AN EXPERIMENTAL STUDY OF NATURAL FREQUENCY OF DAMAGED CABLE NET SUPPORTED FACADE PANEL

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By

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Jejaring kabel yang disokong oleh sistem fasad adalah struktur moden yang telah digunakan secara meluas dan mempunyai banyak kelebihan seperti nilai estetika yang menarik, mudah dibina, penggunaan cahaya yang efisien dan boleh menjimatkan tenaga. Ia biasanya digunakan di terminal lapangan terbang, lobi hotel, dan pusat perdagangan. Kajian ini telah dijalankan secara eksperimen. Fokus utama kajian ini adalah untuk melihat frekuensi semulajadi struktur jejaring kabel yang rosak. Tiga model telah dipertimbangkan dalam kajian ini. Ketiga-tiga model tersebut adalah jejaring kabel, jejaring kabel dengan panel perspek dan jejaring kabel dengan panel perspek dan sealant silikon. Selain itu, kajian ini juga dijalankan untuk melihat sumbangan dan kesan panel perspek dan sealant silikon untuk struktur jejaring kabel. Dalam kajian ini, frekuensi semulajadi jejaring kabel disokong oleh panel fasad dikaji melalui eksperimen dan telah dianalisis dengan menggunakan perisian MATLAB 2015a. Kabel yang rosak di dalam sistem jejaring kabel telah menyebabkan frekuensi semulajadi struktur jejaring kabel berkurang dalam julat 1.40% kepada 2.06% tetapi dengan kehadiran panel perspek dan sealant silikon, frekuensi telah dapat dikekalkan sekitar 70Hz. Walaupun terdapat kerosakan pada kabel, panel perspek menunjukkan kesan yang besar kepada frekuensi semulajadi struktur jejaring kabel. Frekuensi semulajadi keseluruhan struktur telah meningkat dalam linkungan 3.77% kepada 4.96%. Kabel dengan 100% nilai pengurangan dalam daya pra tekanan mewakili kabel yang rosak dalam kajian ini. Sementara itu, bagi kes pengurangan daya pra tekanan, 30% pengurangan nilai daya pra tekanan daripada nilai daya pra tekanan sebenar menunjukkan penurunan frekuensi dalam linkungan 2.73% kepada 4.07% dan 60% pengurangan nilai daya pra tekanan daripada daya pra tekanan sebenar menunjukkan penurunan frekuensi dalam lingkungan 1.06% kepada 1.77%.

Frekuensi semulajadi tertinggi dicatatkan telah dihasilkan oleh struktur jejaring kabel dengan panel perspek dan sealant silikon dengan 77.25hz.

ABSTRACT

Cable net supported facade system that has been widely used is a modern structure and has many advantages, such as pleasing aesthetics, easy constructability, efficient use of natural lighting and energy savings. It is commonly used in airport terminals, hotel lobbies, and trade centre. This research was conduct experimentally. The main focus for this research is to observe the natural frequency of damaged cable net structure. Three models were considered in this research. There were cable net only, cable net with perspex panels and cable net with perspex panel and silicone sealant. Besides that, this research was also carried out to observe the contribution and effect of perspex panel and silicone sealant to the cable net structure. In this research, the natural frequency of cable net supported facade panel was investigated via experiments and has been analyzed by using MATLAB 2015a software. The damaged cable in cable net system had caused the decreased in frequency of the cable net structure in the range of 1.40% to 2.06% but with the present of perspex panel and silicone sealant, the frequency was maintained around 70Hz. Although there was damaged in the cable, the perspex panels showed a significant effect to the natural frequency of the cable net structure. The frequency of the whole structure had increased in the range of 3.77% to 4.96%. The cable with 100% losses value in pre stress force represents the damaged cable in this study. Meanwhile, for the case of pre stress loss, the 30% losses value of the actual pre stress force showed a decrement of frequency in the range of 2.73 % to 4.07% and 60% losses value of actual pre stress showed a decrement of frequency in the range of 1.06% to 1.77%. The highest natural frequency recorded is produced by the cable net structure with perspex panel and silicone sealant with 77.25Hz.

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NOMENCLATURES

L	Length of cable
n	Order of the natural frequency of the cable
T	Tensile force on the cable
m	Mass per unit length of the cable
f_n	nth-order natural frequency of the cable
$f_{n,in-plane}$	Natural frequencies of in-plane vibration
$f_{n,out-of-plane}$	Natural frequencies of out-of-plane vibration
ω	Natural frequency
t_o	Initial pretension
L_o	Original undeformed length
l	Length of cable
H	Tension
m_c	Mass per unit length of the cable
l_c	Cable span
f_n	n^{th} frequency

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Cable net structures represent the ultimate in elegant minimalist structural systems, and provide optimum transparency when the effect of a sheer glass membrane is desired. Cable net structure is a kind of attractive structure because of many advantages such as large flexibility, light weight and small damping. Cable net supported glass facade consists of cables and glass panels. The cables act as a supporting structure for the glass facade. Example of cable net structure with glass facade is shown in Figure 1.1.

Figure 1.1: Cable Net Structure with Glass Facade

Cable net structure is primarily depending on the pre stress force in the cable. The pre stress force is introduced to minimize the deflection and provide a stable structure. The degree of the pre stress force will determine the degree of the cable stiffness. Furthermore, the stiffness of the cable net structure can also be observed based on their frequency. When cable net structure vibrates, it tends to vibrate at a particular frequency. Vibration is a mechanical phenomenon whereby oscillations occur about equilibrium. Vibration has two measurable quantities which are the amplitude and the frequency. Every object has its own natural frequency which is the rate at which an object vibrates when it is not disturbed by an outside force. Resonance will occur if natural frequency equal to the force frequency. Forced frequency is when a free vibration objects is disturbed by an outside force and tends to vibrate at a new rate of vibration. Thus, this situation will affect the stability of the cable net structure.

1.2 Problem Statement

The stiffness of cable net structure is mainly related to the pre stress force in the cables. The pre stress force in the cables can change during the maintenance or the cables undergo stress relaxation that occurs in the cables itself. The changes of pre stress force in cable may change the stiffness of the whole structure. Furthermore, natural frequency of cable net structure will changes when there is changes in the properties of the cable net structures such as presence of facade systems, type of cable and diameter of the cable used. Thus, there will be a difference in natural frequency of the cable net structure with and without facade systems.

1.3 Objectives of the Study

The following objectives are set up to serve as a basis of problem solving and to be a guideline throughout this study. The objectives are as follows:

1. To determine the natural frequency of cable net structures with and without damaged cable.

2. To determine the effect of facade and silicone sealant on the natural frequency of cable net structure with damaged cable.

1.4 Scope of the Study

This study was carried out experimentally. A model of 4 by 4 cable net structure with and without facade panel is considered in this research. There are three model setups that were used in this research namely (i) cable net only, (ii) cable net with facade panel and (iii) cable net with facade panel and silicone sealant. The cable for each model is subjected to 2kN pre stress force. The simulation of damaged cable net was made by reducing the pre stress force in a selected cable. The pre stress force is a cable was reduced to 30% losses, 60% losses and 100% losses of the initial pre stress force. All three models were subjected to vibration and the frequency of each model was observed. This research is concerned about the natural frequency of the damaged cable net with and without facade systems. The type facade used in this study was perspex panels with clamping method.

1.5 Thesis Structure

This thesis consists of five chapters:

Chapter One stretches on the background of the study, the problem statement of this study, objectives of the research and scope of the studies.

Chapter Two discusses the previous literature and findings related to cable net structure, cable, loading and vibration.

Chapter Three explains the details of research methodology that were used. The equipments and materials used in the experiment are also explained. This chapter also describes the flow and testing procedure in the experiment.

Chapter Four presents and discusses the result obtained from the experimental work. This chapter focuses on the result of the natural frequency of damaged cable net supported facade panel.

Chapter Five contains a conclusion and the recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cable net supported facade system that has been widely used is a modern structure and has many advantages, such as pleasing aesthetics, easy constructability, efficient use of natural lighting and energy savings (Feng et al., 2009). They are commonly used in exhibition centers, gymnasia, hotel halls and airport terminals. These flexible cable net supported facade systems mainly consist of pre-tensioned cables and glass panels as shown in Figure 2.1. Cable nets belong to the family of tension structures characterized by geometrically nonlinear behavior (Vassilopoulou and Gantes, 2010).

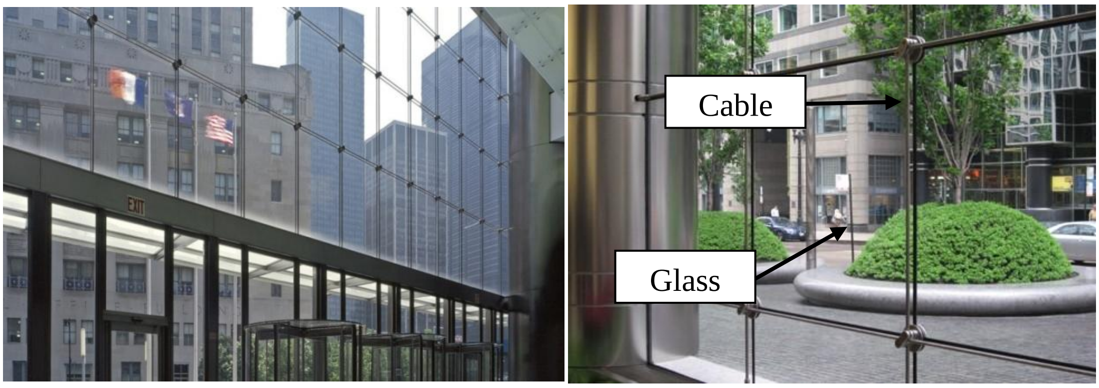

Figure 2.1: Examples of Cable Net Structure with Glass Facade

The stability of the cable net supported facade system is mainly dependent on the stiffness of the cable. The pre stress force of the cable is important in cable net supported facade system to maintain the cable stiffness. Thus, it is very important to check the effect of the pre stress force in the cable in order to maintain the stability and the safety of the structure.

Furthermore, the effect of the facade system on the dynamic performance of cable net supported facade panel is very crucial. This is because the panels are mainly subjected to transverse dynamic loads, such as wind and seismic loads. These loads will cause the panels to vibrate and will eventually affect the stability of the cable net structure.

2.2 Facade System

A facade is an outward appearance of the building. The facade of a building is the first clue that tells us that the structure has something special to offer. An interactive facade is the representation of the architect's creative vision and desire to impress with something unique and out of the ordinary. Facade systems comprise the structural elements that provide lateral and vertical resistance to wind and other actions, and the building envelope elements that provide the weather resistance and thermal, acoustic and fire resisting properties.

There are four type of facade; exposed structure, masonry cladding, curtain wall and structural facade as shown in Figure 2.2. The types of facade system that are used depend on the type and scale of the building. For example, brickwork is often specified as the external facade material, but the modern way of constructing the inner leaf consists of light steel wall elements called infill walling that have effectively replaced the traditional brickwork. In multi-storey buildings, curtain walling is always used as the facade system. Glass has been a very popular facade system for a cable net structure. Glass facade that is using with cable net structure is called glass frameless system.

(a) (b)

Figure 2.2: Various Type of Building Facade, (a) Masonry Cladding (b) Curtain Wall

Research shows that glass panels play an important role in the structural stiffness of cable net structure with glass facade. Study from Feng et al., (2009) showed that the effect of glass stiffness on cable net facade is not very significant for a structure with lower amplitude. The frequency of cable net with glass panels is only 4.8% greater than that of the cable net. However, for the structure with large amplitude, the frequency of the cable net with glass panels is 9.5%-15% larger than those of the cable net, which is mainly due to the contribution of the glass panels. Hence, from their research it is showed that the stiffness effect of glass panel is more obvious for the structure with large amplitude (Feng et al., 2009). Furthermore, cable net structure is said to be less stiffness because of its lightweight but with the present of the glass panels, the overall weight of the cable net structure with glass facade is increase. Thus, it increases the overall stiffness of the structure (Lili et al., 2010). In addition, the increase of overall weight of the structure also affected the natural frequency of the structure. Hence, the structure stability will also improve.

2.3 Cable

Cable or also known as wire rope consist of one or more numbers of strands, laid spirally around one core of steel or fiber core. Cable is made up of three basic components. The components are wires, strand and core.

Cable consists of three basic components, while few in numbers, these vary in both complexity and configuration. Thus, allow the production of cable with specific characteristics for specific purposes (Gabaswire, 2011).

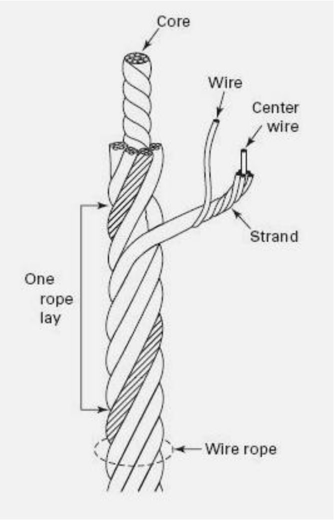

Figure 2.3: Components of Cable (Gabaswire, 2011)

The numbers of wires will form the strand. The wire is made up from several materials such as, steel, iron or stainless steel. Cable is specified by the number of strands in the cable by (X) the number of wires in each strand. Strand is two or more wires wound concentrically in a helix. They are usually wound around a center wire. Strand is normally referred to as 1 by the total number of wires in the given strand (Bell, 2010). Strand formation is the number of strand in a cable, as well as the number and arrangement of wires in a strand. For examples, 1x19 describes one group of nineteen wires; 7x19 describes seven groups of nineteen wires (or seven groups of 1x19).

The wire arrangement in the strand is important in order to determine the factor in cable's functional characteristic such as its ability to meet the operating conditions to which it will be subjected. There are four basic strand patterns in cable (Satyendra, 2013), 7 wire, 19 Warrington, 19 Seale and 25 Filler Wire. The four basic patterns are shown in Figure 2.4.

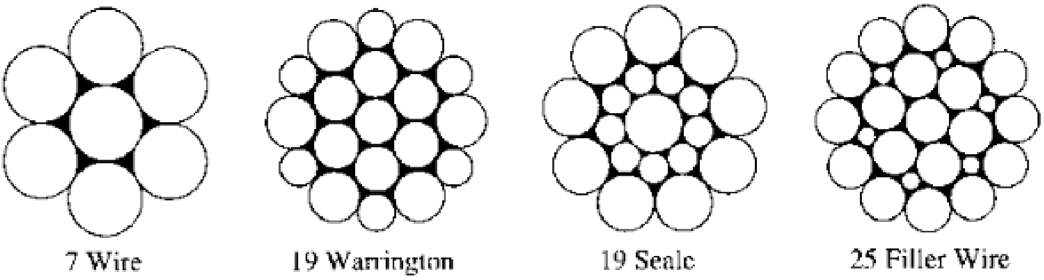

Figure 2.4: Four Basic Strand Pattern (Gabaswire, 2011)

The core is the foundation of a cable. The primary function of the core is to support the wire strands in the cable, maintaining them in their correct relative positions during the operating life of the cable. The strands imbed themselves more firmly into the core as the cable is loaded. The resulting axial movement increases the interstrand pressure where the strands contact each other. It is necessary that the core is strong enough to resist the magnitude of the insterstrand pressure. Figure 2.5 shows the three type of cable core which are fibre core, steel core and strand core.

(a) (b) (c)

Figure 2.5: Types of Cable Core, (a) Fibre Core (FC) (b) Steel Core (IWRC) (c) Strand Core (WSC) (Gabaswire, 2011)

Strength of a cable can be determined by the minimum breaking load of the cable. Minimum breaking load is the limit of the load a cable can withstand without fail or break. Minimum breaking load for cable is different depend on the size, grade and construction of the cable. Table 2.1 shows the example of minimum breaking load for a fiber core (FC), improved plow steel (IPS) cable.

Table 2.1: Minimum Breaking Load for a Fibre Core (FC), Improved Plow Steel (IPS) Cable (Nobles, 2011)

Rope Diameter (mm)	Minimum Breaking Strength (kN)
6.4	24.4
8	37.9
9.5	54.3
11.5	73.6
13	95.2
14.5	120
16	149
19	212
22	286

2.4 Silicone Sealant

Silicone sealant in an insulating glass unit is required to perform two-fold function. The silicone sealant is used to bond the glass panels together. It is necessary to have good adhesion to ensure the seal and continuous contact between the two glasses by adhering perfectly to the glass and the spacer. The silicone sealant should have outstanding resistance to ultraviolet radiation and the capacity to withstand chemical attack from atmospheric agents, such as oxygen, ozone and other pollutants (Amstock, 1997). It also should not contain aggressive volatile product capable of migrating to the interior of the air space of the insulating glass unit and chemically attacking the glass unit. Silicone sealant is also acts a water proving materials for the structure. Among the main three types of sealants that can be found on the market; hardening, plastic and elastic, silicone sealant are particularly appreciated for their elastic behaviour. The ability of silicone sealant to absorb movements is therefore typically the highest compare to other families of sealant, which means that silicone sealants can afford 25–30% joint movement as expressed as the percentage of initial joint width (de Buyl, 2001). Despite being an adhesive and sealant, silicone also can acts as the thermal and chemical ageing resistance. While ensuring full performances to the building owner as silicone sealant not only improve the air and weather tightness of the structure but also support the panels and increase the rigidity of the facade while providing a flexible rubber anchorage that absorbs differential movements between dissimilar materials from thermal or even seismic loading or bomb-blasting. Owing to its excellent adhesion to glass, its thermal stability, its elasticity, and its resistance to UV radiation and ozone, silicone proved to be extraordinarily suitable for the composition of such sealant (de Buyl, 2001).

Figure 2.6: Example of Silicone Sealant

2.5 Behaviour of Cable Net Structure

The stiffness of the cable net supported facade system is obtained by the pretension of the cables. In order to ensure the avoidance of cable slackening under any loading combination, the pretension must be high enough because in that case the net becomes soft and may undergo large deformations (Nam and Nghia, 2011). Cables provide almost negligible bending stiffness and carry loads by axial forces, which lead to a very flexible and highly nonlinear geometrical behavior of the cable net facade. Nonlinear geometrical behavior means that the cables undergo large displacements under loading.

In common cable-supported systems, the stiffness of the glass is generally neglected because the structural stiffness is mainly controlled by the cables (Feng et al., 2009). Nowadays, the stiffness of the glass panels cannot be ignored anymore. This is because the fact that the panels are also subjected to the transverse dynamic loads such as wind loads. Thus, this situation is also need to take into the account in order to observe the dynamic performance of cable net supported facade system.

2.6 Damaged Cable Net Structure

There are three important types of damage of cable net structure. There are horizontal and vertical cable connector failure, pre stress loss in the cable and damage and failure of the cable anchorage end (Yang et al., 2015a).

2.6.1 Horizontal and Vertical Cable Connector Failure

The horizontal and vertical cable connector comprises the pressure part and nut as shown in Figure 2.7. The cables are connected tightly by the pre stress generated by the nut and it also locks the position of the cables. Cyclic loading that pass through the vertical and horizontal cables may cause the pre stress from the nut to decrease. In addition, pre stress loss is also cause by improper construction and material defects. Thus, this will lead to the connector and the cables slide against each other under certain condition.

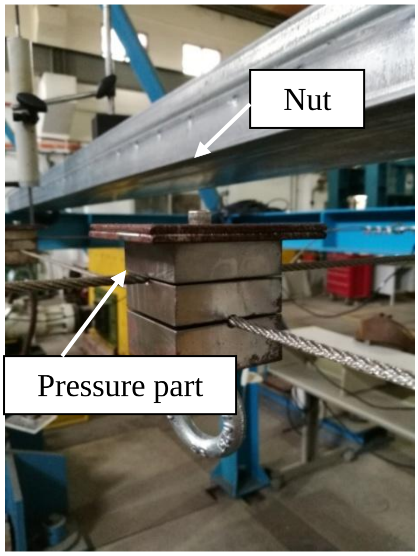

Figure 2.7: Steel Block

2.6.2 Pre Stress Loss in the Cable

The cable net supported glass facade is a flexible supporting system and normally in an undermined state. Therefore in order to maintain the stability of the structure shape and necessary stiffness that will significantly affected the mechanical behavior of the structure, the pre stress force must be applied to the cables. However, the pre tress loss in the cable is avoidable. This is because the stress relaxation of the steel cable. Stress relaxation occurs in all kinds of steels because part of the elastic deformation transforms to plastic deformation due to the accumulation of metal lattice dislocations (Yang et al., 2015a). The amount of relaxation is related to the loads and its ambient temperature under long term loading. The increase in temperature will usually increase the relaxation. Moreover, pre stress loss in the cable is also because of the temperature changes. During the service of the cable net supported glass facade, the ambient temperature changes. When ambient temperature changes, the pre stressed cable expands and the pre stress force is reduced (Sadaoui et al., 2017). The amount of the cable pre stress loss is the product of the temperature difference, the elastic modulus and the linear expansion coefficient of the cable. The loss of the cable pre stress force caused by the stress relaxation and temperature changes is uniform along the cable length and it is independent of other cables.

Based on the research from Sadaoui et al (2017), they concluded that the tension forces in the cables were found to be very sensitive to these temperature changes. A temperature increase of 50 °C was found to cause 58.5% loss of tension in the deck cable. Thus, this will affect the rigidity of the structure. Study made by Yang et al., (2015a) proved that the pre stress loss in the cable result in the higher rate of displacement than that of the intact structure. They used two losses value which were 30% and 60%, then compared the result of the rate of displacement with the intact structure. They also made the conclusion that the rate of displacement depended on the extent of damage as well as the distance to the damaged position. The more severe the damaged position result in the larger rate of deflection, and vice versa.

2.6.3 Damaged and Failure of the Cable Anchorage End

Every cable in the single layer cable net supported glass facade is fixed to the main structure by two-end anchors. The anchors transfer both the pre stress and the stress induced by the loading in the cable. Under long term loading, the anchor would be deformed over time and corrosion may occur due to the surrounding environment. Thus, this would reduce the loading capacity and the stiffness of the anchor. The local load-bearing area, which is near to the anchorage end in the main structure, suffers from the stress concentration and there would eventually undergo plastic deformation. The main structure also carries other loads except the load from the cable net structure, which would lead to various deformation and even damage in the main structure. For example, displacement and damage of the connection area between the main structure and the cable net structure. If the design, the construction or the maintenance is of low quality, the cable anchorage end may be fully damaged in some extreme situations such as complete damage of the anchor itself or localized damage of the main structure at the connection area. Figure 2.8 show the influence of damage or failure of the cable anchorage end will spread from the damage area to the whole cable net and lead to stress and shape redistribution. Therefore, stress change due to damage of the anchorage end is not uniform along the cable length, and damage in one cable anchorage will affect other cables in the cable net structure (Yang et al., 2015a).

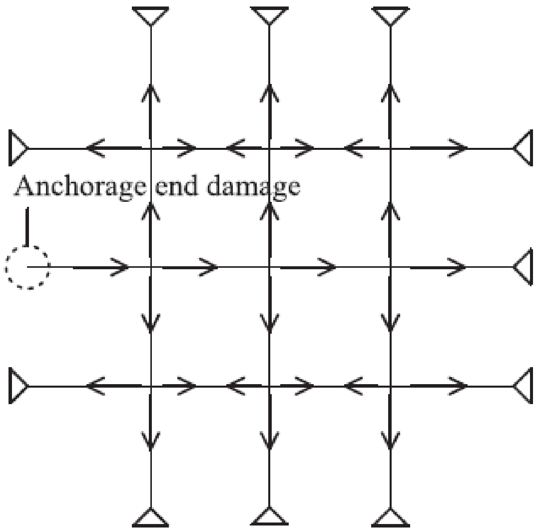

Figure 2.8: Influenced Transfer Caused by the Anchorage End Damage or Failure (Yang et al., 2015a)

The anchorage damage could affect the static structural performance because the cable cannot function and carry load anymore (Yang et al., 2015a). Hence, this will lead to the pre stress loss in the cable and it will result to the significant effect on the local structural stiffness. In their research, they concluded that the pre stressed cable with an anchorage damage leads to a quite large displacement change ratio which is between 18% and 36%. Furthermore, the failure of a pedestrian suspension bridge over Walker Creek near Route 749 in Giles County, Virginia occurred when one of the anchors holding a suspension cable fractured (Dymond et al., 2014). From their research, it is proved that the anchorage failure will cause a significant effect to the structure stability.

2.7 Vibration and Natural Frequency

Free vibrations are oscillations where the total energy stays the same over time. This means that the amplitude of the vibration stays the same. This is a theoretical idea because in real systems the energy is dissipated to the surroundings over time and the amplitude decays away to zero, this dissipation of energy is called damping**.** Forced vibrations occur when the object is forced to vibrate at a particular frequency by a periodic input of force. Objects which are free to vibrate will have one or more natural frequency at which they vibrate, if an object is being forced to vibrate at its natural frequency, resonance will occur and you will observe large amplitude vibrations. The natural frequencies of a structural system are perhaps the most essential characteristics in determining the dynamic behavior of the structure.

Cables are vulnerable to many kind of resonance during their wind-induced vibration because of their geometrical nonlinearity. In undamped or lightly damped linear or nonlinear systems, when the loading frequency equals the eigenfrequency, even a weak excitation may lead to unbounded vibrations, with continuously increasing amplitude, in which case the system is said to be in the well-known state of fundamental or primary resonance (Vassilopoulou and Gantes, 2010). Typical eigenfrequencies of cable net facades are in the range of 0.4−3.5 Hz, depending on geometry, pre stress level and cable diameter (Teich et al., 2012). Thus, it is importance to make the lowest frequency of the structure as high as possible in order to avoid any possibilities of resonance (Arora, 2017). This is because resonance can cause catastrophic failure to the structure.

The property of structure will also affect the vibration and natural frequency of the structure (Spak et al., 2015). In their research they used four types of cable which are 1×7, 1×19, 1×48 single stranded cables and 7×7 multi-stranded cable then observed the natural frequency. They concluded that each of the cable has a different natural frequency.

From the research made by Nam and Nghia (2011), they stated that both pre stress force and natural frequency will affected the rigidity of the structure. In their research, they measured the natural frequency of the cable of Phú Mỹ Bridge. Based on the measured frequency, they calculated the pre stress force in the cable and observe the effect to the structural stiffness of the bridge.

Based on study made by Yang et al., (2015b), they investigated the vibration characteristics of carbon fiber-reinforced polymer (CFRP) and basalt FRP (BFRP) cables that can potentially be used in long-span cable-stayed bridges, compared with the traditional steel cable. The natural frequency is calculated based on the Equation 2.1.

$$f_{n,in-plane} = f_{n,out-of-plane} = \frac{n}{2L}\sqrt{T/m} \tag{2.1}$$

where T = tensile force on the cable; m = mass per unit length of the cable; fn = nth-order natural frequency of the cable; L = length of cable; n = order of the natural frequency of the cable; fn,in-plane = natural frequencies of in-plane vibration; and fn,out-of-plane = natural frequencies of out-of-plane vibration.

Previous study from Kwan (2000) presented a simple approach to calculating natural frequencies of geometrically nonlinear cable structures. Based on the closed-form expression, Kwan had derived and produced an equation to calculate the natural frequency. The equation is presented as Equation 2.2.

$$\omega = \frac{1}{2\pi}\sqrt{\frac{6\,t_0}{3ML_0 + 2\rho L_0^2}} \tag{2.2}$$

where t_0 is the initial pretension and L_0 is the original undeformed length.

In previous study by Maji and Qiu (2014), a finite-element model is presented to simulate cable vibration and cable damping. The natural frequencies of the tested cables are determined by spectral analysis and agree well with those of finite-element simulation and theoretical analysis. The Equation 2.3 is used to calculate natural frequency for theoretical analysis.

$$\omega = \frac{\pi}{l}\sqrt{\frac{H}{m}} \tag{2.3}$$

where l = cable length; H = tension; and m = mass per unit length.

In previous study by Fang and Wang (2012), they used the vibration method to estimate the cable force. This method is widely used because of its simplicity and speediness. According to this method, the frequency of the cable is determined from the cable response, which is excited by manual or ambient sources. Then, this frequency can be applied to estimate the cable force via various theories. If the taut string theory is applied, the cable force (T) can be written as the Equation 2.5.

$$T = 4m_c {l_c}^2 \left(\frac{f_n}{n}\right)^2 \tag{2.4}$$

where m_c= mass per unit length of the cable; l_c= cable span; and f_n= nth frequency.

2.8 Previous Study

The study made by Wang et al., (2015) has found that frequency of the cable-stayed is important to the stiffness of the cable. In their research, they had measured the frequency of a cable-stayed bridge to estimate the force in the cable. Knowledge of the cable force is very important in structural damage detection and condition assessment because cable force governs the internal force distribution and geometry of the deck of a cable-stayed bridge. Thus, a very accurate measurement of cable force has very important practical value for bridge designers and engineers.

According to Yang et al., (2015b) in their study of vibration characteristics of FRP cables for long-span cable-stayed bridges, the vibration characteristics of FRP cables have become a key concern in predicting the dynamic stability of long-span FRP-cable-stayed bridges. FRP cables are assumed to be more sensitive to traffic and wind loads than traditional steel cables. Yang and his friends also stated that cable-deck resonance is also a safety concern for long-span cable-stayed bridges and may occur if the natural frequencies and the modal damping of FRP cables are very low.

Based on previous study made by Maji and Qiu (2014), they stated that vibration damping is critical for structural stability. The understanding of cable damping is particularly significant to the structural performance for structures deployed in space using cables. High flexibility and lightweight cables are inherent of low damping and are susceptible to vibrating. Vibration can be caused by thermal expansion, solar radiation and atmospheric fluctuation. Thus, small vibrations can be problematic and may lead to malfunctions. Their result showed that, the vibration frequency increases with increased tensile force and decreased cable length, and decreases as the number of twists in the cable increases. The cable damping decreases with the increment of tensile force and the number of twists. Also, as the cable length increases, the cable damping decreases until a constant damping ratio is reached.

There was a study made by Liu et al., (2014) on the vibration characteristics of a tunnel structure based on soil-structure interaction. Subway transits system have become for relieving urban traffic problems because of its great passenger-carrying capacity, high speed and punctuality. Thus, determining the self-vibration characteristics of the structure is an important component of the vibration analysis of an underground structure, and the natural vibration frequency of the structure must be obtained before the design load can be determined. From their result, it is stated that the natural frequency of tunnel structure decreases with the increase of tunnel radius, wall thickness, and length.

Lili et al., (2010) stated that all that the pre stressed planar cable net is extremely sensitive to fluctuating wind loads since it has less stiffness, lighter weight, and weak damping. The wind-induced vibration performance has become a vital and challenging problem faced by the scholars and designers for the past few years. They have made a study on the wind-induced response characteristics of a monolayer cable net structure.

In the previous study made by Siringoringo et al., (2013) on dynamic characteristics of an overpass bridge, they found that the changes in frequencies as an indicator of damage presence, while the change in mode shapes can be used to locate the damage. They measure the vibration of a destructed bridge model and observed the dynamic characteristics. Thus, they concluded that the damage of the bridge affected the global stiffness of bridge as the frequency changes.

Gao et al., (2017) have made a study on cracking of reinforced concrete beam and its influence on natural frequency. They said that vibration modal parameters such as natural frequencies and damping ratios are quite sensitive to the damage status of concrete structure. Cracking of a structure could result in a disastrous failure. From their result, they concluded that the decreases in RC beam stiffness, can be identified based on the continuously decreasing natural frequency.

2.9 Summary

This chapter presents an overall literature review of previous study for cable net structure. From these literature review, most researcher study about the dynamic performance of cable net structure without damage of the cable. Only some researcher had study about the dynamic performance of damaged cable net supported glass facade. From their research, it was identified that pre stress force in the cable is the most important element in order to maintain the stability and safety of cable net structure. In cable net structure, glass has been widely used as the facade system but in this research, perspex panels were used during the experiment.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains about the procedure in carrying out the research in order to achieve the objectives of the study. Experimental work was conducted in this research to study the dynamic performance of the damaged cable net supported facade panel. This research is focusing on the natural frequency of the structure. Three experimental set up were considered in order to study the behaviour of cable net supported facade panel under free vibration. A model of 4 by 4 cable net structure was used in this research. There were three tests in this experimental work. Each model was initiated by vibration and the natural frequency for each test was evaluated and compared.

3.2 Specifications of Models

Figure 3.1 shows the layout of the experimental model of cable net without facade systems while Figure 3.2 shows the layout of the experimental model of cable net structure with facade systems. The outline size of the full-scale model is 3.105 m x 3.105 m, composed of 4 x 4 grids and the size of each grid is 0.570 m x 0.570 m. In the cable network, a 4 mm diameter of 7 by 7 wire strand core (WSC), which consists of seven (7) strands with each of those having seven (7) galvanized steel wires were used. The panels were the perspex sheet with the size of 0.560 m x 0.560 m x 0.005 m. The model was surrounded by supporting frame as the main structure. The thickness of the steel frame is 0.15 m and the height of the supporting frame leg is 1.5 m.

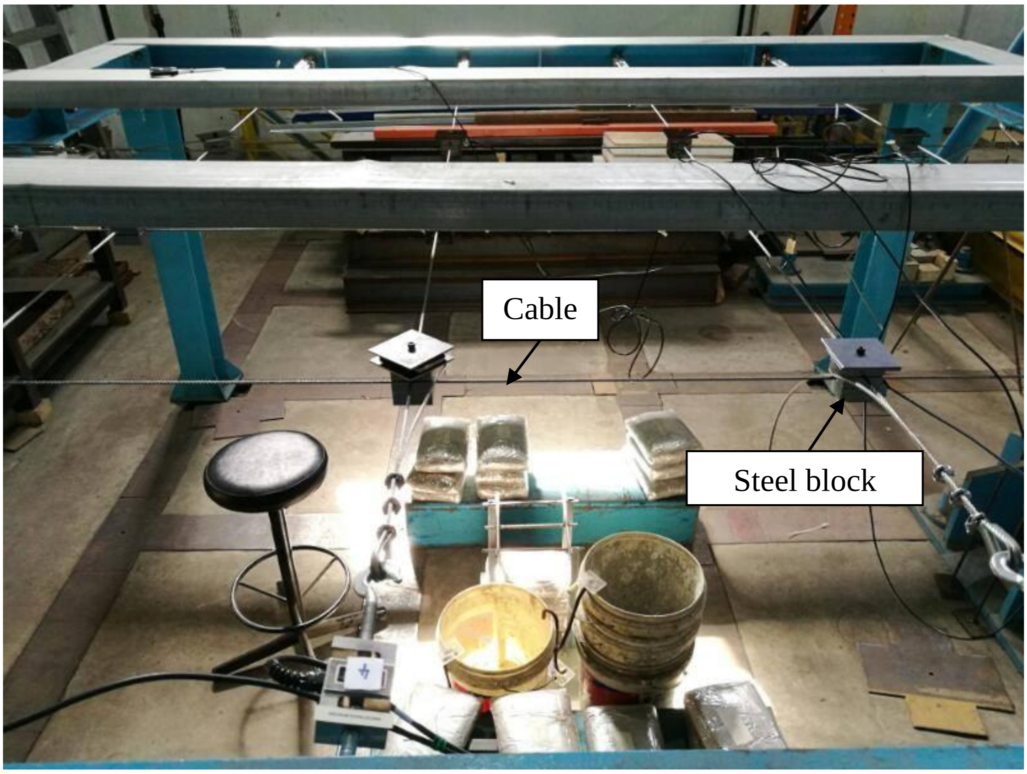

Figure 3.1: Cable Net Model without Facade Systems

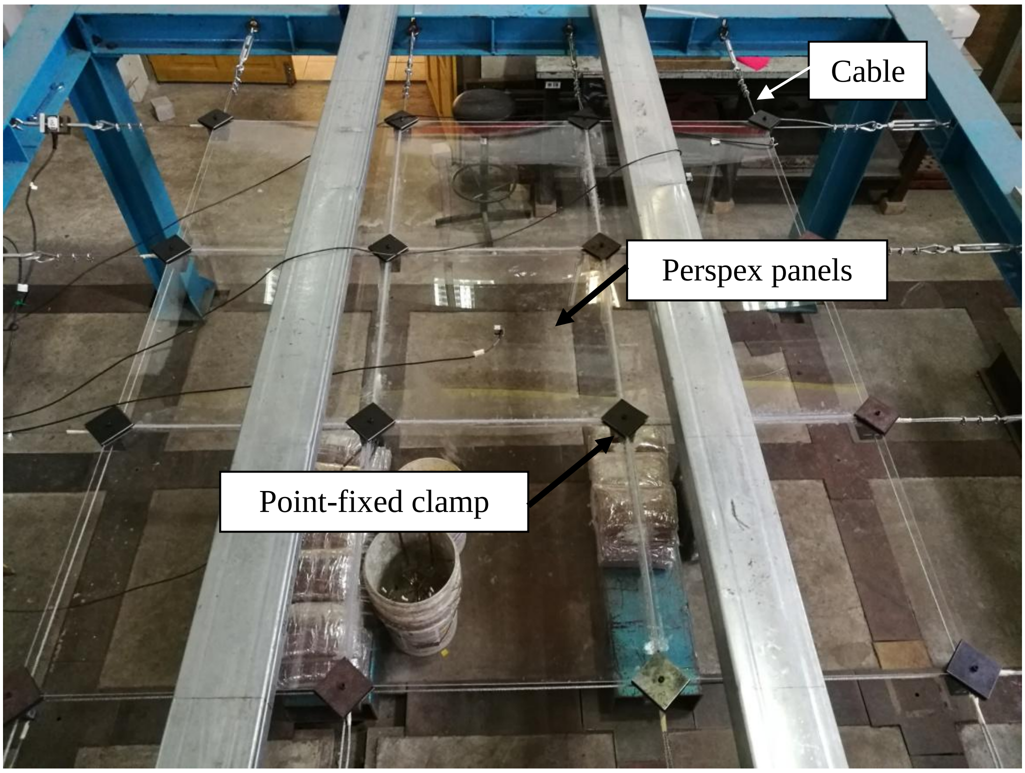

Figure 3.2: Cable Net with Facade Systems