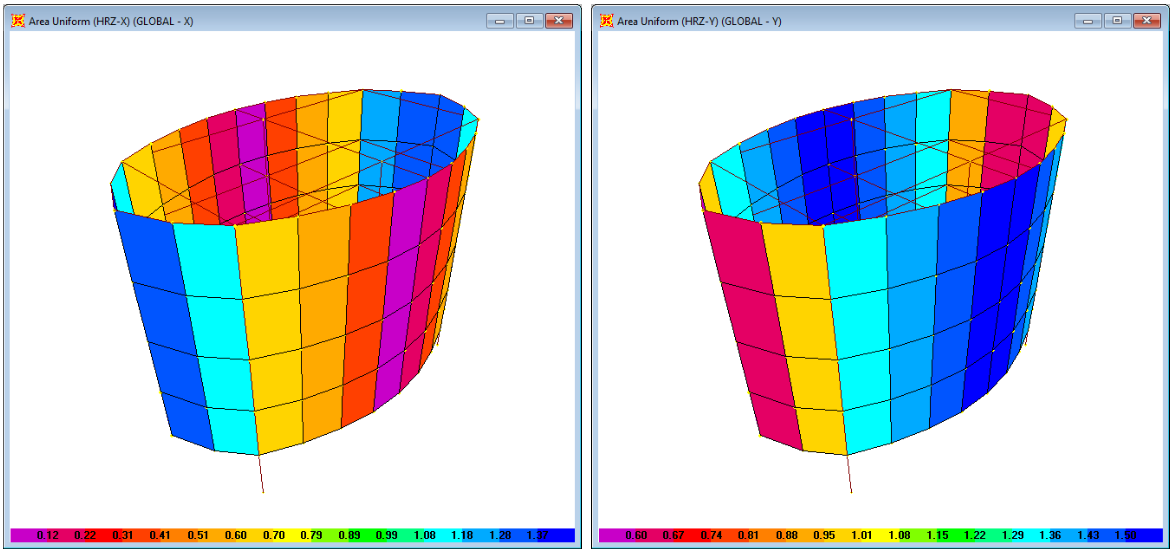


Figure 5.6. D-shaped (Diamond-Oval shape) building: Projected wind loads in global X and global Y directions respectively.

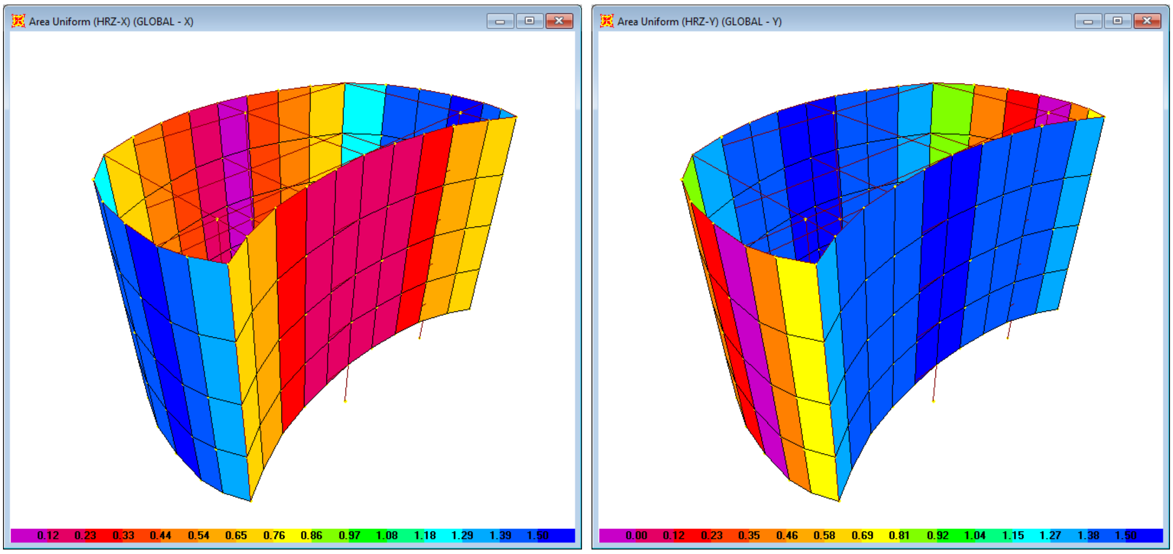


Figure 5.7. C-shaped (Crescent shape) building: Projected wind loads in global X and global Y directions respectively.

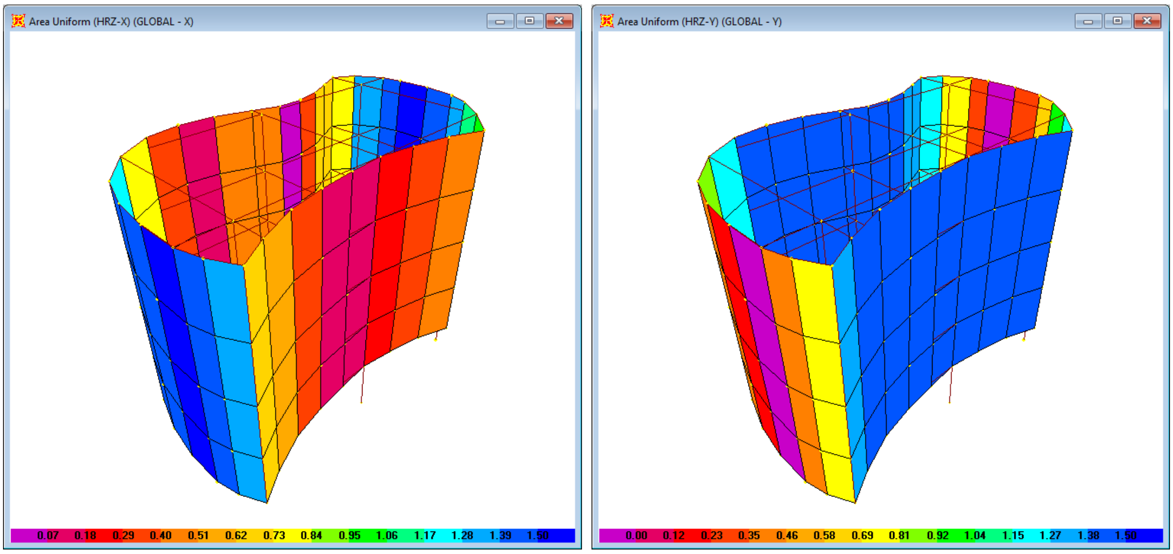


Figure 5.8. S-shaped (Sinuous shape) building: Projected wind loads in global X and global Y directions respectively.

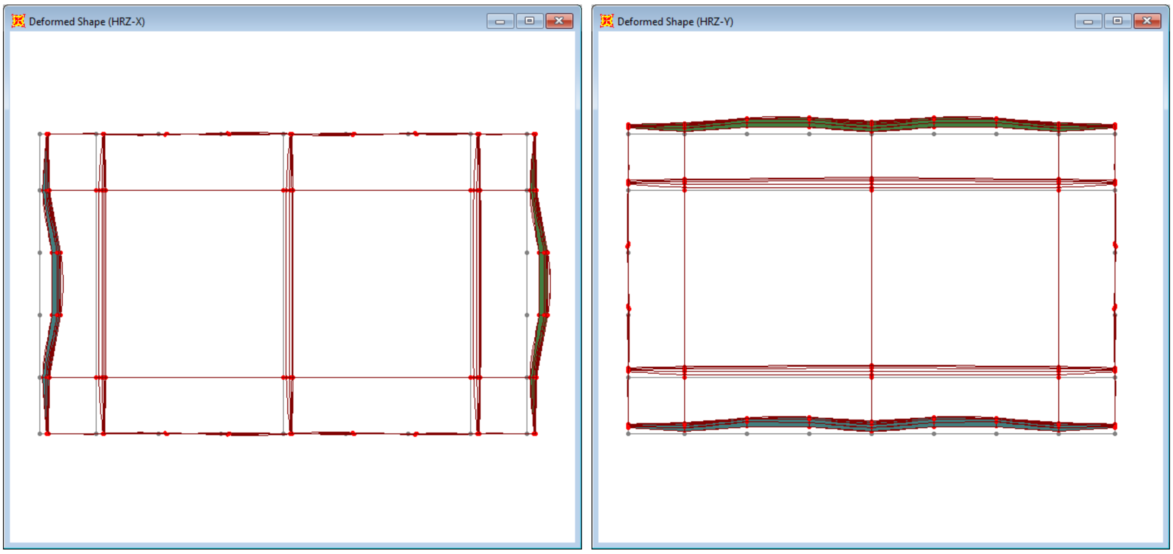


Figure 5.9. Deformed shape of R-shaped (Regular shape) building under wind loads in global X and global Y directions respectively.

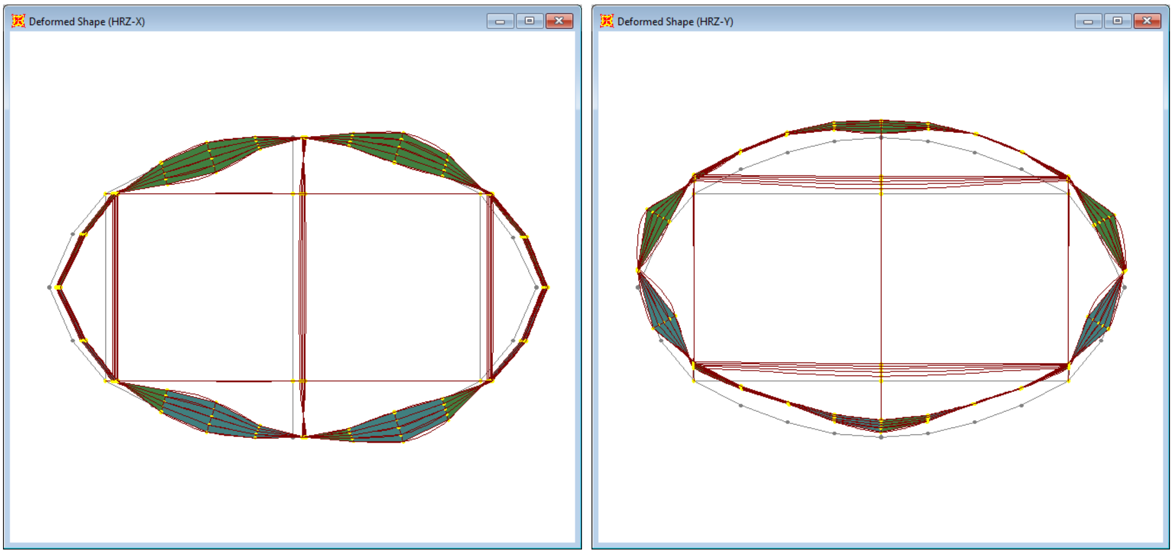


Figure 5.10. Deformed shape of D-shaped (Diamond shape) building under wind loads in global X and global Y directions respectively.

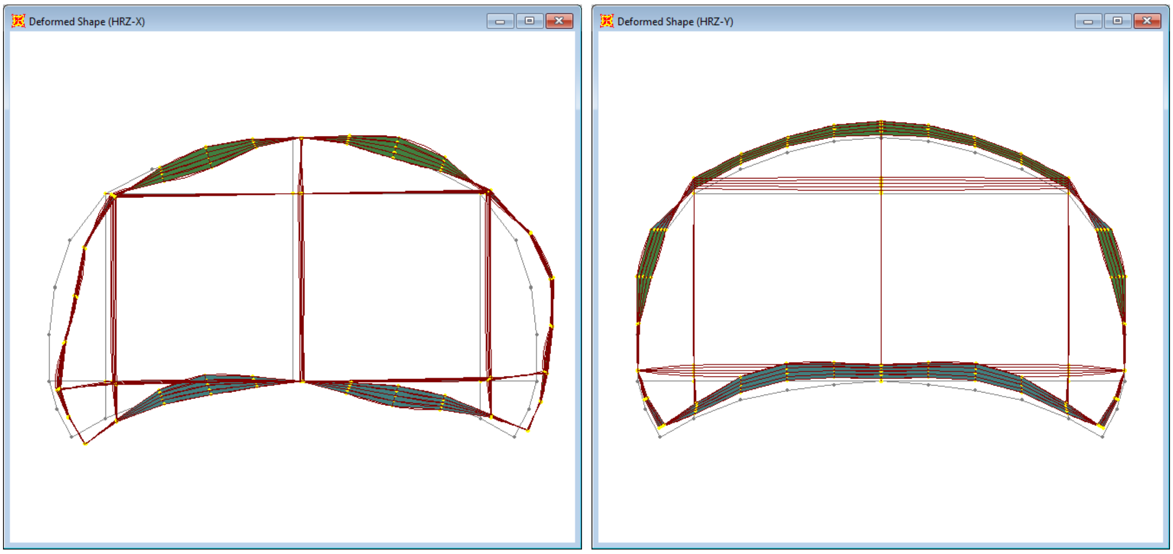


Figure 5.11. Deformed shape of C-shaped (Crescent shape) building under wind loads in global X and global Y directions respectively.

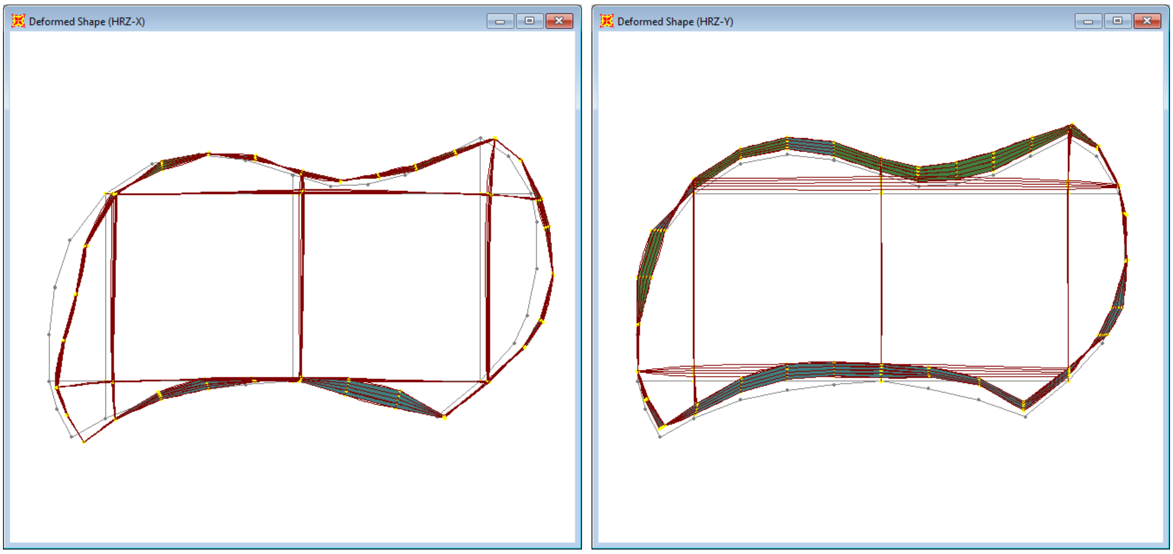


Figure 5.12. Deformed shape of S-shaped (Sinuous shape) building under wind loads in global X and global Y directions respectively.

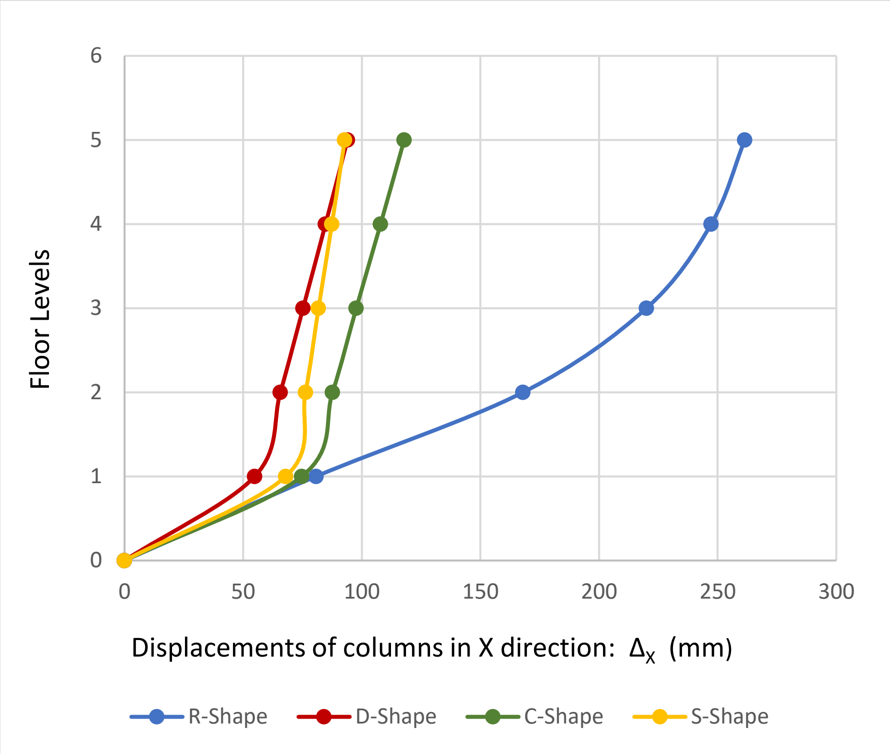


Figure 5.13. Displacements of columns with respect to floor levels in global X direction.

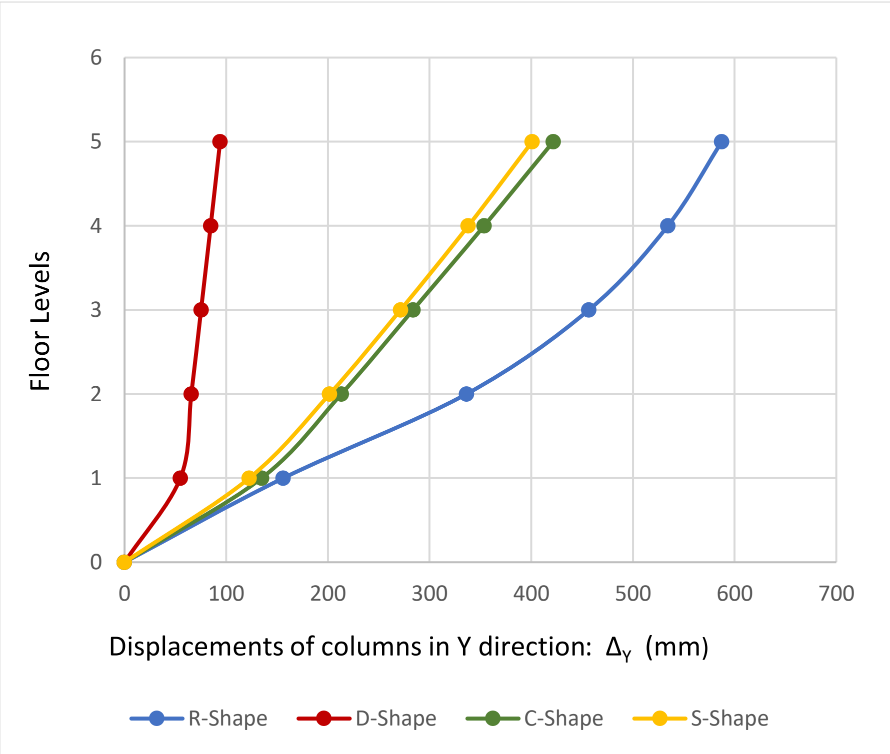


Figure 5.14. Displacements of columns with respect to floor levels in global Y direction.

6. CONCLUSION

Almost all of the buildings defined as high-rise buildings, with their curtain walls and the materials used in their façades, mostly glass, add a symbol to cities and find a place in their silhouettes. Each of these structures is constructed using different construction techniques and structural systems. For this reason, the structural system-façade behavior of these buildings requires a more detailed and comprehensive analysis. With the ever-increasing range of architectural materials and design diversity, complex engineering calculations are needed during the design phase of façades and claddings of buildings. It is possible to make façade design decisions at the design stage with some simplified analyzes without the need for such complex calculations and analysis.

While analyzing the interactions of curtain wall and structural systems of high-rise buildings, because height information is an important point, it comes to the fore in the analysis. Since this study wants to highlight the interaction between the façade and the structural system, rather than bringing the structural system brought by the height information of the buildings to the fore, the analyzes were made by choosing a 5-storey building example. This thesis analyzes the interaction between the main structural system and curtain walls or façade cladding of buildings with these simplified calculations and presents some results that can be useful in the architectural design phase of buildings. This research aimed to identify:

- Is there an interaction between the structural elements that shape the façades and the structural systems of the buildings? To what extent can this interaction be analyzed?

According to the findings, the importance of the form of the curtain wall, namely the geometric shape of the building, is quite high in explaining the interaction between the structural system and the curtain wall of the buildings. As can be seen in the analyzes made in Chapter 5, when wind loads are applied to buildings, it is a normal result that different deformations occur on the façades of buildings due to their different geometric forms. However, although the structural systems are the same, the displacements in the structural systems also differ because the façade forms are different. This is the most important finding that plays a role in explaining the interaction between façade cladding or curtain wall and structural system.

In the study, the following 4 hypotheses were also confirmed, along with the numerical analysis.

- Loads which are not considered and considered in design phase are important for the buildings.
- The behavior of claddings and curtain walls made of the same materials against the loads is related to the shape of the buildings.
- The main structural systems of the buildings are in direct interaction with the shapes of the curtain walls in the direction of external loads.
- Different forms of cladding and curtain walls of the buildings with the identical main structural system directly affect their behavior under lateral loads.

For this study, first of all, a uniform building structure and curtain wall forms with different geometries were created using the SAP2000 computer program. Many structures from two-dimensional to three-dimensional, from simple geometry to complex geometry can be modeled, analyzed and optimized in the SAP2000 computer program. This digital design tool, which enables from the most complex analysis to simplified analysis, was used for simplified analysis in this study. Digital design tools allow designers to model in many different combinations, freeing designers.

When the analysis results of the 4 buildings selected in the numerical analysis, which have the same structural systems and different curtain wall geometries, are examined, it is clearly seen that the geometric configurations affect the structural success of the building. The building form with sinuous curtain wall together with the building structure taken as an example in this study shows successful results with its resistance to wind load. Along with the results of these analyzes, the advantage of a sinuous and curvilinear façade architecture is very important for designers. The stability provided by the geometric configuration of the curvilinear curtain wall, is known by contemporary designers at the architectural design stage of the building, increasing its applicability, and providing an opportunity for extreme designs with its aesthetic appearance.

To summarize, more regular forms are preferred in order to take less risk in the architectural design phase of buildings or to keep the strength of the building strong, but according to the findings obtained from these analyzes, this is not a true phenomenon. The displacements of buildings of unusual geometry buildings which increase when the floor height increases, are less than those of regular geometries. It has been observed that a building with a more complex geometry makes a positive contribution to the structural system in terms of displacements. This thesis, which analyzes the interaction of the façade and the structural system, shows as an example how the façades of the buildings can be shaped at the design stage in some simplified analyzes.

In conclusion, analyzes were made in this study in order to show that some architectural design decisions can be made without the need for complex advanced engineering calculations in the works related to the façades of the buildings, which have become a signature of the buildings, and to show the importance of the geometric forms of the buildings arising from the interaction of the façade-structural system for the buildings. With these analyzes, it is aimed to take the boundaries of the interaction of façade elements such as curtain walls and buildings with the main structural system even further. This thesis is a step towards understanding the diversity and the interaction of structural systems and façade systems with the developing technology in architecture. It should be noted that this work specifically covers geometric exploration. In order to obtain more comprehensive results with the analyzes made, studies should also be carried out on the seismic movements of the buildings. For future studies, tests and analyzes can be made for buildings with different façade cladding materials and different type of structural systems.

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Gazili olmak ayrıcalıktır