ANALYSIS OF HYBRID ARCH AND CABLE-STAYED BRIDGE

HASMIDA BINTI NOORDIN

BACHELOR OF ENGINEERING (HONS) IN CIVIL ENGINEERING
UNIVERSITY MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS / UNDERGRADUATE PROJECT PAPER AND COPYRIGHT

Author's full name : HASMIDA BINTI NOORDIN

Date of birth : 05 MARCH 1992

Title : ANALYSIS OF HYBRID ARCH AND CABLE-STAYED BRIDGE

Academic Session : 2014/2015

I declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)*

☐ **OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledged that University Malaysia Pahang reserves the right as follows:

1. The thesis is the property of University Malaysia Pahang.
2. The Library of University Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

_______________________	_______________________
SIGNATURE	SIGNATURE OF SUPERVISOR
920305115282	KHAIRUL ANUAR BIN SHAHID
(NEW IC NO./PASSPORT NO.)	NAME OF SUPERVISOR
Date:	Date:

NOTES: * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction

ANALYSIS OF HYBRID ARCH AND CABLE-STAYED BRIDGE

HASMIDA BINTI NOORDIN

Report submitted in fulfilling of the requirements
for the award of the degree of
Bachelor of Engineering (Hons) in Civil Engineering

Faculty of Civil Engineering and Earth Resources
UNIVERSITY MALAYSIA PAHANG

JUNE 2015

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering in Civil Engineering.

Signature	:
Name of supervisor	: KHAIRUL ANUAR BIN SHAHID
Position	: SUPERVISOR
Date	:

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : HASMIDA BINTI NOORDIN

ID Number : AA11091

Date :

Dedicated to my parents:

Mr. Noordin Bin Mat Zin and Mrs. Maimun Binti Yusof

and my siblings:

Rezuan, Normualawiah and Helmi

ACKNOWLEDGEMENT

Alhamdulillah, praise to Allah The Almighty. With His will and His bless, I am able to finish my final year project for my degree successfully on time. With His mercy, I am able to finish my project and get ideas on writing this thesis.

Foremost, I would like to express my sincere gratitude to my cheerful advisor, Mr. Khairul Anuar Bin Shahid for the continuous support of my final year project, for giving me chance to do my final year project under his supervise and always giving me guidance and care during this period. His guidance helped me in all the time of research and writing of this report.

Secondly, I would like to give my special appreciation to my family, my parents Mr Noordin Bin Mat Zin and Mrs Maimun Binti Yusof for giving birth to me at the first place and supporting me throughout my life. Without their support I could have not finish my research.

Furthermore, I would like to extend my gratitude to my best friend Siti Aishah, Nur Nadia Amira, Siti Maizatul Ashikin, Nur Azira Ayuni, Nurul Huda and Adam Ismail for the encouragement, for the sleepless night we were working together before the deadlines, and for all the fun we have had in the last four years. Also deepest thank to all my friends for their encouragement and help during this period. I will always remember all the help and memories we make during our four years together.

ABSTRACT

This thesis is about the analysis of the cable-stayed, arch bridge and hybrid arch bridge. The objectives of this thesis is to study the principal component of cable-stayed and arch bridge with hybrid arch bridge and secondly to investigate the structural behavior between normal arch and cable-stayed bridge. The thesis discussed the structure behavior between these three bridges model to obtain the most effective bridge. The structure two-dimensional model was developed using computer programmed, LUSAS 14 Bridge. The models were analyzes using the linear static analysis which are displacement, stress and bending moment in each bridge main components. There were three arch bridge models, three cable-stayed bridge fan system models, three cable-stayed harp system models and one hybrid arch bridge model. Every model is 600m total long with 300m main span and 150m side span. The loading applied was dead load and live load only. The first analysis is to obtain the stronger arch and cable-stayed bridge. The result obtained that the arch bridge with rise-to-span ratio 1:5 and cable-stayed fan system with 80m of pylon height was the stronger model. Finally, the pure arch and cable-stayed bridge were compared with hybrid arch bridge analysis. Result from LUSAS shows that, hybrid arch bridge was the most effective bridge for long bridge because it has lower displacement, stress and bending moment compared to pure arch and cable-stayed bridge. The structure behavior of hybrid arch bridge is seemed to be stronger. The deck of hybrid arch bridge is support by pylon and arch rib make it more durable in cater the loading applied as compared to pure arch and cable-stayed bridge.

ABSTRAK

Penyelidikan ini adalah mengenai analisis jambatan kabel, lengkung dan hybrid lengkung. Objektif utama tesis ini adalah untuk mengkaji prinsip komponen jambatan kabel dan jambatan lengkung dengan jambatan hybrid lengkung dan yang keduanya adalah untuk menyiasat keadaan struktur bagi jambatan kabel dan jambatan lengkung. Tesis ini turut membincangkan keadaan struktur diantara ketiga-tiga model jambatan ini untuk mendapatkan jambatan yang paling efektif. Model struktur dua-dimensi telah dibuat menggunakan program komputer, LUSAS 14 Bridge. Model-model ini dianalisis dengan cara analisis static selari untuk mendapatkan sesaran, tekanan, dan momen lentur untuk setiap komponen-komponent asas jambatan. Tiga model jambatan lengkung, tiga model jambatan kabel sistem kipas, tiga model jambatan kabel system kecapi dan satu model jambatan hybrid lengkung telah dimodelkan. Setiap model mempunyai jumlah panjang 600m dengan span utama 300m dan span sisi 150m. Beban yang digunakan adalah beban mati dan beban hidup sahaja. Analisi pertama dibuat untuk mendapatkan jambatan lengkung dan jambatan kabel yang paling kuat. Keputusan menunjukkan jambatan lengkung dengan nisbah "rise-to-span" 1:5 dan jambatan kabel system kipas dengan ketinggian menara 80m adalah yang model paling kuat. Akhirnya, jambatan lengkung dan jambatan kabel dibandingkan pula dengan analisis jambatan hibrid lengkung. Keputusan dari LUSAS menunjukkan yang jambatan hybrid lengkung adalah yang paling efektif untuk jambatan skala panjang kerana ia mempunyai sesaran, tekanan dan momen lentur yang rendah berbanding dengan jambatan lengkung dan jambatan kabel. Kelakuan struktur jambatan hybrid lengkung didapati lebih kuat. Dek jambatan hybrid lengkung dibantu oleh menara dan lengkung membuatkannya menjadi lebih tahan dalam menolak beban yang dikenakan ke atas jambatan berbanding jambatan lengkung dan jambatan kabel.

TABLE OF CONTENTS

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS & DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ_s	Density of steel
ρ_c	Density of concrete
γ_{premix}	Density of premix
$\sum$	Summation

LIST OF ABBREVIATIONS

2D	Two-dimension
3D	Three-dimension
CSS	Circular stainless steel
DOF	Degree of freedom
FE	Finite element
RHS	Rectangular hollow section
UDL	Uniform distributed load
UMP	University Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Bridge is a common structure to connect a point to another point via a lake, sea, or another circumstance that block people from across it. Before bridge create it history, human use stepping-stones to cross streams and other natural obstacles. Later, human become more advance, they use felled tree trunks as a bridge. Here, a simple beam bridge was created (Ryall et al., 2000).The function of bridge can be divided into two that are highway bridge and pedestrian bridge. Highway bridge is a bridge that been designed to carry over vehicles (large load) while pedestrian bridge is designed to carry people only (small load).Bridge have many types. Every type of bridge has different strength to support loading. The type of bridge depends on function of the bridge, the nature of the terrain where the bridge is going to be constructed and anchored, the material used and the funds available to build it.

Arch bridge is a very common bridge with it famous aesthetical value. Arch bridge history start during 4000 B.C when the community of Sumerians that lived in the Tigris-Euphrates Valley discovers the arch shape advantages in construction. They use sunbake brick to form an arch shape and began to construct small arch bridge (Wai and Lian, 1999). Arch is define as a curved structural member spanning and opening and acts as a support for the loads above the opening. The true perfect arch is which only a compressive force acts at the centroid of each element of the arch. The shape of the true arch can be thought of as the inverse of a hanging chain between abutments. For practice, it is impossible to have a true arch except for one loading condition. The arch bridge is subjected to multiple loading which will produce bending moment stresses in the arch rib that are generally small compared with the axial compressive stress. Arch bridge components are arch, deck and floor beam. Arch bridge advantages are the arch can be built on larger scales, the structure is much lighter because the arch itself can support the loading, the deformations under traffic loads are limited, the malfunction can be detect early and have aesthetical value (Weber, 1999).

However, cable-stayed bridge is famous with it long span that is around 1000m.Cable-stayed bridge span is longer because the cable can support the deck effectively rather than arch bridge. Cable-stayed bridge start it history during year 1883.During that time, the Roebling design a bridge according to suspension bridge design but he assigned additional inclined cables to provide stability against wind and to stiffen the bridge. Thus, the bridge become the first hybrid type of cable bridge name as Brooklyn bridge with total length of 1059.9m and main span of 486.5m (Elsa, 2007). The modern cable-stayed bridge developed on the second half of the twentieth century. It was discover by Dischinger, who realized that stability and stiffness could be achieved with high strength prestressed cables. The first modern cable-stayed bridge is Stromsund Bridge in Sweden, 1956 with total length of 332m and main span of 182.6m.

Bridge construction have been developed in Malaysia since 1960.Malaysia have constructed many cable-stayed bridge type such as the most popular bridge in Malaysia, Penang Bridge. Cable-stayed type bridge is chosen because of its performance and constructability. The main advantage of this type of bridge is the reducing of stress due to the support from the stayed cable. The history of cable-stayed bridge in Malaysia began on 1972.It was constructed in Kota Kinabalu, Sabah (Wahid et al., 2002).Cable-stayed bridge components are tower, cables and deck. To expand span length further, the cable-stayed bridge deck-supporting system is the cable-tower system. The deck system required to be stiffer than those used on beam, truss, and arch bridges. The bridge performance and constructability for the cable-stayed bridge is mainly depend on the structure performance of the cable itself.

Arch bridge has a very limit of increasing length which it rise-to-span ratio would become smaller and arch may become unstable under loads when arch span become longer. The common length of arch bridge is around 500m. Meanwhile, according to Hongwei and Amjad (2015), as the span length increase, the stay cable become ineffective due to several factors that are firstly, as the cable length increase, the cable become heavier which result in cable sag effect becomes more dominant and result in significant reduction of cable stiffness, secondly when the cable length increases, the cable’s frequency increase throughout the entire bridge which result in internal resonance problems, and thirdly corrosion problem due to environmental effect on the cable.

Combination of cable-stayed arch bridge is purposely to overcome the disadvantages of above arch and cable-stayed bridge. Cable-stayed arch bridge is a combination of two different engineering techniques which is arch and cable-stayed that produces a hybrid. The first cable-stayed arch bridge structure is Seri Saujana Bridge in Putrajaya, Malaysia with length of 300m.The capability to support load is come from the components that made up the bridge. The bridge component such as arch for arch bridge is designed to support load from the deck to the tower. While the stayed cable for cable-stayed arch bridge is also design to carry load from the deck to the pylon. But there is different in term of total loading that can be support by these bridge components and to know the different, a research must be conducted to study the principle components of the bridge.

The principle components study that is focusing in this research is only for arch bridge and cable-stayed bridge. This result will be analyze and compare with combine cable-stayed arch bridge. The bridge performance will be analyzed by using Ansys or LUSAS 14 software. The scope of this research only focuses on Highway Bridge. The result or outcome predicted is to obtain the most effective highway bridge in term of structure performance and constructability.

1.2 PROBLEM STATEMENT

Based on the comparison of length span, the cable-stayed bridge is longer than the arch bridge. This is why cable-stayed bridge is commonly constructed compared to arch bridge nowadays. In the construction bridge over the sea, the arch bridge has the disadvantage because the tie girder has to be constructed before the arch ribs can function. While for the cable-stayed bridge, the deck elements and cables are erected simultaneously during the construction process.

In term of structural performance, cable-stayed bridge disadvantage is 1;when the cable length increase, the cable become heavier which result in cable sag effect becomes more dominant and result in significant reduction of cable stiffness and, 2;when the cable length increases, the cable’s frequency increase throughout the entire bridge which result in internal resonance problems. While for arch bridge, the arch may become unstable under loading when arch span become longer (Kang et al.2014).Thus, it have very limit of increasing it length.

Based on research by Lonetti and Pascuzzo (2014), the Brooklyn Bridge, a hybrid suspension bridge is proven more suitable than pure cable stayed and suspension bridge in term of structural and economical point of view. Thus, the combination of cable-stayed bridge and arch bridge may reduce some disadvantages between these two type of bridge in term of components and it constructability. Thus this combination is called hybrid arch bridge. Comparison of cable-stayed bridge, arch bridge and hybrid arch bridge need to be analyze to obtain the most effective highway bridge in term of it structure performance and constructability.

1.3 OBJECTIVE

There are two main objective of this research that are:

1) To study the principle component of cable stayed and arch bridge with hybrid arch bridge.

2) To investigate the structural behavior between normal arch and cable stayed bridge.

1.4 SCOPE OF STUDY

This research is only focusing on Highway Bridge. The scopes of study are:

I. Study and analyze the principle components of cable-stayed bridge that are tower, cables and deck.

II. Study and analyze the structural behavior of arch bridge that are arch, deck and floor beam.

III. The middle span length of arch bridge, cable-stayed bridge and hybrid arch bridge is 300m.

IV. The total length of arch bridge, cable-stayed bridge and hybrid arch bridge is 600m.

V. Loading use is dead load and live load only.

VI. The analysis type use is static linear analysis with 2 dimensional model.

1.5 RESEARCH OUTCOMES

The outcome predicted from this research is to provide the most efficient highway bridge in term of performance and constructability. The performance and constructability is based on the normal cable-stayed and arch bridge components. The performance of bridge between normal cable-stayed and arch bridge can be compared to combine cable-stayed arch bridge to obtain the most effective design for bridge. The design is compare in term of structure behavior which is displacement, stress and bending moment.

CHAPTER 2

LITERATURE REVIEW

2.1 ARCH BRIDGE

The value for horizontal force in arch is depends on the rise-to-span ratio. For analysis, the depth of the rib and the tie girder affect the total moment between the tie and the rib of the arch bridge. Deck can be explained as the roadway orthotropic steel plate or concrete slab and has structural supports. The value for rise-to-span ratios is between 1:4.5 to 1:6 (Brencich and Sabia, 2008).The material for steel arch rib is usually made up of plates in rectangular box shape and the tie is plate girders or welded steel box girders. A research have been done and state that the welded connection cannot use for plates of the steel girders together but to use angle and use bolt as a connection. This method is to prevent crack appeals in welded tie girder.

2.1.1 STRUCTURE BEHAVIOR

Arch is define as a curved structural member spanning and opening and acts as a support for the loads above the opening. The true perfect arch is which only a compressive force acts at the centroid of each element of the arch (Brencich and Sabia, 2008).The shape of the true arch, can be thought of as the inverse of a hanging chain between abutments. For practice, it is impossible to have a true arch except for one loading condition. The arch bridge is subjected to multiple loading which will produce bending moment stresses in the arch rib that are generally small compared with the axial compressive stress. Arch bridge components are arch, deck and floor beam (Figure 2.1)

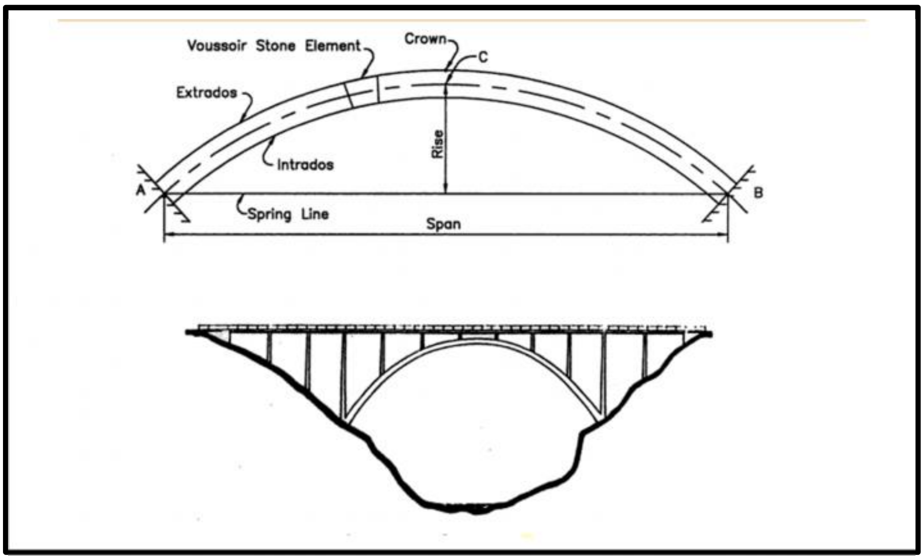


Figure 2.1: The components of arch bridge

Source: Brencich and Sabia, 2008

The reason why arch bridge should be curve is because the curve of the arch cross-section has internal force in two significant points. First is when the vertical and self-weight of arch push the arch down and secondly the compressive forces push the structure up. Thus, the reaction force will have different direction according to the various points taken from the section of the arch. Finally, the angle resulting from these force form the curve shape (see Figure 2.2).While for a simple beam, the section only have linear axis due to shear stress and bending is in equilibrium with vertical loads. All arch structures are under compressive force and should be built on a strong support to avoid failure due to arch push over the support. An arch should be completed and stable only when it is hung by cables or held by a mold. Also, an arch cannot be built as cantilever because a large force of the bridge have horizontal component that need to be transfer to supports without significant displacements. According to Frunzio et al. (2001), when the arch bridge is constructed over a road, the curvature of the arch needs to be greater to make a clear distance.

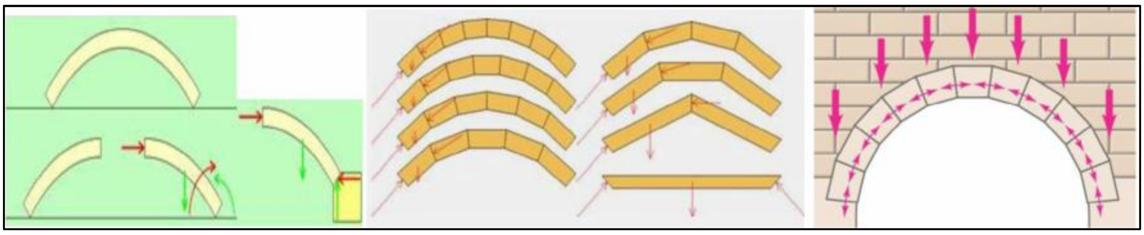


Figure 2.2: Force acting on arch rib

Source: Frunzio et al., 2001

2.1.2 TYPE OF ARCH BRIDGE

Ach bridge have many types and been classified based on type of material used and shape of course. There are a few type of arch bridge that have been practice from the first it been founded until now that are corbel arch bridge, aqueducts and canal viaducts, deck arch bridge, through arch bridge and tied arch bridge. The further description and it structure behavior are discuss below.

2.1.2.1 CORBEL ARCH BRIDGE

This type of bridge is made up by lay a composed of stone or masonry with each having successfully larger cantilevers. It does not have function exactly like other type of arch bridge because it does not transfer force through the arch. Despite of that, this corbel arch bridge is define under arch bridge because of it look which can be created to look very similar to other type of arch bridge (see Figure 2.3).

Figure 2.3: Arkadiko Bridge, Greece

Source: Robert, 2011

2.1.2.2 AQUEDUCTS AND CANAL VIADUCTS

This type of bridge is design for a large distance bridge. It is built with a series of supports which is connected with arches made of stone. These arches structures were butt with several layer of height (Figure 2.4).

Figure 2.4: Pont Du Gard Bridge, France

Source: Monginuox

2.1.2.3 DECK ARCH BRIDGE

This arch bridge design located the deck bridge on the top of the arch (Figure 2.5). The deck section is thicker than the arch section because the deck is under buckling and bending effect but arch is under the compression effect only. But, compare to a simple beam bridge, this deck arch bridge have thinner deck thickness because load is transfer from the deck to the arch.

Figure 2.5: Perrine Bridge, USA

Source: Daniel, 2004

2.1.2.4 THROUGH ARCH BRIDGE

This bridge deck is place above the deck but not completely, it suspended via tie bars or cable and travels in one part below the arch. The example is Sydney Harbour Bridge (Figure 2.6).

Figure 2.6: Sydney Harbour Bridge, Australia

Source: Anup, 2014

2.1.2.5 TIED ARCH BRIDGE

The tied arch bridge is also called as bowstring arch bridge (Figure 2.7). It design has tie between two opposite ends of the arch and it is use material fully steel. This type of bridge can be built on soft foundation because it is a self-balance structure (Jung, et al. 2009) proposed a new practice for tied arch bridge to withstand a longer span bridge. The research compares the nonconventional thin-walled arch rib with conventional single arch rib in term of their structural behavior. The result shows that the nonconventional thin-walled arch rib bridge model have a better structural behavior when test under design load cases. This will provide a good engineering practice for a tied arch bridge to be constructed on soft foundation with a longer span.

Figure 2.7: Lowry Avenue Bridge, Minnesota

Source: Madeleine, 2009

2.2 CABLE-STAYED BRIDGE

Cable-stayed bridge is a bridge with hinges at intersection between the deck and the pylon and all cable anchor points. This system will transfer axial force resistance of the deck to the pylon. There are two main cable systems that are fan stay system and harp stay system (Ryall et al.2000).

2.2.1 STRUCTURE COMPONENTS

Cable-stayed bridge components are tower, stayed cables and deck. To expand span length further, the cable-stayed bridge deck-supporting system is the cable-tower system. Tower or pylon is defines as an upright structure that is used to support the deck by connecting stayed cable from pylon to the deck. The deck system required to be stiffer than those used on beam, truss, and arch bridges. The stay cable is a tension component used to connecting the deck and pylon. Meanwhile, for the minor component, the most important component is the anchor because the failure of anchor in cable stayed bridge will produce the worst damage to the bridge (Lonetti and Pascuzzo. 2014). These failures are due to preexisting failure effect from long term damage and also failure due to accident. For the comparison of length span, the cable-stayed bridge is longer than arch bridge. The arch bridge disadvantage is that the tie girder has to be constructed before the arch ribs can function. While for the cable-stayed bridge, the deck elements and cables are erected simultaneously during the construction process. The pylon length is usually 1/5 of span bridge.

2.2.2 TYPE OF CABLE-STAYED BRIDGE

Cable-stayed bridge has four types or systems which are fan, harp, and semi harp system (Walter et al. 1999). In this research, only two type will be analyzed that are fan system and harp system.

2.2.2.1 FAN CABLE SYSTEM

The first cable system in the cable-stayed history is the fan cable system (Figure 2.8). This method introduces the method of the cable laid from the deck to the top of the pylon. It will reduce the moment applied to the pylon. The advantage of this system is the number of stay cable distributes large uniformity of forces to the deck providing a continuous elastic support. Thus, the deck becomes lighter in construction.

Figure 2.8: Millau Viaduct Bridge, France

Source: Punithav, 2011

2.2.2.2 HARP CABLE SYSTEM

The harp cable system is just another cable system in cable-stayed arch bridge. In this system, every stays are anchored at equal spacing over the pylon and are placing parallel to each other (Figure 2.9). The force is distributes from the back span to the main span. The main disadvantage in this cable system is when there is one side of loading, the load may be divide into symmetrical and anti-symmetrical components of loading. The symmetrical loading can be resist by the triangle force produce by the stays, pylon and deck but the un-symmetrical loading can only be resisted by bending of the deck, pylon or combination of both depend on their relative stiffness.

Figure 2.9: Second Penang Bridge, Malaysia

Source: Arup, 2015

2.3 HYBRID ARCH BRIDGE

Hybrid arch bridge is combination of bridge with other type of bridge. Hybrid arch bridge is a combination of two different engineering techniques which is arch and cable-stayed that produces a hybrid. The first hybrid arch bridge structure is Seri Saujana Bridge in Putrajaya, Malaysia with length of 300m. Based on research by Dai Yu-wen and Wang You-yuan (2012), the longest hybrid arch bridge in the world is Liancheng Bridge in China with span 120m + 400m +120m.

The hybrid arch bridge is better in dynamic behavior which have lower torsional and vertical modes than pure arch bridge thus the span can be more longer (Kang et al, 2014).The research analytical and experimental dynamic behavior of a new type of cable-arch bridge have been conducted by comparing finite element method with experiment in term of ambient test with frequency and mode shape. Analytical method is use to test the stringer's stiffness, the effect of oblique angle of main arch and wind bearing. In order to analyze the dynamic behavior of the model bridge, the research use testing method to analyze the initial tension force and the effect number of cable.

2.3.1 STRUCTURE BEHAVIOR

Hybrid arch bridge has very unique structure which the stayed cables is anchored on the arch rib and the upper end on the pylon. This system is not only eye-catching but also has an importance system which the cables help to transfer load from the arch to the pylon. The bridge is made up of cable hoisting system with cable, anchor and tower. While the arch rib system is shipped to the spot after they had been made and it is usually made up of steel tube with separate segment. The arch bridge and cable stayed bridge is mix to obtain the advantages between these two bridges. The arch can decrease the height of the pylon because the arch rib increases the stiffness of the bridge. The pylon can provide supporting to tower of hoisting system when the cable is anchored to pylon and temporary stayed-buckle cables. While for cable stayed bridge advantages is it can take load with arch, improve the stiffness of the structure, adjust the curve of arch and lower the effect of arch horizontal force.

Dai Yu-wen and Wang You-yuan, (2012) had made a research to cable force optimizing calculation of cable stayed arch bridge. In this research, the try to find the method to make the construction of arch curve adjustment become easier by optimize the calculation of cable force. They modify influence matrix and develop calculation program by using ANSYS APDL language. Then, the research compares the cable removal construction with influence matrix. Their model is Lian-cheng bridge, the bridge is predicted as symmetrical structure. The quarter arch rib is taken into calculation for simplify the calculation.

The model simulation is made by omitting the displacement of pier and pylon at the precondition of construction accuracy. Simulation of cable is using the link element while simulation of steel tube is by using beam element. The cantilever erection processes use the sequential forward algorithm. At the beginning, the entire element is killed and the elements are active according to the cantilever process. Then the cable is removed and a force with same value is put on the same spot with but in a reverse direction to the cable. This simulation is done by using ANSYS program with parameterization program language APDL language to build the model. The result of this research show the different is only 8% and meet construction request.

2.3.2 TYPE OF HYBRID ARCH BRIDGE

This type of bridge only has one type that is combination of arch and cable stayed bridge. This is because hybrid arch bridge is still a new finding in bridge history. That is why only two hybrid arch bridge exist in world that is Saujana Bridge in Malaysia and Lian- Cheng Bridge in China (see Figure 2.10).

Figure 2.10: Liancheng Bridge, China

Source: www.skycrappercity.com

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The research is focusing on the structure behavior of the bridge in term of performance and constructability. In order to evaluate the nonlinear analysis, LUSAS Bridge modeler has been used. LUSAS Bridge is world-leading finite element analysis software for the analysis, design and assessment for all types of bridge structures. LUSAS modeler is for analysis only while for design, the designer need to install the additional installer for design. This software is using coordinate system as an input to build up the model. LUSAS software is easy to understand because it shows a direct preprocessing and post-processing step by step in the tutorial module.

This research is focusing until analysis only, thus only LUSAS modeler is used. The bridge is model as 2- dimensional only. The flow of the process is beginning with data collection which is dead load and live load. All the data need to be calculated based on Euro Code 2 standard. Then, the loading will be assigning to all models with the same value. This precaution is to make sure that all models can go through the same analysis. There are ten models of bridge comprising of three arch, six cable-stayed and one hybrid arch bridge. All the models were made by using LUSAS and analyze using linear static analysis. Linear static analysis is when all loads are applied fixed and remain constant. This analysis only calculates the displacement, stress, strain and reaction. Nonlinear analysis is a case when the loading produce significant changes in the stiffness. Every model is analyzed to obtain the value of bending moment, shear force, normal force and displacement of the bridge structure component.

3.1.1 FLOW CHART

The research flow from the start until end is shown in Figure 3.1 below. The start of project began on September 2014 with literature review on principal component of arch, cable-stayed and hybrid arch bridge. Then follow by analysis of component for cable-stayed bridge and arch bridge. Cable-stayed, arch and hybrid arch bridge are then analyzed by using LUSAS software to obtain and compared their structure performance. Then, the most effective bridge can be obtained.

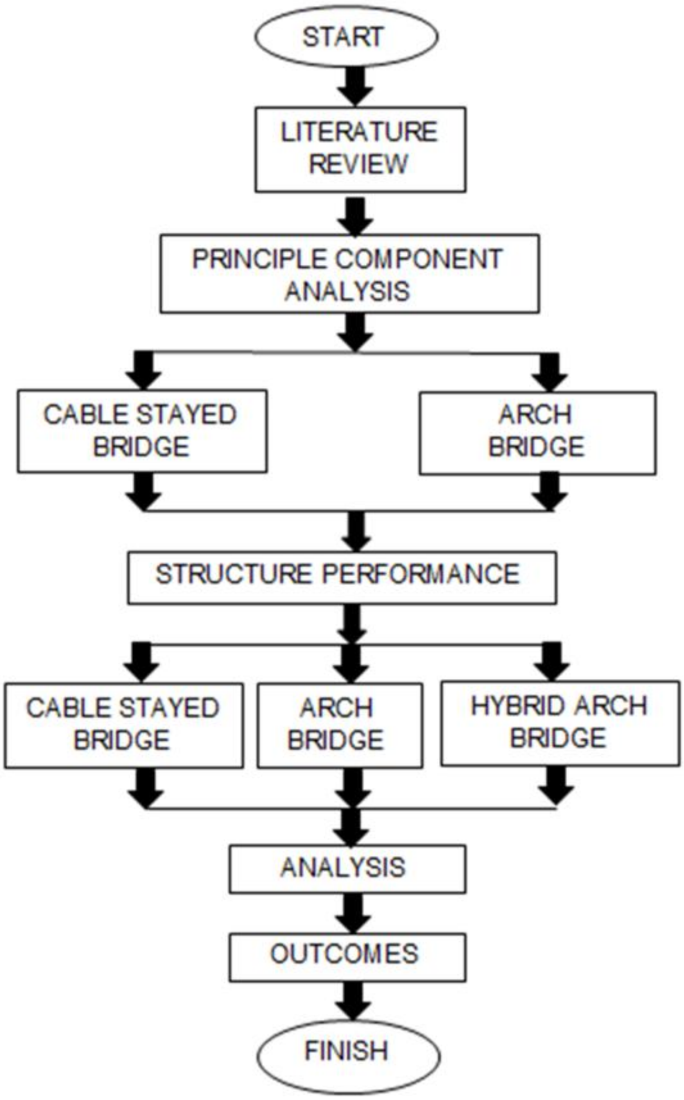


Figure 3.1: Flow Chart

3.2 BRIDGE LOADINGS

All data collection needs to be collected before making the model. The collection of data is dead load and live load value only. The effect of wind loading, current loading and earth quake loading were not considered. Dead load and live load values will be use and assign in the model later. All the values are calculated based on the real project to make sure the model is analyzed such a real project model.

3.2.1 DEAD LOAD

Dead load is a permanent load or self-weight of the structure. The dead load of a large span bridge gives the most of the bridge loads. Bridge dead load is calculated from the materials that build it up. In this research, the bridge is made up of concrete deck slab with premix layer, steel I-beam, concrete parapet and railing, concrete column cap and steel pier (Figure 11). The material constants are value as follows. The density of steel ρ_s = 78.5 kN/m^3 and the density of concrete ρ_c = 25kN/m^3. As refer to Euro Code 1991.2.2003, the calculation for dead load is as below:

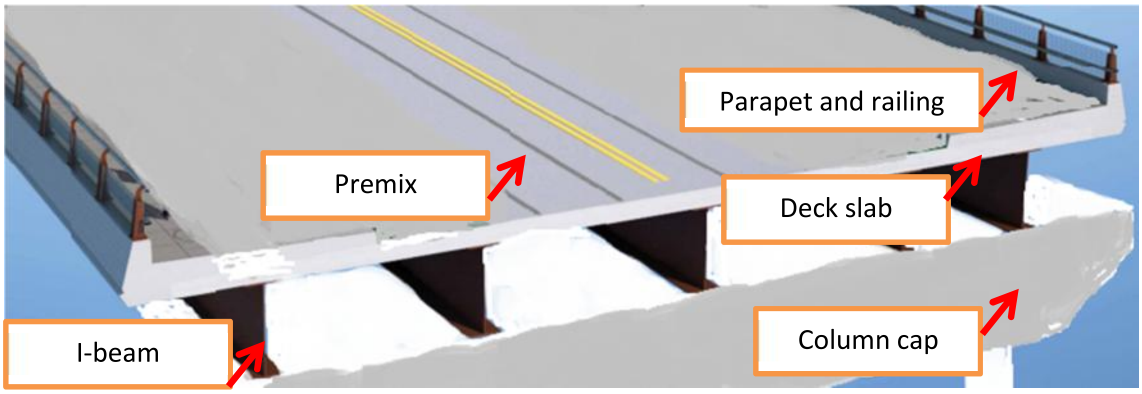


Figure 3.2: Bridge components

Structural dead load:

1) Beams

   Total length = 10 m

   X-section area = 0.332 m^2

   Density of steel = 78.5 kN/m^3

No. of beams = 60 per length (5 per width)

Total weight of 80 beams = A x length x Density of steel

= 0.332 m^2 x 10 m x 78.5 kN/m^3

= 260.62 kN x 60 x 5

= 78186 kN

2) Diaphragms

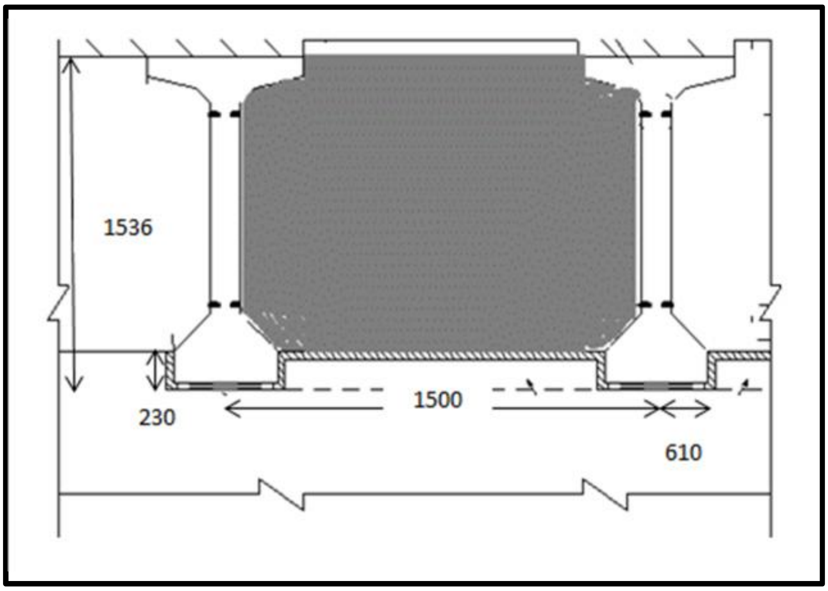


Figure 3.3: Diaphragms layout

Cross section axes of one diaphragm,

= [91.5x1.536)-0.467-91.5-0.61)] x 0.23

= 1.63 m^2

Equivalent no. of diaphragm = 11 nos /row

Intermediate = 9 nos. With 150 mm thick

= 2 nos. With 380 mm thick

Intermediate :

Total weight = 9 x 0.15m x 1.63 m^2 x 25kN/m^3 = 55.01 kN

End row = 2 x 0.38m x 1.63 m^2 x 25kN/m^3 = 30.97 kN

Total weight of diaphragms = 55.01 + 30.97 = 85.98 kN

3) Deck slab

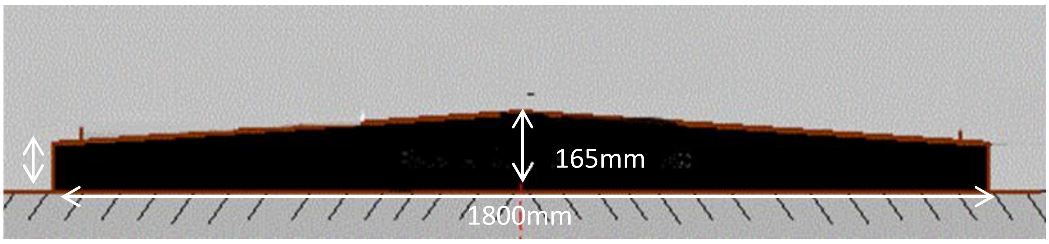


Figure 3.4: Deck slab dimensions

X-section area:

$= [\ \frac{1}{2}(0.125 + 0.165) \times 9\ ]2$

$= 2.61\ m^2$

Total weight $= A \times \text{total length} \times \gamma_{concrete}$

$= 2.61\ m^2 \times 600\ m \times 25\ kN/m^3$

$= 39150\ kN$

4) Parapet and railing

Weight per meter run = 7.315 kN/m

Total weight of 2 parapets = 2 x 7.315 kN/m x 600 m

= 8778 kN

Superimposed dead load:

1) Premix

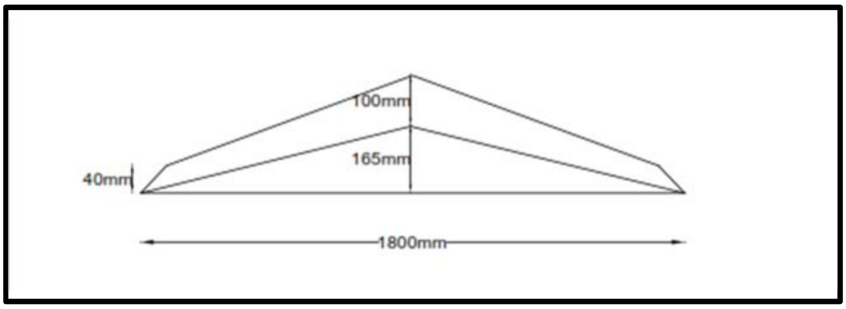


Figure 3.5: Premix layers dimension

Density of premix = 22.6 kN/m^3

X-section area $= \frac{1}{2}(0.04 + 0.1) \times 18$

$= 1.26\ m^2$

Total weight = A x total length x γ_{premix}

$= 1.26\ m^2 \times 600\ m \times 22.6\ kN/m^3$

= 17085.60 kN

<u>Summary of Dead Loads</u>

1) Beams	= 78186 kN
2) Diaphragms	= 85.98 kN
3) Deck slab	= 39150 kN
4) Parapet and railing	= 8778 kN
5) Premix	= 17085.60 kN
∑	= 143285.58 kN

Dead Load/abutment $= \frac{143285.58\ kN}{2}$

= 71642.79 kN

Total UDL $= \frac{71642.79\ kN}{\text{Bridge length}}$

$= \frac{71642.79\ kN}{600m}$

= 119.40kN/m

3.2.2 LIVE LOAD

Live load is the variables load that acting on the structure. As for the highway bridge, the live load is referred to vehicle loading. The value and calculation is referred to Euro Code 1991.2.2003.The calculation is as below:

Calculation of bridge' width:

Width, w = (3.5 x 4) = 14 m > 6m

N_1 = Int[$\frac{w}{3}$] = Int[$\frac{14}{3}$] = 4 m

w_r = w- $3N_1$ = 14-3(4) = 2 m

Total width for bridge = (3.5 x 4) + (2 x 2) = 18 m

Calculation for live load:

Table 1: Distributed and concentrated loads on the conventional bridge lanes

Conventional lane	Q_k (kN)	q_k (kN/m^2)
Lane 1	300	9.0
Lane 2	200	2.5
Lane 3	100	2.5
Residue Area	0	2.5

Source: EN 1991-2:2003

Assume:

α = 0.8 for first conventional lane

= 1.0 for other lanes

Thus;

Total lane = 4

Design load for each lane = α x q_k

Lane 1 = 0.8 x 9 = 7.2 kN/m^2

Lane 2 = 1 x 2.5 = 2.5 kN/m^2

Lane 3 = 1 x 2.5 = 2.5 kN/m^2

Residue area = 1 x 2.5 = 2.5 kN/m^2

Total live load, q = q_{lane} (w_L) + q_{RA} (w_r)

= (7.2 + 2.5 + 2.5)3.5 + 2.5(2)

= 47.7 kN/m

3.3 MODEL STRUCTURE

The models uses for this research are arch, cable-stayed and hybrid arch bridge. There are three arch bridge models, three cable-stayed bridge fan system, three cable-stayed bridge harp system and one hybrid arch bridge. Thus there are ten models all. The entire models have same total length of 600m, main span length of 300m and the side span length of 150m both. The middle span should accomplish about 60% of total bridge length and the side span should be equally divided (P. Dayaratnam, 2000). The loading use also same as from the above loading calculation is 119.40kN/m for dead load and 47.7kN/m for live load. All the geometry size, and type of material used are same for the entire models.

3.3.1 ARCH BRIDGE

The chosen type of arch bridge is the steel through tied arch as shown in Figure. The bridge is model with different rise to span ratio of 1:4.5, 1:5 and 1:5.5. Every model is fixed with span length of 300m and total bridge length is 600m. As for the arch with ratio 1:4.5, the height of arch is 67m (Figure 3.6). While for ratio 1:5, the height is 60m (see Figure 3.7) and ratio 1:5.5 the height is 55m (Figure 3.8). Using LUSAS, the bridge is model begin with input the coordinate values to from nodes and lines. The meshing attribute used are 2D thick beam with four divisions for deck, 2D bar with 1 division for cable-stayed and thick beam with 100 divisions for arch rib. The post-processing values will be more accurate when the division is increase. But the bar must be in division one only because bar have elongation and contraction.

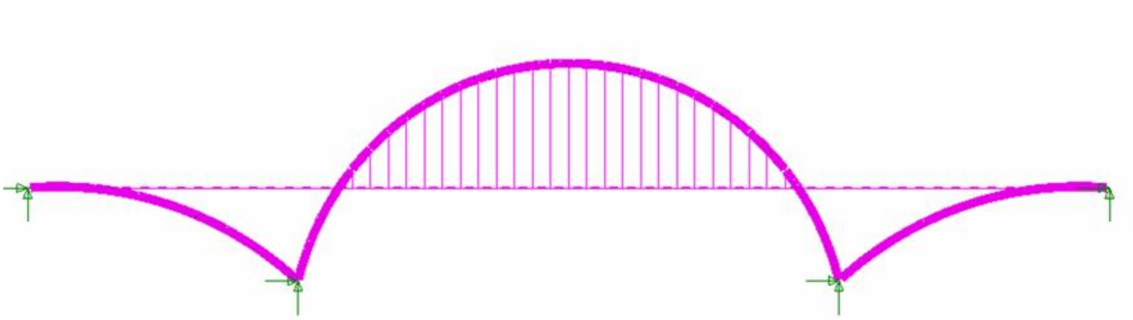


Figure 3.6: Arch bridge with ratio 1:4.5

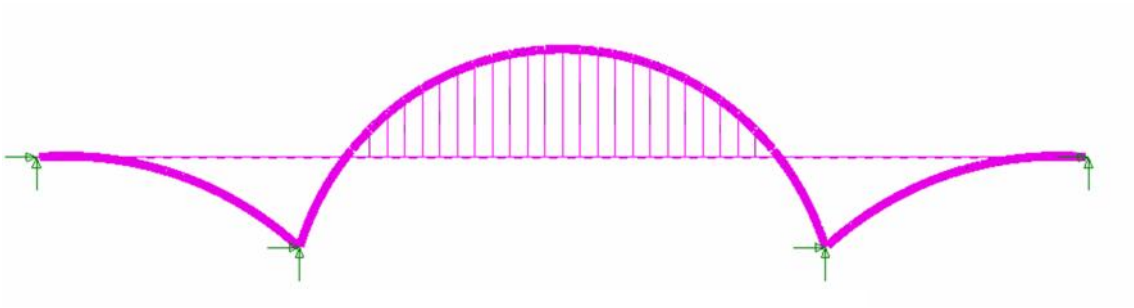


Figure 3.7: Arch bridge with ratio 1:5

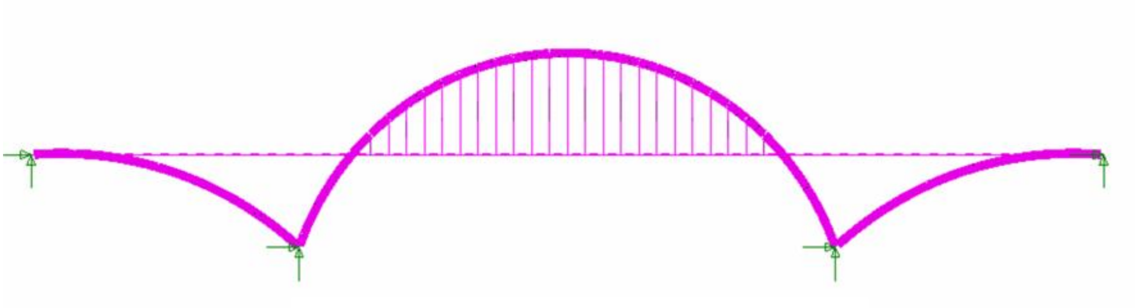


Figure 3.8: Arch bridge with ratio 1:5

The geometric used are as for main arch rib is a space truss made up of rectangular hollow section with size of width 5 m and depth of 6m. The bridge deck geometric is I-beam cross section steel with depth of 1.04m, width 0.51m, flange 0.2m and thickness 0.2m in y-major. The main arch rib has steel wire rope hangers, each with diameter of 160mm. These cables were consisting of five numbers of 32mm diameters of bar strand together. The stay cable is anchor from the arch rib to the deck at interval of 10m. The rest consist of longitudinal box girders. The material use is mild steel ungraded. The entire model use pinned as support. Arch bridge with ratio 1:4.5 has 25 numbers of hanging bar and 60 numbers of I-beam. For the arch bridge with ratio 1:5 has 26 number of hanging bars and 60 numbers of I-beams. While for arch bridge with ratio 1:5.5 has 23 number of hanging bars and 60 number of I-beams.

3.3.2 CABLE-STAYED BRIDGE

Cable-stayed bridge is test on the pylon height with three different values and two types system, fan and harp system. The pylon heights are 40m, 60m and 80m. Every model is using the same type of material. There are 60 number of cables in total were anchored from the pylon to the deck. For the cable-stayed bridge fan system, there are three models that are; fan system with pylon height 40m (Figure 3.9), fan system with pylon height 60m (Figure 3.10) and fan system with pylon height 80m (Figure 3.11)

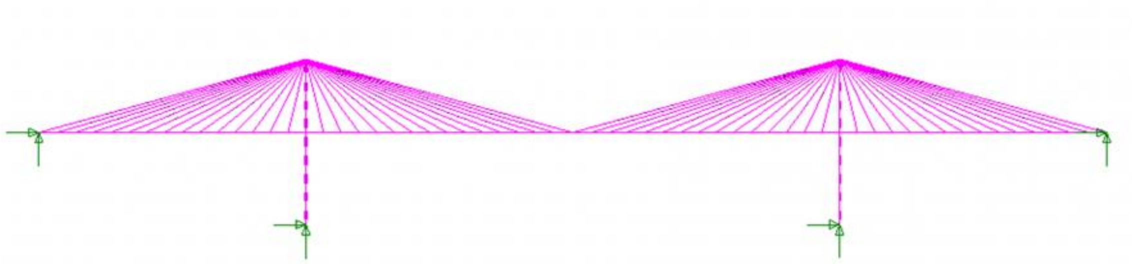


Figure 3.9: Cable stayed bridge fan system with pylon height 40m

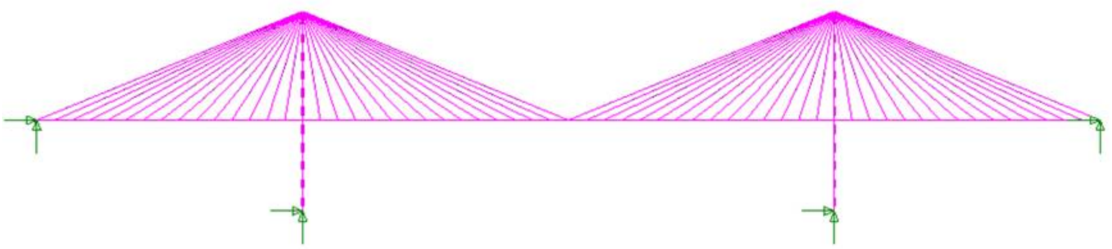


Figure 3.10: Cable stayed bridge fan system with pylon height 60m

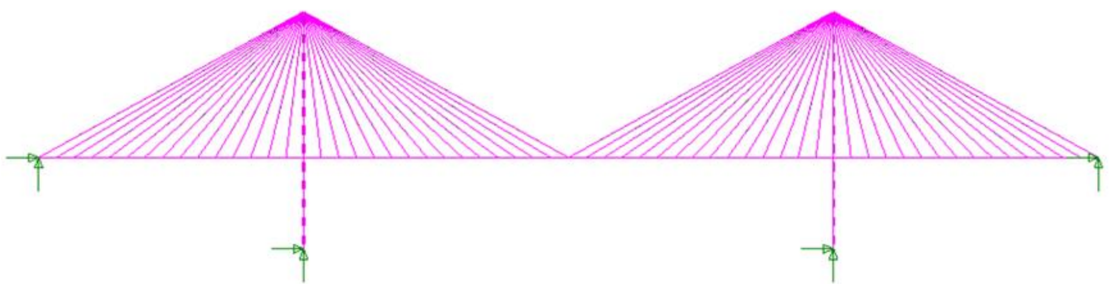


Figure 3.11: Cable stayed bridge fan system with pylon height 80m

Cable-stayed bridge harp system also has three different models. These models are cable-stayed bridge harp system with pylon height 40m (Figure 3.12), cable-stayed bridge harp system with pylon height 60m (Figure 3.13) and cable-stayed bridge harp system with pylon height 80m (Figure 3.14).

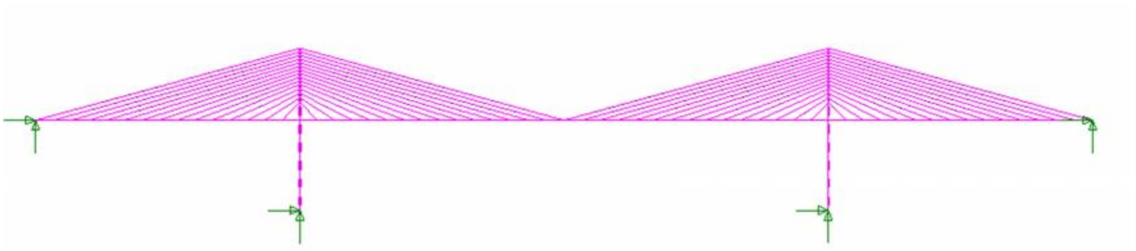


Figure 3.12: Cable stayed bridge harp system with pylon height

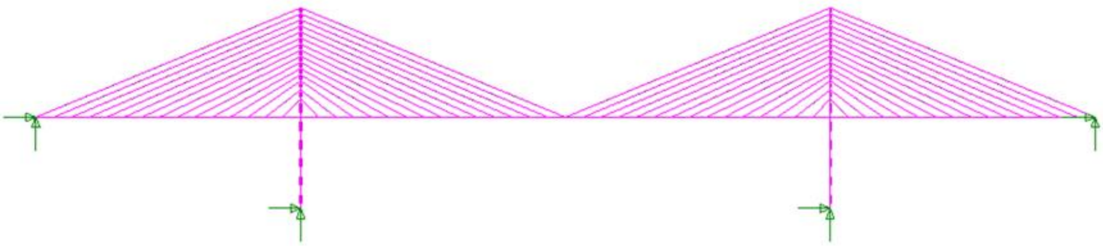


Figure 3.13: Cable stayed bridge harp system with pylon

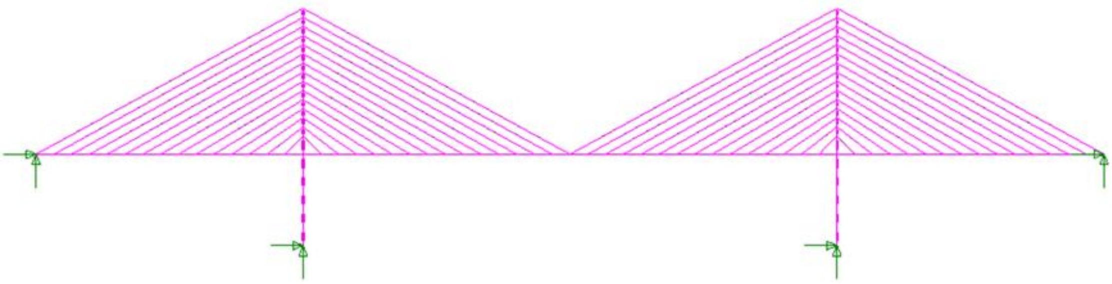


Figure 3.14: Cable stayed bridge harp system with pylon

Fan system and harp system have same properties except for the cable arrangement. The cable arrangement for fan system is the cable is anchored from the top of the pylon to the deck in 10 m interval. While for harp system, the cable arrangement is different for each case. The fixed criteria in each harp system cases are the last cable from bottom is in 10m distance from the deck and were anchored to the deck in 10 m interval.

Starting with the coordinates input, the models were constructed in LUSAS modeler. Then, construct the line for deck, cables and pylon. The meshing for deck and pylon is 2D thick beam with four divisions. The cables use 2D bar with one division. The geometric for deck is I-beam cross section steel with depth of 1.04m, width 0.51m, flange 0.2m and thickness 0.2m in y-major. The cables use circular solid section with diameter of 160mm. While the pylon use rectangular hollow section with depth of 2m, width 1.5m and thickness of 0.2m. The rest consist of longitudinal box girders. The material use is mild steel ungraded. The support is pinned at both deck side and pylon bottom.

3.3.3 HYBRID ARCH BRIDGE

After all, there are a few results that will be observed which are bending moment, displacement, shear force and normal force. The strongest cable-stayed bridge and arch bridge will be chosen. Then, a hybrid bridge will be modeled using the best arch and cable-stayed bridge as shown in Figure 3.15. The analysis result then will be compare with pure arch and cable stayed bridge. The model meshed with 2D thick beam with four divisions for deck and pylon, 2D bar with one division for cable-stayed and 2D thick beam with 100 divisions for arch rib.

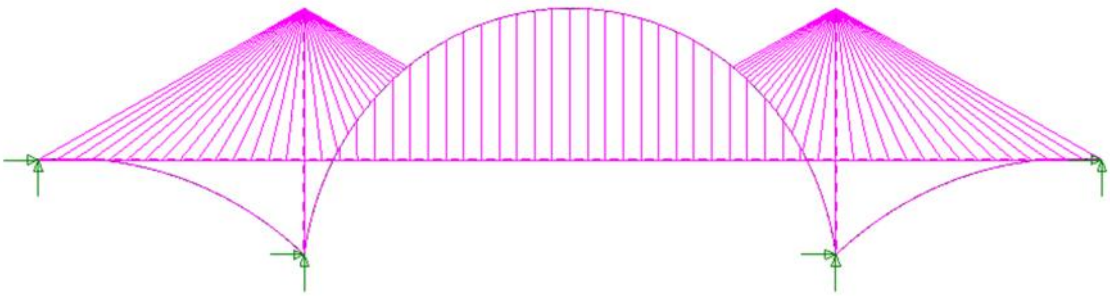


Figure 3.15: Hybrid arch bridge

The geometric for deck is I-beam cross section steel with depth of 1.04m, width 0.51m, flange 0.2m and thickness 0.2m in y-major. While the cables for rope hanger and stayed use the circular solid section with diameter of 160mm. The pylon use rectangular hollow section with depth of 2m, width 1.5m and thickness of 0.2m.The rest consist of longitudinal box girders. The arch rib is in rectangular hollow section with size width of 5m and depth of 6m and thickness 0.5m.The material use is mild steel ungraded. The model is pinned at the support.

3.4 LUSAS MODELLING PROCEDURE

The result is obtained by constructing the models by using the LUSAS modeler. The processes of modeling using LUSAS have three stages: Pre-processing, processing and post-processing. The elastic model was used to analyze the structure behavior of each types of bridge under dead load and live loads. The models were analyzed under nonlinear analysis with automatic loading increment. The summaries of step are:

Pre-processing:

1. Specify title , unit and vertical axis
2. Define geometry
3. Define mesh
4. Define the geometric properties
5. Define material properties

Solution

6. Assigning support
7. Assigning loading
8. Solve

Post-processing

9. Checking the displacement, stress and bending moment

Exit the LUSAS program.

The step by step design is as follows:

1. Specify title, unit and vertical axis

   The design need to start with setup of data. Firstly, specify the title for the project (see Figure 3.16). Define the unit use in kN,m,t,s,C. This unit will use for the entire unit later. Use the standard startup template for easier attribute assign later. Choose vertical axis Y for 2D element. Then press OK.

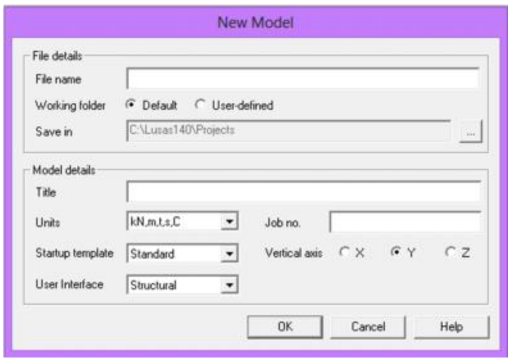


Figure 3.16: Model startup

2. Define geometry

   Geometry need to start with input at least two coordinates to define a line (Figure 3.17). Input the coordinates and construct the line by tick the points and press the new line button.

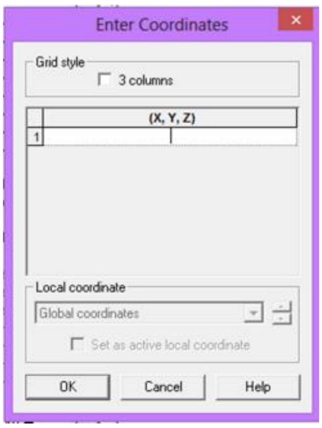


Figure 3.17: Coordinates box

3. Define mesh

After constructed the model, go to attribute, mesh, line as shown in Figure 3.18. Mesh the model according to component type. The full finite element model for arch consist of 2D thick beam element for deck, 2D bar element for cables and 2D thick element for arch rib. The cable-stayed consist of 2D thick beam element for deck and pylon and 2D bar element for cables. While for hybrid arch model consist of 2D thick beam element for deck and pylon, 2D bar element for cables and 2D thick element for arch rib. (see Figure 3.19). The number of divisions is 1 for bar, 4 for deck and pylon and 100 for arch. The more divisions use, the more accurate the result. Drag and drop the meshing to the each element of the model.

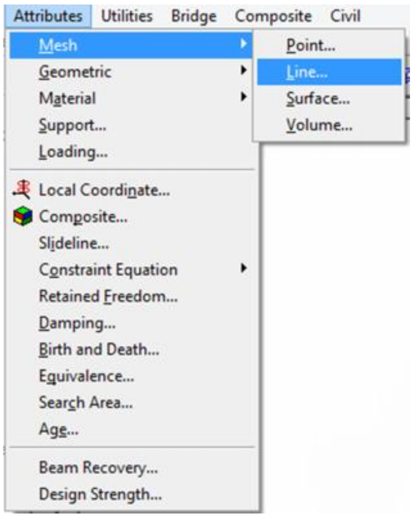


Figure 3.18: Attribute mesh

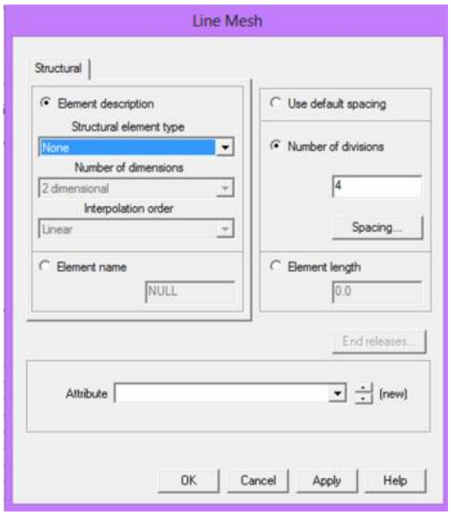
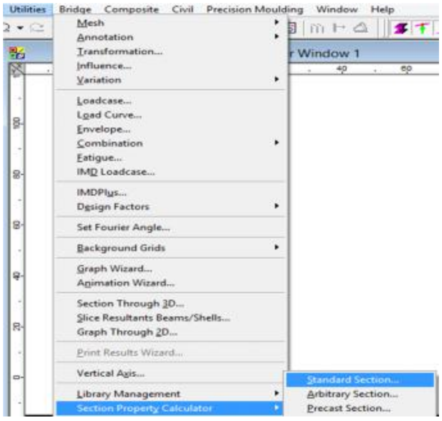


Figure 3.19: Line mesh box

4. Define the geometric properties

The section that required by this thesis is not available, thus the section need to be design first. Go to utility, section property calculator, standard section (see Figure 3.20). A standard section property calculator box will appear (see Figure 3.21). Choose rectangular hollow section with size of width 5 m and depth of 6m for arch rib then press OK. Repeat step for deck, cables and pylon. The deck use I-beam cross section steel with depth of 1.04m, width 0.51m, flange 0.2m and thickness 0.2m in y-major. The cable use circular solid section with diameter of 160mm. While the pylon use rectangular hollow section with depth of 2m, width 1.5m and thickness of 0.2m.



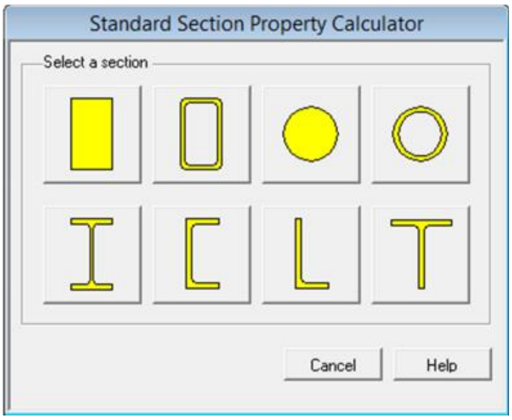
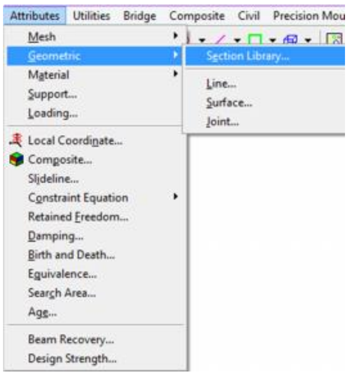


Figure 3.20: User-define section

Figure 3.21: The standard section property calculator box

Define geometry mean choose the geometry type, shape and size (Figure 3.22). Go to attribute, geometric and section library. Then, refer to Figure 3.23, the section library box will appear. Choose user section, type is I-section for deck, RHS for pylon and arch rib and CSS for cables. Drag and drop the geometry to each element of model.



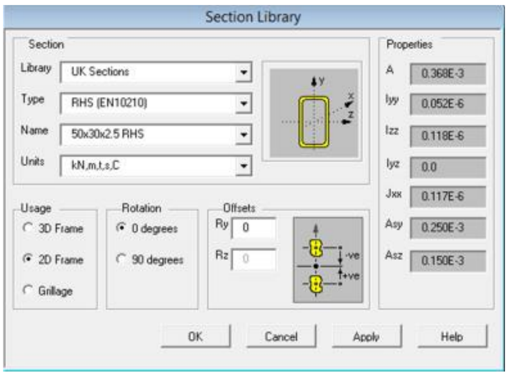
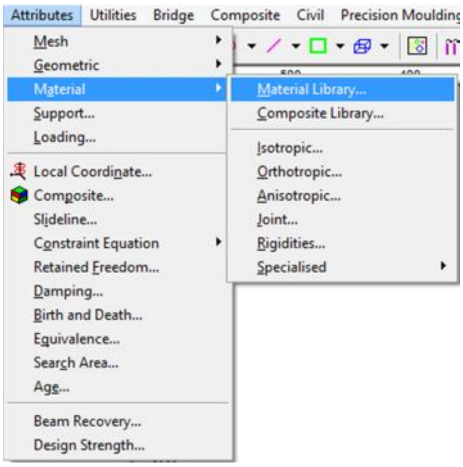


Figure 3.22: Geometric attribute

Figure 3.23: Section library box

5. Define material properties

Material use for the entire model in this thesis is mild steel ungraded. Go to attribute, material (see Figure 3.24). A material library box will appear. Choose mild steel for material, grade ungraded and press OK. Drag and drop the material to the entire model.



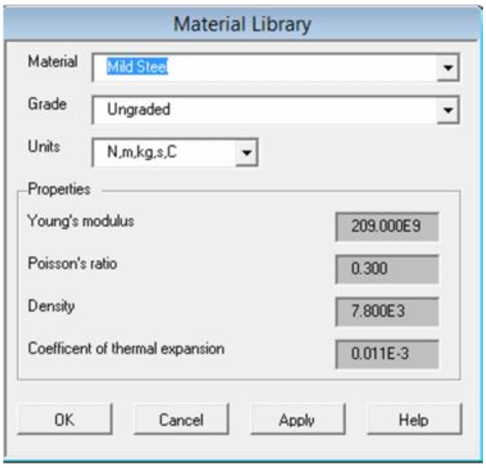


Figure 3.24: Material properties **Figure 3.25:** Material library box

6. Assigning support

Support is defined in attribute, support (see Figure 3.26). A box structural support will appear. Choose pinned support for all models. Tick fixed in translation x, y and z. Choose free for rotation, hinge rotation and pore pressure (Figure 3.27). Drag and drop the support to the each end of the bridge support.

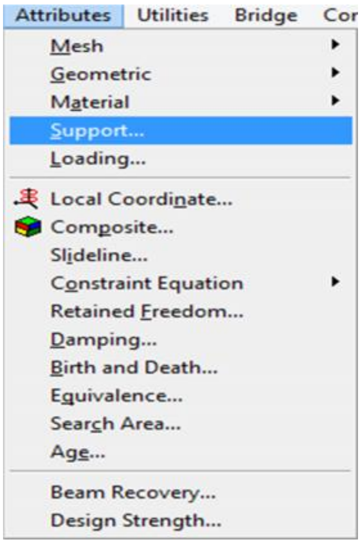


Figure 3.26: Attribute support

Figure 3.27: Structural support box

7. Assigning loading

Loading is defined in attribute, loading see Figure 3.28). A structural loading box will appear (Figure 3.29). Choose local distributed for dead load and live load. Input 47.7kN/m for live load and 119.4kN/m for dead load. Drag and drop the loading to the deck. The loading were assigned as a line uniform distributed loading (UDL) along the deck. To obtain a static linear analysis, the loading was control as linear analysis option.

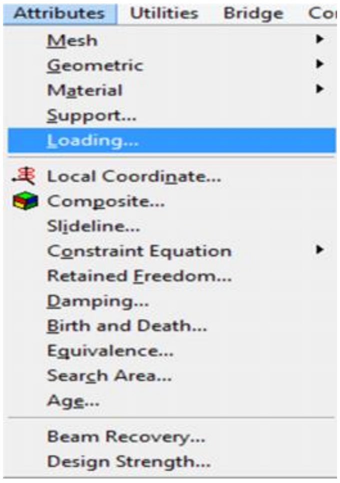


Figure 3.28: Loading attributes

Figure 3.29: Structural loading box

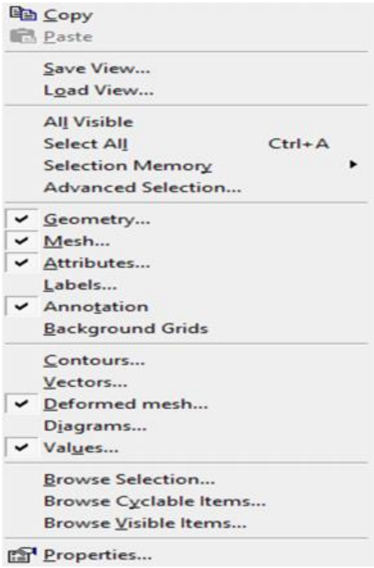
8. Solve

After assigning the entire attribute, save and solve the model by click the solve now button. This required a few moment for the LUSAS to solve the model.

9. Checking the displacement, stress and bending moment

Check the displacement, stress and bending moment value by right click the mouse button, tick values (see Figure 3.30). A property box will appear (Figure 3.31). Choose entity displacement and component is DX for displacement in x-direction. Repeat this step for all entity. In the first stage, there were nine model were analyzed which are cable-stayed and arch bridge. There are four tests that are carried out on the bridge structure: displacement, shear force, normal force and bending moment. Firstly, the maximum displacement of the deck, arch, pylon and cable were measured. Then, the maximum normal force, shear force and bending moment of deck, arch and pylon were recorded.

Preliminary result from the LUSAS analysis was used to determine the strongest arch bridge, cable-stayed harp system bridge and cable-stayed fan system bridge. The strongest model is basically model with lower value of displacement, stress and bending moment. On the second stage, the strongest arch and cable-stayed bridge will be combined to become hybrid arch bridge. Again, arch, cable-stayed and hybrid arch bridge will be compared in term of displacement, stress and bending moment to obtain the strongest bridge.



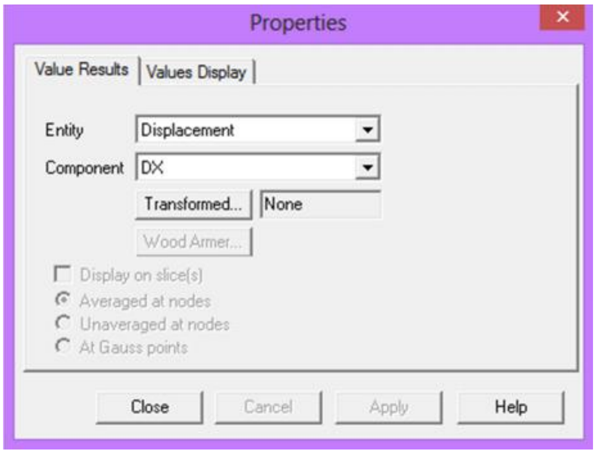


Figure 3.30: Post-processing component

Figure 3.31: Properties box

3.5 CASE STUDY

Refer to journal Analytical and experimental dynamic behavior of a new type of cable-arch bridge by Kang et al. (2014), the research is about hybrid arch bridge but using dynamic analysis. Analysis of model is by using Ansys FE analysis. The arch model use truss arch member, cross-girder, side beams, side arch members and piles using two-node beam elements (BEAM44) with six degree of freedom per node.BEAM44 is used because it allow for the nodes to be offset from the centroid axis of the beam elements. While for connecting members between substructures were modeled as two node beam elements (BEAM4) that have three degree of freedom and three rotational DOF at each node. The hangers were modeled as truss element using LINK10 with three degree of freedom per node. The gusset plate and web plate of the main arches use four-node shell elements with six degree of freedom per node (SHELL63). Lastly for the abutments, cushion caps and collar beams of the abutments were modeled use eight-node solid elements with three degree of freedom per node (SOLID45).

Model for cable stay bridge is modeled using the same type of beam as arch bridge, that are cross-girder, side beams and piles using two-node beam elements

(BEAM44) with six degree of freedom per node. Connecting members between substructures were modeled as two node beam elements (BEAM4) that have three degree of freedom and three rotational DOF at each node. While for the cable, the model uses LINK10 with three degree of freedoms per node. For the abutments, cushion caps and collar beams of the abutments were modeled use eight-node solid elements with three degree of freedom per node (SOLID45).Mass elements with six degree of freedom (MASS21) is used to model the diaphragms at the side arch rib.

Hybrid bridge were modeled using the combination of arch and cable stayed bridge and is exactly same procedure. This type of bridge modeled use truss arch member, cross-girder, side beams, side arch members and piles using two-node beam elements (BEAM44) with six degree of freedom per node. Connecting members between substructures were modeled as two node beam elements (BEAM4) that have three degree of freedom and three rotational DOF at each node. The hanger, cable and pre-stressed cable were modeled as truss element using LINK10 with three degree of freedom per node. The gusset plate and web plate of the main arches use four-node shell elements with six degree of freedom per node (SHELL63).The abutments, cushion caps and collar beams of the abutments were modeled use eight-node solid elements with three degree of freedom per node (SOLID45).

3.6 PROBLEM ENCOUNTER AND ACTION TAKEN

During the research, there were some problems happen related to LUSAS 14. The models are quit large and make when the model is constructed, there are some lag happen. This is due to the many nodes and materials used. Thus, the models need to be constructed early to avoid delay for submission. Besides that, for the student version, LUSAS have some function that cannot be used in this version such as the element type for pylon. There are limited functions that available. Thus, for pylon, the material used is rectangular hollow section (RHS).

CHAPTER 4

RESULT & DISCUSSION

4.1 INTRODUCTION

There were ten models constructed and analyzed in LUSAS modeler. The result highlight were displacement in y and x direction, normal and shear force and bending moment. Displacement was analyzed for bar, beam, pylon and arch. While the normal, shear, and bending moment were analyzed for beam, pylon and arch rib.

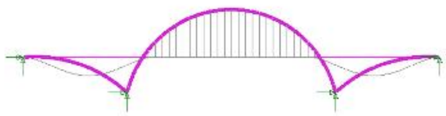
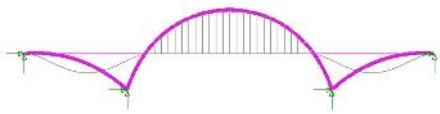
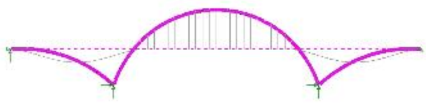
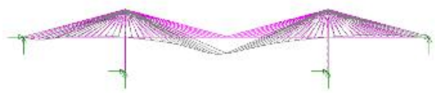
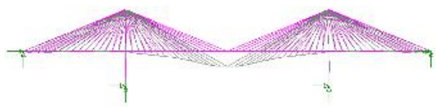
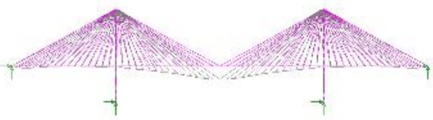
4.2 COMPARISON BETWEEN ARCH AND CABLE-STAYED BRIDGE

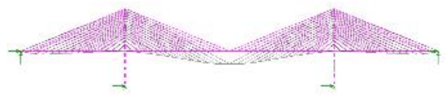
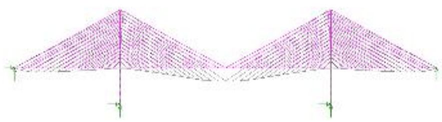
The arch and cable-stayed model will be compared based on their structure behavior in term of displacement, stress and bending moment. This will result in the strongest arch model and cable-stayed model.

4.2.1 ANALYSIS OF DISPLACEMENT

Displacement is the deformation of the structure when the loading is applied on it. Mostly loading is from the self-weight it-self, cause by the beam, slab, pier and other bridge's structure. The value of displacement in each component of models is shown in the Table 2 below. The example of displacement value taken from LUSAS is shown in appendix 1.

Table 2: Displacement value for each component

Model	In cable (m)	In deck (m)	In arch (m)	In pylon	Model shape
1	4.30E-3	X=41.2E-19 Y=0.088	5.600E-6 0.129E-4	-	
2	0.08E-3	X=44.2E-19 Y=0.08	7.600E-6 0.158E-4	-	
3	0.21E-3	X=0.014E-19 Y=90.00E-3	7.990E-6 0.144E-4	-	
4	2.20E-3	X=0.034E-3 Y=1.500E-3	-	0.200E-3 0.020E-3	
5	0.18E-3	X=0.012E-3 Y=0.890E-3	-	0.172E-3 0.029E-3	
6	0.14E-3	X=0.009E-3 Y=0.610E-3	-	0.156E-3 0.034E-3	
7	0.23E-3	X=0.270E-3 Y=1.820E-3	-	0.233E-3 0.020E-3	

8	0.18E-3	X=0.019E-3 Y=0.920E-3	-	0.175E-3 0.023E-3	
9	0.05E-3	X=0.016E-3 Y=0.616E-3	-	0.154E-3 0.025E-3	

*1=Arch with ratio 1:4.5, 2=Arch with ratio 1:5, 3=Arch with ratio 1:5.5, 4=Cable-stayed fan system with pylon height 40m, 5= Cable-stayed fan system with pylon height 60m,, 6= Cable-stayed fan system with pylon height 80m, 7= Cable-stayed harp system with pylon height 40m, 8= Cable-stayed harp system with pylon height 60m, 9= Cable-stayed harp system with pylon height 80m, 10= Hybrid arch

4.2.1.1 MAXIMUM DISPLACEMENT ON CABLE

In general, the parameter of cables influences the static characteristics of the bridge structure. Here, the displacement of cables is observed to study the effect toward the bridge structure. The comparison of displacement in arch bridge shows that smallest displacement occur in model with ratio 1:5, with value of 0.00008m compared to arch model with ratio 1:4.5 and arch with ratio 1:5. When the ratio increase, the rise of arch rib increase and thus makes the cables increase in length. The ideal of cable length is when the arch height is 60m from the deck. It also can be seen from the model, there is 25 numbers of hanging cable anchored from the arch rib to the deck, which is extra two cables than arch with ratio 1:5.5.

In the cable-stayed bridge fan system, the smallest displacement in cable is model with pylon height 80m, with displacement of 0.00014m compared to model pylon height 40m and model pylon height 60m. The value is affected by the height of pylon which resulting in different numbers of stayed cable in models. The numbers of stayed cable are 60 bars which is same in each model, thus not give any effect to the models. But, the degree of stayed cable is different due to the different height of pylon. Thus, the steeper the degree of cables to the deck, the less displacement occurs in stayed cable.

While for cable-stayed bridge harp system, the smallest displacement in cable is model with pylon height 80m, with displacement of 0.00005m compared to model pylon height 40m and model pylon height 60m. The height of pylon in harp models are different, thus the degree of cables to the deck also different. It can be conclude that the displacement in cable is lees when the degree of cables to the deck becomes steeper. The comparisons between each model are shown in Figure 4.1 below:

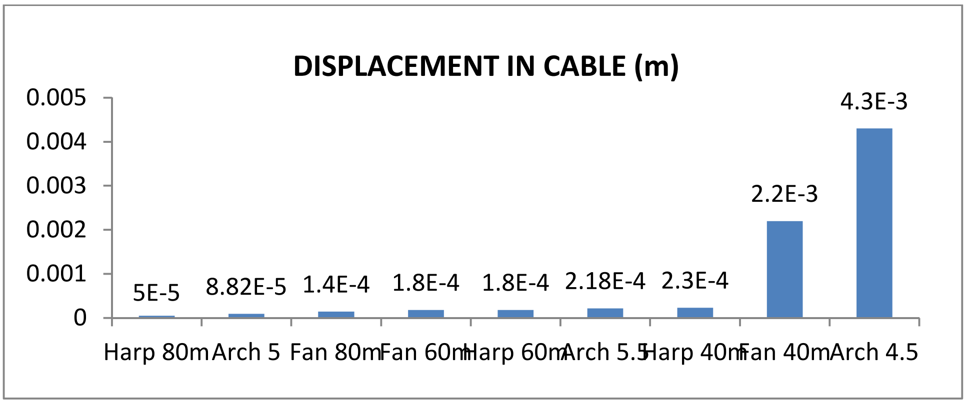


Figure 4.1: Chart for displacement in cables

4.2.1.2 MAXIMUM DISPLACEMENT ON DECK

The displacement in deck gives the most effect to the static behavior of the bridge. In arch bridge model, the displacement in x –direction contribute the least value in arch with ratio 1:5.5 with value 0.14E-19m compared to arch 1:4.5 and arch 1:5 (see Figure 4.2). While for displacement in y-direction, the least value is arch with ratio 1:5 with value of 0.08m compared to arch 1:4.5 and arch 1:5.5 (see Figure 4.3). The rise of arch rib contributes to the deflection in deck. This is because, according to Ren et al (2004), the compressive forces from the arch rib push the bridge structure up. Thus, from the analysis model, in x – direction, the displacement is least when the arch rib height increase. While in y-direction, the displacement is least when the arch rib higher.

In cable-stayed bridge fan system, the smallest displacement value in x-direction is model fan 80m with value of 0.034e-3m compared to fan 60m and fan 40m. While in y-direction, the smallest value also model fan 80m with value 0.00061m compared to fan 60m and fan 40m. As the pylon height increase, the displacement in beam decrease.

This reason also applies to harp system because the smallest value in x –direction is harp 80m with value 0.016e-3m compared to harp 60m and harp 40m. The smallest value of displacement in y-direction also in harp 80m with value 0.616e-3 compared to harp 60m and harp 40m.

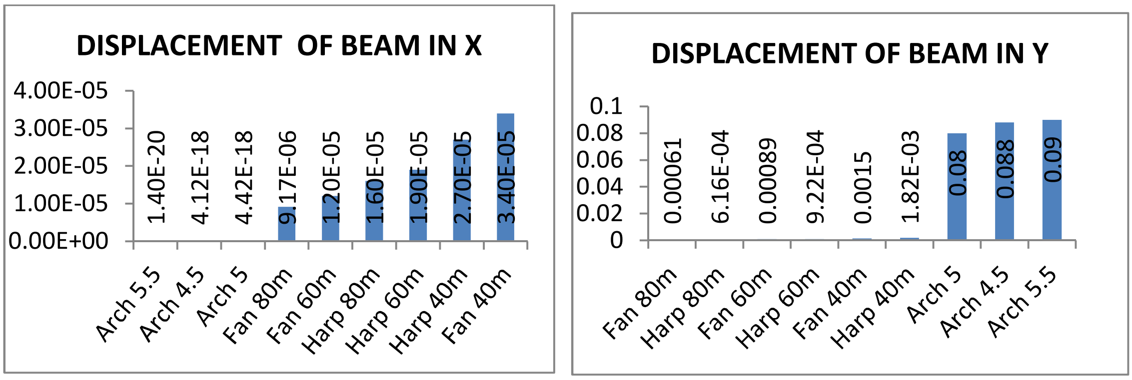


Figure 4.2 & 4.3: Chart for displacement of beam in x and y-direction

4.2.1.3 MAXIMUM DISPLACEMENT ON ARCH

The smallest displacement value in x-direction is in arch 1:4.5 with value 5.6E-6m compared to arch 1:5 and arch 1:5.5 (Figure 4.4). The smallest value of displacement in y-direction is 0.129E-4m in arch 1:4.5 compared to arch 1:5.5 and arch 1:5 (Figure 4.5). Arch rib height are different, thus contributes to different deflection value in arch rib. As the height of arch rib increase, the displacement value in arch also increases.

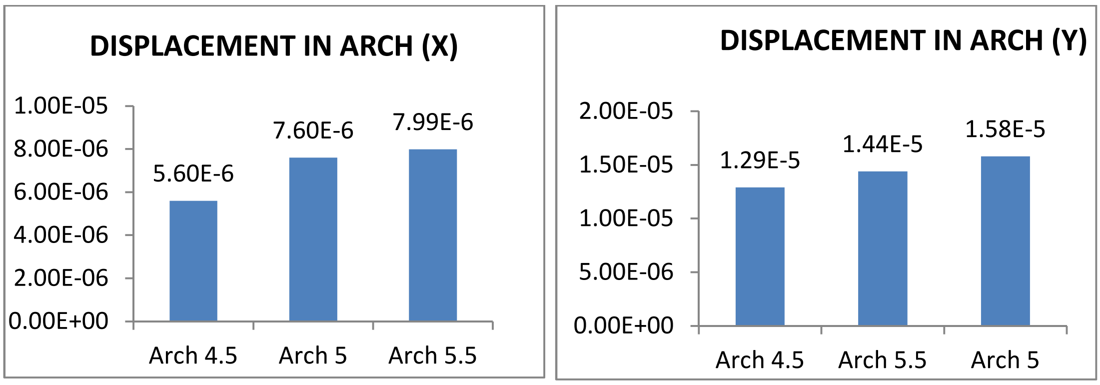
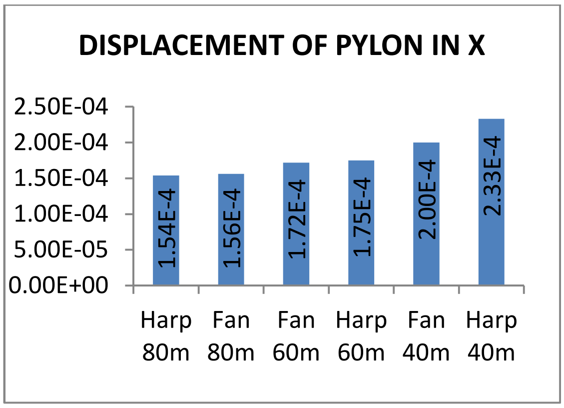


Figure 4.4 & 4.5: Chart for displacement of arch rib in x and y-direction

4.2.1.4 MAXIMUM DISPLACEMENT ON PYLON

Displacement in pylon gives a huge effect to cable-stayed bridge. This is because the pylon transfers the loading from the deck to the ground. Thus the least displacement value in x-direction is harp 80m with value of 0.154e-3m and fan 80m with value of 0.156e-3m compared to other cable-stayed models (see Figure 4.6). The model with longer height of pylon gives the less value of displacement. Harp system is lesser value than fan system model. While in y-direction, the least displacement value is in harp 40 with value of 2 e-5m followed by fan 40m with value of 2.3e-5m (see Figure 4.7).



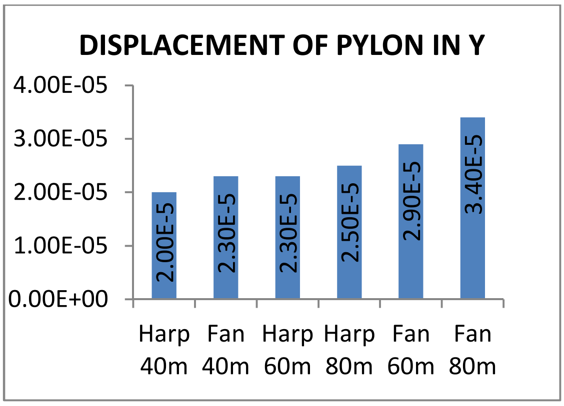
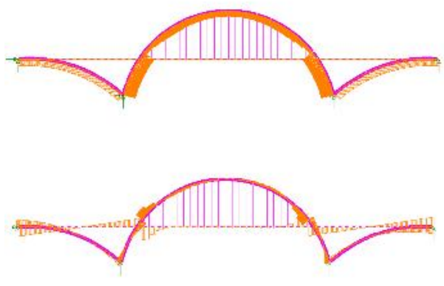
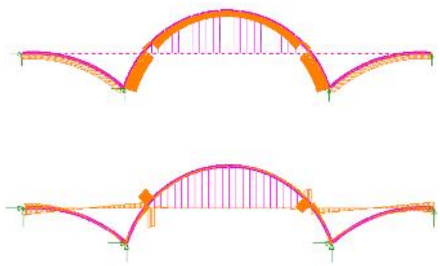
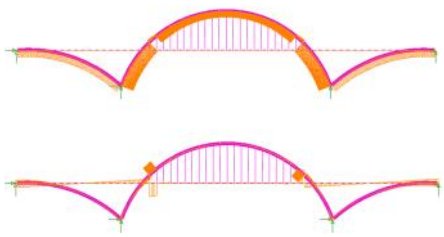
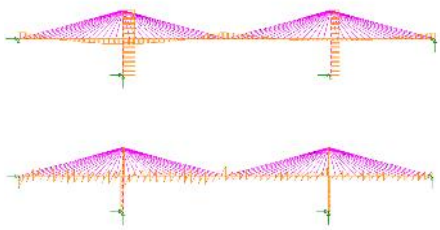


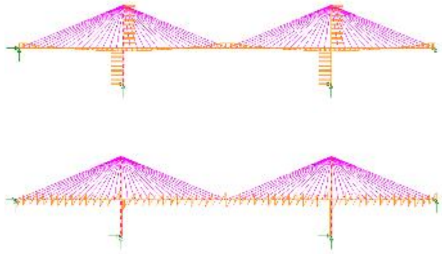
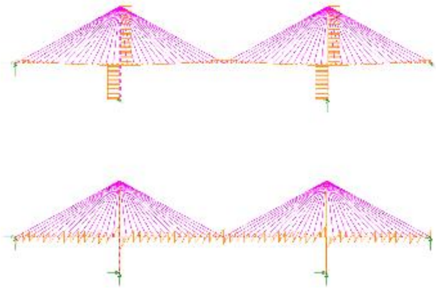
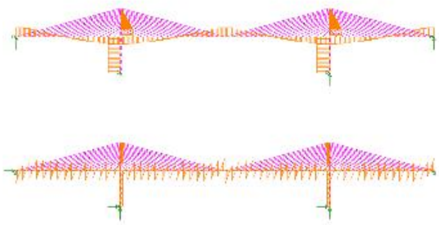
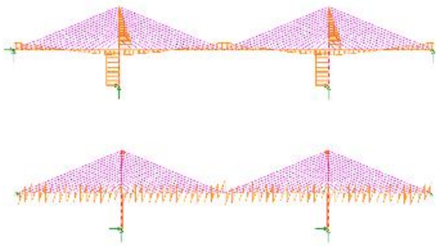
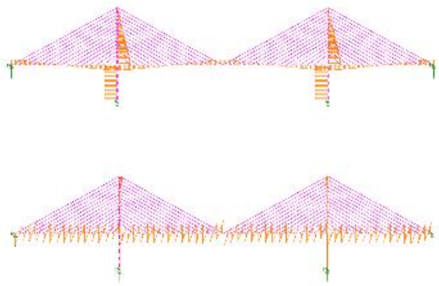
Figure 4.6 & 4.7: Chart for displacement of pylon in x and y-direction

4.2.2 ANALYSIS OF STRESS

The value of stress is taken directly from LUSAS and is observe one by one the value in each component of bridge. The sample of stress taken from LUSAS is shown in appendix 2

Table 3: Shear stress value and diagram in each component.

Model	In cable (KN/m²)	In deck (KN/m²)	In arch (KN/m²)	In pylon (KN/m²)	Model shape
1	4.89E4	X=4.19E-8 Y=28.33E3	52.88E3 17.93E3	-	
2	8.55E4	X=1.7E-9 Y=64.9E3	53.60E3 42.6E3	-	
3	9.08E4	X=4.21E-12 Y=68.60E3	53.70E3 49.9E3	-	
4	7.38E3	X=32.5E3 Y=1.81E3	-	68.6E3 321	

5	5.35E3	X=25.6E3 Y=1.95E3	-	69.8E3 170	
6	4.35E3	X=19.3E3 Y=2.09E3	-	69.8E3 108	
7	8.53E3	X=50.4E3 Y=1.62E3	-	69.7E3 612	
8	6.14E3	X=35.3E3 Y=1.49E3	-	69.8E3 392	
9	5.01E3	X=28.4E3 Y=1.43E3	-	69.8E3 322	

*1=Arch with ratio 1:4.5, 2=Arch with ratio 1:5, 3=Arch with ratio 1:5.5, 4=Cable-stayed fan system with pylon height 40m, 5= Cable-stayed fan system with pylon height 60m,, 6= Cable-

stayed fan system with pylon height 80m, 7= Cable-stayed harp system with pylon height 40m, 8= Cable-stayed harp system with pylon height 60m, 9= Cable-stayed harp system with pylon height 80m, 10= Hybrid arch

4.2.2.1 STRESS ON CABLE

Stress in cable comes from the loading from the deck and transfer it to the pylon and ground. The smallest value for arch model occurs in arch 1:4.5 with value 4.89e4 compared to other arch models. Refer to Figure 4.8, it can be shows that the higher rise to span ratio, the higher value of stress in cable. Cable-stayed bridge fan system has the lowest stress value in fan 80m with value of 4.35e3m. While for harp system, the lowest stress value in cable is model harp 80m with value 5.01e3m. The stress in cable becomes smaller when the pylon height increases.

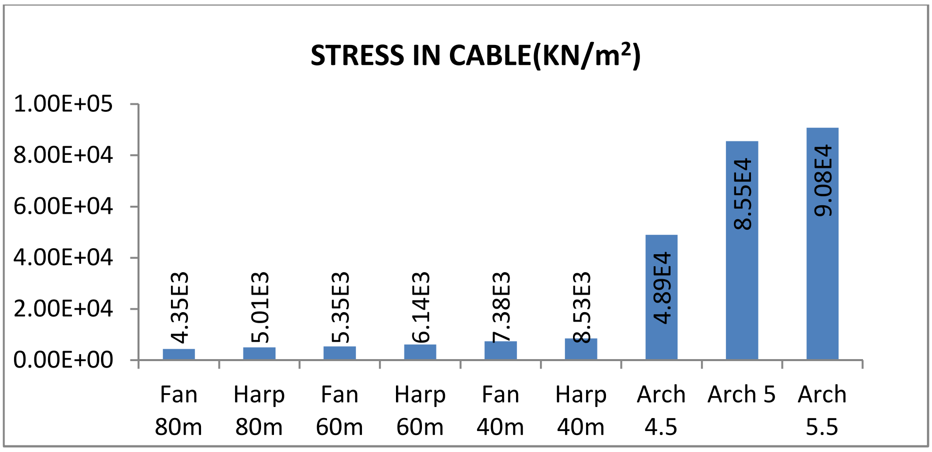


Figure 4.8: Chart for stress in cable

4.2.2.2 STRESS ON DECK

Stress also termed as force is calculated in unit Pascal or N/m^2. Normal stress is the force acting in x-direction toward the body or surface. The smallest normal stress on beam for arch model is arch 1:5.5 with value of 4.21e-12kn/m^2 (see Figure 4.9). This is due to arch rib height. The higher arch rib, the stronger the arch to counter the normal stress in beam. In cable-stayed bridge fan system, the smaller normal stress is fan 80m with value 32.53e3kn/m^2. While for harp system, the smaller normal stress is harp 80m with value of 28.4e3kn/m^2. It can be seen that the higher pylon height, the lesser value of stress in beam.

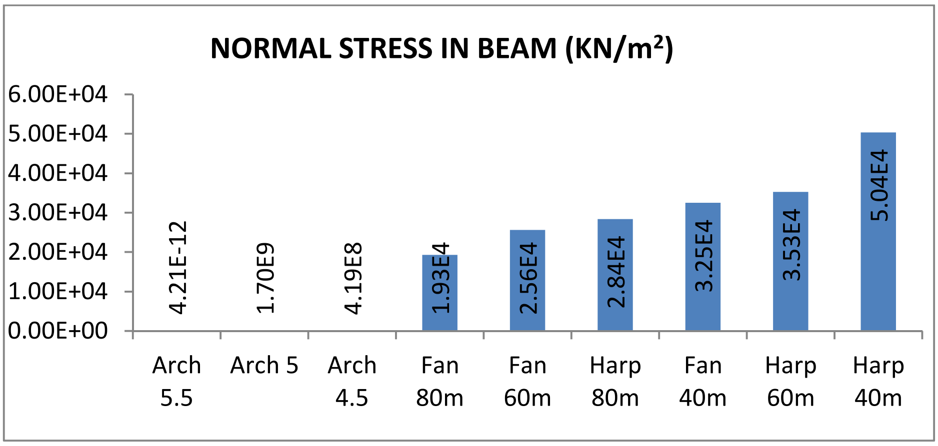


Figure 4.9: Chart for normal stress in beam

Shear stress on deck is defines as component of stress that act vertically to the deck. In arch bridge model, the lowest shear stress is in arch with ratio 1:4.5 with value of 2.8e4 kn/m^2 compared to arch 1:5 and arch 1:5.5 (see Figure 4.10). Thus, the shear stress in beam decrease as the rise to span of arch decreases. In cable-stayed bridge harp system, the lowest shear stress occur in harp 80m with value 1.43e3 kn/m^2 as compared to harp 60m and harp 40m. While fro the fan system, the lowest shear stress in beam occurs in fan 40m with value 1.81e3 kn/m^2 compared to harp 60m and harp 80m. The pattern in harp system is reverse to fan system as the stayed cables arrangement also different.

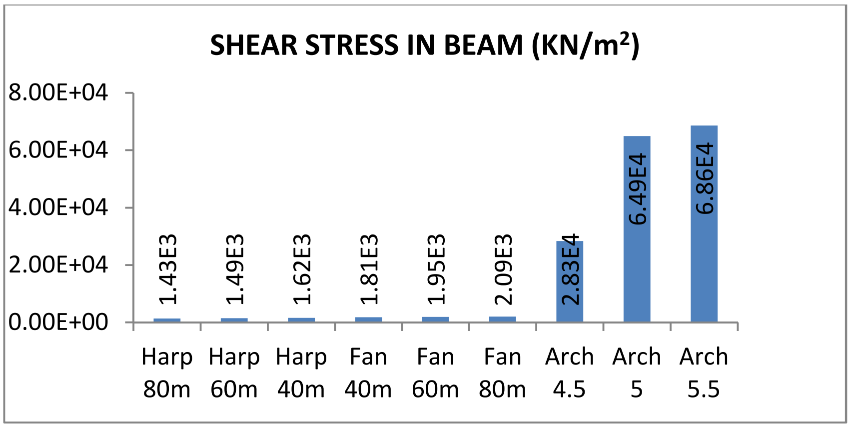


Figure 4.10: Chart for shear stress in beam

4.2.2.3 STRESS ON ARCH

Normal stress act on arch rib is lower in arch1:4.5 rather than arch 1:5 and arch 1:5.5 (see Figure 4.11). The higher rise to span ratio, the higher stress occur in arch rib. The stress becomes higher when the arch rib is higher.

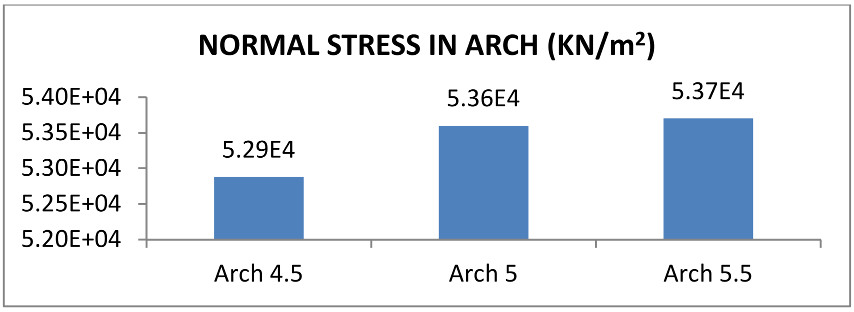


Figure 4.11: Chart for normal stress in arch

The shear stress in arch is lowest in arch 1:4.5 with value of 1.79e4 kn/m2 follow by arch 1:5 and arch 1:5.5 (see Figure 4.12). The vertically stress is higher as the arch rib height increases.

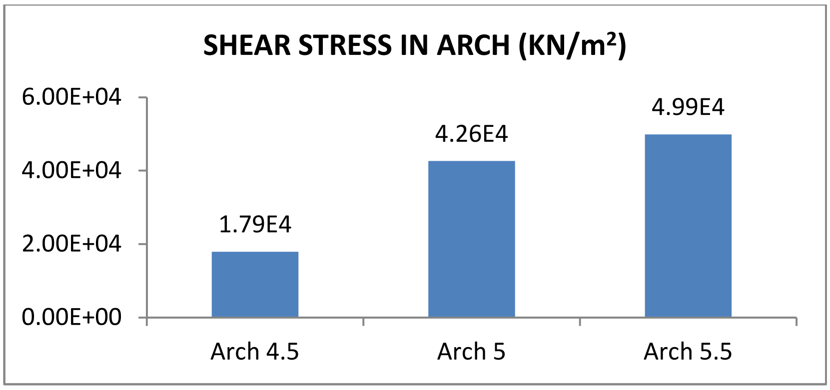


Figure 4.12: Chart for shear stress in arch

4.2.2.4 STRESS ON PYLON

The normal stress is the component of stress that acts horizontally in pylon. From the analysis, model fan 40m and harp 40m have the lowest normal stress in pylon with value 6.97e-4 kn/m^2 (see Figure 4.13). The value is same for both system and pylon height. The normal stress is lower when the height of pylon lower, as it can be seen from the bar chart below.

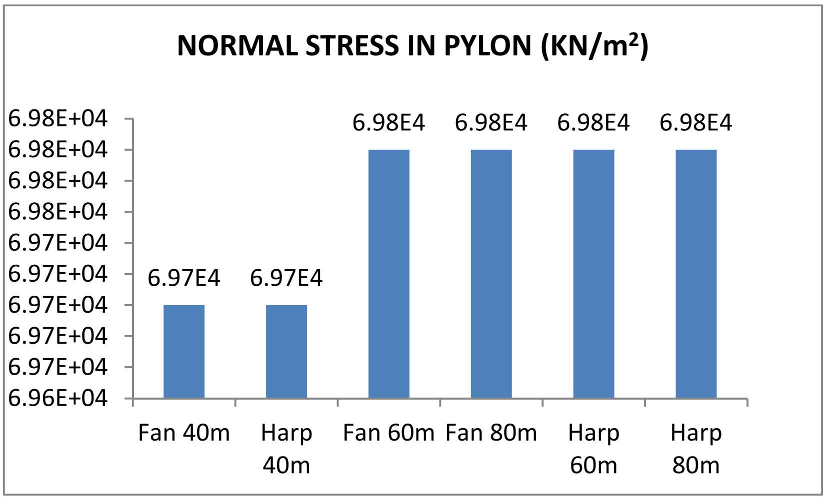


Figure 4.13: Chart for normal stress in pylon

Shear stress in pylon is lower in cable-stayed fan system 80m with value of 108kn/m^2 as compared to fan 60m and fan 40m (see Figure 4.14). While for harp system, the lowest shear stress act in pylon is harp 80m with value 322kn/m^2 as compared to harp 60m and harp 40m. The higher pylon height, the lower stress occurs in pylon.

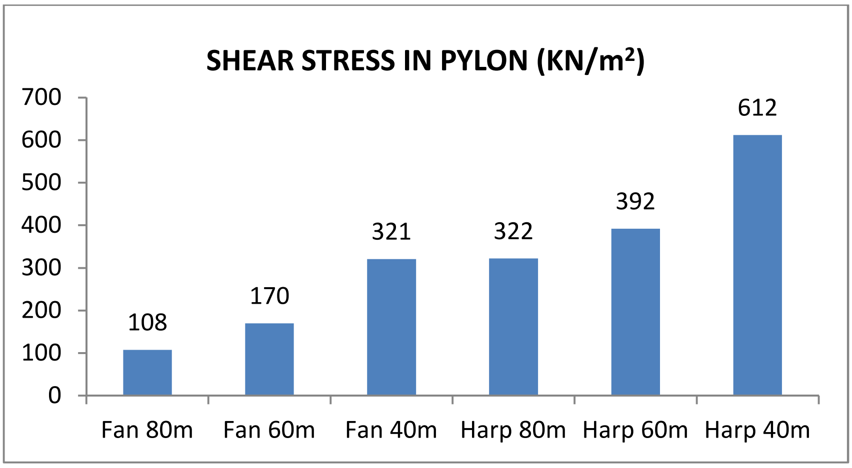
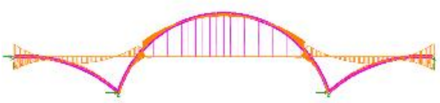
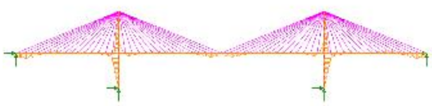
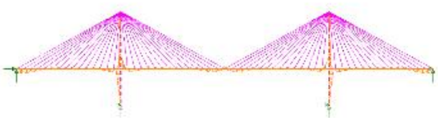


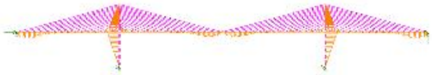
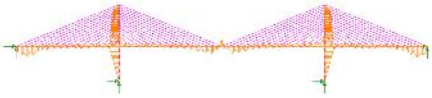
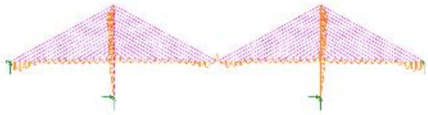
Figure 4.14: Chart for shear stress in pylon

4.2.3 ANALYSIS OF BENDING MOMENT

Bending moment is the reaction occurs in a structural element when an external force or moment is applied to the element causing the element to bend. The example of bending moment taken from LUSAS is shown in appendix 3. The value and diagram for each component are shown in Table 4 below:

Table 4: Value and diagram for bending moment in each component.

Model	In deck (m)	In arch (m)	In pylon	Model shape
1	6.96E5	6.61E5	-	
2	66.3E3	6.40E5	-	
3	7.28E5	7.02E5	-	
4	9.16E3	-	15.2E3	
5	7.49E3	-	8.08E3	
6	8.28E3	-	5.11E3	

7	7.47E3	-	15.0E3	
8	5.8E3	-	4.97E3	
9	4.99E3	-	3.63E3	
*1=Arch bridge with ratio 1:4.5, 2=Arch bridge with ratio 1:5, 3=Arch bridge with ratio 1:5.5, 4=Cable-stayed fan system with pylon height 40m, 5= Cable-stayed fan system with pylon height 60m,, 6= Cable-stayed fan system with pylon height 80m, 7= Cable-stayed harp system with pylon height 40m, 8= Cable-stayed harp system with pylon height 60m, 9= Cable-stayed harp system with pylon height 80m, 10= Hybrid arch bridge				

4.2.3.1 MAXIMUM BENDING MOMENT ON DECK

The bending moment on deck is lower in arch 1:5 with value of 6.6e4knm as compared to arch 1:4.5 and arch 1:5.5 (see Figure 4.15). For the cable-stayed bridge fan system, the lowest bending moment occur in fan 40m with value of 9.16e3knm compared to fan 60m and fan 80m. For the harp system, the lowest bending moment is harp 80m with value of 4.99e3knm compared to harp 60m and harp 40m.

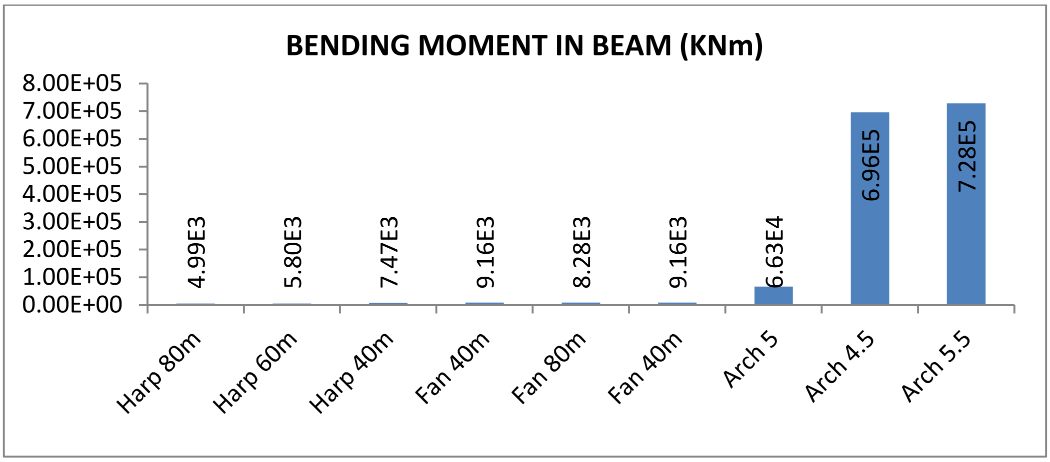


Figure 4.15: Bending moment value in beam

4.2.3.3MAXIMUM BENDING MOMENT ON ARCH

Arch with ratio 1:5 has the lowest bending moment in arch rib with value of 6.4e5Knm as compared to arch 1:4.5 and arch 1:5.5 (see Figure 4.16).

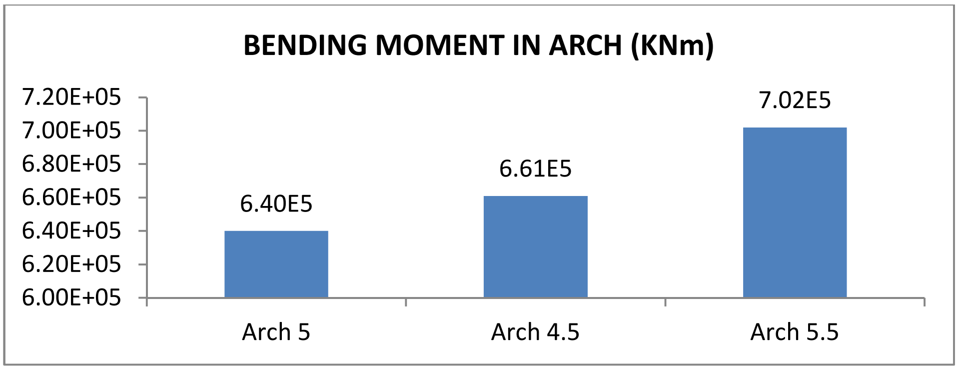


Figure 4.16: Bending moment in arch

4.2.3.3 MAXIMUM BENDING MOMENT ON PYLON

Model cable-stayed harp system 80m has the lowest bending moment in pylon with value 3.63e3KNm compared to harp 60m and harp 40m (see Figure 4.17). The fan system 80m has lowest bending moment in pylon with value of 5.11e3KNm compared to fan 60m and fan 40m.

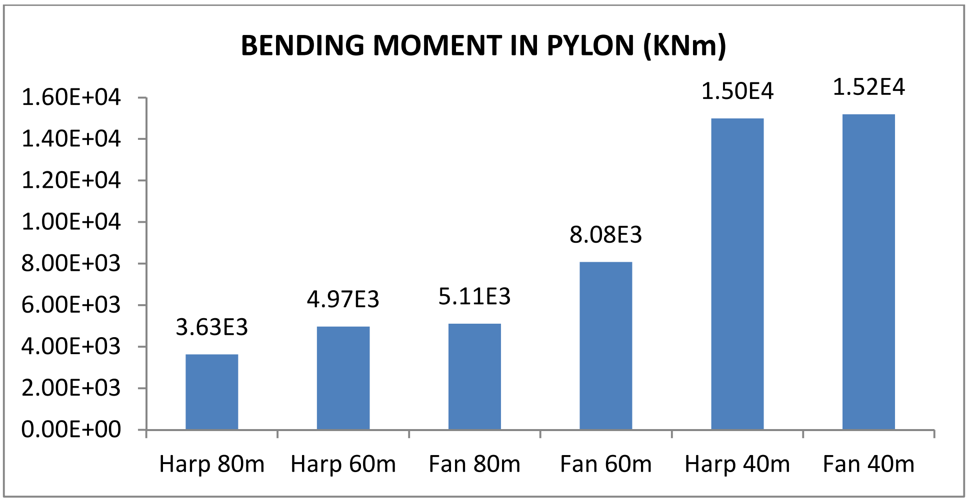


Figure 4.17: Bending moment value in pylon

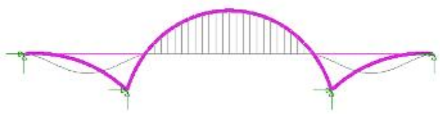
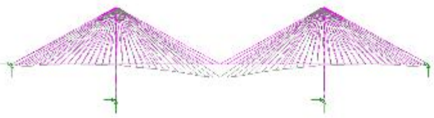
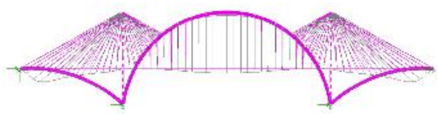
4.3 COMPARISON BETWEEN ARCH, CABLE-STAYED AND HYBRID ARCH BRIDGE

The result from LUSAS analysis shows that arch with ratio of span-to-rise 1:5 and cable-stayed bridge fan system with pylon 80m are the most effective bridge. After finish the analysis for cable-stayed and arch bridge, the two models were combined together, produced hybrid arch bridge.

4.3.1 ANALYSIS OF DISPLACEMENT

Displacement analysis in three stronger models is observed. The analysis is observed in four components of bridge which are cable, deck, arch rib and pylon. The values and diagram for displacement in each component is shown in Table 5 below.

Table 5: The value and diagram of displacement in each component

Model	In cable (m)	In deck (m)	In arch (m)	In pylon	Model shape
1	0.08E-3	X=44.2E-19 Y=0.08	7.600E-6 0.158E-4	-	
2	0.14E-3	X=0.009E-3 Y=0.610E-3	-	0.156E-3 0.034E-3	
3	0.07E-3	X=0.013E-3 Y=0.474E-3	62.70E-6 0.247E-4	0.137E-3 0.020E-3	
*1=Arch bridge with ratio 1:5, 2= Cable-stayed fan system with pylon height 80m, 3= Hybrid arch bridge					

In cables, the displacement is smallest in hybrid arch bridge with value of 7.14e-6m compared to arch 1:5 and cable-stayed model fan 80m as shown in Figure 4.18. It shows that cables in hybrid arch bridge is less displaced from the original point as compared to arch bridge and cable-stayed bridge.

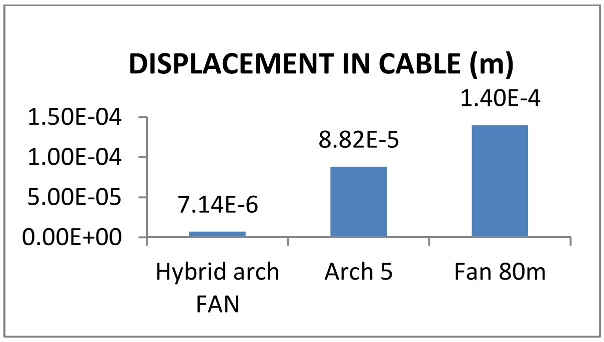


Figure 4.18: Chart for displacement in cable

Displacement of beam in horizontal direction is lower in model hybrid arch bridge with value of 4.42e-18m compared to arch 1:5 and fan 80m (refer to Figure 4.19) .The beam of hybrid arch model is vertically displaced less from the original point compared to cable-stayed and arch bridge model. Refer to Figure 4.20, the value of displacement in vertical direction also smallest in hybrid arch model with value of 0.000474m.

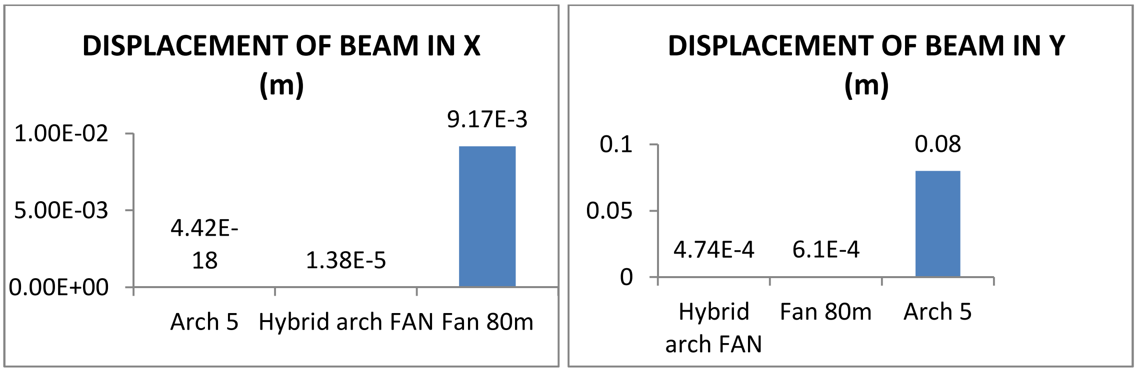
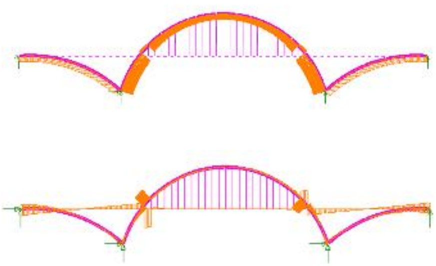


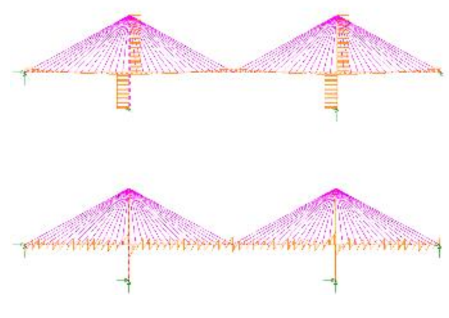
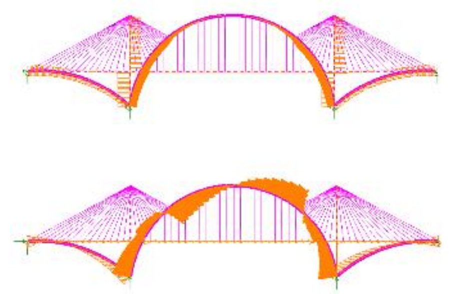
Figure 4.19 & 4.20: Displacement chart for beam in x and y-direction

4.3.2 ANALYSIS OF STRESS

Stress are analyze in each component in arch, cable-stayed and hybrid arch bridge model in term of normal stress and shear stress. The values and diagram of stress in each model is shown in Table 6 below.

Table 6: Stress values in each component

Model	In cable (m)	In deck (m)	In arch (m)	In pylon	Model shape
1	8.55E4	X=1.7E-9 Y=64.9E3	53.60E3 42.6E3	-	

2	4.35E3	X=19.3E3 Y=2.09E3	-	69.8E3 108	
3	5.00E3	X=19E3 Y=4.74E3	43.1E3 379	26.8E3 17.3E3	
*1=Arch bridge with ratio 1:5, 2= Cable-stayed fan system with pylon height 80m, 3= Hybrid arch bridge					

In Figure 4.21, normal stress in beam is observed smaller in arch with ratio 1:5 with value of 1.7e-9 KN/m^2 followed by hybrid arch bridge and cable-stayed bridge. While in Figure 4.22, the shear stress is observed smaller in cable-stayed fan system 80m with value of 2.09e3 KN/m^2 followed by hybrid arch and arch bridge.

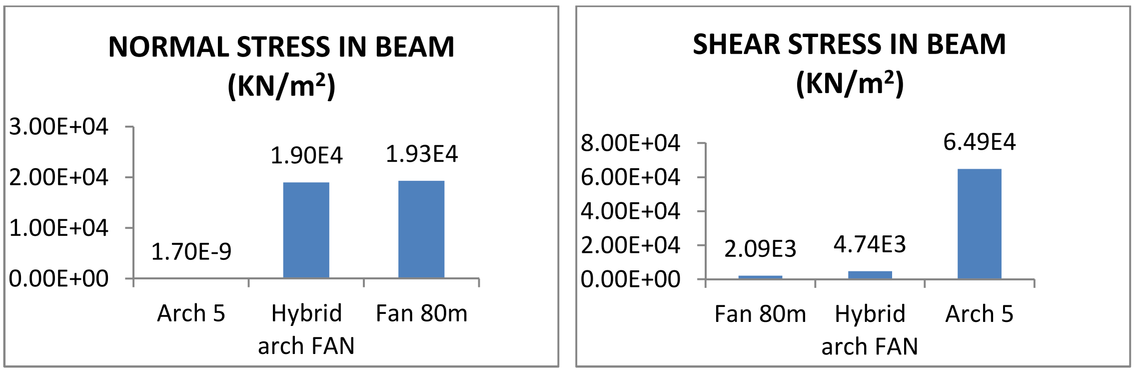


Figure 4.21 & 4.22: Chart for normal stress and shear stress in beam

In pylon component, the smaller normal stress (refer to Figure 4.23) occurs in hybrid arch with value of 4.31e4 KN/m^2 compared to arch bridge. While for shear stress, the smaller value is also cable-stayed fan 80m bridge with value of 108 KN/m^2 compared to hybrid arch bridge (refer to Figure 4.24).

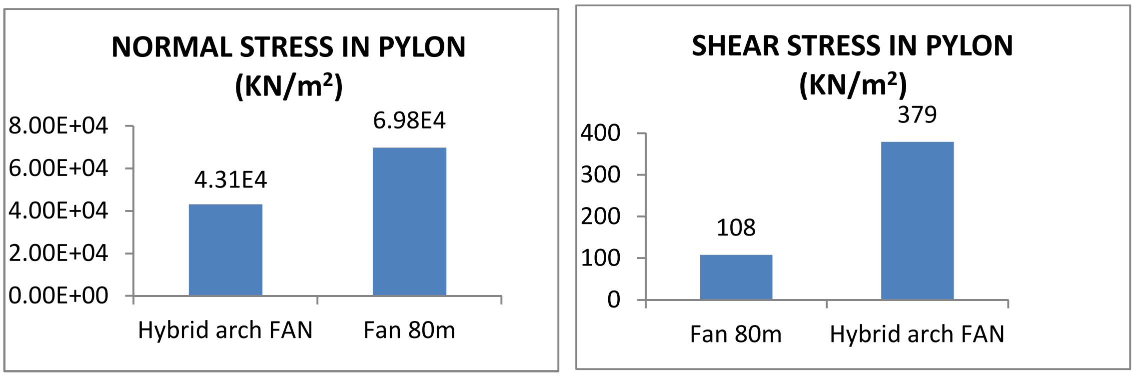


Figure 4.23 & 4.24: Normal stress and shear stress in pylon

While for arch rib component, the normal stress is smaller in model hybrid arch bridge with value of 2.68e4KN/m^2 pared to arch bridge (refer to Figure 4.25). For shear stress, the hybrid arch have the lowest value 1.73e44.31e4 KN/m^2 compared to arch bridge (see Figure 4.26).

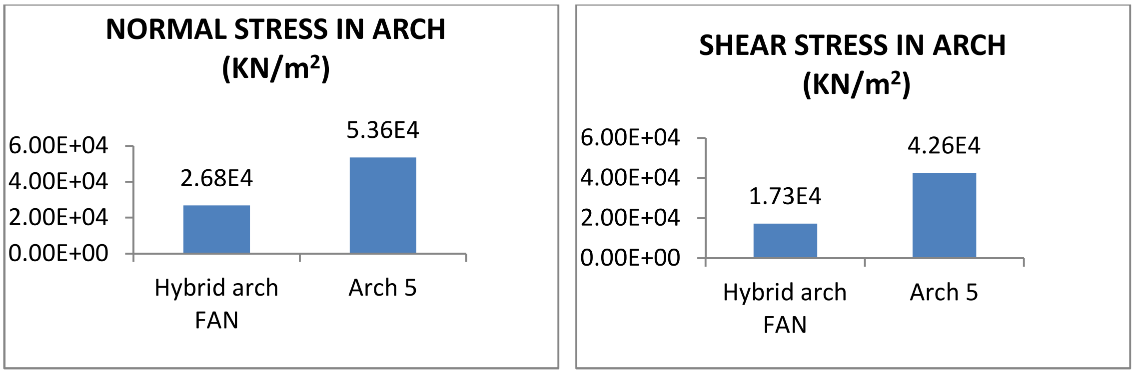
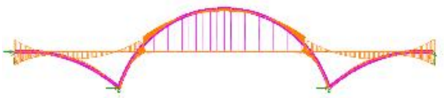
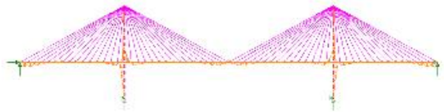
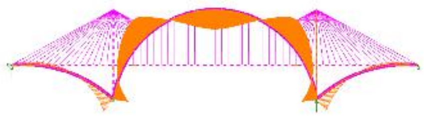


Figure 4.25 & 4.26: Chart for normal stress and shear stress in arch

4.3.2.3 ANALYSIS OF BENDING MOMENT

Bending moment analysis is compared between hybrid arch, cable-stayed and arch bridge. The value is observed to see the lowest bending moment value between these three models (see Table 7).

Table 7: Bending moment value and diagram in each component

Model	In deck (m)	In arch (m)	In pylon	Model shape
1	66.3E3	6.40E5	-	
2	8.28E3	-	5.11E3	
3	30.4E3	5.66E5	8.08E3	
*1=Arch bridge with ratio 1:5, 2= Cable-stayed fan system with pylon height 80m, 3= Hybrid arch bridge				

The value for bending moment in beam is smaller in cable-stayed fan 80m with value of 8.28e3knm compared to hybrid arch and arch 1:5. Refer to chart in Figure 4.27 below, the bending moment in beam for hybrid arch bridge is 3.04e4knm which is between cable-stayed and arch bridge.

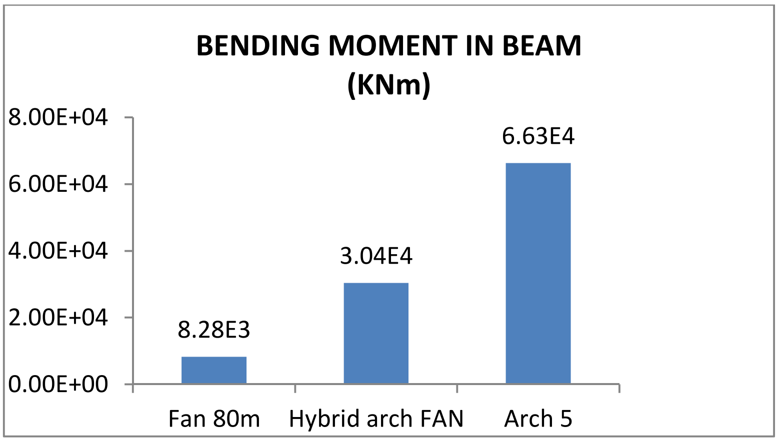


Figure 4.27: Chart for bending moment in beam

Bending moment in pylon is smallest in model cable-stayed bridge with value of 5.11e3 compared to hybrid arch model with value of 8.08e3. The chart in Figure 4.28 shows that the different value between cable-stayed model and hybrid arch model is quit smaller.

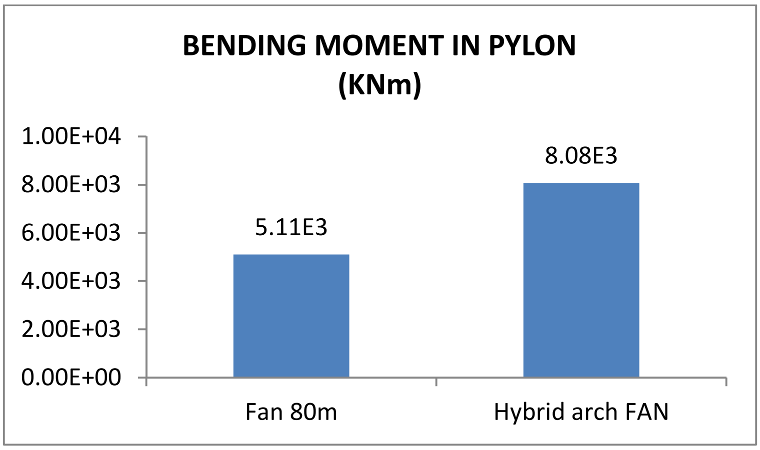


Figure 4.28: Chart for bending moment in pylon

The value for bending moment in arch is smaller in hybrid arch bridge with value 5.66e5knm compared to arch bridge with value 6.04e5knm. As shown in Figure 4.29 below, the different value between these two models is quit higher.

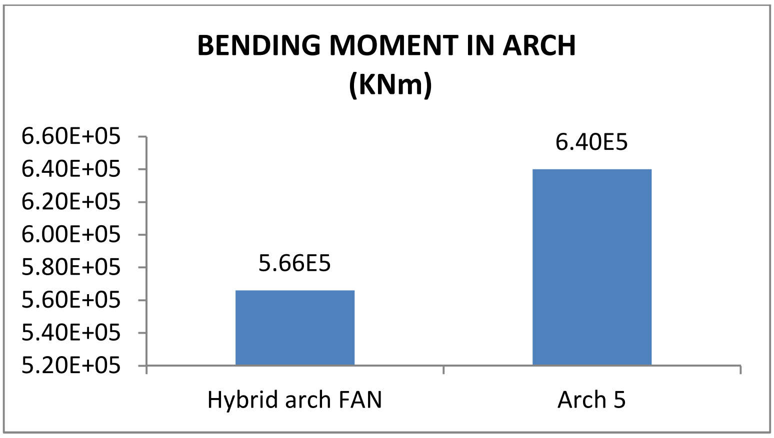


Figure 4.29: Chart for bending moment in arch

4.4 ANALYSIS SUMMARY

The summary of comparison between cable-stayed and arch bridge is shown in Table 8 below. From LUSAS analysis, the most effective bridge for arch is arch with rise-to-span ratio 1:5. While for cable-stayed bridge, the most effective is fan system with pylon height of 80m. The comparison between arch, cable-stayed bridge and hybrid arch bridge, the most effective bridge is the hybrid arch bridge.

4.4.1 COMPARISON BETWEEN ARCH AND CABLE-STAYED BRIDGE

Analysis of each arch and cable-stayed model shows that the stronger arch bridge is arch with ratio 1:5 which has arch rib height of 60m from the deck. The ratio of rise-to-span 1:5 shows that it is the most ideal ratio for arch bridge. The structure behavior of arch with ratio 1:5 bridge is stronger to cater the vertical displacement in beam. In cable-stayed bridge, the stronger model is fan system with pylon height 80m. From the analysis, the higher the pylon height, the better the bridge. The pylon act to cater the loading from the bridge and transfer it to the ground. Thus, the pylon needs to be strong as well as high. Fan system is better than harp system because fan system have better structure behavior. The structure component of cable-stayed fan system is stronger to cater the stress in cable, the displacement in beam, the normal stress in beam and shear stress in pylon. The comparison of arch and cable-stayed bridge is shown in Table 8 below.

Table 8: Comparison of value for displacement, stress and bending moment in each component

Type of bridge	Arch 4.5	Arch 5	Arch 5.5	Fan 40m	Fan 60m	Fan 80m	Harp 40m	Harp 60m	Harp 80m
CABLE									
DISPLACEMENT (m)	0.0043	8.815E-5	21.81E-5	0.0022	0.00018	0.00014	0.00023	0.00018	0.00005
STRESS (KN/m)	4.89E4	8.55E4	9.08E4	7.38E3	5.35E3	4.35E3	8.53E3	6.14E3	5.01E3
BEAM									

[DECK, continued]									
DISPLACEMENT(X) (m)	4.12E-18	4.42E-18	0.14E-19	0.034E-3	0.012E-3	0.00917E-3	0.027E-3	0.019E-3	0.016E-3
DISPLACEMENT(Y) (m)	0.088	0.08	0.09	0.0015	0.00089	0.00061	1.82E-3	0.922E-3	0.616E-3
NORMAL STRESS (KN/m^2)	4.19E-8	1.7E-9	4.21E-12	32.5E3	25.6E3	19.3E3	50.4E3	35.3E3	28.4E3
SHEAR STRESS (KN/m^2)	28.33E3	64.9E3	68.60E3	1.81E3	1.95E3	2.09E3	1.62E3	1.49E3	1.43E3
BENDING MOMENT (KNm)	6.96E5	66.3E3	7.28E5	9.16E3	7.49E3	8.28E3	7.47E3	5.8E3	4.99E3
PYLON									
DISPLACEMENT(X) (m)	-			0.20E-3	0.172E-3	0.156E-3	0.233E-3	0.175E-3	0.154E-3
DISPLACEMENT(Y) (m)	-			0.023E-3	0.029E-3	0.034E-3	0.020E-3	0.023E-3	0.025E-3
NORMAL STRESS (KN/m^2)	-			68.6E3	69.8E3	69.8E3	69.7E3	69.8E3	3.63E3
SHEAR STRESS (KN/m^2)	-			321	170	108	612	392	322
BENDING MOMENT (KNm)				15.2E3	8.08E3	5.11E3	15.0E3	4.97E3	3.63E3
ARCH									
DISPLACEMENT(X) (m)	5.6E-6	7.6E-6	7.99E-6	-	-	-	-	-	-
DISPLACEMENT(Y) (m)	0.129E-4	0.158E-4	0.144E-4	-	-	-	-	-	-
NORMAL STRESS (KN/m^2)	52.88E3	53.60E3	53.70E3	-	-	-	-	-	-
SHEAR STRESS (KN/m^2)	17.93E3	42.6E3	49.9E3	-	-	-	-	-	-
BENDING MOMENT (KNm)	6.61E5	6.40E5	7.02E5						

4.4.2 COMPARISON BETWEEN ARCH, CABLE-STAYED AND HYBRID ARCH BRIDGE

After the stronger arch and cable-stayed bridge is chosen, a hybrid arch is model and is compared to the models. From the analysis, the hybrid arch model is stronger than pure arch and cable-stayed bridge in term of structure behavior. The hybrid arch have stronger structure behavior in term of displacement in cable, beam and pylon, better in normal force in pylon and arch, better in shear stress in arch also better in bending moment in arch. The summarize value is shown in table below.

Table 9: The value of displacement, stress and bending moment in each component.

Type of bridge	Arch 5	Fan 80m	Hybrid arch FAN
BAR			
DISPLACEMENT (m)	8.815E-5	14.0E-5	0.714E-5
STRESS (KN/m^2)	8.55E4	4.35E3	5.00E3
BEAM			
DISPLACEMENT(X) (m)	4.42E-3	9.17E-3	0.0138E-3
DISPLACEMENT(Y) (m)	0.08	0.00061	0.000474
NORMAL STRESS (KN/m^2)	1.7E3	19.3E3	19E3
SHEAR STRESS (KN/m^2)	21.3E3	2.09E3	4.74E3
BENDING MOMENT (KNm)	6.52E5	8.28E3	30.4E3
PYLON			
DISPLACEMENT(X) (m)	-	0.156E-3	0.137E-3
DISPLACEMENT(Y) (m)	-	0.034E-3	0.0208E-3
NORMAL STRESS (KN/m^2)	-	69.8E3	43.1E3

SHEAR STRESS (KN/m^2)	-	108	379
BENDING MOMENT	-	5.11E3	8.08E3
ARCH			
DISPLACEMENT(X) (m)	7.6E-6	-	62.7E-6
DISPLACEMENT(Y) (m)	0.158E-4	-	0.247E-4
NORMAL STRESS (KN/m^2)	53.70E3	-	26.8E3
SHEAR STRESS (KN/m^2)	42.6E3	-	17.3E3
BENDING MOMENT	6.40E5	-	5.66E5

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 INTRODUCTION

The new type of bridge is importance to be analyzed and observed to know their strength, specialty and their disadvantages. The hybrid arch bridge is analyzed to observe it strength compared to pure arch and cable-stayed bridge. In research only focus on static linear analysis in 2-dimension only. The cable-stayed bridge model is analyze for two different system which is fan system and harp system with three different pylon height, 40m, 60m and 80m. The arch bridge is model for three different rise-to-span ratio, 1:4.5, 1:5 and 11:5.5. All models are 2-dimensional model and have 300m for the main span and 150m for the side span. Total length is 600m. The loading use is live load and dead load only with value of 47.7knm and 119.4knm. The loading is assume static linear and assign as a line to the deck of the bridge. The computer program, LUSAS 14 is use to model and analyze the entire bridge models.

The model is analyze and compared to each other to obtain the most effective design for arch and cable-stayed bridge in term of their structure behavior. The models is analyze from the static analysis which are displacement, stress and bending moment in each components. The most effective arch bridge is arch with rise-to-span ratio 1:5 while for cable-stayed bridge is fan system with pylon height 80m. A hybrid arch bridge is modeled by combining models arch 1:5 and fan 80m. Then, the hybrid arch, arch 1:5 and cable-stayed fan 80m are analyzed and compared to each other to obtained the most effective bridge. After the further analyze, the hybrid arch bridge is seen to be the most effective bridge compared to arch bridge and cable-stayed bridge. The hybrid arch bridge has better structure behavior which can cater the displacement in cable, arch and deck better. In term of stress, the hybrid arch bridge can cater the normal force in pylon and arch. The hybrid arch bridge also stronger in arch component to cater the shear stress and bending moment in arch.

5.2 CONCLUSION BASED ON OBJECTIVE

This research focuses on two main objectives only. The first objective for this research is to study the principal component of cable stayed and arch bridge with hybrid arch bridge. The second is to investigate the structural behavior between normal arch and cable stayed bridge.

5.2.1 OBJECTIVE 1

The main components of arch bridge are deck, arch rib and hanging cable. The deck consists of road layer which are wearing coarse, base-course, road base and sub grade. The arch rib is the curved structure that spanning through the deck of bridge. The arch rib performs as a support for the loads above the opening which is loading in deck and the bridge structure itself. Arch shape is usually curved and the height of arch is calculated by using the rise-to-span ratio ranging from 1:4.5 to 1:5.5.

Cable stayed bridge main components are deck, pylon and stay cable. Tower or pylon is defines as an upright structure that is used to support the deck by connecting stayed cable from pylon to the deck. The stay cable is a tension component used to connecting the deck and pylon. Deck is the main component of bridge which is acting both compression and tension. Hybrid arch bridge components are deck, arch, tower, stayed cable and hanging cable. The characteristic of hybrid arch components is same as for arch and cable stayed bridge.

5.2.2 OBJECTIVE 2

The effectiveness of a bridge structure is determined by the structure behavior of each component of the bridge. Structure behavior of arch bridge is observed based on the deck, arch rid and hanging cables. Each component is analyzed in LUSAS 14 based on static linear analysis. The behavior or arch is seem to be effective in cater the compression force from the loading applied to bridge. The curve shape of arch rib will be bent downward when loading is applied on the bridge. Thus, the greater the loading, the less curve shape of the arch rib. The hanging cables act as a support to deck when it is anchored from the arch rib to the deck. Hanging cable behaves under tension and it elastic characteristic help it to elongate when loading is applied. From the analysis, the cables become less effective when it length increases.

The structure behavior for cable stayed bridge is observed from the deck, pylon and stayed cable. Meanwhile, the arrangement of stayed cables also gives a different behavior for the cable stayed bridge. The pylon is under compression. The height of pylon gives effect to the bridge performance. Analysis shows that the structure of cable stayed bridge becomes more effective when the pylon height increase. While for stayed cable, the cable is under tension. The different arrangements between fan system and harp system have its own advantages. But, for long bridge structure, the fan system shows the best performance because the cable less deflect when loading is applied to the bridge.

5.3 RECOMMENDATION

The new hybrid arch bridge is a new founding in bridge world. Thus there are many research can be done on it. As for the future research, there are a few recommendations that can be done. This research only focuses on linear static analysis which estimates displacement, stress and bending moment analysis only. Thus, for the future, another researcher can do a non-linear dynamic analysis to compare dynamic analysis between hybrid arch bridge with cable-stayed bridge. A non-linear analysis is importance to estimate the safety of the bridge in term of wind load and earthquake response. Every model can be built in 3D representation using LUSAS, ANSYS FE, or other bridge analysis computing program. Dynamic analysis of each model can be compared in term of model parameters, load intensity and damping ratio.

REFERENCES

This thesis is referred from:

Armstrong, D.M., Sibbald, A., Fairfield, C.A. and Forde, M.C. 1995. Modal analysis for Masonry arch bridge spandrell wall separation identification. *NDT&E International.* **28**(6):377–86.

Brencich, A. and Sabia, D. 2008. Experimental identification of a multi-span masonry bridge: the Tanaro bridge. *Journal of Construction Building Material* **22**(10):2087–99.

Dai, Y. and Wang, Y. 2012. A research to cable force optimizing calculation of cable-stayed arch bridge. *Proceeding of The Second SREE Conference on Engineering Modeling and Simulation (CEMS 2012).*pp. 155-160.

Dayaratnam,P. 2000. *International conference on suspension, cable supported, and cable stayed bridges:,India hyderabad.* Universities Press. *19-21* November, 1999.

Dirk, P. and Pieter, V.G. 2009. *Safety of Historical Stone Arch Bridges.* New York: Springer-Verlag Berlin Heidelberg.

Elsa, D. S. C. 2007. *Cable Vibrations in Cable-Stayed Bridges*. Switzerland: ETH Honggerberg.

Frunzio, G., Monaco, M. and Gesualdo A. 2001. 3D F.E.M Analysis of a Roman arch bridge, in :Historical Constructions, Lourenco, P.B., Roca, P., University of Minho, Multicomp Lda., Portugal, 591-597

Gongkang, F.2013. *Bridge Design and Evaluation:LRFD and LRFR*. New Jersey.

Hongwei, C. and Amjad, J.A. 2015. On the design and optimization of hybrid carbon fiber reinforced polymer-steel cable system for cable-stayed bridges. *Journal of Composites: Part B.* **68**: 146-152.

Jung, Jae-Hong, K., Hyo-Chan, Y. and Woo-Jong, K. 2009. Design and construction of the balanced arch bridge on the deep foundation, In: Proceedings of Chinese-Croatian Joint Colloquium., Fuzhou,05–09

Kang, H.J., Zhao, Y.Y., and Zhu, H.P. 2014. Analytical and experimental dynamic behavior of a new type of cable-arch bridge. *Journal of Constructional Steel Research*. **101**: 385-394.

Ryall, M.J., Parke, G.A.R., and Harding, J.E. 2000. *Manual of Bridge Engineering.* London: Thomas Telford Ltd.

Lonetti, P. and Pascuzzo, A. 2014. Vulnerability and failure analysis of hybrid cable-stayed suspension bridges subjected to damage mechanisms. *Journal of Engineering Failure Analysis*. **45**: 470-495.

Ren, W.X., Zhao T. and Harik, I.E. 2004. Experimental and analytical modal analysis of steel arch bridge. *Journal of Structure Engineering.* **130**(7):1022–31.

Toker, S. and Unay, A. 2004. Mathematıcal modeling and finite element analysis of Masonry arch bridges. *Journal of Science.* **17**(2):24–5.

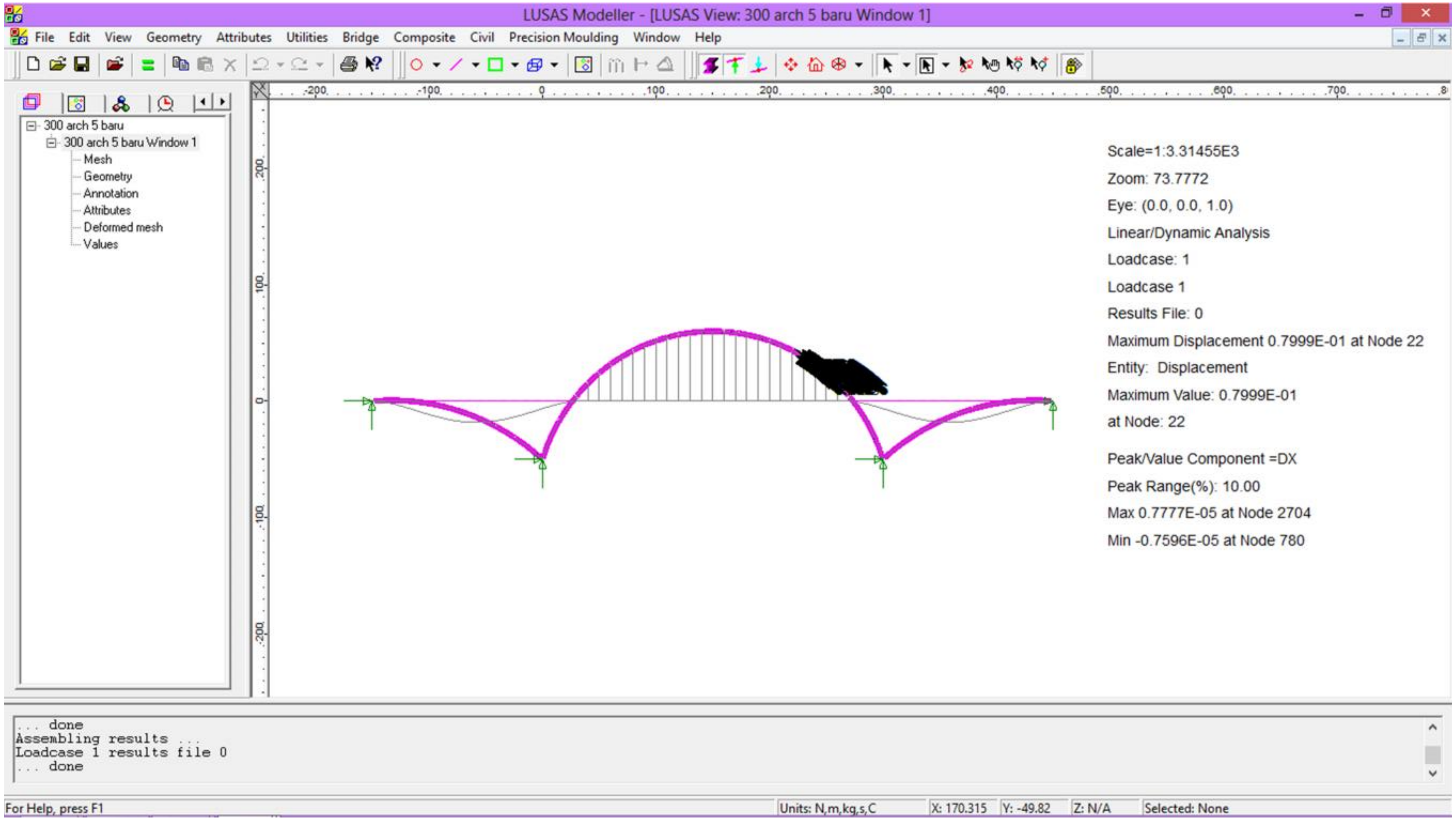
Wahid, O. and Mohamad, R.O. 2002. Overview and Development of PC Cable-Stayed Bridges In Malaysia. Technical Report. Kuala Lumpur.

Wai-Fah, C. and Lian, D. 1999. *Bridge Engineering Handbook.*US: CRC Press.

Walther, R., Houriet, B., Isler, W., Moia, P., and Klein, J.F. 1999. *Cable-Stayed Bridge*. London: Thomas Telford Publishing.

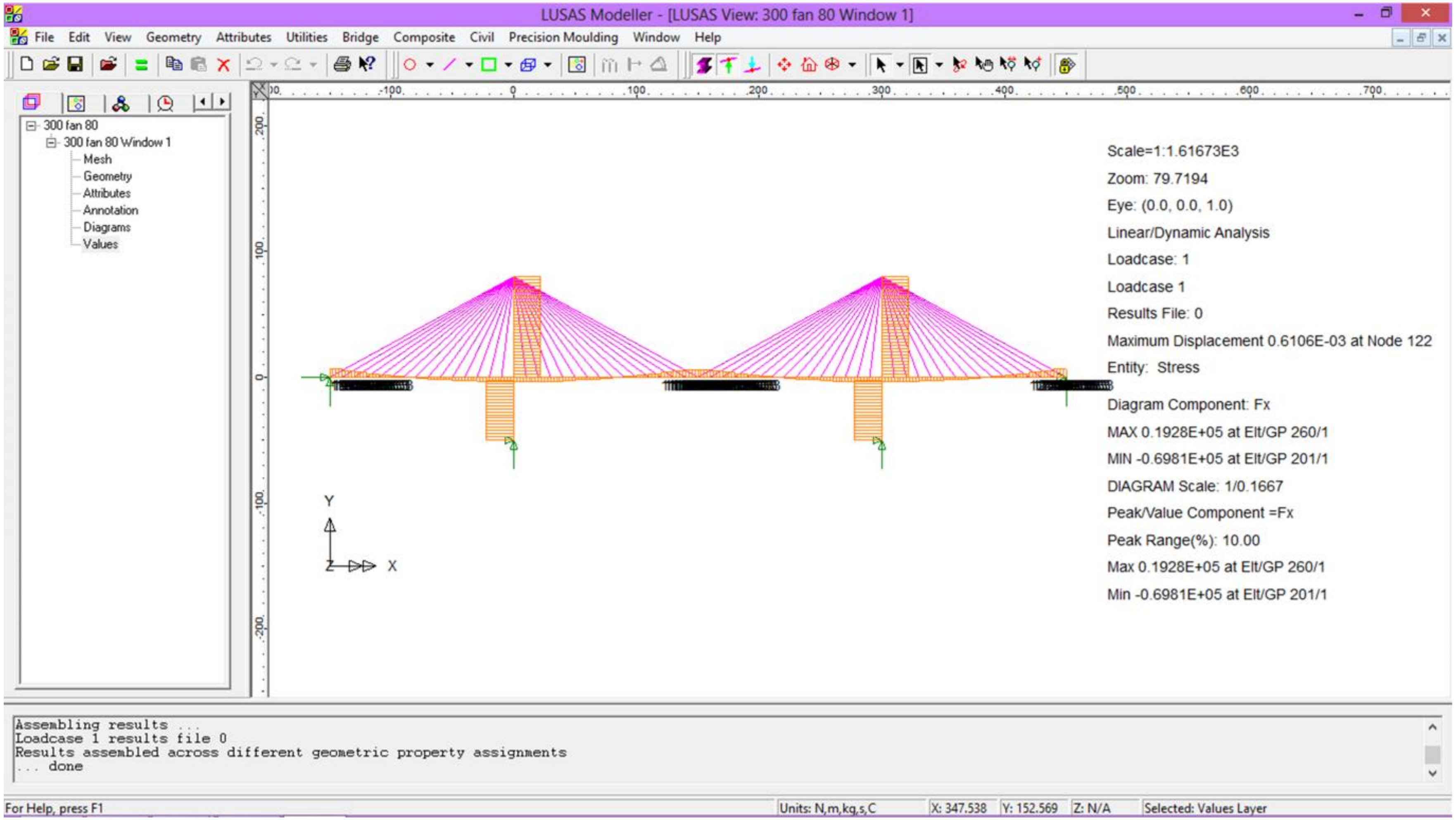
APPENDIX A

SAMPLE OF MAXIMUM DISPLACEMENT ON ARCH FROM LUSAS 14



APPENDIX B

SAMPLE OF MAXIMUM NORMAL STRESS IN BEAM FROM LUSAS 14



APPENDIX C

SAMPLE OF MAXIMUM BENDING MOMENT IN ARCH FROM LUSAS 14