THE INFLUENCE OF DAMAGES ON THE STATIC PERFORMANCE OF SINGLE-LAYER CABLE NET STRUCTURE SUPPORTED GLASS PANEL

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SCHOOL OF CIVIL ENGINEERING
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Date :

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Alhamdulillah, all praises to Allah for endowing me with the health, strength and the useful knowledge to completely finish research. This thesis is dedicated to all the person who helped me to complete this research without much troubles. Here, I would like to acknowledge some individual and parties who had given me the opportunity to gain invaluable experience during my final year project (FYP).

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ABSTRAK

Fon telus kaca yang disokong oleh jejaring kabel adalah sejenis struktur yang terdiri daripada banyak kelebihan seperti kelihatan menarik, mudah dibina dan nilai estetika yang menyenangkan. Ciri ini biasanya digunakan di terminal penumpang lapangan terbang, pusat pameran dan dewan hotel. Dalam kajian ini, prestasi statik struktur jejaring kabel tanpa panel kaca dan jejaring kabel dengan panel kaca dikaji melalui satu eksperimen. Pengaruh kerosakan yang berpotensi terhadap prestasi statik pada struktur jejaring kable satu lapisan juga dikaji dalam kajian ini. Terdapat tiga jenis kerosakan yang utama yang dipertimbangkan dalam kajian ini antaranya ialah kerosakan pada penyambung kabel, kehilangan pra-tegangan dalam kabel dan kerosakan pada penambat kabel. Selain itu, sumbangan kekuatan kaca pada keseluruhan struktur jejaring kabel ditunjukkan dalam kajian ini. Keputusan eksperimen menunjukkan bahawa kegagalan pada penyambung kabel memberi sedikit pengaruh terhadap prestasi statik struktur jejaring kabel satu lapisan. Nilai perubahan maksimum pada sesaran nod dan ketegangan dalam kabel adalah 2.78% dan 1.65% untuk kedua-dua kabel dengan panel kaca dan tanpa panel kaca. Selain itu, kegagalan pada penambat akhir kabel memberi kesan yang ketara kepada struktur jejaring kabel dengan mendorong perubahan sesaran nod sehingga 16% dan 19% untuk kabel dengan dan tanpa panel kaca. Walaubagaimanapun, perubahan maksimum pada nilai ketegangan di dalam kabel untuk kerosakan pra-tekanan dan kerosakan pada penambat akhir kabel tidak melebihi 13.64%. Hasil daripada keputusan yang diperolehi, ia dapat disimpulkan bahawa pengaruh kegagalan atau kerosakan adalah lebih tinggi pada nilai sesaran nod berbanding perubahan tegangan dalam kabel. Disamping itu, kekuatan pengaruh kerosakan pada keseluruhan struktur adalah bergantung kepadan kedudukan nod dengan kerosakan dan sejauh mana kerosakan berlaku. Jika kedudukan nod adalah hampir dengan kerosakan, sesaran nod akan menjadi lebih tinggi. Namun begitu, nilai perubahan bagi sesaran nod adalah lebih rendah untuk struktur jejaring kabel dengan panel kaca berbanding struktur jejaring kabel tanpa panel kaca. Ini menunjukkan bahawa kesan kaca memperkuatkan keseluruhan struktur jejaring kabel. Keputusan juga menunjukkan bahawa sumbangan kaca kepada kekuatan keseluruhan struktur adalah lebih tinggi untuk kebel dengan nilai pra-tegangan yang lebih tinggi. Sumbangan kekuatan kaca adalah diantara 21.08 % hingga 25.04%, 14.33% hingga 21.10% dan 7.56% hingga 12.97% bagi daya pra-tekanan 2000 N, 1500 N dan 1000 N.

ABSTRACT

Cable-net supported glass facade is a kind of structure consists of many advantages such as attractive in apparent, constructible and pleasing aesthetics. This kind of structure is commonly used in airport passenger terminals, exhibition centre and hotel hall. In this research, the static performance of the single layer cable-net structure with and without glass panels was investigated through the experiment. The influence of potential damages on its static behaviour of single-layer cable-net structure were also investigated in this study. Three types of damage were considered in this research which are failure of cable connector that is between two spanning cables, loss of pre-stress in cable and cable anchorage failure. The results also indicated the glass stiffness contribution of the whole structural system. The experimental results show that the failure in cable connector has little influence on the static performance of single layer cable-net. The maximum change in nodal displacement and cable tensile force are 2.78% and 1.65% for both cable-net with and without glass panels. Furthermore, the cable anchorage failure affects significantly the local part of the structure induced by the changes in nodal displacement up to 16% and 19% of the cable-net with and without glass panels, respectively. In contrary, for the pre-stress loss occurred in horizontal cables, the percentage of change in nodal displacement is lower (3.23%) as compared to the pre-stress loss occurred in both directions where the change in nodal displacement is up to 32.52% for the pre-stress loss occurred in both directions of the cables. The maximum values change in cable forces was not exceeding 13.64% for all cables under the pre-stress loss and cable anchorage failure. From the results, it can be concluded that the influence of damages was stronger for the on nodal displacements than cables tension force. Other than that, the intensity of the influence damage depends on the location and the extent of damage. The near the position of node to the damage, the higher the nodal

displacement. However, the percentage of the nodal displacement is lower for the cable-net with glass panels compared to cable-net systems without glass panels. The effect of the glass stiffer the cable-net structure. The stiffness contribution of the glass is between 21% to 25.04%, 14.33% to 21.10% and 7% to 21.1% for the respective pre-stress force of 2000 N and 1000 N, 1500 N.

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LIST OF ABBREVIATIONS

SGFs	Structure glass facades
FCN	Flat cable-net
CCN	Curve cable-net
AISI	American Iron and Steel Institution
PS	Plow steel
IPS	Improved plow steel
EIPS	Extra improved plow steel
IWRC	Independent wire rope core
C	Wire core
FC	Fibre core
NFC	Natural fibre core
SFC	Synthetics fibre core
WSC	Wire strand core
IGU	Insulating glass unit
PVB	Polyvinyl butyral
LVDT	Linear variable differential transform

CHAPTER 1

INTRODUCTION

1.1 Project Overview

Cable net structure supporting the glass façade is a new kind of structure that has been widely used in recent decade because of their attractive in appearance and simplicity. The cable net structure used in structural glass system normally consist of pre-stresses cable net, glass panel and glass support attachment that are commonly used in gymnasia, airport passenger terminal and hotel halls. This new type of load-bearing structure also has many advantages of the usage such as easy construction, pleasant aesthetics and efficient use of natural lighting combined with energy saving. The example of cable net structure with glass system are shown in Figure 1.1.

Figure 1. 1: Example of cable-net supporting glass façade system.

The cable system consist of nonlinear geometry that could lead to large deflection. In addition, it also would inevitably be subjected to different kind of damage during the service such as the loss in cable pre-stress and failure in cable anchorage end. The loss in cable pre-stress normally due to it stress relaxation of the steel cable and the temperature change (Yang et al., 2015). This factor will affect not only the mechanical behaviour of the cable-structure but also the stability and durability of the structure. Other than that, there are also a few studies show the significant contribution of the glass to the stiffness of the whole structure. The contribution of the glass to the whole structure is generally neglected (Shi et al., 2010) and the structural stiffness mainly controlled by the cable (Feng et al., 2009).

There are many influences that can manipulate the stiffness of the whole structure. Therefore, the performance of cable net structure with glass system is compulsory to be understood in order to determine the significant contribution to stiffness of the whole structure and failure that could occur in the cable system.

1.2 Problem Statement

In many real-life applications, cable net structure supported glass system would inevitably subjected to various types of damages throughout the service, where it can lead to change in cable pre-stress force. Moreover, the pre-stress force in the cables also change during the maintenance work and the stress relaxation that occurs in the cables itself. The change in cable pre-stress force will not only affect the mechanical behaviour, but also affect the stiffness of the whole structure. The reduction of the structural stiffness will lead to decrease the loading capacity of the structure. Three types of damages that are considered such as damage in cable connector, cable anchorage and pre-stress loss in the cable. The effect of damages to the changes in cable pre-stress force as also the structural stiffness are determined through a model with two different configuration with and without glass panels under this three damages.

1.3 Research Objectives

The main purpose of this study is to determine the stiffness contribution of glass panels to single layer cable net supported glass systems with or without damage to ensure optimum performance. With this as aim, below are the objectives to be achieved from this study:

1. To analyse the performance of the cable net structure with and without glass panels under the static loads.
2. To investigate the influence of damaged cable on the static behavior of single-layer cable net structure glass system.

1.4 Thesis Organization

This thesis consists of five chapters, which includes introduction, literature review, research methodology, result and discussion and conclusion. Chapter 1 mainly consists of project overview, problem statement and the research objective of this study. Chapter 2 discusses about the basic concept of the cable net structure supported glass system, type and properties of cable systems, various types and characteristic of glass, failure in the cable net system and a brief introduction on the cable net structure supported glass facade. A brief overview about the factors affecting the failure in a cable net system supporting glass façade by other researchers are discussed in this chapter. Chapter 3 presents about the research methodology of this study. Chapter 4 simply presents the results of the test conducted and analysis the stiffness contribution of glass to the whole structure. Finally, chapter 5 presents the conclusion that can be drawn from the comparative study that carried are out based on results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, research papers that are related to the cable-net system supporting glass façade (SGFs) such as the type and properties of cable systems and the failure in a cable-net system that affect the stiffness of the whole structure are discussed. Furthermore, some introduction to the glass used as well as the significant contribution of the glass to the stiffness of the structure are reviewed and summarized. A brief overview about the factors affecting the failure in cable-net system supporting glass façade by other researchers are also presented in this chapter.

2.2 Cable-Net Supported Glass Façade Systems

Cable net supported glass facade system (SGFs) that has been widely used is a type of modern structure and has many advantages, such as pleasing aesthetics, easy constructability, efficient use of natural lighting and energy savings (Zhang et al., 2009). They are commonly used in exhibition centers, gymnasia, hotel halls and airport terminals. There are three main components, namely glass, glazing system and structural systems. The lateral load acting and load from glass self-weight is transmitted to the structural support system which is cable-net structure via the glazing system. The various types of the structural systems such flat and curve cable-net used in SGFs are shown in Figure 2.1.

Figure 2. 1: Various types of cable-net structure supported glass façade systems

2.3 Cable-Net Structure

Cable nets represent the ultimate in elegant minimalist structural systems and provide optimum transparency when the effect of a sheer glass membrane is desired. This structural system supports glass by a net geometry of pre-tensioned cables. Designs can be flat, or the net can be pulled into double curvature. A clamping component locks the cables together at their vertices and fixes glass to the net. The net structure’s large pre-stress loads require early coordination of the facade contractor with the building engineer. Besides, cable is a linear and flexible structural member that offers no resistance when bend or compress in a curve shape and sustain only the tensile loading. Cable is common material that is used in engineering to support and transmit the load that comes from one point to another point when used in suspension roof and bridge. Cables are the main load carrying elements in the structure (Vilnay, 1987). The usage of cable in structural glass façade (SGFs) is due to its advantages such as high strength to weight ratio and good stability. The tension that occurs in the cable results in good cable stability. There are several structure types that represent the SGF technology such as cable-net, double-curve cable-nets and glass fin supported glass façade.

2.3.1 Flat Cable-Net (FCN)

The horizontal cables to a straight plan geometry of the vertical cable system produces a flat cable-net structure (FCN). Figure 2.2 shows two example of the FCN structure that are used in structural glass façade systems. Other than that, the addition of the horizontal cables makes controlling system deflection easier which results in decreased amounts of pre-stress requirements in cable element. Simple FCN is usually described with span 50 meters or more (Wang et al., 2017) .

Figure 2. 2: Example of flat cable-net structure supporting glass façade system

2.3.2 Double Curved Cable-Net (CCN)

The condition of the curved cable-net is when the horizontal cables are aligned to a curve in elevation opposing curvature of the vertical cables in plan, the horizontal and vertical cables can be tensioned against each other to form a double-curved (anticlastic) surface with unique properties (Figure 2.3). Besides that, the opposing curvature provides stability to the cable net that a flat cable net does not have. It also significantly limits the deflections under wind load and thus requiring lower pre-stress forces in the cables. However, the facility of the orthogonal grid such as the double curved net produces a variety of trapezoidal shapes that greatly complicate the requirements of the glazing system.

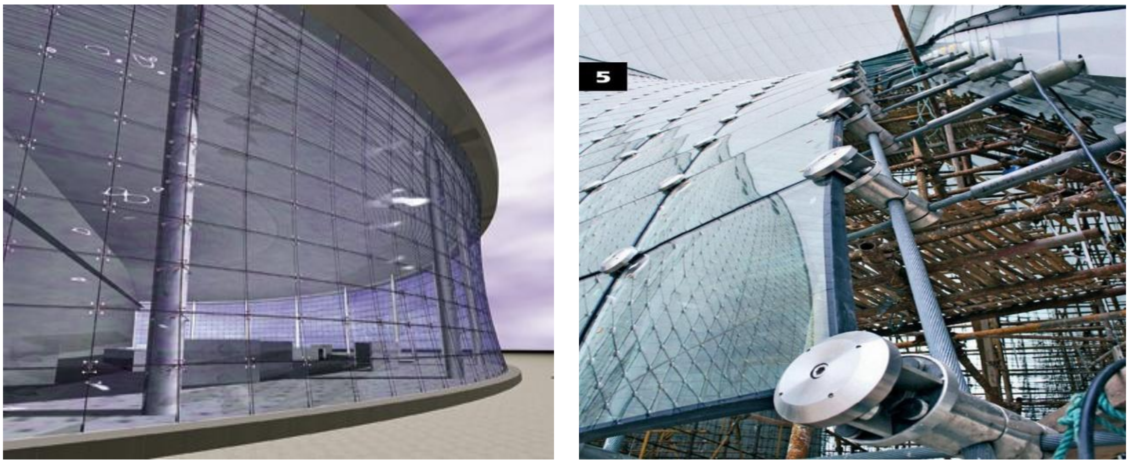
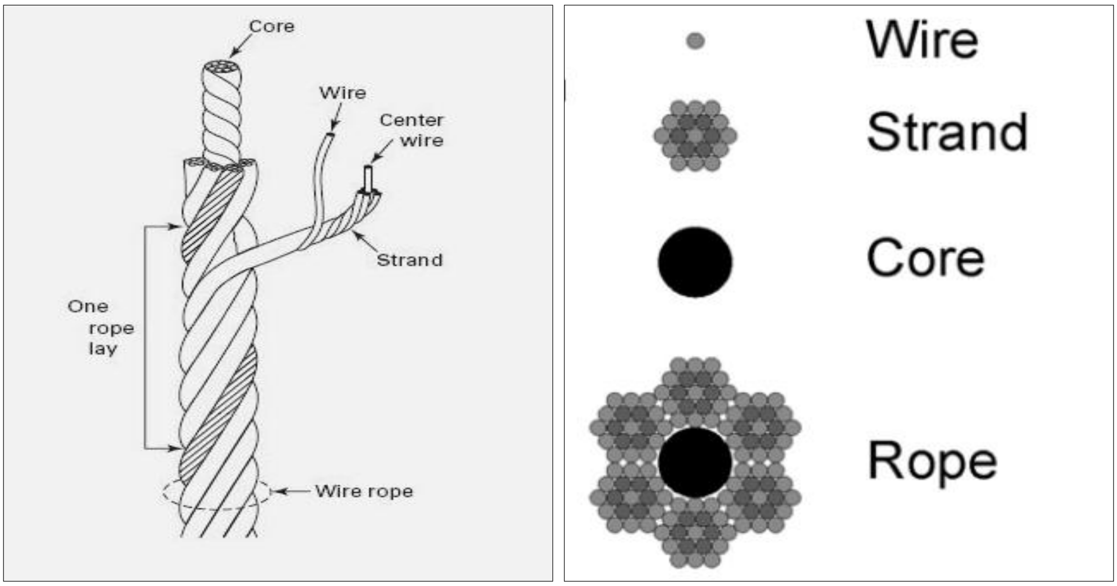


Figure 2. 3: Sea-Tac Airport, Seattle; double curved cable-net, Fentress Bradburn Architects 2005 (ASIDI).

2.3 Cable

The cable comes as a strand or wire ropes. The development of the first modern technology is first developed in Germany in the 1830's by the German mining engineer Wilhem Albert. Wire ropes consist of one or more number of the strand that laid spirally around the core of the steel or fibre core. Commonly, the most widely used ropes are of six strands. There are three basic components in wire ropes that are designed in such way that it consists of wire (come from the strand), the core and multi wire strand which is laid helically around the core. The basic components of standard wire rope and the wire rope construction are shown in Figure 2.4.



(a) (b)

Figure 2. 4: (a) Example of the basic component of the wire ropes (Gabaswire, 2011), and (b) main component of the cable (Wire Ropes, 2008)

2.4.1 Wires

Wire rope is a correct term for a group of strands covered in a uniform helix around the core. The wire for rope is normally made from the several materials such as steel, iron and stainless steel. Steel wires are the world's foremost construction material which is made from an iron alloy that contains between 0.2 to 1.5% carbons by weight. According to American Iron and Steel Institute (AISI), steel can broadly categorize into four groups based on their chemical composition such as carbon steel, alloy steels, stainless steels and tool steels. Moreover, wire rope consists of three primary grades which is Plow Steel (PS), Improved Plow Steel (IPS) and Extra improved Plow Steel (EIPS). The different grades of the wire rope give different values for the strength as shown in Table 2.1.

Table 2. 1: Different strength of the wire rope according to the grades (Gabaswire, 2011)

Wire Rope Grades	**Strength (N/mm^2)**
Plow Steel (PS)	1570
Improved Plow Steel (IPS)	1770
Extra improved Plow Steel (EIPS)	1960

2.4.2 Strand

A strand is made by the multiple wires that are twisted helically. They are usually laid spirally around a centre wire or core. The wire arrangement in the strand is important in order to determine the factor of the cable's functional characteristic such as its ability to meet the operating conditions to which it will be subjected. The wires in the strand may be all the same size or mix of the size. The most common strand construction is ordinary, scale, Warrington and filler (Integrated Publishing, wire rope, 2013). Other than that, the strand produces the tensile strength of a cable rope and over 90 % of the strength of typical 6-strand wire rope with an independent wire rope core (IWRC). The properties like fatigue resistance and resistance to abrasion are directly affected by the design of the strand. In addition, there are various types of strand construction (Figure 2.5) that consists of different number of the wire in a strand. Furthermore, the different type of laying direction of the strand rope and types of strand rope particularly has a great influence on the characteristic of the rope. For instance, the standard stranding method can cause the wire crossings between the wire layers within the strand results in high stress concentration. Hence, the premature damage will be the consequence (Wire Rope, 2013). There are two types of lay directions for the rope which are right hand lay and the left hand lay shown in Figure 2.6.

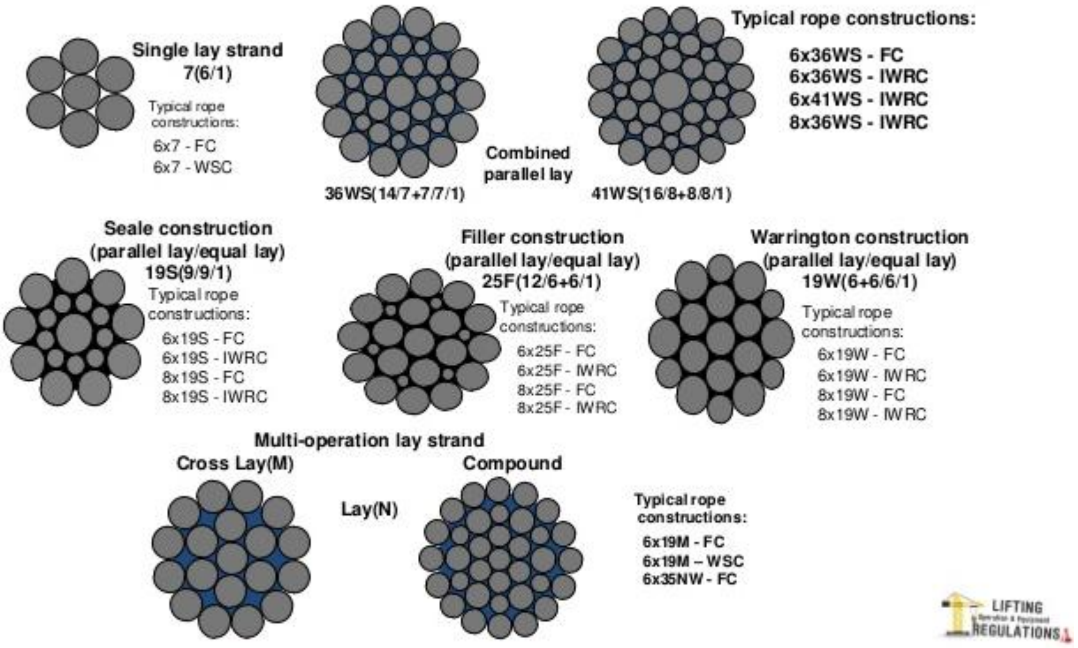


Figure 2. 5: various types of strand construction (Wireco World Group Brand, wire rope classification and feature, 2014).

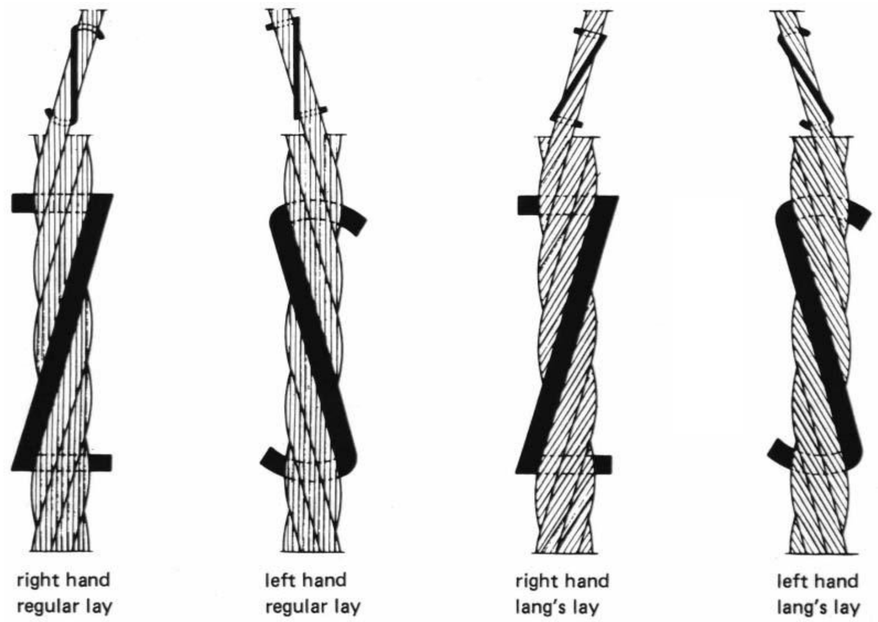
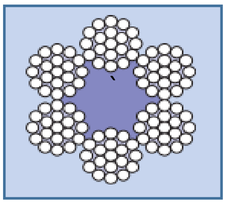
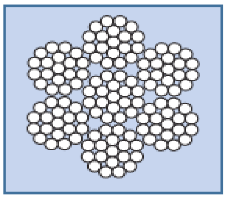
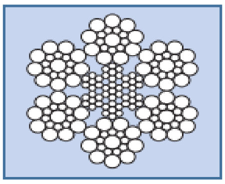
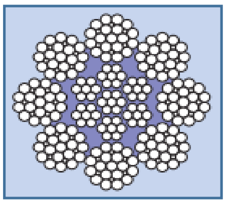


Figure 2. 6: the different types of the strand direction lay construction (PFEIFER, Wire Rope, 2013).

2.4.3 Rope Core (C)

The inner part of the single layer rope surrounded by the outer strands is normally filled by the wire rope. Rope core is separated according to the material use and its design. The main function of the rope core (C) is to support the outer strands. By using the steel core, it increases the load bearing metallic across the section (PFEIFER, Wire Rope, 2013). There are many advantages of their usage, such as reduced the tendency for the rope to rotate and longer life span of the rope during operating at higher temperature. In addition, rope core offers less stretch and have better load carrying capacity. There are three types of rope core for the wire rope which is fibre core (FC), steel core (WC) and independent wire rope core, plastic coated as described in Table 2.2.

Table 2. 2: Three type of the core used in wire rope (PFEIFER, Wire Rope, 2013).

Type of Core	**Description**	**Example of Wire Rope Core**
Fibre Core (FC)	▪ The core of rope consists of natural (NFC) or synthetic fibre (SFC). ▪ Fibre core is restricted to conditions where the load is light	
Steel Core (WC)	a) Wire strand core (WSC) ▪ The core of a round strand rope consists of a strand b) Independent wire rope core (IRWC) ▪ The core of the rope strand rope consists of a rope strand.	 
Independent Wire Rope Core, plastic coated	▪ The core consists of a plastic-coated steel core.	

2.5 Glass

Glass is a liquid that has cooled to a rigid state without crystallizing. Soda-lime glass is the common form of the glass and the material used in the float process by which the architectural flat glass is produced. Glass consists of 100% recyclable material and various properties such as high in transparency, durability, and resistance to corrosion and relatively low cost. Hence, it’s classified as unique material for application in architectural. The common glass used in SGFs is almost annealed flat product yielding from the float glass process and subjected to modification through secondary process. The secondary process includes the various combinations of heat treating, laminating and coating.

2.5.1 Heat-Treating

Heat-treating refer to the post processing of the float glass product. The purpose of this process is to improve the strength and alter breakage behaviour of the glass. Glass is annealed as part of the float glass process and annealing itself is a form of heat-treating. Annealing is a process of slowly cooling hot glass objects after they have been formed, to relieve residual internal stresses introduced during manufacture. Heat-treating or toughening is a process developed by the French in 1928. There are two kinds of heat-treated glass which is heat-strengthened and fully tempered. The characteristic of the various productions of glass is shown in Table 2.3

Table 2. 3: Characteristic of the various productions of glass

Feature \ Glass	Tempered glass	Heat-strengthened glass	Annealed glass
Safety	good	common	No
Mechanical strength	120Mpa	70Mpa	45Mpa
Thermal shocking	200℃	100℃	40℃
Surface compression	≥90Mpa	24-69Mpa	------
Fragmentation	Obtuse-angle grain	Radial crack	sharp
Spontaneous breakage	Yes	No	No
Thermal stress breakage	No	No	Yes

2.5.2 Annealed Glass

Annealed glass is the basic flat glass produce by the first result of the float process. It is also the most recent technique that is used in production of the glass panel for the façade from the float process. Annealing is a process whereby the heating and cooling of the material are controlled in a manner to remove the internal stresses. Besides, annealing is required in order to facilitate easier and uniform cutting of the glass. However, the subsequent processing such as bending during which glass is heated may require the glass to be annealed again.

2.5.3 Toughened Glass

Toughened or tempering is the glass that are produced from the annealed glass that has been treated with the thermal tempering process. The annealed glass is heated to above its 'annealing point' of 600 °C. The surface then undergoes rapid cooling while the inner portion of the glass remains hot. The different rates of cooling at the surface of the glass and inside of the glass produces different physical properties resulting in comprehensive stresses in the surface balance by tensile stresses in the body of the glass.

2.5.4 Insulating Glass Unit (IGU)

Insulating glass system consist of the two-glass component that is separated by an air spacer hermetically sealed. Inherently, insulating glass increases a window's thermal performance (Viracon, 2008). The primary purposes for using multiple-glazing or insulating glass units (IGU) is its enhanced thermal performance. The air cavity confined or trapped between the two-glass panel acts as an effective insulator. IGU is most frequent double-glazed panels, but more layer of the glass is possible. Figure 2.7 shows the diagram of the insulating glass units (IGU).

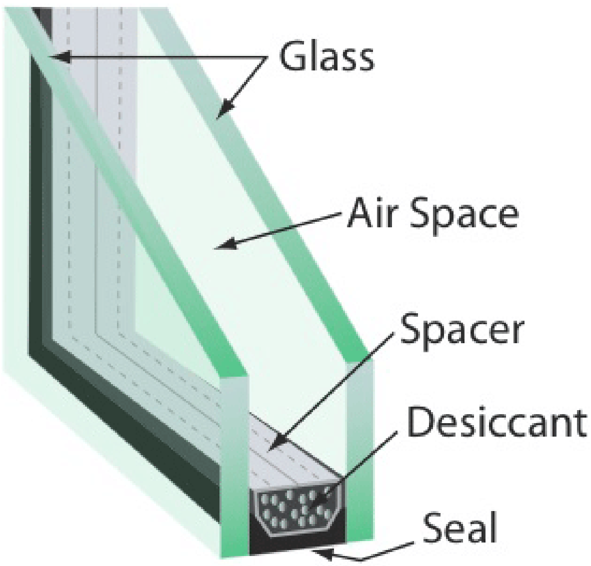


Figure 2. 7: Diagram of insulating glass units (IGU) (Viracon, 2006)

2.5.5 Laminated Glass

Laminated glass is made of two or more layers of the glass that bonded together by a piece of plastic/vinyl called polyvinyl butyral (PVB). A minimum interlayer thickness of 0.76mm meets the requirement of CPSC 16 CFR 1201 safety glazing standard (Viracon, 2008). The laminated glass can utilize tinted glass, high-performance coatings and pigment interlayers together and alone. Other than that, it also offers many advantages such as safety and security. The gluing or laminating between the two layers of the glass evolved a strategy to strengthen the glass panel and provide additional safety by eliminating the risk of injury from sharp glass shards.

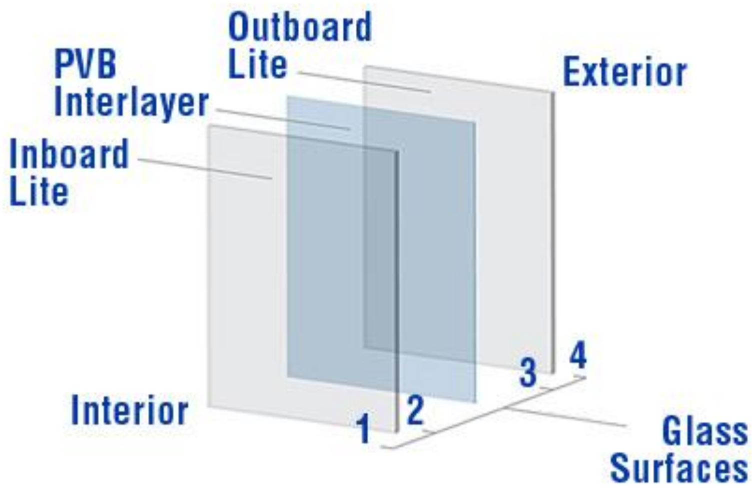


Figure 2. 8: A sheet of polyvinyl butyral (PVB) bonded together with two glass panels that produce laminated glass (Viracon, 2006)

2.6 Glazing system

Structural glazing system is a system that bond the glass together with the building's structural framing member by using the high strength and high performance of the silicone sealant. This method has become a popular method of finishing especially for the multi-storey buildings. The glazing system utilizes the technique of fastening the glass to the building frame using silicone sealants as mention above. Since the sealants has a function to bond the glass to the building, the external load that acts on the building are transferred from the sealants and vice versa. Normally, there are two types of sealant supports that are used in the glazing system such as four-sided sealant support and two-sided sealant support (Vallabhan et al., 1997). Table 2.4 shows the main and basic component in the structural glazing system.

Table 2. 4: The component in structural glazing system (Structural Glazing, 2014)

Component in structural glazing	Description
Mullions (Vertical member)	Mullions are provided basically to transfer the dead load of the curtain wall.
Transoms (Horizontal member)	Transoms are an aluminium section provided in between the mullions horizontally.
Silicone Sealants	Silicone sealants are used to bond the glass panel with the buildings. It also carries external load of the buildings.
Setting Blocks	Setting blocks are used to provide the support in the relation to the size of the glass, glazing techniques and condition of use.

2.6.1 Framed System

Framed systems support the glass continuously along the two or four sides. The framed glazing system such as the curtain walling have evolved considerably over the year. These systems typically consist of an internal structural frame and pressure plate. Framed glazing systems are most widely accepted and cost effective and more commonly used in large commercial applications (Glazetted, 2018). There are many variations of the frame glazing system that are available such as stick, veneer and panel system. Conventional utilized curtain wall system is seldom with the structural glass facades. There are three types of framed glazing system as shown in Figure 2.9.

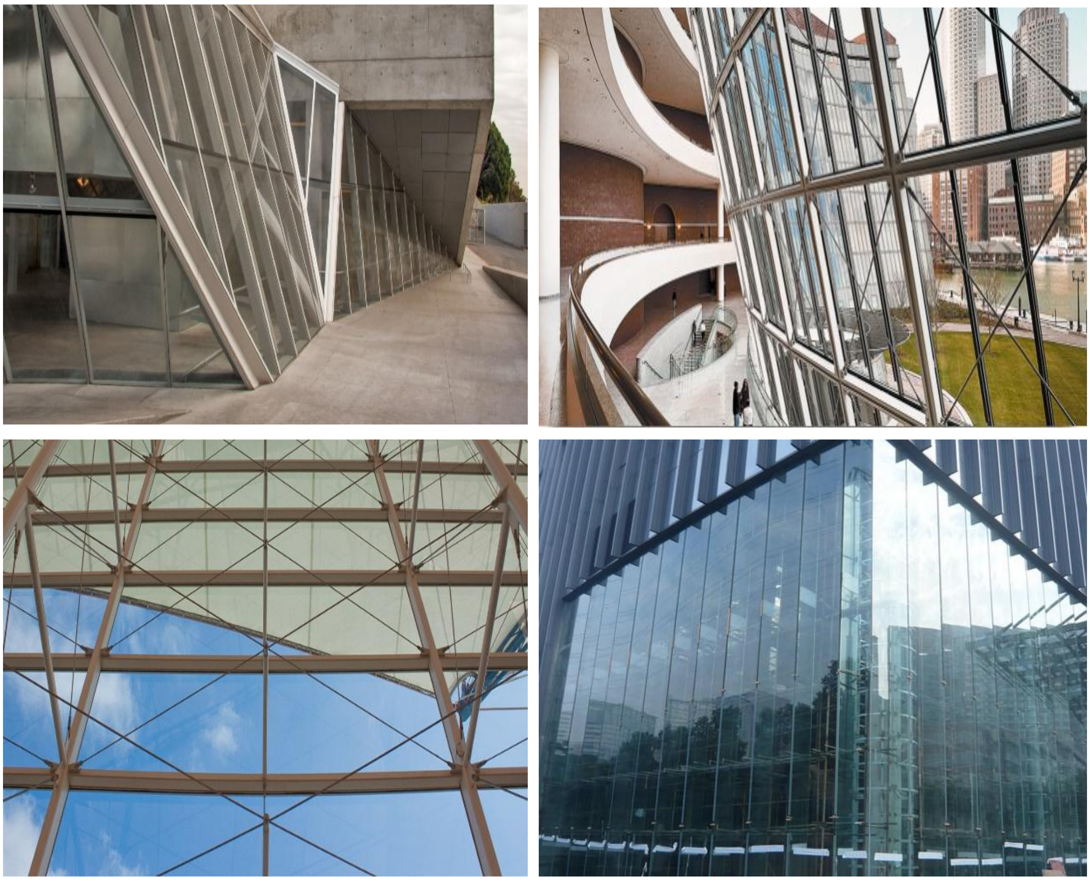


Figure 2. 9: Various types of framed glazing system: Stick system (Top left), Panel Wallem (Top right), Curtain wall (Bottom right) and Veneer system (Bottom left)

2.6.2 Frameless system

Frameless glass façade systems utilize the glass panel that is fixed to a structural system at a discrete point normally near the corners of the glass panel (point fixed). The glass is directly supported without the use of other perimeter of the framing elements. Besides that, the glass that is used in the point fixed application usually is typically heat treated. There are two types of the frameless glazing system (point-fixed) which are point-fixed bolted and point-fixed clamped as shown in Figure 2.10. Both of the systems are used to hold and transfer the dead load (glass self-weight) to the structural support system.

Figure 2. 10: Frameless (point-fixed) glazing systems comprises of point-fixed bolted (left) and point-fixed clamped (right)

2.7 Damage in Cable-Net System

Cable-net structure would inevitably be subjected to damages, especially during services and maintenance. There are three common damages that occur in the cable-net system such as failure in horizontal and vertical cable connector, loss in cable pre-stress and failure in anchorage end. These various types of damages not only affect the mechanical behaviour of the single-layer cable-net structure such as the loading capacity and stiffness, but also the durability and stability of the structure (Shi et al., 2010) . The component of single-layer plane cable-net supported glass façades is shown in Figure 2.11.

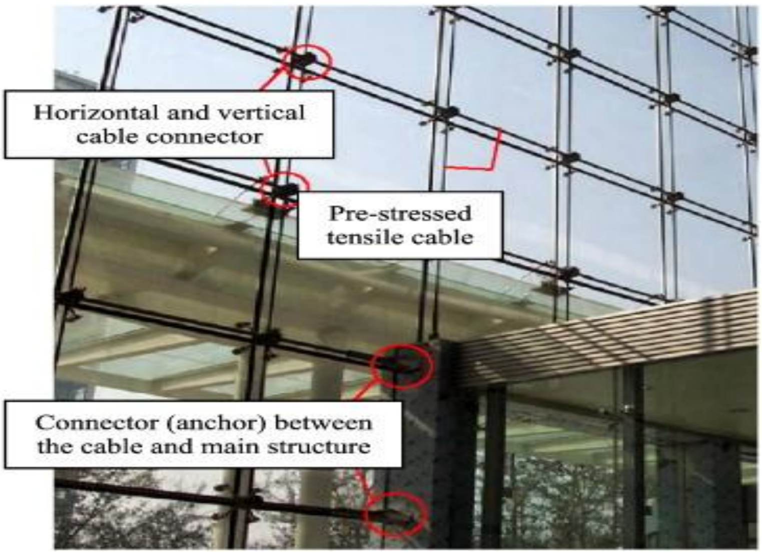


Figure 2. 11: The component of a single-layer plane cable-net structure

2.7.1 Horizontal and Vertical Cable Connector Damage

The horizontal and vertical cable connector consists of the pressure part, screw and nut (Figure 2.11). The vertical and horizontal cable connector is connected tightly by the pre-stress that has been generated by the screwing the nut. It also helps to lock the cable in position to avoid from sliding under the loading. The pre-stress from nut-screwing may lose due to cyclic loading that passing through the horizontal and vertical cables.

2.7.2 Loss in Cable Pre-stress

The loss in cable pre-stress is unavoidable for the cable during loading. There are two factors that affect the loss in pre-stress cable which are stress relaxation and temperature change. Stress relaxation occurs in all kinds of the steels due to part of elastic deformation transform to plastic deformation. Under the long-time loading, the amount in the steel cable is related to the load and the ambient temperature. The relaxation normally increases as the loading and temperature are increased. The temperature change during the service cause the pre-stress cable expands and the amount of the pre-stress decreased.

2.7.3 Damage in Cable Anchorage End

Every cable in single-layer cable net structure are fixed to the main supported structure by the two end anchors. The anchor will deform over the time under the long-time loading and the corrosion that occur in the cable due to the surrounding environment. This damage that occurs in the cable net system will reduce the loading capacity as long the stiffness of the anchor.

2.8 Previous Study

In the previous study by (Feng et al., 2009) on the dynamic performance of the cable net structure, they found that the structural stiffness is mainly controlled by the cable while the stiffness of the glass panels is generally neglected. However, they also mention that the structural stiffness is largely controlled by the geometric nonlinearity of the cable since the deflection of the cable net façade no longer small.

Consequently, (Yang et al., 2015) carried out an experiment on the influence of failure on the static behaviour of single-layer cable net structure. They concluded that for the pre-stress loss or cable anchorage failure in cable, the change in ratio of nodal deflection is usually larger than the change ratio of the cable force, which means these two types of damages have a larger influence on nodal deflection than on cable force. In addition, they also made the conclusion that the influence of the cable pre-stress loss to single-layer cable net structure is not significant and the change of the nodal deflection is usually within 15%.

(Shi et al., 2010) also investigated the influence of damage on the static behaviour of single-layer cable net supported glass curtain wall. They consider three types of damage in their experimental investigation, namely the damage in horizontal and vertical cable connector, loss in cable pre-stress and failure in anchorage end. The results show that the maximum change rate of nodal deflection is 13.78% for the damage in cable pre-stress loss, while the change rate of nodal deflection is between 7% and 22% for the damage of cable anchorage end failure. They also found that the stiffness contribution of glass panels increases with load increase. Under the same condition, the stiffness contribution of glass panels to the damaged structure is greater than that to the intact structure.