# DESIGN AND PRODUCTION OF STEEL BUILDINGS: A CASE STUDY IN ANKARA

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ÖZGE BEŞGÜL

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Approval of the Graduate School of Natural and Applied Sciences

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# ABSTRACT

DESIGN AND PRODUCTION OF STEEL BUILDINGS:
A CASE STUDY IN ANKARA

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It is vital that Turkey keep abreast of developments in the world and build up its technology to become a developed country. Steel construction is one of these areas. In this context, the main purpose of this study was to define, analyze and evaluate the general characteristics of structural steel and steel construction with the purpose of throwing new light on its advantages and disadvantages.

Within this framework, a literature survey was conducted on structural steel components and structures; and on steel construction in Turkey. Additionally, a case study was carried out on a steel office building in Ankara. In this, the Türkiye Esnaf ve Sanatkar Kredi Kefalet Kooperatifleri Merkez Birliği (TESKOMB) Building was investigated in terms of the design and production criteria for steel structures and to determine problems faced during these processes. As a result of this study, the existing condition of the construction sector and the means to improve use of structural steel in Turkey were discussed more realistically.

Keywords: Steel, Structural Steel, Steel Construction, Steel Structures, Steel Production, Steel Components, Steel Connections.

# ÖZ

ÇELİK BİNALARIN TASARIM VE ÜRETİMİ:
ANKARA'DA ÖRNEK BİR ÇALIŞMA

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Türkiye gelişmiş bir ülke olabilmek için dünyada olan gelişmeleri takip etmeli ve teknolojisini ona göre düzenlemelidir. Yapılarda çelik kullanımı da bu alanlardan biridir. Bu kapsamda, bu çalışmanın ana amacı strüktürel çeliğin ve çelik inşasının genel özelliklerini tanımlamak, incelemek ve değerlendirmek ve çelik inşasının avantaj ve dezavantajlarını anlatmaktır.

Bu düşünceler çerçevesinde, strüktürel çelik elemanlar ve yapılar; ve Türkiye'de ki çelik inşası üzerine bir literatür çalışması yapıldı. Ek olarak, Ankara'da ki çelik strüktürlü bir ofis binası üzerine bir çalışma yürütüldü. Bu çalışmada, Türkiye Esnaf ve Sanatkâr Kredi Kefalet Kooperatifleri Merkez Birliği (TESKOMB) Binası, çelik yapılarının inşasının tasarım ve üretim süreçleri açısından ve bu süreçlerde karşılaşılan problemleri belirleyebilmek için incelendi. Bu çalışmanın sonucunda, inşa sektörünün şu anki durumu ve Türkiye' de strüktürel çelik kullanımını geliştirmek için alınacak önlemler daha gerçekçi bir biçimde tartışıldı.

Anahtar Kelimeler: Çelik, Strüktürel Çelik, Çelik İnşaat, Çelik Yapılar, Çelik Üretimi, Çelik Elemanlar, Çelik Bağlantılar.

To my family

for their support and love

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Finally, I would like to express my thanks and love to my parents Serpil Beşgül and Atilla Beşgül and to my grandparents for the education they provided me and for their continuous love, patience and support, which gave me encouragement to complete this study.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AISC | American Institute of Steel Construction |
| ASCE | American Society of Civil Engineers |
| CITIC | China International Trade and Investment Corporation |
| EAF | Electric Arc Furnace |
| HSFG | High Strength Friction Grip |
| ISO | International Standards Organization |
| IISI | International Iron and Steel Institute |
| OECD | Organization for Economic Co-Operation and Development |
| OSB | Oriented Strand Board |
| PVC | Polyvinyl Chloride |
| TESKOMB | Türkiye Esnaf ve Sanatkar Kredi Kefalet Kooperatifleri Merkez Birliği (Central Union of Retailers' and Artisans' Credit-Underwriting Co-operatives of Turkey) |
| YÖK | Yükseköğretim Kurulu (Higher Education Council) |

# CHAPTER 1

# INTRODUCTION

In this chapter, in Section 1.1 the framework and the underlying concern of the study are presented and the scope of the study is discussed. The objectives of the study are described in the next section. The procedure of the study is explained in Section 1.3, and the chapter is finalized with a disposition of the topics of research.

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## 1.1 Argument

The last quarter of the $19^{th}$ Century saw a meteoric growth in the total world output of steel and developed countries were using it as a construction material by the beginning of the $20^{th}$. Currently, steel has become the most common structural material in developed countries due to its greater potential and flexibility that give it the ability of creating new structural forms. With new methods of fabrication and erection, steel frames go up more rapidly, thus reducing financing cost and allowing the building to generate profits sooner. Also, availability of steel in a variety of dimensions and forms enables economical framing of both short- and long-span structures. When compared to other materials, steel has the highest rate of recyclability and recent research in earthquake regions shows that steel is the most reliable structural material against seismic loads.

In Turkey, steel became an option for constructing buildings only in the last quarter of the $20^{th}$ Century. It has been generally used in the construction of industrial buildings, whereas in Europe, in the USA and even in its neighbor, Iran different types of structures are being constructed with steel. Turkey has several mills producing steel and it has the technology to manufacture the necessary equipment and components for steel construction. Another reason to opt for steel as a structural material is that Turkey happens to be located in a high risk seismic zone, and steel structures perform well against earthquake loads.

Most architects, engineers and contractors in Turkey do not have much experience in designing commercial/residential buildings with steel. Standardization in manufactured steel elements also makes architects and engineers stay away from steel since it is felt that this limits design creativity. Apart from lack of knowledge and experience in steel construction, another important problem is economy. Again, it is generally thought that steel is an expensive material that increases construction costs. To the contrary, steel can cost less than concrete if it is designed and used appropriately. In this respect, this study focused on the importance of steel as a construction material in order to abolish prejudice in favor of concrete.

In Turkey the use of steel as a construction material is limited to factory buildings, hangars, temporary structures and large-span public buildings. Although recently a few steel buildings are coming up in the larger urban centers of the country, steel construction is still not as wide spread as it should be, considering the earthquake resistance requirements for buildings. For this reason, architects need to acquire knowledge about steel construction in general and steel components and construction details in particular. This study was initiated with the aim of investigating the various types of steel-building structures and their erection details from the point of view of architectural design.

## 1.2 Objectives

There were three main objectives in conducting this study:

- The first objective of this study was to examine and summarize the basic architectural, structural and constructional design principles of structural steel and steel-building construction. The aim was also to highlight the advantages and disadvantages of steel construction, especially in the context of Turkey.

- The second objective of this study was to investigate the design and erection processes of steel buildings in Turkey, by observing the construction of a selected steel building in Ankara from start to finish.

- The last objective was to propose rational strategies for encouraging the use of steel in the Turkey's construction sector.

### 1.3 Procedure

Firstly, a literature survey on an overview of the theses and publications found in the Libraries of the Higher Education Council (YÖK), Middle East Technical University (METU), Bilkent University (BU) and Gazi University (GU) was conducted. Web sites related to the subject were also visited, and information, statistics and photos were downloaded from these web sites as needed.

Secondly, the 'Türkiye Esnaf ve Sanatkar Kredi Kefalet Kooperatifleri Merkez Birliği (TESKOMB)' Building in Ankara was chosen as a case study. The construction work was monitored from the initial to the final stages. The progress was documented visually and photos of the building were taken at regular intervals during its construction. Construction details were examined and technical drawings and other related photos of the building were obtained from the architects. Additionally, interviews were conducted with the architects and engineers of the building to understand the construction process and to find out their negative and/or positive opinions about the use of steel in constructing this building.

## 1.4 Disposition

This study consists of five chapters. The first one is the introduction chapter which includes the argument, objectives, procedure of the study; and its disposition in this thesis.

In Chapter 2, a literature survey was presented about the essential elements of structural steel and steel construction. Firstly the fabrication process of the structural steel, its components, structural connection types and characteristics of steel construction are described. These are followed by a typology of steel buildings and their examples from around the world. Then the advantages and disadvantages of steel as a building material are stated in comparison with concrete. Finally, steel construction in Turkey and problems affecting its use are discussed.

In chapter 3 the case study on a steel building in Ankara is examined by describing the survey material and survey methodology. In the following chapter, Chapter 4, results and discussions of the survey are presented. Finally, in Chapter 5 the conclusions of the research are presented. Results are discussed and recommendations are presented.

# CHAPTER 2

# LITERATURE SURVEY

This literature review is based on information taken from thirty-three published sources and fourteen websites. It covers topics related to structural steel, components of steel structures and structural connections, erection of steel structures, types of steel structures and advantages and disadvantages of steel construction. Also steel construction in Turkey is explained regarding the need for steel construction and problems of it.

## 2.1 Structural Steel

According to Thomas (2003), the term, 'structural steel', is generally taken to include a wide variety of elements or components used in the construction of buildings and other structures; they include beams, girders, stanchions, trusses, floor plates and purlins. Many of these elements are made from standard hot rolled sections, cold formed shapes or made up from plates using welding. These components are joined at connections using plates, structural components, welding or fasteners. The author also points out that, a variety of steel types are used to produce these structural elements, plates and other components, depending on the intended use, cost, weight of the structure and corrosion resistance.

Watson (1986) asserts that, the making of steel involves the oxidation of the ore, removal of the impurities and addition of other materials to produce a desirable composition. Landers (1983) identifies four principal methods of making steel; the open hearth process, the oxygen process, the electric furnace process, and the vacuum process. According to Moores (1993), the molten steel thus produced is used in manufacturing raw steel products, such as structural sections, plates and wire. There are three basic shaping processes by which the iron ingots are formed into the final product; namely rolling, forging and extruding. Moores (1993) describes these processes as follows:

*a) Rolling:* Rolling is the most common method used for shaping and is particularly suitable for products of simple, constant cross section such as universal beams and columns, plate and sheet. Starting in the form of a slab the steel is reheated before passing through a system of rotating rolls. The reheating process can be either 'batch' or 'continuous'. The rolls are arranged and shaped to change the rectangular cross-section of the slab into the required form; both horizontal and vertical rolls are used simultaneously to modify the profile of the section and hence produce a range of universal beams and columns, identified by serial size and mass per unit length as shown in Figure 2.1.

*b) Forging:* Forging is generally preferred where the end product has a complicated shape. The technology involves either hammer forging, in which shapes are altered by blows from a moving weight, or press forging in which a steady squeeze is applied.

*c) Extruding:* Extruding implies producing steel close to the final shape, by forcing it through a die. Products of complicated cross-section can be produced by this technique. Some seamless tubes, including lighting columns, are produced by this way. Typical extruded forms can be seen in Figure 2.2.

*d) Shaping Tubular Sections:* The two principal methods of making structural hollow sections are the seamless method or by welding. Seamless tubes are produced by the rotary forge method from circular or tapered fluted ingots. Seamless hollow sections can be produced in circular form in sizes up to 500 mm and in thicknesses up to 50 mm. welded hollow sections are produced by a range of processes including butt or continuous weld, electric weld, spiral weld and submerged arc welding. Most hollow sections used in buildings are required in the shape of circular, square or rectangular hollow sections as shown in Figure 2.3.

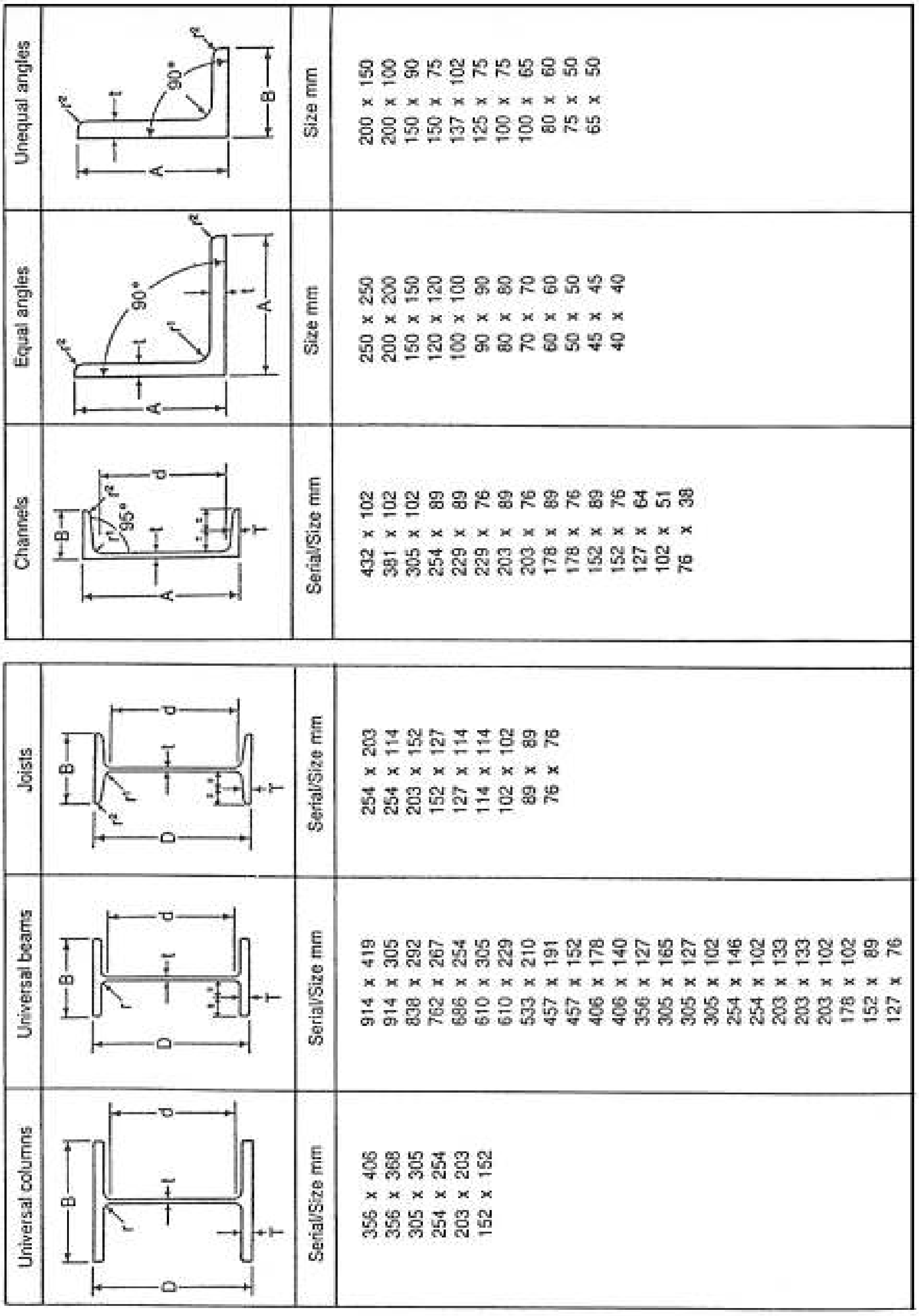



**Figure 2.1.** Range of serial sizes for structural sections (Source: Moores, 1993)

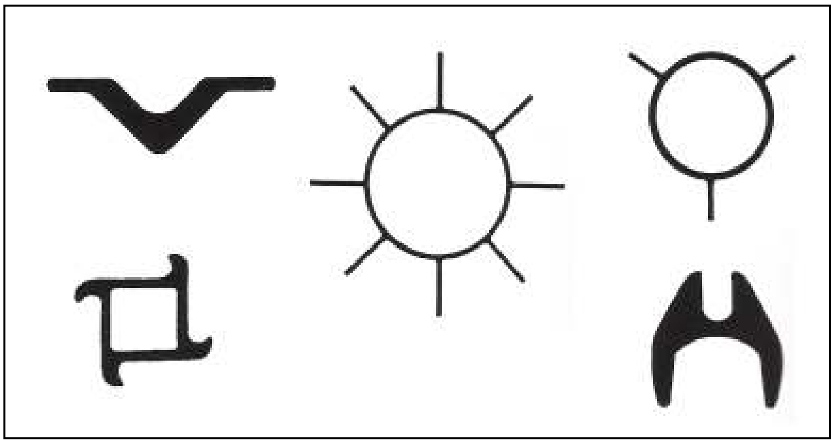
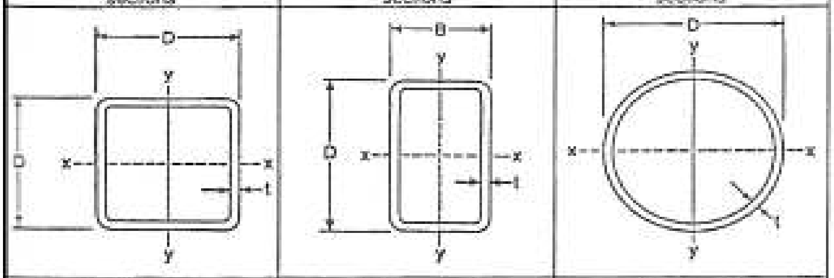


**Figure 2.2.** Typical extruded forms

(Source: Moores, 1993)




| Square hollow sections | Rectangular hollow sections | Circular hollow sections |
|---|---|---|
| Size D x D mm | Size D x B mm | Outside diameter mm |
| 20 x 20 | 50 x 25 | 21.3 |
| 25 x 25 | 50 x 30 | 26.9 |
| 30 x 30 | 60 x 40 | 33.7 |
| 40 x 40 | 80 x 40 | 42.4 |
| 50 x 50 | 90 x 50 | 48.3 |
| 60 x 60 | 100 x 50 | 60.3 |
| 70 x 70 | 100 x 60 | 76.1 |
| 80 x 80 | 120 x 60 | 88.9 |
| 90 x 90 | 120 x 80 | 114.3 |
| 100 x 100 | 150 x 100 | 139.7 |
| 120 x 120 | 160 x 80 | 168.3 |
| 140 x 140 | 200 x 100 | 193.7 |
| 150 x 150 | 250 x 150 | 219.1 |
| 180 x 180 | 300 x 200 | 244.5 |
| 200 x 200 | 400 x 200 | 273 |
| 250 x 250 | 450 x 250 | 323.9 |
| 300 x 300 | 500 x 300 | 355.6 |
| 350 x 350 | | 406.4 |
| 400 x 400 | | 457 |
| | | 508 |

**Figure 2.3.** Serial sizes for tubes

(Source: Moores, 1993)

## 2.2 Components of Steel Structures

Hart (1992) states that, in its simplest terms in steel frames, similar to the other systems, the vertical load carrying structure comprises a system of vertical load carrying columns and other elements interconnected by horizontal beam elements which support slab system. According to the author, the resistance of lateral and vertical loads is provided by diagonal bracing elements, secondary beams and slab systems. Figure 2.4 shows the typical components of the steel frame.

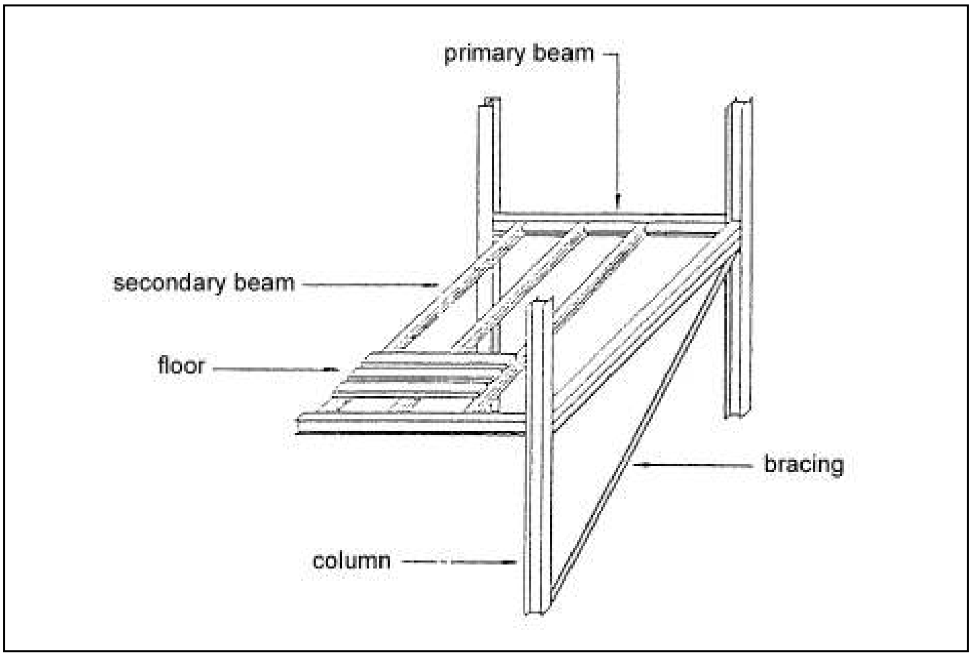



**Figure 2.4.** Typical components of a steel frame
(Source: Hart, 1992)

### 2.2.1 Columns/Stanchions

Copeland, Glover, Hart, Hayott and Marshall (1983) assert that, usually universal columns, standard hot rolled sections, are used for the vertical load transferring in the steel structures since they provide the easiest connection details. According to them, rectangular and circular hollow columns have better stability as a result of their higher stiffness to weight ratio but involve the use of complicated connections.

Hart (1992) explains that, in multistory structures the dimensions of the steel columns can easily be kept constant with changing the thickness and grade. If the loading requirements exceed the capacity of the required section, additional plates may be welded to the section to form plated columns. Also, as stated by Keyder (1993), places where wide flange column sections are not produced, like in Turkey (see Section 2.8.2 c), built-up columns are used. According to Keyder's (1993) classification, there are three main kinds of built-up columns as shown in Figure 2.5:

- Solid wall column; built up from profiles and plates,
- Solid wall with perforated cover plates; built up from individual profiles connected with perforated plates,
- Open type columns; built up from individual profiles and connected with lacing or battens. This is the most common type of built-up columns.

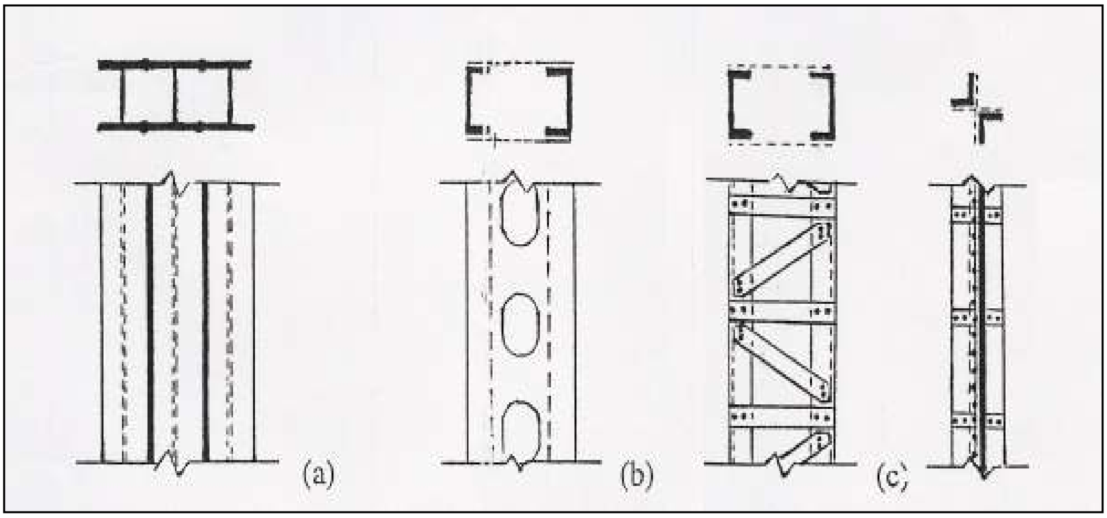



**Figure 2.5.** Built-up columns; (a) solid wall column, (b) solid wall column with perforated cover plates and (c) open type column (Source: Keyder, 1993)

Akşar (1990) points out that, in addition to the columns, load bearing shear walls, tension elements carrying the slab loads by means of tension, transition beams transferring the upper column loads to the lower when the column system is changed in the lower floors and suspension bars used in suspension structures can all be expected to be an element of vertical load carrying elements.

### 2.2.2 Beams and Girders

As mentioned by Copeland, Glover, Hart, Hayott and Marshall (1983), members that carry transverse loads are beams. According to them, the structural steel floor construction generally consists of secondary floor beams (generally named as joists) of supporting a thin precast or in-situ concrete slab. The most efficient floor plan in steel structures is in rectangular shape. The secondary floor beams which are closely spaced on the longer distance are supported by primary beams (generally named as girders) which are spanning the shorter distance between columns. They also explain that, the primary beams are usually of rolled sections but can often take the form of castellated beams, fabricated plate girders or taper beams because of heavy loading, deeper construction and the possible need for service penetration.

Berktin (1994) states that, for medium-to-lightly-loaded floors and long spans, castellated beams fabricated from standard sections are generally used (Figure 2.6). According to her, conventional universal beams span a maximum of about 15 m. The author further states that, taper beams are similar to plate girders except that their depth varies from a maximum in mid-span to a minimum at supports thus achieving a highly efficient structural configuration (Figure 2.7). Trusses used as floor beams (floor and roof trusses, open web joists and girders) also give way to span much longer distances. Today; fabrication techniques allow the economical production of plate girders (Figure 2.8). Especially non-symmetric ones allow more economic construction in excess of 15 m.

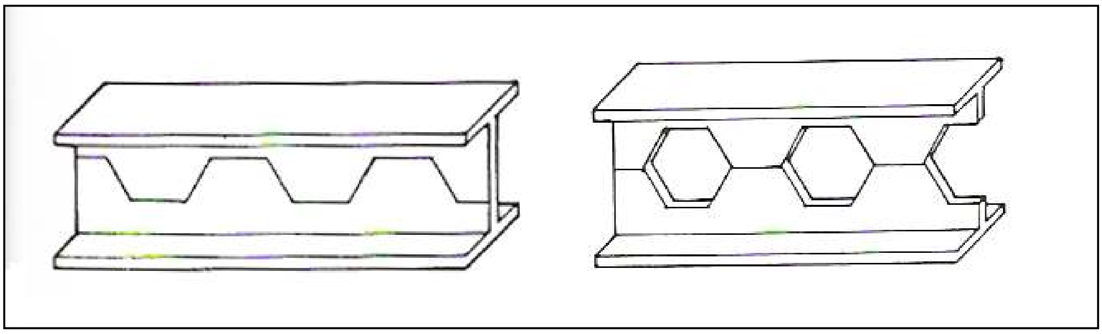


**Figure 2.6.** Castellated beams

(Source: Taggart, 1993)

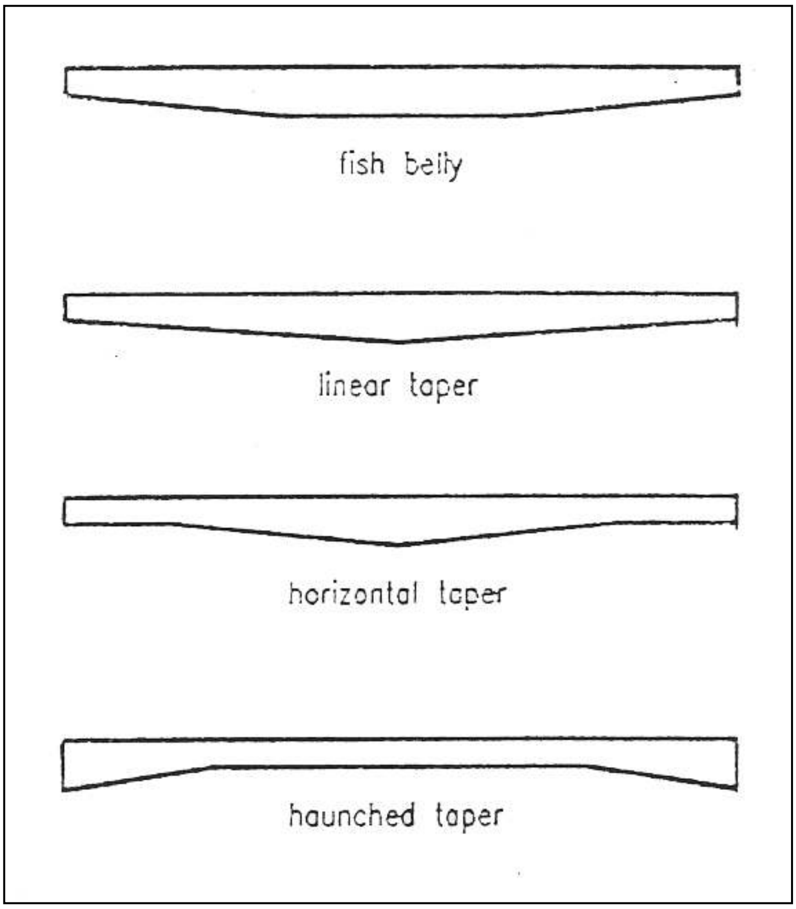



**Figure 2.7.** Tapered beams

(Source: Berktin, 1994)

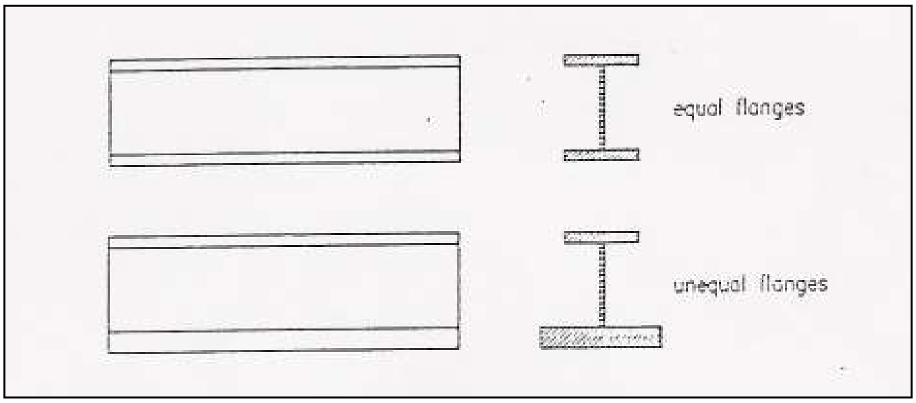



**Figure 2.8.** Fabricated plate girders (Source: Berktin, 1994)

### 2.2.3 Joists

Steel joists, frequently placed beams to carry floor loads, have always been popular for several reasons as summarized in Engineering News Record (1992):

- High strength to weight ratio and multi-directional strength,
- Lower building cost: As a result of the latter and the low price per pound of joist contribute significantly to lower building costs. Also the joists lightweight enables structural supports, such as beams, columns and foundations to be lighter and less costly,
- Cost saving erection: An example of the low cost and flexibility of steel joist is cantilevering. Cantilevering is an expensive, labor-intensive procedure, when it is done in concrete. With steel joists, cantilevering can be achieved simply by specifying an extended end or full-depth cantilever. All the fabrication is done at the factory,
- Ease of inspection,
- Design flexibility; because each joist is fabricated to the designer's specifications, there is an infinite flexibility in the design of a steel joist building. An extensive number of depths, spans and load carrying capacities can be specified and produced at the factory, avoiding expensive on-site labor.

2.2.4 Slab Systems

As stated by Hart (1992), the most widely used construction system for slab systems is metal decking (Figure 2.9). Composite action provided by studs through the metal decking onto the beam flange, enables the floor slab to work with the beam enhancing its strength and reducing deflection. The author also asserts that, there are many types of metal deck systems depending on the type and section of the metal sheet, which is controlled by many criteria related to strength, developing adequate composite action and efficient transfer of forces. According to Aşkar (1990), in-situ or precast concrete or ceramic are also used as slab systems in steel structures.

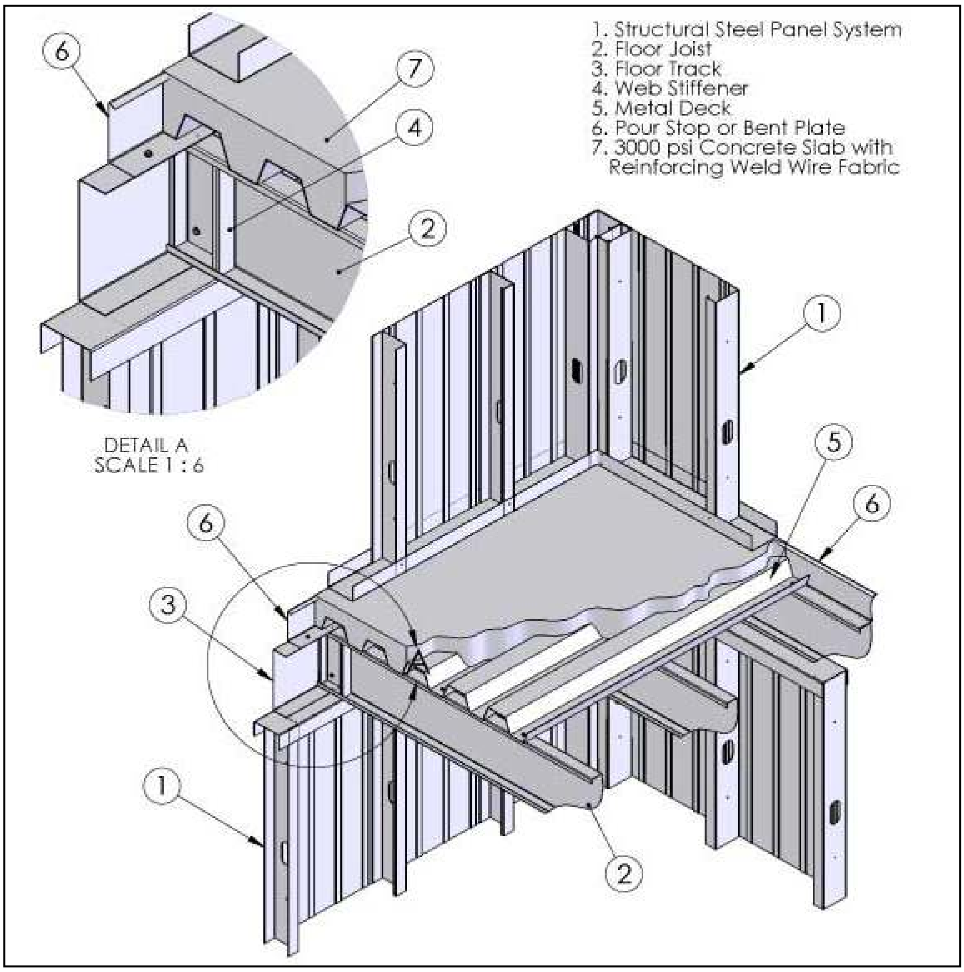



**Figure 2.9.** Steel deck floor system

(Source: www.nexgenhomes.net, retrieved 2006)

Additionally, Copeland, Glover, Hart, Hayott and Marshall (1983) points out that services distribution is an important factor effecting building structure, mainly slab system. The greater depth of steel construction does not necessarily result in an increase in building height if the services are integrated in the building zone occupied by the structure. The authors define two basic approaches to this problem; integration or separation. Integration requires either deep, highly perforated structural components to allow relatively impeded routing of services (either by means of castellated beams or stub girders) or vertical zoning of structure and services (Figure 2.10). Separation requires the horizontal zoning of structures and services which is best done in suspended ceiling or raised floor voids (Figure 2.11).

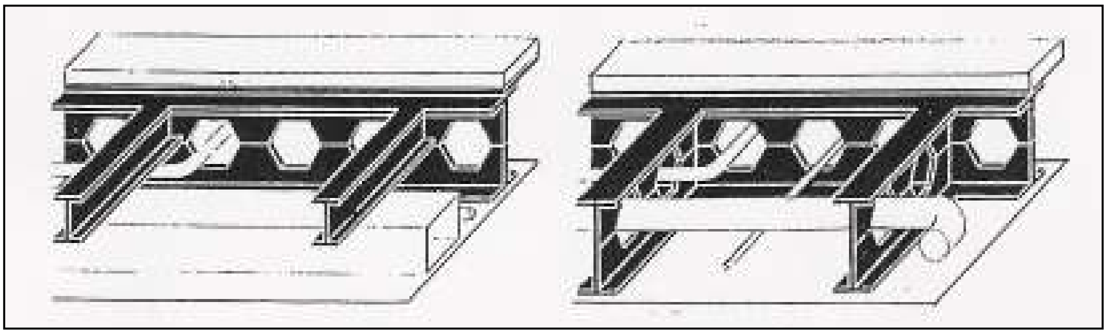


**Figure 2.10.** Unimpeded routing of services
(Source: Copeland, Glover, Hart, Hayott and Marshall, 1983)

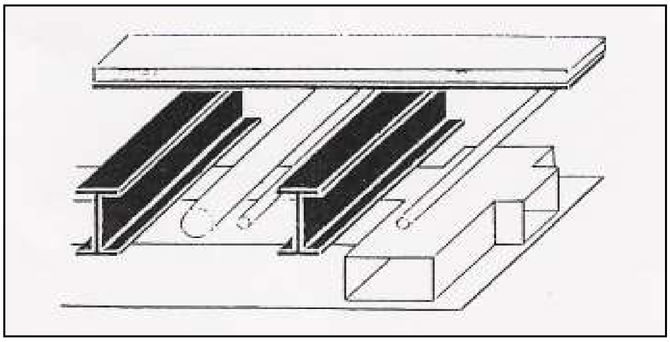


**Figure 2.11.** Lateral zoning
(Source: Copeland, Glover, Hart, Hayott and Marshall, 1983)

### 2.2.5 Bracings

According to Hart (1992), as the height of the building increase the systems ensuring lateral stability gains more importance. Arda, (1978) explains that to avoid breaking and cracking of shear walls and to ensure the serviceability of the building on behalf of the occupants, the lateral movement of the structural system should be kept in certain limits. Generally the excepted upper limit is that; the total lateral movement of building should not be exceed the total height/500 and for individual floors the movement should be kept smaller than the floorheight/500. Hart (1992) asserts that, lateral stability in steel structures is generally provided by steel bracings as shown in Figure 2.12. Rigidly jointed frames or reinforced concrete walls are also used for lateral stability.

**Figure 2.12.** Use of external steel bracings in the John Hancock Center in Chicago, USA (Source: www.hispago.com, retrieved 2006)

### 2.2.6 Cables and Ropes

According to Moores (1993), cables and ropes are produced from wire and their main use in buildings and structures is in guyed and suspended structures, suspension bridges and lifting equipment. Moores (1993) states that, cables and wire ropes are made up of a number of individual steel wires which are spun into a strand. A number of strands (usually six) are woven around a central core to form a rope, and a number of ropes (again usually six) form a cable. The author also explains that, the largest ropes normally produced are approximately 100 mm in diameter and are made up with six strands each containing 52 wires. The largest cables normally produced are made up of six ropes of approximately 70 mm diameter. The function of the core is to provide support to the strands and hold them in the correct position under working conditions. Cores may be of fibre or steel composition.

Moores (1993) continues that, ropes can be protected by zinc coating/galvanizing which provides sacrificial protection to underlying wires against corrosion. Alternatively, synthetic sheathing can be used to provide a barrier between the rope and the environment. Sheathing can be nylon or PVC, which can be colored. Some ropes are manufactured using stainless steel wires which are particularly suitable for many corrosive environments. According to the author, ropes do not have an indefinite life. Usual visible signs of rope deterioration are corrosion, excessive wear, broken strands, and distortion. However, the rope’s life can be extended considerably by adequate attention to maintenance, regular inspection and lubrication, correct handling and prevention of mechanical damage.

## 2.3 Connections in Steel Structures

MacGinley (1981) describes that, connections are required to join individual members of the steel structures together to ensure composite action thus to transfer axial loads, shear, moment and torsion from one component to another. The design of connections between individual frame components is the most important aspect of structural steelwork for buildings.

As defined by Watson (1988), there are several methods of connecting steel members. The selection of a particular connection system should be governed not only by its capability to support the applied load, but also by the ease of connection to other components. Also other criteria, such as code requirements, fabricator's preference and economical considerations are also effective in the selection. Watson (1988) asserts that, connections may be realized either by bolting or welding.

### 2.3.1 Bolting, Riveting and Welding

Lui (2003) states that, steel sections can be fastened together by rivets, bolts, and welds. Although rivets were used quite extensively in the past, their use in modern steel construction has become almost obsolete. Bolts have essentially replaced rivets as the primary means to connect non-welded structural components. As discussed by Schollar (1993), it is generally cheaper to make a bolted joint than a welded one (particularly on site) so a designer will usually choose bolted work for both site and workshop with some shop welding where warranted by engineering design. According to the author, site welding is utilized where the full strength of a member must be used at a connection and where tolerance, geometry or aesthetics require welded connections. In externally exposed work, welding is often preferred to avoid rainwater penetrating behind splice plates on exposed steel.

#### a) Bolting and Riveting

Biggs (1993) asserts that, bolting and riveting were the only possible ways of making joints in cast and wrought iron. Riveting involved the close hammering of a red hot river into prepared holes: as the rivet contracted upon cooling the plates were locked together, essentially, by the tensile stress in the rivet. The author continues that, high strength friction grip (HSFG) bolts work in much the same way. The bolt is tightened to some predetermined stress and it is this prestress which holds the two components together by friction. HSFG bolts are made from quenched and tempered alloy steel in order to obtain a high yield point combined with good ductility. As with all heat treated steel no heat should be applied or the properties will be affected.

b) Welding

According to Thomas (2003), welding is perhaps the most important process used in the fabrication and erection of structural steelwork. It is used very extensively to join components to make up members and to join members into assemblies and structures. Additionally as mentioned by Schollar (1993), welding can save costs and reduce member sizes by dispensing with the need for brackets and plates at connections and by allowing the use of the whole cross-section of a member by eliminating holes for bolts.

According to Schollar's (1993) classification, the two basic types of weld are the fillet weld and the butt weld. Fillet welds are normally used where the connection does not need to develop the full strength of the connected plates (Figure 2.13 a). They are relatively cheap because the edges of the plates do not have to be machined or shaped, the amount of weld metal placed is small, and inspection is easier than for butt welds. Butt welding (Figure 2.13 b) is used for highly stressed connections, and the plates are machined and chamfered so that the weld metal is placed across the whole plate thickness.

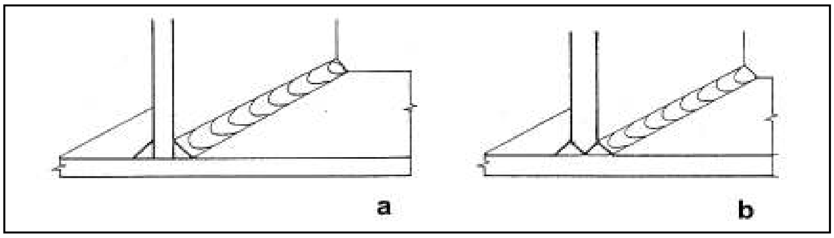



**Figure 2.13.** Typical welds: (a) Fillet weld and (b) butt weld
(Source: Biggs, 1993)

Thomas (2003) states that welding used and done well helps in the production of very safe and efficient structures because welding consists of essentially joining steel component to steel component with steel that is intimately united to both. It can lead to very efficient paths for actions and stresses to be transferred from one member or component to another. Conversely, welding used or done badly or inappropriately can lead to potentially unsafe or ineffective structures (welds containing defects or inappropriate types or forms of joints can cause failure or collapse of members or structures with little or no warning). Thus, care is required in the design of welds, in the design or specification of welding processes, in the actual process of welding components one to another, and in the inspection of welding to assure that it is as specified and fit for purpose. According to the author, as with the production of the structural steel components, specialist expertise is required for successful welding. This is built on a foundation of knowledge of the metallurgy of steel but also requires knowledge of the processes and materials involved in welding.

Thomas (2003) also explains that, welding of structural steel is usually the process of joining two pieces of similar (not necessarily identical) steel by casting a further quantity of steel between them and fused to each of them, but it may equally involve no filler material, simply the melting together of the two pieces to be joined. The process involves heating and melting the surfaces of the pieces to be joined and, when required, the steel to make the weld.

According to Biggs (1993), all welding involves essentially the same sequence of operations, the temperature of the steel is raised, locally, to its melting point when additional metal may or may not, be supplied. It is then allowed to cool naturally, the cooling rate being affected by the size and shape of the parent components. Biggs (1993) claims that, whatever the process, all welds should comply with two requirements. The author summarizes these requirements as follows:

- Ideally there should be complete continuity between the parts to be joined and every part of the joints should be indistinguishable from the parent material. In practice, this is rarely achieved, though welds giving satisfactory performance can be made.
- The joint materials should have satisfactory metallurgical properties, though poor welding practice can affect the end result.

2.3.2 Commonly-used Connections

In this section, commonly used connections are discussed, with examples and simple diagrams to illustrate the points made. By this way, advantages and disadvantages of these connections are expressed.

a) Column Section in Compression

As mentioned by Schollar (1993), the simplest concept is a welded profile as shown in Figure 2.14 b, where stress is transferred directly from the column above, through the weld, to the column below. A connection like this would be made in the factory. The author continues that, an alternative (Figure 2.14 a) is to use shop-welded capping plates to each column length. These are bolted on site to locate the plates together. A considerable advantage is that different cross-sectional sizes can be accommodated. The end of the column must be accurately cut square to the shaft so that the upper column will be vertical when it sits on the lower column. Packing plates between the capping plates can be used to allow adjustment of levels. According to the author, splice plates (Figure 2.14 c) are another common detail, which require no welding in the fabrication shop, and allow some directional tolerance during erection.

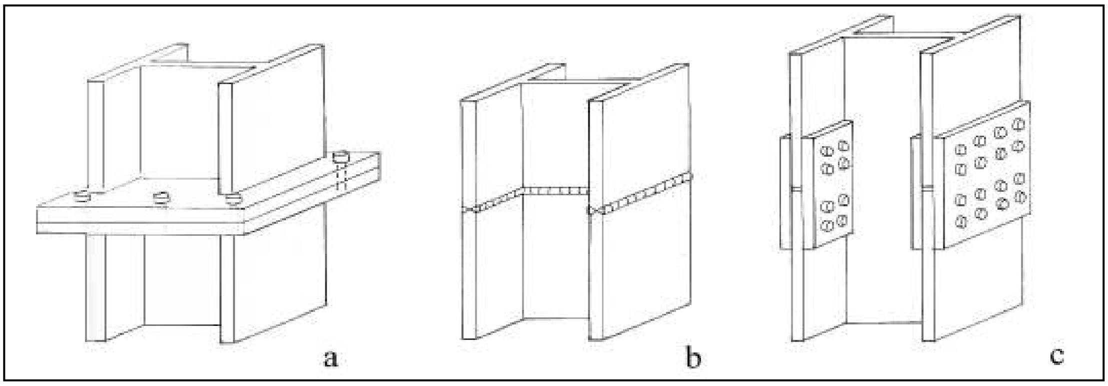



**Figure 2.14.** Direct compression in a column joint carried by (a) end plates, (b) on welds, and (c) on splice plates (Source: Schollar, 1993)

Schollar (1993) further states that, looking at other aspects of these connections, the profile weld and capping plate can be contained within the net column size, thus minimizing the size of the clad column. According to the author, splice plates are unlikely to be acceptable for an exposed connection, and cannot be used for columns of circular hollow section. Welded joints are very suitable for use in trusses which are fully fabricated in the shop, and for exposed work are much better than using splice plates which can trap water and for this reason cause corrosion.

b) Section in Tension

As stated by Schollar (1993), the same connections (Figure 2.14) could be used in tension as well as compression. However, the capping plate detail shown in Figure 2.14 (a) is unlikely to be suitable because the tension forces would develop tension in the bolts and bending in the capping plates. Splice plates (Figure 2.14 c) could be suitable, providing the member is not fully stressed in tension; otherwise the holes drilled for the bolts could make the net section too small.

c) Beam-to-beam or Beam-to-column Connection

Thomas (2003) claims that, beam-to-beam connections are possibly the most common type of connection and the most straightforward to construct. The author continues that, bolted angle cleats are ideal for rectangular grids (Figure 2.15). A popular variation of this is the welded end plate shown in Figure 2.16 which can be splayed to suit non-square joints. Shear loads are carried in the webs of I-beams, and both of these connections take the shear load directly from the web of the secondary beam and transfer it to the web of the supporting beam. The author further explains that, an angle is sometimes placed under the end of the supported beam (Figure 2.17). In this case the load is transferred from the web through the bottom flange of this beam and into the web of the main beam through the angle. The same principles are used in beam-to-column connections. Where the beam is connected to the web of the column the load is transferred almost concentrically. However, if the beam is connected to the column flange, the column is loaded with some eccentricity and this must be allowed for in the design of the column.

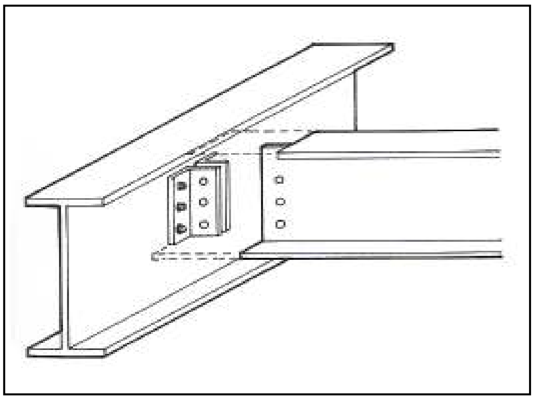


**Figure 2.15.** Beam-to-girder connection using web cleats (Source: Thomas, 2003)

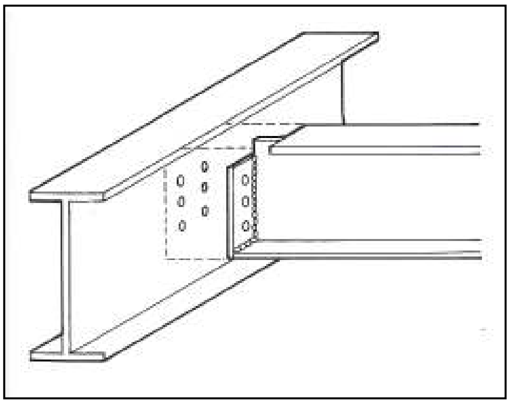


**Figure 2.16.** Beam-to-girder connection using a welded end plate (Source: Thomas, 2003)

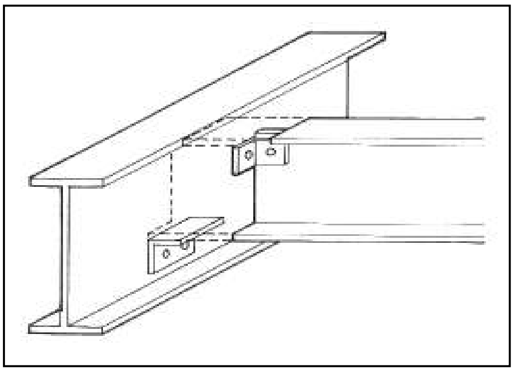


**Figure 2.17.** Beam-to-girder connection using seating and restraining cleats. (Source: Thomas, 2003)

Thomas (2003) explains that, beam-to-column moment connections are used in rigid construction such as portal frames. The moment and shear actions at such a connection can be balanced by a pair of flange forces; tension in the top flange and compression in the bottom flange, with the shear staying in the web. Each of these forces must then be carried into the column, where they create shears in the web and compression in the flange. To reduce the magnitude of these forces, a gusset is often detailed at the end of the beam. Figure 2.18 shows a beam-to-column connection for moment connection using a gusset.

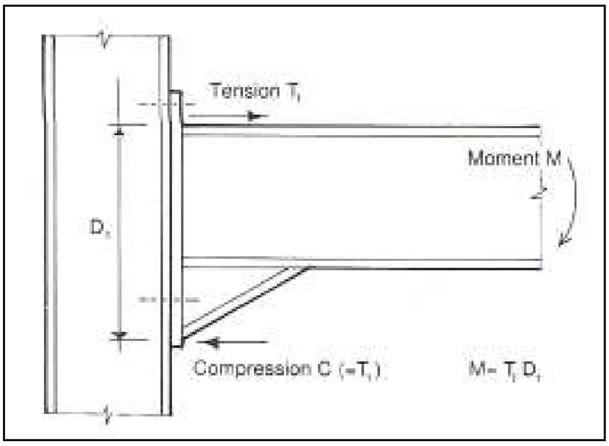



**Figure 2.18.** Beam-to-column moment connection using a gusset
(Source: Schollar, 1993)

2.3.3 Special Connections

As stated by Schollar (1993), wire ropes, which can carry the highest stresses, cannot be threaded or welded. The author explains that, for low loads the rope can be clamped, but for large loads the force is transferred by spreading the individual wires out in a conical shaped steel casting as shown in Figure 2.19, and pouring molten zinc into the cone to socket the wires. The casting is attached to an anchorage or another length of rope by means of a pin or threaded coupler as shown in Figure 2.20. According to the author, the working stresses for couplers are lower than those for the rope itself, and consequently the coupling will be larger. Although the working stresses are lower for a tension or tie bar, welding is often difficult or impossible and connections are formed by threading. The thread is not cut for the highest strength bars, but rolled onto the bar so that no sectional area is lost (Figure

2.21). The coupling as shown might be the simplest way to achieve a connection, but if such a joint is exposed, a more expensive form may be required. In such cases a pin joint is often used (Figure 2.22). Although these seem to cause great excitement, in engineering terms a pinned joint is simply an abstraction which allows the designer to control the distribution of forces in a structure.

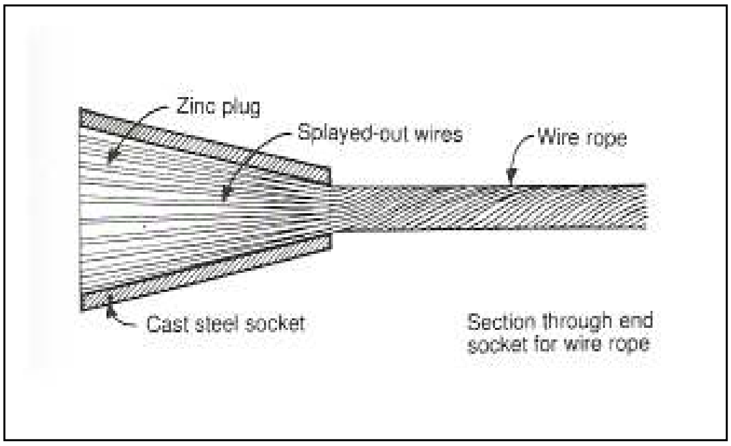



**Figure 2.19.** Diagram of splaying out of wire rope
(Source: Schollar, 1993)

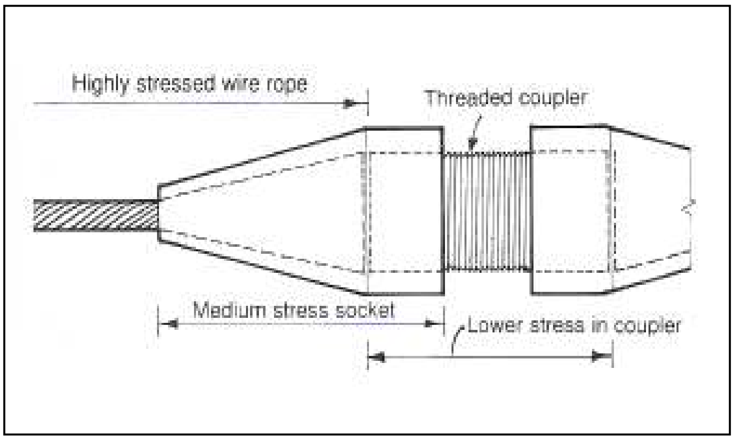



**Figure 2.20.** Threaded coupling for wire rope sockets
(Source: Schollar, 1993)

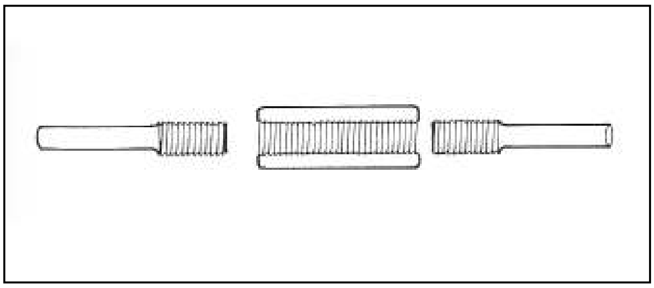


**Figure 2.21.** Threaded coupling for bars
(Source: Schollar, 1993)

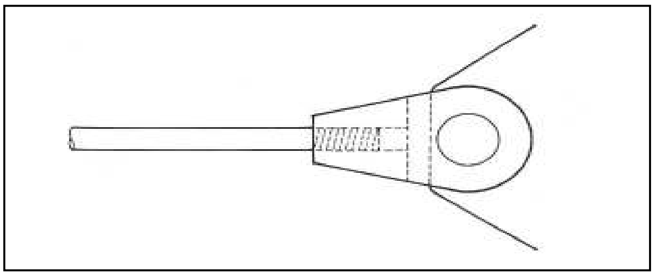


**Figure 2.22.** Pin joint connection for bar
(Source: Schollar, 1993)

Schollar (1993) further explains that, joints in hollow sections also require special connections. They are fundamentally different from those used in open wall sections, as tubes have few surfaces on which to fit splice plates and bolts. A number of straight tube-to-tube joints are shown in Figure 2.23. The connection with end plates (Figure 2.23 a) is suitable for compression, but less good for tension. If the loads are large many bolts and thick plates will also be required. A fish plate connection can be made between tubes with enough bolts to transfer the load through the connection plates (Figure 2.23 b). The joint in Figure 2.23 (c) is likely to work for any combination of applied loads, but it gives little scope for tolerance if erection and fabrication are not absolutely perfect. According to Scholar (1993), joints in tubular trusses are usually welded, because full profile welded joints not only look better, but are also cheaper than creating elaborate bolted joints.

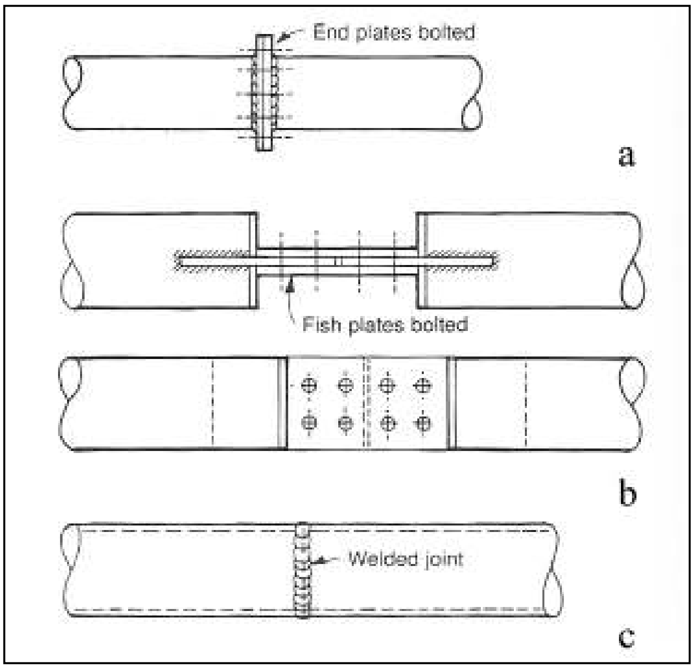



**Figure 2.23.** Tube-to-tube splice.
(Source: Schollar, 1993)

## 2.4 Erection of Steel Structures

When the decision to use a steel frame has been taken, framing plans which define the size and type of each member, typical details of connections and full information about setting out each structural component are produced (Fenton, 1983). The choice of structural form and method of connection detailing have a significant impact on speed of both fabrication and erection. In this section the stages making steel members ready for the erection phase and the erection process are described.

a) Preparation

Taggart (1993) asserts that after completing the fabrication of steel members, the second step is converting them into structural elements which can be readily assembled on site according to demands of the architects or engineers. As mentioned by the author, cutting to length is the first task to be conducted and, for the heavier sections, a circular saw is the principal tool employed. Lighter angle sections are often sheared on a cropping machine which is not only much quicker but relieves demand on the saws. Cropping is particularly useful for substantial quantities of relatively short cut lengths such as small bracings or cleats. The author also states that, plates and similar flat products are not only more awkward to handle but require different cutting techniques. Accordingly, a different route is used where cutting to size is either conducted by shearing on a guillotine or by flame-cutting. Perhaps the most widely publicized example of flame cutting is the castellated beam (an idea credited to the Chicago Bridge Co. in 1910).

According to Taggart (1993), another step is holing. The author explains that, in most cases holes are formed by drilling, although punching, which is extremely rapid, is widely used for secondary members or thinner components such as gusset plates. On newer machines punching can also be combined with cropping. Generally when considerable repetition can be established, holes are increasingly being drilled in groups on semi-automatic machines. These machines can operate on three separate axes, which means that holes can be drilled through the web and both flanges of a universal section at the same time.

Fenton (1983) points out that, together with the production of primary structural elements, components for fitting and assembly, such as brackets, gusset plates and stiffeners, also have to be manufactured separately. As this is often labor intensive, jigs and templates are used to ensure consistency and to save time, particularly where quantity production is involved. According to Fenton (1983), as a general rule, shop connections tend to be welded in preference to bolting but, depending upon the nature of the structure, some shop bolting may be used if only for trial alignment and fitting. The choice between shop bolting and welding is generally one of cost and convenience related to the facilities offered by a particular fabricator.

b) Erection

Taggart (1993) explains that steelwork erection normally occupies a relatively short period on the construction program, but during this time considerable activity occurs, which is instrumental to the performance of the contract as a whole. According to the author, the steel framework should not be seen in isolation but as an integral link in the construction chain where the time saved can have considerable impact in lowering overall costs. Early consideration should be given to erection methods during design and detailing in order to realize the full benefits of structural steel.

As stated by Biggs (1993), the method of erection selected will depend upon the type of building and other related factors. If the site presents unusual difficulties, single storey buildings are not erected quickly and easily. The majority of industrial buildings are portal frames and it is common practice to bolt-assemble the joints at ground level and then lift the complete frame upright with the help of a mobile crane. Biggs (1993) describes that, generally, multi-storey buildings are erected storey by storey because floors can be completed earlier (offering access, overhead safety and weather protection). Additionally, where the site is long and narrow access may only be possible on a limited scale. In this kind of situations, the best solution may be to erect the steelwork bay by bay. Alternatively, this method and storey by storey erection can be combined to the best advantage where circumstances allow.

Taggart (1993) asserts that, the speed of steelwork erection is subject to various factors, some of which are beyond the control of the building designer. Those which can be controlled include the end connection types, the extent of bolting or welding and the number of separate elements. In addition, according to Taggart (1993), decisions at the design stage may have predetermined the size and weight of main elements and therefore the degree of site assembly required. Naturally, site welding is expensive and is dependent on suitable weather conditions. Accordingly, site joints tend to be bolted which also means that only hand tools are required and this is a considerable advantage when working at heights. However, welding may be more suitable for alterations. Also particular benefit is gained by standardizing bolt sizes and grades during. By eliminating the need for constant identification and selection, bolting up is simplified and the hazards to the workers are minimized, especially in unsafe positions.

## 2.5 Types of Steel Structure

The classification of steel structures is generally based on the form or system used. The author purposes four categories for steel structures. These are:

- Single-storey structures,
- Multi-storey structures,
- Special structures,
- Lightweight steel structures.

These are described in more detail, following:

### 2.5.1 Single-storey Steel Structures

The term ‘single-storey structures’ comprises both single and multi-bay steel structures. In this section, single and multi-bay steel structures are examined. Attention is again focused on single storey construction, although some of the examples used are low-rise buildings of which systems can be considered in the same way.

#### a) Single-bay Steel Structures

MacGinley (1981) explains that, these structures require greater distances between supports that can not be spanned by the simple post and beam frame. To span the distance between supports than, girders, trusses, arches, rigid frames, or several other types of framing and systems including special systems (see Section 2.5.3) may be used.

According to Watson (1986), where the depths are limited, a built-up girders and columns of skeleton framing are used. This consists of plates and shapes built-up to necessary strength. Either castellated or tapered beams may be provided to suit the design. The individual parts may be assembled by welding. Where the depth of the structural member is not the limiting factor, it is usually more economical to use lattice girders (trusses) to span large areas (Figure 2.24 a). The author further states that, these systems are both used for flat roof systems and they can also take form of pitched and sawtooth roof systems (Figure 2.24 b).

As mentioned by Arda and Yardımcı (1989), prestressing which can both be applied to individual structural members, and to single bay frames, whether composed of truss or solid wall members, to increase the strength of the total structure against external loading (Figure 2.24 c).

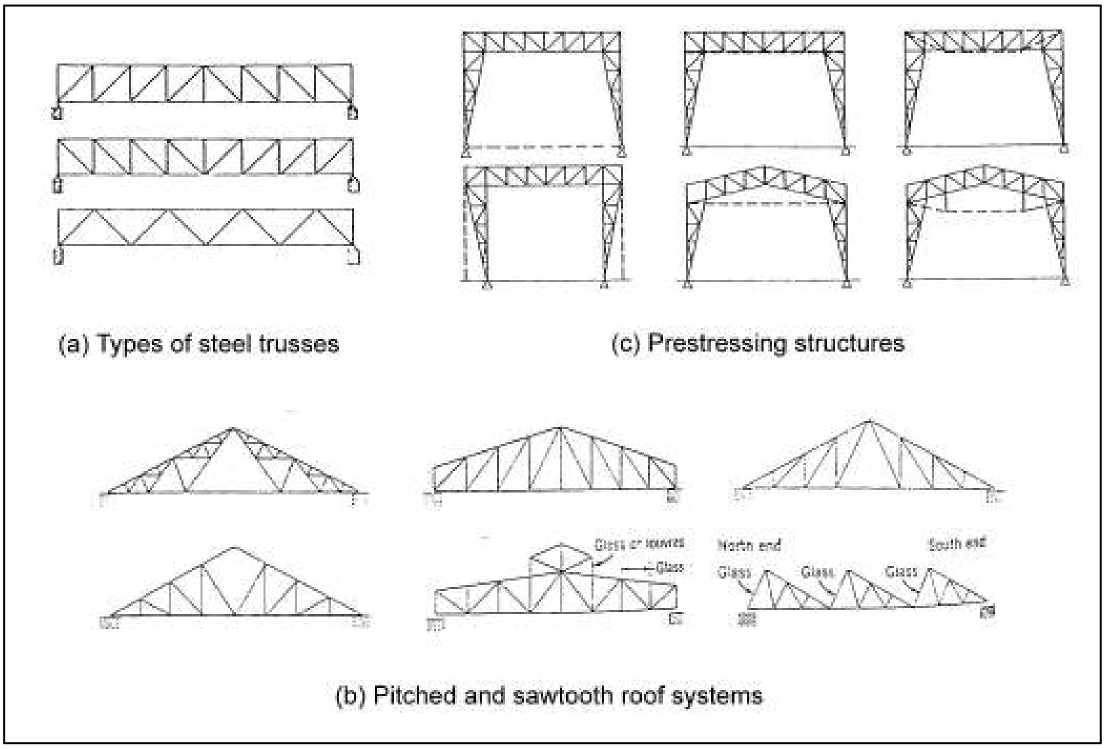



**Figure 2.24.** Structural systems for single-storey structures
(Source: Watson, 1986)

Watson (1986) explains that, when extremely long spans are needed transverse framing, or bents, may take the form of solid or open-web arches which will support not only the roof structure, but also the walls (Figure 2.25). According to the author, a hingless arch may be used if soil conditions are suitable. A two-hinged arch consists of a trussed arch resting on large pins at foundation. A three-hinged arch rests on two large pins used to connect the arch to the foundation and a third pin connecting the two halves at the center. The roof of the Channel Tunnel Terminal building in London is an example for the three pinch arch system. The cross-section of the structure can be seen in Figure 2.26.

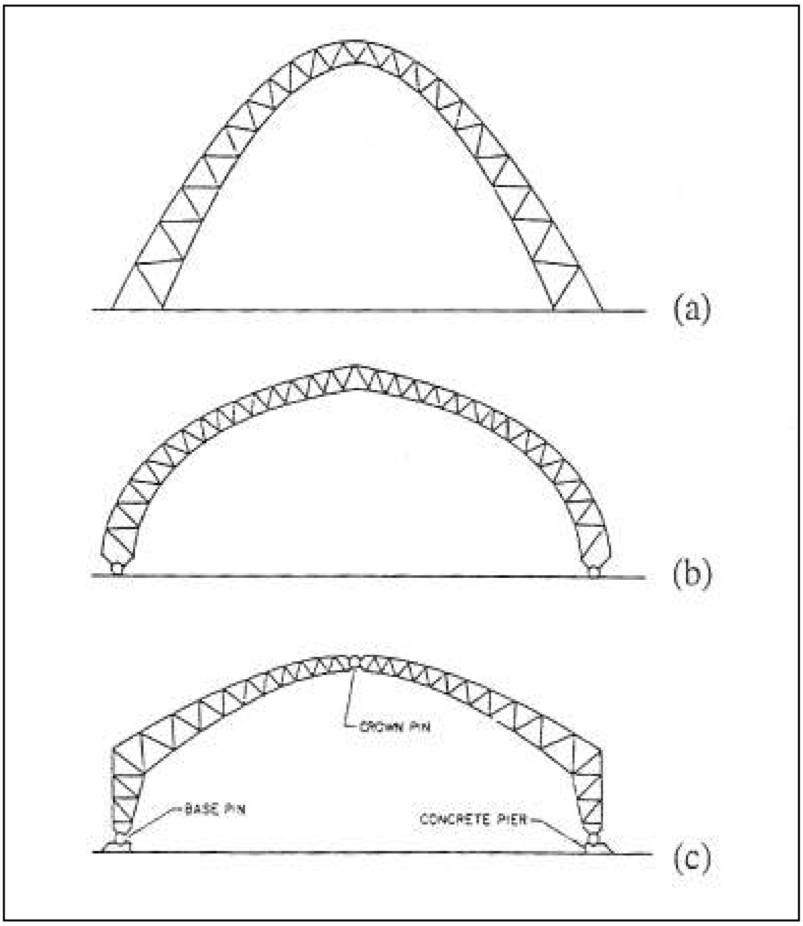



**Figure 2.25.** Typical steel arches; (a) hingless arch, (b) two-hinged arch and (c) three-hinged arch (Source: Watson, 1986)

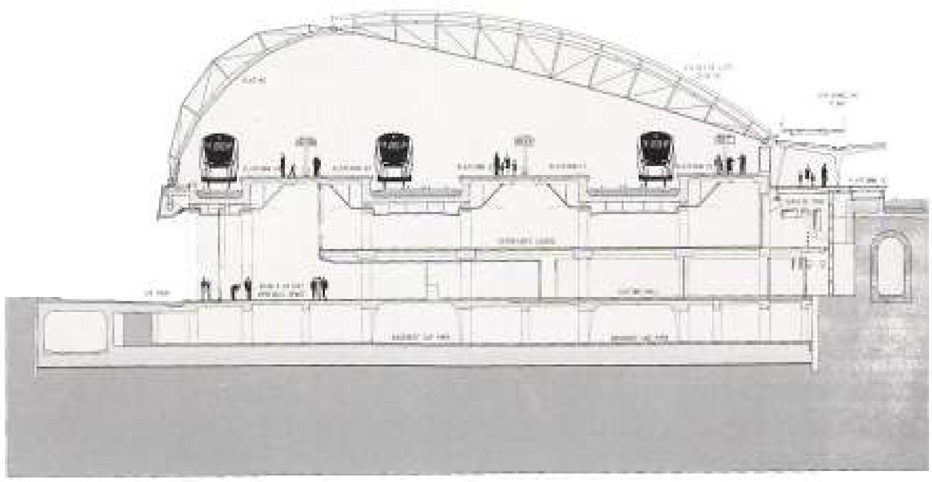


**Figure 2.26.** Cross-section of the Channel Tunnel Terminal Building in London, England (Source: Plank, 1993)

b) Multi-bay Steel Structures

Plank (1993) asserts that, multi bays are normally a repetition of single bay structures. This repetition offers opportunities to reduce the size of some members if continuity is considered in the design. The traditional behavior for multi-bay roof construction was to use a series of pitched roof trusses, supported on parallel rows of columns. This did not allow the possibility of taking advantage of structural continuity, and the structural behavior is little different from single span buildings of this type. The author continues that, as for single bay construction, the roof trusses can take a variety of different forms. For instance, north light trusses were commonly used for factory roofs, and shallower pitches can be done using a truss with a finite depth at the eaves. An example for north light form of construction is shown in Figure 2.27.

Plank (1993) states that pitched roof steel portal frames are the principle structural form for industrial buildings. This is largely because of economic factors associated with the efficiency of both their construction and structural behavior. For multi-bay buildings the continuity associated with portal action offers even greater advantages. According to the author, in many cases the construction is simply in the form of pairs of rafters with equal pitches as this is probably most efficient from a structural point of view, but other shapes such as mansard, monitor or north light can also be used (Figure 2.28).

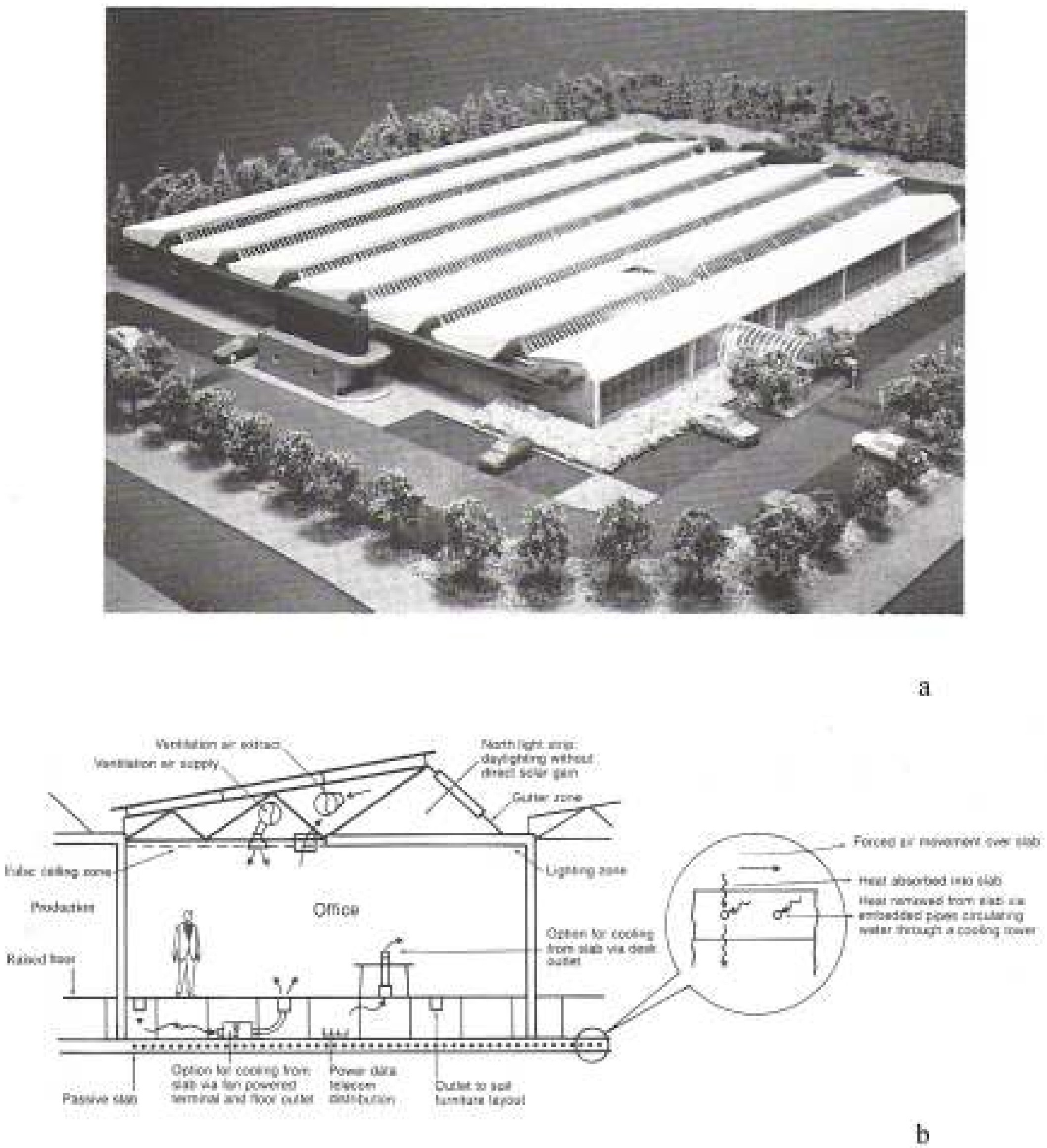



**Figure 2.27.** Spectrum 7 Building, Milton Keynes, UK; (a) photo, (b) cross-section (Source: Plank, 1993)

Plank (1993) continues that, another structural system for carrying the roof structures of multi-bay buildings is a multi-bay flat roof structure. Flat, or nearly flat, roof structures minimize the enclosed volume and avoid problems of valley gutters but clearly require very careful consideration with regard to water-proofing. The structural form could be a series of simply supported beams, which may take the form of universal beams, castellated beams or lattice girders.

Furthermore, space frames can be utilized for the construction of multi-bay structures. As mentioned by Plank (1993), space frames are the ultimate expression of such two-way spanning continuous systems, but suffer from problems associated with the cost of the specialized joints which are required. Large-scale space frames offer the most stimulating visual quality, particularly where the forms are expressed both externally and internally.

**Figure 2.28.** Pitched roof structure: Princess of Wales Conservatory in London, England (Source: Plank, 1993)

### 2.5.2 Multi-storey Structures

Watson (1993) asserts that, the term ‘multi-storey building’ includes a wide range of building forms that are made possible by the flexibility and adaptability of structural steel. The basic elements of a multi-storey structure are floor slabs, beams, columns and bracing. According to Watson (1993: p-197):

> The choice of a structural system is governed by what may be called the three ‘R’s of building design: Rigidity, Robustness and Rapidity. The designer must first ensure that the structure is rigid enough to sustain the applied loads. The system chosen on this basis must be sufficiently robust to prevent the progressive collapse of the building under accidental loading. Lastly, the structural system must facilitate the fast and economical construction of the project.

The factors affecting choice of structural system are summarized by Watson (1993) in three parts as below.

a) Column Layout

Structural steel floor systems consist of prefabricated standard components, and columns should ideally be laid out on a repetitive grid which establishes a standard structural bay. Maximum repetition of the floor components reduces fabrication costs and erection time. The function of the building will frequently determine the column layout. For example, financial dealing floors require clear, open spaces located on the lower floors, which would dictate a different structural solution to the rest of the building. Large, column-free areas at ground floor level may necessitate the use of a transfer structure at first floor to carry the upper floors on an economical column grid.

b) Integration of Building Services

The overall depth of the floor construction depends on the type and distribution of the building services in the ceiling void. The integration of the services with the structure is an important factor in the choice of an economic structural floor system. The designer may choose to separate the structural and services zones, or accommodate the services by integrating them with the structure, allowing for the structural system to occupy the full depth of the floor construction.

c) External Wall Construction

The external skin of a multi-storey building is supported off the structural frame. In most high quality commercial buildings, the cost of external cladding systems greatly exceeds the cost of the structure. According to Watson (1993), this influences the design and construction of the structural system in the following ways:

- The perimeter structure must provide a satisfactory platform to support the cladding system and be sufficiently rigid to limit deflections of the external wall.
- Reducing the floor zone may be more cost-effective than an overall increase in the area of cladding.
- Fixing to the structure should facilitate rapid erection of cladding panels.
- Reducing the weight of cladding at the expense of cladding costs will not necessarily lead to a lower overall construction cost.

Multi-storey structures are also classified within themselves according to their structural form and the method of the construction. Structures may consist of a combination of various types (Figure 2.29). Iyengar (1993) explains that, buildings up to about 20 storeys can be shaped without undue influence of the structure. In the range of 20-40 storeys, a specific structural system, its composition and efficiency, and the flexibilities for shaping offered by the system must be identified. Structures which are 40-60 storeys tall will have more specific restrictions regarding asymmetry of profile and plan. The ability of the system to resist asymmetrical gravity loads and resultant torsions determines its effectiveness. Structures beyond 60 storeys are more decidedly affected by the structure. The primary structural concern is to develop sufficient lateral stiffness.

Iyengar (1993) further states that the systems selection process allows for considerable latitude in the choice of an appropriate system which is suited to a particular building. Recognition of the merits of different systems together with enhanced abilities to perform complex three-dimensional computerized structural analyses has made it possible to design varieties of symmetric and asymmetric forms.

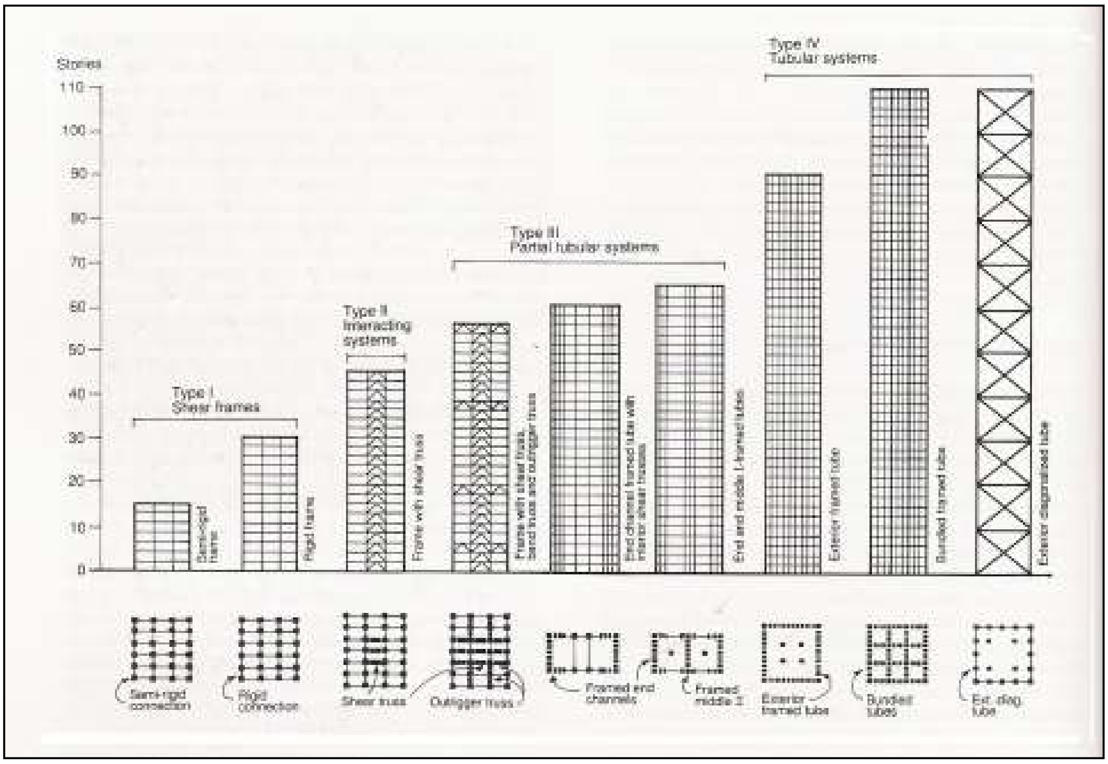



**Figure 2.29.** Comparison of structural systems
(Source: Iyengar, 1993)

2.5.3 Special Structures

The construction of special buildings that requires large areas unobstructed by columns such as auditoria, sport arenas, transportation structures is made possible with the help of some special structural systems. Some of these systems are described below.

a) Space Frame Structures

MacGinley (1981) states that space frame structures are roof structures covering column free large areas. There are two main types of space frame structures: two-way spanning roof systems, grids and space decks, and domes which may form the roof only or the complete structures. According to Berktin (1994), the main advantage of space frame structures is with very small structural depth large areas can be spanned, so that with not more than 1.5 m depth 100 m of column free area can be spanned. The examples for this system are illustrated in Figure 2.30 and 2.31.

**Figure 2.30.** Sainsbury Center in Norwich, England
(Source: www.people.cornell.edu , retrieved 2006)

**Figure 2.31.** Nagoya Dome in Nagoya, Japan
(Source: www.takenaka.co, retrieved 2006)

b) Cable Supported Structures

As mentioned by Reid (1984), in structures where the roof deck is directly constructed on cables, by intersecting a grid of horizontal cables running between the outside walls, a very thin roof can be established, which can only support itself by tension. In these systems, however, the span has to be sufficiently great to exploit the potential of the suspension principle, and the structure should be stiff enough for structural safety. Reid (1984) also explains that, the curvature of the roof deck is the major consideration in the load carrying capacity of the system, establishing the necessary stiffness against flutter or flapping of the structure in even moderate winds. Figure 2.32 shows an example of cable supported structures.

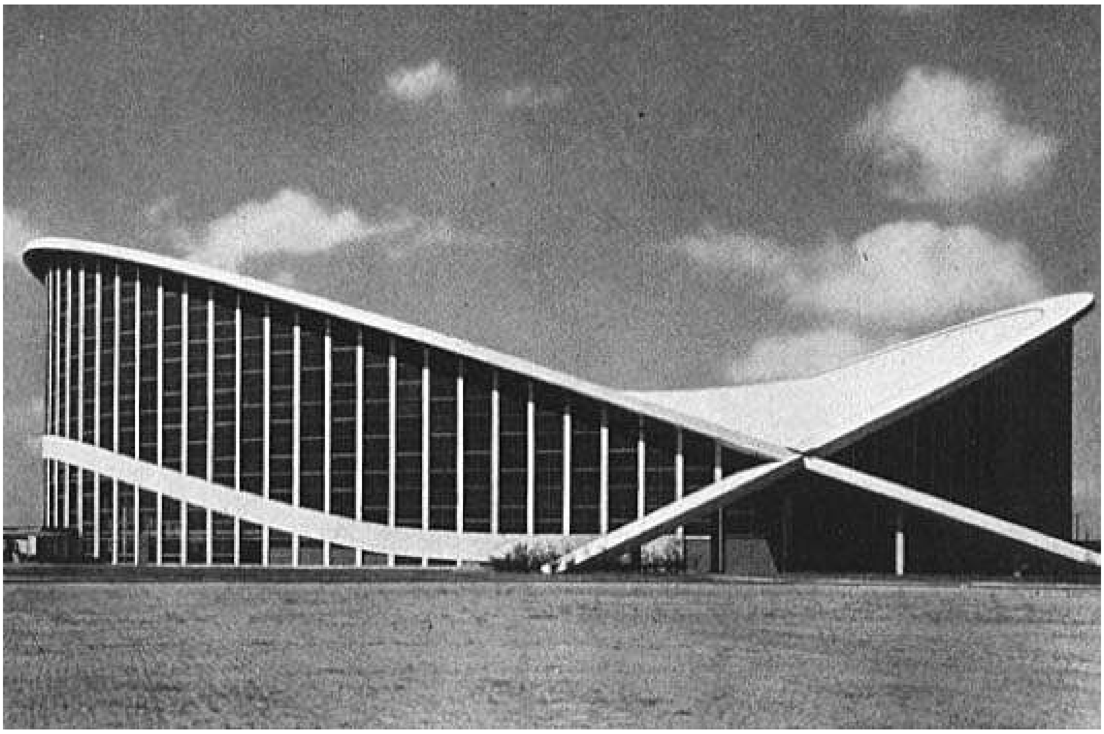


**Figure 2.32.** Raleigh Arena in North Carolina, USA
(Source: www.ou.edu, retrieved 2006)

c) Transfer Structures

According to Bird (1993: p-253), “transfer structures take loads where they can conveniently be collected and transfer them to where they can conveniently be resisted. At one end of the spectrum, this can mean that a column line has to be interrupted to get round an obstruction or provide an opening. At the other end of the spectrum whole buildings might have only minimal areas of the site where foundations can be put down. In finished buildings they are often hidden”. The First Exchange House building in London had to be constructed over an active rail way. In order to span the rail way, arches were integrated into the whole building frame (Figure 2.33). In this example, the architects also used the transfer structure as a significant part of their design instead of hiding it.

**Figure 2.33.** First Exchange House in London, England

(Source: moment.mit.edu, retrieved 2006)

### 2.5.4 Lightweight Steel Structures

According to Dudas (2003), utilizing light steel structures in residential house construction is a new building technology came to the foreground because of the rapid development in the building industry; surely it has a lot of advantages from the technological point of view, which meet all the requirements these days. However, it is more important beside the points of view mentioned above that the construction of these buildings protects the natural environment and suits the standpoints of sustainable development and guarantees a healthy environment for the users for the whole lifespan of the building. Dudas (2003) summarized the building system characteristics as follows:

• The light construction residential house's frame is assembled from cold formed steel profiles. In the gaps between the elements of the frame heat insulation material is placed and the frame is supplied with surface layers made of various materials, forming a layered structure.

• Generally, the elements of the frame structure are constructed of C and U profiles with a dry, assembly style building technology. Numerous steel fasteners, stiffeners and other complementary profiles are connected to the basic elements of the structure.

• The applied materials filling the gaps between the elements of the frame not only perform heat insulation, but also meet acoustical requirements and they are an efficient fire protection tool. With the application of efficient heat insulation materials a good level of fire protection and an excellent heat and sound insulation can be achieved.

• The inside cover is mostly made by plasterboard. Composite layers by wood as basic material (e.g. OSB) are preferably used as outside wall board cover and floor slabs. With this, the advantage of high strength can be utilized, which provides stiffening function.

## 2.6 Advantages of Steel as a Structural Material

There are various advantages in using steel as a structural material both from the point of view of architectural and engineering solutions. In this section, the advantages of structural steel are specified by making comparisons with other structural materials, especially with concrete, the most popular construction material in Turkey.

### 2.6.1 Design Flexibility

Berktin (1994) explains that, steel is a material which is strong both in tension, bending and compression. Steel's great strength is the basis of its uniqueness among the four basic materials. The form characteristics of linearity and thinness exist because of this exceptional strength and render it preferable for tall structures (Figure 2.34) and large spans. According to Patterson (1990), this flexibility in design makes remodeling easy even after the construction is completed. As shown in Figures 2.35, 2.36 and 2.37, the use of steel makes possible the creation of large, column free internal spaces. As stated by Berktin (1994), these spaces can be divided by partitions, and by eliminating the external wall as a load-bearing element, allows the development of large window areas incorporated in prefabricated cladding systems.

### 2.6.2 Lightness

Copeland, Glover, Hart, Hayott and Marshall (1983) states that, steel is an efficient material for structural purposes because of its good strength-to-weight ratio (lightweight construction). If the detailing of cladding and finishes is also geared to lightness, a steel farmed building is likely to be about 60 to 75% of the weight of a comparable reinforced concrete building. They claim that, the taller the building the more benefits offered by lightweight construction; including the size of foundations and cost criteria. The size of the foundations of a steel structure is almost 20% less than that of reinforced concrete structure of the same digressions

**Figure 2.34.** Burj Al Arab Hotel in Dubai, United Arab Emirates
(Source: www.burjalarab.dubai-city.de, retrieved 2006)

**Figure 2.35.** Oita Prefecture Sports Park Main Stadium in Oita City, Japan
(Source: www.takenaka.co, retrieved 2006)

**Figure 2.36.** United Airways Terminal in Chicago, USA
(Source: Akbay, 2006)

**Figure 2.37.** The Florida Aquarium in Florida, USA
(Source: www.sysk.com, retrieved 2006)

According to Akbay (2006), as the weight of structure decreases by utilizing steel, these results are emerged in parallel:

- Size of all structural elements in the building decreases and by spanning longer spaces, the usable areas increases,
- The limits of the architectural flexibility expand and extraordinary structures can be applied,
- Because of the reduced foundation dimensions, amount of excavation decreases,
- The opportunity to build a structure even on bad grounds comes out,
- Amount and variety of the material that is going to be transported decrease,
- More resistant to earthquake and taller buildings can be built by means of a decrease in the horizontal loads used in seismic calculations due to the decrease in the structure's weight.

### 2.6.3 Speed of Construction

As stated by Akbay (2006), steel frames are fast to erect. The author explains that, this results from the use of factory-produced, interrelated structural parts, prepainted roof and wall panels, and other elements that can be selected in advance of the project and quickly assembled on site. For example, the construction of Safeco Baseball Stadium in Seattle finished in 27 months only (including the production drawings which took 9 months). It is a baseball stadium with a capacity of 47,000 seats and it can be closed with a roof when required. Additionally, specific measures were taken against earthquake loads.

According to Hart (1992), the time taken to realize a steel building from concept to completion (no matter which method of planning and construction is used) is generally less than that for other alternatives, namely; concrete. This reduces time related building costs, enables building to be used earlier and produces an earlier return on the capital invested. In other words, although the initial cost of structural steel frame construction is high, the reduced construction time can also mean large savings on the overall financing.

### 2.6.4 Economy

Morreau (1993) states that, most of the arguments in the past about the relative advantages of steel and concrete buildings have concentrated on the relative costs of them. Much has been written on this subject and the result is that much depends on the greater speed of steel construction. The author also states that, a steel frame is likely to be more expensive to buy and build than a concrete one. However, after including the cost of the time taken to complete the building (the contractor's overheads, the interest on the money to finance the project) and the benefits of earlier completion, either in earlier rental income or earlier use of new facilities, the economic advantage of steel construction can be seen clearly.

Akbay (2006) asserts that, the short construction time and the advantages due to its lightweight mentioned above make steel framed structures more economical. In addition to these qualities, as stated by Akbay (2006), steel framed structures;

- are prefabricated,
- do not require a formwork or a catwalk,
- can be constructed in every weather conditions,
- can be controlled easily during the construction process.

Ersoy and Çıtıpıtıoğlu (1988) argue that, in steel buildings, different from other construction materials, the material cost for structural steel members or plates often exceeds the labor cost (lifting and setting costs). On the other hand the reason for the choice of an economical structural system will not necessarily be to use the minimum weight or length of structural steel. Figure 2.38 shows the cost shares of every phase in the total construction respectively. As can be seen from this figure material costs represent only 30% of the total cost of structural steelwork. According to Akbay, (2006), calculation of weight of the steel used per square meter causes incorrect evaluations for the reason that production, assembly and the other costs are not taken into consideration.

Beyond all these explanations, Turkey being located in a seismic zone, steel framed structures are safer and in this sense cheaper than reinforced concrete structures constructed in Turkey.

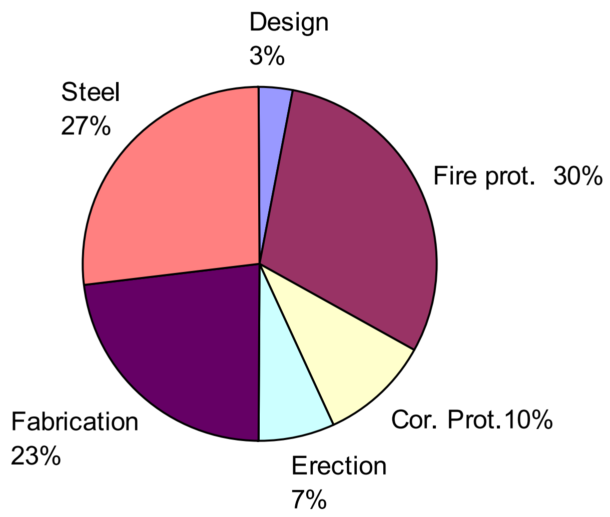



**Figure 2.38.** Pie chart showing cost breakdown for steel construction projects (Source: Latter, 1985)

2.6.5 Quality Control

As stated by Engineering News Record (1992), the elements of the framework are generally computer-designed and are manufactured and fabricated under the controlled conditions of a factory, establishing quality procedures. Many steel building system manufacturers participate in a Quality Certification program developed by the AISC. This recognizes manufacturers displaying the ability to design and produce high quality metal building systems. The overall objective of the program is to ensure that the metal building system meets stringent requirements for design, integrity and fabrication quality. As a result, the end user can be more assured of getting a quality product.

Furthermore, Akbay (2006) asserts that, condition of the structural steel members and joints that are not covered can be easily controlled at every phase of the building, according to the regulations. This property is very important to prevent the non-perceivable damages emerging after earthquakes, especially in the reinforced concrete structures.

### 2.6.6 Modifications

According to Engineering News Record (1993), steel structures adapt well to changing needs. In many cases, concrete buildings cannot support the load that additional stories would impose, but in steel structures this problem can easily be solved, by means of minor additions like a transfer trusses (bracing). Also, they are uniquely suited to expansion. In many cases a steel structure can be enlarged simply by removing the end wall, or walls erecting new framework and then adding matching wall and roof covers. Often the original end walls can be reused. This flexibility greatly reduces the time inconvenience typically associated with expansions or additions to existing traditional construction.

### 2.6.7 Renovations

As mentioned by Engineering News Record (1993), steel is the material chosen for restoration and renovation of existing buildings, both when demolition is out of consideration or a change in function is required. The economy, ease of erection, lightweight, rigidity and ductility of steel give new life to existing buildings. It is possible with steel to renew a given building without removing the roof, by just replacing the main load carrying structure at first and then replacing the rest of the structure.

Akbay (2006) explains that, also by a renovation program traced by the existing buildings seismic resistance can be improved utilizing the properties of steel. It is essential to modify a building that undertakes a new function (for this reason it can require reduction in number of columns or additions such as an elevator or stairs) or that was damaged in an earthquake and needs reinforcement. The author further explains that, if this structure is a steel framed structure, the modification can be done in a short time and economically, and if it is a reinforced concrete structure, it is hard to achieve this without using steel members as well. Figure 2.39 shows the Sather Gate Garage renovation. This city owned parking structure was seismically reinforced with exterior steel braces.

**Figure 2.39** Sather Gate Garage renovation in Berkeley, USA
(Source: www.dbarchitect.com, retrieved 2006)

Akbay (2006) also states that after the ‘1992 Erzincan Earthquake’ some experiments were made in the Middle East Technical University (METU) and it is understood that the steel cross-bracings applied for the reinforcement of the structures damaged in that earthquake are very effective and economic. However, in the ‘1999 Gölcük and

Düzce Earthquakes', authorities did not regard these experiments and preferred to reinforce the damaged buildings with concrete shear walls despite the fact that they are expensive, heavy and risky.

### 2.6.8 Recyclability

Undoubtedly, it is one of significant superiorities of steel structures that they can be reused with very little loss after dismantling. Sometimes, they are used in new structures after a little maintenance and sometimes (if they can not be reused as their existent shapes) they are melted and utilized for different purposes once more.

According to IISI (2006), recycled steel (scrap) is a required and essential component of new steel, making steel a naturally environmentally responsible material. In basic oxygen steelmaking, scrap represents up to 30 percent of the raw materials charged into the furnace. It represents between 90 and 100 percent of the charge in electric arc furnace (EAF) production. Steel is 100 percent recyclable: moreover, it can be used over and over again with no downgrading to a lower quality product. On the other hand, as stated by Akbay (2006), the reinforced concrete buildings have to be demolished if they become uninhabitable due to different reasons such as earthquakes or damage.

### 2.6.9 Earthquake and Wind Resistance

According to Engineering News Record (1993), steel is also the material of choice for harsh environments including limitations of geography, high winds, hard soil and temperature movements and most importantly risks of hurricanes, typhoons and earthquakes. With the design flexibility and fast construction ensured by steel, steel structures become the first choice in hard conditions. Also as the lateral resistance for wind and seismic loading is provided by combined steel systems and various bracings, structural safety is well ensured

Bouwkamp (1990) explains that, although present specifications stipulate earthquake resistant design requirements for reinforced concrete, failures continue to occur mostly because of poor design details (reinforcing steel layout), poor workmanship, and inadequate in-site quality control and inspection. On the contrary, steel systems enhance earthquake performance. Bouwkamp (1990) also asserts that, steel has not only been used successfully in rigid jointed frames, but has also found efficient application in so called concentrically braced frames. More recently, research starting in 1977 has resulted in the development of eccentrically braced frames, combining the basic stiffness characteristic of conventional braced frames with the ductility and energy dissipating capacity of conventional moment resistant frames.

According to Engineering News Record (1994), steel performs well in earthquakes because of its high elastic limit (modulus of elasticity), its great plastic deformation quality and the internal strengthening mechanism of strain hardening. Because elastic behavior means a steel structure will return to its original position after an earthquake, designers can predict its deflection during moderate earthquakes. When earthquake are beyond moderation, when extreme earthquake forces push a structure beyond its elastic limit, a steel structure can deform plastically and dissipate the unanticipated energy imposed by the earthquake. It is impossible to assume the time of an earthquake or to prevent it. On the other hand, we can minimize the loss of life and money by constructing steel structures in seismic regions.

### 2.6.10 Potential of High-rise Construction

Akbay (2006) asserts that, by using reinforced concrete core or retaining walls, reinforced concrete multi-storey structures can be built. However, because of the limitations in the number of storeys, the difficulties due to producing the load bearing elements in site and the extension in the construction time, reinforced concrete is not a preferable material for high-rise structures. The author continues that, steel framed structures have a great potential in building high-rise structures, which is why after the developments in the steel construction, number of high-rise buildings and their heights increased rapidly. In some steel high-rise structures reinforced concrete can be utilized as a core and this provides an increase in the number of storey whereas it brings difficulty in the construction.

## 2.7 Disadvantages of Steel as a Structural Material

While steel has several advantages as mentioned above, it has some disadvantages such as the necessity of fire and corrosion protection. In this section fire and corrosion problems of steel members are discussed and some measures are presented.

### 2.7.1 Strength Reduction in Fires

Akbay (2006) explains that, all structural materials are affected by fire to some extent. Steel, also, loses its load bearing property after a definite temperature and all of its mechanical properties at very high temperatures during a fire (Figure 2.40). Experiments on structural steel show that steel will exhibit a loss of strength when exposed to temperatures in the range of 1,100 F. In spite of this property, steel is utilized in the construction sector as a structural material confidently, by fire-proofing according to the regulations. As mentioned by Patterson (1990), steels vulnerability to fire also falls between that of wood and masonry. Although steel and masonry are not combustible like wood, after a certain temperature they melt.

According to Robinson (1993), it is important that in building fires the structure should not weaken to the extent that collapse occurs prematurely even as the occupants are seeking to make their way to safety. For this reason it is necessary for designers to provide a degree of ‘fire resistance’ to the structures that they build. The author explains that, fire resistance is expressed in the Building Regulations in units of time, ½ h, 1 h, 1 ½ h, 2 h and 4 h. It is important to recognize that these times are not allowable escape times for building occupants or even survival times for the structure. They are simply a convenient way of grading different categories of buildings by fire load from those in which a fire is likely to be relatively small (e.g. low-rise offices) to those in which a fire might result in a major conflagration (e.g. a multi-storey library). The survival times in a standard fire, defined by BS 476, is illustrated in Figure 2.41. Robinson (1993) argues that, the fire resistance periods refer to the time for which an element of structure (a column, beam, compartment wall *etc.*) should maintain:

- Stability (It should not collapse),
- Integrity (It should not crack or otherwise allow the passage of flame to an adjoining compartment.),
- Insulation (It should not allow passage of heat by conduction which might induce explosion). With steel structural members there is normally little problem in achieving the requirements of integrity and insulation but most attention and cost is directed at satisfying the stability.

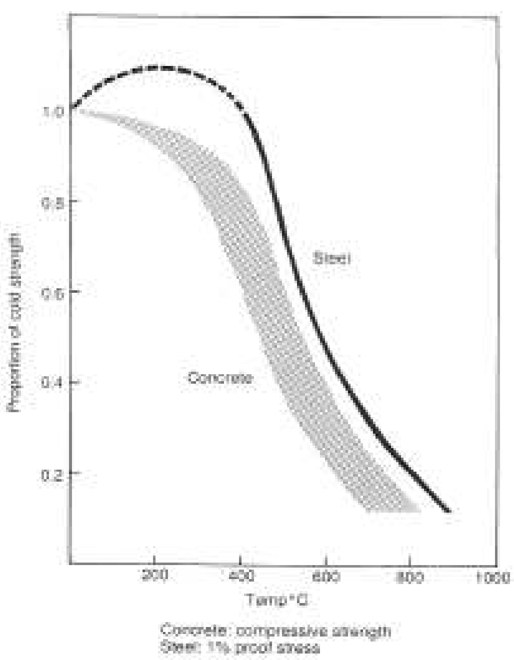



**Figure 2.40** Strength reduction at high temperatures (Source: Robinson, 1993)

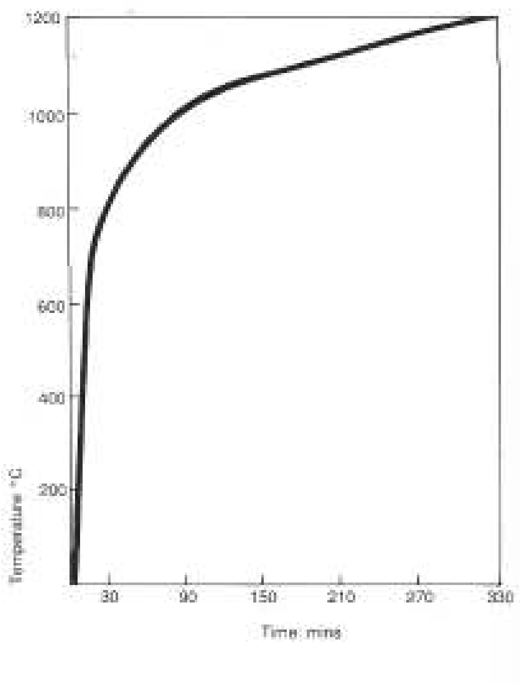



**Figure 2.41** Standard fire-curve (Source: Robinson, 1993)

In the reinforced concrete or steel structures, the primary measures for fire safety are planned during the design process. The fire protection methods are explained by Robinson (1993) as below.

For many years the principal method of achieving fire resistance in steel structures has been to apply insulation materials. The fire protection is applied after the erection process and acts as an insulating barrier between the steel and the fire to slow the heat transfer. The first protective coatings were made from heavyweight materials such as concrete, brick and plaster and these may still be the optimum solution in some situations (for instance where there is a risk of impact damage). However, by the 1920s, various types of asbestos-based sheet and spray coatings had become available. These were lighter and cheaper than the traditional materials. Asbestos is no longer used for fire protection because of health hazards, but other asbestos-free materials have been developed. These materials gain their insulating properties from rock-fibre or exfoliated vermiculite and they are available either as spray or boards.

Sprays are the cheapest method since application is fast and it is easy to coat complex shapes or connections. However, they are applied wet, which can create problems in winter conditions. Their appearance is often poor, so they are most often used in hidden areas such as on beams above suspended ceilings or in plant rooms and basements.

Boards tend to be more expensive because they require higher labor content for fixing. They are fixed by gluing, stapling or screwing, so there is less interference with other trades on site, and the hollow box appearance is often more suitable for frame elements, such as freestanding columns. A further advantage is that the casing work can accommodate vertical services. Rock wool can be used to wrap structural sections to provide effective insulation. This can be supported by clipping into place or within a lightweight casing.

Intumescent coatings do insulation in a completely different way. The coating is applied as a thin layer (perhaps as thin as 1 mm) but it contains a compound in its formulation which releases a gas when heat is applied. The gas turns the coating into a thick carbonaceous foam, which provides heat insulation to the steel members. The coatings are available in different colors and can also be used for decorative and practical reasons.

Additionally, according to Robinson (1993), the fire resistance of tubular members can be improved by making use of the hollow interior, either for cooling by water-filling, or for load transference by filling with concrete. However, this method is expensive. The concept was adopted for the Pompidou Center, Paris (1972-1977) which has water-filled columns (architects Piano and Rogers; engineers Ove Arup and Partners) and there are other examples in the world

The progress of fire proofing methods used for steel framed structures in England is shown in Figure 2.42. It is observed that enclosing with boards have taken the place of covering with concrete in the fire proofing.

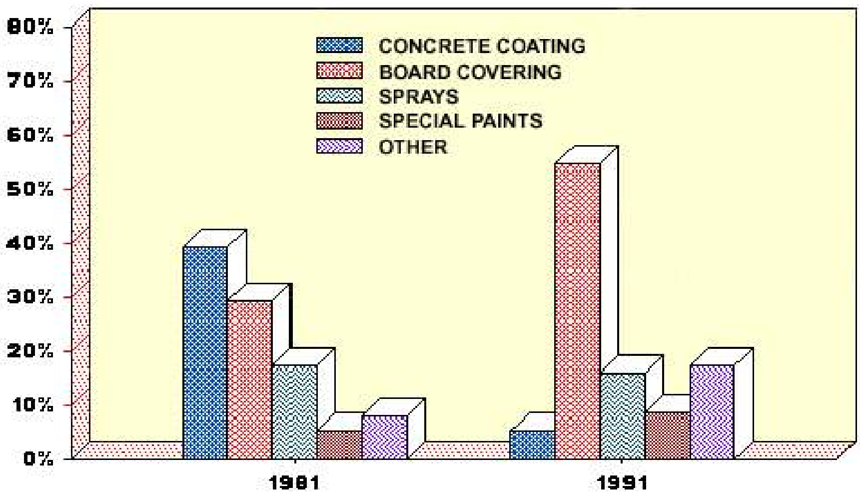



**Figure 2.42.** Fire proofing methods used for steel framed structures in England (Source: Akbay, 2006)

### 2.7.2 Strength Reduction by Corrosion

According to IISI (2006), many elements and materials react chemically with other elements. When steel comes into contact with water and oxygen there is a chemical reaction and the steel begins to change into iron oxide. In most modern steel applications this problem is easily overcome by coating. Many different coating materials can be applied to steel. As written in 'Principles of Modern Building' (Vol.1, 1959):

> The use of metals in building calls for special care in design, in choice of materials and in protection, if serious corrosion problems are not, sooner or later, to arise. Not only is the cost of corrosion alone extremely high, but what is perhaps even more serious is the consequent trouble and expense resulting from it. Thus the steel frame of a building may rust and in so doing crack the external cladding. If the reinforcement in concrete rusts, the surface spills and disintegration becomes progressive.

Thomas (2003) asserts that, in certain circumstances, corrosion can get worse by pollutants or other contaminants in the water. Such materials can include common salt (sodium chloride) and many industrial chemicals. According to Thomas (2003), where such materials are present special measures should be taken to protect exposed steelwork. In the absence of such materials (such as steel members that are not subjected to periodic wetting by rain or other sources of moisture) requires no corrosion protection. If steel members need corrosion protection, the usual methods are paint systems and galvanizing. In considering a protection system it is necessary to consider the type of building or structure under consideration, its use, its life and the merits of initial cost against maintenance costs.

Thomas (2003) also explains that paint systems vary between simple barrier systems that provide a protective film over the steel separating it from oxygen and moisture, and complex systems that include components that provide additional means of protection should, for example, the paint system be damaged by small scratches or holes.

Landers (1983) states that steel sheets may be protected against rust and corrosion by a galvanized aluminum and zinc coating. According to Thomas (2003), galvanizing consists of coating the steel with zinc (in some cases with significant quantities of other materials) to provide both barrier protection and cathodic (sacrificial) protection. Sacrificial protection means that the coating preferentially corrodes leaving the steelwork intact. The zinc coating is metallurgically bonded to the steel providing a tough barrier. In addition, in most commonly occurring circumstances zinc is anodic to steel and thus provides cathodic protection should damage or minor discontinuities occur to the barrier. An important attribute of all barrier systems is adhesion to the surface of the element to be protected. Thus careful preparation of the surface to be protected is required. Thomas (2003) point outs that, all corrosion systems have a limited life and the system used must be appropriate to the exposure and the lifetime required.

Moreover, as mentioned by Thomas (2003), weathering steels possess high enough levels of corrosion resistance that they can be used in certain applications uncoated. They are most commonly used in highway bridges, but are also used in buildings and other structures. Although weathering grade steels are more expensive than equivalent normal grades of steel, they can be cost-effective through the elimination of painting. Successful use of weathering grade steels requires careful detailing of the structure. Additionally, according to Patterson (1990), carbon steels falls between wood and masonry in their ability to resist deterioration.

## 2.8 Steel Construction in Turkey

Akbay (2006) argues that, structural steel utilization has arrived at big ratios in the countries that are developed and mostly found in earthquake zone such as the USA, Japan, Germany, England, Sweden, Spain, France and Finland. Also in Japan, people can come through big earthquakes with small loss of human and money. Unfortunately, in Turkey, the use of structural steel is limited with railway bridges and industrial buildings. Although Turkey holds the $11^{th}$ position according to the 2005 world steel production figures of 'International Iron and Steel Institute', buildings are rarely constructed with steel. On the other hand, this material is gaining wider application in developed countries compared to other materials. This can be seen from Figures 2.43 and 2.44, where material selections for structural system in England and in Japan are shown. The consistent increase in the use of steel is obvious in both these examples.

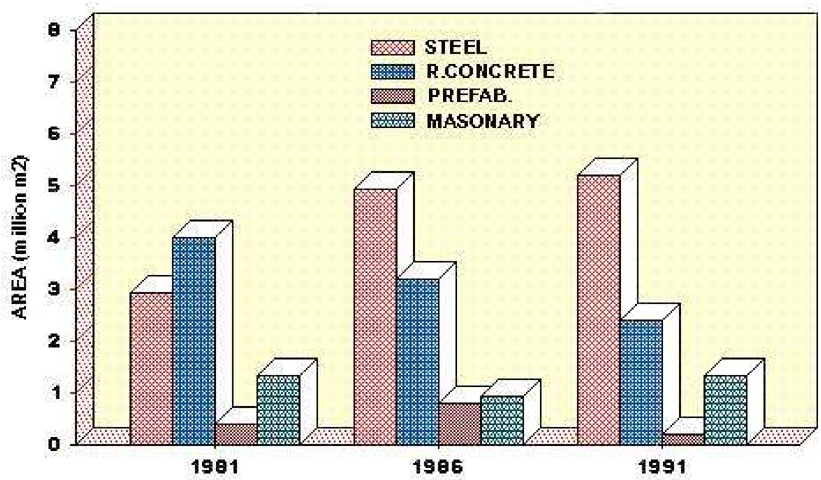



**Figure 2.43.** Building types according to material of structural system in England (Source: Akbay, 2006)

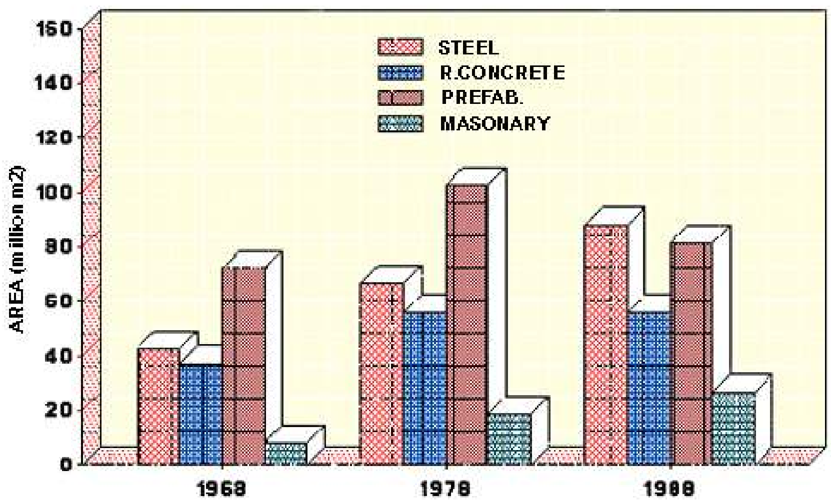



**Figure 2.44.** Building types according to material of structural system in Japan (Source:Akbay, 2006)

According to Berktin (1994), if 60% of the industrial buildings' and 1% of cultural buildings' construction areas in Turkey (including the probable attic and space truss constructions) are accepted to be steel construction, it comes out that steel construction utilization constitutes only 3% to 5% of total constructed area. On the other hand the same ratio is 85% for reinforced concrete construction. The existing situation of low-rise and high-rise steel construction in Turkey is described below.

a) Low-rise Steel Structures in Turkey

Berktin (1994) explains that structural steel has a good share in the construction of industrial buildings and structures where high ceilings and large spans are required, like big hangars, depots, sport halls and exhibition halls. The other low-rise structures in Turkey are built mostly in reinforced concrete as mentioned above. On the other hand, today lightweight steel framing becomes popular in the construction of residential structures due to the big earthquakes that occurred in 90s. Figure 2.45 shows a steel-framed house construction in Istanbul and Figure 2.46 shows its final photo.

**Figure 2.45.** A view of the steel-framed house in Istanbul, Turkey, during its construction phase (Source: www.zeytinsuyutepesi.com, retrieved 2006)

**Figure 2.46.** A view of the steel-framed house after completion
(Source: www.zeytinsuyutepesi.com, retrieved 2006)

b) High-rise Steel Structures in Turkey

As stated by Öke (1989), although steel is widely used in the construction of industrial buildings in Turkey, the case is not so for multi-storey and high-rise building construction. After the mid seventies buildings started getting taller and taller so much so that by the mid eighteen buildings with 30 to 50 storeys could be seen in major cities. At present, there are 50-60 storey multistory structures in Turkey (Figure 2.47). 'Mersin Trade Center' and 'Isbank Towers' in Istanbul are the examples of these structures. These are 52-55 storey reinforced concrete structures and 150-180 meters high. However, the high structures in the world reach to 500 meters by the utilization of steel, which means they are 3-4 times higher than structures in Turkey. Figure 2.48 shows the tallest buildings of the world and except the CITIC Plaza in China, all of them utilized steel and composite systems.

Tabak (2003) explains that, the first building in Figure 2.47, which is called 'Diamonds of Istanbul', is under construction now and when it finishes, it will be the first high-rise steel building and also the tallest building of Turkey with a height of

270 meters. Nevertheless, if the examples of high-rise buildings in the world are considered as shown in Figure 2.48, this height becomes inconsequential.

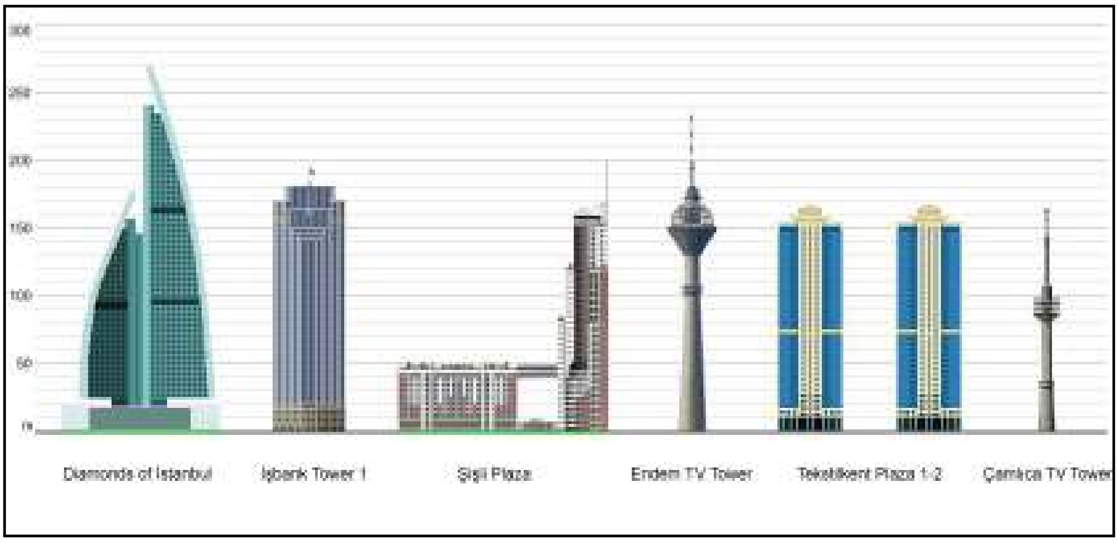



**Figure 2.47.** Chart showing high-rise buildings in Istanbul
(Source: http://www.istanbul.com, retrieved 2006)

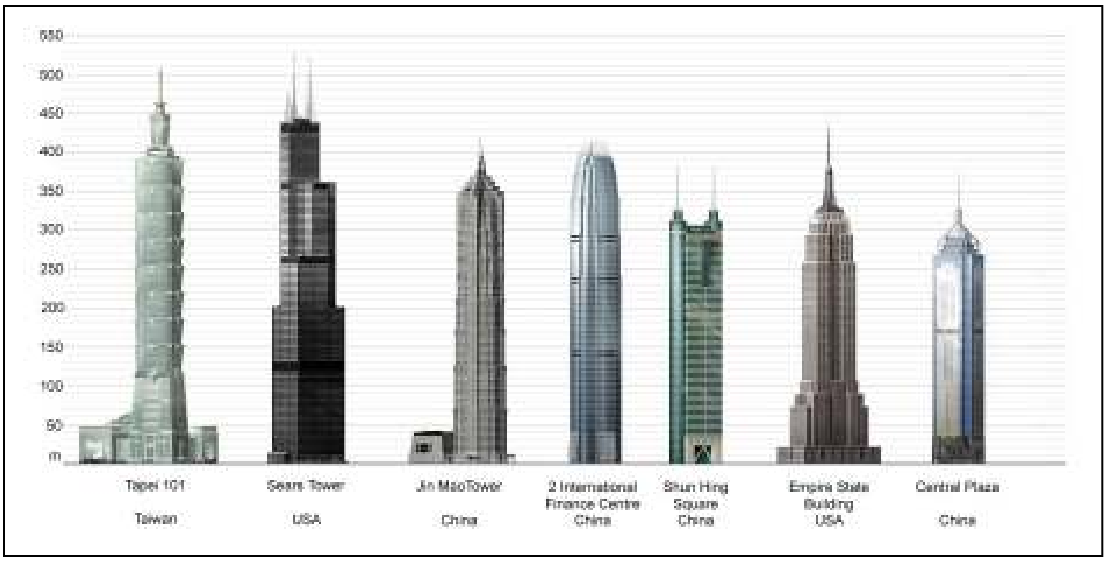



**Figure 2.48.** Chart showing high-rise buildings in the world
(Source: http://skyscraperpage.com, retrieved 2006)

It is an accepted fact that steel is more advantageous than concrete in building high-rise structures, which is why almost all high structures in the world have been constructed in steel. However, in Turkey reinforced concrete is still preferred for almost all kinds of structures including multi-storied structures. As stated by Özşen and Yamantürk (1989), such a development is quite dangerous for both Istanbul and other developing cities located in the earthquake region.

In order to understand how important it is to utilize steel construction in such cases it is better to study the world applications. According to Özşen and Yamantürk (1989), when the 73 buildings lower than 55 floors, through the world, are examined, it is seen that 67% utilize steel and composite construction. Additionally, in countries where high-rise buildings have been constructed in earthquake zones, it is seen that nearly 95% utilized steel and composite systems. Also when the table showing the '100 tallest buildings of the world', prepared by Öke (1989), is examined, it will be seen that only 13 utilize reinforced concrete construction while 22 were built with composite system and 65 utilize steel construction.

### 2.8.1 Need for Steel Construction in Turkey

Berktin (1994) claims that Turkey's geographical location and sociological conditions (including earthquake risks, climatic conditions, high rate of population increase and fast urban development) both requires an improvement in structural steel construction. This improvement is also required due to the structural steel's success in bringing historical buildings back to life.

As stated by Arda (1994), Turkey is located on one of the world's main earthquake regions. Additionally, in Turkey's earthquake map it is seen that all the big cities (80% of the built up area thus 70% of the total population) are faced with earthquake risk. This is one of the main reasons why it is necessary to develop the existing conditions and improve the utilization of steel construction.

In addition to these, according to Berktin (1994), in some regions of Turkey (such as in East and Southeast Anatolia) the construction time is restrained to two or three months due to the cold weather conditions. Steel construction should be more favored than concrete at these conditions since the construction process is mainly independent of climatic conditions and fast.

Berktin (1994) asserts that, the last example, demonstrating the advantages of the use of structural steel, shows the reason why the use of structural steel construction can bring freshness to the cities, besides the natural necessities. With giving way to fast and effective renovation and rehabilitation of historical buildings, the big possibility of bringing these buildings back to life, with both protecting and utilizing them arises (see Section 2.6.6 and 2.6.7).

### 2.8.2 Problems of Steel Construction in Turkey

According to Berktin (1994), in order to break down the continuing resistance towards the use of structural steel, it is important to put forward and evaluate well the main reasons behind the rare use of structural steel architecturally in Turkey. Only after improving these derived points it will be possible to achieve the necessary increase in the use.

Onat (1988) asserts that, steel utilization in construction field has not been developed yet, in Turkey. According to the author, the main reason why steel is not favored by the contractors, disregarding the natural necessities, in Turkey is explained in terms of economical reasons. Except in projects where it is inevitable to use structural steel, such as; railway bridges, large span highway bridges, industrial buildings, large span roofs, use of structural steel construction is negligible. Lack of knowledge and experience, lack of technology, workmanship and quality control and variety in production are the other factors that effect the steel utilization in Turkey.

a) Lack of Knowledge and Experience

As mentioned by Copeland, Glover, Hart, Hayott and Marshall (1983), the first statement in the German steel construction standards is; "Steel projects and steel constructions can only be done by the capable and experienced contractors/ engineers". They explain that, as a flexible material, to make the best use of structural steel, a particular approach to design and construction is required. Such an approach must recognize the need for strong design discipline, where all the items must be developed in parallel and brought to a particular level of detail before finalizing the steel structure design. Also it must appreciate the properties of the structural material and how it is assembled and combined with the rest of the fabric. Such a design process requires a continuous interaction between architect, structural engineer, service engineer and quantity surveyor.

However, as stated by Berktin (1994), most architects, engineers or quantity surveyors have no experience of designing with steel in Turkey. Additionally, the resistance towards change and learning new techniques are bound to be powerful forces against the adoption of steel frame construction.

Moreover, Çıtıpıtıoğlu and Keyder (1990) state that in Turkey, project offices that are able to design steel structures can be found only in big cities. Except a few big firms which have experience in the construction and erection of steel structures in big cities, there is almost no architectural/engineering office making structural steel design. On the other hand the architects, engineers and workers who have experience in building with concrete, are found in every part of the country.

b) Lack of Technology, Workmanship and Quality Control

Berktin (1994) explains that, using developed machinery both in the fabrication and the erection phases increase the quality of the construction with more precision in the work done, and also decreases both labor and construction time. Moreover, utilizing computers and robots in necessary stages, like both in the design and fabrication, decreases costs since less scrap brings out. According to the author, although such modernization requires high initial capital, it is worth for such results, since the investment will be paid back with high profits in a very short period of time. Therefore, experienced and qualified work force is important for economical fabrication and erection; except for a few companies such a work force is unavailable in Turkey.

Additionally, as stated by Çıtıpıtıoğlu and Keyder (1990), lack of quality control is an important factor that effects the steel utilization in Turkey. As in Turkey quality control organizations do not have personnel to make control quality during the fabrication phase, in the workshop this control is left to the producer. At site since the elements are not subjected to quality control the situation reflects an irregularity.

c) Lack of Variety in Production

According to OECD (1989), growth of steel demand may be considered to be on a scale that requires improvement in the production technology; alternatively, the introduction of new technologies increases the scale of demand with more economic and good quality production.

Çıtıpıtıoğlu and Keyder (1990) argue that, in Turkey, wide flange sections are not produced although they are most commonly used in steel construction. In Europe, 220 different types of wide flange sections are being manufactured, while in the USA this number reaches 300. According to Tabak (2003), these different types of sections are not produced randomly. They are designed after several studies to find the right and economical shapes. Wide flange sections are in great demand for the construction of high-rise steel structures.

Unfortunately, according to Çıtıpıtıoğlu and Keyder (1990), in Turkey, designers and the construction sector are forced to use imported steel sections, uneconomical I-beams, channels or built-up sections which increase the initial cost and construction time. Odabaşı (1990) explains that, absence of intermediary profiles, result in material losses between 11%-18% and these percentages increase in extreme examples. Accordingly, as they are more advantageous and economical, reinforced profiles are used instead of using an upper grade profile. Besides, since the profiles larger than I-380 do not exist in the market, generally from plates I-section is built, which is called built-up section. Both using the reinforced profiles and the built-up sections require extra time and labor.

d) Economic Considerations

There is a common belief that steel construction is expensive, since it requires equipment for assembly and qualified workforce. As mentioned by Tabak (2003), it can not be generalized that steel is more expensive than concrete or vice versa. Firstly, the design and purpose of the building must be examined to find out which material is more suitable. Tabak (2003) argues that, steel can be more economic when we think about the simplicity of erection or time savings, if these criteria are important for the contractor/owner. Necessity of fire and corrosion protection also causes designers or contractor not to prefer steel because of economic considerations.

According to Berktin (1994), in order to be able to make steel construction, the owner or the contracting firm in Turkey must invest high initial capital, although it will be paid back in very short period of time. Because today, due to economical conditions, no one wants to make investments with such high initial costs, except for very big projects, steel construction can not achieve its rightful place in the construction market.

# CHAPTER 3

# MATERIAL AND METHOD

In this chapter the material and the method of the study on steel construction in Turkey are presented. A case study was carried out on the TESKOMB Office Building in Ankara; this building is presented as ‘The Survey Material’. The method of the study and analysis are presented as ‘The Survey Methodology’ in the following section.

## 3.1. The Survey Material

A survey was performed on designing and producing a steel building in Turkey and the TESKOMB Office Building, which was a steel office building under construction in Ankara was chosen as the case study. In this regard, information about the TESKOMB Office Building and general characteristics of the steel construction process are described in the following pages.

The TESKOMB Office Building is located on Cinnah Avenue, which is one of the most important roads of the city, in Çankaya district of Ankara (Figure 3.1). The project of the building was designed by architects Mehmet Soylu and Mete Öz in the year 2000 and it won the first prize in a national competition, which had 163 projects.

The construction company which built the TESKOMB building is ‘Feka İnşaat’ and its structural consultant firm belongs to civil engineer Kenan Özbek. This was the first steel project of ‘Uz Mimarlık’, not including some industrial buildings, and the construction firm did not have much experience in steel construction as well. Therefore, 'Rona Mühendislik', which is specialized in steel construction, fabricated and erected the steel structure.

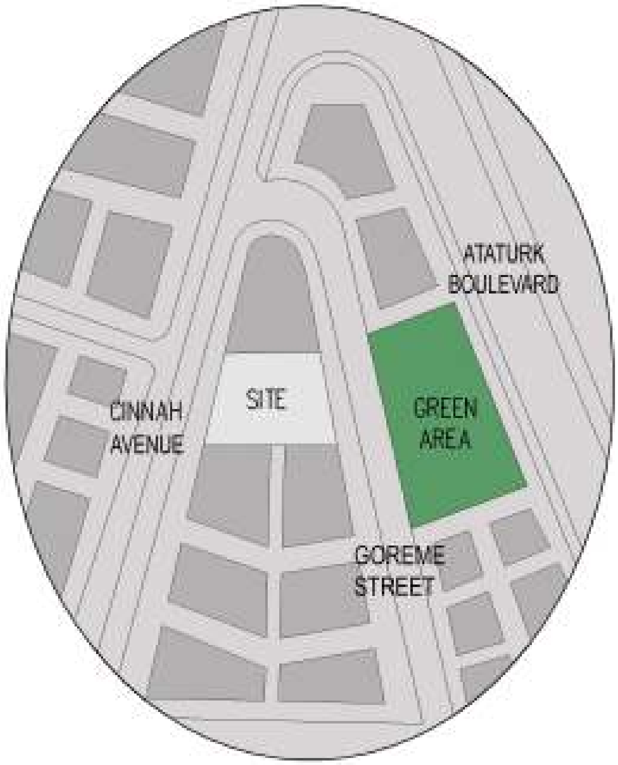



**Figure 3.1.** Plan showing location of TESKOMB Building

The building had been designed as an office building and a guest house for the competition but it was converted into an office building on the request of the owner, after the competition. Accordingly, some changes were done in the design and the production drawings were completed in 2002. After taking the approval of the Çankaya Municipality, the construction of the building started in 2003 and finished after two years, in 2005, when the building was opened to use.

According to the architects, the main idea of the project is 'transparency'. The aim was to connect the main street with the offices and the green area at the back street visually (Figure 3.2). Therefore, the architects split up the building into two parts and created a void between them, which functions as a passage area. The office rooms were placed on these two sides and were connected with each other with small bridges.

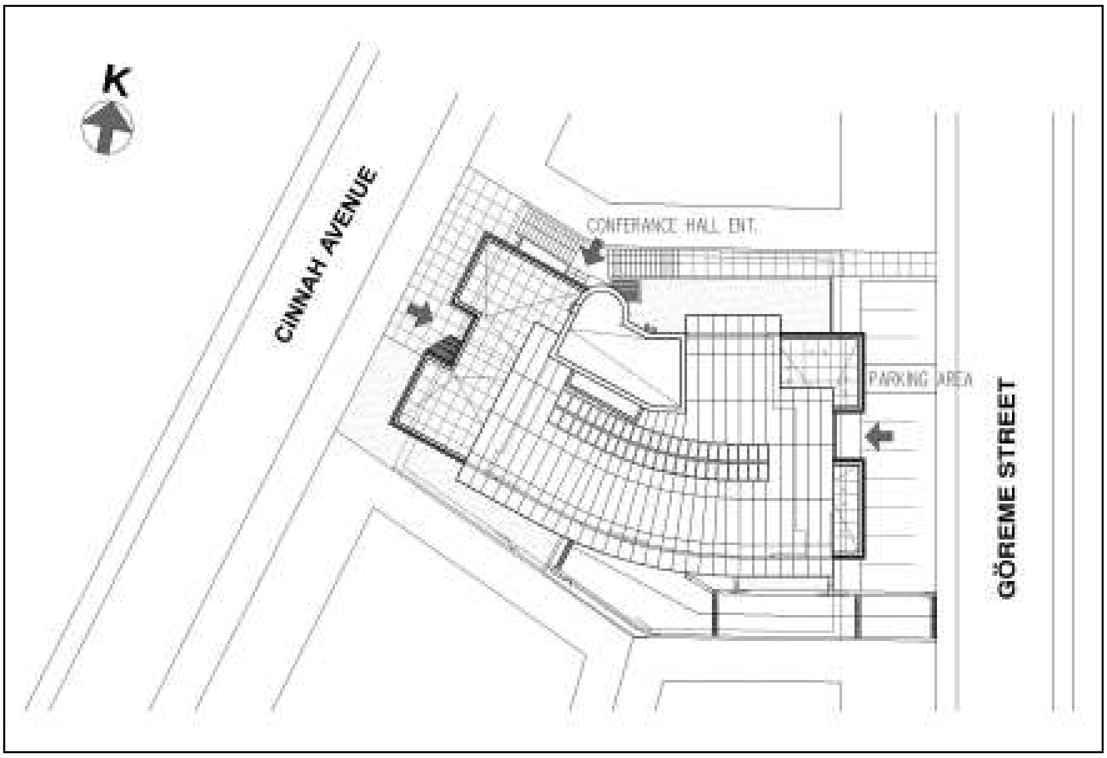



**Figure 3.2.** Site plan of TESKOMB Building

The building is located on a site which is approximately 1040 m². It is 21 meters high and there are ten storeys in the building as shown in Figure 3.3. Reinforced concrete was used for the construction of the four floors below the ground level and the other six floors were supported by steel structure. Accordingly, the area of the reinforced concrete floors is nearly equal to the area of the floors supported by steel. Total construction area is 5100 m².

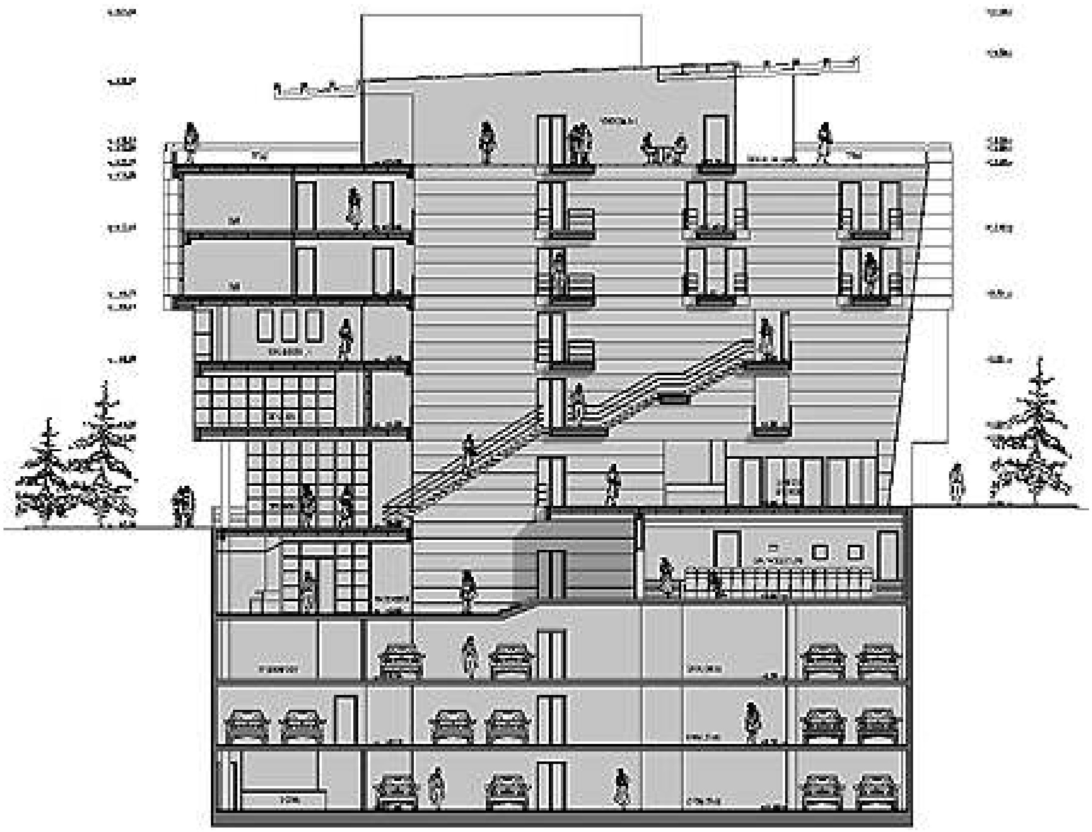


**Figure 3.3.** Section AA of TESKOMB Building

There are two entrances to the building. The main entrance is at the west façade which looks on to the Cinnah Avenue and it opens to a big entrance hall and an exhibition hall near it. The other entrance is on the east façade, which opens out on Göreme Street at the back of the building and serves for the staff of the building. There is a reception and a few office rooms on the entrance floor as shown in Figure 3.4.

On the first basement floor of the building, a conference hall with a capacity of 250 people is located. The reason for placing the conference hall on the ground floor is that the owner wanted it to open directly to the outside, so there is also an entrance and a small foyer on the north façade of the building that works independently from the building. In Figure 3.5 the plan of the first basement floor showing the conference hall and other public facilities, accessible from the outside is seen.

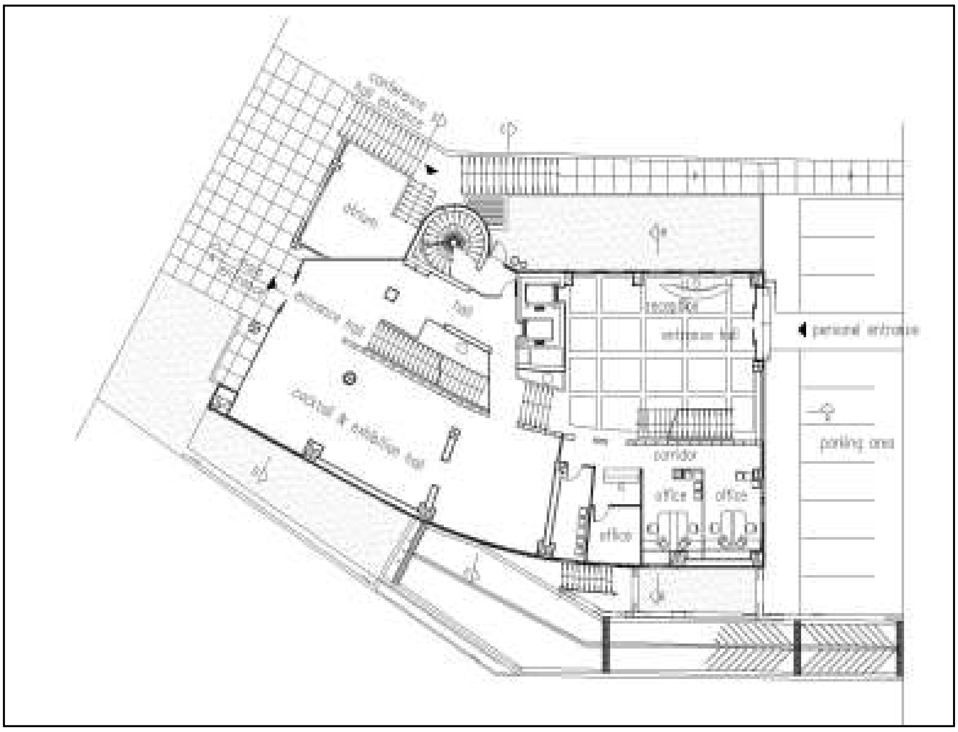



**Figure 3.4.** Entrance floor plan of TESKOMB Building

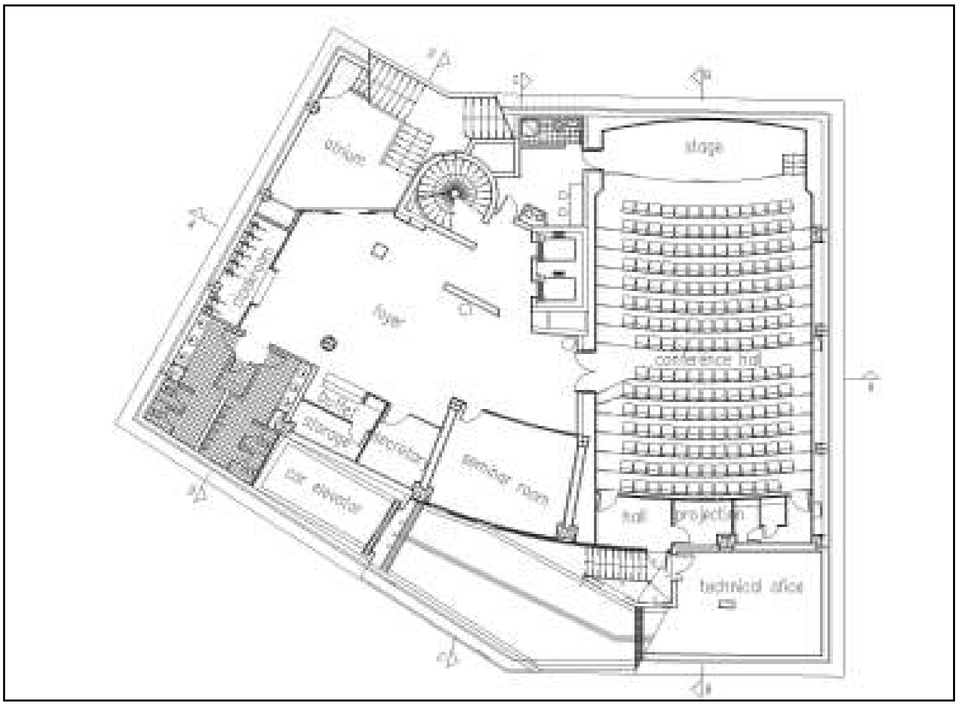



**Figure 3.5.** Plan of the first basement showing the conference hall

The three of the four basement floors under the ground were planned as garages and the total car parking capacity of the building is 70, as required by the municipality. In order to achieve this capacity, architects had to design two more floors under the ground in order to provide parking areas for 70 cars and that increased the total cost and time of the construction (Figure 3.6).

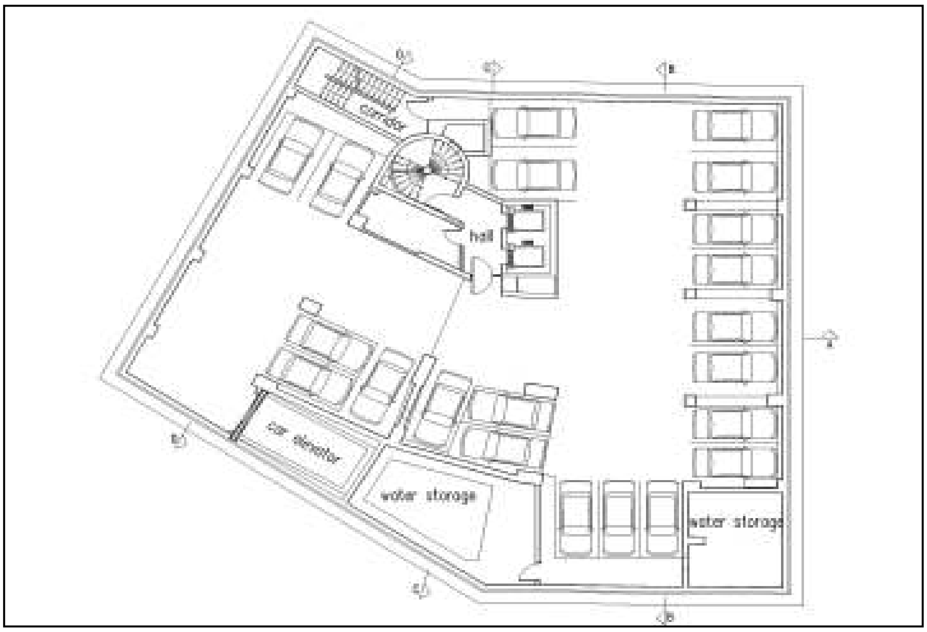



**Figure 3.6.** Third basement floor designed as a garage

The other four floors of the building are designed to accommodate office rooms. There is also a small library and a meeting room for the staff of the building on one of these floors. Two elevators, the main stairs in the gallery and the fire escape stairs provide vertical access. The second floor plan showing the office rooms is seen in Figure 3.7.

- On the top floor, there is a restaurant with large terraces as shown in Figure 3.8. The roof of the restaurant is supported by steel arches and there is a sun roof on it. Additionally, there are toilets and a kitchen serving the restaurant on that floor.

External views of the two accesses, from Cinnah Avenue and from Göreme Street, can be seen in Figures 3.9 and 3.10.

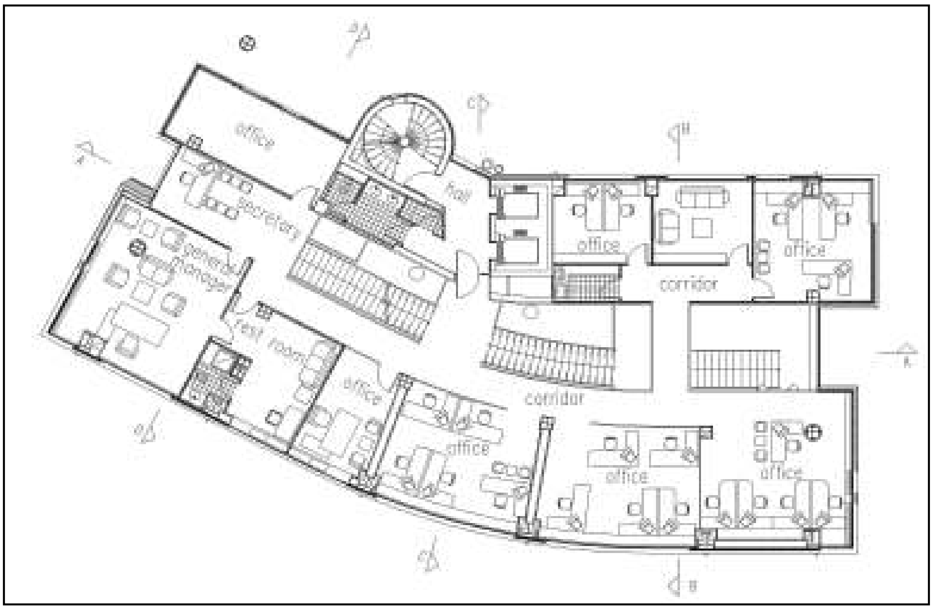



**Figure 3.7.** Second floor plan of TESKOMB Building

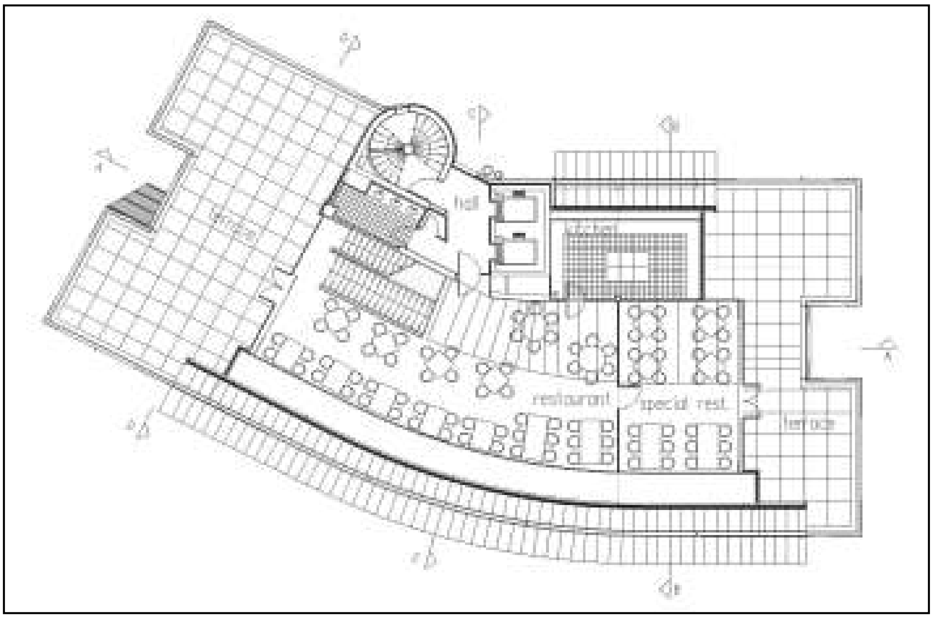



**Figure 3.8.** Top floor plan of TESKOMB Building

**Figure 3.9.** East façade of TESKOMB Building

**Figure 3.10.** West façade of TESKOMB Building

## 3.2 The Survey Methodology

The TESKOMB Office Building in Ankara was chosen as the subject of the survey. The reason for the selection of this building was that it was one of a few steel structures of Ankara and its construction had just begun at the decision phase of the author, which gave the author the chance to monitor the building right from the beginning of the project to its finish.

The study also focused on the general characteristics of steel construction. Construction details, the structural system, connection details and finishing method selected for the project were therefore studied by examining production drawings and details of the project and periodic observations on sites

All technical data, architectural designs, construction and technical drawings and some photos of the TESKOMB Office Building were obtained from Feka İnşaat and Uz Mimarlık. Additionally, the photos of the building were taken by the author from the beginning of the construction to the end.

Interviews were conducted with the architects and engineers of the building to obtain information about the design and construction processes and also to elicit their opinions, negative or positive, about steel construction. Moreover, related web sites were visited to gather more information about the project.

While carrying out this study, AutoCAD 2006 software was utilized for drawing the plans and sections of the building. In addition, Adobe Photoshop 7.0 was used for organizing the photographs and drawings.

At some stages of the study, comparisons were made between steel construction and reinforced concrete construction according to design and production processes. The results of the evaluation are presented in Chapter 4.

# CHAPTER 4

# RESULTS AND DISCUSSION

In this chapter, the results and discussions of the study on the TESKOMB Building are presented. The building is evaluated in terms of its design considerations and the construction process; and also problems faced during the design and production processes are explained.

## 4.1 Design Considerations

The TESKOMB Building was chosen the case study within the scope of this research. The construction of this building had just begun, therefore, the whole process could be observed easily from the beginning to the end. This also provided a chance to observe the advantages, disadvantages and problems in constructing a steel building in Ankara.

As noted earlier, the design of this building was commissioned after a competition. The architectural consultant firm of the building is Uz Architecture Ltd. and the architects are Mete Öz and Mehmet Soylu. Since the site of the project was located in a dense urban area, it was difficult to create urban spaces and the design was limited within the boundaries of town-planning codes and the neighboring buildings. As stated by the architect Mehmet Soylu, they aimed to create a visual connection between the Cinnah Road and the green area across the back street by their design. They provide this by separating the building into two parts and forming an atrium between them. The allocation of the office rooms and the other units were described in detail in the previous chapter.

This was the first steel building designed by 'Uz Mimarlık' excepting a few industrial steel buildings. Therefore, they did an exhaustive literature survey during the design process. According to the architects, the structure of the project was thought as steel from the beginning of the design. The reasons for that are listed below.

- The main reason of choosing steel as a structural system is the idea of keeping the atrium that was designed for architectural purposes. The architects confirmed that if they had decided to make this project from reinforced concrete, they would have lost the main idea of the design, which made them get the first prize in the competition. Architect Soylu said that when they completed the cost analyses, they saw that steel was 30% more expensive than reinforced concrete, which caused them to think about the structural system once more because of financial concerns. However, when they checked up the 'earthquake regulations', it was understood that they could not create the atrium they want by using reinforced concrete since it does not provide the necessary strength in the single bay systems. Additionally, steel would be a good choice for the construction of bridges providing the access between two parts as seen in Figures 4.1 and 4.2.

- Another important reason is the matter of height which was limited by the building regulations. This directed the designers to choose steel. For instance, the conference hall in the ground floor was designed for 250 people and 12 meters-width had to be spanned. According to architects' calculations, beam depth would be 80-90 cm, if reinforced concrete was used, which meant an increase in the height of the ground floor and accordingly an increase in the amount of excavation.

  Also, there was a problem of installation. An additional height was necessary for the raised floor required by the owner to place the computer cables and for the air-conditioning and ventilation-system. If the building was a reinforced concrete structure, the number of storeys would decrease or the floor height would be less than 3 meters. Utilizing steel decreased the beam depth and provided the required height without decreasing the number of storeys or the floor height. However, installation of cables and pipes was still a problem, so designers decided to place them into the columns. The details are given in the following section. According to the designers, this is an important advantage of steel construction.

- The roof structure spans 15.5 meters and there is a sun roof on it. As stated by Soylu, steel was the best choice for supporting the roof because of its ability to span long distances and lightness. According to Soylu, the lightness of steel also provided a chance to design a glass floor. The part of the floor that is above the gallery of the building is covered with glass on the top floor, so it is possible to view the gallery below while sitting in the restaurant.

**Figure 4.1.** The construction of the bridges and the atrium

**Figure 4.2.** Bridges inside the building connecting the two blocks

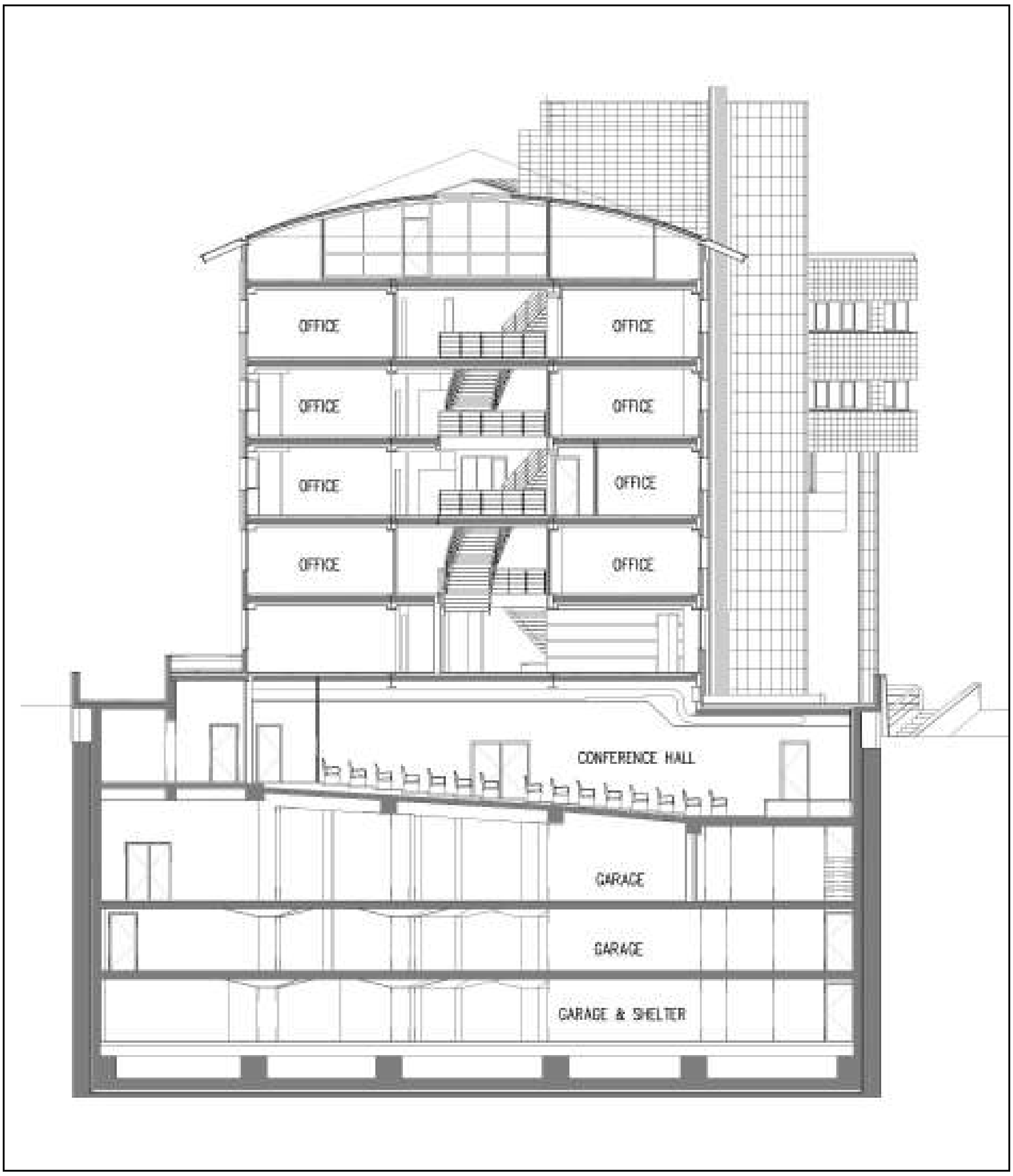



**Figure 4.3.** Section BB of TESKOMB Building

According to the town-planning codes, a 70-cars-capacity garage was required because of the conference hall on the ground floor; even though the number of occupants was 40. An extra basement floor was designed (Figure 4.3) and accordingly, the building had to be dug 14.90 deep into the ground to fulfill this requirement which gave rise to the problem of safety of the neighborhood. Also, since the distances were not proper for a ramp, the access to the garages was provided by car elevators. Consequently, this increased the cost of the building by 852 000 € (in 2003).

## 4.2 Construction Process

The main contractor for the building was Feka İnşaat Ltd. and the manufacturers of the steel structure was 'Rona Mühendislik ve Danışmanlık Ltd.' which developed the design and details as well as fabricated the steel members and erected the steel structure of the building. The structural calculations of the building (both for the reinforced concrete and steel) were done by civil engineer Kenan Özbek.

Shop drawings were prepared by Rona since structural steel design requires specialized knowledge and practice, as compared to concrete design. After shop drawings of the structure were completed, the fabrication process of the sections began. Figure 4.4 below shows the layout of the steel columns and beams for a typical floor of the steel structure.

Additionally, since reinforced concrete structures are not built up as precisely as steel structures, Rona had to take measurements at the construction site at regular intervals during the fabrication process, in order to adjust the steel members according to the actual concrete foundations. On account of these measurements, they changed the dimensions of some of the members. The components used in the structure, their connections and erection of the whole structure are described in the following sections.

### 4.2.1 Components of the Structure

Similar to the other systems, this structure has a system composite of columns and beams which support slab system. Additionally, the resistance of lateral and vertical loads was provided by bracing elements, stiffeners, gussets and girders. Components of this structure are described in four parts below.

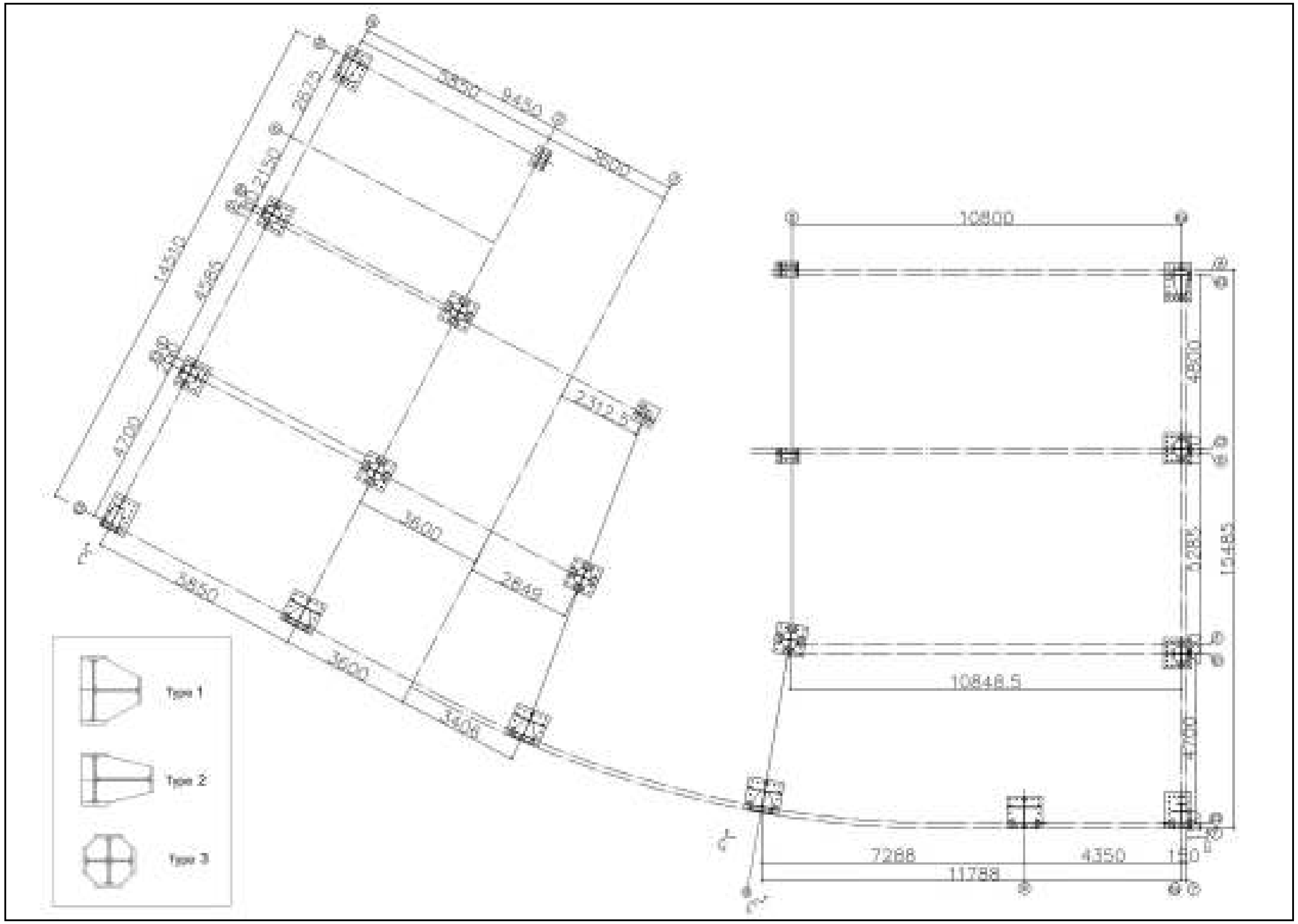



**Figure 4.4.** Structural plan showing location and sizes of columns and beams (Source: Rona Mühendislik)

a) Columns/Stanchions:

In order to produce the columns of the structure, industrial type of steel sections were used since the sections fabricated for buildings, such as dwellings, offices, *etc*., are not produced in Turkey. Accordingly, Rona had to design and produce built-up sections for the structure. Three kinds of open type built up sections were used as shown in Figure 4.5. Two built-up sections were connected to each other in order to form one column. The heights of these sections are 11, 10.5 and 7.4 meters (see Appendix B). Also, many stiffeners were welded to the sections at the factory to strengthen the columns.

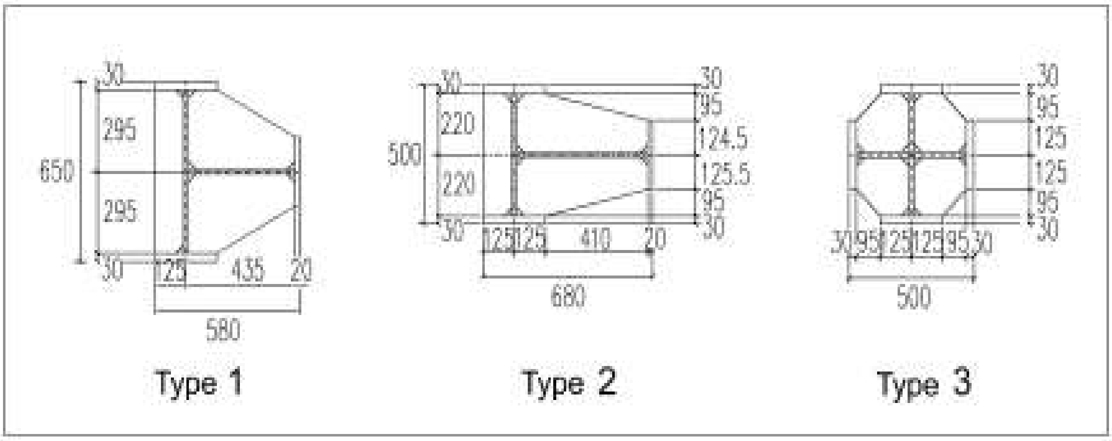
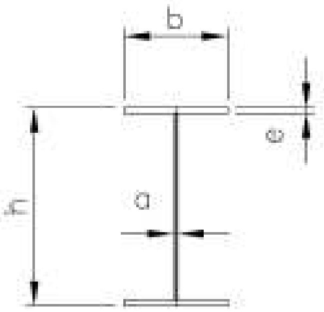



**Figure 4.5.** Three types of built up sections produced as columns for the TESKOMB Building

b) Beams and Girders:

Typical I-sections were used as beams and girders in the structure. Four kinds of I-sections were produced as shown in Figure 4.6. The depths of these sections are 25, 30, 50 and 54 cm; and they span minimum 4.3 and maximum 10.8 meters. Girders were connected to the beams with 60 cm intervals.




| | BEAM TABLE | | | | |
|---|---|---|---|---|---|
| | NAME | h (mm.) | b (mm.) | a (mm.) | e (mm.) |
| 1 | HI300-20-30*250 | 300 | 250 | 20 | 30 |
| 2 | HI250-15-20*250 | 250 | 250 | 15 | 20 |
| 3 | HI500-20-30*250 | 500 | 250 | 20 | 30 |
| 4 | HI540-30-50*250 | 540 | 250 | 30 | 50 |

**Figure 4.6.** Beam sections and the various dimensions, used in the structure

On the other hand, the exposed beams at the west façade were designed differently from these sections, for decorative purposes. Perforated steel sections were chosen for the façade (Figure 4.7). Additionally, beams at the south façade and beams carrying the roof were designed in curvilinear shape. Rona produced curved steel beams by welding short steel sections to each other. The curved beams supporting the roof structure spans 15.5 meters and they are connected to each other by steel cables as tension members as shown in Figure 4.8.

**Figure 4.7.** Perforated steel beams

**Figure 4.8.** Curved steel beams

c) Slab Systems:

Metal deck floor system was chosen as a slab system. Galvanized corrugated sheets were placed on the steel girders and wire-mesh reinforcement was put over these sheets in order to bind the sheet with concrete as shown in Figure 4.9. After pouring concrete in 8 cm depth, the floor deck was paved with boards.

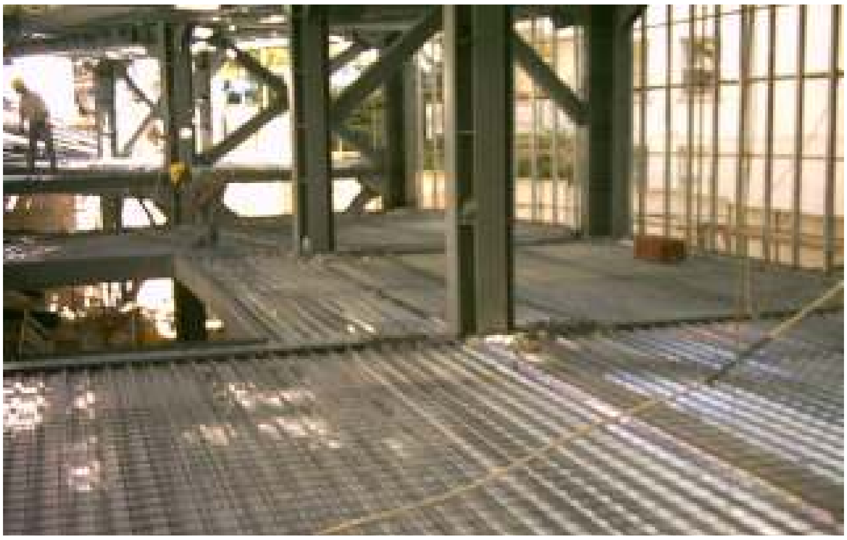


**Figure 4.9.** The construction of metal deck floor

d) Bracings:

Lateral stability of the structures was provided by using diagonal steel bracings. In the first floor, bracings were constructed in the horizontal direction (see Appendix B). Steel channel sections, which have 20 cm depth, were bolted to each other and used as bracing elements. They were bolted to the beams by the help of shop-welded steel plates as shown in Figure 4.10. Additionally, larger steel bracings were constructed in the vertical direction (see Appendix B). Steel I-sections, with 24 cm depth, were used and they were bolted to each other and to the structure by using shop-welded plates as shown in Figure 4.11.

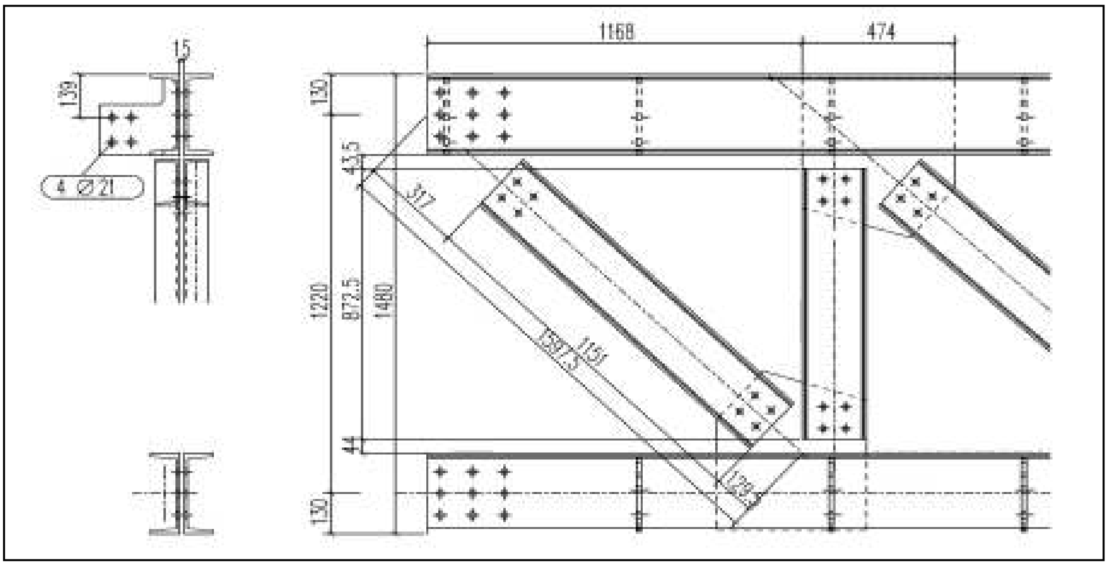



**Figure 4.10.** The section and elevation of the bracings used on the first floor

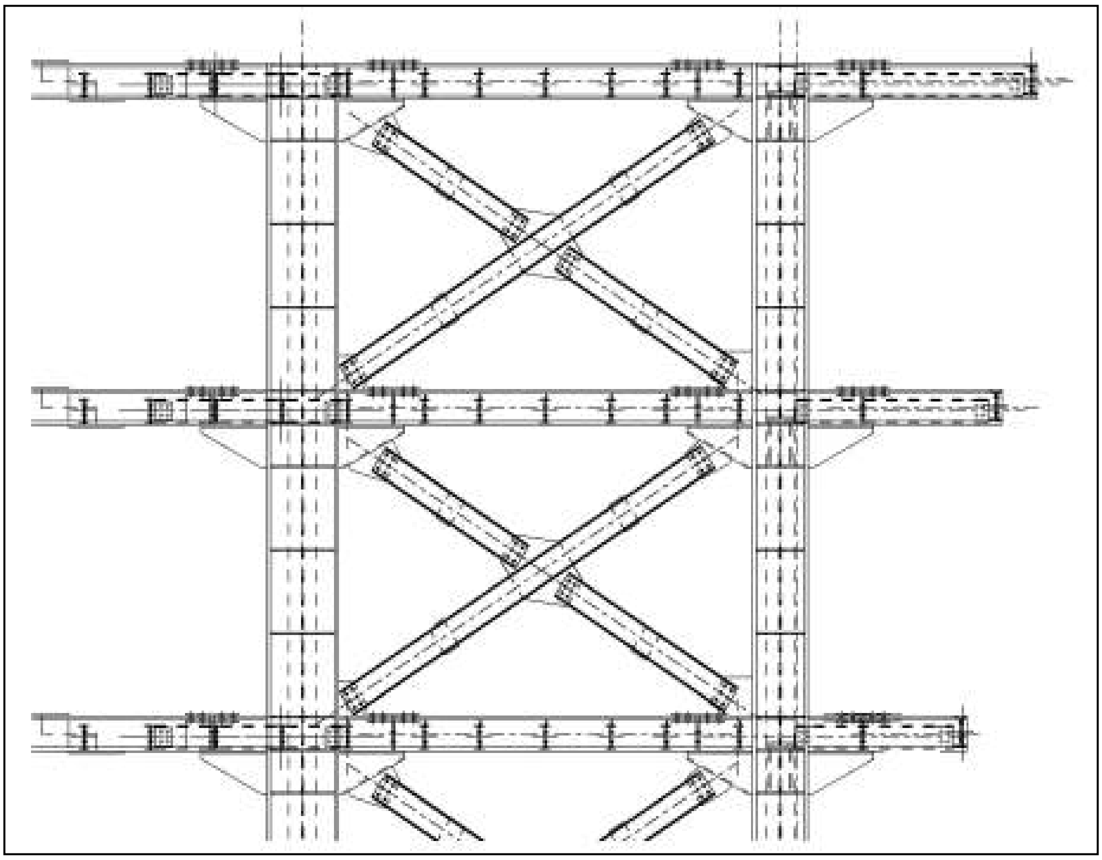


**Figure 4.11.** The bracings used in the vertical direction

4.2.2 Connections in the Structure

Built up sections were bolted to each other to form columns by the help of steel splice (fish) plates. Triangular gussets were welded to the built-up columns at the column-beam connection points, in the factory, in order to consolidate the connection. Short pieces of I-sections were also welded on gussets to make the assembly process easier (Figure 4.12). One of the engineers of Feka stated that another reason for adding these pieces was idea of avoiding from the problems that could emerged because of inappropriateness in the lengths. I-beams were bolted to these pieces. Also steel splice plates were used at these points to stiffen the connection as shown in Figure 4.13.

**Figure 4.12.** A free-standing column before connecting the beams

**Figure 4.13.** Column-beam connection with splice (fish) plates

After connecting the beams with columns, girders were attached to the beams with bolted connections. Steel plates with bolt-holes on them were welded at two sides of the beams and girders at the manufacturing plant to make the assembly process easier on site (Figure 4.14). Girders were bolted at these points with 60 cm intervals as shown in Figure 4.15.

**Figure 4.14.** A plate welded to the beam for the girders

**Figure 4.15.** Connection between beams and girders

4.2.3 Erection of the Structure

As stated in Chapter 3, reinforced concrete was used for the construction of the first four floors (ground floor and three basement floors) and the other six floors are of steel. The foundation of the structure is reinforced concrete strip foundation. Mushroom slab system is used for the first two basement floors and beam-column system is used for the third basement floor.

After completing construction of the foundation and the basement floors, erection of the steel structure began. Rona executed the erection and the civil engineers of the construction firm and building control firm monitored this process. Firstly, columns were anchored to the concrete plinth as shown in Figure 4.16. Subsequent to the anchorage process, the column sections were bolted to each other by using splice plates (Figure 4.17).

**Figure 4.16.** Anchorage of the columns to the concrete plinth

**Figure 4.17.** Assembly of the columns by using splice plates

Once the columns were erected (Figure 18), horizontal members (beams and girders) were assembled. Since every part of the structural system was designed carefully before the construction, workers only assembled the members on site by the help of a crane as seen in Figure 4.19. After the assembly of these beams, steel curved beams were assembled for supporting the roof.

**Figure 4.18.** Assembly of the columns

**Figure 4.19.** Assembly of the steel structure

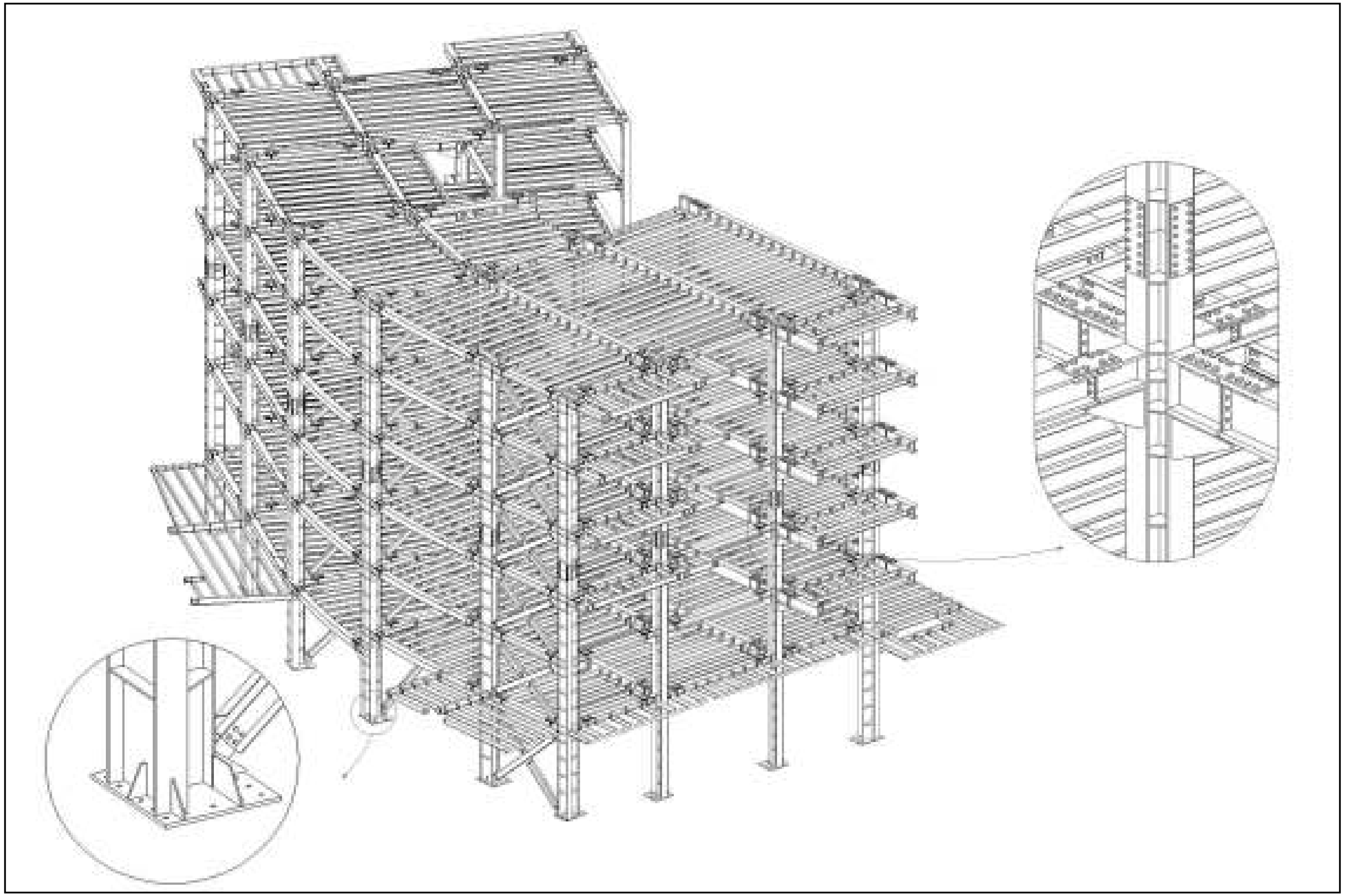


**Figure 4.20.** 3D drawings showing the structural system prepared by Rona Mühendislik for the TESKOMB building

4.2.4 Finishing Techniques

Feka İnşaat moved in to complete the other works on the building, after the steel structure was erected by Rona. First of all, metal supporting system of the curtain wall was constructed, and then building was clad with OSB, thermal insulation, acoustic boards, and brick facing respectively (Figure 4.21 and 4.22). Metal finishing was used on the façade at the entrance floor instead of brick finishing. Double glazing (low-e glass with 9mm interval) and insulated metal framing were used for the windows.

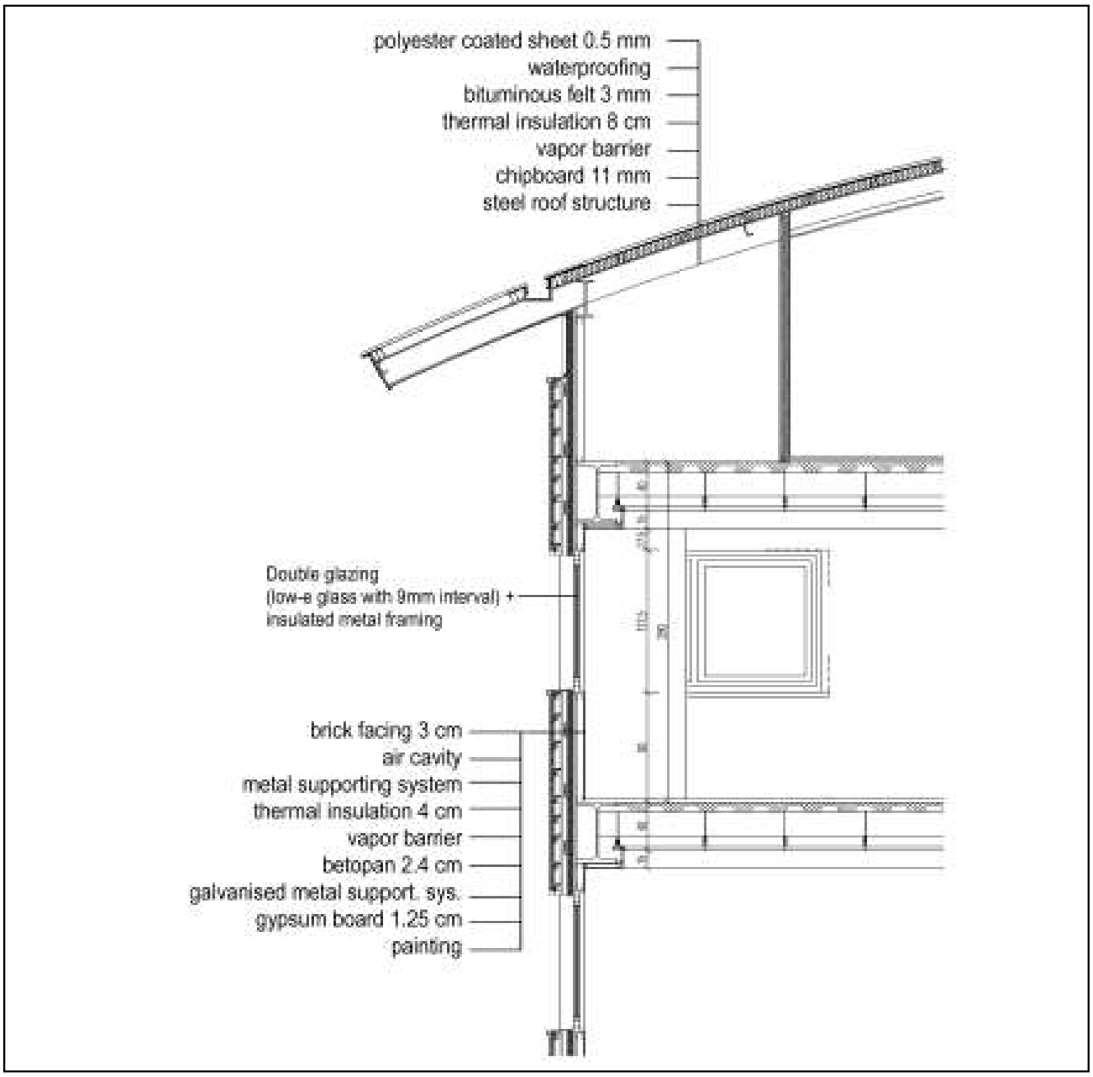



**Figure 4.21.** Detail drawing of the building

**Figure 4.22.** Construction of the curtain wall and its final photo

There were no installation channels in the horizontal direction; the vertical channels are integrated into the T-shaped steel columns, which are encased within gypsum board panels as shown in Figure 4.23. These channels are accessible in the rooms under the doors.

Painting was not preferred as a fire protection method because of financial concerns and the preference of the client. Therefore, steel structural members were covered with gypsum boards and rock wool for fire protection. All columns were covered in a rectangular shape (Figure 4.24) except the ones at the corner of the building, which were covered with circular boards for decorative purposes as shown in Figure 4.25. Some of the steel components were left uncovered and they were painted with special dyes in order to provide fire proofing. The exposed steel elements at the top floor are seen in Figure 4.26.

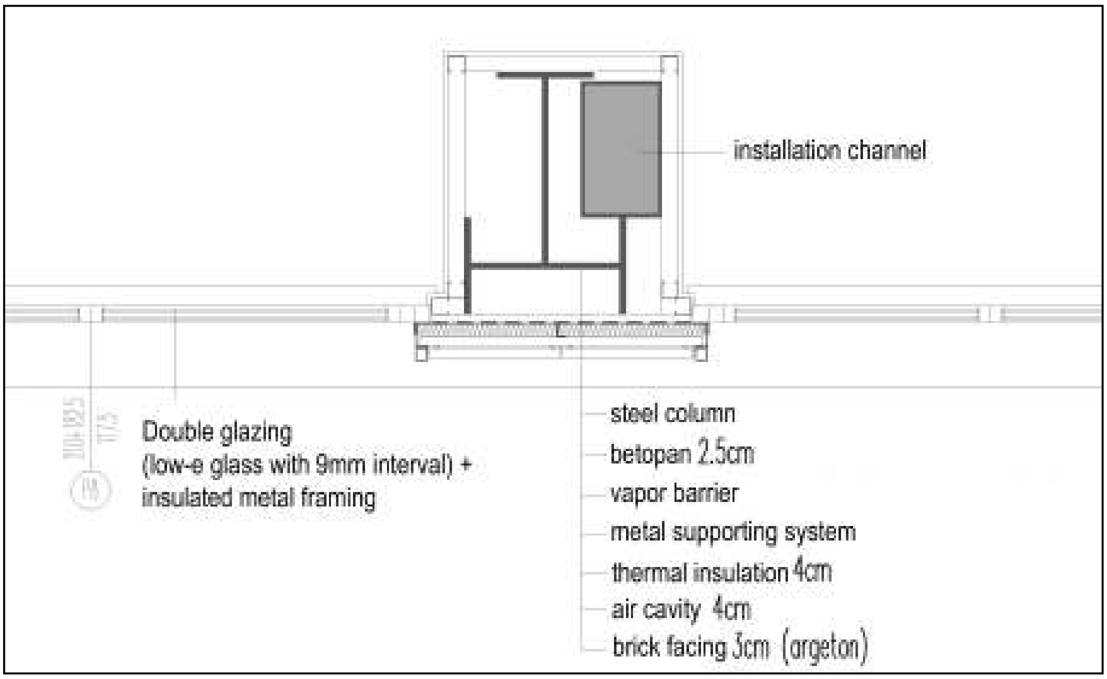



**Figure 4.23.** A detail showing the installation channel adjacent to the steel column

**Figure 4.24.** The steel column and the installation channel enclosed within gypsum board casing

**Figure 4.25.** Circular encasement for columns at the façade

**Figure 4.26.** Exposed steel elements at the top floor

The suspended ceiling was constructed to conceal the steel structure from below. Perforated boards were assembled to the beams and girders by utilizing steel box sections as shown in Figure 4.27.

As mentioned in the previous chapter, there are large terraces on the top floor. To assemble the roof, on top of the galvanized corrugated sheets; concrete, bituminous primer, water insulation, heat insulation, felt, PVC cleat and granite were placed in layers as shown in Figure 4.28 and 4.29. The steel arch beams forming the roof are covered with chipboard, vapor barrier, heat insulation, water insulation and steel sheet. The detail drawings of the roof and also the concealed gutter used on the roof can be seen in Figure 4.30.

**Figure 4.27.** A view showing the suspended ceiling

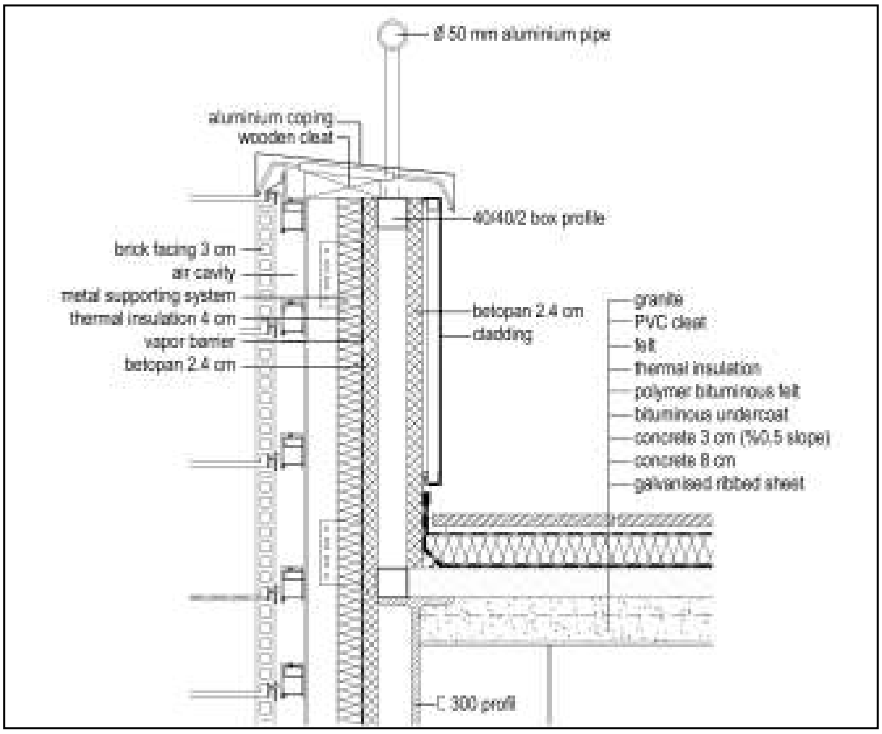



**Figure 4.28.** A detail drawing of the terrace-roof and parapet wall


**Figure 4.29.** A detail from terrace showing the insulation materials

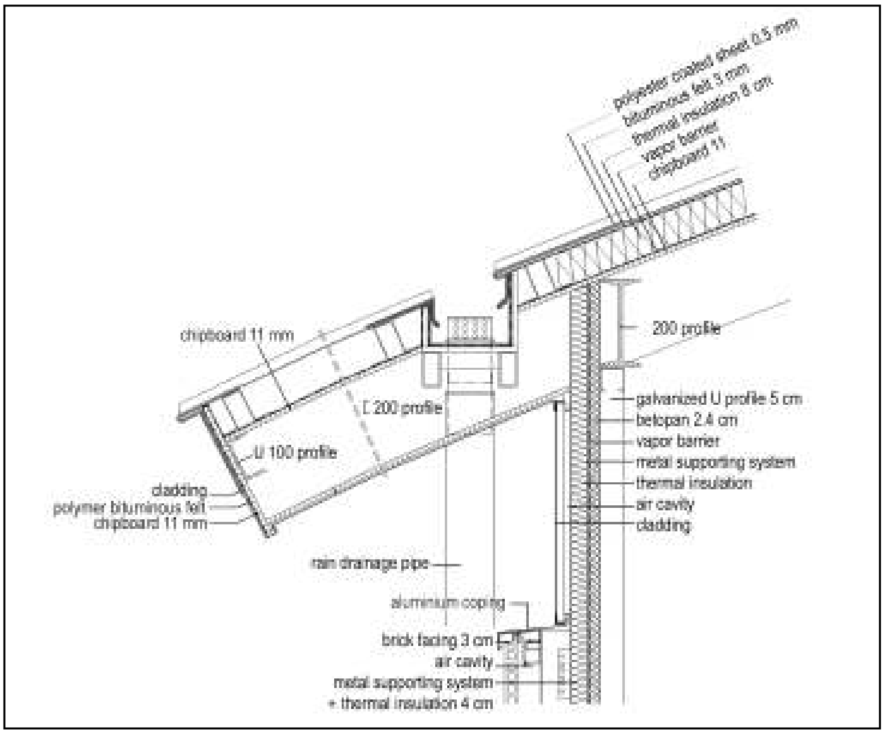



**Figure 4.30.** A point detail of the curved steel roof

## 4.2 Problems Encountered

The construction did not finish on the due date. It took two years and according to Soylu, this duration is almost same as that for a typical reinforced concrete construction in Turkey. This meant that they could not benefit from one of the main advantages of steel construction, which is short duration for construction works.

The main reason for this delay was economic. The required equipment and material flow was interrupted because of financial problems. The final bill of material for steel components had exceeded the initial estimate, which increased the cost of construction and the budget was not sufficient to cover this extra cost.

The second reason was the lack of knowledge of the client, who did not know much about the construction process and did not have a project manager either. At the request of the architects, a project management firm was appointed to represent the client. However, mid-way through the construction, the client changed this firm and a new project manager was appointed who wanted to go through the steel cost analyses all over again; this caused a further delay of 3 to 4 months.

The absence of a project manager had caused a delay in the design process also. The client had no idea about the bureaucracy of authorization and approval procedures in the Municipality and therefore there was a 6 months delay into starting the construction even after production drawings were ready.

Another reason that delayed the construction was the difficulty of the design. According to Soylu, it was not easy to adapt the design of the building to the codes of the Municipality. The capacity of the parking area, the boundary wall between the neighboring buildings, and the number of stairs and the level of the surrounding all caused problems which extended the process.

Many problems were encountered during the design as well as the production stages; these are described in more detail in the following sections.

### 4.3.1 Design Problems

Some problems occurred during the design process of the structure due to the safety problems, including fire proofing and earthquake safety, the discrepancy between architectural and structural drawings and the lack of precision in the design. These problems were explained below.

#### a) Fire Proofing

Architects wanted to leave the steel members with a brutalist approach. However they met with two problems: The first one was the opposition of the owner who did not like the idea of seeing the steel structure inside the building. The second one was the fire proofing problem.

Steel members must be painted if they will be left uncovered as discussed in Chapter 2 and painting the members with special dyes costs more than covering them. Therefore, it was decided to clad the steel elements with gypsum board and rock wool but except for the stairs, small beams at the façade and beams supporting the roof so as to keep the character of a steel building. Additionally, fire stairs were of reinforced concrete as opposite to the main stair case which was steel because of safety issue. Architects also point out that, there was not a sufficient fire regulation during the design process of the building and the fire regulation matching with the new European standards and answering for the requirements of Turkey was made in 2002. As a result, they performed a research in order to find the right solutions for fire proofing of the steel structure.

b) Seismic Safety

Kenan Özbek who, according to Soylu, calculated the safety factor to be 30% more than that in developed countries. The reason for this over cautiousness being that Özbek wanted to be on the safe side, since the labor force does not have much experience in steel construction in Turkey (as mentioned in Chapter 2); also he was not sure about the quality of steel. In the TESKOMB building 130-150 kg steel was used for each meter square. According to Soylu, this amount is 100-120 kg per meter square in the world, especially in America and Europe. Rona Engineering and Consultancy Ltd. did not dispute the calculations of Özbek, since the responsibility of the structure belong to him, and fabricated the members as he designed. An extra 70 to 80 tons of steel were used as a result of this over cautiousness. Similarly, the architects of Feka claimed that, thickness of the sections used in the building is also over designed, which can carry the load of another 4 floors.

Moreover, many stiffeners were welded to the columns and beams, especially to the columns, during the manufacturing process to stiffen the structure. In addition to stiffeners cross bracing beams were placed at some parts of the structure for lateral loads, as planned during the design process and according to the calculations of the civil engineer. Also gussets and fish plates were used at the connection points. According to the engineers, adding too many stiffeners and gussets is unnecessary.

c) Discrepancy between Architectural and Structural Drawings:

The production drawings were not accompanied with the detail drawings. Therefore many problems emerged during the production and construction periods.

Workers assembled the steel cross braces on a wrong frame because of the discrepancy between architectural and structural drawings (Figure 4.31). Consequently, the specified door could not be opened on that wall and this problem was rectified by the engineers as seen in Figure 4.32.

**Figure 4.31.** Incorrect structural bracing

**Figure 4.32.** Rectified structural bracing

Another mistake was made in the dimensions of the gussets. Engineers did not consider the height of the suspended ceiling while designing the gussets; and accordingly, suspending ceiling could not be assembled. Therefore, triangular pieces were cut out from most of the gussets in order to place the suspended ceilings as shown in Figure 4.33.

**Figure 4.33.** The modification made on gussets

d) Lack of Precision:

Some points in the structure were not designed by the architects in detail and some elements were forgotten in the architectural drawings. Consequently, engineers faced several problems during the construction process.

Lack of detailing caused water insulation problems in the structure. There were mistakes in the production of the sunroof at the top floor; hence water leaks in from the connection points. There is water leakage from the connection point of steel and concrete core, too.

Another problem occurred during the installation of the pipes and channels. Pieces were cut out from the stiffeners to place the rain drainage pipe as seen in Figure 4.34 since the designers did not think about the drainage pipe initially and give its detail drawings. Moreover, installation channels were placed at the two sides of the T-shape columns as mentioned in the previous section. The stiffeners were also cut and deck was perforated for this reason (Figures 4.35 and 4.36).

**Figure 4.34.** Modification made for the roof downleads

**Figure 4.35.** A view showing the conduit installed next to the column

**Figure 4.36.** A view showing the hole on the steel deck for the installation channel

4.3.2 Production Problems

Industrial types of steel sections were used in the structure due to the absence of different types of steel sections in Turkey. Therefore, Rona had to produce built-up sections, which means extra time and labor.

Production of the curvilinear beams also became a problem. The architects claimed that, one of the reasons for choosing steel was the curvilinear beams in the structure (beams at the south façade and beams carrying the roof), since curved reinforced concrete beams would be difficult to pour. They thought that curved steel beams produced at the factory would make this process more effortless. However, these curved steel beams were not produced at the factory, as planned, because of economic reasons and, instead, they were made by welding short steel sections to each other on the site (Figure 4.37).

**Figure 4.37.** Curved beams supporting the roof

# CHAPTER 5

# CONCLUSION

There is a need to increase architectural utilization of structural steel in Turkey due to its location within the earthquake zones. In spite of the structural integrity of steel buildings and despite the amount of steel being produced in this country there is a marked lack of using steel in the construction industry. In order to promote its use architects and architectural education should focus on its advantages.

The TESKOMB building in Ankara was studied to investigate the design and erection processes of steel buildings in Turkey. The whole process was monitored from the beginning to the end and the problems encountered were examined.

It was observed that the lack of an experience of project team can prove to be an important drawback. Therefore, project owners should work with consulting teams that consist of architects and engineers who have experience in steel construction. The lack of a qualified team causes delays and difficulties both during the design and the construction stages.

The owner and/or the contractor must ensure high initial capital in order construct steel structures. According to the architects interviewed, due to economical conditions in Turkey people do not want to make investments with such high initial costs, except for very big projects; although they can recover their investment in a short period of time.

Additionally, problems emerged due to the design and production processes also; the reasons for which can be summarized as follows:

a) Design:

- Steel requires more precision both in the design and construction processes. However, in Turkey, architects do not have to submit detail drawings (in 1/1, 1/2, 1/5 or 1/10 scale) and contractors do not demand this drawings either. This lack of detailing increases the number problems in the structure.

- The design of a building involves the integration of not only architectural requirements but also engineering (structural, mechanical, electrical *etc*.) services. If the architectural and engineering drawings do not match, problems emerge during the construction stage due to discrepancies in the drawings.

b) Production:

- As explained in Section 2.8.2, steel sections/elements produced in Turkey are very limited in variety, therefore, designers are forced to use either imported steel sections or locally produced I-beams, channels or built-up sections, etc, which increase both the initial cost and construction time.

- Current production technology needs updating. After modernization of the production technology, different steel sections, such as wide flange sections which are not available in Turkey, can be produced in order to save on costs, time and manpower; and to meet the demands of the construction sector.

- Companies involved in fabrication and erection of steel structures also must utilize current technologies, in each phase, to facilitate the production of steel structures.

- There is an absence of qualified and experienced workers in steel construction in Turkey. Therefore, the time losses and the workmanship costs increase whereas the quality of the steel structures decreases.

Based on the above conclusion, following recommendations are made to improve the current state-of-art of producing steel buildings:

1) Production drawings must be provided with all the relevant detailed drawings in scale of 1/10, 1/5, 1/2 and 1/1.

2) The architectural, structural and mechanical projects must match in their entirety. Care should be taken to check them against each other to remove any discrepancies before production is started.

3) Steel components and sections selected for the design of the structure should be available in the market or easily manufactured to specification.

4) Companies must conduct training programs for their workers (welders, bolt erectors *etc*.) to ensure a nucleus workforce comprised of qualified and experienced workers. Consequently, both material and time losses and workmanship costs can be decreased significantly.

More research is necessary to examine the problems of steel construction in Turkey since this study is concerning only the basic characteristics of structural steel and steel construction. In addition, similar surveys can be performed on high rise steel structures in Turkey.

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# APPENDIX A

# ARCHITECTURAL DRAWINGS OF TESKOMB BUILDING

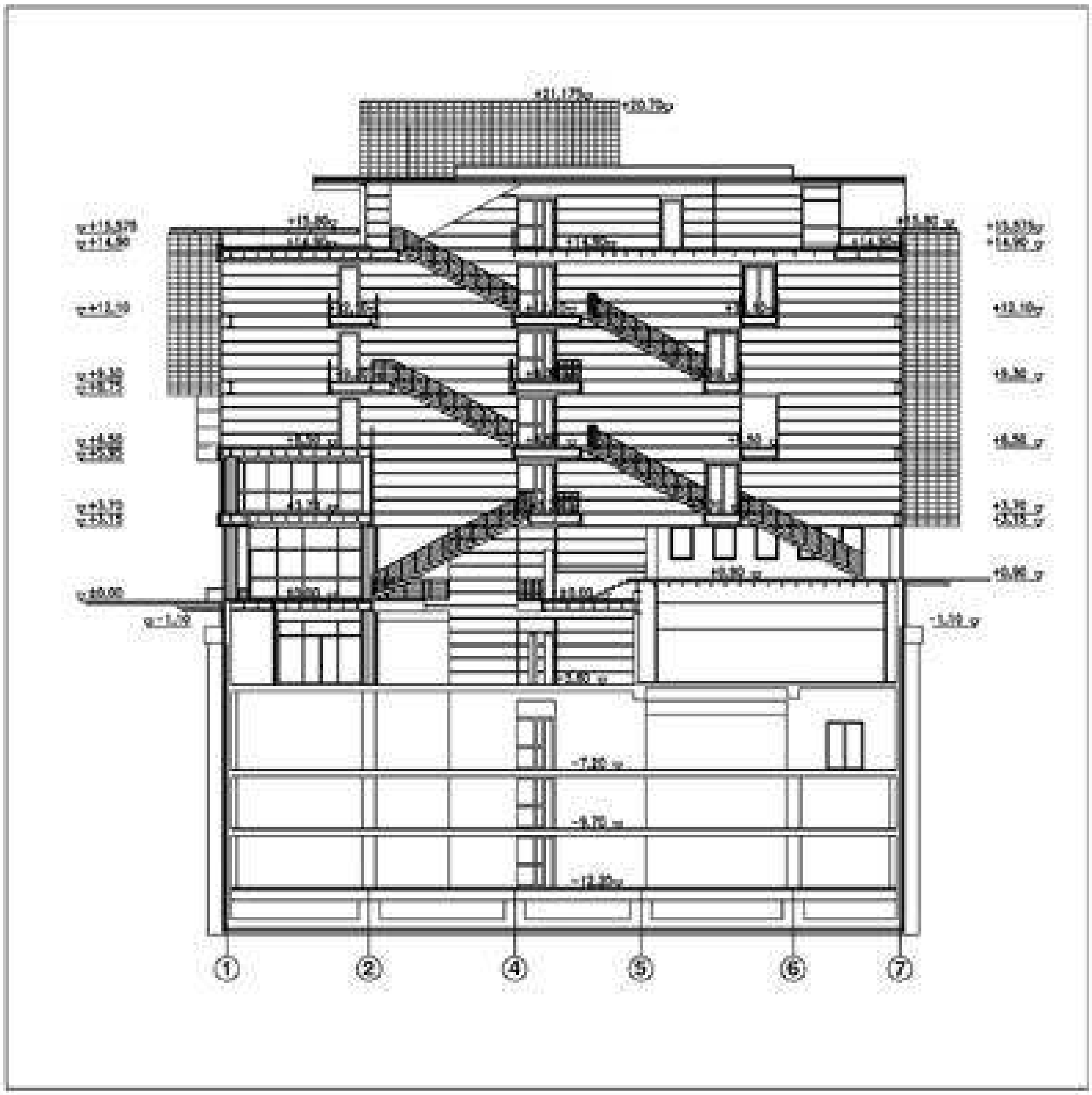


**Figure A.1.** Section AA of TESKOMB Building
(Source: Uz Mimarlık)

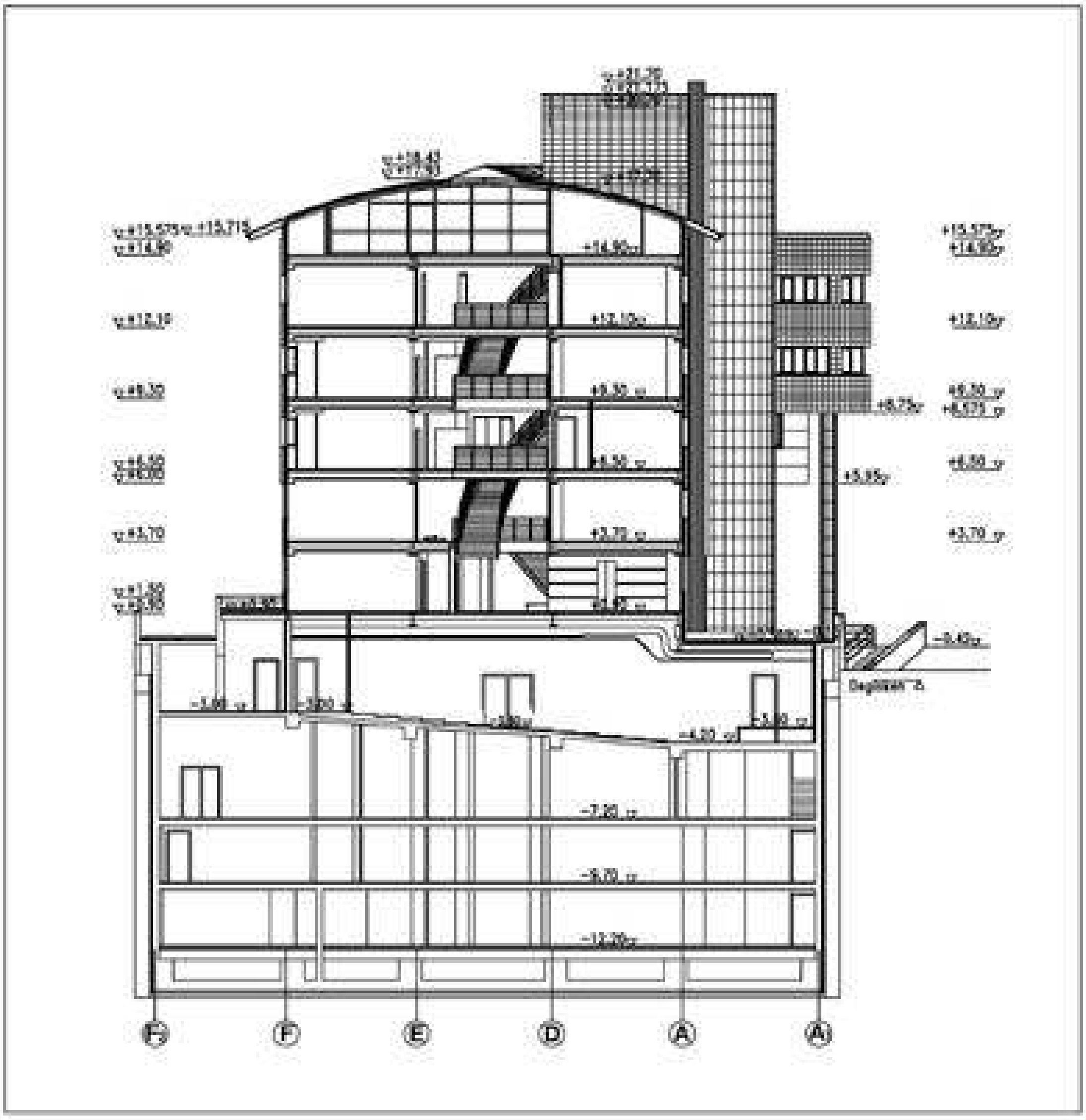


**Figure A.2.** Section BB of TESKOMB Building

(Source: Uz Mimarlık)

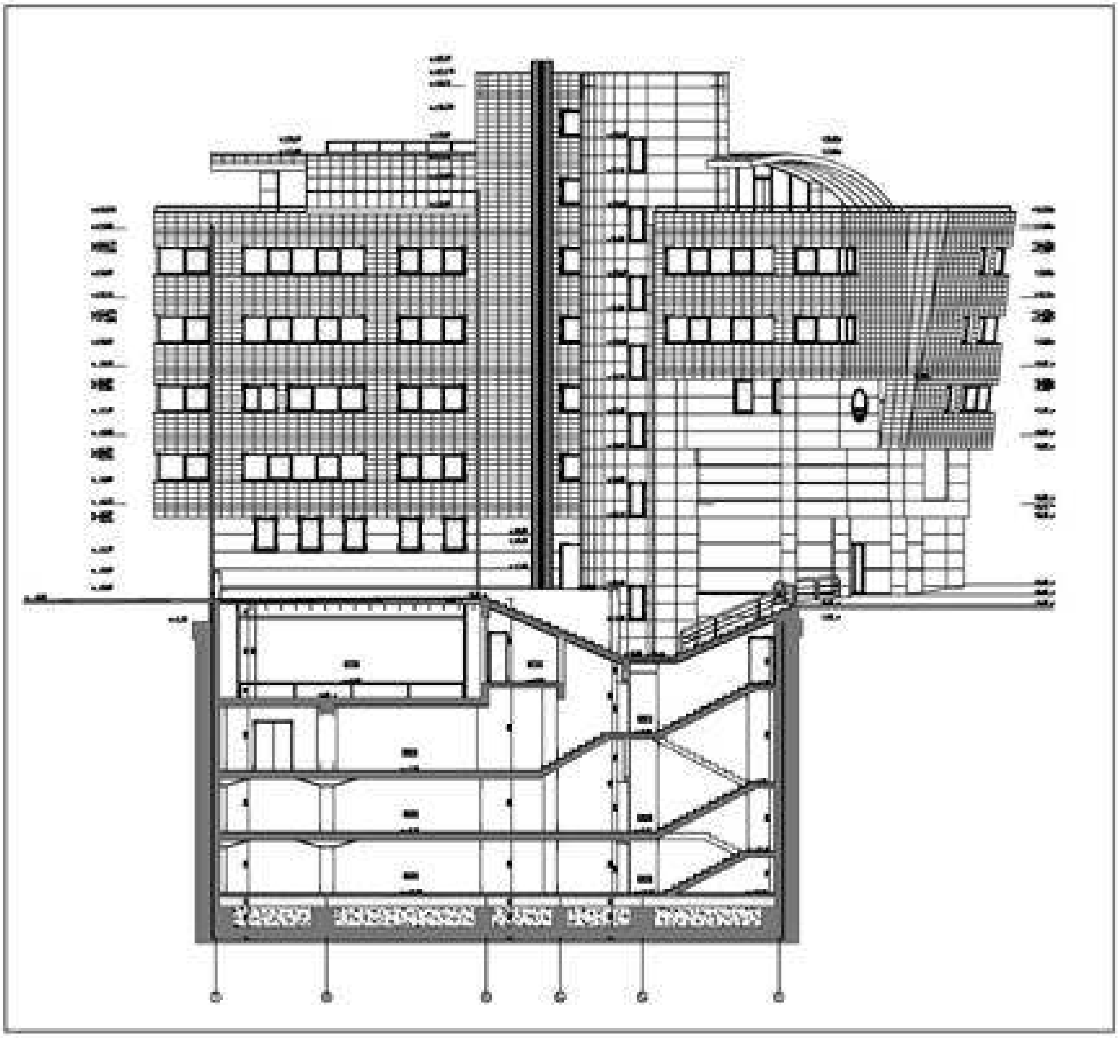

**Figure A.3.** North elevation of TESKOMB Building
(Source: Uz Mimarlık)

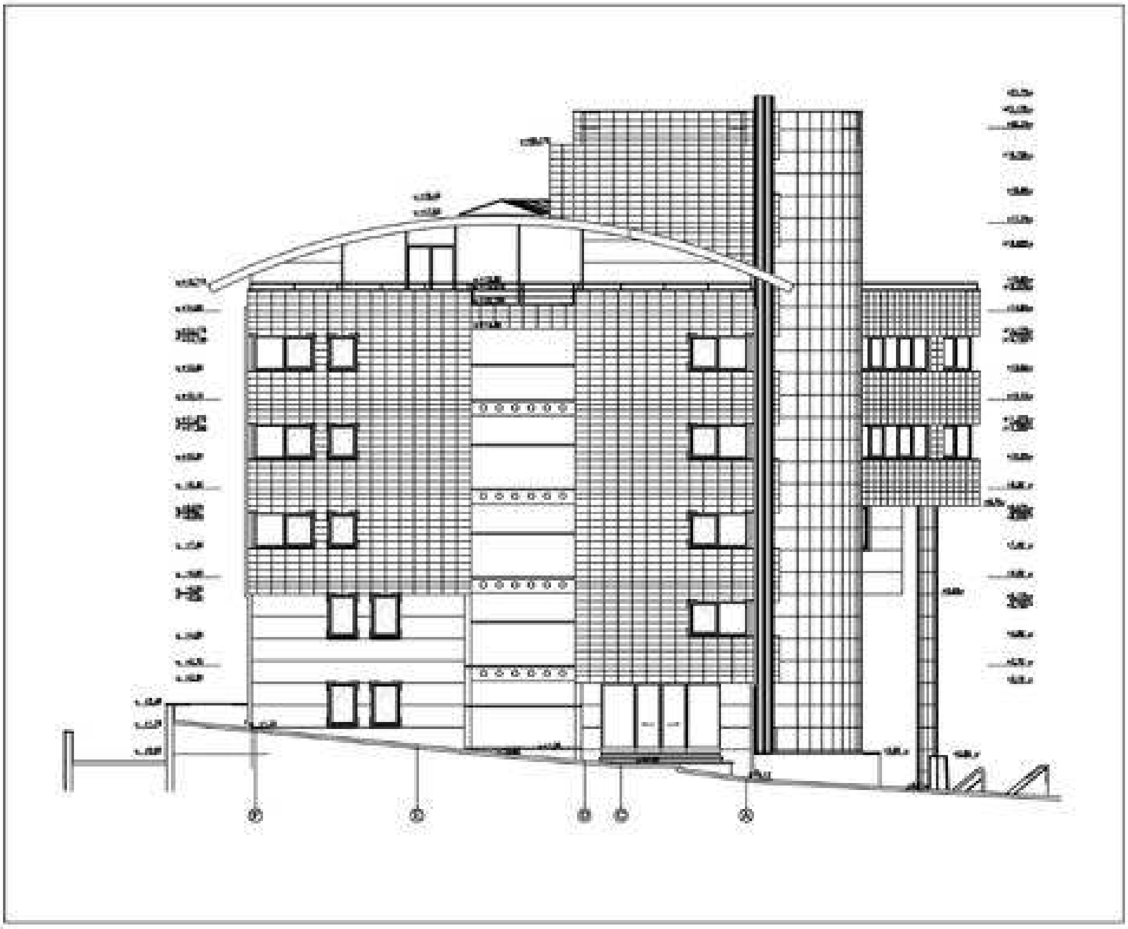

**Figure A.4.** East elevation of TESKOMB Building

(Source: Uz Mimarlık)

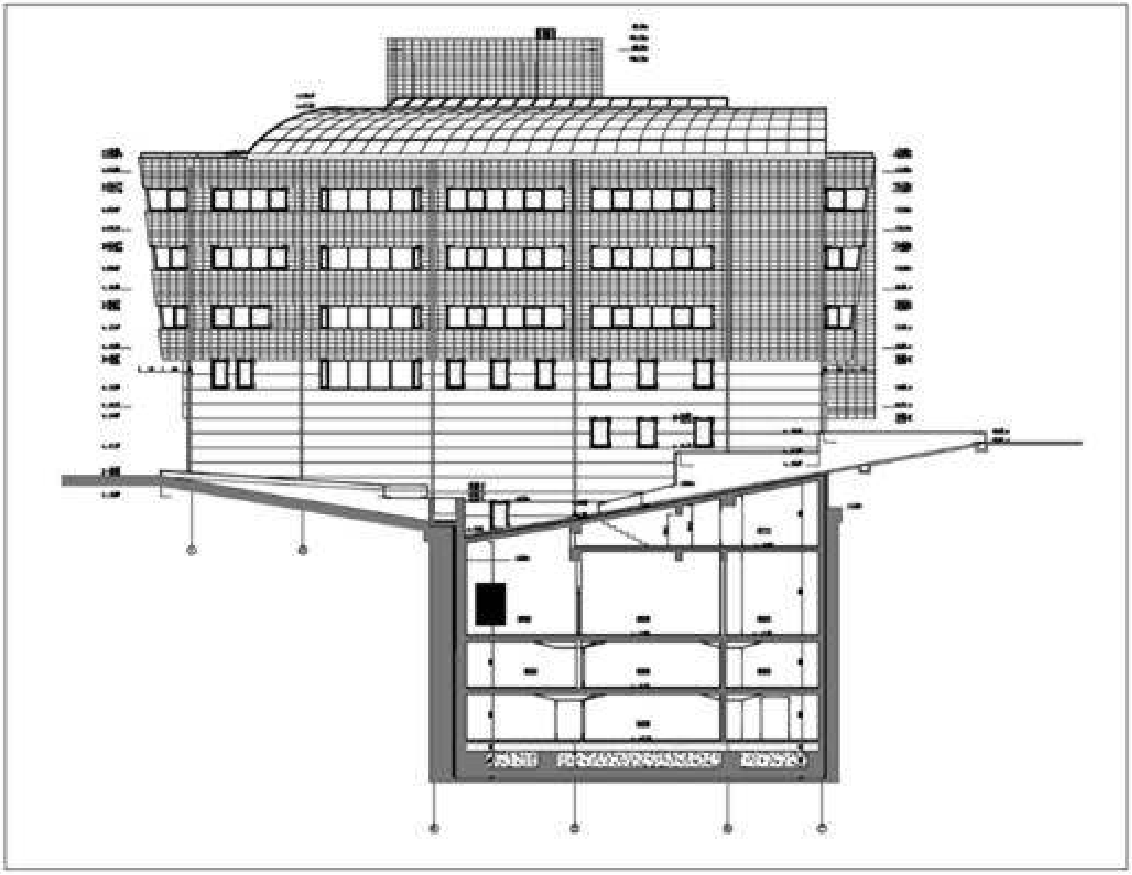

**Figure A.5.** South elevation of TESKOMB Building
(Source: Uz Mimarlık)

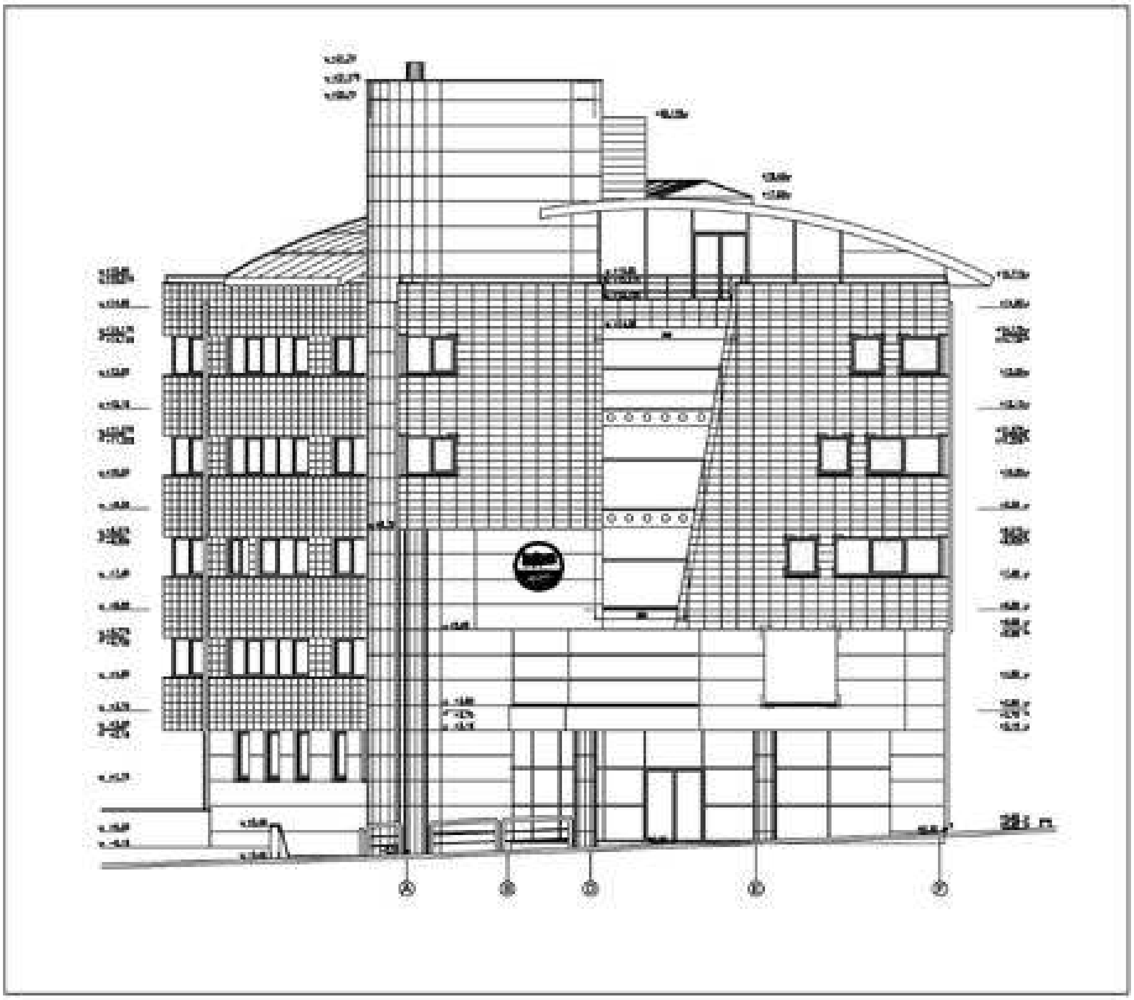

**Figure A.6.** West elevation of TESKOMB Building

(Source: Uz Mimarlık)

## APPENDIX B

## STRUCTURAL DRAWINGS OF TESKOMB BUILDING

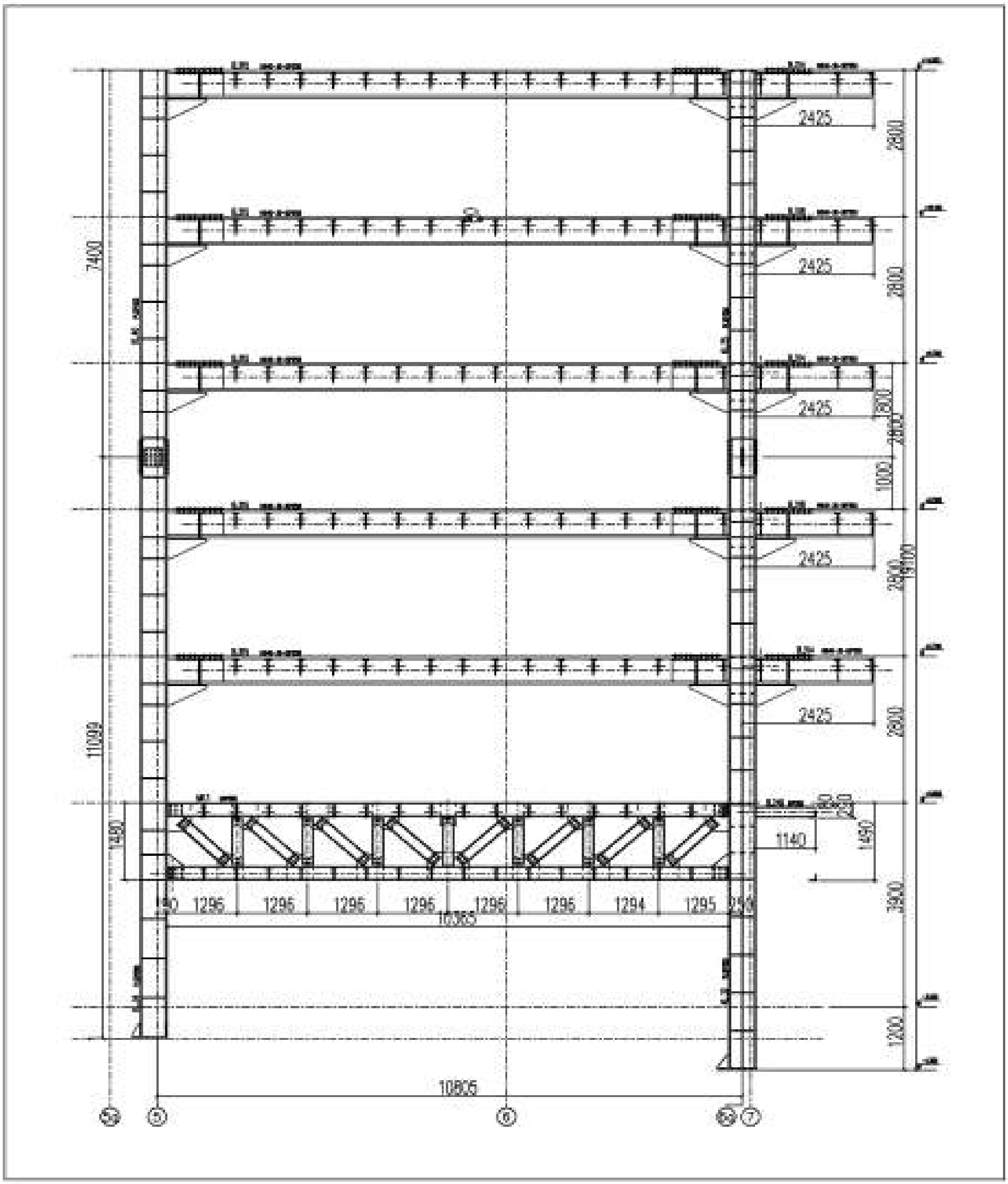


**Figure B.1.** Section CC (Source: Rona Mühendislik)

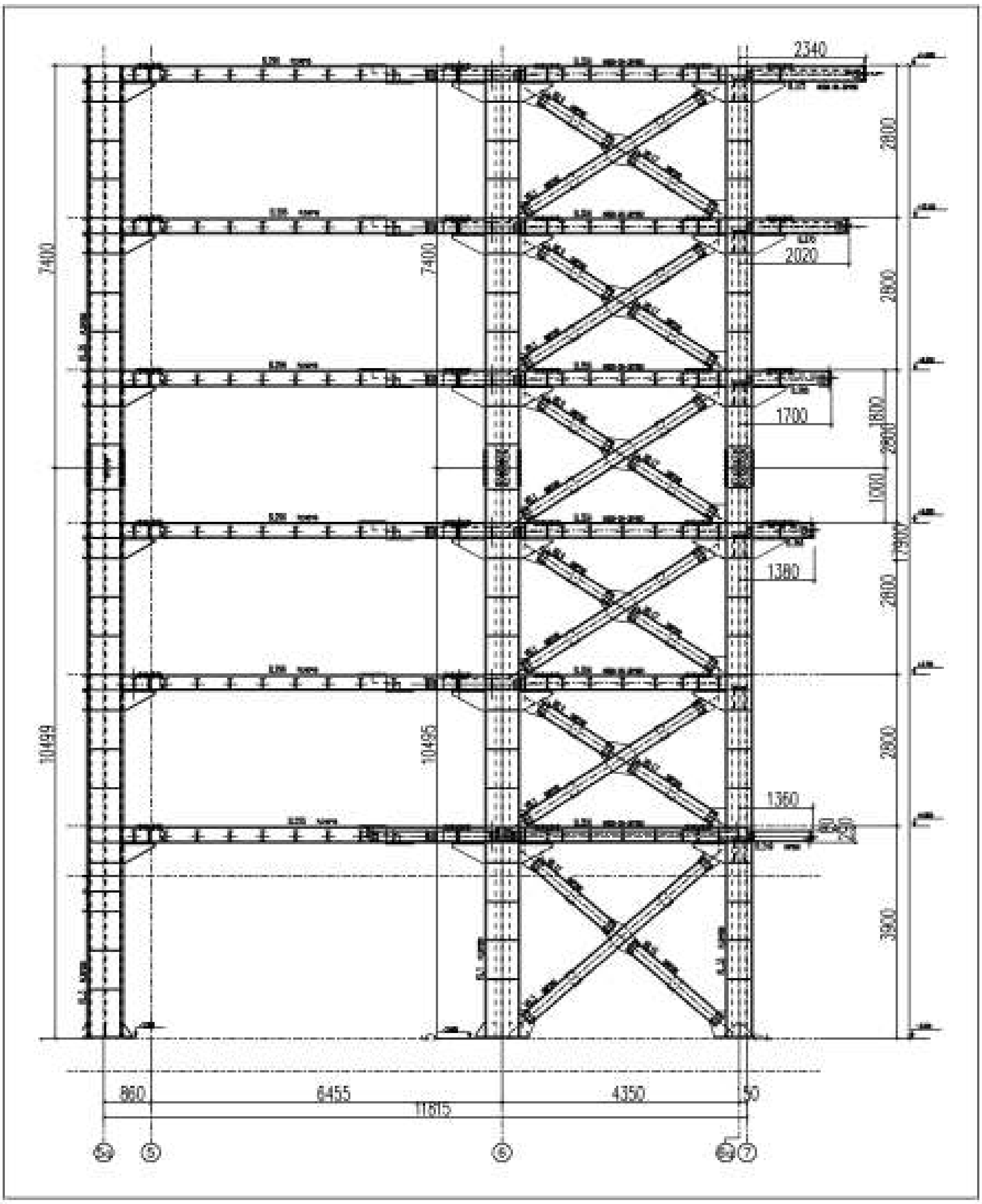


**Figure B.2.** Section GG (Source: Rona Mühendislik)