AN APPRAISAL OF STRUCTURAL GLASS WALL SYSTEMS WITH EMPHASIS ON SPIDER FITTING DETAILS

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ABSTRACT

AN APPRAISAL OF STRUCTURAL GLASS WALL SYSTEMS WITH EMPHASIS ON SPIDER-JOINT FITTING DETAILS

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The technological and innovational developments in steel and glass industries has enabled designers to create completely transparent façades. Building façade articulations designed to attain maximum transparency, have thus been executed with the contribution of elegant steel supporting systems, having heavy load bearing capacities, by minimizing the dimensions of structural systems.

The aim of this study was to define, analyze and evaluate the accumulated knowledge on structural glass wall systems in general, with particular emphasis on those that may be denoted as 'spider' glass fitting elements for potential applications, to formulate a design guide for professional designers. Hence, the primary elements of the system; the support structure, glass, glass connection joints and the other secondary elements have been evaluated within the architectural context.

In the second part of the study, glass connection fitting elements were examined. Additionally the products developed by the manufacturing firms and commonly used in various projects were evaluated. Thereafter, whole document, data, photos of the spider fittings were combined in a spider fitting selection table, prepared and created by the author, which describes the types of spider fittings in detail.

Finally, technical adequacy, experience, level of organization and workmanship within the context of Turkey, to evaluate the level of knowledge, were studied. In this regard, the glass wall façade of the Akman Condomunium Business Center-Medicorium building, constructed with local materials and local manufacturing companies, was examined and compared with the Boeing Headquarters building in USA, which was constructed with a similair glass wall façade system.

Keywords: Transparent Glass Façade, Point Supported Glass Pane, Steel Supporting Structure, Transparency, Spider-Joint Fitting

ÖZ

STRÜKTÜREL CAM CEPHE SİSTEMLERİNİN DEĞERLENDİRİLMESİ VE BAĞLANTI ELEMANLARI DETAYLARININ İNCELENMESİ

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Çelik taşıyıcı ve cam sektöründeki teknolojik ve endüstriyel gelişmeler, saydam cephe giydirme sistemi tasarımlarına yeni bir anlayış getirmiştir. Yüksek dayanımlı çelik gergi ve çelik makas sistemleri, taşıyıcı eleman ebatlarını minimuma indirmiş ve maksimum şeffaflık amacı güden cephe tasarımlarına olanak vermiştir. Bu bağlamda geliştirilen strüktürel cam cephe sistemleri, son yıllarda şekillenen modern mimari üslübun bir parçası olarak, bina cepheleri, bina ortak mekanları ve bina ana sirkülasyon mekanlarına, mimari proje gereği maksimum şeffaflık ve ışık kullanımı gayesi ile sıkca kullanılan bir cephe giydirme sistemi olmuştur.

Bu çalışma, strüktürel cam cephe sistemleri ve bağlantı elemanlarının, potansiyel proje ve uygulama olanakları göz önünde bulundurularak , temel mimari tasarım, strüktürel özellik ve uygulama kriterleri çerçevesinde, tasarımcılara sistemi tanımlayan ve sorgulayan bir kaynak olması amacıyla, analiz edilmesini ve değerlendirilmesini kapsar. Bu kapsamda sistemi oluşturan ana öğeler; taşıyıcı sistemler, cam ve cam bağlantı elamanları ile

sistemi tamamlayan ikincil öğelerin temel mimari ve mühendislik özellIikleri, tasarım prensipleri vurgulanmıştır.

Bir sonraki bölümde, sistemin önemli bir parçası olan, bağlantı elemanları detaylı olarak incelenmiş. Üretici firmalar tarafından kullanılan ve geliştirilen bağlantı elemanları; yük kapasiteleri, şekil ve malzeme kriterleri göz önünde bulundurularak değerlendirilmiş. Elde edilen bu veriler, yazar tarafından biraraya getirilerek örümcek cam bağlantı elemanı, seçim tablosu oluşturulmuştur.

Son olarak, tanımlanan sistemi sınamak ve Türkiye'de strüktürel cam cephe sistemleri ile ilgili bulunulan durumu değerlendirmek için, yerli malzeme ve yerli üretici firmalar tarafından yapılmış olan Akman Kondomunium İş Merkezi, Medicorium Binası'nın strüktürel cam cephe uygulaması detaylı olarak incelenmiş ve benzer sistemle yurt dışında yapılmış olan Boeing Ana Yönetim Binası'nın cephe sistemi karşılaştırılmıştır.

Anahtar kelimeler: Saydam Cam Cephe, Noktasal Destekli Cam Yüzey, Çelik Taşıyıcı Sistem, Saydamlık, Örümcek Bağlantı Elemanı

To My Mother Gülten BÜYÜKKILIÇ, My Father Fahri BÜYÜKKILIÇ,

My Sister Aybige BÜYÜKKILIÇ

and

My Fiance Gülgün ACAR

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CHAPTER 1

INTRODUCTION

In this chapter, in the section 1.1 the framework and the underlying concern of the study is explained, and the scope of the study is discussed. Similar ideas and concepts with respect to architectural perspective are argued. The aim of the study is described at next part. The procedure of the study is presented at section 1.3, and finally, the contents of the study are presented under disposition.

1.1 Argument

Probably no other material enjoys a greater popularity with architects and engineers at present than glass. Its transparency and lightness are properties embodied in the design theories and works of the modern movement. Structure and skin can be considered a building envelope's fundamental technical components. The structure supports it and the skin keeps the weather out. Lighter, more compact, and efficient structures allow the skin to play a larger and more responsible role with regards to light: the critical ingredient in the perception of architecture. The skin can become a filter of light as a transparent, translucent or even a variable chameleon type surface that can change its nature.

Technology has permitted a slow and gradual transformation of building walls from thick walls, with only small holes for light to penetrate through, to thin envelopes which modulate and control light and architectural transparency as well as energy gain and loses. Technological advances in buildings and developments in structural engineering have removed structure from bulky building envelopes. The removal of structural elements has allowed the skin to become more transparent and translucent because it no longer has to hold the building up. The skin lets in more light and allows it to play a larger part in architectural composition. Developments in glass technology have created new possibilities for the skin beyond letting in more light and air.

One of the major trends of contemporary architecture is to link interior space to the exterior with minimum compromise. According to the important technical advances of recent years, glass has come to be regarded as the ideal medium for this concept. Glass is the material which balances light, transparency and appearance with the practical functions of thermal insulation, solar control, safety and security, acoustic insulation, fire protection and so on.

Technological and innovational developments in the glass and steel industries have enabled us to generate different facade treatment opportunities. Structural glass wall systems allow designers to glaze large openings in buildings without the use of metal frame mullions, thus providing the creation of light and space in buildings with a minimum of visual barriers. Conventional curtain walls usually consist of very deep aluminium mullions and backer steel trusses comprised of bulky tubes and angles. Actually slim, stainless steel rods and articulated fittings creating tensile wall systems can support more with less. The system minimizes the structural elements by substituting high strength stainless steel tension rods or cables for larger compression elements. Point supported glazing systems in strengthened glass provide the minimal glass membrane to a clad tension structure.

A structural glass wall system is a kind of light-weight curtain wall system to envelope the facades of a building. Structural glass walls provide floor to ceiling vision areas that can extend up to 20 m in height, creating both stunning visual effect and a highly functional exterior wall. A combination of heavy tempered glass panels, glass fins, metal patch fittings and well-articulated slim structural elements create a barrier to the exterior environment while maximizing visual exposure. A structural glass wall system provides a flush glass surface using countersunk holes, stainless steel fittings to fix the glass facade to the structure instead of the conventional framing systems. The result is a fully engineered system with the minimum of structure and maximum visual clarity.

A structural glass wall system can be coordinated with all types of steel structures, ranging from simple pipe columns to those incorporating complex truss systems. It can be used either vertically, horizontally or in roofs and skylights at any angle.

Structural glass wall systems have reached extensive possibilities through a better understanding of the structural potential of glass itself and the analytical techniques made possible with computers. As Wiggington puts it: ''Our own phobias regarding the fragileness of glass are gradually being replaced by an acceptance of its structural potential.'' This liberation of glass as an architectural component has led to a greater potential in the articulation of wind bracing structures by cable ,steel and glass itself.

The skin and the structure make the façade composition together; all structural elements like trusses rods cables tubes pipes and all sophisticated joint fittings have an architectural role to articulate the façade. In other words , exhibit the structure of the skin. The understanding of the symbiotic relationship between these bracing structures and the glass leads to a change of attitude toward these two traditionally distinct domains glass belonged to cladding and curtain wall trades, while structure belonged to a separate steel trade. The building industry's professional designers and contractors are adopting their working methods to the new potentials of glass and its bracing structure in architecture and a different relationships within the industry.

The structural glass wall system is the only system to have and to design a *completely transparent* three storey or higher glass wall. Because, as in the case of three storey and higher glass facades, every glass pane should be mechanically fixed to the supporting structure for the security of the people in terms of a danger of injuries from a falling glass pane when the façade is subjected to effective lateral loads like the seismic movements or the winds. The other system, to have a large glass wall system is the structural silicone glazing curtain wall system. The conventional structural silicone glazing curtain wall systems are not suitable for designing of three storey or higher glass walls in terms of security conditions. Because the glass panes are bonded to the structural support systems, especially alumunium supports, by the elastomeric glazing sealant. In that system, glass surface should be covered by the reflectively coating material to hide structure and glass connection, that is, bonding details. In some Europen countries like in UK and Germany, the mechanical fixing of a glass pane or mechanical fasteners are a must to design a three storey or higher glass wall facade.

1.2 Objectives

To achieve a better integration between the aesthetic and functional objectives of design, some or all of the behaviour must be understood and handled by the designer. Architects and engineers working in the building industry are in a unique position to achieve this fusion, by custom and by law they control the projects - buildings or construction works - for which they are responsible. They have the skills to understand and to process the information necessary to control the design and the implementation of a given project. Positive cooperation between designers and industry are needed to reach high architectural, structural and constructional standards.

Comprehension of the basic and necessary governing rules of the relation between structure, glass and connection fitting elements in structural glass wall systems has demonstrated the different approaches which could actually be implemented. In this respect, one of the most important purpose of this study was to evaluate accumulated knowledge on structural glass wall systems in general, with particular emphasis on those that may be denoted as ‘spider fittings’ and thus to create a design source for professionals like architects.

Structural glass cladding systems are widely used in Europe and America, however, in Turkey the knowledge of some material properties and reliable construction details of the system is limited. The designer, responsible for the architectural project and construction phase, must have all the relevant data to take the most relevant decisions during the execution of the project. Hence, one of the main aim of this study was to define, analyse and outline the basic architectural, structural and constructional design principles governing structural glass wall systems currently in use and to point out advantages and disadvantages of the system from the architectural perspective within the area of the study. Determination of the basic architectural, structural and constructional concepts and parameters of structural glass wall systems will be a departure point for most economic and aesthetic results for possible applications in Turkey.

Another aim of this study was to point out structure -skin and form –function relations within the architectural, constructional and structural perspectives. Moreover, the applicability, construct-ability, technical adequacy and architectonic quality of structural glass wall systems were also studied in the study.

The other objective of this study was, to evaluate and classify springplate spider fittings and connection joints of the system and also to introduce different , feasible joint fitting solutions prepared and created by manufacturing companies in professional working environment. Accordingly that, the main properties, forms, dimensions, articulations, durability, material and aesthetic aspects of the spider fitting elements were researched.

1.3 Procedure

In the first phase of the study, the literature survey was based on an overview of the theses and publications found in the Council of Higher Education (YÖK) library and Bilkent and Middle East Technical University libraries. Use of Internet and the opportunity to contact interested people involved in structural glass wall systems applications was very useful. During the study, web sites related to subject were visited. The catalogues, booklets, technical drawings and related photos of structural glass wall systems were gathered from different companies working at that sector. The executed masterpiece projects in other countries were analyzed and meetings were done with the contractor firms of that projects to get detailed information. Interviews were conducted with architects and engineers to get detailed information about the structural glass wall systems within different approaches.

In the third phase, the study was formatted to describe spider fitting systems and mainly to classify the types of spider fittings. In this regard, information was obtained from manufacturing companies and existing structural glass wall projects. Some of documents downloaded from web sites but the main part of documents posted by manufacturing companies. After gathering all documents related with the subject as raw data, whole documents are investigated to explore the differences and similarities between spider fittings produced and executed at projects. Thereafter, whole document, data, photos of the spider fittings were combined in a spider fitting selection table.

At the second phase of third chapter, the Akman Condominium Business Center-Medicorium Building was chosen as subject. The glass wall of west façade of the building was studied. The survey was formatted to describe the individual properties of the structural glass wall system used at the façade of the building. The structural system, type of glass and glass fittings executed at that project were examined. The application details were studied. The interview was executed with the occupants of the building to get their negative and positive thoughts about the building.

Finally, comparison study was done between Akman Condominium Business Center, Medicorium Building and the Boeing Headquarters building, which was chosen because of sharing the same structural glass wall system. Information describing the structural glass wall project of Boeing Headquarters building was given These two buildings were compared according to their application details, structural support, glass types and glass fitting types.

1.4 Disposition

Including this introduction, the study consists of five chapters. In Chapter 2, a literature survey was presented regarding the fundamental elements of structural glass wall systems, their support structures, types of glass used for the skin and joint fitting elements. Historical developments and initial ideas about the structural glass wall systems were discussed. Description of structure supporting the glass surface and main principles about structural behaviour were mentioned. Structural properties, parameters and limitations were analyzed. Hierarchy of the structure and the loads taken by structure were explained. Technological developments in glass industry is studied. Design considerations of glass walls were explained. Moreover, executed applied pioneer examples will be presented. Finally the main components of glass to structure connection joint elements such as spiders and other glass fitting elements are argued.

In chapter 3 the survey material and survey methodology were described. At following chapter, results and discussions of materials were presented. Firstly, the general characteristics of spider fittings were analyzed. At next part, the case study was made. The façade of the Medicorium building was studied. At final part of this chapter, comparison study was done between Akman Condominium Business Center, Medicorium Building and the Boeing Headquarters building. Finally, Chapter 5 covers the conclusions of this research and proposes questions for further research in this field.

CHAPTER 2

LITERATURE SURVEY

This chapter presents a literature survey on the main components and general design considerations of structural glass wall systems. Basically this chapter analyzed under four main topics: structural support, glass envelope, connection joint fittings and pioneering examples of structural glass wall systems. First, the structural glass wall systems are described and then three key concepts: process, predictability, hierarchy are explained. Then, structural support system is analyzed. The importance of structural hierarchy between the main structure and its components is discussed. The structural loads: live and dead loads are discussed. Secondly, general properties and different types of glass used at the structural glass wall systems are presented. Transparency and brittleness property of glass concepts are expressed. Current glass support systems are shown. Then, technological developments and innovations in glass sector are argued. The basic considerations of glass wall design are put forward. Then, the connection elements of the system: bolts and spider fittings are described. At final part, pioneering examples of the structural system is presented.

2.1 Supporting Structure

According to Dorris (1993), architects are beginning to take advantage of slim, stainless steel rods and fittings to create tensile wall systems that can support more with less. Such technology was first considered by Buckminster Fuller in the late 1940s and has been applied to many structures in Europe, especially In Britain and in France, over the past decade. One of the most significant glass-clad tension-supported buildings is the 1985 Museum of Science and Technology at La Villette in Paris, designed by Rice Francis Richie.

Richards, (1998) says that, the quest for the structural glass wall systems (SGWS), in which the glass cladding is freed of the primary structure and ultimately the secondary framing structure, has continued. The evolution of SGWS contributed substantially to the realization that sheet glass could be exploited more fully, and the subsequent development of laminating processes permitted glass to be a more efficient structural material, since the polyvinyl butyral (PVB) interlayer accounts for the additional performance that was previously provided by the steel structure.

Richards (1998) also claims that, Since 1977, the US designer James Carpenter has made major innovations in testing glass as a structural material in architectural applications as a means of reducing the supporting structure to a minimum. Interesting schemes in the 1990s include projects by Richard Meier in New York and SOM in Los Angeles in conjunction with Ove Arup & Partners' New York office. The Los Angeles Grand Palace Tower project exploits a "glass rod wall" construction, which is conceived as a public screen. It uses a vertical tensile truss system that explores the compressive strength of glass, with glass rods as the principal compression members. The exterior plane of the building continues to utilize the SGWS to bear dichromic glass, which plays with specific colours of the spectrum - to Carpenter's specification - as an art installation.

According to Rice and Dutton (1995), three concepts - process, pre-dictability and hierarchy - are the key conceptual bases for the SGSW. It is important to understand the design process used in the SGWS to analyze how it works. This requires a clear understanding of the structure’s behaviour and its architectural objectives, plus a knowledge of the possibilities made available by industry. SGWS is the result of long research into the behaviour of glass, as well as the fixings, the cables and the structures that support it. The results of each design stage were compared with the aesthetic and architectural objectives. This type of design process is somewhat analogous to that for industrial products. The fact that the design process is a combination of research, information, current practice, experience and application of aesthetic objectives is typical of our time and of the nature of modern industry. The aesthetic objective is reduced to a superficial veneer on a product primarily designed to fulfil its function correctly.

Rice and Dutton (1995), continue that, to achieve a better integration between the aesthetic and functional objectives, some or all of the behaviour must be understood and handled by the designer. Architects and engineers working in the building industry are in a unique position to achieve this fusion: by custom and by law they control the projects - buildings or construction works - for which they are responsible. They have the skills to understand and to process the information necessary to control the design and the implementation of a given project. But when it comes to its execution, the initiative belongs to the manufacturers and contractors. This does not imply that industrial products are bad - they may be functional and even aesthetic. However, the objectives of industry are different from those of the designer and are often too conventional and limiting. Great designers of the past, like Jean Prouve and Pier Luigi Nervi, joined with industry and created within that very context. There is no doubt that industrial concerns are willing to commit themselves and are able to be cooperative. They are often keen to encourage adventure and experiment, but right from the start, they must be convinced of the feasibility of the project. Their scepticism can be explained by the fact that they, too, will be responsible for everything that will be built. The design team should have a great deal in understanding the technical requirements of the manufacturing process in relation to the required shape of the part of SGWS. The comprehension of the methods made evident which shapes could actually be produced. All this information has greatly influenced the design.

Rice and Dutton (1995), further state that, to understand fully the concept on which SGWS is conceived, it is necessary to understand the physical and structural characteristics of glass. A very simple logic links the solutions finally adopted to the physical properties of the glass. Nothing in the solution is arbitrary. Each joint, each bearing, reflects the way in which glass behaves. And, therefore, apart from emphasizing the idea of transparency and creating an immaterial space, the guiding principle of the SGWS is 'predictability'. Each part, each detail of the structure has been chosen so that its behaviour under load can be predicted exactly. The design tries to indicate, as far as possible, how the loads are transferred into the various parts of the structure, to isolate the functions particular to each element and to allow the behaviour of each assembly to be understood. This approach facilitates the 'predictability' - so important with a material as fragile as glass - of the performance that can be expected from the system. Should a glazed unit break, it is then easy to calculate analytically the loads thus created. The principle of predictability can be applied to any glazed surface design; it entails removing all uncertainty about the behaviour of the design by eliminating those elements whose structural behaviour might be ambiguous or unclear.

This principle is particularly relevant to the structure of the SGSW: glass is a material that carries load in a simple linear fashion up to the threshold at which fracture occurs, after which there is failure of an almost explosive nature. The more common building materials such as steel, timber and concrete show some resistance to crack growth. Small fissures or flaws can occur within the material without causing failure because their structure is resistant to crack propagation. But glass does not have these properties. In design terms, this means that one has to be sure of the loads and stresses to which the glass is being subjected. Because of their ductile behaviour, common building materials are very tolerant to high local stresses and discontinuities in their support; this means that steel assemblies can be rigidly bolted since some plastic flow in the material will relieve any high stresses that may occur. None of this is true of glass, where any stress or distortion that exceeds the linear strength will cause brittle failure. In traditional glass construction, this problem has been resolved by adding a flexible and absorbing substance, such as a rubber seal or pad, between the glass and its support. The approach adopted in the SGWS design was different. The support system was conceived so that there was always a clear analysable load path. The stresses in the glass have been very precisely predicted under all load conditions. The design of the spherical bearing assemblies at the glass support points and of the compressed spring support system are two examples of the application of these principles. The requirements for predictable behaviour under load were used in a positive way to express the inherent physical characteristics of the glass and to enhance the transparency and lightness of the whole.

Rice and Dutton (1995) also, emphasize that, a third concept employed in the design of the SGWS is that of 'hierarchy'. In a structure the notion of hierarchy indicates that all the elements that constitute the structure lie in a naturally correct relationship with one another. This means that each part, each section, can be immediately identified as being an integral part of the logical reasoning behind the whole building. This means that all details of the various elements must be designed and drawn in order to ensure that the elements under load will always be the same in relation to each decision taken with respect to each detail.

Rice and Dutton (1995) claim that, the key consideration of structural glass wall system is that of the structure. It connects all parts together and therefore controls the form. The second consideration is that of tension: tension in the structure, tension in the glass, all implying a way of bearing the loads that can clearly expresses the cohesion between the parts and the whole. The design flow entirely from these two considerations. These are the rules that are the basis of the structural hierarchy of the SGWS. The structural composition follows the hierarchical sequence. Another aspect of this quest for hierarchy concerns differences of scale. Some elements of the whole carry heavy loads over a long span. Others carry small well-defined segments. They must not be confused. Both exist and must be understood according to their functions, while being perceived as part of the same logic of expression. The recent mathematical studies of fractals show that this phenomenon may contain a fundamental key to the natural environment and to natural structures. The decreasing sequence of the elements of a structure forms an entirely carefully put together and in which the smallest and the largest elements are directly linked. The rigorous exclusion of any superfluous or inadequate element or material is an important stage in the search for a hierarchy that has been correctly achieved. Natural structures posses this same property. Each part of an oak grows according to the same hierarchical logic as the rest of the tree. It ‘s only the scale of the phenomenon that varies. The same rules apply both on a macroscale and on a microscale. These rules must be deduced in order to understand how the hierarchy and the cohesion of the structure work.

Dorris (1993) states that, tensile systems reduce the size of structural members by replacing the lateral load-resistings structure of a curtain wall with an intricate network of rods. Conventional curtain walls usually consist of aluminium mullions up to 18 inches deep and backer steel trusses comprised of bulky tubes and angles. While both tension and compressive forces are resisted by a single member in conventional structures, tension members are designed only to resist tensile loading from a specific direction and are useless if thrown into compression. Wind forces on an exterior glazed wall, usually compensated for by a structural member located perpendicular to the wall, can be withstood by a pair of tension rods separated by compressive struts, one resisting inward forces and the other resisting outward forces. Tensile structures are usually built from rods, rather than cables, because rods are stronger and small in diameter. These rods consist of steel with a breaking strength of 200,000 pounds per square inch, about four times the strength of ordinary steel.

Dorris (1993) also writes that, tensile technology has also been advanced by the development of the computer tools needed to calculate the dynamic behaviour of tensile structures, enabling engineers to correctly size the members. Non-linear systems are especially challenging to design, because the tension elements are left slack and are tensioned only as needed to resist building movement. Tensile structural systems have-also grown more sophisticated with the advent of computerized numerical-controlled manufacturing, which facilitates the production of a range of fittings with slight but essential variations, such as those required to create curved, glass-clad walls. To achieve near total transparency, glass can be attached to the tensile system without mullions. In other applications, the glass is held in standard mullions or narrow channels that are fastened to structural members. Alternately, the glazing can be adhered to the tensile rods with structural silicone. The high degree of customization required of many glazed tension structures has meant a high price, but projects such as the Medical Center Library at Vanderbilt University, with its hybrid tensile system, and Pilkington and TriPyramid's standardized, systems promise to break down cost barriers. Such developments will enable more architects to experiment with the lightness, delicacy, and transparency inherent in tensile cladding systems.

2.1.1 Structural Loads

Rice and Dutton (1995) emphasize that, in the design of a building, one starts by evaluating all the loads that it will have to bear; then one continues to the analyses and calculations. Four categories of load have been taken into account for the structure of the SGWS; its own weight, environmental loads (wind and snow), forces engendered by temperature variations and the weight of the maintenance equipment (this last is not substantial and did not constitute an important criterion in the design of the structure). The vertical loads are composed of the weight of the glass itself and that of the structure - the larger of the two obviously being that of the glass. The weight of the structure itself cannot be established until after the structure has been defined. A preliminary estimate is made, based on the form this structure takes from previous experience; then one can proceed to initial sizing. The loads are then checked and used in all subsequent calculations.

Rice and Dutton (1995) also claim that, the weight of the glass presents a more complex problem. Once the thickness of the glass has been chosen, its actual weight will be known; and once the glass support system has been defined, the bending forces induced in the structure by the offset position of the glass with respect to it can be calculated. Taking the breakage of glass into account poses a problem. Following the loss through breakage of a glass sheet, the total weight of the glass is of course less. However, at the same time the loads are redistributed, which could have detrimental consequences for the structure. Moreover, the breakage of a sheet results in a significant temporary overload, since the shock wave is cushioned by distortion and energy absorption in the structure. Because of the difficulty of predicting the effects of such shocks, prestressed shock-absorbing springs should be introduced at the glass suspension points. Consequently, the maximum load that the structure has to be able to carry is limited.

Moreover, Rice and Dutton (1995) also continue that, forces arising from the wind and from snow are the external environmental loads applied to the structure. This data remains pertinent in defining the performance of the structure and determining the required level of pre-stress. Apart from the statistical analysis of wind loads, the appreciation of the different wind-loads diagrams represents one of the most difficult problems in the design of the structure. There is little chance of arriving at a symmetrical load distribution on such a large surface and in an urban environment, where numerous obstacles lying in the path of the wind can create turbulence. Significant positive and negative pressures can occur near the corners of the building. It is advisable also to take into account forces parallel to the building and combine them with forces perpendicular to the building, so the wind can be trapped between two facades and exert a lateral force on each of them, while inward or outward pressures are applied to the whole of the building. The calculation of the wind loads requires an important interactive analysis. What is needed is to select the wind forces that are liable to produce the largest forces on individual structural members. This necessitates a preliminary study of the structure in order to become familiar with its behaviour under different load conditions; when this information has been obtained the load patterns most likely to be critical are selected.

Rice and Dutton (1995) also explain that, the snow load only affects the roofing and the north facade. The actual distribution of the loads is not particularly significant: the maximum overall load will always result in maximum forces in the structure. Thus, drifting of the snow on the roof is not a problem. However, an accumulation of snow against the glass wall can create forces in the north face; this constitutes a case of a particular pattern that must be considered in the calculations.

Therefore, Rice and Dutton (1995) also say that, the main temperature-induced stresses are due to differential heating of the structure in relation to the main building which supports it. Each horizontal wind-braced element of the structure is linked at its ends to the main supports. It is assumed that the distance between these elements does not change because each support is separately anchored to the ground. The structure can heat up in summer as a result of solar gain and be cool in winter; this will induce stresses in the structure and a diminution in tension in the prestressed elements. These stresses arising from changes in temperature must be considered where they are likely to result in major alterations in the forces in the system. Furthermore, this means that the facade can grow or shrink vertically at the attachment points to the supports; thus, hinged connections were required. There are four types of load that must be considered in order to analyse how SGWS works structurally, as explained before. These loads entail certain modifications to the constraints; it is therefore reasonable to establish a series of hypotheses relating to the tolerances to which the structure has been erected and prestressed and to analyse the resulting implications. The vertical loads transmitted by the horizontal elements create a moment on the vertical members of the structure; primarily due to the weight of the glass, this moment is located outside the plane of the structure, which creates torsion and flexion of the members in it. The vertical columns transfer these loads onto the brackets at the base of the structure. An important feature of these vertical loads lies in the fact that once the structure is completed, they change very little. No distortion is therefore transmitted in the plane of the glazing. This glazed plane is flexible as long as the joints remain unsealed; but once the joints are made, the silicone resists deformation so that the whole of a panel behaves as a rigid sheet.

According to Rice and Dutton (1995), the horizontal loads can occur in different patterns, and resistance to them is provided at each main level by the U-shaped horizontal frames and by the pre-stressed tie-rod system that works with them. Thus the wind-bracing system comprises three parts (Figure 2.1): the U-shaped frame (a), the prestressed tie rods acting against the inward loads (b), and the prestressed tie-rod system taking the outward loads (c); (b) and (c) are prestressed against each other. They work together until the tension lost in the system causes a member to go into

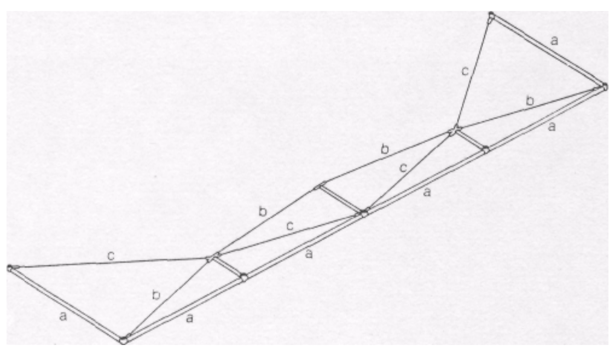

Figure 2.1. A horizontal structure diagram showing wind bracing components.
Source: Rice and Dutton,1995

compression. For example as shown in Figure 2.2, for a load coming from the outside, i.e. a positive wind pressure, (b) offers resistance through a growing tension and (c) through a decreasing tension until it reaches zero; the tie rod (b) is then left to offer resistance on its own. As with the cable truss, the prestressing serves to rigidity the system in the lower load ranges - statistically the most likely. Prestressing the tie rod (b) results in compression in the front horizontal member of the facade, compression which grows with the increase in tension in (b).

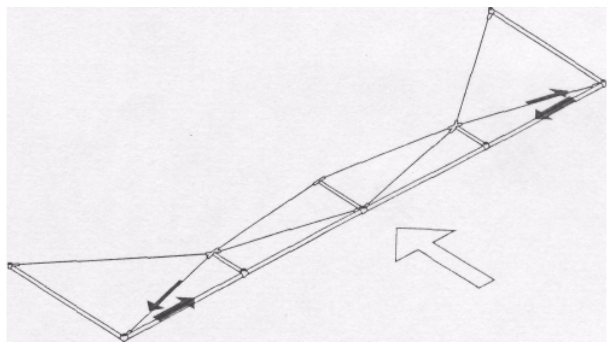

Figure 2.2. The wind bracing's principle of action.
Source: Rice and Dutton,1995

Rice and Dutton (1995) emphasize that, this system makes full use of modern computer techniques. The structure and bar-bracing system changes its topology (structural form) according to the load conditions. Modern structural analysis allows for changes in the form of a structural system in the course of the calculation. This implies exclusive use of tension members (because they must 'disappear' from the structure when they go into compression). In this topologically free structure two special cases can arise. The first arises when a large inward pressure is accompanied by lateral pressure. Because of the inward pressures shown in Figure 2.3, tie rod (b) can 'lose' its tension; but it still remains indispensable in resisting lateral loads. To bring this member into play once more, a lateral displacement of the structure occurs. Predicting this type of behaviour

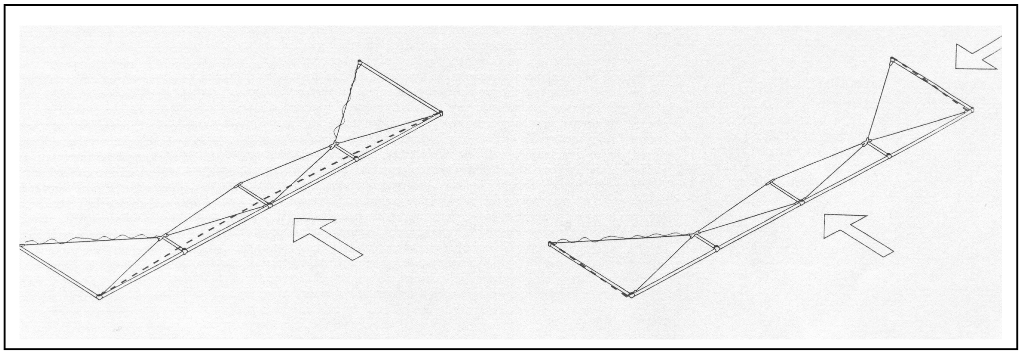

Figure 2.3. An inward pressure and lateral measure.
Source: Rice and Dutton,1995

would have been difficult using classical analytical techniques. Such techniques assume in effect that all deformations are small in magnitude with respect to the geometry of the whole system and are consequently negligible, and, further, that all elements contributing to the structural integrity remain active under all load conditions.

Rice and Dutton (1995) also claim that, the second special case also occurs when major inward loads induce large tensions in tie rods (b) and make tie rods (c) go slack as shown in Figure 2.4. This involves a large compression in the horizontal tubular members (a) of the structure. This means that the front horizontal member could buckle if it were poorly restrained at the nodes. Buckling is a phenomenon that occurs in compression members: the axial force gives rise to extra internal loads, which at some level of axial force overcome the stiffness of the member. The degree of restraint at the intermediate nodes is fundamental in determining the force at which buckling will occur. To examine this problem, the front member was loaded to failure and this load was compared with that which a classical calculation of buckling would predict: the two values were very close. The stiffness of the jointing required to satisfy the predictions of classical theory was in fact higher than was found to be necessary in reality. Temperature changes can

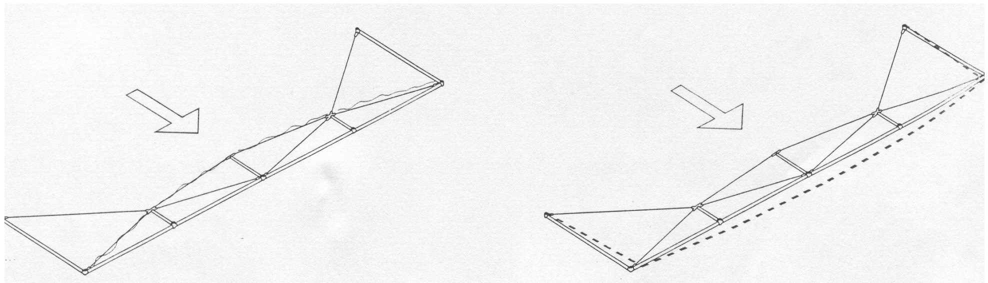

Figure 2.4 : An inward pressure.
Source: Rice and Dutton,1995

modify the actual prestress in the members compared with the intended levels. All the calculations were made with different hypotheses of prestressing, while taking into account temperature differentials between the facade and the building and allowing for margins of error resulting from constructional inaccuracy. These hypotheses do not affect the general strength of the building, but mainly apply to the rigidity of the structure, which we already know is not a critical effect.

Rice and Dutton (1995) describe that, the structural functions of each element can be defined in terms of the structural hierarchy of the system, of which the main frame structure is the primary element. The wind-bracing systems, the attachments to the building, the glazed assemblies and the bracing trusses are all linked to the primary structure by castings welded to the members or by lugs forming part of the main structural frame cast nodes. All the secondary elements of the structure are stretched and articulated; their function is to reinforce the primary structure. In visual terms they are lighter than the elements of the structure to which they are fixed. Their attachment to these is achieved by what might be termed 'sculpted' castings in such a way as to transfer loads into the structure while avoiding excessive local reinforcement. These secondary components have to adopt specific forms in order to satisfy the load transfer requirements. The fact that these elements are castings, accentuates the jointed nature of the assemblies and forms a contrast with the essential character, giving the impression that the structure is unbroken and continuous. Certain elements lower down the hierarchy are also attached to the structure by special castings: the V-brackets, the spring connections, the perimeter glass suspension points and the maintenance rail. The visual and functional separation between the elements constitutes an important conceptual characteristic in the legibility of the structure. As far as possible, the project tries to show the way in which the loads are transferred into the different parts of the structure and to separate the individual functions of each element to make the way in which each assembly works understandable. This contributes to making the predictability of the performance of the system easier - a critical point when dealing with a material as fragile as glass. The articulations and spherical bearings incorporated in the links between the elements guarantee achievement of this objective of understanding the structural behaviour.

2.1.2 Structural Systems

There are two types of structural support system commonly used at the structural glass wall projects; steel structures and glass fin systems.

- **Steel Structures**

Various forms of steel structures can be used to support a glass wall. These alternatives are described as follows:

<u>Hybrid-Supported Structures</u>

Kallioniemi (1999) claims that, in hybrid-supported structures either a horizontal beam or a vertical column is replaced by a stainless steel cable or rod. The most common way in facades is to replace the vertical column by cables as shown in Figure 2.5. Then the vertical cables take the dead load of glass panes and the wind load. In higher glass facades it is necessary to construct a horizontal truss (or many) to take the wind load. Otherwise deflection of facades will be too big. The main difference between hybrid-supported structures and cable supported mechanism is that in cable supported mechanism glass panes carry their own dead load. These are called suspended glass facades. There are several ways of designing the cables as shown in Figure 2.6, the most common forms are shown. Model D has the biggest stiffness. It is the optimal form, if both upper and lower supports are equally stiff. Often the upper support is not equally stiff, then the bigger the distance of two ends the more difficult it is to pre-stress both cables to the same stress level. Therefore a mixture of models C and D (down cables like in D and up like in C) would be optimal. It was a compromise between designer and architect.

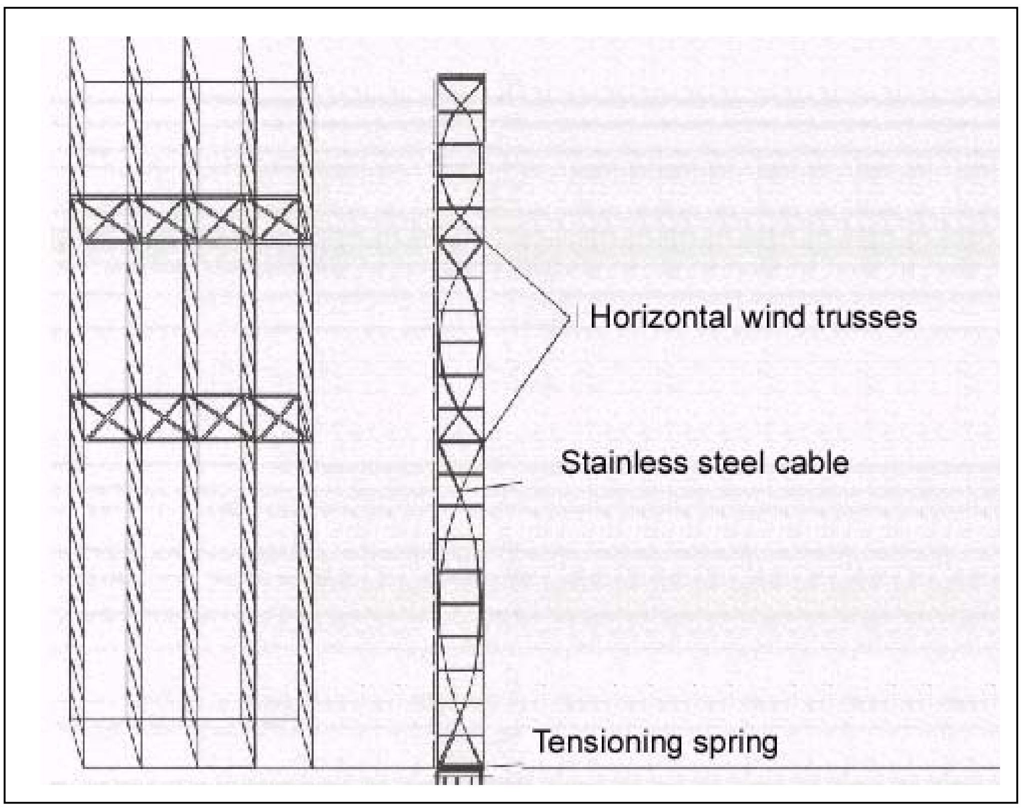

Figure 2.5. Sketch drawing of hybrid-supported glass façade.
Source: Kallioniemi ,1999

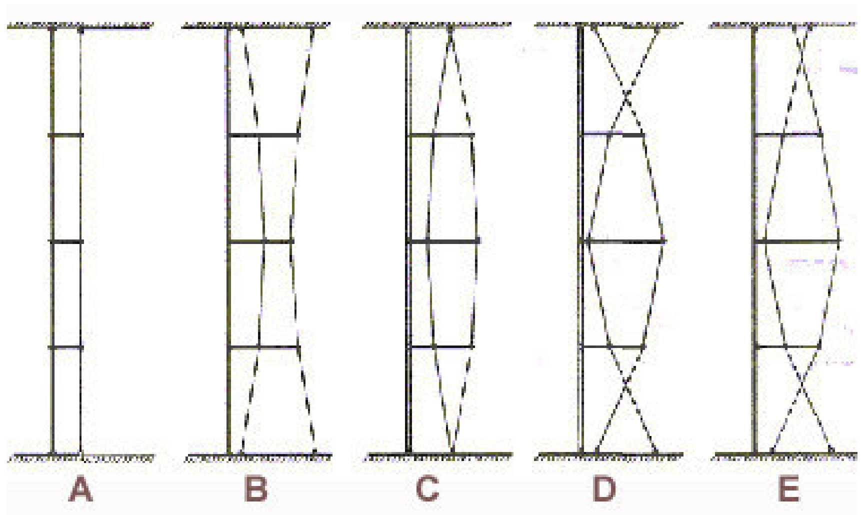

Figure 2.6. Various cable installation forms.
Source: Kallioniemi,1999

The problem with E and the mixture of models C and D is the asymmetrical form of cables. The asymmetrical form creates an asymmetrical S-form deflection due to the wind load. For a hybrid-supported structure system to work, the cables and rods have to remain in tension under all loading conditions. Consequently, one of the key structural design problems that has to be overcome for these walls is thermal expansion. Thermal expansion causes detension in the cable system and ultimately the system becomes unstable. To prevent detension and unstable systems the cables are pre-tensioned. Nevertheless, there is a certain height of the wall for any design temperature range above which it becomes impossible to put sufficient initial pre-tension into the cables to overcome the effects of thermal expansion. The solution used in higher walls is to use springs for each vertical truss to pre-tension the cables and rods. The variation in the tension over design temperature range is greatly reduced and all the elements of the structural system always remain in tension. The height, when springs have to be used, depends on a diameter and material of cable and the place of cables (in warm, in half warm or external) side of the buildings (south or north). To design this kind of higher walls with spring systems non-linear structural analysis is needed to determine the forces, stability and the natural frequency response. Despite all modern design programs a certain amount of trial and error is still required to balance the rod and catenary system with the floor spring.

Kallioniemi (1999) continues that, when using slender structures, especially cables, deformation often becomes the determining factor. How much deformation can be allowed depend on, a threshold of permissible deformation which is established for frequent wind loads that are compatible with the glass or cladding systems involved. The joints in these systems permit degrees of movement that are compatible with the threshold. Above the threshold the cladding can be damaged. In pinned joints quite large deformation thresholds can be permitted, because the system allows a considerable degree of movement. However, there is a further limit to deflection; even if the cladding fixing system permits a considerable deflection, there is a psychological limit that is the point at which the movement disturbs the general public.

Kallioniemi (1999) also says that, Often hybrid-supported structures are used in high buildings. The panes are connected to each other by some kind of steel list. Then the structural difficulty is in designing the structure, pretensioning the cables and installing the panes and not in fastening details of the glass pane. Important buildings that are constructed with hybrid supported structures can be cited as the Korean World Trade Center, Düsseldorfer Stadttor, Bauwenshaus in Leipzig and Sanomatalo in Helsinki.

Supporting Cable Mechanism

Kallioniemi (1999) claims that, one special form of supporting structures is the supporting cable mechanism. Conventional tubular frames are replaced by cables and rods in both vertical and horizontal directions. Glazed structures, that consist of steel as a supporting cable mechanism, are remarkable for their aesthetics their light weight structural system.

Especially the light weight concept, which is achieved by a minimum use of material and often by the use of glass as a load carrying element requires careful design in accordance with the safety criteria used in structural engineering, since there are no design standards for load carrying glass members. There are various possibilities to carry the wind and dead load which are the main loads for facades. In one of the most commonly used systems, glass itself carries dead load and horizontal or vertical cable supports carry wind load (see Figure 9). This is also called a suspended glass facade.

Suspended Glass Façade

Kallioniemi (1999) state that, as the underlying principle of the suspension system, is the predictability, that the suspension elements must be such that the designer will be able to predict exactly how each panel will behave under various deflections and movements. There are three types of deformation as shown in Figure 2.7, that need to be taken into account. Firstly, the main frame can deform under strong wind if the truss has no diagonal bracing members. If wind bracing is used, then this deformation is not to be considered. Secondly, the top suspension tube can deflect under weight of snow on the roof and under live loads on different levels. Thirdly, the deflections of the cable truss, caused by wind, must be taken into account. The first two deflections are particularly significant because they can cause deformation of the plane of the suspended glass. Each sheet of glass remaining rigid and perfectly square, any movement is thus concentrated at the support points between two sheets and between the glass curtain and its supporting structure. Deflections of the cable truss are concentrated around the holes drilled in the glass.

Kallioniemi (1999) further explains that, the performance required of the glass suspension system is very simple:

- it must take the weight of the glass

- it must brace against wind loads
- pretensioning must hold under temperature changes

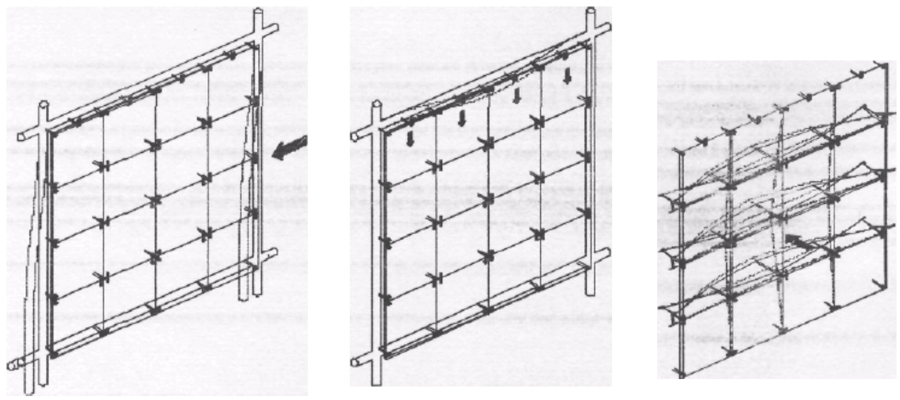

Figure 2.7. Types of deformation that the facade can undergo, left: Lateral deformation of the framework, middle: Bending of the top tube and right: Deformation of the cable trusses
Source: Kallioniemi ,1999

It does not take any load coming from other directions; for instance, it offers no resistance to the loads caused by the main frame deformation, and thus no unpredictable loads to the glass. The glass is suspended in vertical rows of sheets, one above the other each connected to the upper connection pieces at their corners. The upper sheet of each row is then hung from the main frame at the centre of its top edge. With this central suspension point, the glass is able to find its own balance and to hang perfectly vertical, irrespective of straightness of the support tube. Furthermore, this single and central suspension point guarantees that no movement can affect the system, not even a lateral load as shown in Figure2.8. If the rows of glass sheets were fixed using two rigid suspension points the system would resist lateral loads and would have to be designed to take these as well as the weight of the glass. Each sheet of glass is then individually suspended from the one directly above by two-hole connections fixing the distance between the horizontal edges of two sheets of glass so that the joints are even width. To ensure that the connections do not attract lateral loads, they are articulated and can therefore rotate sideways. A bay consists of rows of sheets, each hanging independently of others. All horizontal connections are hinged, thus preventing all possible transfer of vertical loads -either from one row to an adjacent one or into the frame of the main, structure behind the glass. The fact that the rows can slip relative to each other that the top tube can sag without any change in the hypotheses that have been offered so far concerning the loading of the glass structure.

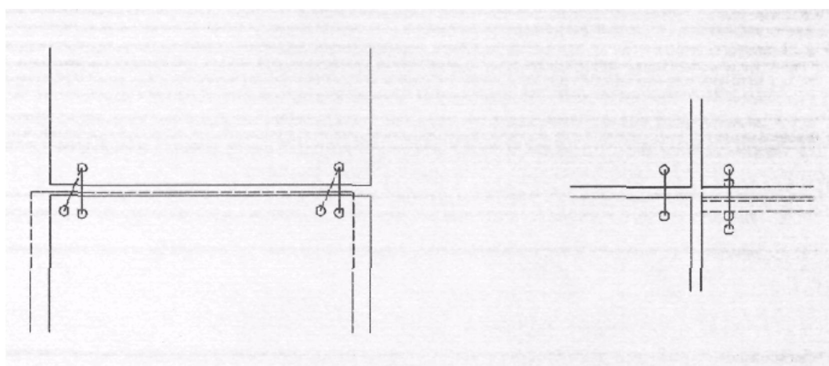

Figure 2.8. Sketch about vertical and horizontal movement of sheet.
Source: Kallioniemi ,1999

Each sheet of glass is braced against wind loads at all four corners. Wind loads are transferred either into the cable trusses or straight to the main frame. At all mid-panel connections, the two vertical elements of the four-hole support assembly are linked by cross-bar, itself connected to one cable truss strut. At the perimeter of the panel, the connecting bar fastens two sheets of glass (two-hole connection) and links them directly to the main structural frame. A small strut (one-hole connection) links the glass sheet to the main structural frame at all four corners of each panel. All these connections are hinged in two places so that they do not resist any lateral loads parallel to the plane of glass. This freedom from lateral restraint means that the plane is not affected by the tendency of the main frame to adopt a parallelogram shape under lateral load conditions. The only part of the suspension system offering a resistance to lateral loads in the plane of the glass is in middle of the top tube of a main structural frame bay. It is hinged vertically and so does not alter the structural hypothesis when deflection is in the main frame top tube; nor does it interfere with the freedom of the panels with regard to the main frame parallelogram action, since it is located on the top tube itself. Temperature fluctuations cause the frame and the glass to expand and contract at different rates. The fact that there is only one fixed point between these two systems in the plane of the glass and that all other connection points are free to rotate allows for differential thermal expansion.

Kallioniemi (1999) states that, although each of the rows of a glass panel are theoretically free to slip relative to each other, the resistance provided by the silicone weatherproofing of the joints must be taken into account. In fact entire facade has a tendency to behave as one single sheet. Lateral loads in the plane of the glass would create support moments and might cause significant changes in the loads at each support point. This is why a pretensioned spring mechanism is incorporated into each support bracket in such a manner as to ensure that the weight of the whole panel is always evenly distributed between all support points. Each mechanism remains rigid until it is subjected to loads greater than the weight of the glass and fittings. This "fuse" action is necessary to enable prediction of the loads that can be applied to the glass and each support point of the structure frame. The springs also act as shock absorbers for the entire glass system in the event of a fracture in a sheet of glass and consequent instant change in the load path. The joint between the panes must satisfy three requirements; firstly, it must allow the panels to move in relation to one another, secondly, it must not protrude from the glass external skin, thirdly, it must be watertight. The designer must provide capacity for adjustment to allow for manufacturing and assembly tolerances of the system. It must be possible to adjust each element according to the differences discovered, on site, between the theoretically dimensions and the real dimensions of the structural frame and of the holes in the glass sheets. Small inaccuracies can be found even in the most precise work, and the accumulation of these inaccuracies can produce considerable dimensional problems at the time of installation. Some inaccuracies are unavoidable, such as the position of the holes in toughened glass. It has been seen that the glass changes shape slightly in toughening oven as a result of the extreme heat. The glass system consists of screw thread assemblies which enable the length of the components to be changed in order to accommodate dimensional error. These assemblies must have been made so that they do not become accidentally unscrewed. Assemblies can become adjustable simply because they are hinged. For instance, the spring support assembly has a double hinge which makes lateral adjustment possible. If a rigid bracket were used instead, and should it be inaccurately welded to the main structure, it would be impossible to correct this defect when fitting the glass sheet.

- **Glass Mullion System**

Button and Pye (1994) explains that, one method of providing a frameless glazing facade is to fix together a matrix of toughened glass paned, hung from the building structure. A system of this type, commonly referred to as a suspended glass assembly, was designed and developed in the 1960s by Pilkington Glass Limited. It allowed designers to glaze large openings in buildings, without the use of metal frames or mullions, providing the creation of light and space in buildings with a minimum of visual barriers (Figure2.9).

The system comprises a series of specially processed and toughened glass panes, bolted together at their corners by means of small metal patch fittings as shown in Figure 2.10.

Figure 2.9. Ontario Convention Centre, California, USA
Source: Pilkington Planar, 2000

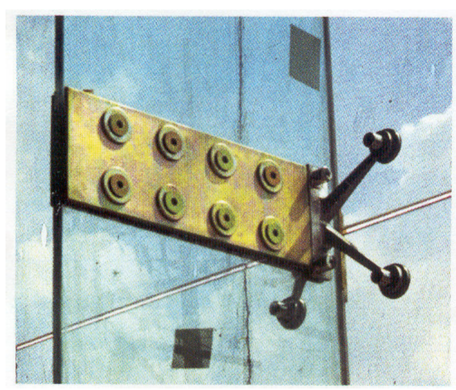

Figure 2.10. A metal patch fitting.
Source: AGA autvision, 2000

Button and Pye (1994) also states that, pane to pane joints are sealed with a silicone building sealant, and toughened glass stabilizers are used at each vertical joint to provide lateral stiffness against wind loading. The assembly (Figure 2.11) so produced is suspended from the building structure by hangers bolted to its top edge, and is sealed to the building in peripheral channels by means of neoprene strips or non-setting mastic. The concept of the design ensures that the facade is, at all times floating in the peripheral channelling, and problems which might arise due to differential movement between component parts are eliminated. Assemblies can, therefore, be used to advantage when vibratory or seismic forces must be taken into account in the design.

Button and Pye (1994) claims that, weather sealing is carried out all joints in the facade using a structural silicone building sealant. In the design calculations the structural properties of the sealant, in providing greater stiffness to the facade, are not recognized. However, from extensive laboratory and on-site testing it is known that the sealant does improve the load bearing capabilities of the facade, and its use is therefore an added safety factor in design. The principle behind the design of the fittings for a suspended glass assembly is that all in-plane forces transferred between components are resisted by friction developed at the metal gasket glass interfaces, arising from the tension developed in the fixing bolts. The use of friction to forces between glass and fittings makes it essential that bolts are the correct size and quality, that are tightened to the specified torque, are used. Although the holes in the glass resist considerable bearing forces from the bolt, through the hard bush this is only taken into account limitation for assembly constructions. The friction grip is particular importance in the design of the splice joints and root support of the stabilizers, where the bearing strength of the holes is unlikely to be able to resist the turning moments generated in the stabilizers when an assembly is subjected to wind forces. If required, the coefficient of friction at the metal gasket glass interface can be enhanced by the application of a suitable adhesive.

Button and Pye (1994) discuss that, the facade panes resist lateral wind forces through the small metal patch plates, supporting the four corners of adjacent panes off the stabilizers. These metal patch plates clamp the glass at the corners of each pane, developing significant stress concentrations at

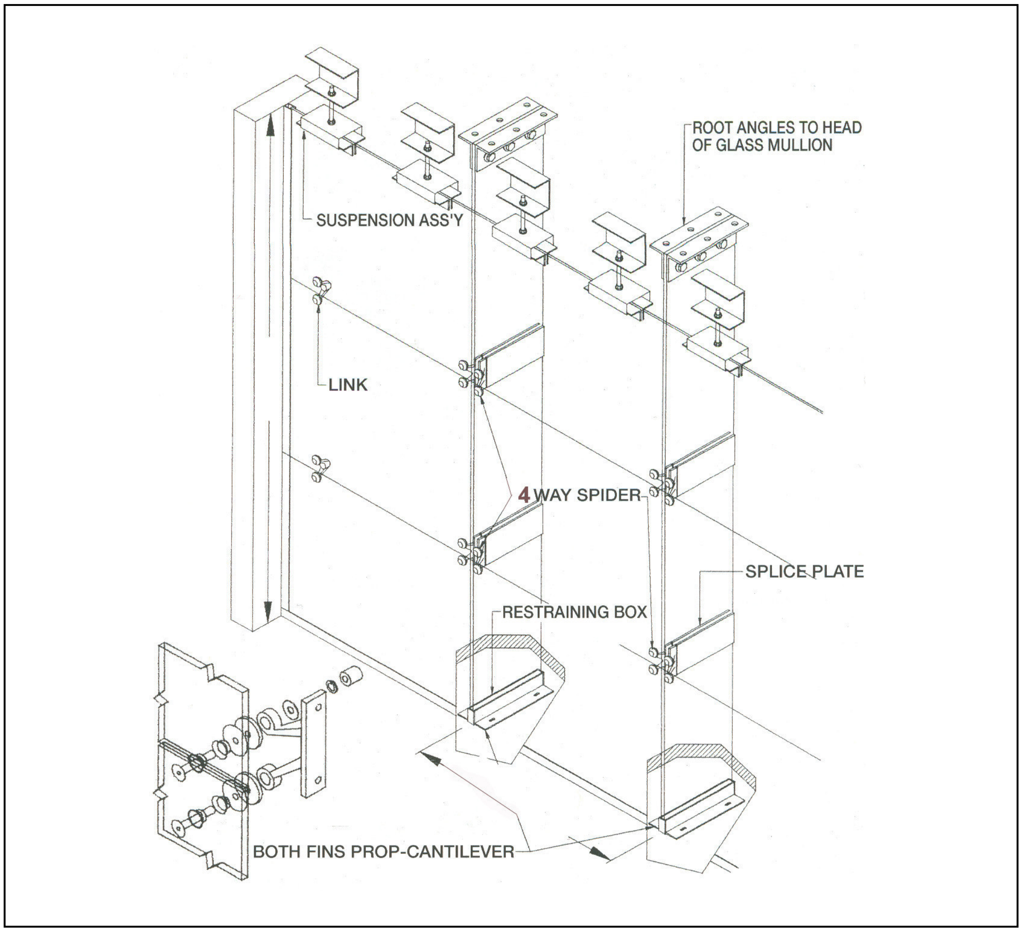

Figure 2.11. Glass fin system.
Source: AGA autvision, 2000

the edges of the patch plate and around the bolt hole. In order to safely design panes supported in this way, it is essential to have a detailed knowledge of the stresses generated around and under the patch plates, for various shapes of pane subjected to different levels of lateral load. Equally essential is knowledge of the strength of the toughened glass at and around the fixing holes. The size of suspended assembly facade panes is rarely limited by deflections. The clamping effect of the patch plates, which reduces deflections, together with the relatively high stresses generated, dictates that most assembly facade panes are stress limited rather than deflection limited in the design.

The use of glass mullion system allows us to produce vertical structural glass wall. Glass fins are used as support for maximum transparency and to transfer wind loading to the structure. Structures of this type are usually suspended from the structure above, with the glass panels fastened to the mullions by fittings. This means the weight of both the panels and the mullions are carried by the connection at the head of each fin. This allows you to design very high facades that don't exert large in-plate loads on the glass panels. Anti-buckling fin technology was developed to allow designers to have longer fins, wider modules, and work with higher windloads. Anti-buckling rods are 1/4" diameter stainless steel tension rods bolted to the back edges of the glass fins to provide lateral support preventing the fin from buckling or flipping out of plane during load. Extensive testing for projects in Asia, where windloads were 250 psf, led to innovation in this technology. This technology gives the architect the ability to design and provide soaring glass facades with minimal additional structural support over and above the glass fin itself. (Pilkington Architecture,2000)

2.2 Glass Skin

An aphorism of Le Corbusier offers a fascinating context for the future of glass in architecture. In "Vers une Architecture", he said: "Architecture being the masterly, correct and magnificent play of masses brought together in light, the task of the architect is to vitalize the surfaces which clothe these masses."

Acoording to Micheal Wigginton (1998), glass is arguably the most important material in architecture. Other materials may have been around longer: timber and stone have for thousands of years provided the physical support man needed to create structures which he could occupy. Until the arrival of glass, however, the resulting enclosures were either dark, or open to the vagaries of the weather, with no protection. Glass has provided buildings with eyes and has opened interior space to the benefit and beauty of light. Glass architecture, originally an essentially northern European phenomenon, has always flourished when the thirst for light and the need for protection from the elements have conspired together. In the 20th century, glass, underpinned by new technology, has fulfilled its promise to architects to make wonderful architecture and become a vital ingredient, aesthetically as well as technically. As we look to the future of this extraordinary material, many aspects of its nature and use become the evident sources of potential development: firstly, the method of fixing it and making it into building skins; secondly, potential for designed thermal and luminous performance; thirdly, the rich palette generated by the development of thin-film and nanometric technology; and fourthly, the aesthetics which flow from all these. A fifth, and perhaps revolutionary, aspect of glass design remains available to us in terms of the chemistry itself.

Micheal Wigginton (1998) also states that, the use of glass in the making of skins has developed greatly in the last 20 years. We are now in a design environment where only manufacturing size and sealant technology is constraining us. However, these constraints are real and, to the ambitious designer, frustrating. The sizes in which glass is made, set by the width of float plants, give us the essential measures of a glass wall. Our efforts now (apart from trying to persuade the manufacturers to build wider float lines) lie in minimizing the impact of the joint as we strive for the seamless wall. The methods of constructing glass walls seem largely to have settled in technological terms, as the bolt and silicone adhesive have given us two basic modes of fixing. Until we learn to weld glass, probably by changing its chemistry, we would seem to have reached a technical plateau, and it may well be that we shall not need to progress from this, at least in the next few decades. Of course, seamless glass walls are only one design objective in architecture. The exploration of performance is potentially a richer area. Glass is increasingly seen as the substrate to a set of designed films which can be incorporated into multiple walls of hitherto imaginable performance.

Micheal Wigginton (1998) further states that ‚glass is invisible, solid, made from a liquid and almost in disguise as a functional hi-tech architectural building product. Glass provides both light and vision yet imposes separation and in some instances isolation. Glass can form a building envelope, provide the illusion of space or let you see without being seen. It can be decorative or functional and architects are now using the medium of glass to produce facades which play on the transparency of the product with screen printing or other textured elements. The technological advances of the 20th century have opened up endless possibilities and structural silicone glazing, bolted assemblies and the development of coatings are the manifestation of some of these. In addition to it's primary purposes of light admittance and protection against the elements glass has now assumed new properties in response to other demands for climate control, sound control, fading control and risk control. The capacity of glass to meet these challenges has radically altered the image of glass and it now stands out as a multi-purpose essential material for the modern age. Of all materials, glass is more than ever representative of modern trends in the 21st century meeting the aspirations of designers for the free communication between people and spaces.

In this regard, Kallioniemi (1999) claims that, one of the major trends of contemporary architecture is to link interior space to the exterior with minimum compromise. According to the important technical advances of recent years, glass has come to be regarded as the ideal medium for this concept. Glass is the material which balances light, transparency and appearance with the practical functions of thermal insulation, solar control, safety and security, acoustic insulation, fire protection and so on.

More significantly however, glass is no longer considered as a non-structural element. It is increasingly called upon to constitute innovative structural components of a building, such as flooring, fins, beams or complete bolted glass assemblies in facades.

In such applications the mechanical performance of the glass is paramount. It is imperative therefore, that the design of the glass components accommodates the forces and movements imposed on them when incorporated into a building's structure. Two basic functional constraints must be borne in mind:

- the accurate management of design loads,
- a clear provision for the differential rate of movement between constituent elements.

2.2.1 The Basic Properties of Glass

Glass in its pure form is an extremely strong, perfectly elastic non-crystalline brittle solid. In commercially available float products, its bending strength is limited by the surface tensile strength of the inevitable surfaces defects, flaws or cracks (figure 2.12). These defects reduce the glass strength by a factor in excess of 100 compared to the strength of pure glass. The property of pure elasticity with brittleness means that the glass cannot be permanently deformed by load as is the case for most solids such as metals and plastics, and that it fails without warning. Other phenomena affecting the surface flaws and thus the strength of the glass relate to the manufacturing process (with different strengths produced on the tin side and the air side), the duration of the load and presence of water which leads to static fatigue, the physical environment and cleaning processes used. (www.metropglass.com, 2003)

Moreover, Micheal Wigginton (1998) point outs that, materials are rarely perfect, they are likely to contain small crack-like defects. When a crack of a given size is loaded beyond a certain critical stress, the crack will propagate and failure by fracture is likely to result. The material property that relates critical stress to the size of the crack is the fracture toughness. Steels have

GENERAL GLASS PROPERTIES

Thermal Conductivity (K value)	1.05W/m°C
Coefficient of Linear Expansion (room temperature to 350°C)	$\frac{9.0 \times 10^{-6}}{°C}$
Hardness Mohs' Scale	6.0
Density	2500 kg/m^3
Young's Modulus (Elasticity)	69 GPa
Poisson's Ratio	0.23
Softening Point	730°C
Refractive Index	1.52
Specific Heat 0-100°C	0.20
Compressive Strength (25mm cube)	248 MPa
Tensile Strength* - Annealed	19.3 – 28.4 MPa
Tensile Strength* - Toughened	175 MPa

* Modulus of Rupture – sustained loading

Figure 2.12. General glass properties.
Source: www.metropglass.com, 2003

a relatively high fracture toughness. For typical defect sizes, the critical stress for a steel component is usually well in excess of the yield stress.

Steel can therefore redistribute load or absorb energy by yielding, which makes its behaviour ductile as shown in Figure 2.13. Glass can be very strong, much stronger than structural steel. However, because glass has a relatively low fracture toughness, such strengths can only be achieved when it is virtually free of defects, as a freshly drawn glass fibre might be. Normally glass will contain defects, the surface being particularly prone to getting scratched, chipped or attacked by the atmosphere. In this condition, as soon as the critical stress is exceeded, the glass will fracture. The behaviour is brittle, with no ability to redistribute load or absorb impact energy. To counter the fragility of glass, the industry has developed a number of methods to strengthen it. These do not change its nature, but either raise the threshold at which cracking occurs, or incorporate additional ductile materials that absorb the energy and therefore prevent total failure when an

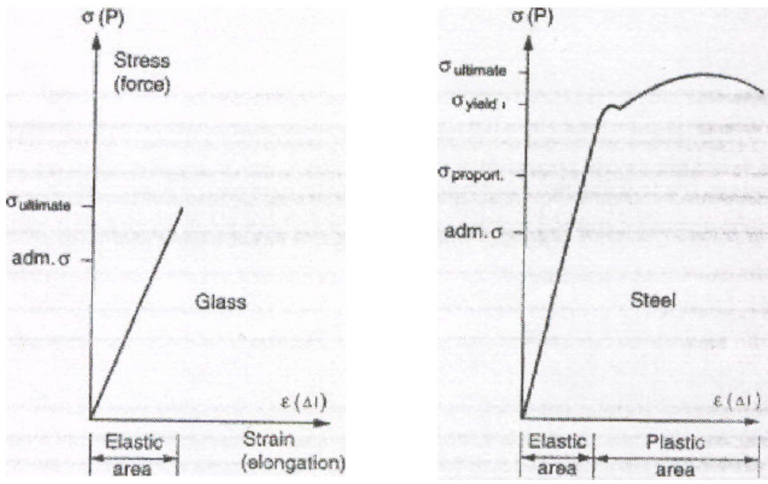

Figure 2.13. Comparison of the stress-strain curves of glass and steel
Source: Kallioniemi ,1999

unit has cracked. Among these, the three most commonly used methods are toughened or tempered glass, laminated glass and wired glass.

Heinz W.Krewinkel (1998) claims that, the basic properties of glass - its transparency and weatherproof quality - allow it to meet a wide range of needs. Glass is also environmentally sustainable, since it is inert and can be recycled without difficulty. Furthermore, it can be exploited to create a "solar trap". Five main technologies have contributed to its present state of development, which as follows:

- the pioneering of laminated safety glass;
- the prestressing of glass to form single-layer safety glass;
- the edge sealing of glass to create multiple-layer insulated glazing;
- the float glass process;

- and the coating of glass to reduce its emissive properties (thermal and solar screening)

Other aspects include fire-protection and sound-insulation measures, surface printing with ceramic substances, the use of various intermediate layers, and light-deflection systems.

Heinz W.Krewinkel also (1998) discuss that, the versatility of glass as a material is paralleled by constructional development including improvements in the insulation of window frames; the pioneering of frameless transparent membrane facades with point fixings and supported by cable network structures or trussed bowstring beams; and the design of double-layer facades and roofs that allow indoor climate control. One problem encountered in developing structural uses of glass is that of gaining building permission. The relevant authorities usually grant permission only in individual cases. One reason for this is the lack of criteria and standards by which to assess such structures. The specific problem connected with glass is its brittleness and its liability to spontaneous fracturing. One solution is the use of laminated safety glass, which, on breaking, retains an adequate residual structural strength as a result of the strong elastic bonding of the PVB film.

Brent Richards (1998) states that, over the past 70 years, there has been a comprehensive realization of glass architecture, both structurally and aesthetically, as a new methodology of construction. A closer consideration indicates that the immediate future of glass architecture will be a new stage of alchemy, an age of phenomenal transparency. Glass today can function as an environmental interface, as a cladding envelope, and as a structural support. In its most recent forms, it also has the capacity to provide a dynamic visual palette, comprising colour, surface texture and imagery, and it can act as a unique communication medium through the advanced use of interlayers, chromafusion, screen printing and the back-projection of images directly on to the glass surface.

2.2.2 Types of Glass

The key selection criteria when considering the choice of glass in a project are climate control, sound control, fading control and risk control. The types of glass were classified below, in terms of their indicative properties for the selection criteria of structural glass wall systems. This part will assist the designer in generally meeting the 'best fit' solution for the project concerned.

Laminated Glass

Laminated glass, often called "safety glass", consist of two lites of equal thickness bonded together (Figure 2.14), with a plastic interlayer, or polyvinyl butyral (P.V.B.). In the event that the glass should break, the P.V.B. interlayer will allow the glass to remain in the skylight framing. Colored PVB's which allow a virtually unlimited range of color are incorporated in many skylights. The interlayer can be as little as 0.4 mm thick or as much as 6 mm. Though two layers of glass is the most common arrangement, over 25 layers have been successfully bonded in an assembly over 100 mm thick. Laminates can incorporate many thicknesses and many combinations of glass types to give a range of products with the required range of mechanical and optical properties. Other materials such as polycarbonates can be included. Annealed, heat-strengthened and toughened glass can all be laminated, as can bent glass. Heat-strengthening and toughening both cause small amplitude waves (caused by the rollers over which the heated glass travels) in the glass. These increase the separation between sheets being laminated and make pvb laminating impractical. The solution is to use resin laminating. (The Institution of Structural Engineers,1999)

Structural behaviour: This behaviour depends on the type(s) of glass used and on the properties of the interlayer. Hooper (1973) showed that, for the interlayer materials he considered, short-term out-of-plane loads were resisted by the laminate acting compositely. Long-term out-of-plane loads were simply shared by the two sheets of glass in proportion to their relative stiffnesses, because of deformation of the interlayer.

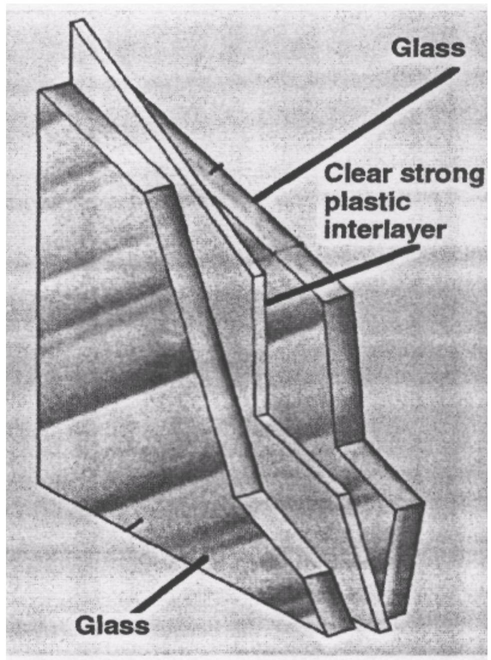

Figure 2.14. Laminated glass layers.
Source: The Institution of Structural Engineers, 1999

Norville (1999) argues that both test data and theoretical studies indicate that laminated glass displays strength and behaviour under short-term loading equivalent to monolithic window glass of the same type and nominal thickness. Sobek, Kutterer and Messmer (1999) describe the time and temperature dependence of the shear stiffness of the interlayer. Increasing temperature softens the interlayer and reduces composite behaviour, which can be significant in double-glazed units, which can act as solar collectors. Laminated glass offers a number of performance benefits, which are as follows:

Safety: If an impact or other cause breaks one layer or both layers of glass, the interlayer can prevent penetration and any broken pieces of glass will remain bonded to the interlayer. This minimises the likelihood of serious cuts or injuries caused by falling glass. Moreover, Intumescent resin interlayers are available. In a fire these turn into a foam which not only prevents the passage of fire but also reduces the conduction and the radiation of heat through the glass. This protects people who may need to pass it on their way out of the building. (The Institution of Structural Engineers,1999)

Security: The use of thicker interlayers increases the penetration resistance of the panel, giving protection from sledgehammer attack. Multilaminates also provide increased resistance. Some bullet-resistant laminates include sheets of polycarbonate to improve their performance. Laminated panes can, if properly held at their edges, also improve safety from bomb blasts. (The Institution of Structural Engineers,1999)

Solar control: Tinted and translucent interlayers are available which modify the passage of solar radiation. There are even laminates which when examined minutely show themselves to have interlayers that are louvered in the manner of Venetian blinds. These can be used to exclude, for example, high altitude summer sun while admitting low altitude winter sun. (The Institution of Structural Engineers,1999)

Sound control: Laminated glasses are better than single sheets at absorbing sound, because of the damping effect of the interlayer. This is more effective at higher frequencies (The Institution of Structural Engineers,1999)

Toughened Glass

Glass is toughened by heating it to about 700°C, then carefully cooling it using air blowers to cool the surfaces rapidly while the centre is still viscous. The surfaces harden and are then put into compression as the centre cools and contracts. With no overall load applied to this glass, the toughening process produces a balanced stress condition across the thickness of the glass. The high surface compressive stresses are equilibrated by smaller tensile stresses acting over a greater proportion of the cross-sectional area. Glass failure is most likely to be initiated by surface cracks, because these tend to have the worst geometries and are subject to the highest stresses due to bending. If the loads to which the glass is subjected do not create enough surface tension to overcome the surface compression, no crack will propagate. Toughening, therefore, increases the effective strength and impact resistance of the glass.

There is one further advantage of toughened glass where the glass is under significant permanent load which is the case with suspended glass. In a non-toughened condition, the glass will creep and lose its strength under a permanent load. The long-term (one year or more) strength of glass under permanent load is about one-third of its initial short-term strength. This is due to the tendency of defects to increase in size. Panes of non-toughened glass subjected to a permanent load are therefore likely to suffer instantaneous failure. By contrast, when the glass is toughened, the outer layers are always in compression and the tendency for crack growth of the material is thus counteracted.

All hole drilling and other machining of the glass had to be done before the toughening was carried out: any drilling or cutting done after toughening would have broken the stress relationship between the inner layer and the outer layers and would have precipitated cracking and fragmentation of the glass. Many factors can cause a variation in the level of prestress in toughened glass: the oven temperature, the length of time in the oven, the cooling time. (The Institution of Structural Engineers,1999)

Insulated Glass:

Insulated glass is used in skylights and sloped glazing over a conditioned space. When energy efficiency is of paramount concern. The hermetically sealed air or gas in the space between the glass in units by virtue of Boyle's Law ensures that the individual pieces of glass share the applied load in proportion to their respective stiffness. Therefore for two pieces of equal thickness glass, the load is shared 50:50.(www.metroglass.co.nz,2003)

Annealed Glass:

Annealed glass is the state in which float glass becomes after it is poured from a molten state into a bed of molten tin. This glass is allowed to solidify, and then is cooled under controlled conditions which turns the glass into an annealed state. This glass is rarely used in sloped glazing. (The Institution of Structural Engineers,1999)

Tempered Glass:

Tempered glass is produced by heating annealed glass to approximately 1150 degree F, then cooling the glass rapidly by blowing air on both surfaces of the glass simultaneously. Tempered glass is about four times as strong as annealed glass of the same size and thickness. When tempered glass is broken, it breaks into very small pieces. One problem that exists with tempered glass is spontaneous breakage; the glass will break for no apparent reason. (The Institution of Structural Engineers,1999)

Heat Strengthened Glass:

The heat strengthened glass process is similar to that of tempered glass. The annealed glass is heated to approximately 1100 degrees F, but the cooling process is slower than that for tempered glass. Heat strengthened glass is about twice as strong as annealed glass of the same size and thickness. One of the benefits of heat strengthened glass is that it is far less susceptible to spontaneous breakage. Due to this, it is recommend to use of heat strengthened glass for skylights.

Coated Glass

There are two basic types of coated glass: solar control (reflective) and low-emissivity (low-E). The major differences are visible light transmission, ultraviolet (UV), visible, and near infrared wavelengths of energy that are reflected, and the directions in which these wavelengths are usually reflected. The solar spectrum consists of ultraviolet (UV) light with wavelengths ranging from 300 to 390 nanometers (nm), visible light (390 to 770 nm), and infrared (IR) light (770 to 2,100 nm). The distribution of energy within the solar spectrum is approximately 2 percent ultraviolet, 46 percent visible, and 52 percent infrared. Solar-control glass may have a variety of metal coating layers that are highly reflective of solar energy, i.e., those energy wavelengths, from 300 to 2,100 nm, that constitute the solar spectrum. The major attributes of reflective solar-control glass include the following:

Aesthetic Appeal: The various silver, blue, gold, and copper reflective coatings, when applied to clear and/or tinted float glass, allow the architect considerable flexibility with exterior design.

Energy Savings: Due to its ability to reflect, absorb, and radiate solar energy, solar reflective glass will substantially reduce indoor solar heat gain. The added cost of the coating will generally be offset by the reduced size and operating cost of the HVAC system.

Occupant Comfort: Occupant comfort is improved when heat gain/loss differentials between sunny and shaded elevations are substantially reduced. Indoor temperature differentials are less and thus easier to control.

Low-E glass may have various combinations of metal, metal oxide, and metal nitride layers of coatings that are nearly invisible to the eye. Some low-E coatings are highly reflective for the infrared part of the solar spectrum, and all low-E coatings reflect long wave infrared energy. Long wave infrared can be described as the radiant heat given off by an electric coil-type heater, as well as the heat that comes from a hot air register. The re-radiated heat from room furnishings that have absorbed solar energy is still another form of radiant heat. A low-E coating on the second surface of an insulating glass unit is more effective at controlling solar heat gain, especially when used in conjunction with tinted glass. The low-E coating will reflect re-radiated heat (IR), while the tinted glass reduces the solar radiation through the glass, resulting in less glare and heat gain. When using low-E glass in commercial buildings, this is generally the most practical way to maintain comfort levels.

When using clear glass in insulating glass units, the coating may be placed on either the number two or number three surface. The low-E coating reduces heat loss through the glass in winter by reflecting interior long wave IR back into the office or home. Low-E coatings can be combined in an insulating glass unit with a solar reflective coating and gas filling to create an insulating unit having lower U-values and a lower shading coefficient. (The Institution of Structural Engineers,1999)

Tinted Glass:

Tinted glass is used to reduce the amount of direct sunlight and glare that enters a building. Tinted glass is available in many different colors; green, grey, bronze and blue-green are standard colors which are most readily available. Premium colors included blue, evergreen and azurlite. (The Institution of Structural Engineers,1999)

Ceramic Frit Coated Glass:

Ceramic frits are often applied to glass to produce architectural enhancing features to skylights. Ceramic frits can help to reduce glare, and decrease solar transmission. The ceramic material is silkscreened on to the glass, and then is heat fired to the glass. The patterns can range from a simple dot pattern to a one of a kind custom pattern as shown in Figure 2.15. The frits are also available in a wide range of colors. The maximum lite size of most frit patterns is 150cm x300 cm. (The Institution of Structural Engineers,1999)

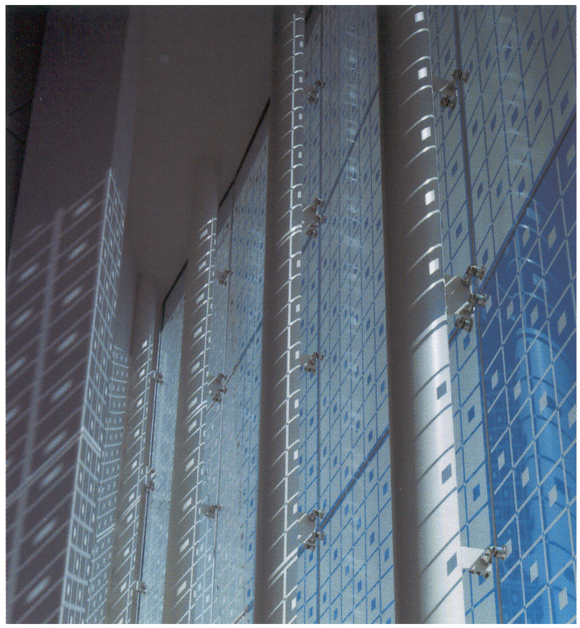

Figure 2.15. AMC Theatre ,California USA.
Source: Pilkington Architectural, 2000

2.2.3 Design Considerations of Glass Walls

Barry (2001) states that, the transparency of glass often leads designers to attempt the creation of an all-glass wall with no visible supports or stiffeners. Reality, however, imposes certain limitations; before the wall can be designed, the following values are required:

- How great are the loads on the glass?
- How much glass deflection under load can be tolerated?
- What glass size and thickness limitations exist?

Loading

The windload must be known by the glass designer. Wind speed alone will not provide enough information. The shape and exposure of the building, plus the relevant building variables in the applicable building code are needed for the calculation of windload for a given wind speed. The glass designer/fabricator/supplier is typically not able to convert wind speed to uniform pressure load. This means that the edges can rotate slightly, or slide in the plane of the opening, but they cannot move in a direction normal (at right angles) to the plane of the opening. If this lite, 8.53 m wide and 2.54 m high is 19 mm thick annealed glass, it will withstand a uniform windload of around 25 psf (1.2 kPa). At 15 psf (0.72 kPa) the center of glass deflection is about 10 mm. Glass supported on all four edges is stiffened by membrane action. As the glass bends under a uniform load it also has to stretch because the four edges, confined to the plane of the frame, provide resistance to this membrane or stretching action. While there is no limit set for center of glass deflection in the standards or building codes, it is generally accepted that deflections greater than 19 mm can give rise to aesthetic questions caused by distorting reflections and other effects.

Dimensioning

Barry (2001) also emphasizes that, it would be very difficult and costly to find, fabricate, transport, and install the single glass lite. The maximum size glass readily available today is 19 mm thick and about 5.18 m by 3.30 m. A much simpler design method is to edge glue smaller vertical strips of glass with black silicone with only the two opposite edges (top and bottom) held in the frame. But glass supported on two opposite sides is generally much more flexible than that which is supported on all four sides. This is true when the glass width and height are nearly equal. But when the aspect ratio is large (long dimension is much greater than short dimension), then the stiffness under load will be about the same for both support conditions.

Glass stiffness is proportional to the cube of its thickness. This means that if the thickness is doubled, the glass becomes eight times stiffer or will only deflect 1/8 as much under the same load, Therefore, using 19 mm thick glass in the above example will reduce the deflection from 76 mm to about 10 mm.

Barry (2001) further states that, a seldom-considered option is to change the glazing detail from "simple support" to a "clamped edge" design. The bottom edge of a glass balustrade set in expanding grout in the floor is an example of effective clamping. The top edge of window requires different treatment: The glass edge must be free to expand and contract in its vertical plane to accommodate thermal expansion, building component creep and movement, etc. When the top edge is restrained from any rotation (but still allowed to slide vertically) then the glass will become five times stiffer; therefore, the deflection of 10 mm thick what would be only approximately 15 mm.

Sealing

Barry (2001) also states that the tempered glass lites were effectively held in place using slim silicone rubber spacers to keep the width of the structural silicone joints between the 6 mm lites to about 1.5 mm. This installation would be much stiffer if the frame detail around the perimeter of the assembly could provide a clamped condition rather than simple support. A method seldom used, and then usually then without the insulating glass fabricator's approval, is to install sealed units supported along the top and bottom edges only. The sealant must be dual seal PIB and silicone to withstand the solar UV exposure. Such units have shown that the seal can withstand the high sealed air space pressures generated on hot days without the damping effect of a traditional glazing frame. While the windload will be equally shared between the two lites of the unit, a careful calculation must be made of the shear stress developing in the sealant. This stress could potentially cause the seal to fail long before the limiting stress for the glass was reached. The units made with two lites of 1/4 inch (6 mm) glass, felt very stiff when a hand load was horizontally applied, though a close examination did show the fog of a failed seal inside one of the three unit.

Support systems

Kallioniemi (1999) claims that, unlike conventional supported glass pane systems, the glass in point supported systems has no continuous perimeter edge contact with a framing system or substructure. The point supported systems require careful and integrated design, fabrication and installation of the primary support structure, the point fixing assembly and the insulating glass unit. Point supported glass panes can be divided into different parts by the type of support, the location of the support's centre of gravity and esthetical point of view .The type of the support can be rigid, movable-elastic or pure pinned ball hinge as shown in Figure 2.16. Type of support effects on stresses caused by displacements of the glass pane.

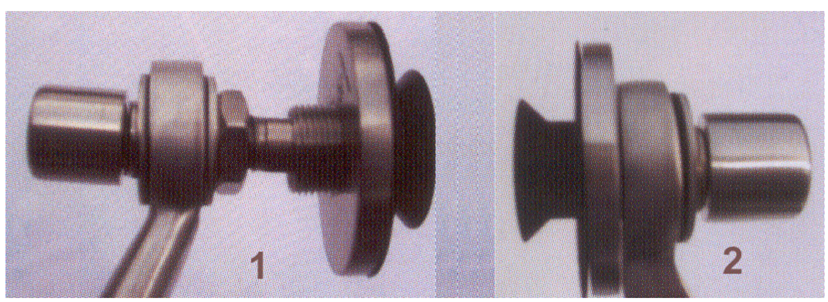

Figure 2.16. Type of supports: 1.movable-elastic and right pinned ball hinged, 2.rigid.
Source: Pilkington Architectural, 2000

Kallioniemi (1999) also further claims that, in architects' point of view the point supports can be divided into three various aesthetic parts. The head of the bolt can be above the glass pane which is the easiest and oldest way of constructing point supports. A more delicate way is to level the bolt head to the glass pane plane. Then the point support cannot be seen from the side of the glass pane. The newest way is to leave the bolt head inside the glass pane. Then the head is "invisible" as shown in Figure 2.17.

Loads

Kallioniemi (1999) explains that, in this delicate system the possible loads are to be calculated carefully. Too big loads in the point support lead to cracks in the glass and then to a possible fail of the pane. The main problems to overcome with point supported glass panes are:

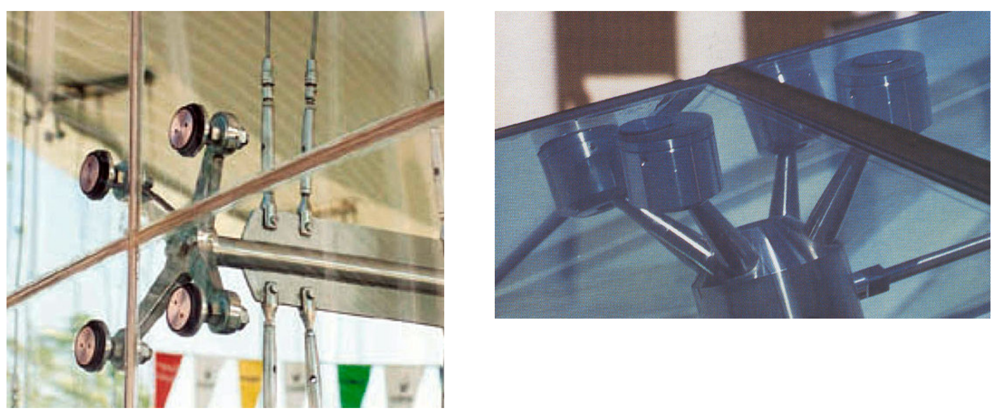

Figure 2.17. Aesthetical view points; left: bolt head is on the glass pane and right: bolt head is in the glass pane.
Source: Pilkington Architectural, 2000

- high stresses at the edges of the drilling holes
- small tolerances in the joint.
- restraint loads caused by temperature
- additional loads to insulation glass panes

High stresses

Because of clear, determined stress distribution, line supported glass panes in facades can be designed easily with values in tables. Glass panes with point supports on contrary need more careful design calculations. The condition of edges and glass surface in the drilling area has an essential effect on load capacity. When designing the joint detail, the joint has to be modelled with a FE-program. Because of the importance of the edge, the main concern has to be in modelling the liner material between glass and fastener. Simplified FE-model without liner modelling in drilling area is not adequate. Decisive in point supported glass panes are normally principal tension stresses. The following matters have very much effect on the stresses at the edges of a hole:

- Type of the joint. The stresses are higher with fixed joints with eccentricity than with pinned ball joints.
- The drilling of the glass. it depends on diameter, condition of the glass, type of the hole e.g. cone-shaped
- Geometry
- The liner material. It depends on thickness and stiffness of liner.

Small tolerances

Kallioniemi (1999) discusses that, when designing glazed structures required tolerances might be essentially smaller than in normal construction. The more transparent the structure is the smaller the tolerances are. The needed tolerances depend on the point support system. If the joint can move in many directions, then the required tolerances of load-bearing structures are not so small. Otherwise load-bearing structures have to be constructed with tolerances that are unusually small to many constructors.

Restraint loads

Kallioniemi (1999) also continues that, restraint loads can easily break glass products where stress peaks cannot be removed. There the panes have to be fastened so that stresses caused by restraint loads are the lowest possible. This relates especially to the restraint caused by temperature. Therefore various coefficients of thermal expansion of inner structures and glass have to be considered of. Glass can be e.g. pinned fastened with a ball joint. When this is the case the system is statically determined and restraint loads are avoided. Glass as a material has no ability to form local plastic deformations like e.g. steel has. Therefore the contact of the glass to other materials with equal or bigger modulus of elasticity should be avoided. Instead plastic materials or aluminium are recommended to use as liner e.g. in drilling and supporting areas. Durability of the liner against UV light, water, etc. and its permanence has to be considered. It is better to ensure fitting possibilities for geometrical inaccuracies already in the design phase, repairing the drilling area afterwards in heat strengthened laminated glass is not possible.

Additional loads to insulation glass panes

Kallioniemi (1999) claims that ,point supports in insulation glass panes need special attention. One sheet glass panes with the different locations of the point supports and with the different distance of centre of gravity of the support arc possible to design, fabricate and install without restraint loads caused by normal tolerances and external loads. These can be determined by simple static calculations. Insulation glass panes has have two additional problems. Deflection of glass panes under external loads effects relative displacement of inner and outer glass sheet. This effect is showed in figure 2.18. This additional stress exists only, if inner and outer glass sheets can have relative displacements. Then the highest displacements are of course at the edge areas of the pane, where the supports also are. The displacements cause this additional stress to the area which is already weakened by drilling hole.

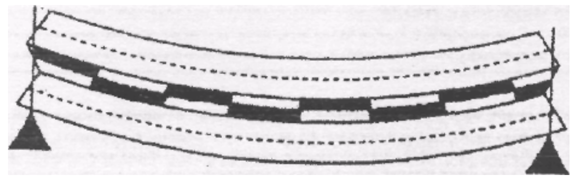

Figure 2.18. Effect of relative displacement.
Source: Kallioniemi, 1999

Climatic loads cause another stress to the drilling area. Inside two glass sheets and hermetically sealed edge seal under-and overpressure can exist. Under- and overpressure cause deformation inwards (underpressure) or outwards (overpressure) of the sheets. These deformations have relative constant value at the edge. Deformation varies to the middle of the sheet by pressure situation and is different in different heights of the pane. Edge sealing is normally constructed so that the sheets can bend freely. The point supports are not in edge and at the point support area the sheets would have been deflected without obstruct of the support. This obstruct causes an additional stress to the glass and point support. This is avoided by using pressure equalisation between the glass sheets.

Drilling the Hole

Kallioniemi (1999) claims that, point loads in drilled glass panes always cause high stresses in the drilling zone. Because of the material properties of glass, it breaks often at a point of a crack. There are cracks on glass sheets and also on the drilling holes. The problem is that there are lots of various drilling machines and drill bits, whose effect on quality of the surface of the drilled holes changes. This might have effects on the strength of the glass. Also the use of toughened glass brings uncertainties. In the study of University of Stuttgart it was found that:

- Strength of glass with diamond milled hole is on the average 26% higher than with water jet drilled hole. Strength of glass with polished holes are approximately the same as with diamond milled holes. The difference between diamond milled holes and water jet drilled holes is probable caused by more energy brought to the hole by water jet. More energy causes deeper cracks and that lessens the strength of glass.

- The rate of load application has influence on ultimate stress. The slower the rate of load application is the higher the ultimate stress is.

- Pretensioning the joint bolt has only an insignificant influence (compared to needed work) on the ultimate stress. With IOOkN pretension in the bolt the ultimate stress of the glass is ca. 5% higher than without pretension.

Optimal position of Glass Panes' Point Support

The FE method is used to design optimal position of glass panes' point support and design point supported glass panes in general. With the help of FE method the maximum main tensile stress is searched which is normally decisive. Modelling the drilling area, geometry of the fastener, liner material between glass and steel is important to do carefully because of their major influence on the results. It is expensive to do such exact calculations but cheaper and rough calculations are not reliable. Therefore optimising the place of the point support is not economically profitable to do in individual projects. In individual projects the architect normally decides the place of the point support after which the needed glass thicknesses and joints are calculated. Point support fasteners that are available in market differ in static point of view in two substantial areas:

1. Distance from the middle of the glass pane to the centre of the rotation.

2. Fasteners' possibility to rotate changing from pinned to stiff.

An additional load to the glass pane is brought by moment caused by eccentric place of the centre of rotation. The influence is especially extensive in restraint caused by temperature expansion. Placing the centre of the rotation on the middle of the glass pane this additional load is avoided.

In table 2.1, the optimal positions for point supports are shown.

- When designing glass panes for dead load, edge distances have only minor effect on main tension stresses.

- When designing glass panes against wind pressure the influence of the edge distance is essential. For rectangular plate there is only a minor effect on main tension stresses when changing b_r as shown in Figure 2.19, but optimising a_r has essential influence. For square plate optimising both a_r and b_r have an essential influence.

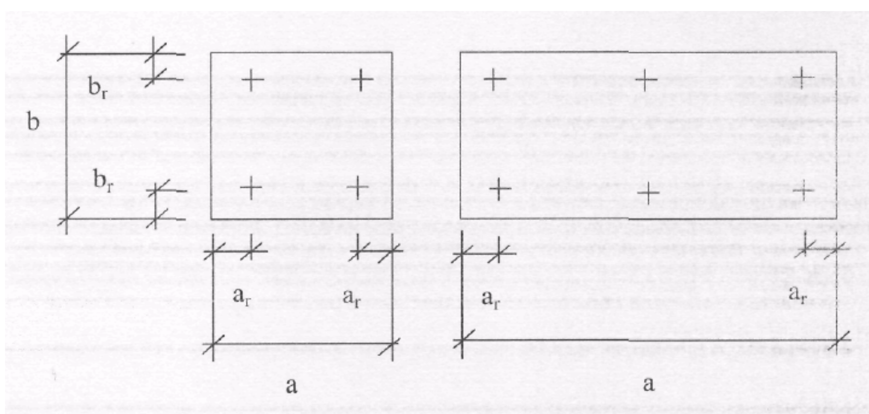

Figure 2.19. Definition of the edge distance for support in 4 or 6 points.
Source: Kallioniemi, 1999

- When designing glass panes for temperature expansion or contraction, the rigidity of the joint effects the most. With pinned or soft joint changing a, or b_r has no effect on main tension stresses. With a rigid joint effect edge distances are essential.

- When designing glass for load combination, main tension stresses act like in a wind pressure case, because wind pressure is the determining load.

Table 2.1. Optimal position for point support to minimise the principal tension
Source: Kallioniemi, 1999

Number of fastaner	The type of glass	Rigidity of the support	Edge distance a r	Edge distance b r
4	TG	soft	0,170*a	0,l70*b
4	LSG	soft	0,200*a	0,200*b
4	TG or LSG	stiff	0,225*a	0,225 * b
4	TG or LSG	rigid	0,225*a	0,225*b
6	TG or LSG	soft	0,145*a	0,170*b
6	TG or LSG	stiff	0,145*a	0,225*b
6	TG or LSG	rigid	0,145*3a	0,225*b
TG=tempered glass, LSG= laminated safety glass, a=length of the pane, b=width of the pane				

2.2.4 Watertightness of the Glass Panes

The seals between the glass panels are made of silicons. This material is used either as a mastic or as extrusions glued together with mastic. The mastic is used on the small joints between glass sheets in a glass panel, and the extrusions are used on the larger joints between panels. Silicone adheres perfectly to glass when applied according to the following precautions: the glass must be absolutely clean and dry; the area of the joint must not be too wide - this could prevent its total polymerization. Under these conditions, silicone has a remarkable adhesive power, a fact which was confirmed by the tests carried out: the joints expand up to four times their original size, and in case of failure they are cohesive and not adhesive, which means that the failure will occur in the joint itself and not on the glued surface. The joint must satisfy three requirements: firstly, it must allow the panels to move in relation to one another; secondly, it must not protrude from the glass external skin; and, thirdly, it must be watertight. The extrusion process involves forcing the basic material through a die. The extruded joint is translucent, which minimizes its presence: it must neither suggest a frame for the suspended glass system, nor disturb the perception that the glass hangs directly from the structural steel frame. Since this type of application for extruded joints was unknown, the joint has been rigorously tested in an accelerated aging device which subjected it, under load, to alternate cycles of humidity, frost and heat.

2.3 Glass Fittings

Structural glass walls overcome the restrictions of conventional frames to provide the ultimate all glass facade. They use proprietary mechanical fixings and toughened safety glass and combine strength and visible lightness to provide high performance window systems. Structural glass is secured to a support structure by a variety of fittings options which are designed to meet the unique requirements of the project. These fixings absorb forces when the glass flexes under load and provide a secure connection between the glass component and the support structure.

The glass fittings shall provide a tolerance capability which will cope with the thermal movement occurring as a result of differential temperature. The components used within the system shall withstand all thermal movements, buckling, distortion, cracking, failure of joint seals or undue stress on the glass and fixing assemblies.

2.3.1 Bolts

According to Rice and Dutton (1995), if an articulated assembly is mounted outside the glass plane, bending or twisting loads will be applied to the glass. This is the case with a stud assembly and with the Pilkington Planar system. With the articulated bolt, the articulated assembly is positioned in the plane of the glass this method ensures that no bending or twisting loads are taken by the glass as shown in Figure 2.20. The Figure 2.21 shows a comparison between the two possible positions of the articulated assembly, i.e. outside or inside the plane of the glass. This has been confirmed by tests, which have shown the benefits that may result from preventing bending loads in the glass. The shear bolt assembly was compared with the articulated bolt system. The mean capacities were respectively 2 and 4.5 tonnes. The articulated bolt ensures that no bending load can be applied to the glass, allowing the designer to predict that all loads will remain in the plane or perpendicular to the plane of the glass. The designer should know the exact behaviour of the assembly. The articulated bolt consists of a head which rotates freely on its stem. The stem ends in a ball on which the head is added using the standard spherical bearing techniques of the mechanical and aviation industries. The head is then machined to the required specifications: countersunk flange, thread, key holes, etc. A threaded washer is screwed onto the head and holds it against the glass. The washer is tightened to a precise torque so as to avoid any unknown or unpredictable stress which may otherwise result from the site assembly of the parts.

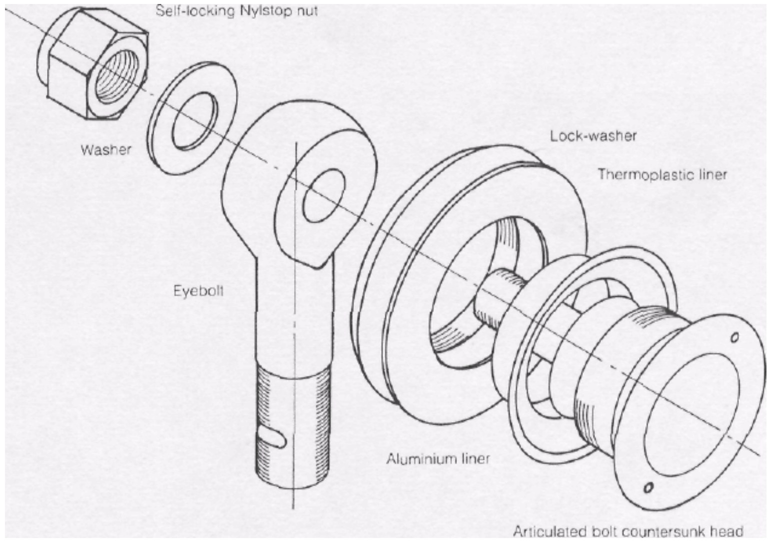

Figure 2.20. Component parts of the articulated bolt.
Source: Rice and Dutton ,1995

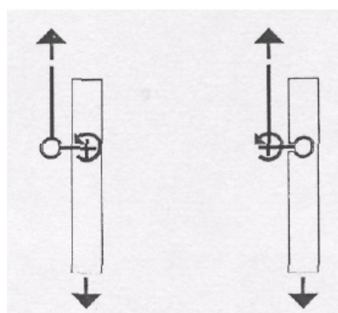

Figure 2.21. Left, in the Pilkington Planar system or in the stud assembly, bending forces can be created in the glass: right, in the articulated bolt system, the bending forces are carried into the support.
Source: Rice and Dutton ,1995

The liner:

Rice and Dutton (1995) states that, steel must never come into direct contact with glass as it has too hard a bearing surface. For this reason a thermoplastic spacer is commonly used between the steel bolt and the hole in the glass. The slightly ductile nature of the liner ensures that the entire bearing surface of the hole is put to work, not just the high points. However, thermoplastics have a tendency to creep which could restrict the fixing point's capacity, eventually allowing the steel to touch the glass. Pure aluminium is used instead because it is a fairly soft metal. Metals creep much less than plastics, and aluminium is soft enough to take the imprint of the glass and of all drilling imperfections, but strong enough to prevent any long-term deformation. The liner is finished with a teflon coating to prevent bi-metallic corrosion between the stainless steel bolt and the aluminium liner.

Industrial process and design:

Resolving the technical problems relating to the hole in the glass and to the articulated boll requires a thorough understanding of the design, manufacture and assembly of the components used. Understanding these different stages means that they can each benefit from the other; for instance, if the manufacturing processes are well understood, this knowledge can be exploited at the design stage. A close working relationship with industry is a key element at the design stage and a must even before the concept is determined. For instance, it was necessary to consult the industry in order to ascertain what glass sizes were feasible, even before the very first architectural drawing of the projects was done. Similarly, the positioning of the holes in the glass, the glass thickness, the methods available for the manufacture of assembly components, etc. are all matters that are solved through consultation assembly. Once the concept is determined, its feasibility must be demonstrated by the manufacturers, then confirmed by sample testing.

Testing

Feedback from testing allows the design to evolve. One concept will be retained, another rejected. The limits of a design are empirically quantified, and in this way confidence in the reliability of unconventional and untried solutions can be established. Such tests have confirmed that the articulated bolt performance is superior to that of the shear stud assembly. The selection of the articulated bolt is a perfect illustration of the impact that testing may have on the project as a whole.

Manufacturing

The tests also showed the correlation between the quality of the glass drilling and the performance of the assembly. The glass must be drilled simultaneously from both sides in order to prevent spelling on the side opposite the drill. If the drill bits are not perfectly coaxial, the hole will have a shoulder. Such a shoulder will cause a higher stress concentration than a smooth hole, where the load is equally distributed. The first and second passes of the drill are designed to meet in the countersunk area so that with the third pass or countersinking operation, any shoulder that may have formed will be eliminated. Spalling of the drilled area may be caused by drilling imperfections due to a blunt drill bit, the presence of foreign matter in the hole, imperfections in the drilled glass or insufficient lubrication of the bit. A hole showing spalling will also cause an unequal stress distribution. Furthermore, spalling causes crack-like detects and, given the brittle nature of glass, cracks may propagate instantly under load. It is, however, extremely difficult to avoid spalling around a perfectly cylindrical hole.

Erection

Any design must take the erection procedure into account. Fastening the articulated bolts is a complex procedure which calls for controlled tightening torques. Such an operation would be unthinkable, or would at least be badly executed, if carried out on scaffolding on a windy day. The articulated bolts are therefore designed to be correctly fixed to the glass on the ground under fairly controlled conditions. Then the whole pane! (with the bolt stems protruding) is hoisted up and fixed to each support in one single bolting operation. Once the concept is determined, its feasibility must be demonstrated by the manufacturers, then confirmed by sample testing.

2.3.2 Current Glass Support Systems

Rice and Dutton ,1995 states that, to appreciate these difficulties as well as the consequences of the countersunk hole design, it may be useful to describe the behaviour of the hole according to the various structural support systems currently available. The list of five mechanical glass support systems below is followed by a detailed description of the system.

Standard Bolt:

The weight of the glass is concentrated at the holes in it. The glass is fixed firmly to the support structure and the assembly does not allow any differential movement between the glass and the supporting structure as shown in Figure 2.22

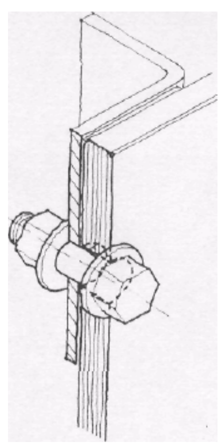

Figure 2.22. Standard bolt: The weight of the glass is taken by the area around the hole.
Source: Rice and Dutton, 1995

Patch Plate:

This component was used by Norman Foster in the glass wall of the Willis Faber & Dumas building. It is an improvement on the standard bolt in that the weight of the glass is not taken only by the area surrounding the hole as shown in Figure 2.23. The patch plate is glued to the glass and the entire assembly is clamped together by a bolt. The weight of the glass is thus taken by its bonding with the patch plate, which is itself retained by a bolt. The hole (with its small drilling imperfections) is no longer subjected to the load of the glass. As in the previous system, the glass is firmly fixed, permitting no differential movement.

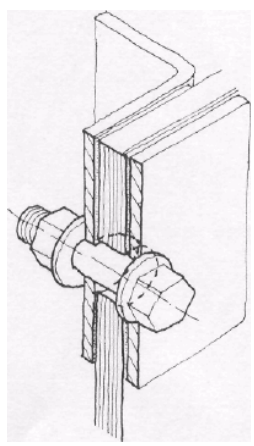

Figure 2.23. Patch plate:The weight of the glass is taken by bonding and friction against the patch plate.
Source: Rice and Dutton, 1995

Simple Countersunk Bolt:

With a countersunk bolt it is possible to achieve a flush outer surface (for this reason it is commonly used in all-glass squash courts). All the loads applied to the hole (weight of the glass, wind, impacts, etc.) are concentrated on the small area around the countersunk hole as shown in

Figure 2.24. Given the brittle nature of glass, high concentrations of stress at local points or in holes with drilling inaccuracies can easily lead to fracture of the glass; As with the other systems mentioned above, this assembly does not allow differential movement.

Stud Assembly:

It can take relatively heavy loads while allowing the outer surface to retain a perfectly smooth appearance. The weight of the glass is taken by a large cylindrical stud and the horizontal external loads are taken by small countersunk screws as shown in Figure 2.25. These screws fit in an oversized hole allowing them to slide vertically, thus ensuring that they will

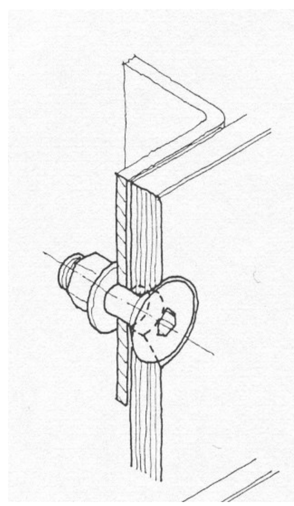

Figure 2.24. Simple counter bolt: The weight of the glass and the loads are concentrated around the countersunk hole.
Source: Rice and Dutton, 1995

not take any vertical load. Within a suspended glass system, the weight is taken by the upper part of the hole. The larger the hole, the wider the load-bearing surface, and the pressure applied to the glass is therefore reduced. Since the support plate, stud and screw assembly do not allow any differential movement, this component was coupled with an articulated assembly in order to achieve the required movement capacity.

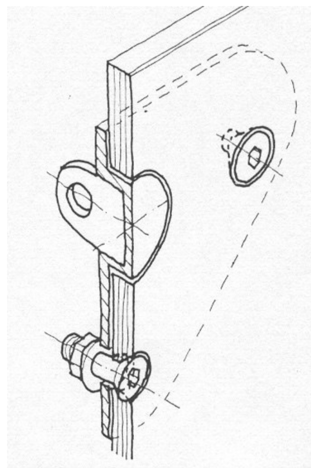

Figure 2.25. The stud assembly: The weight of the glass is taken by the stud. The other loads are taken by the areas around the countersunk holes.
Source: Rice and Dutton, 1995

The Pilkington Planar System:

This system, invented by Pilkington Glass, is widely available commercially. It allows the panes of glass to move in relation to their supporting structure while maintaining a perfectly smooth outer surface appearance as shown in Figure 2.26. When large panes of glass bend under wind loads, a high load concentration will occur in the area of the hole if the retaining bolt is firmly fixed to the supporting structure. The Pilkington Planar system allows the bending pane of glass and the bolt to move by using flexible washers at the fixing to the supporting structure. The above analytical comparison underlines the major design issues concerning the hole in the glass. In brief:

- a supporting system at point locations causes high load concentrations;

- the hole in the glass is very sensitive, particularly if it s countersunk;
- enlarging the hole can reduce the load in the bearing surface;
- articulated assemblies allow the differential movemets between the glass and the structure to be absorbed.

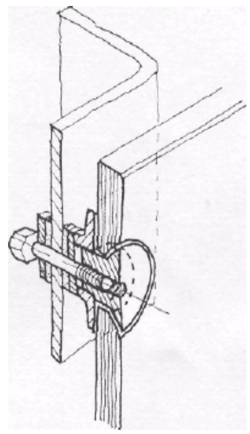

Figure 2.26. The Pilkington Planar system: Flexible washers placed at the contact points with the supporting structure allow the bolt the move in relation to the support.
Source: Rice and Dutton ,1995

2.4 Pioneering Examples

There are several completed projects where the system was developed, implemented and enriched with special and standard components. In this part, the frontier structural glass wall projects were introduced.

2.4.1 Channel Four Headquarters Building

Location: Horseferry Road, London

Developer & Owner: Channel 4 Television

System: Fully suspended curved entrance glazing with cable net structure

Architect: Richard Rogers Partnership

Engineers: Ove Arup & Partners

Contractor: Bovis Construction Ltd.

Contractor (Glazing) Permasteelisa / Eiffel

Completion: December, 1993

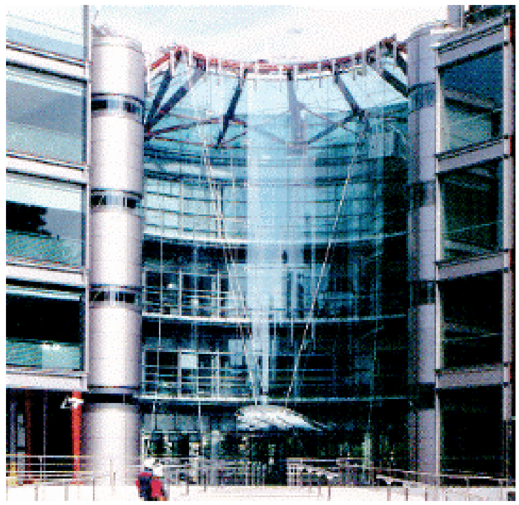

Figure 2.27. Channel Four Headquarters Building.
Source: www.permasteelisa.com, 2003

The Channel Four TV Headquarters Building has become a London landmark and occupied a prominent corner plot on Horseferry Road, near Victoria, and comprises 15,000 m² of headquarters and studios, an underground car park and a landscaped garden square. Its distinctive entrance is through a dramatic, concave laminated glass facade. (Figure 2.27) A stepped ramp leads from the street, over a laminated glass bridge (Figure 2.28) spanning a laminated glass skylight to the TV studio area below. (Figure 2.29)

Figure 2.28 . Laminated glass bridge
Source: www.permasteelisa.com, 2003

Figure 2.29. Channel Four Headquarters Building
Source: www.permasteelisa.com, 2003

Behind the entrance foyer a restaurant fills the curve with views over the garden. A sweeping roof-top terrace extends from the top level board rooms.

The main aim of architect for preference of structural glass wall system is to achieve maximum transparency for the building. A 20 m high curved screen surrounding returns on both sides and a roof light was to be fully suspended from a cantilevered steel structure to form a light and structure freed entrance screen running the height of the building. In addition a canopy was to be supported by the same structure.

The two four-storey wings containing office space are arranged in an L-shape, which addresses the corner of the street with a curved connecting space framed by two 'satellite towers'. To the left are four conference rooms stacked one on top of the other, and to the right lifts and plant, topped by transmission antennae. The entrance, through a dramatic concave suspended glazed wall, is the predominant feature of the scheme. A stepped ramp leads from the street over a glass bridge spanning the roof-light of the studio area below.

At this project, a heavy top cantilever structure was executed for supporting suspended facade and a cable net structure was used for carrying horizontal wind loading. In addition,12 mm toughened glass is preferred to cover glass wall of the facade and also 20 mm toughened laminated glass was used for rooflight. The articulated bolt fittings and spider fittings were used to fix the glass panes. (www.permasteelisa.com,2003)

2.4.2 New Leipzig Fair

Location: Leipzig, Germany
System: Suspended Structural Glass Vault
Architect: Von Gerkan, Marg and Partner (GMP)
Engineers: Ove Arup and Partners
Contractor: MERO GmbH & Co.
Completion: 1996

Figure 2.30. The New Leipzig Fair
Source: www.mero.de, 2003

The new Leipzig Trade Fair building, designed by architects von Gerkan, Marg and Partner (GMP) of Hamburg and completed in 1996. The New Leipzig Fair is the largest frameless suspended glass shell ever to have been built. It is a barrel vault shape and its length is 244 metres, width 80 metres and it is 35 metres high (Figure.2.30) The most spectacular aspect to the Leipzig Trade Fair is undoubtedly its laminated glass hall, designed by Ian Ritchie Architects of London. (Figure.2.31)

The glass hall represents a late 20th century equivalent of London's Crystal Palace – a totally glazed enclosure using laminated glass in all 28,000m^2 of its overhead glazing. It is the principal building through which all visitors to the Trade Fair enter and provides a surface area of 242m x 79m for reception, information and meetings. It is linked directly to the Trade Fair's exhibition halls through a series of tubular, laminated glass bridges. Transparency and safety were two primary design objectives for the glass hall. For maximum transparency, the aim was to minimize silhouette without compromising safety. Toughened laminated glass was the viable safety

Figure.2.31. The Laminated Glass Hall.
Source:www.mero.de, 2003

choice for such extensive overhead glazing; to improve transparency still further, another goal was to support the laminated glass with unobtrusive point fixings rather than conventional framing. The load-bearing structure of the construction can be divided into three different parts; the barrel, the bent truss and the front wall structure. The main tasks were to construct joints without restrain stresses in glass pane and still maintain stability and sealing. The barrel is constructed of zinc-coated welded tube grid with 3 metres deep. The connections of the grid are all rigid, and to avoid stresses caused by temperature expansion the tubes are connected to the ground with sliding support. The idea is to let all tubes expand equally in longitudinal direction. The bent truss is constructed of zinc-coated steel tubes. Specialities of the truss are the A-form diagonals (Figure.2.31), which create service stairs onto the bottom chord. The front wall structure is also constructed of zinc-coated steel tubes. Because of the sliding support of the barrel grid, the wind loads in longitudinal direction are only carried by front wall. The grid can only transfer the wind loads. The main functions of the load carrying steel structure is to carry glass structures with a minimum

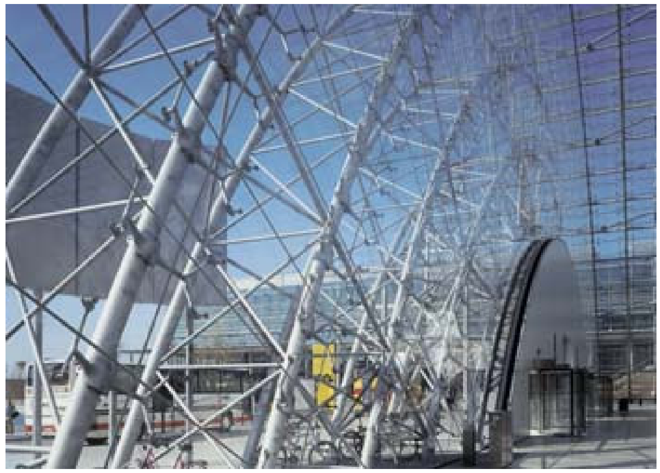

Figure.2.32. The girder.
Source:www.mero.de, 2003

cost and to satisfy the architect's image of the building. The laminated glass panels of the overhead glazing are 3.105 x 1.525m in size, made in two layers of 8mm and 8+10mm toughened glass laminated with a 1.5mm PVB interlayer. This laminated glass construction is stabilized and supported by primary trusses at 25m centers with outriggers stabilizing the grid between these. The glass structure requires exceptionally small tolerances. The joints are constructed of stainless steel point supports. The ideal point support would have been pinned joints, because then the joint itself does not create any stresses, when there are displacements of the glass pane, but in suspended glass panes, pinned joints do not compensate existing longitudinal and transversal displacements. Therefore three different kinds of joint types were used in connecting the panes to steel structure:

- Support is fixed in every direction.
- Support allows movement in x-direction.
- Support allows movement in x- and y-directions.

The joints allow thermal expansion of glass panes without any stresses and prevent restrain loads caused by displacements of load-bearing structures. The glass panes are connected together only with silicone and without additional mechanical fastener. A special requirement of the joints is large displacements of the pane. The displacements can reach !8 mm between two individual panes. The traditional sealing technique had been used, expansion cracks would have been unavoidable. Therefore a new, many component sealing system was developed. The scaling was accomplished with prefabricated silicone profile and squeezable silicone. The prefabricated silicone profile takes the displacements of the glass panes and the function of the squeezable silicone is sealing and bonding the glass panes together.

CHAPTER 3

MATERIAL & METHOD

Here is presented the material, method of the study of spider joint fittings and a case study: the Akman Condomunium Business Center-Medicorium Building in Ankara. First is presented 'The Survey Material.' Then, the method of the study and analysis are presented as 'The Survey Methodology.'

3.1 The Survey Materials:

A survey was carried on different types of connecting springplates also referred to as spiders. A case study was conducted on the Akman Condominium Business Center-Medicorium Building in Ankara. In this regard, The Boeing Headquarters Building, which was constructed with a similair glass wall façade system with the Medicorium Building was analyzed. In following section, the general properties and main applications of spider fittings are described briefly and then the case study building is described in detail.

3.1.1 The Springplates:spiders

Structural glass wall systems have fulfilled the modern design demands that have begun to push the envelope to maximize glass area in architectural projects. With this concept in mind, the "Spider" type of glass fitting was developed. Spider type of glass fittings are the one of the most important parts of the structural glass wall systems because they work between glass panels and lateral structural systems. One of the main duties of the spider glass fittings is to transfer the loads from glass panels to the supporting structure. Spiders are designed to create the glass curtain walls, and carry the loads associated with wind load and stack pressure. They transfer these loads to the structure. In spite of having same structural purpose, there are different types of spiders available for use in projects.

3.1.2 Case Study: The Akman Condominium Business Center-Medicorium Building

The Akman Condominium Business Center is located in Balgat district of city of Ankara. The project of the building was executed by architect Mustafa Yücesan of Doku Architectural Firm, in 1997.

The center is composed of three individual buildings (Appendix A). The main body is a high rise hotel block with 31 storeys and a 110 m height of as shown in Figure 3.1. The Medicorium is a health centre as shown in figure 3.2. The third building, Emporium is a shopping mall. The survey was conducted on the Medicorium building.

Figure 3.1. Akman Condomunium Business Center.
Source: www.tugut.com, 2003

Figure 3.2. Medicorium building.
Source: www.tugut.com, 2003

The Medicorium building is connected to the main body with a laminated glass bridge supported by a steel structure. The main entrance of the building is at the south façade. The west façade of the Medicorium building was articulated by a 30 m long and 9.5 m high three storeyed curvilinear glass wall, executed with the structural glass wall systems, over looking the street #399 passing in front of the center as shown Figure 3.3. Its main entrance at south façade is covered with laminated glass canopy supported by the steel structure.

Figure 3.3. The façade of Medicorium building.
Source: www.tugut.com, 2003

The Boeing Headquarters Building is a 4 storeyed office building which is located in Seattle, Washington designed by Loschky Marquardt & Nesholm. The curvilinear entrance façade was executed by 13.5 m high and 40 m long structural glass wall system, as shown in Figure 3.4.

Figure 3.4. The Boeing Headquarters building.
Source: www.mero.de, 2003

3.2 The Survey Methodology

As stated earlier, the survey consisted of two parts; 'Springplates:spiders' and 'The case study: The Akman Condominium Business Center-Medicorium Building.'

3.2.1 The Springplates:spiders

For the survey of springplate spider type fitting elements, one of the main components of the structural glass wall systems, were chosen as subject. The main purpose was to classify and organize the available spider fittings produced by manufacturing companies and used in structural glass wall projects.

The survey was formatted to describe spider fitting systems and mainly to classify the types of spider fittings. At first, main characteristics and basic applications of spider fittings are discussed. Glass-spider fitting details created by manufacturing companies are presented and discussed within the architectural perspective. The basic goal of this section was to demonstrate general principles influential in the designing phase of the fittings.

Secondly, the classifying study was done according to similarities and dissimilarities between spider fittings. In this regard, information was obtained from manufacturing companies and existing structural glass wall projects in Turkey. Moreover main aim of this part is to put forward the organized and classified possible spider fitting samples which can be used to design a glass wall by designers. Therefore, all spider fitting producers, available both in Turkey and abroad, and finished structural glass wall projects were studied and listed. Accordingly, some of producer companies working in Turkey, Hasmatik Ltd Şti and Metric Ltd.Şti ,were visited and engineers, architects who are responsible for designing and producing process of fitting elements were interviewed on their products. All related documents, technical data, CAD drawings and photos of their products were taken. The rest of the companies working in Turkey were contacted by phone call and they sent their catalogues and documents by postal service.

Moreover, the other companies working abroad were made contact by visiting their web sites. Some of documents downloaded from web sites but the main part of documents posted by them.

At next step, frontier executed structural glass wall projects both in Turkey and abroad were studied. For the projects abroad, the detailed information were obtained by web sites related with these examples. All data about the projects and documents for spider fittings used at projects were downloaded.

Moreover, to get information about some of the executed projects in Turkey the construction firms of the projects were visited. The architectural departments of these firms were contacted to get related documents. The remaining part of projects constructed in Turkey was visited individually in

İstanbul and Ankara. The photos of the building, façade, structural glass wall system and its fittings were taken by the author and also written document about the project obtained by construction firms.

After gathering all documents related with the subject as raw data, whole documents are investigated to explore the differences and similarities between spider fittings produced and executed at projects. At the end of the evaluation phase of information, to make a classifying study with these products, the author determined following three basic categories: the materials with surface finishes ,load carrying capacities and structural support system with used them. Thereafter, whole document, data, photos of the spider fittings were combined in a spider fitting selection table describes the types of spider fittings in detail.

During executing of this study, ACAD 2000 and 3d Max software programs were used to draw detail drawings and render 3d view of some spider fittings.

3.2.2 Case study : The Akman Condominium Business Center-Medicorium Building

For the survey ,The Akman Condominium Business Center, Medicorium Building was chosen as subject. The glass wall of west façade of the building was studied. The survey was formatted to describe the individual properties of the structural glass wall system used at the façade of the building. The structural system, type of glass and glass fittings executed at that project were examined. The application details were studied.

In this study, the structural glass wall system of the facade is investigated under main four topics; the design considerations the structural system, the type of glass and the glass fittings used at system. In this regard, information was gathered by visiting Doku Architectural Office and Tugut

Construction Company. The interview was executed with the occupants of the building to get their negative and positive thoughts about the building. All related documents, architectural projects and data about the building were taken. Moreover, related web sites were visited. The photos of the building were taken by the author.

In the next part of the study, comparison study was done between Akman Condominium Business Center, Medicorium Building and the Boeing Headquarters building, which was chosen because of sharing the same structural glass wall system. Information describing the structural glass wall project of Boeing Headquarters building was given. The documents about the building gathered from web site and the catalogue constructer firm: Mero GmbH & Co. These two buildings were compared according to their application details, structural support, glass types and glass fitting types.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this chapter, first the results and discussions of spider fittings were presented. The spider joint fittings were analyzed under three main topics; the type of materials with surface finishes, load carrying capacities and structural support system with used them. At next step, the evaluations of the Medicorium building were executed in terms of design considerations, supporting structure properties and characteristics of the main components of structural glass wall systems. Thereafter, the Boeing Headquarters building was analyzed and compared with the Medicorium building. Finally, the criticisms derived from investigations of both buildings were stated.

4.1 The Springplates: spiders

The spider fittings are designed to support a maximum loading and allow flexibility to reduce stresses around the glass holes. Spiders assist the glass façade in absorbing any dynamic movement while allowing maximum transparency. The loads are transferred from the glass through the spider fittings into the supporting structure. There are mainly three considerations affecting the design of a spider, described as follows:

- **Load Bearing Capacity**

The load combination acting on the spiders is an important criteria for designing phase of the spider fittings. That is one the most important factors to determine the dimensions of a spider fitting. The length and thickness of the arms of spider fittings are decided after making load calculations. In this respect, to determine the dimension of a spider: first, the loading paths of spiders are analyzed as shown in Figure 4.1. Then, the vertical and lateral capacities of spiders are tested. The load bearing capacities of the spiders are calculated by compression and tension tests to graph the load and displacement relation as shown in Figure 4.2. After executing compression and tension tests, with respect to the results of the tests, the load-displacement curve is obtained as shown in Figure 4.3. After calculating the load taken for an arm of the spider, the production dimensions are determined.

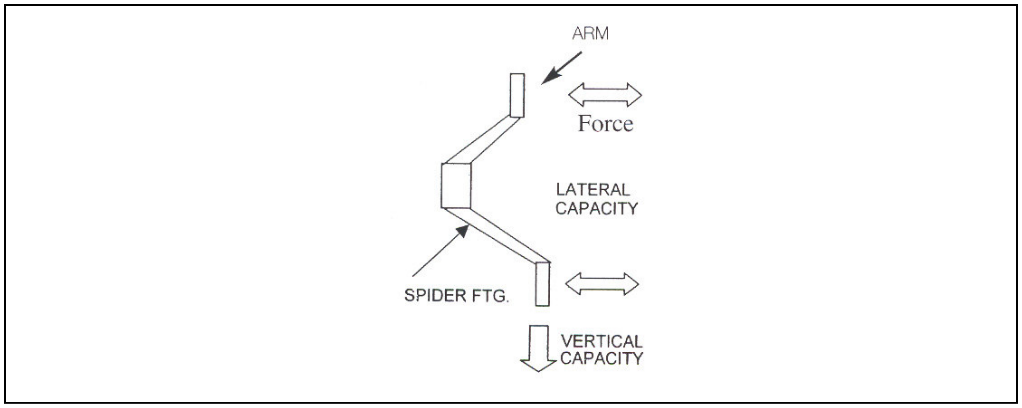

Figure 4.1. Load bearing diagram of a spider fitting.
Source: Australian Glass Assemblies, 2003

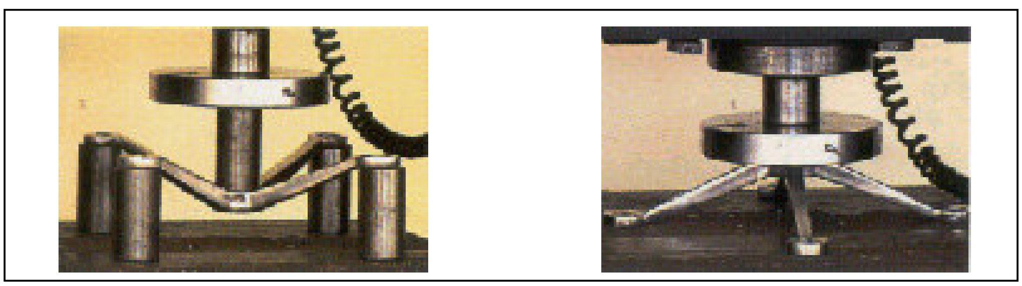

Figure 4.2. Compression and tension tests of spider fittings.
Source: Australian Glass Assemblies, 2003

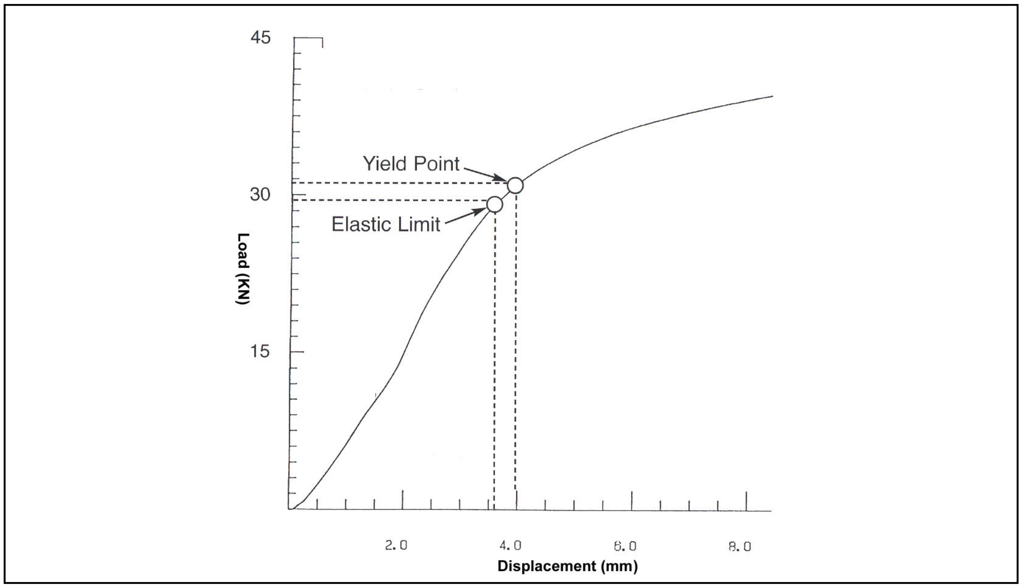

Figure 4.3. Tension and compression graph of a spider.
Source: Australian Glass Assemblies, 2003

In this regard, the spiders can be divided into the two groups in terms of their load bearing capacities as follows:

The heavy duty spiders

The heavy duty spiders are used to carry large, heavy glass panes and big amount of lateral loads, in multistorey structural glass walls. To determine the dimensions of the spider the local lateral load data and the weight of the glass panes are needed. They are produced by lost wax casting method from stainless steel (Figure 4.4), steel, aluminium (Figure 4.5) and rarely from brass with polished, satin and epoxy painted finishes as shown in Figure 4.6. They are produced in the form of 1,2,3,4 armed. The number of arm of a spider depends on location in glass pane. Moreover, they are produced for steel supported systems and glass fin supported systems. The thickness of the arm is deeper than a conventional spider. The thickness of the arm can be obtained according to the amount of load taken by the spider.

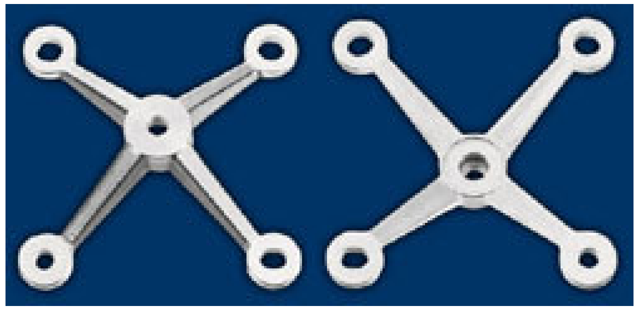

Figure 4.4. Stainless steel with polished finished surface, produced by lost wax casting method, heavy-duty spiders for steel supported structures.
Source: www.sadev.com, 2003

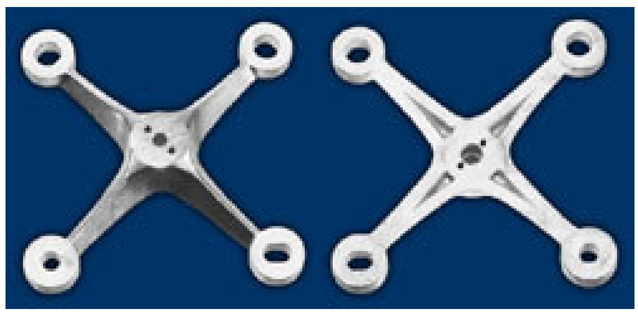

Figure 4.5. Aluminium with satin finished surface, produced by lost wax casting method, heavy-duty spiders for steel supported structures.
Source: www.sadev.com, 2003

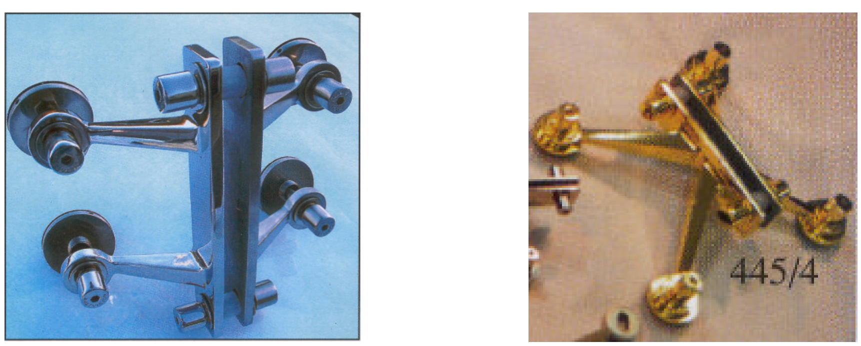

Figure 4.6. Stainless steel and brass with polished finish heavy-duty spiders produced by lost wax casting method for glass fin systems.
Source: www.sadev.com, 2003

The light duty spiders

The light duty spiders are used to carry light glass panes and small amount of lateral loads in single or double storey buildings. They are generally produced by cut plate and lost wax casting method from aluminium and stainless steel with polished, satin and epoxy painted finishes as shown in Figure 4.7 and Figure 4.8. They are produced in the form of 1,2,3,4 armed. Moreover, they are produced for steel supported systems and glass fin supported systems.

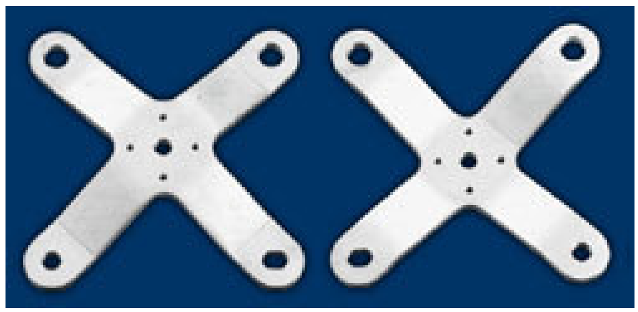

Figure 4.7. Aluminium with satin finished surface light-duty 4- armed spiders produced by cut plate method for steel support structures.
Source: www.sadev.com, 2003

Figure 4.8. Aluminium with satin surface light-duty 4- armed spiders produced by cut plate method for steel support structures.
Source: www.sadev.com, 2003

For the cut plate method, the thickness of the arm depends on the thickness of the ready-made material so the thickness of the arm especially changes between 8-14 mm.

- **The material**

There are mainly three types of materials: stainless steel, aluminium used for the production of spider fittings described as follows:

Stainless Steel

Stainless steel is the most preferred material for production process of spider fittings. There are three types of stainless steel: marsentisic, ferritic and austenic. These are defined by their chemical compositions and by the treatment the material has undergone. The most popular type of the stainless steel used in production of spider fittings is austenic steels because it can be easily formed and welded so It is suitable for special application cases.The most important reason for preference of this material by spider fitting manufacturing companies are high resistance to corrosion and seawater. It doesn't corrode nor turn dark in outdoor climatic conditions. It contains lots of chrome which creates a protective chrome dioxide coating. Therefore it does not have to be covered with covering materials and also it doesn't need extra service for its long life span. These products are suitable for internal and external applications especially for glass canopies (Figure 4.9) and some structural glass wall systems having support structures outside of the building as shown in figure 4.10.

Figure 4.9. A Glass canopy.
Source: www.pilkington.com, 2003

Figure 4.10. Structural system placed at outside, Western Morning News, Plymouth, UK.
Source: www.pilkington.com, 2003

Moreover, stainless steel spider fittings can be divided in two parts according to surface finishes:

Polished finish surface, which is available for stainless steel spider fittings. Surface finish choise generally depends on appearance as shown in Figure 4.11.

Non-polished (satin) surface, which is available for stainless steel spider fittings as shown in Figure 4.12.

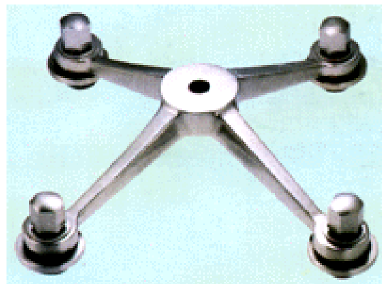

Figure 4.11. Polished finish surface spider.
Source: Autvision Glass Assemblies, 2003

Figure 4.12. Non-polished finish surface spider.
Source: Autvision Glass Assemblies, 2003

Aluminium

Aluminium is a light, corrosion resistant material that needs only a little service. It's weight is only one third of stainless steel but its strength is half of stainless steel's. Thus aluminium type of spider fittings are suitable for light-weight duties. (Figure 4.13)

Aluminium is not easily welded and therefore not used for individual cases. It is difficult to weld large forms and lists without distortion. Moreover, the pained finish surfaces in all RAL epoxy colors are also available with aluminium spiders as shown in Figure 4.14

Figure 4.13. Aluminium with satin finished surface spider.
Source: Autvision Glass Assemblies, 2003

Figure 4.14. Aluminium with epoxy painted surface spider.
Source: www.sadev.com, 2003

- **The Support Structure Type**

The type of spider fittings changes according to support structure of structural glass wall types. There are two basic support structures effecting the duty and shape of spider fittings: steel structures and glass fins systems. The type of spider chances according to connection geometry between glass panes and support structures.

Glass Fin System

The support structure of the system is glass sheets so the spider fitting elements should capture the glass supports. The spider fittings transfer the loads to the glass vertical columns. The type and form of the spider fittings depend of the location at the structural system (Figure 4.15).

Figure 4.15. Glass Fin System.
Source: C.R.Laurance Co.Inc, 2003

The spider joint fittings used in glass fin systems were listed below in accordance with their number of arms.

- *One armed wall mounted fin stabilized type of spider (Figure 4.16)*
- *One armed post mounted fin stabilized type of spider (Figure 4.17)*
- *Two armed wall mounted fin stabilized type of spider. (Figure 4.18)*
- *Two armed post mounted fin stabilized type of spider. (Figure 4.19)*
- *Three armed post mounted fin stabilized type of spider.(Figure 4.20)*
- *Four armed post mounted fin stabilized type of spider.(Figure 4.21)*
- *Four armed post mounted fin stabilized type of spider.(Figure 4.22)*

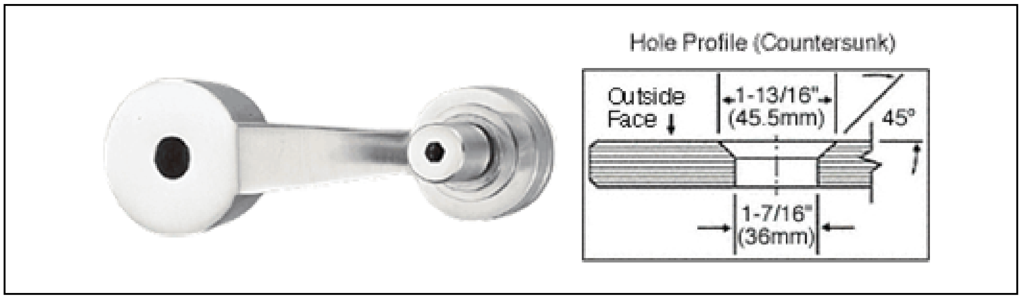

Figure 4.16. One armed wall mounted fin stabilized type of spider. Source: (C.R.Laurance Co.Inc, 2003

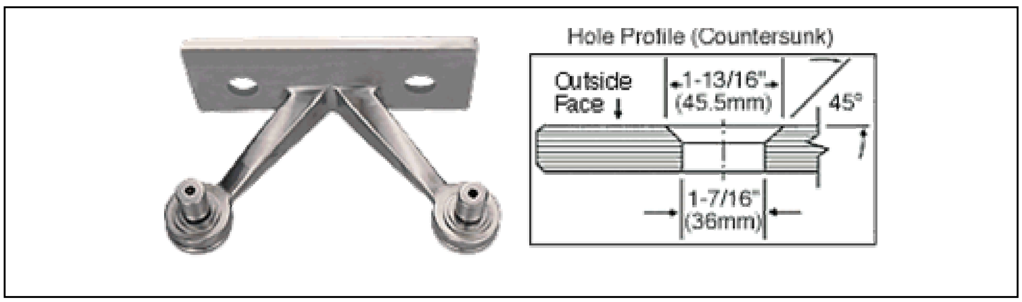

Figure 4.17. One armed post mounted fin stabilized type of spider. Source: C.R.Laurance Co.Inc, 2003

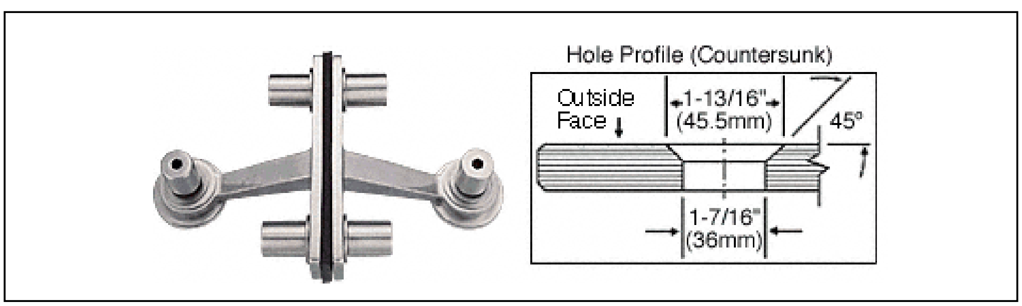

Figure 4.18. Two armed wall mounted fin stabilized type of spider.

Source: (C.R.Laurance Co.Inc, 2003)

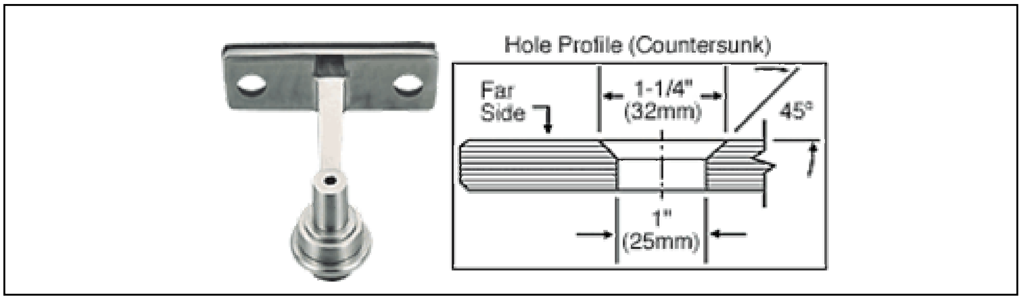

Figure 4.19. Two armed post mounted fin stabilized type of spider.
Source: (C.R.Laurance Co.Inc, 2003)

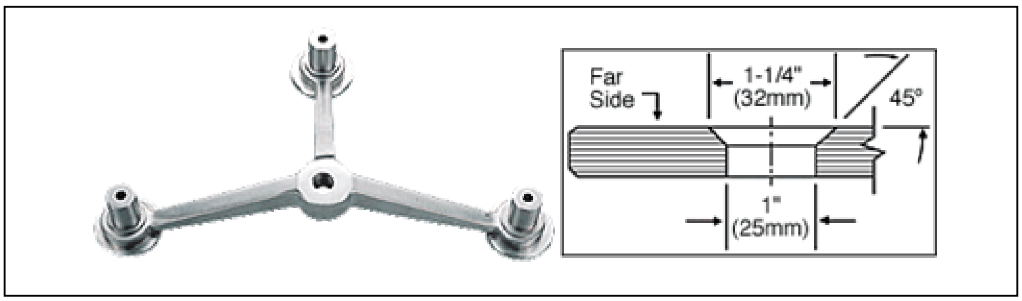

Figure 4.20. Three armed post mounted fin stabilized type of spider.
Source: C.R.Laurance Co.Inc, 2003

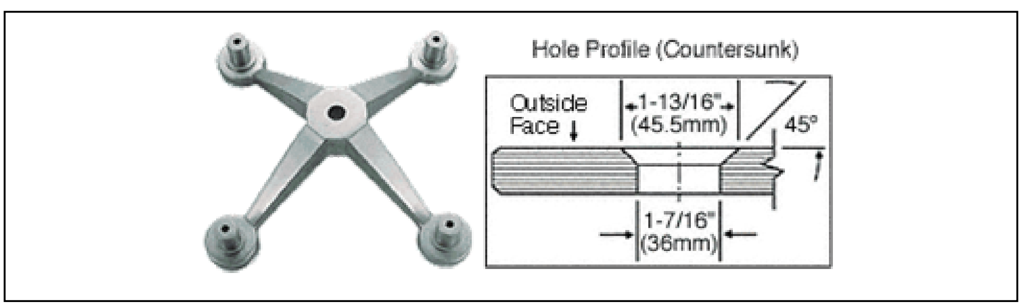

Figure 4.21. Four armed post mounted fin stabilized type of spider.
Source: C.R.Laurance Co.Inc, 2003

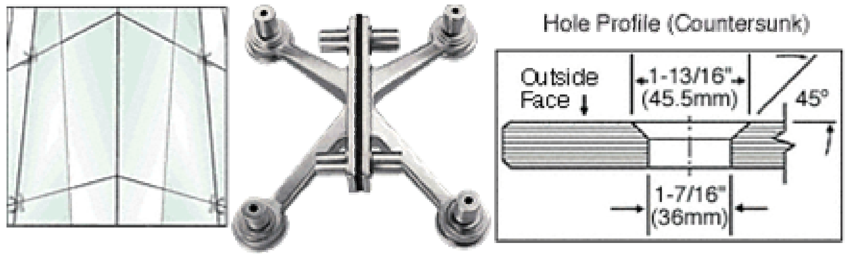

Figure 4.22. Four armed post mounted fin stabilized type of spider.
Source: (C.R.Laurance Co.Inc..2003)

4.1.1 Spider fittings selection guide

In accordance with the detailed study on spider fittings stated at previous part, the documents describing and defining the spider joint fittings, were combined by the author in a spider fitting selection table indicating the types of spider fittings in detail (Table4.1). In the first and second rows of Table 4.1, the heavy duty spider fittings and light duty spider fittings were described in terms of their material and surface finish types of the products executed by different manufacturing firms. The glass fin systems and steel supported systems were explained briefly in the first column. The rest of the columns depict, one armed, two armed, three armed and four armed spider fittings individually (with the pictures of the products) in terms of their material type, surface finish type and location in the structural glass wall system.

Table 4.1. The fitting selection guide

4.2 Case study: The Akman Condominium Business Center-Medicorium Building

As noted earlier, Akman Condominium business center is composed of three buildings, one of which is 3 storey Medicorium building connected to the main hotel block with a steel supported glass bridge. The Medicorium building is used as a Maternity Hospital and a Tube Baby Centre. The main construction firm of the building is Tuğut Construction Engineering Ltd. and also the glazing construction is Çağtek Aluminium Ltd which was developed application details and constructed the structural glass wall façade of the building. This façade was executed as first structural glass wall in Turkey with only local produced materials. The structural calculations of steel supporting system was done by Alhan Gedik.

The Medicorium building is a semi-circular building which has a 30 m long and 10 m high curvilinear glass façade. The façade of the building was executed with steel supported structural glass wall system, which resembles to some extent the structural supporting system and design of the façade of the Boeing Headquarters building in Washington as shown in Figure 4.23.

In subsequent sections, the comparisons will be made with respect to similarities and dissimilarities of these two buildings, while describing structural glass wall system of the Medicorium building.

Figure 4.23.: Right, a closer view of the façade of The Boeing Headquarters Building, Left: a closer view of the façade of The Medicorium Building.
Source: Doku Architectural Firm, 1999 and www.mero.de, 2003

4.2.1 Design Considerations

The Medicorium building is a semicircular building surrounded by a double layered curvilinear three storeyed glass façade executed by structural glass wall system as shown in Figure 4.24. The façade of the building is composed of two layers; the first layer consists of a glass wall and the other layer is a conventional solid wall with 1.2mX1.2m windows in the rooms on inside boundary as shown in Figure 4.25.

Figure 4.24. Façade of the medicorium building.
Source: Çagtek alumunium, 2003

Figure 4.25. Façade of the Medicorium building
Source: Çagtek alumunium, 2003

There is a 60 cm gap between glass and solid walls. This gap continues along the whole façade and works like a quilt surrounding the building. It prevents building from thermal heat loss. In other words, it works like a heat insulation material covering the façade at winter seasons.

On the other hand, the glass façade and also the gap between facade layers look to the west direction and this situation causes over heating problem at summer time.

Besides, that property of the façade also creates some problems in terms of architectural articulation of the spaces directly related with facade. The volume of the space blocked between layers of the facade doesn't open to the common spaces of the building. It means that the occupants of the building cannot use this space effectively.

According to the architectural project of the building, the patient rooms are located behind the double layered façade. These rooms cannot establish direct relation with the outside. They cannot utilize fresh air and direct sun light which are valuable necessities for patients. In this regard, the structural glass wall facade becomes a visual and a solid barrier for the rooms at periphery of the building. The structural glass wall system is a fixed system, all glass panes are fixed to the structural supporting system. In other words, spaces namely rooms behind the glass wall cannot open to the outside like in the event of the Medicorium building. The occupants of building cannot benefit from the garden in front of the west facade. This situation causes a big disadvantage for the building in terms of utilization of spaces by occupants. The main reason of this problem is the wrong use of structural glass wall system in that project according to the architectural design principles.

On the other hand, as stated before a similar system was used at the Boeing Headquarters building. The Boeing Headquarters building is a 4 storey office building located at Renton, Washington. The building is surrounded by 14m high and 45m long curvilinear structural wall façade as shown in Figure 4.26.

Figure 4.26. Four storey height of façade of the Boeing Headquarters building.
Source: www.mero.de, 2003

The system of structural glass wall façade of the building carries some similarities with the façade system of Medicorium building in terms of steel structural supporting type, glass types and glass fitting connection elements. The structural support system of the façade is almost the same with the Medicorium building. In spite of having such similarities, the case of Boeing Headquarters building differs in terms of architectural design approaches. The design principle of the building follows logical sequence in terms of integrity of interior and exterior spaces.

There is a well articulated 4 storey height lobby atrium, main core of the building faces the Longacres Park campus through fully transparent steel supported glass wall as shown in Figure 4.27. Moreover, the spacious, welcoming atrium defined by the structural glass wall provides a dramatic entrance to the building's lobby. Unlike in the Medicorium building, the whole highly articulated elegant glass wall can be perceived from inside of the building by occupants. The structural glass wall has an additional role for articulating the interior and exterior façades as an architectural element as well as being an part of the façade of the building.

Figure 4.27. Atrium lobby of the Boeing Headquarters building.
Source: www.mero.de, 2003

One of the most important features of structural glass wall is to achieve fully transparent facades to have natural day light inside and to integrate exterior and interior spaces of the building. This purpose can be understood clearly in Boeing headquarters building in terms of effective use of fully transparent glass façade.

4.2.2 Supporting Structure

The steel structural supporting system of the structural glass wall system is composed of basically three components: first, horizontal placed 3D space framed truss, second, vertical placed wind bracing rod system and last part, vertical load carrying columns of the building. The main component of the structure is a space framed 3D bent horizontal truss (figure 4.28) composed of two substructural elements: one of them is of ϕ 500 mm X 3mm, paint finished steel tubes, working as main structural elements at outer

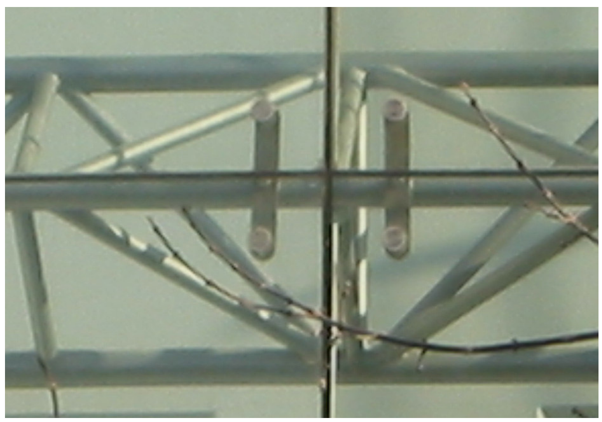

Figure 4.28. 3D space framed horizontal truss.
Source: By author, 2003

boundaries and second elements, combining these main tubes are ϕ 250mmX 2 mm as paint finished steel tubes. The depth of the truss is 37 cm. The main truss is in curvilinear form 34.5 m long and combined with 6 individual trusses, five of them is 6mt and one of them is 4.5 mt. These trusses were bolted to the each other. In other words they are demountable. These trusses were come together at construction site. All tube elements constituting trusses were bended according to the curvilinear form of the façade (Figure 4.29).

Figure 4.29. Curvilinear form of the façade.
Source: Çagtek alumunium, 2003

There are three rows of bent space framed trusses fixed to the columns of main structure of the building with hinged supports at five different points as shown in Figure 4.30.

Figure 4.30. The space framed truss hinged to the column.
Source: By author, 2003

The main structural function of truss is to carry self weight of the glass panes with stainless steel two armed joint fittings directly connected to the main trusses with bolts and to resists against lateral loads with the help of vertical steel rod bracings. The main supporting structure is fixed to the main steel structure of the building by bolting to let the system move in any directions in the event of thermal, seismic movements and extreme wind loads. All glass connection fittings, (spiders) are bolted to the main trusses.
Whole load carrying assembly is produced from steel and manufactured by local producers in Ankara.

On the other hand, as stated earlier, the structural support system of the Boeing Headquarters building carries some similarities in terms of type and form of main structural system of the glass façade. Like in the Medicoruim building, there are three rows of trusses located at the façade of the building as shown in Figure 4.31. The truss installed at the first row is a 3D space framed horizontal bent truss like that of the Medicorium building as shown in Figure 4.32.

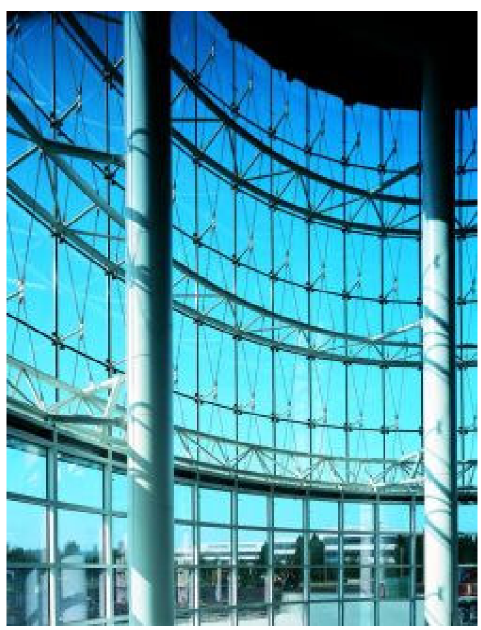

Figure 4.31. Three rows of trusses.
Source: www.mero.de, 2003

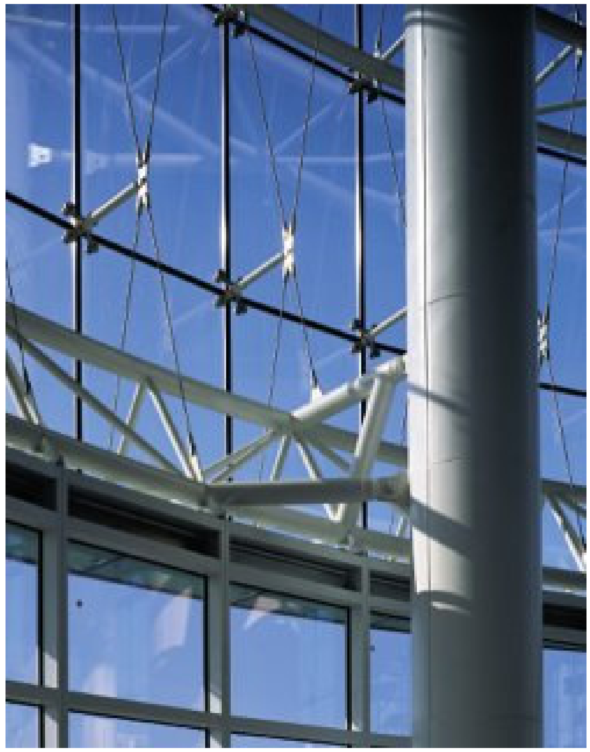

Figure 4.32. Space framed bent 3D horizontal truss
Source: www.mero.de, 2003

Figure 4.33. 2D plane truss
Source: www.mero.de, 2003

The other trusses located at second and third rows of the façade, were 2D plane trusses as shown in figure 4.33. All trusses connected to each other by wind bracing steel rods. The wind bracing structural system is more complicated than in the event of the Medicorium building. There are extra transversal diagonal wind bracers as shown in figure 4.34. These diagonal wind bracers reduce deformation of glass panes against lateral loads. Moreover, these wind bracers increase the level of architectonic quality of the supporting structure with their elegant design.

Figure 4.34. Diagonal wind bracers
Source: www.mero.de, 2003

The trusses were located perpendicular to the glass panes and installed to the load carrying structural system of the building by hinged bolts as shown in figure 4.34.

Figure 4.35. Hinged support
Source: www.mero.de, 2003

4.2.3 Components of Structural Glass Wall System

The structural glass wall system of the Medicorium building was studied under three main topics. One of them was the supporting structure of the system as discussed in section 4.1.2 of is chapter. The other topics are the glass and glass connection fittings are presented in the section.

<u>Glass</u>

12 mm tempered single layer glass was used at the structural glass wall. In this regard, there is no pvb interlayer at compositions of glass panes. As stated before, the pvb interlayers prevents explosion of glass particles when the glass pane is broken. Then, one of the most important disadvantage of tempered glass is sudden refraction in the case of overloading by existing loads. Thus, in the event of Medicoruim building, this situation becomes a safety problem for the occupants of the building in the case of sudden breakage of a glass pane. Moreover, tempered glass used at this project is also weak in thermal performance with compared to the double layered heat insulated glass and laminated glass types. This disadvantage of the glass is important to obtain feasible climatic conditions of building in both summer and winter seasons. With respect to these negative statements for the

tempered glass type, it is not advisable to use tempered glass for large and high glass walls. Therefore, every pane of glass is fastened to the supporting structure with 6 holes as shown in Figure 4.36.

Figure 4.36. A glass pane with 6 holes.
Source: By author, 2003

The maximum producible dimension of a glass pane is 150 cm X 320 cm in Turkey. These glass panes are located in vertical direction. The weight of a glass pane is 155 kg. The joints between glass panes are filled with structural glazing silicone elastic material. The structural glass silicone combines all glass panes together and enables every pane of glass to behave as a single sheet against lateral wind forces.

On the other hand, in the case of the Boeing Headquarters building the 20 mm toughened laminated glass type is used at the façade of the building. Toughened laminated glass was the viable safety choice for such large glass walls. The other advantage of the laminated glass depending on the pvb interlayer in the composition of a glass pane, is to reduce thermal heat loss and gain, that is important to reach climatic comfort standards of the building, and to prevent glaring problem for the large atrium gallery. Unlike the Medicorium building, the glass panes are fixed to the structure with 4 holes for a single glass pane in the Boeing Headquarters building. In this regard, the dimension of a glass panes is smaller than that used in Medicorium building. The dimension of a glass pane used at the façade is 230 cm X120 cm.

Glass joint fittings

As stated before, the façade of the Medicorium building was in curvilinear form. In this regard, the glass panes were brought together at an angle to suit the form of the façade. Moreover, the bolt between the glass pane and the spider is fixed type. In other words, the bolt cannot be adjustable according to the angle between glass panes. For this reason, separate two armed post mounted stainless steel spider fittings were used at the structural glass wall system of the façade as shown in Figure 4.37.

Figure 4.37. Two armed post mounted spiders of the façade
Source: By author, 2003

The spiders were located vertically on the glass plane and supporting steel truss. These spiders were fixed individually to the supporting structure by bolting them. In this respect, each spider can move against lateral loads. The spiders positioned at the left, right, bottom and top perimeters of the glass wall are fixed directly to the solid walls of the building by hinge bolts as shown in Figure 4.38.

Figure 4.38. The position of the spiders attached to the periphery of the building.
Source: By author, 2003

The ball point type bolt is used to fix the glass panes to the spider fittings. As described before, this type of bolt can move in x and y direction in the case of thermal expansion of glass panes and seismic movements of the facade. It absorbs energy which is generated during these movements. The stainless steel material is used to produce glass fittings. The finish of the surface of the material is satin.

In the case of the Boeing Headquarters building, in spite of having same form of façade of the Medicorium building the stainless steel four armed post mounted spider fittings were used as shown in Figure 4.39. The adjustable bolts were used to fix the glass panes to the spiders. These bolts can be rotated according to the angle between two glass panes coming ogether as shown in Figure 4.40. The ball point bolt type which let the bolt move in x and y direction, is used between glass and spider.

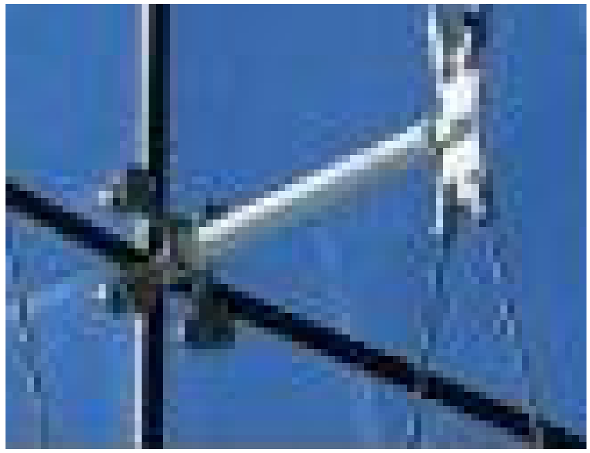

Figure 4.39. The position of the spiders attached to the sides of the building.
Source: www.mero.de, 2003

4.2.4 General Evaluations

In the previous part of study, the structural glass wall systems, executed with the façade of the Condomunium building and the façade of the Boeing Headquarters building, were discussed and compared in terms of architectural, structural and constructional design approaches, supporting systems and the components of the structural glass wall systems. In this regard, the conclusions are derived as follows:

- The occupants of the building are not satisfied with the transparent glass wall façade of the building. They have some complaints about uncomfortable climatic conditions especially in summer seasons, because of the wrong orientation of the glass wall.
- The unconditioned space between two layers of the façade can not be utilized effectively by the occupants of the building. There is no

contribution of that space to the common spaces of the building in architectural terms. In additionaly, it works a visual and a physical barrier in front of the rooms.

- Despite, the primary contribution of structural glass wall system is to attain complete transparency, there is no adequate visual connection between interior and exterior spaces of the building through the wholly transparent glass wall.

- The cleaning process of the large glass wall can not be executed effectively because of the inadequate, narrow distance between the glass panes and the solid walls of the rooms.

- In the case of a fire, it is not possible to escape from the rooms located behind the glass wall. It causes a dangerous situation for the occupants of the building.

With respect to the statements executed above, the occupants of the building are not glad with the transparent glass wall, despite the structural glass wall works at required level in terms of structural and constructional evaluation parameters. As such, this situation points to the importance of architectural project of the building. The success of the structural glass walls directly depends on the architectural project of the building. The contribution of the structural glass wall in terms of articulation of the interior and exterior spaces, should be determined and examined seriously in the architectural project phase by the architect of the building.

CHAPTER 5

CONCLUSIONS

In this research, the fundamentals of the structural glass wall systems were studied. The basic architectural, structural and constructional design principles of the system were described, and the main components of the system were explained. The production parameters of the components, and the limitations and delimitations of the manufacturing process of the structural glass wall systems were discussed within the area of study. The responsibilities of the architects and engineers were argued with respect to their roles in designing and manufacturing periods of the projects.

The accumulated knowledge of the structural glass wall systems and spider fittings was evaluated to create a design source for professionals like architects. To evaluate the level of the knowledge, technical adequacy, experience, level of organization and workmanship regarding parameters of the structural glass wall system within the conditions of Turkey, the glass wall façade of the Akman Condomunium Business Center-Medicorium, building constructed with local materials and local manufacturing companies, was examined and compared with the Boeing Headquarters building in the USA, in terms of basic architectural, structural and constructional approaches of the structural glass wall systems. In this regard, the conclusions and recommendations derived from the study, explained briefly above, are stated below:

One of the major trends of contemporary architecture is to link interior space to the exterior with minimum compromise. In addition to it's primary purposes of light admittance and protection against the elements glass has now assumed new properties in response to other demands for climate control, sound control, fading control and risk control. The capacity of glass to meet these challenges has radically altered the image of glass and it now stands out as a multi-purpose essential material for the modern age. The transparency of glass often leads designers to attempt the creation of an all-glass wall with no visible supports or stiffeners. Reality imposes certain limitations. To achieve a better integration between the aesthetic and functional objectives in designing process of the structural glass wall systems, all of the behaviour must be understood and handled by the designer. It is important to understand the design process used in the structural glass wall systems to analyze how it works. This requires a clear understanding of the structure's behaviour and its architectural objectives, plus a knowledge of the possibilities made available by industry.

- One of the main aspect in designing structural glass wall systems is the behaviour of glass with respect to the lateral loads. Refraction property of glass is the critical point in steel-glass structures. Steel can redistribute load or absorb energy by yielding. Glass has a relatively low fracture toughness. In this regard, as soon as the critical stress is exceeded, the glass will fracture without forewarning. Therefore, It is necessary to understand the physical and structural characteristics of glass. This means that one has to be sure of the loads and stresses to which the glass is being subjected; it involves removing all uncertainty about the behaviour of the design by eliminating elements whose structural behaviour might be unclear. From this point of view, one solution is the use of laminated safety glass, which, on breaking, keeps an adequate structural strength. If an impact or other cause breaks one layer or both layers of glass, the interlayer can prevent penetration and any broken pieces of glass will remain bonded to the interlayer. This minimises the serious cuts or injuries caused by falling glass.

- The key consideration of structural glass wall system is the structure. It connects all parts together and controls the form. Each part of the structure has been chosen so that its behaviour under load can be predicted exactly. The structural composition follows the hierarchical sequence. Some elements of the structure carry heavy loads, others carry small well-defined segments.

- Point supported systems has no continuous perimeter edge contact with substructure unlike conventional supported glass pane systems. The point supported systems require careful and integrated design, fabrication and installation of the primary support structure, the point fixing assembly and the insulating glass unit

- Basically, four types of load influence the structure of the structural glass wall systems; own weight of glass panes, environmental loads (wind, snow loads and seismic movements), forces produced by temperature variations and the weight of the maintenance equipment. Temperature fluctuations cause the steel structure and the glass to expand and contract at different rates. The rigidity of the joint effects the designing phase of the structural glass wall systems in terms of temperature expansion and contraction. The weight of the structure cannot be determined after the structure has been defined. The weight of the glass panes depend on the thickness of the glass has been chosen. Moreover, the designer must know the wind load. In this respect, the shape of the building, plus the relevant building variables in the applicable building code are needed for the calculation of wind load.

- When designing glazed structures required tolerances might be essentially smaller than in normal construction. In other words, the more transparent the structure is the smaller the tolerances are. The designer must provide capacity for adjustment to allow for manufacturing and assembly tolerances of the system. It must be to adjust each element according to the differences discovered, on site, between the determined dimensions and the real dimensions of the structural frame and of the holes in the glass sheets. Structural glass systems are secured to a support structure by a variety of fittings options which are designed to meet the requirements of the project. These fixings absorb forces when the glass flexes under load and provide a secure connection between the glass component and the support structure. The glass fittings shall provide a tolerance capability which will cope with the thermal movement occurring as a result of differential temperature. The components used within the system shall withstand all thermal movements, buckling, distortion, cracking, failure of joint seals or excessive stress on the glass and fixing assemblies.

- The joint between the panes must satisfy three requirements; firstly, it must allow the panels to move in relation to one another, secondly, it must not protrude from the glass external skin, thirdly, it must be watertight. The condition of edges and glass surface in the drilling area has an essential effect on load capacity. When designing the joint detail, the joint has to be modelled with a FE-program. Modelling the drilling area, geometry of the fastener, liner material between glass and steel is important to do carefully.

- For the designer, one of the most important design considerations of structural glass wall systems in negative term, is the weak thermal insulation property of glass, in terms of reaching desired comfort level. Apart from the structural glass wall systems, this is the main problem of large glass walls executed by all types of glazing systems. The proper orientation of glass wall, the selection of suitable type of glass and the utilization of vertical and horizontal sun louvres in front of the glass wall facades are the main criteria to reach desired comfort level in buildings.

- The maintenance problem of the structural glass wall systems is the other important consideration for the designer. The special equipments like gondolas, suspended from the top of the building or lifts are needed to clean every glass pane of the system. It means that the cost of the maintenance of the structural glass wall system is much higher than conventional, ones. This is also one of the main problem of glass wall systems in building which may or may not be constructed with the structural glass wall systems.

The architectural project of the building is also another important design parameter for the structural glass wall systems. The success of the structural glass walls directly depends on the architectural project of the building. From this point, as described before in the case study section the architectonic quality of the structural glass wall in relation with the common spaces of the building should be examined and argued at designing period of the architectural project before application and construction phase. The effective utilization of the structural glass wall by the occupants of the building can be obtained by well-articulated architectural project.

Proper orientation of the glass façade in terms of climatic conditions is another design merit which should be solved within the architectural project phase. The architectural project decisions also influence the cost of the glass wall system. The cost of the structural system is higher than the conventional glazing systems so the purpose of usage of structural glass wall should be strictly defined by the architect responsible for the architectural project. Therefore, it is necessary to consult the industry in order to ascertain what glass sizes are feasible, before the preliminary design stage. Similarly, the positioning of the holes in the glass, the glass thickness, the methods available for the manufacture of assembly components are all matters that are solved through consultation assembly.

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APPENDIX A

ARCHITECTURAL DRAWINGS OF AKMAN CONDOMINIUM BUSINESS CENTER-MEDICORIUM BUILDING

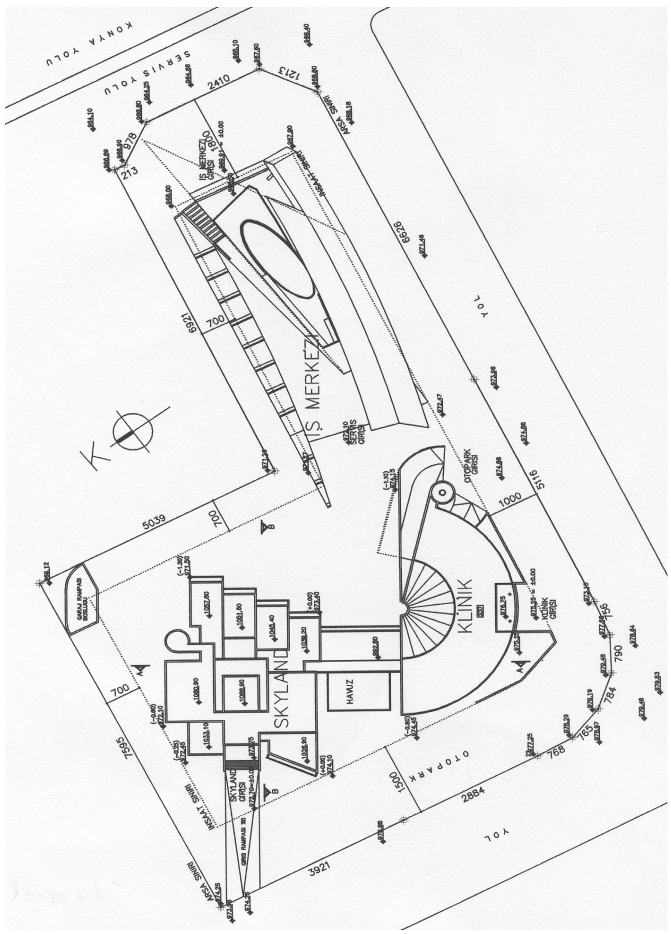

Figure A.1. Site Plan of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003

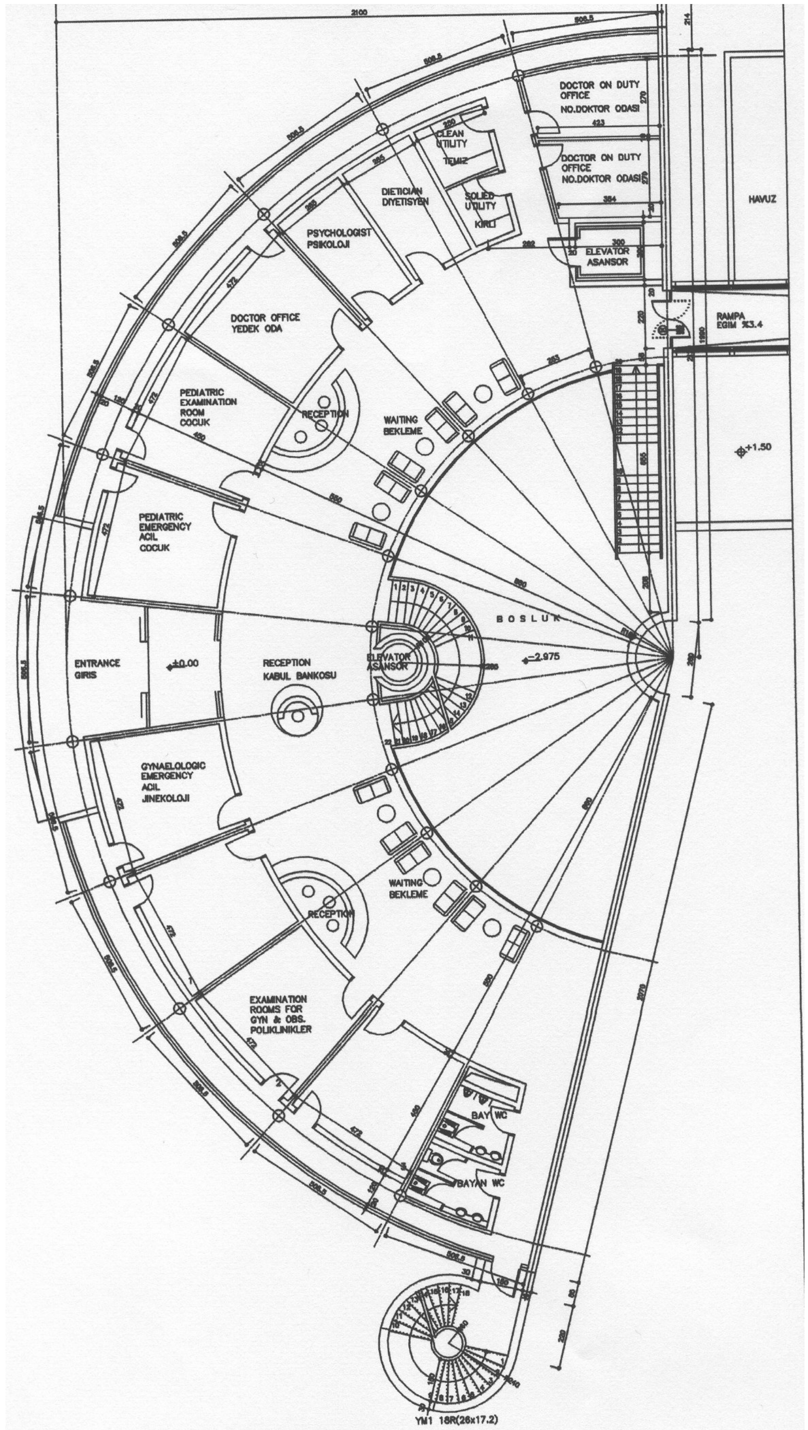

Figure A.2. Ground Floor Plan of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003

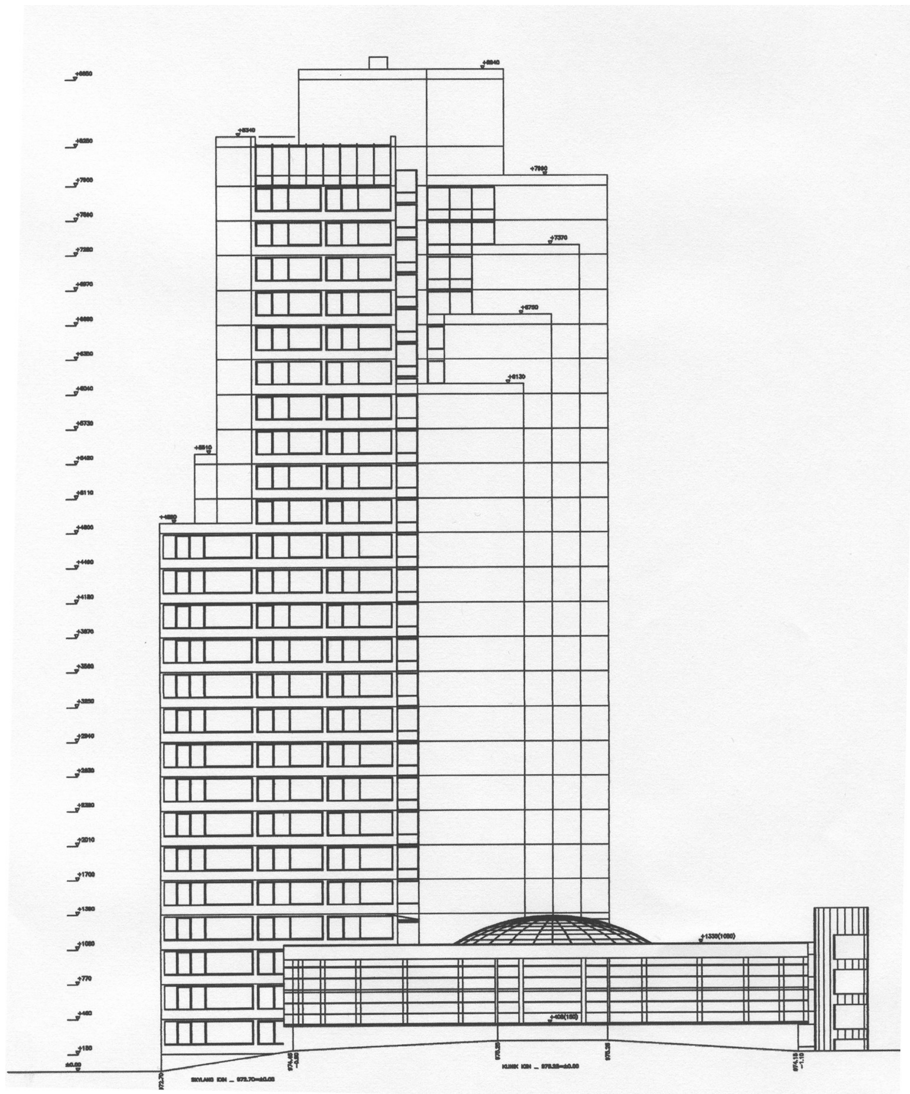

Figure A.2. West Facade of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003

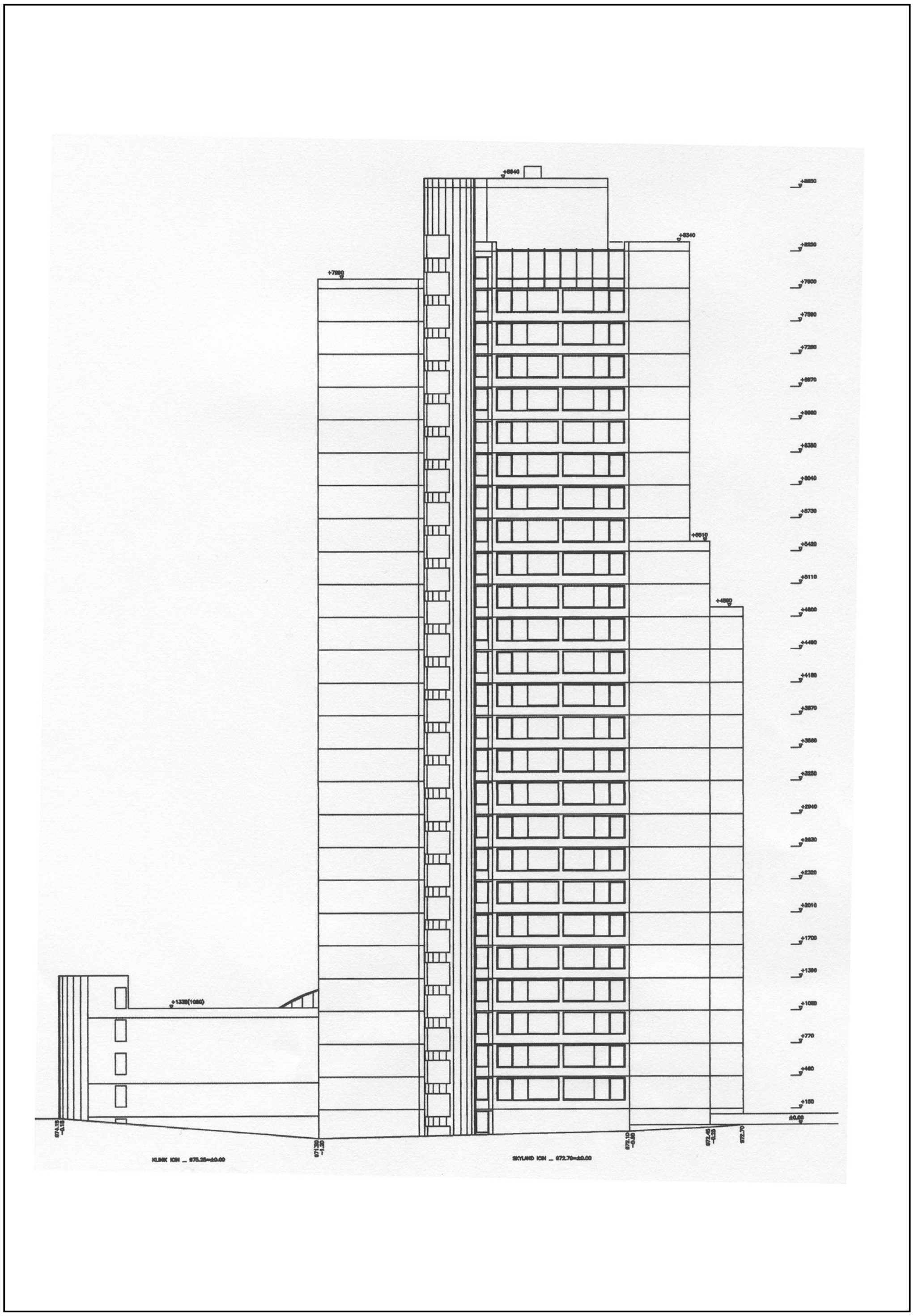

Figure A.4. East Facade of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003

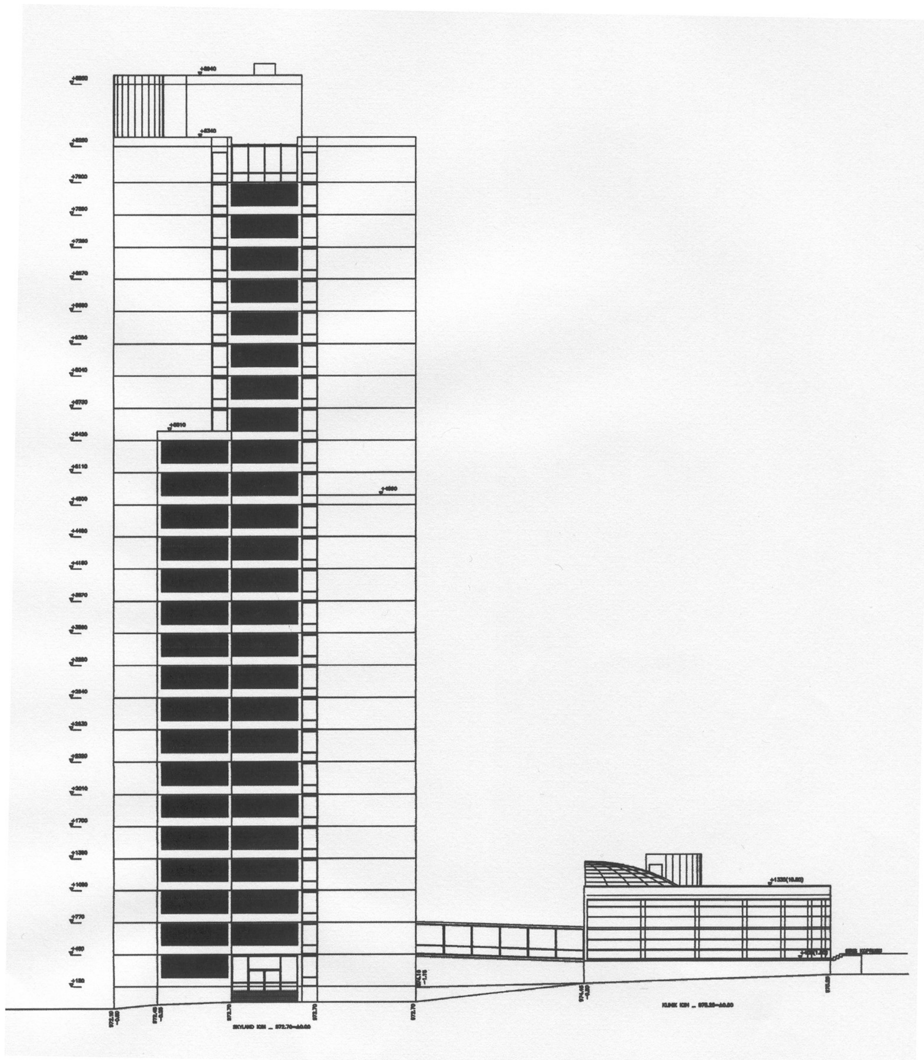

Figure A.5. North Facade of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003

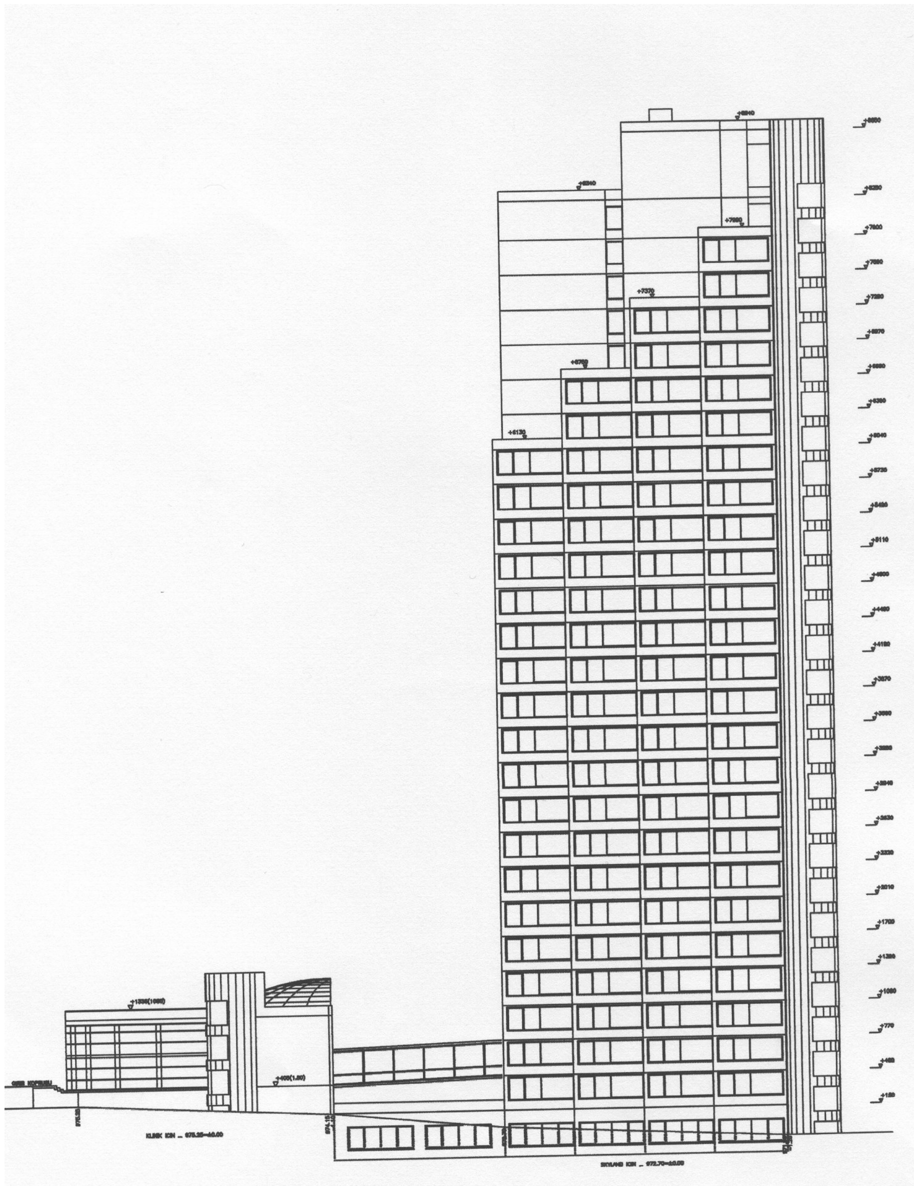

Figure A.6. South Facade of Akman Condomunium Business Center.
Source: Doku Architectural Firm, 2003